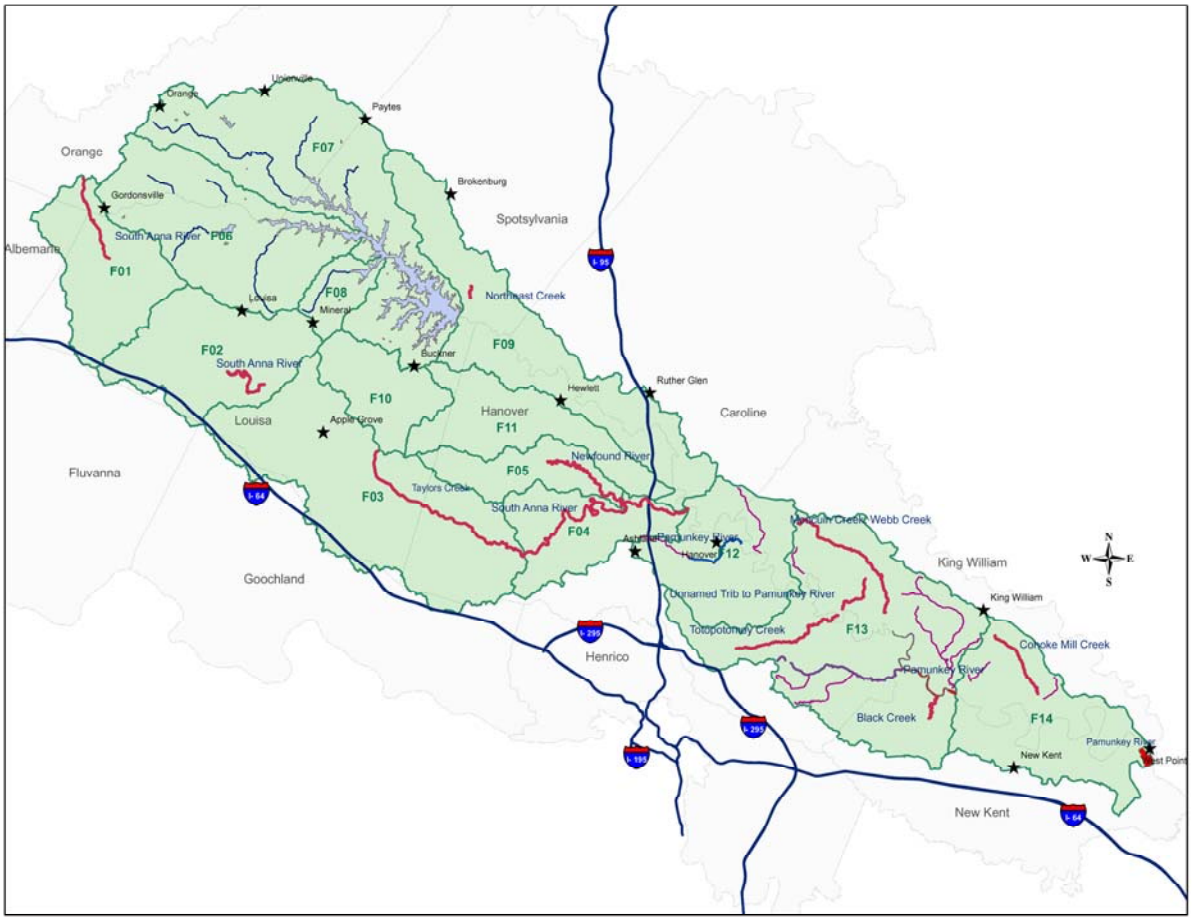
This report has been modified, but the changes are not reflected in the report below.

To view the EPA approved modification document, please return to the approved reports page located at https://www.deq.virginia.gov/TMDLDataSearch/ReportSearch.jspx and enter your query. In the results table, select “MODIFICATION” in the Final Reports column.

Bacteria Total Maximum Daily Load Development for the Pamunkey 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
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

South Anna River (VAP-F04R-02) and Pamunkey River (VAP-F13E-02) were first listed as impaired streams in 1998 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003a) indicating that the swimmable use goal was not being met. The stream segments were further listed in 2002 and 2004 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b, 2004) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. South Anna River (VAN-F01R-01), South Anna River (VAP-F04R-01), Taylors Creek (VAN-F03R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Monquin/Web Creek (VAP-F13R-04), and Black Creek (VAP-F13R-05) were initially listed as impaired stream on Virginia's 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b) and remained on the 2004 Section 303(d) (VADEQ, 2004) list due to water quality violations of the bacteria standard. South Anna River (VAN-F02R-01) and Newfound River (VAP-F05R-01) 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 violations of the bacteria standard.

The impaired portion of South Anna River (VAN-F01R-01) delineated by VADEQ, beginning at the headwaters of the South Anna River and continuing downstream approximately 7.0 miles to the confluence of Dove Fork to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR097.82. The impaired portion of South Anna River (VAN-F02R-01) delineated by VADEQ, beginning at the confluence of Roundabout Creek and continuing downstream approximately 6.27 miles to the confluence of Beaver Creek to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR070.96. The impaired portion of South Anna River (VAP-F04R-01) delineated by VADEQ, beginning at the confluence with Taylors Creek and continuing downstream approximately 22.22 miles to the Ashland Municipal STP discharge near the confluence with Falling Creek to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR021.22. The impaired portion of South Anna River (VAP-F04R-02) delineated by VADEQ, beginning at the Ashland Municipal STP discharge near the confluence with Falling Creek to the South Anna River and continuing downstream approximately 4.63 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR001.11. The impaired portion of Taylors Creek (VAN-F03R-01) delineated by VADEQ, beginning at the headwaters of Taylors Creek and continuing downstream approximately 16.26 miles to the confluence with the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-TLR002.54. The impaired portion of Newfound River (VAP-F05R-01) delineated by VADEQ, beginning from the confluence of Needstan Creek and continuing downstream approximately 10.61 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of

the bacteria standard at stations 8-NFD002.26. The impaired portion of Northeast Creek (VAP-F09R-01) delineated by VADEQ, beginning at the confluence with tributary upstream of Route 622 and continuing downstream approximately 1.04 miles to the confluence with tributary downstream of Route 622, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-NST003.46. The impaired portion of Totopotomoy Creek (VAP-F13R-02) delineated by VADEQ, beginning at the confluence of Strawhorn Creek and continuing downstream approximately 9.6 miles to its mouth (confluence with Pamunkey River), is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-TPT004.37. The impaired portion of Moncuin/Webb Creek (VAP-F13R-04) delineated by VADEQ, beginning at the headwaters of Webb Creek and continuing downstream approximately 11.83 miles to the swampy area around river mile 2.0, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-MNQ004.19. The impaired portion of Black Creek (VAP-F13R-05) delineated by VADEQ, beginning at the Southern Branch Clompton Swamp downstream of the first major upstream tributrary and continuing downstream approximately 2.61 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-BLC001.77. The impaired portion of Pamunkey River (VAP-F13E-02) delineated by VADEQ, beginning at Route 654, Pampatike Landing and continuing downstream approximately 0.84 square miles to the confluence of Macon Creek to the Pamunkey River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-PMK048.80.

The South Anna River (VAN-F01R-01) watershed area is approximately 6,010 acres consisting mainly of forest (48%) and pasture/cropland (45%).The remaining area is split between residential (4%) and water/wetland (3%). The South Anna River (VAN-F02R-01) watershed is approximately 95,070 acres in size. South Anna River (VAN-F02R-01) is mainly a forested watershed (about 69%) with pasture/cropland, residential, and water/wetland comprising 26%, 2%, and 3% of the area, respectively. The South Anna River (VAP-F04R-01) watershed area of approximately 262,860 acres is comprised of forest (68%), pasture/cropland (28%), residential (2%), and water/wetland (2%). The 298,300 acres in the South Anna River (VAP-F04R-02) watershed consists of approximately 67% forest, 30% pasture/cropland, 1%residential, and 2% water/wetland land uses. The approximately 25,530 acres of Taylors Creek (VAN-F03R-01) watershed consists of 71% forest, 27%, pasture/cropland, and the remaining 2% split between residential and water/wetland land uses. The Newfound River (VAP-F05R-01) watershed area of 26,250 acres is comprised of forest (59%), pasture/cropland (38%), residential (1%), and water/wetland (2%). The approximately 26,990 acres of Northeast Creek (VAP-F09R-01) watershed are mostly forested (about 75%) with 23%, 1%, and 1% of the remaining acreage consisting of pasture/ cropland, residential, and water/wetland land uses, respectively. The Totopotomoy Creek (VAP-F13R-02) watershed is approximately 20,050 acres in size. Totopotomoy Creek is mainly a forested watershed (about 53%) with pasture/cropland (33%), residential (12%) and water/wetland (2%) land uses contributing the difference. The approximately 15,710 acres of Moncuin/Webb Creek (VAP-F13R-04) watershed are mostly forested (about 68%) with 28%, 1%, and 3% of the remaining acreage consisting of

pasture/cropland, residential, and water/wetland land uses, respectively. The Black Creek (VAP-F13R-05) watershed area of approximately 20,730 acres is comprised of forest (77%), pasture/cropland (19%), residential (<1%), and water/wetland (4%). The approximately 872,620 acres of Pamunkey River (VAP-F13E-02) watershed are mostly forested (about 65%) with 29%, 2%, and 4% of the remaining acreage consisting of pasture/cropland, residential, and water/wetland land uses, respectively.

VADEQ personnel monitored pollutant concentrations throughout the South Anna River (8-SAR097.82, 8-SAR070.96, 8-SAR021.22, 8SAR001.11), Taylors Creek (8-TLR002.54), Newfound River (8-NFD002.26), Northeast Creek (8-NST003.46), Totopotomoy Creek (8-TPT004.37), Monquin/Web Creek (8-MNQ004.19), Black Creek (8-BLC001.77), and Pamunkey River (8-PMK048.80) watersheds. Of the 18 water quality samples collected from January 1998 through December 2002 (the 2004 Section 303(d) 5-year listing period) at VADEQ station 8-SAR097.82, 50.0% of the samples exceeded the then-applicable instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of South Anna River (VAN-F01R-01) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2004 Section 305(b) water quality assessment report and was included in the 2004 Section 303(d) list (VADEQ, 2004).The instantaneous fecal coliform bacteria standard was exceeded in two of 18 (11.1%) samples collected during the 2004 Section 303(d) assessment period at station 8-SAR070.96. This segment of South Anna River (VAN-F02R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (19 samples) at station 8-SAR021.22 yielded sufficient exceedance (26.3%) of the fecal coliform bacteria instantaneous standard to assess this segment of South Anna River (VAP-F04R-01) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list (VADEQ, 2004). South Anna River (VAP-F04R-02) does not support the Recreation Use goal due to nine of 48 (18.7%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-SAR001.11. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in three of 20 (15.0%) samples collected during the 2004 Section 303(d) assessment period at station 8-TLR002.54. This segment of Taylors Creek (VAN-F03R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (18 samples) at station 8-NFD002.26 yielded sufficient exceedance (27.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of Newfound River (VAP-F05R-01) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list (VADEQ, 2004). Northeast Creek (VAP-F09R-01) does not support the Recreation Use goal due to six of 27 (22.2%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-NST003.46. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in three of 23 (13.0%) samples collected during the 2004 Section 303(d) assessment period at station 8-TPT004.37. This segment of Totopotomoy Creek (VAP-F13R-02) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (17 samples) at station 8-MNQ004.19 yielded sufficient exceedance (11.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of Moncuin/Webb Creek (VAP-F13R-04) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list

(VADEQ, 2004). Black Creek (VAP-F13R-05) does not support the Recreation Use goal due to five of 18 (27.8%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-BLC001.77. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in five of 47 (10.6%) sample s collected during the 2004 Section 303(d) assessment period at station 8-PMK048.80. This segment of Pamunkey River (VAP-F13E-02) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004).

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

There are one, seven, 13, one, and one permitted point discharges located in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), and Moncuin/Webb Creek (VAP-F13R-04) 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds. In addition, the USEPA Water Quality Analysis Simulation Program (WASP) coupled with the USEPA Link-Node Tidal Hydrodynamic Model (DYNHYD) was selected as the modeling framework to simulate fecal coliform transport and fate in the Pamunkey River impairment. To identify localized sources of fecal coliform, the watersheds were divided into subwatersheds. These subdivisions were based

primarily on homogeneity of land use. The South Anna River model was calibrated using observed flow values from USGS station #01672500 near Ashland, VA for the period October 1, 1992 to September 30, 1997. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions, as well as seasonal variations. The calibrated HSPF data set was validated on a separate period from October 1, 1989 to September 30, 1992. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable. The Totopotomoy Creek model was calibrated using observed flow values from USGS station #01673550 near Studley, Virginia for the period October 1, 1992 to September 30, 1997. The model was validated for the period October 1, 1987 to September 30, 1992.

Observed stream flow values were not available for Northeast Creek (VAP-F09R-01), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02), therefore the South Anna River and Totopotomoy Creek models were used as a “paired watershed” for hydrologic calibration and validation of those watersheds. Hydrology calibration and validation were performed based on the physical, hydrologic, and land use data for the South Anna River and Totopotomoy Creek watersheds. After calibration and validation completion, the parameterization for the South Anna River model was transferred to the Northeast Creek and the parameterization for the Totopotomoy Creek model was transferred to Moncuin/Webb Creek, Black Creek, and Pamunkey River models. Parameters describing watershed characteristics such as land use, slope, infiltration rate, and F-Tables were updated to reflect the physical properties in Northeast Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River watersheds.

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 8-SAR097.82, 8-SAR070.96, 8-SAR021.22, 8-SAR001.11, 8-TLR002.54, 8-NFD002.26, 8-NST003.46, 8-TPT004.37, 8-MNQ004.19, 8-BLC001.77, and 8-PMK048.80 within the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) impairments, respectively, were used to calibrate the water quality component of HSPF between January 1998 and December 2002. The model was validated for period January 1993 to December 1998. 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01),

Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 violations. 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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
South Anna River (VAN-F01R-01)	100	100	99	97	97	90	0
South Anna River (VAN-F02R-01)	100	100	100	99	99	92	0
South Anna River (VAP-F04R-01)	100	100	98	95	95	41	0
South Anna River (VAP-F04R-02)	100	100	94	94	94	94	0
Taylors Creek (VAN-F03R-01)	100	100	97	99	100	97	0
Newfound River (VAP-F05R-01)	100	100	99	90	90	90	0
Northeast Creek (VAP-F09R-01)	100	100	94	94	94	94	0
Totopotomoy Creek (VAP-F13R-02)	100	99	99	83	83	83	0
Monquin, Webb Creek (VAP-F13R-04)	100	100	99	99	99	99	0
Black Creek (VAP-F13R-05)	100	100	83	83	83	83	0
Pamunkey River (VAP-F13E-02)	100	100	83	83	83	83	0

DD – direct deposition

Using equation [E.1], summaries of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) bacteria TMDLs for the selected allocation scenario are shown in Tables E.2 through E.12, respectively.

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

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

Table E.2. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F01R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.64E+12	3.67E+12	N/A	5.31E+12

N/A – not applicable because MOS was implicit.

Table E.3. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F02R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.48E+12	7.96E+12	N/A	9.44E+12

N/A – not applicable because MOS was implicit.

Table E.4. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.02E+12	2.98E+13	N/A	3.08E+13

N/A – not applicable because MOS was implicit.

Table E.5. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-02) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	3.48E+12	3.13E+13	N/A	3.48E+13

N/A – not applicable because MOS was implicit.

Table E.6. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.89E+09	1.89E+11	N/A	1.91E+11

N/A – not applicable because MOS was implicit.

Table E.7. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Newfound River (VAP-F05R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	2.89E+10	2.89E+12	N/A	2.92E+12

N/A – not applicable because MOS was implicit.

Table E.8. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Northeast Creek (VAP-F09R-01) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	2.30E+10	2.30E+12	N/A	2.32E+12

N/A – not applicable because MOS was implicit.

Table E.9. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Totopotomoy Creek (VAP-F13R-02) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.62E+10	1.62E+12	N/A	1.64E+12

N/A – not applicable because MOS was implicit.

Table E.10. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Moncuin/Webb Creek (VAP-F13R-04) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	8.71E+10	1.81E+11	N/A	2.68E+11

N/A – not applicable because MOS was implicit.

Table E.11. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Black Creek (VAP-F13R-05) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.26E+10	1.26E+12	N/A	1.27E+12

N/A – not applicable because MOS was implicit.

Table E.12. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Pamunkey River (VAP-F13E-02) watershed.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	7.40E+12	7.40E+14	N/A	7.47E+14

N/A – not applicable because MOS was implicit.

Stage 1 Implementation

Staged implementation is a key component to restoring water quality in South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02). 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 violation rate below 10% and 0% reduction in loads from wildlife. The goal was not met in Taylors Creek whereby a reduction in wildlife direct deposition was needed to meet the 10% water quality standard violation rate goal. Stage 1 reduction scenarios are listed in Table E.13.

Table E. 13. Stage 1 reduction scenarios.

Impairment	Percent Reduction in Fecal Coliform Loading from Existing Conditions						
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest
South Anna River (VAN-F01R-01)	100	95	95	95	95	0	0
South Anna River (VAN-F02R-01)	100	89	89	89	89	0	0
South Anna River (VAP-F04R-01)	100	60	60	60	60	0	0
South Anna River (VAP-F04R-02)	100	70	70	70	70	0	0
Taylors Creek (VAN-F03R-01)	100	100	97	99	100	58	0
Newfound River (VAP-F05R-01)	100	91	91	91	91	0	0
Northeast Creek (VAP-F09R-01)	100	76	76	76	76	0	0
Totopotomoy Creek (VAP-F13R-02)	100	90	94	90	90	0	0
Monquin, Webb Creek (VAP-F13R-04)	100	98	98	98	98	0	0
Black Creek (VAP-F13R-05)	100	70	70	70	70	0	0
Pamunkey River (VAP-F13E-02)	100	70	70	70	70	0	0

DD – direct deposition

Public Participation

During development of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) TMDLs, public participation was encouraged through three public meetings. The first public meetings were held at the Louisa County Government Center in Louisa, Virginia and King William High Scholl in King William, Virginia on April 13, 2005 and April 20, 2005, respectively, to discuss the need for a TMDL and the process for TMDL development. The second public meetings were held at the Louisa County Government Center in Louisa, Virginia and Eastern Hanover Volunteer Company in Mechanicsville, Virginia on December 7, 2005 and December 8, 2005, respectively, to discuss the draft watershed source assessment and to review the approach for TMDL development. The third and final public meetings were held at the Eastern Hanover Volunteer Company in Mechanicsville, Virginia and Louisa County Government Center in Louisa, Virginia on March 22, 2006 and March 23, 2006, respectively, to discuss the source allocations and reductions required to meet the TMDL. Two written comments were received during the third 30-day comment period provided with this project.

In addition to keeping the public apprised of progress in the development of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) TMDLs, a TMDL Technical Advisory Committee (TAC) was also established to help advise the TMDL developers. TAC meetings were held on November 16, 2005 and March 9, 2005 at the Ashland Council Chmabers in Ashland, Virginia. 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 Cooperative Extension; Abemarle, Caroline, Fluvanna, Goochland, Hanover, King William, Louisa, New Kent, Orange, and Spotsylvania County

Planning Departments; and Colonial, Culpeper, Hanover-Caroline, Monacan, Thomas Jefferson, Three Rivers, and Tri-County/City SWCDs.

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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Hanover County Government

Randolph-Macon College

Richmond Regional PDC

South Anna Monitoring Project

Town of Ashland

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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 violate 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 violating 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

South Anna River (VAP-F04R-02) and Pamunkey River (VAP-F13E-02) were first listed as impaired streams in 1998 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003a) indicating that the swimmable use goal was not being met. The stream segments were further listed in 2002 and 2004 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b, 2004) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. South Anna River (VAN-F01R-01), South Anna River (VAP-F04R-01), Taylors Creek (VAN-F03R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Monquin/Web Creek (VAP-F13R-04), and Black Creek (VAP-F13R-05) were initially listed as impaired stream on Virginia's 2002 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2003b) and remained on the 2004 Section 303(d) (VADEQ, 2004) list due to water quality violations of the bacteria standard. South Anna River (VAN-F02R-01) and Newfound River (VAP-F05R-01) 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 violations of the bacteria standard.

The impaired portion of South Anna River (VAN-F01R-01) delineated by VADEQ, beginning at the headwaters of the South Anna River and continuing downstream approximately 7.0 miles to the confluence of Dove Fork to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR097.82.

The impaired portion of South Anna River (VAN-F02R-01) delineated by VADEQ, beginning at the confluence of Roundabout Creek and continuing downstream approximately 6.27 miles to the confluence of Beaver Creek to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR070.96.

The impaired portion of South Anna River (VAP-F04R-01) delineated by VADEQ, beginning at the confluence with Taylors Creek and continuing downstream approximately

22.22 miles to the Ashland Municipal STP discharge near the confluence with Falling Creek to the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR021.22.

The impaired portion of South Anna River (VAP-F04R-02) delineated by VADEQ, beginning at the Ashland Municipal STP discharge near the confluence with Falling Creek to the South Anna River and continuing downstream approximately 4.63 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-SAR001.11.

The impaired portion of Taylors Creek (VAN-F03R-01) delineated by VADEQ, beginning at the headwaters of Taylors Creek and continuing downstream approximately 16.26 miles to the confluence with the South Anna River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-TLR002.54.

The impaired portion of Newfound River (VAP-F05R-01) delineated by VADEQ, beginning from the confluence of Needstan Creek and continuing downstream approximately 10.61 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at stations 8-NFD002.26.

The impaired portion of Northeast Creek (VAP-F09R-01) delineated by VADEQ, beginning at the confluence with tributary upstream of Route 622 and continuing downstream approximately 1.04 miles to the confluence with tributary downstream of Route 622, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-NST003.46.

The impaired portion of Totopotomoy Creek (VAP-F13R-02) delineated by VADEQ, beginning at the confluence of Strawhorn Creek and continuing downstream approximately 9.6 miles to its mouth (confluence with Pamunkey River), is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-TPT004.37.

The impaired portion of Moncuin/Webb Creek (VAP-F13R-04) delineated by VADEQ, beginning at the headwaters of Webb Creek and continuing downstream approximately 11.83 miles to the swampy area around river mile 2.0, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-MNQ004.19.

The impaired portion of Black Creek (VAP-F13R-05) delineated by VADEQ, beginning at the Southern Branch Clompton Swamp downstream of the first major upstream tributrary and continuing downstream approximately 2.61 miles to its mouth, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-BLC001.77.

The impaired portion of Pamunkey River (VAP-F13E-02) delineated by VADEQ, beginning at Route 654, Pampatike Landing and continuing downstream approximately 0.84

square miles to the confluence of Macon Creek to the Pamunkey River, is listed as impaired by fecal coliform bacteria on Virginia's 2004 list (VADEQ, 2004) due to water quality violations of the bacteria standard at station 8-PMK048.80.

1.1.3 Watershed Location and Description

South Anna River impairment watersheds are located in Orange, Albemarle, Louisa, Fluvanna, Goochland, and Hanover Counties, Virginia. Taylors Creek impairment watershed is located in Louisa County, Virginia and Hanover County, Virginia. Newfound River and Totopotomoy Creek impairment watersheds are located in Hanover County, Virginia. Northeast Creek impairment watershed is located in Spotsylvania County, Virginia. Moncuin / Webb Creek impairment watershed is located in King William County, Virginia. Black Creek impairment watershed is located in New Kent County, Virginia. Pamunkey River impairment watershed is located on the border of New Kent, King William, and Hanover Counties, Virginia (Figure 1.1).

Table 1.1. Area with percentage of land use draining to impairments.

Impairment	Area	Land use			
		Forest	Pasture / Cropland	Residential	Water / Wetland
	(ac)	(%)	(%)	(%)	(%)
South Anna River (VAN-F01R-01)	6,010	48	45	4	3
South Anna River (VAN-F02R-01)	95,070	69	26	2	3
South Anna River (VAP-F04R-01)	262,860	68	28	2	2
South Anna River (VAP-F04R-02)	298,300	67	30	1	2
Taylors Creek (VAN-F03R-01)	25,530	71	27	1	1
Newfound River (VAP-F05R-01)	26,350	59	38	1	2
Northeast Creek (VAP-F09R-01)	26,990	75	23	1	1
Totopotomoy Creek (VAP-F13R-02)	20,050	53	33	12	2
Moncuin/Webb Creek (VAP-F13R-04)	15,710	68	28	1	3
Black Creek (VAP-F13R-05)	20,730	77	19	<1	4
Pamunkey River (VAP-F13E-02)	872,620	65	29	2	4

Source: National Land Cover Data, Multi-resolution Land Characterization (MRLC) Consortium

The South Anna River begins slightly north of the Town of Gordonsville, Virginia and continues downstream to confluence with North Anna River northeast of Ashland, Virginia. Taylors Creek and Newfound River drain directly into South Anna River. Northeast Creek drains directly into the North Anna River just below the Lake Anna outlet. North Anna River combines with South Anna River to form Pamunkey River. The Totopotomoy Creek, Moncuin/Webb

Creek, and Black Creek drain directly into the Pamunkey River. The Pamunkey River joins the York River (USGS Hydrologic Unit Code 02080106) before emptying into the Chesapeake Bay.

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 violation 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 in non-tidal waters. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

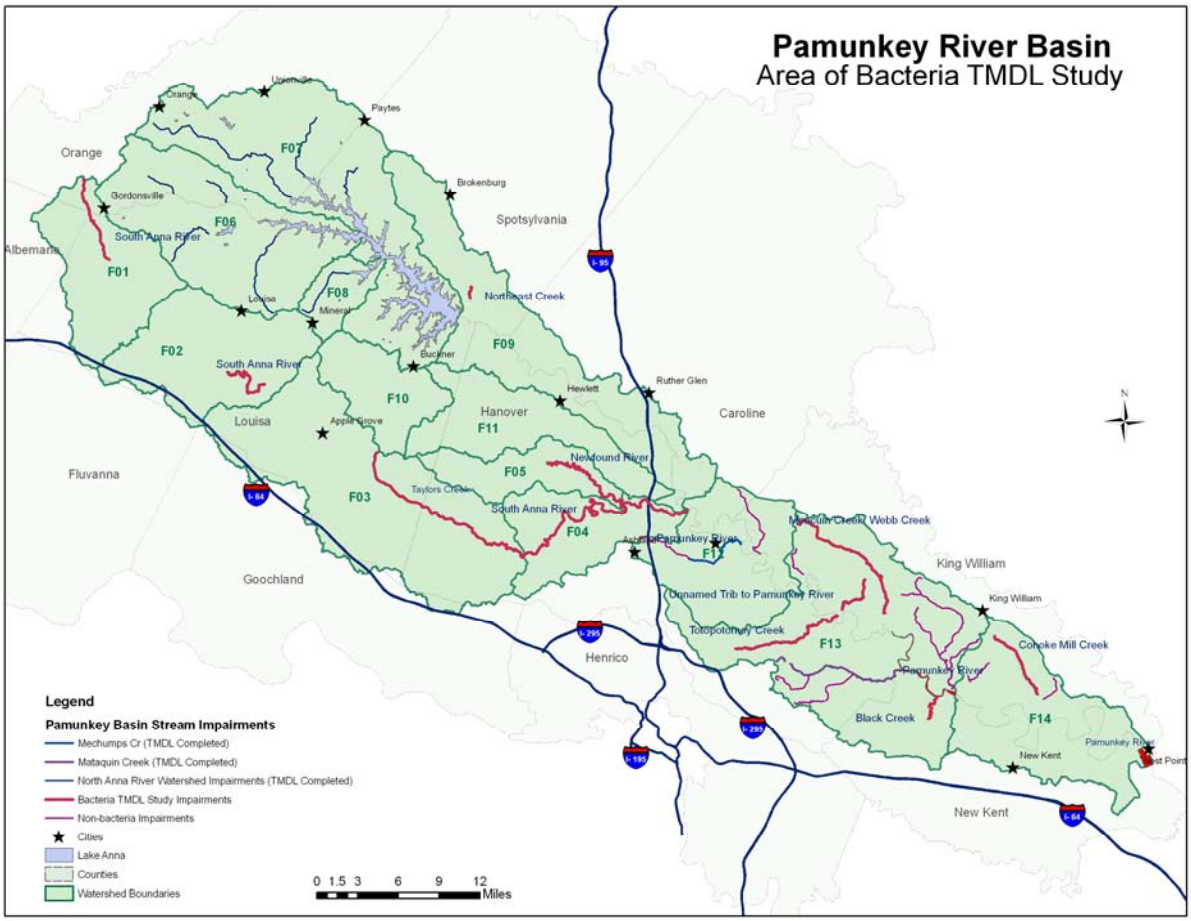

Figure 1.1. Location of South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Monquin/Web Creek, Black Creek, and Pamunkey River watersheds.

1.2 Designated Uses and Applicable Water Quality Standards

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

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

The goal of the Clean Water Act is that all streams should be suitable for recreational uses, including swimming and fishing. **Fecal coliform and *E. coli* bacteria** are used to indicate the presence of pathogens in streams supporting the **swimmable use goal**. Bacteria in South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Monquin/Web Creek, Black Creek, and Pamunkey 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 any assessment period, if more than 10.5% of a station's samples exceed the applicable standard, 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 South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Monquin/Web Creek, Black Creek, and Pamunkey River was based on violations 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 because of the 2003 water quality standard change. 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds were subdivided into sub-watersheds for fecal coliform modeling purposes, as discussed in Section 4.2. The main branch of South Anna River runs for approximately 95.6 miles from the headwaters to the confluence with North Anna River. Taylors Creek flows for approximately 16.2 miles from the headwaters to the confluence with South Anna River. Newfound River flows for approximately 20.7 miles from the headwaters to the confluence with South Anna River. North Anna River runs for approximately 30.4 miles from the outlet of Lake Anna to the confluence with South Anna River. Northeast Creek flows for approximately 9.9 miles from the headwaters to the confluence with North Anna River. Pamunkey River runs for approximately 34.5 miles from the confluence of North Anna River and South Anna River to the outlet of the impairment. Totopotomoy Creek flows for approximately 16.8 miles from the headwaters to the confluence with Pamunkey River. Moncuin, Webb Creek flows for approximately 13.7 miles from the headwaters to the confluence with Pamunkey River. Black Creek flows for approximately 11.8 miles from the headwaters to the confluence with Pamunkey River.South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River are all perennial streams with a trapezoidal channel cross-section.

2.2 Ecoregion

The South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), and Northeast Creek (VAP-F09R-01) watersheds lie entirely in the Piedmont ecoregion. The South Anna River (VAP-F04R-02) watershed is split between the Piedmont and Coastal Plain ecoregions. Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds lie entirely in the Coastal Plain Ecoregion.

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 monadnocks (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.

The Coastal Plain ecoregion from east of the fall line to the Chesapeake Bay consists of low elevation flat plains, with many swamps, marshes, and estuaries (Woods et al., 1999). Forest cover in the region, once dominated by longleaf pine in the Carolinas, is now mostly loblolly and some shortleaf pine, with patches of oak, gum, and cypress near major streams (Woods et al., 1999). Its low terraces, marshes, dunes, barrier islands, and beaches are underlain by unconsolidated sediments. Poorly drained soils are common, and the region has a mix of coarse and finer textured soils.

2.3 Climate

The climate of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), and Northeast Creek (VAP-F09R-01) watersheds is characterized based on the meteorological observations from 08/01/1948 to 09/30/2005 assembled by the Southeast Regional Climate Center for the Louisa, Virginia (445050) station. Average annual precipitation is 43.14 inches with 53% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2006). Average annual snowfall is 18.3 inches with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 56.0°F. The highest average daily temperature of 87.4°F occurs in July while the lowest average daily temperature of 24.8°F occurs in January (SERCC, 2004).

The climate of the Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds is characterized based on the meteorological observations from 08/01/1948 to 03/31/2004 assembled by the Southeast Regional Climate Center for the Richmond WSO Airport, Virginia (447201) station. Average annual precipitation is 43.72 inches with 56% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2004). Average annual snowfall is 13.6 inches with the highest snowfall occurring during January (SERCC, 2006). Average annual daily temperature is 58.0°F. The highest average daily temperature of 88.7°F occurs in July while the lowest average daily temperature of 27.5°F occurs in January (SERCC, 2006).

2.4 Land Use

General depiction of land use draining to impairments is listed in Table 1.1. Details of landuse used in this study are described in Section 4.3 with landuse per subwatershed listed in Tables 4.2 through 4.5.

For purposes of this study, it was assumed that residential development in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), and Newfound River (VAP-F05R-01) watersheds will continue at the overall average rate of 3.4% annually. Residential development in the Northeast Creek (VAP-F09R-01) watershed was assumed to conitune at a rate of 3.9% per year. It was assumed that residential development in the Totopotomoy Creek (VAP-F13R-02) watershed would continue at an average rate 5.9% annually. Residential development in the Moncuin/Webb Creek (VAP-F13R-04), Black Creek

(VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds will continue at at an average rate of 4.2% per year.

2.5 Water Quality Data

2.5.1 Historic Data for Fecal Coliform

Of the 18 water quality samples collected from January 1998 through December 2002 (the 2004 Section 303(d) 5-year listing period) at VADEQ station 8-SAR097.82, 50.0% of the samples exceeded the then-applicable instantaneous standard of 1,000 cfu/100 mL. Consequently, this segment of South Anna River (VAN-F01R-01) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2004 Section 305(b) water quality assessment report and was included in the 2004 Section 303(d) list (VADEQ, 2004).The instantaneous fecal coliform bacteria standard was exceeded in two of 18 (11.1%) samples collected during the 2004 Section 303(d) assessment period at station 8-SAR070.96. This segment of South Anna River (VAN-F02R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (19 samples) at station 8-SAR021.22 yielded sufficient exceedance (26.3%) of the fecal coliform bacteria instantaneous standard to assess this segment of South Anna River (VAP-F04R-01) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list (VADEQ, 2004). South Anna River (VAP-F04R-02) does not support the Recreation Use goal due to nine of 48 (18.7%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-SAR001.11. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in three of 20 (15.0%) samples collected during the 2004 Section 303(d) assessment period at station 8-TLR002.54. This segment of Taylors Creek (VAN-F03R-01) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (18 samples) at station 8-NFD002.26 yielded sufficient exceedance (27.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of Newfound River (VAP-F05R-01) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list (VADEQ, 2004). Northeast Creek (VAP-F09R-01) does not support the Recreation Use goal due to six of 27 (22.2%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-NST003.46. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in three of 23 (13.0%) samples collected during the 2004 Section 303(d) assessment period at station 8-TPT004.37. This segment of Totopotomoy Creek (VAP-F13R-02) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004). Sampling (17 samples) at station 8-MNQ004.19 yielded sufficient exceedance (11.8%) of the fecal coliform bacteria instantaneous standard to assess this segment of Moncuin/Webb Creek (VAP-F13R-04) as not supporting the Recreation Use goal and subsequent placement on the 2004 Section 303(d) list (VADEQ, 2004). Black Creek (VAP-F13R-05) does not support the Recreation Use goal due to five of 18 (27.8%) samples exceeding the instantaneous fecal coliform bacteria standard at station 8-BLC001.77. This segment was included in the 2004 Section 303(d) list (VADEQ, 2004). The instantaneous fecal coliform bacteria standard was exceeded in five of 47 (10.6%) sample s collected during the

2004 Section 303(d) assessment period at station 8-PMK048.80. This segment of Pamunkey River (VAP-F13E-02) was assessed as not supporting of the Recreation Use goal and was included in the 2004 Section 303(d) list (VADEQ, 2004).

VADEQ personnel monitored pollutant concentrations throughout the South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Monquin/Web Creek, Black Creek, and Pamunkey River watersheds. Monitoring data with corresponding 6-day antecedent precipitation used in assessment of the impairments, as well as in this study, are included in Appendix A. Time series data of fecal coliform concentration from 1990 through the most recent data collected at the time this report was written are plotted in Figures 2.1 – 2.11. Data from bacteria monitoring stations (8-SAR097.82, 8-SAR070.96, 8-SAR021.22, and 8-SAR001.11) in the South Anna River watershed are shown in Figures 2.1 through 2.4. Figure 2.5 lists fecal coliform concentration at bacteria monitoring station 8-TLR002.54in the Taylors Creek watershed. Data at bacteria monitoring station 8-NFD002.26 in the Newfound River watershed are listed in Figure 2.6. Figure 2.7 lists fecal coliform bacteria concentrations at station 8-NST003.46 in the Northeast Creek watershed. Fecal coliform data at station 8-TPT004.37 in the Totopotomoy Creek watershed are listed in Figure 2.8. Figure 2.9 lists fecal coliform bacteria concentrations at station 8-MNQ004.19 in the Monquin, Webb Creek watershed. Data from bacteria monitoring station 8-BLC001.77 in the Black Creek watershed are shown in Figure 2.10. Figure 2.11 lists fecal coliform concentration at bacteria monitoring station 8-PMK048.80 in the Pamunkey River watershed. The Most Probable Number (MPN) and membrane filtration methods were used for analyzing water samples for fecal coliform concentration.

For station 8-SAR001.11, the unusually flat appearance of the data for the years 1990-1993 and 2000-2002 are due to the method used to analyze the samples, combined with low streamflows just by coincidence (Figure 2.4). During these periods, VADEQ had the state lab, DCLS, analyze the samples by the Fecal Coliform, Membrane Filter method, plated in M-FC Broth and incubated at 44.5°C. This is a longtime accepted method for bacterial sample analysis. The minimum detection limit is 100 cfu/100ml and the maximum detection limit is 8,000 cfu/100ml. The upper detection limit is not higher due to the inaccuracies of counting more than more than 80 colonies on a petri dish. The average flow for this 7-year period was a low 607 cfs at the Pamunkey River near Hanover, VA gaging station. Low flows generally result in lower fecal coliform levels because there is less NPS runoff flushing bacteria to state waters.

The higher concentration appearance of the data for the years 1994 - 1999 are due to a different analysis method, combined with high streamflows by coincidence. During this period, VADEQ had the state lab analyze the samples by the Fecal Coliform, Most Probable Number Fermentation Tube method incubated at 44.5°C. This is also a longtime accepted method for bacterial sample analysis. The minimum detection limit is 18 cfu/100ml and the maximum detection limit is 16,000 cfu/100ml, much preferable to the FCMF det lims, except that this method costs three times as much as the FCMF method. The average flow for this 6-year period was twice as high as above, 1,224 cfs, at the Pamunkey River near Hanover, VA gaging station. High flows generally produce higher fecal coliform levels because of increased NPS runoff carrying high concentrations of fecals to state waters.

Through the 1980s and up to 1993, VADEQ Piedmont Regional Office used Fecal Coliform, Membrane Filter method because all VADEQ regions used the same method and no entity had yet commented on the detection limits. In 1994, VADEQ Piedmont Regional Office began using Fecal Coliform, Most Probable Number Fermentation Tube method because of VDH concerns that the minimum 100 cfu/100 ml detection limit for Fecal Coliform, Membrane Filter method was not low enough to spot potential human health risks. VADEQ Piedmont Regional Office also found the higher detection limit for Fecal Coliform, Most Probable Number Fermentation Tube method more accurate at a higher concentration than for the Fecal Coliform, Membrane Filter method. In 2000, the VADEQ had to cut back on sample costs due to budget reductions, and because the primary reason for fecal coliform sampling was to indicate human health risk at concentrations greater than the 1,000 cfu/100 ml state water quality standard, VADEQ returned to the Fecal Coliform, Membrane Filter method method, which yielded accurate data to show water quality standard violations at one third the cost.

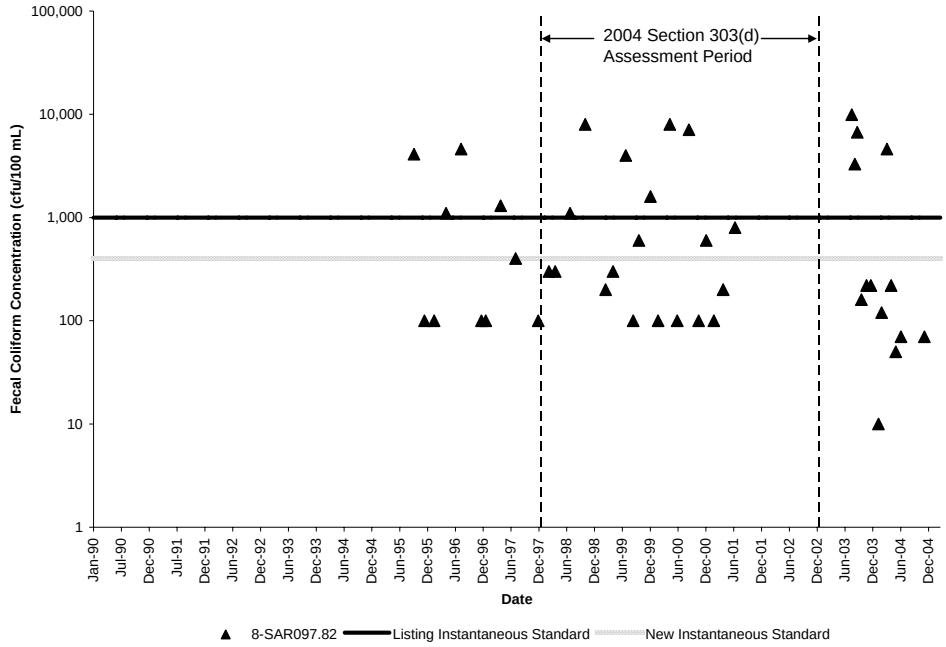

Figure 2.1. Fecal coliform concentrations (VADEQ station 8-SAR097.82) in the South Anna River (VAN-F01R-01) impairment.

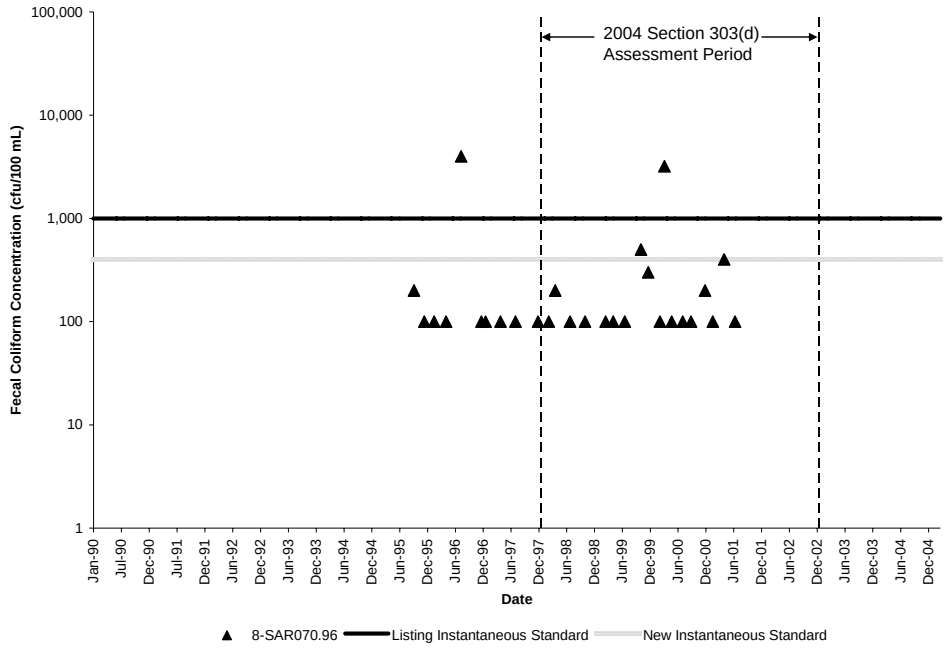

Figure 2.2. Fecal coliform concentrations (VADEQ station 8-SAR070.96) in the South Anna River (VAN-F02R-01) impairment.

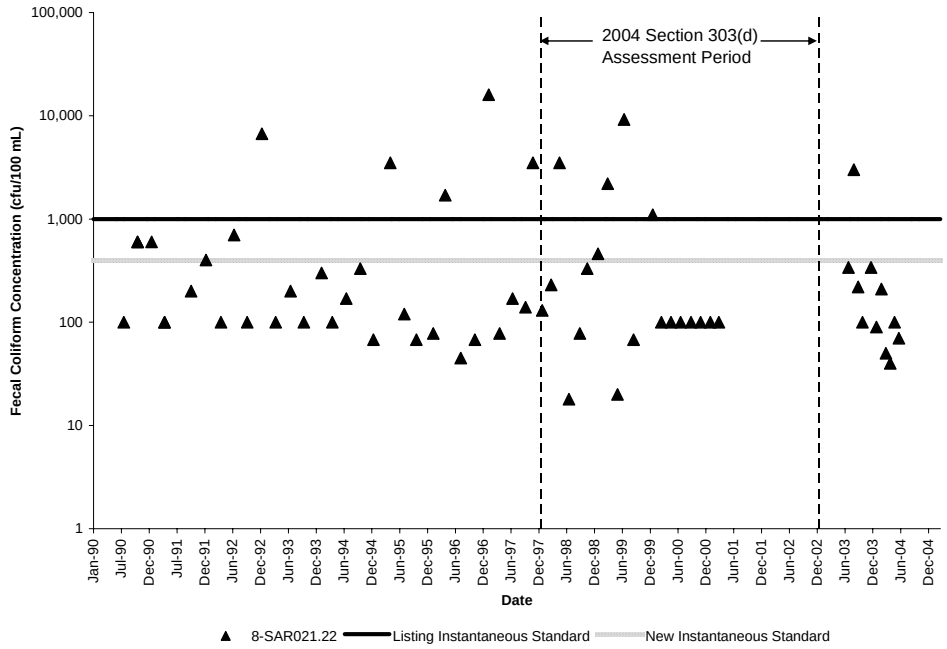

Figure 2.3. Fecal coliform concentrations (VADEQ station 8-SAR021.22) in the South Anna River (VAP-F04R-01) impairment.

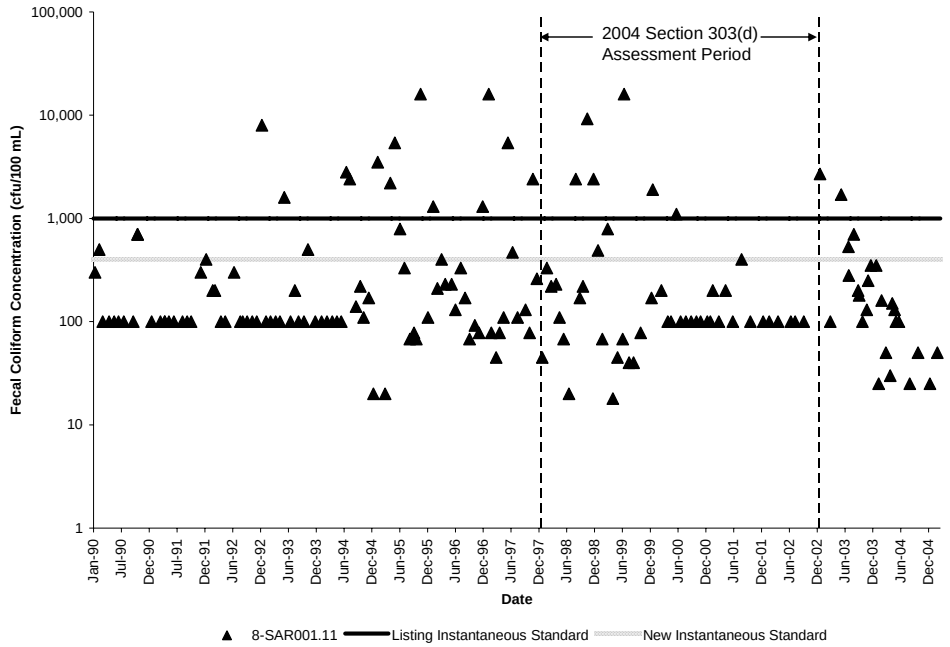

Figure 2.4. Fecal coliform concentrations (VADEQ station 8-SAR001.11) in the South Anna River (VAP-F04R-02) impairment.

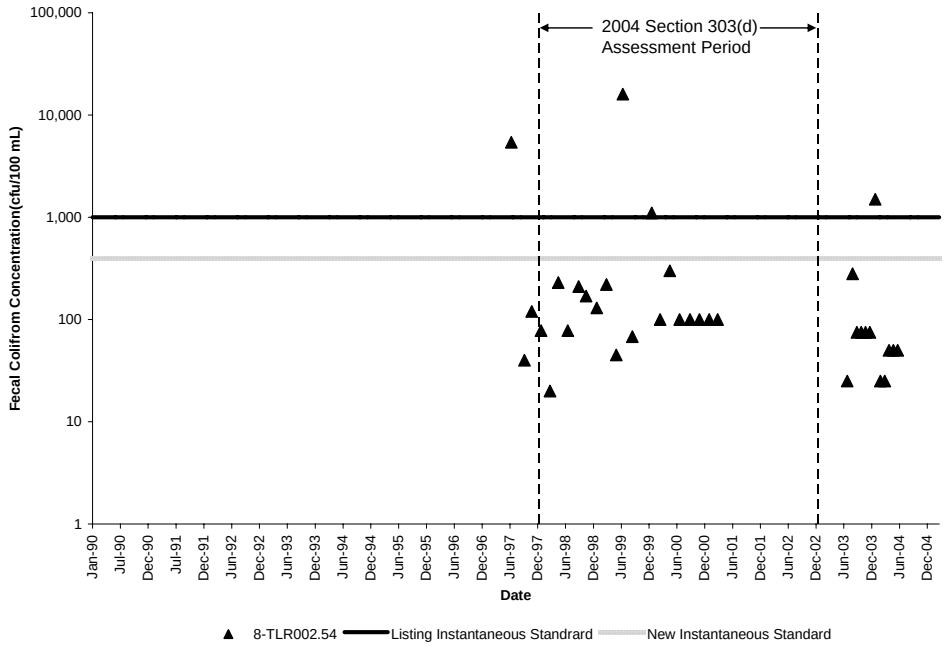

Figure 2.5. Fecal coliform concentrations (VADEQ station 8-TLR002.54) in the Taylors Creek (VAN-F03R-01) impairment.

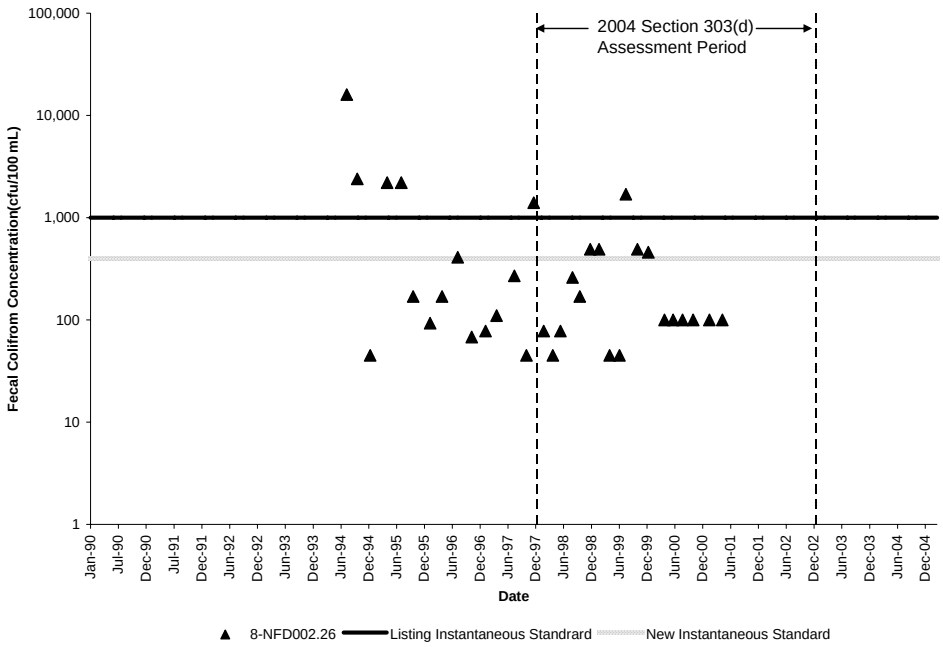

Figure 2.6. Fecal coliform concentrations (VADEQ station 8-NFD002.26) in the Newfound River (VAP-F05R-01) impairment.

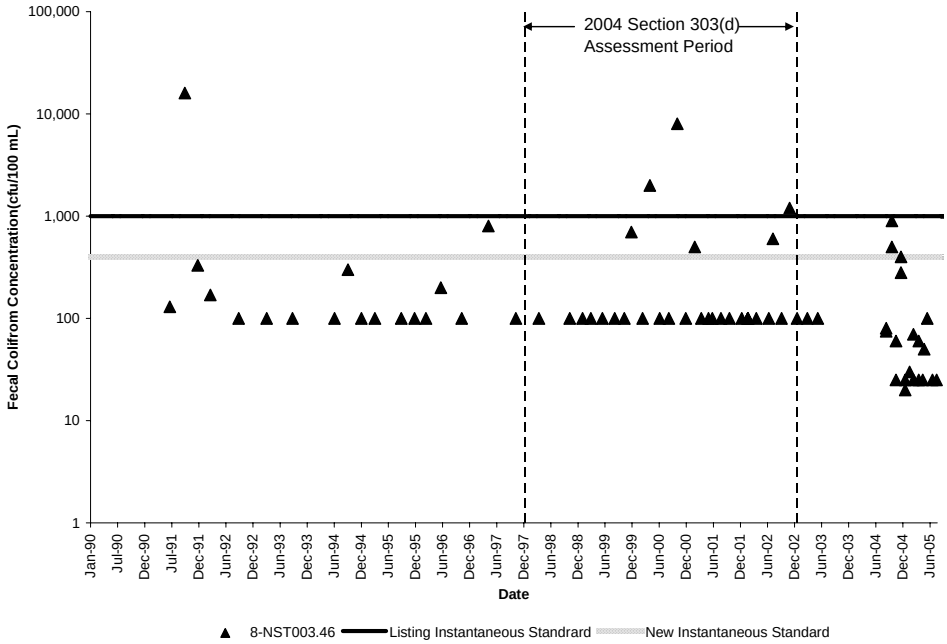

Figure 2.7. Fecal coliform concentrations (VADEQ station 8-NST003.46) in the Northeast Creek (VAP-F09R-01) impairment.

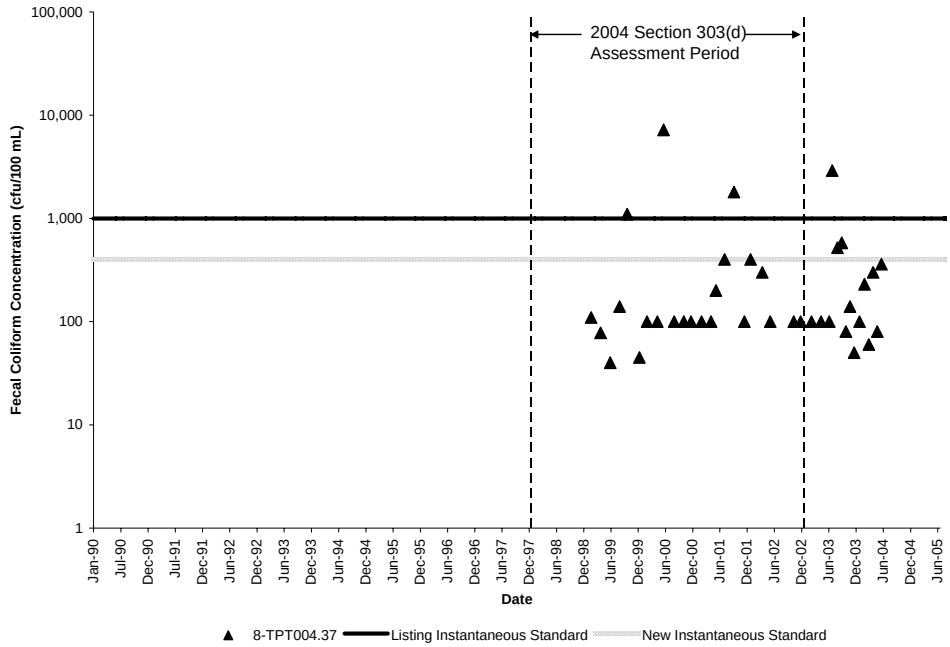

Figure 2.8. Fecal coliform concentrations (VADEQ station 8-TPT004.37) in the Totopotomoy Creek (VAP-F13R-02) impairment.

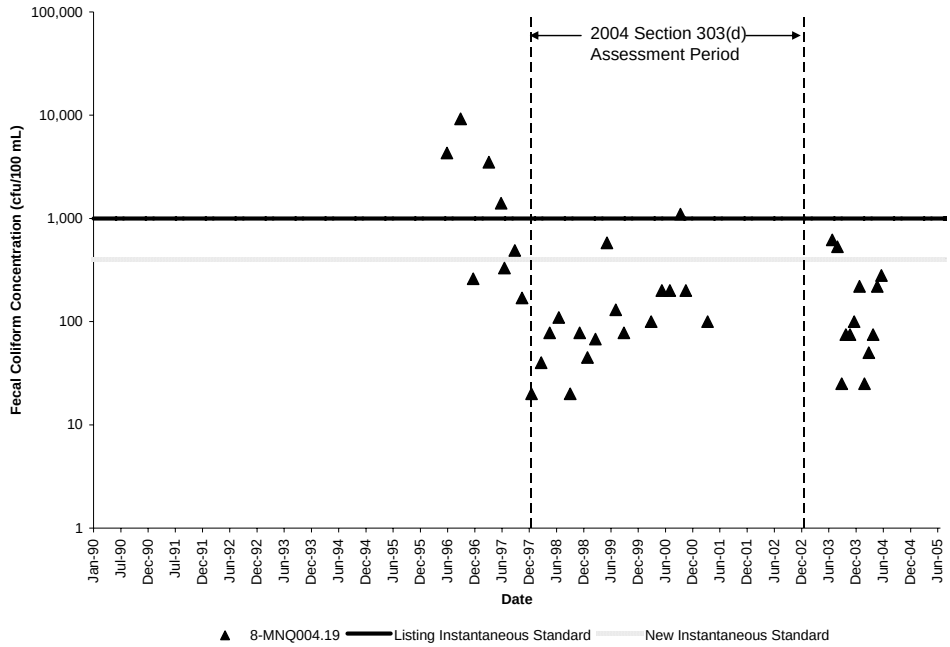

Figure 2.9. Fecal coliform concentrations (VADEQ station 8-MNQ004.19) in the Monquin, Web Creek (VAP-F13R-04) impairment.

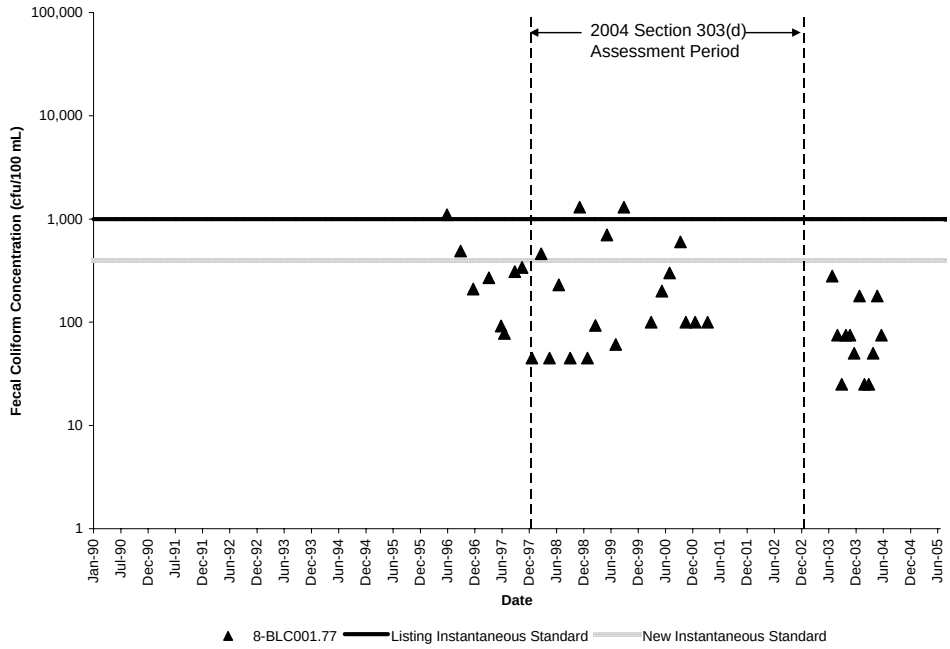

Figure 2.10. Fecal coliform concentrations (VADEQ station 8-BLC001.77) in the Black Creek (VAP-F13R-05) impairment.

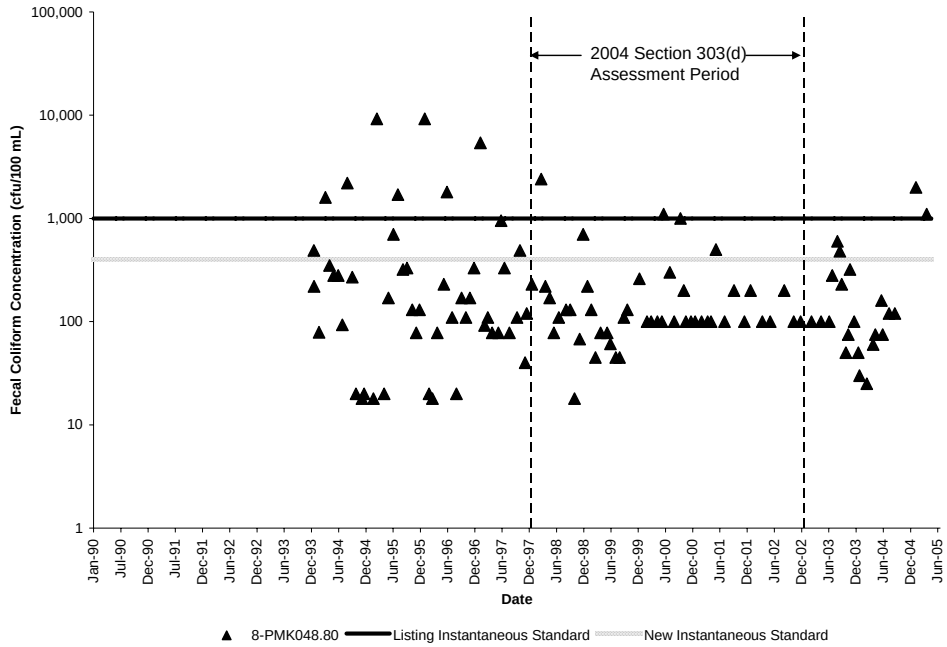

Figure 2.11. Fecal coliform concentrations (VADEQ station 8-PMK048.80) in the Pamunkey River (VAP-F13E-02) impairment.

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 16 values for each month; the number of values varied according to the available number of samples for each month in the 1990 to 2005 period of record (Tables 2.1 – 2.3). Mean monthly fecal coliform bacteria concentration were plotted for stations 8-SAR097.82, 8-SAR070.96, 8-SAR021.22, 8-SAR001.11, 8-TLR002.54, 8-NFD002.26, 8-NST003.46, 8-TPT004.37, 8-MNQ004.19, 8-BLC001.77, and 8-PMK048.80 (Figures 2.12 - 2.22).

The summer months at station 8-SAR097.82 had the highest mean fecal coliform concentration with September the highest (Figure 2.12). The lower concentrations occurred in the winter months. The highest mean concentration occurred in March followed by July with the remaining months having an uniform distribution at station 8-SAR070.96 (Figure 2.13). At station 8-SAR021.22, mean fecal coliform bacteria concentrations fluctuated throughout the year and a noticeable seasonal difference was not detected (Figure 2.14). The highest average values were detected in August, January and July. Figure 2.15 illustrates that each season contained a month that the mean fecal coliform concentration was elevated, therefore a seasonal difference could not be determined at station 8-SAR001.11. The highest mean concentration occurred in July followed by January with the remaining months having an uniform distribution at station 8-TLR002.54 (Figure 2.16). No samples were collected during several months at station 8-NFD002.26 not enabling seasonality observance (Figure 2.17). Of the months data was collected, the highest averages were recorded in August and July. At station 8-NST003.46, the data indicate that higher in-stream fecal coliform concentrations occur

during the summer and fall months, particularly in September (Figure 2.18). The summer months at station 8-TPT004.37 had the highest mean fecal coliform concentrations with June the highest (Figure 2.19). Figure 2.20 shows a month with a higher mean fecal coliform concentration in the summer, spring and winter seasons, particularly in September, June and March, therefore seasonality was not distinguishable at station 8-MNQ004.19. At station 8-BLC001.77, mean fecal coliform bacteria concentrations fluctuated uniformly throughout the year and a noticeable seasonal difference was not detected (Figure 2.21). The mean fecal coliform concentration in the winter months tended to be higher with the highest mean fecal coliform bacteria concentration occurring in January and March at station 8-PMK048.80 (Figure 2.22).

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) 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 2.12 – 2.22.

Table 2.1. Number of samples collected per month from 1/1/90 to 3/1/05 in the South Anna River impairments.

Month	Samples Collected at			
	8-SAR097.82 (#)	8-SAR070.96 (#)	8-SAR021.22 (#)	8-SAR001.11 (#)
January	2	1	16	16
February	5	4	14	13
March	2	2	14	15
April	7	5	15	15
May	1	1	14	14
June	3	1	14	14
July	5	5	12	13
August	3	0	14	13
September	2	2	15	15
October	4	2	12	13
November	2	0	12	12
December	6	5	14	14
TOTAL	**42**	**28**	**166**	**167**

Table 2.2. Number of samples collected per month from 1/1/90 to 8/1/05 in the Taylors Creek, Newfound River, and Northeast Creek impairments.

Month	Samples Collected at		
	8-TLR002.54 (#)	8-NFD002.26 (#)	8-NST003.46 (#)
January	5	4	3
February	1	2	4
March	5	0	8
April	1	7	5
May	4	0	4
June	1	3	7
July	5	2	1
August	1	5	4
September	5	0	7
October	1	7	7
November	4	0	2
December	1	3	7
TOTAL	**34**	**33**	**59**

Table 2.3. Number of samples collected per month from 1/1/90 to 4/1/05 in the Pamunkey River, Tototopotomoy Creek, Monquin / Web Creek, and Black Creek impairments.

Month	Samples Collected at			
	8-PMK048.80 (#)	8-TPT004.37 (#)	8-MNQ004.19 (#)	8-BLC001.77 (#)
January	11	2	4	5
February	11	5	2	2
March	12	2	7	7
April	12	5	2	2
May	10	3	4	4
June	10	4	4	4
July	11	2	6	6
August	12	3	3	3
September	9	2	6	6
October	10	4	2	2
November	8	2	5	5
December	10	4	3	3
TOTAL	**126**	**38**	**48**	**49**

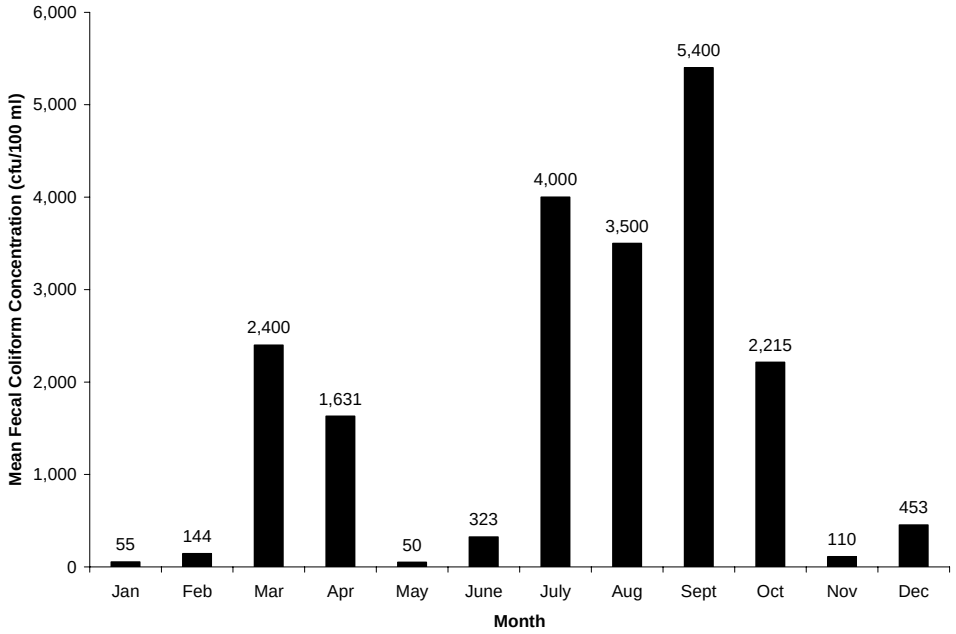

Figure 2.12. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-SAR097.82) in the South Anna River (VAN-F01R-01) impairment from September 1995 through June 2004.

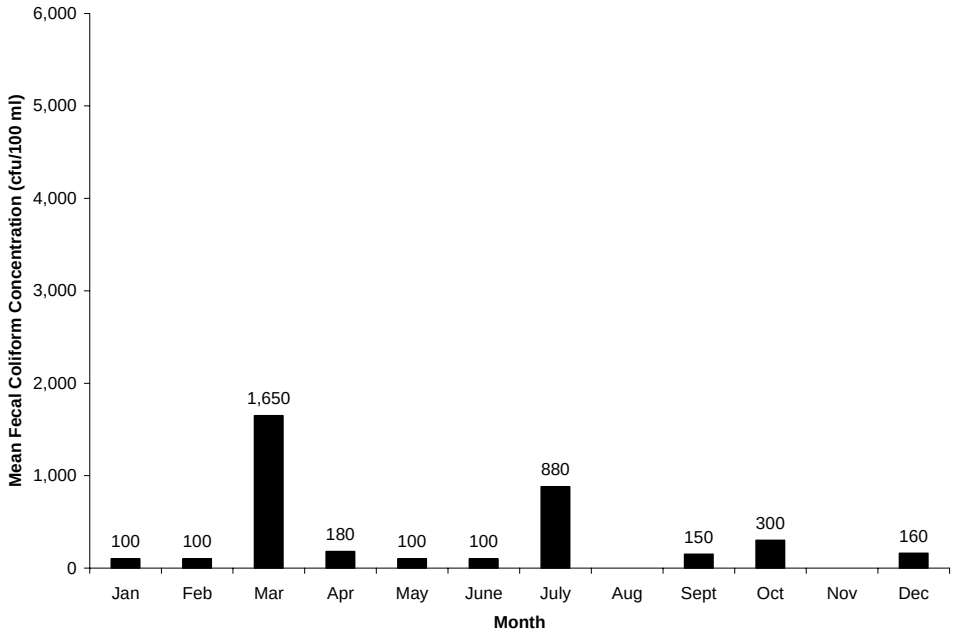

Figure 2.13. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-SAR070.96) in the South Anna River (VAN-F02R-01) impairment from September 1995 through June 2001.

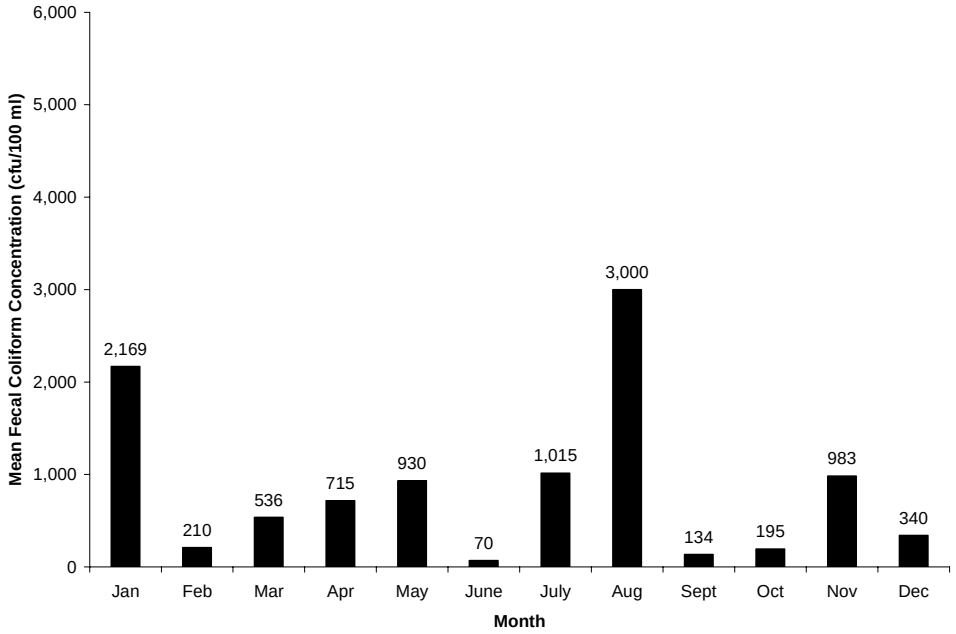

Figure 2.14. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-SAR021.22) in the South Anna River (VAP-F04R-01) impairment from July 1990 through June 2004.

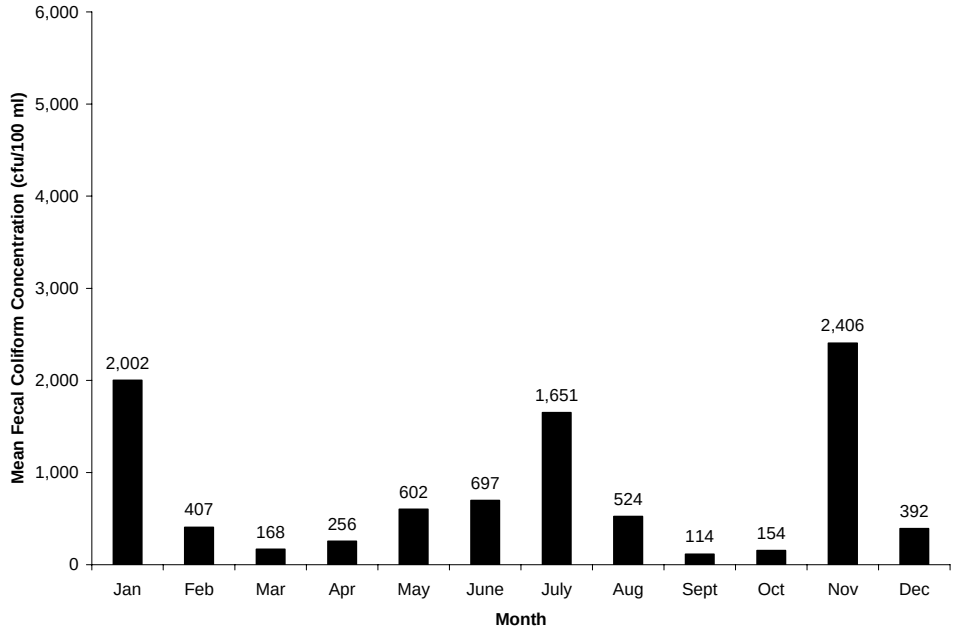

Figure 2.15. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-SAR001.11) in the South Anna River (VAP-F04R-02) impairment from January 1990 through February 2005.

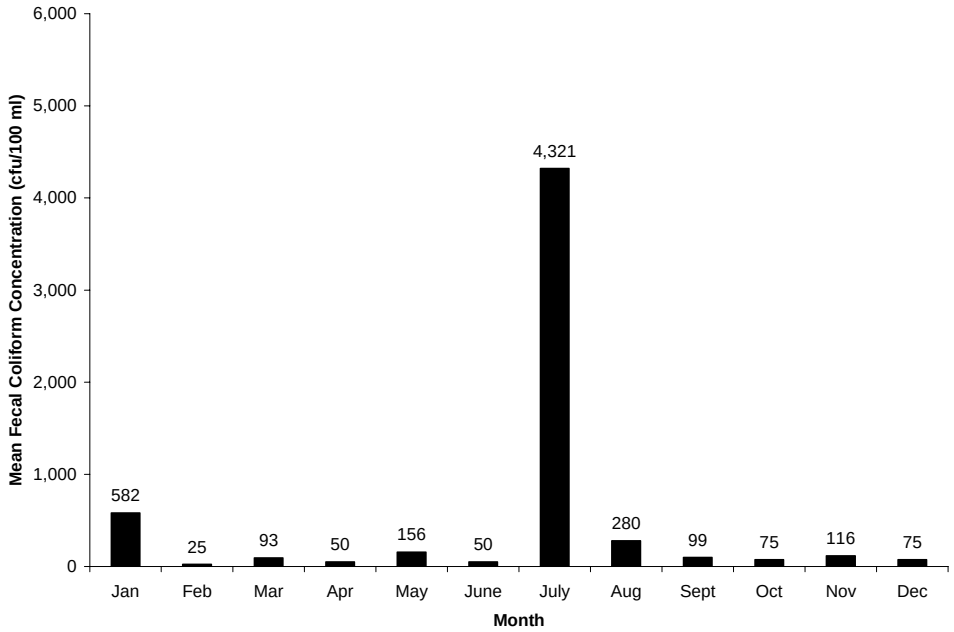

Figure 2.16. Impact of seasonality on fecal coliform (VADEQ station 8-TLR002.54) in the Taylors Creek (VAN-F03R-01) impairment from July 1997 through June 2004.

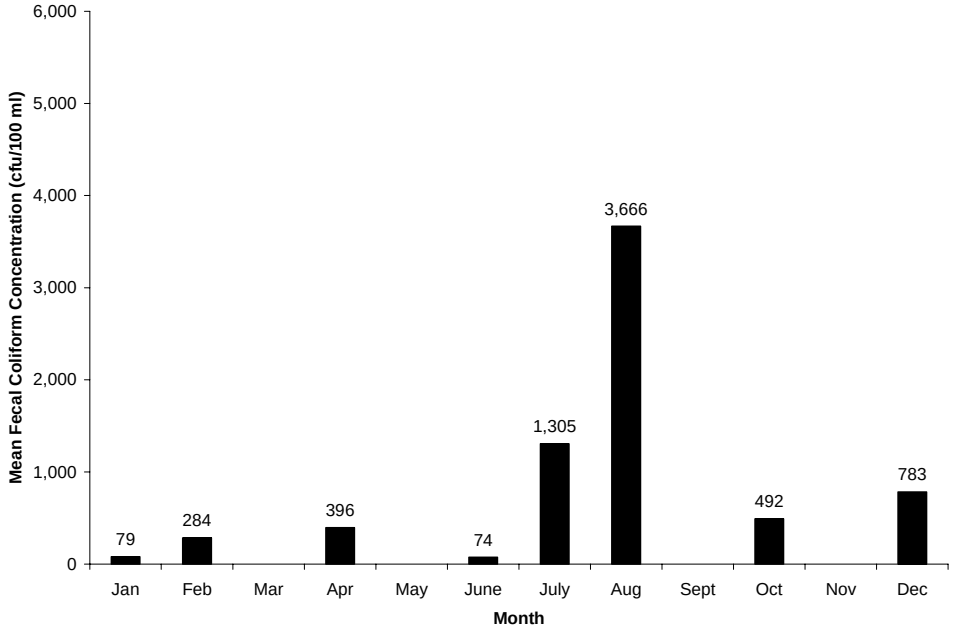

Figure 2.17. Impact of seasonality on fecal coliform (VADEQ station 8-NFD002.26) in the Newfound River (VAP-F05R-01) impairment from August 1994 through April 2001.

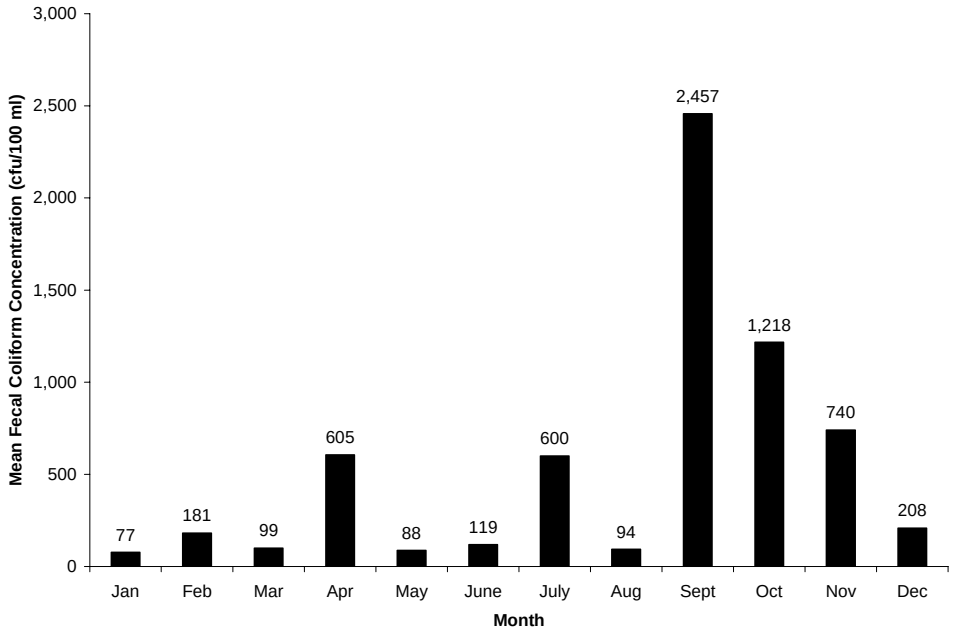

Figure 2.18. Impact of seasonality on fecal coliform (VADEQ station 8-NST003.46) in the Northeast Creek (VAP-F09R-01) impairment from June 1991 through July 2005.

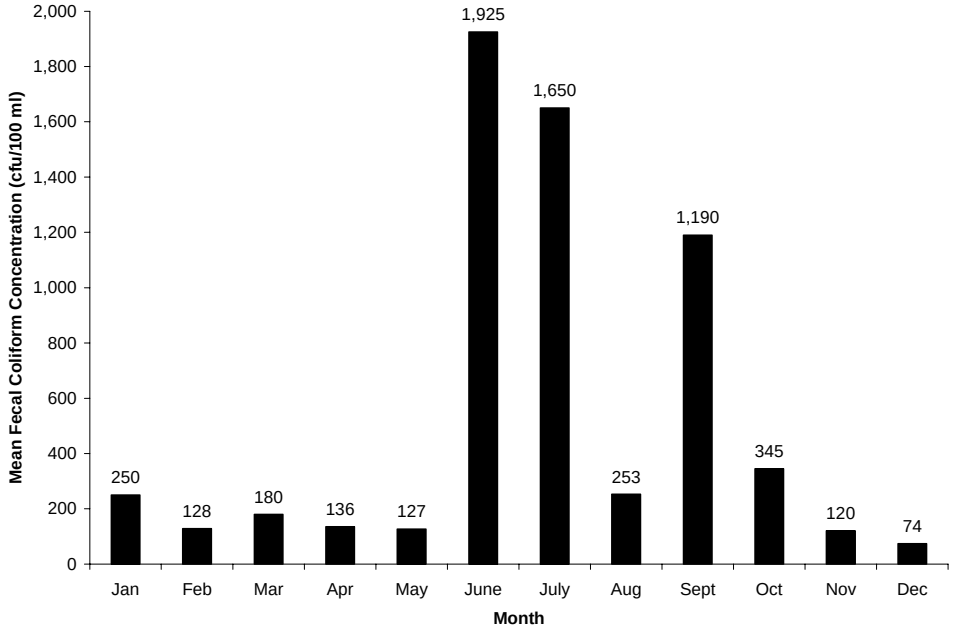

Figure 2.19. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-TPT004.37) in the Totopotomoy Creek (VAP-F13R-02) impairment from February 1999 through June 2004.

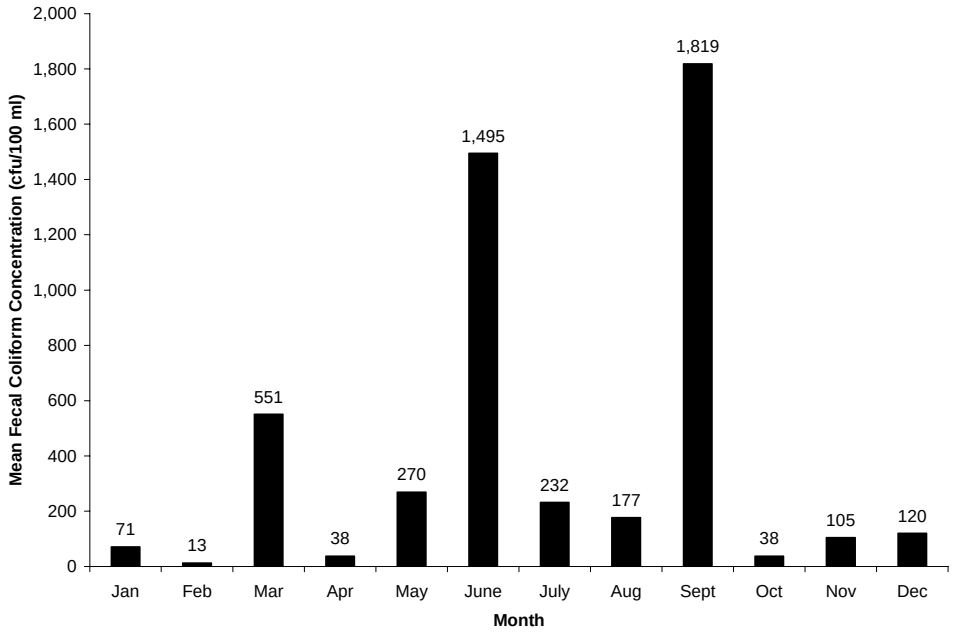

Figure 2.20. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-MNQ004.19) in the Monquin, Web Creek (VAP-F13R-04) impairment from June 1996 through June 2004.

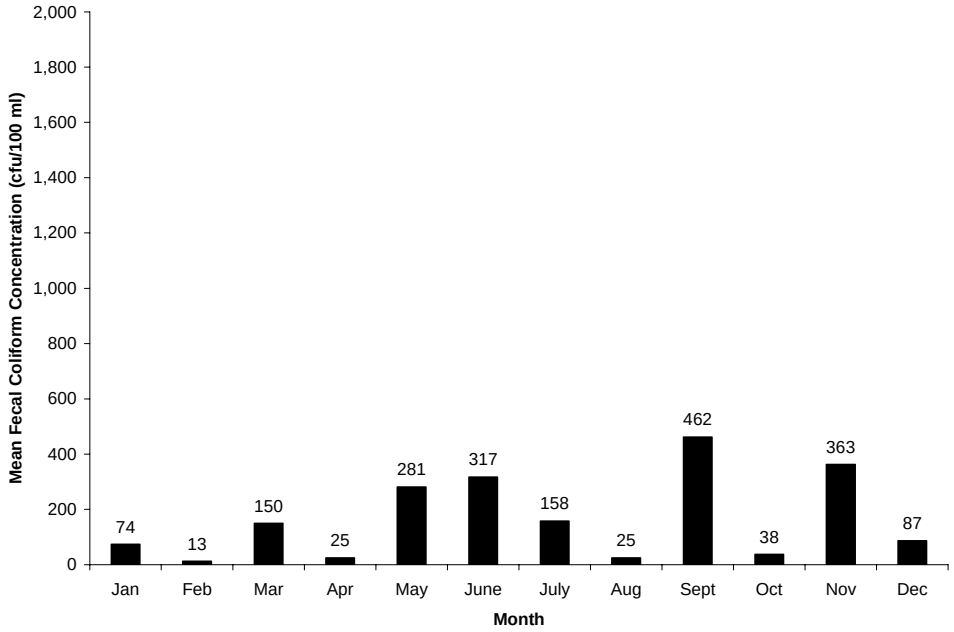

Figure 2.21. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-BLC001.77) in the Black Creek (VAP-F13R-05) impairment from June 1996 through June 2004.

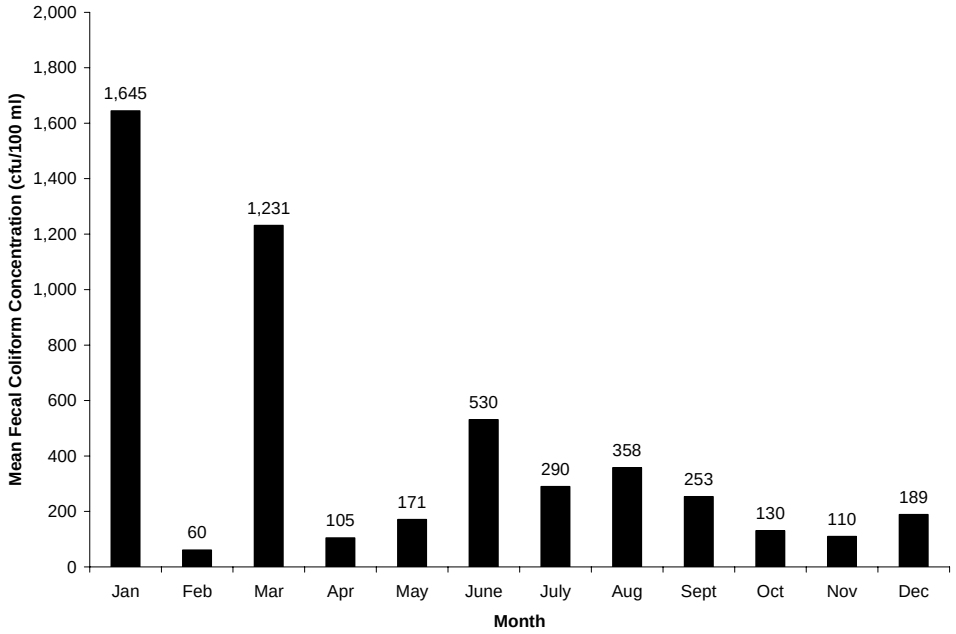

Figure 2.22. Impact of seasonality on fecal coliform concentrations (VADEQ station 8-PMK048.80) in the Pamunkey River (VAP-F13E-02) impairment from January 1994 through March 2005.

2.5.2 Historic Data for E. coli

VADEQ staff examined water samples collected at stations 8-SAR097.82, 8-SAR021.22, 8-SAR001.11, 8-TLR002.54, 8-NST003.46, 8-TPT004.37, 8-MNQ004.19, 8-BLC001.77, and 8-PMK048.80 for their concentration of *E. coli* (Figures 2.23 through 2.29). This analysis was conducted concurrently with other monthly testing at the stations from July 2003 through July 2005. At stations 8-SAR097.82, 8-SAR021.22, and 8-SAR001.11; five of 12 (41.7%), one of 11 (9.1%), and one of 22 (4.5%) samples violated the instantaneous *E. coli* bacteria standard, respectively. Of the 12 water quality samples collected at station 8-TLR002.54, 8.3% of the samples exceeded the instantaneous *E. coli* bacteria standard of 235 cfu/100 mL. Four of the 20 (20.0%) samples analyzed from station 8-NST003.46 exceeded the instantaneous *E. coli* bacteria standard. The instantaneous *E. coli* bacteria standard was exceeded in two of 12 (16.7%) samples collected at station 8-TPT004.37. Five of the 23 (21.7%) samples analyzed from station 8-MNQ004.19 exceeded the instantaneous *E. coli* bacteria standard. At station 8-BLC001.77, one of 23 (4.3%) samples violated the instantaneous *E. coli* bacteria standard. The instantaneous *E. coli* bacteria standard was exceeded in three of 19 (15.8%) samples collected at station 8-PMK048.80.

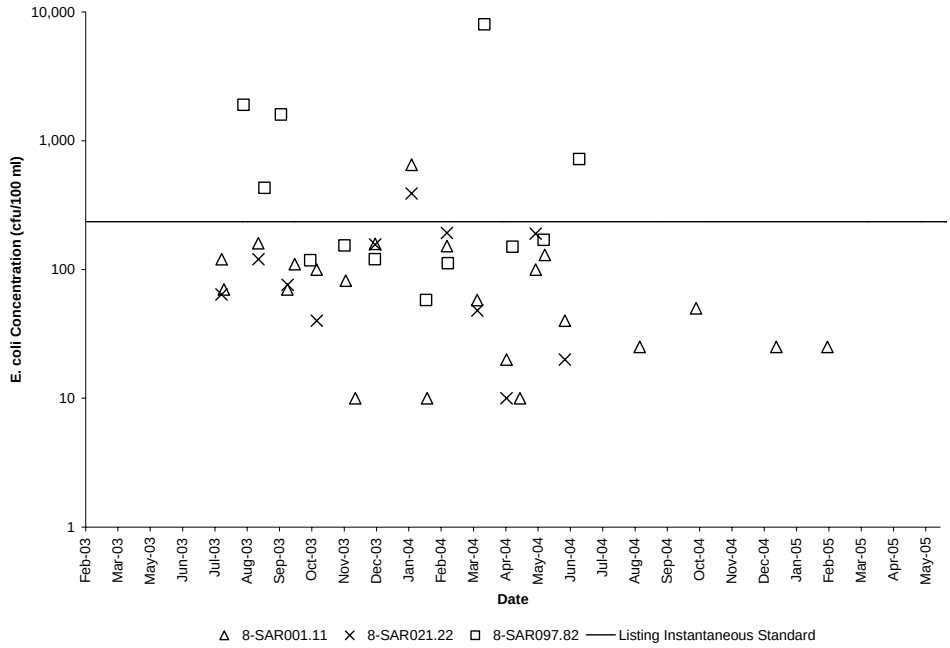

Figure 2.23. *E. coli* concentrations (VADEQ stations 8-SAR001.11, 8-SAR021.22, 8-SAR097.82) in the South Anna River.

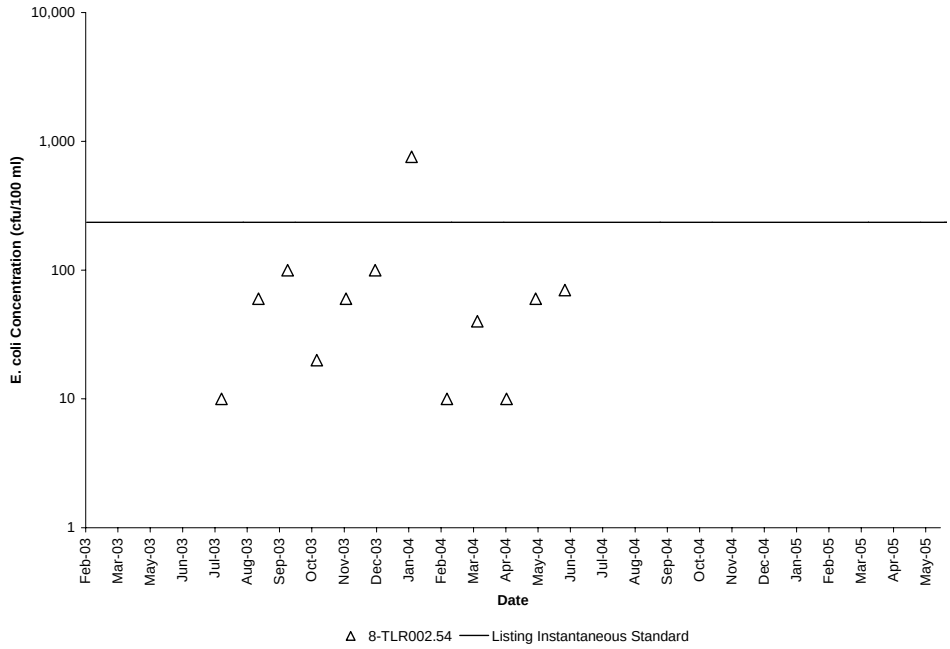

Figure 2.24. *E. coli* concentrations (VADEQ station 8-TLR002.54) in the Taylors Creek (VAN-F03R-01) impairment.

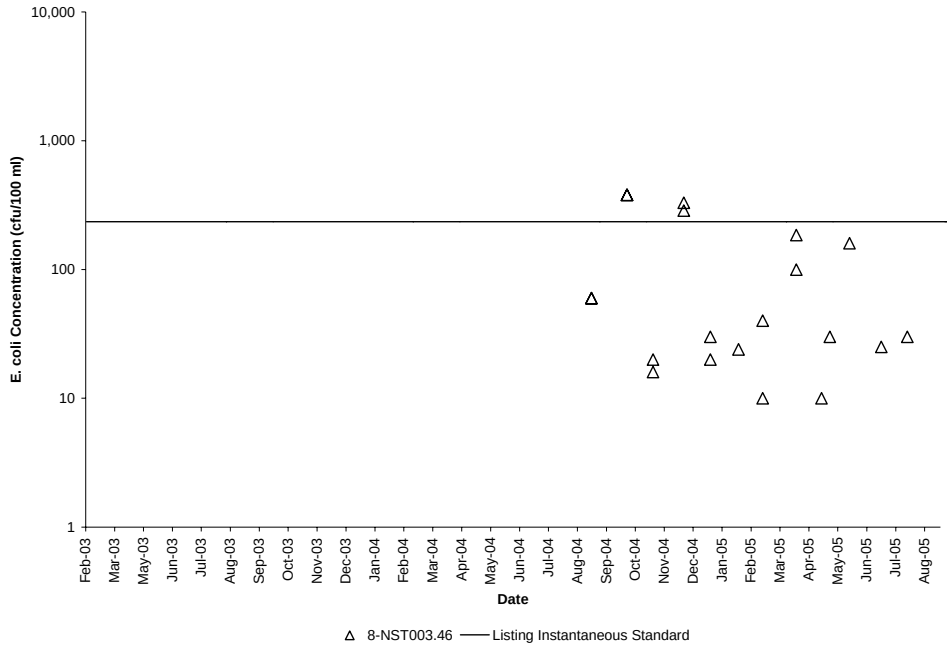

Figure 2.25. *E. coli* concentrations (VADEQ station 8-NST003.46) in the Northeast Creek (VAP-F09R-01) impairment.

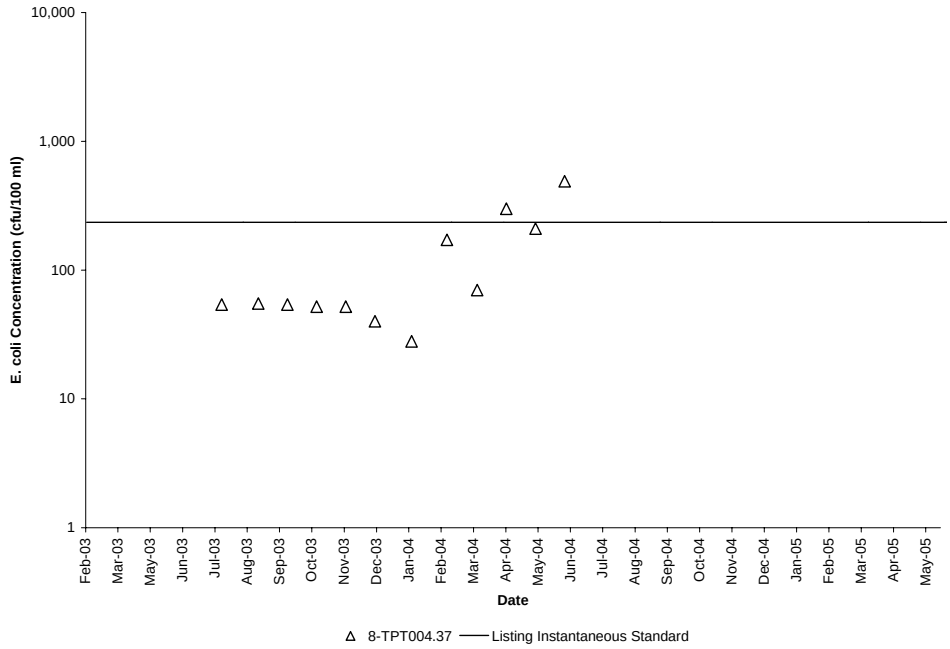

Figure 2.26. *E. coli* concentrations (VADEQ station 8-TPT004.37) in the Totopotomoy Creek (VAP-F13R-02) impairment.

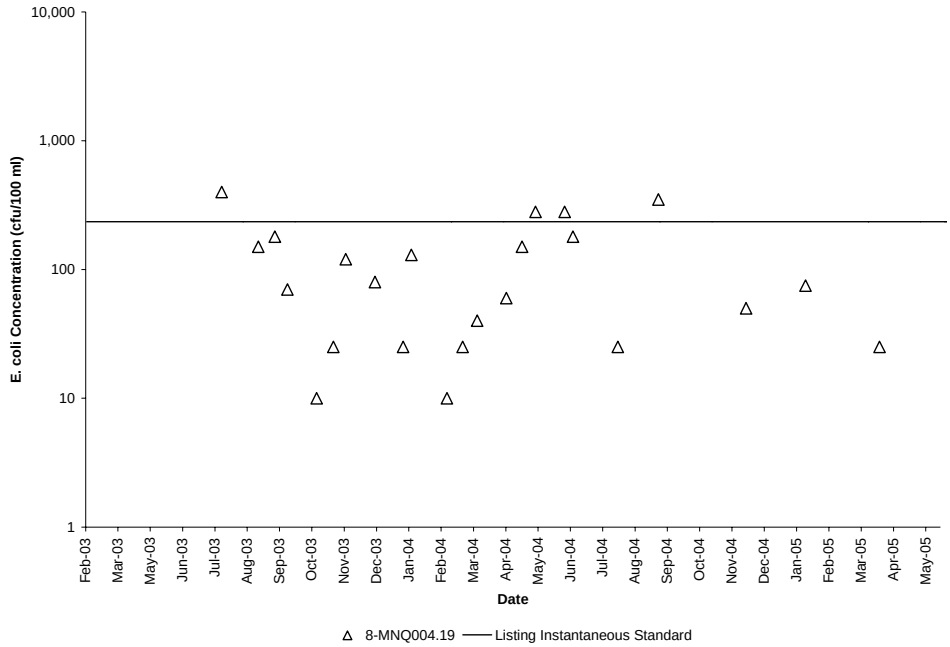

Figure 2.27. *E. coli* concentrations (VADEQ station 8-MNQ004.19) in the Monquin, Web Creek (VAP-F13R-04) impairment.

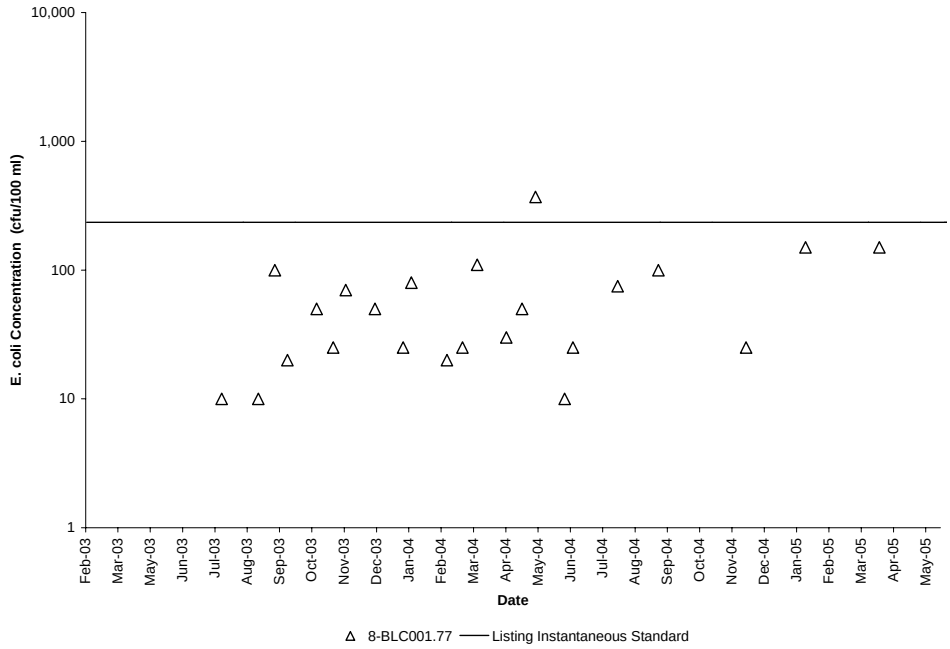

Figure 2.28. *E. coli* concentrations (VADEQ station 8-BLC001.77) in the Black Creek (VAP-F13R-05) impairment.

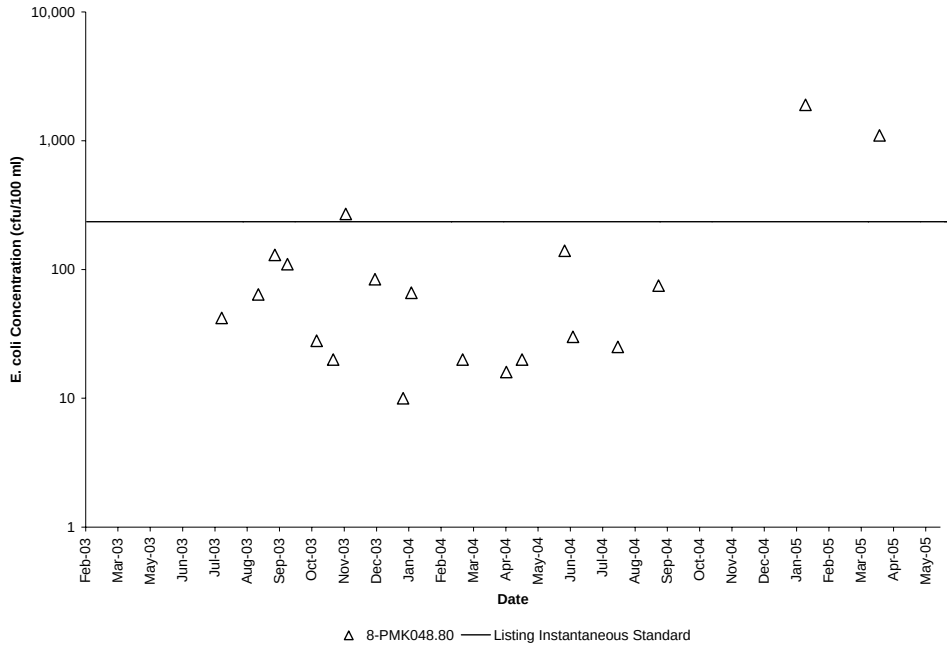

Figure 2.29. *E. coli* concentrations (VADEQ station 8-PMK048.80) in the Pamunkey River (VAP-F13E-02) impairment.

2.5.3 Historic Data for Bacteria Source Tracking

The results from 12 monthly bacteria source tracking (BST) samples collected at stations 8-SAR097.82, 8-SAR021.22, 8-SAR001.11, 8-NST003.46, 8-TPT004.37, and 8-PMK048.80 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 included 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 South Anna River, Northeast Creek, Totopotomoy Creek, and Pamunkey 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 2.9 summarize the results of the presence/absence analysis of the BST data. The BST data were used to verify modeling methods and assumptions.

Table 2.2. Presence/absence analysis of bacteria sources at station 8-SAR097.82 in South Anna (VAN-F01R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	50	40
Human	25	20
Livestock	92	100
Pet	25	20

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

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

Table 2.3. Presence/absence analysis of bacteria sources at station 8-SAR021.22 in South Anna (VAN-F04R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	58	0
Human	8	0
Livestock	75	100
Pet	42	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 2.4. Presence/absence analysis of bacteria sources at station 8-SAR001.11 in South Anna (VAN-F04R-02) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	50	33
Human	25	0
Livestock	67	67
Pet	58	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 2.5. Presence/absence analysis of bacteria sources at station 8-NST003.46 in Northeast Creek (VAP-F09R-01) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	75	0
Human	50	0
Livestock	67	100
Pet	75	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., two) 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 8-TPT004.37 in Totopotomoy Creek (VAP-F13R-02) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	67	60
Human	17	20
Livestock	42	40
Pet	67	60

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

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

Table 2.7. Presence/absence analysis of bacteria sources at station 8-PMK048.80 in Pamunkey River (VAP-F13E-02) watershed.

Bacteria Source	Frequency of Presence in All Samples[1] (%)	Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%)
Wildlife	67	0
Human	33	100
Livestock	75	100
Pet	75	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.

Fecal coliform and *E. coli* enumerations were also performed on the BST samples. These data can also be found in Appendix B. At station 8-SAR097.82, 41.7% (five of 12) of the samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard. The violations occurred in July, August, September of 2003 and March, June of 2004. Two of 12 (16.7%) samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard at station 8-SAR021.22. The violations occurred in August of 2003 and January of 2004. The three violations (25.0%) of either the fecal coliform or E. coli bacteria instantaneous standard occurred in July, August of 2003 and January of 2004 at station 8-SAR001.11. At station 8-NST003.46, 16.7% (2 of 12) of the samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard. The violations occurred in September, November of 2003. Five of 12 (41.7%) samples exceeded either the fecal coliform or E. coli bacteria instantaneous standard at station 8-TPT004.37. The violations occurred in July, August, September of 2003 and April, June of 2004. The two violations (16.7%) of either the fecal coliform or E. coli bacteria instantaneous standard occurred in August, November of 2003at station 8-PMK048.80.

Chapter 3. Bacteria Source Assessment

Potential bacteria sources in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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); Abemarle, Caroline, Fluvanna, Goochland, Hanover, King William, Louisa, New Kent, Orange, and Spotsylvania County Planning Departments; Natural Resources Conservation Service (NRCS); Virginia Department of Agricultural and Consumer Services (VDACS); Colonial, Culpeper, Hanover-Caroline, Monacan, Thomas Jefferson, Three Rivers, 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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
	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 of fecal coliform bacteria in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds include all municipal and industrial plants that treat human waste (individual permits), as well as private residences that fall under general permits (less than or equal to 1,000 gallons per day). Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. Point sources with an individual or general permit were 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Moncuin/Webb Creek (VAP-F13R-04) watersheds, there are no active permitted facilities discharging bacteria in the Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 facilities with MS4 permits discharge within the South Anna River, Northeast Creek, Totopotomoy Creek (VAP-F13R-02), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds.

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

Impairment	Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	*E. coli* Load (cfu/yr)
SA 01	VA0021105	Gordonsville Sewage Treatment Plant	SAR-2	0.940	2.6E+12	1.6E+12
SA 02	VA0088706	Virginia Oil - Zion Crossroads	SAR-6	0.040	1.1E+11	6.9E+10
SA 02	VA0090743	Zion Crossroads WWTP	SAR-6	0.700	1.9E+12	1.2E+12
SA 02	VA0076678	Shenandoah Crossing	SAR-6	0.100	2.8E+11	1.7E+11
SA 02	VAG116048	Ready Mixed Concrete	SAR-06	0.001	2.7E+09	1.7E+09
SA 02	VAG251002	Klochner Pentaplast -	SAR-06	0.001	2.7E+09	1.7E+09
SA 02	VAG406073	Residence	SAR-06	0.001	2.7E+09	1.7E+09
SA 02	VA0088421	Twin Oaks Community STP	SAR-12	0.010	2.8E+10	1.7E+10
SA 03	VA0067954	Louisa Regional Sewage	SAR-14	0.400	1.1E+12	7.0E+11
SA 03	VA0090409	Gum Spring Sewage	SAR-15	0.016	4.4E+10	2.8E+10
SA 03	VA0090140	Six O Five Village M H P STP	SAR-15	0.040	1.1E+11	7.0E+10
SA 03	VA0067105	Missionary Learning Center	SAR-16	0.025	6.9E+10	4.4E+10
SA 03	VAG404000	Resident	SAR-20	0.0005	1.3E+09	7.9E+08
SA 03	VAG404200	Elks Lodge 45	SAR-20	0.0005	1.4E+09	9.0E+08
SA 03	VAG404205	Resident	SAR-20	0.001	2.7E+09	1.7E+09
SA 03	VAG404210	Resident	SAR-20	0.0005	1.3E+09	7.9E+08
SA 03	VAG404217	Resident	SAR-20	0.0006	1.6E+09	1.0E+09
SA 03	VA0022641	Patrick Henry High School	SAR-21	0.040	1.1E+11	7.0E+10
SA 03	VA0060232	Country Club Hills Lagoon	SAR-21	0.060	1.7E+11	1.0E+11
SA 03	VAG404222	Resident	SAR-21	0.0005	1.3E+09	7.9E+08
SA 03	VAG404066	Lees Mobil Service	SAR-21	0.001	2.7E+09	1.7E+09
SA 04	VA0024899	Ashland WWTP	SAR-27	2.000	5.5E+12	3.5E+12
Moncuin / Webb	VA0088102	King William STP	PAR-6	0.050	1.4E+11	8.7E+10

SA 01= South Anna River (VAN-F01R-01) Impairment; SA 02= South Anna River (VAN-F02R-01) Impairment
SA 03= South Anna River (VAN-F04R-01) Impairment; SA 04= South Anna River (VAN-F04R-02) Impairment

3.2 South Anna River (VAN-F01R-01) Sources

3.2.1 Humans and Pets

There are 114 homes served by municipal sanitary sewer in the South Anna River (VAN-F01R-01) watershed. Wastewater from 153 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The South Anna River (VAN-F01R-01) watershed has an estimated population of 590 people (268 households at an average of 2.20 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 1.15×10^{12} cfu/day (4.20×10^{14} cfu/year) in South Anna River (VAN-F01R-01) watershed.

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

3.2.1.1 Failing Septic Systems

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

Total septic systems were classified into one of three age categories (pre-1984, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the South Anna River (VAN-F01R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was

determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.33 persons/household was 4.29×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.4.

3.2.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 ft of streams and 2% of mid-age houses (1967 – 1987) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded two houses that potentially could be classified as straight pipes in the South Anna River (VAN-F01R-01) watershed (Table 3.4).

3.2.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 2,809 acres; 3,095 acres; 1,759 acres; and 863 acres in 2000, 2001, 2002, and 2003, respectively, in Orange County. Class B biosolids were applied to 1,108 acres and 734 acres in 2001 and 2003, respectively, in Albemarle County. In Louisa County, 5,326 acres; 1,505 acres; 969 acres; and 1,503 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the South Anna River (VAN-F01R-01) watershed were not available. To estimate biosolid applications within each South Anna River (VAN-F01R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 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 through 4.4 for location of subwatersheds).

Table 3.3. Estimated average annual biosolids application amount for each subwatershed in the South Anna River (VAN-F01R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-1	127
SAR-2	147
SAR-3	56
SAR-4	17
Total	**347**

3.2.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 142 dogs and 161 cats were projected to reside in the South Anna River (VAN-F01R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 268 for South Anna River (VAN-F01R-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 South Anna River (VAN-F01R-01) watershed is 1.2×10^{11} cfu/day (4.4×10^{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 sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the South Anna River (VAN-F01R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-1	254	43	75	0	0	30	1	120
SAR-2	214	62	24	8	0	11	1	95
SAR-3	102	8	27	5	4	12	0	44
SAR-4	21	0	5	1	2	2	0	9
Total	**590**	**114**	**131**	**14**	**6**	**55**	**2**	**268**

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

3.2.3 Livestock Sources

In the South Anna River (VAN-F01R-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 South Anna River (VAN-F01R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.2.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the South Anna River (VAN-F01R-01) watershed. Based on information provided, it was determined that there were 160 milk cows, 80 dry cows, and 80 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.5). Beef cattle in the South Anna River (VAN-F01R-01) watershed (146 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 South Anna River (VAN-F01R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
SAR-1	0	0	130
SAR-2	0	0	143
SAR-3	320	1	40
SAR-4	0	0	12
Total	**320**	**1**	**325**

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

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on

discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

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

Table 3.6. Time spent by cattle in confinement and in the stream in South Anna River (VAN-F01R-01) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time,

the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.7 for dairy cattle and in Tables 3.8 for beef cattle.

Table 3.7. Distribution of the dairy cattle[a] population in the South Anna River (VAN-F01R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	184.00	73.09	18.30	4.58	0.03	40.00
February	184.00	73.09	18.30	4.58	0.03	40.00
March	64.00	121.80	30.50	7.63	0.08	96.00
April	48.00	121.78	30.50	7.62	0.10	112.00
May	48.00	121.74	30.49	7.62	0.15	112.00
June	48.00	121.59	30.45	7.61	0.35	112.00
July	48.00	121.59	30.45	7.61	0.35	112.00
August	48.00	121.59	30.45	7.61	0.35	112.00
September	48.00	121.74	30.49	7.62	0.15	112.00
October	48.00	121.78	30.50	7.62	0.10	112.00
November	64.00	121.80	30.50	7.63	0.08	96.00
December	184.00	73.09	18.30	4.58	0.03	40.00

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

Table 3.8. Distribution of the beef cattle population (pairs) in the South Anna River (VAN-F01R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	284.55	71.26	17.82	0.12	0.00
February	0.00	334.04	83.66	20.91	0.14	0.00
March	0.00	343.89	86.12	21.53	0.21	0.00
April	0.00	353.73	88.59	22.15	0.29	0.00
May	0.00	363.51	91.04	22.76	0.45	0.00
June	0.00	372.93	93.40	23.35	1.07	0.00
July	0.00	382.81	95.87	23.97	1.10	0.00
August	0.00	392.69	98.34	24.59	1.13	0.00
September	0.00	403.07	100.94	25.24	0.50	0.00
October	0.00	247.36	61.95	15.49	0.20	0.00
November	0.00	259.77	65.06	16.26	0.16	0.00
December	0.00	272.18	68.16	17.04	0.11	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 South Anna River (VAN-F01R-01) watersheds is 14,312 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.79×10^{10} cfu/day (6.52×10^{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

Dairy (Table 3.7) and beef (Table 3.8) cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of each type of cattle (milk cow, dry cow, heifer, and beef) on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the South Anna River (VAN-F01R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,852; 3,428; and 1,711 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 South Anna River (VAN-F01R-01), averaged over the year, are 3.14×10^{12}, 1.58×10^{12}, and 7.88×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.2.3.4 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 South Anna River (VAN-F01R-01) watershed is 425,102 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 3.4 acres of cropland and 103.2 acres of pasture 1 in the South Anna River (VAN-F01R-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 3.9. Dry cows and heifers were assumed to produce only solid manure.

Table 3.9. Schedule of cattle waste application in South Anna River (VAN-F01R-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.

3.2.3.5 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 3.10.

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 3.10). 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 3.10). 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 3.9. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 0.0 acres of the cropland and 18.7 acres of the pasture 1 in South Anna River (VAN-F01R-01) received solid manure application.

Table 3.10. 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 South Anna River (VAN-F01R-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	80	1,400	115.0	2.17	4.20
Heifer	80	640	40.7	2.17	
Beef (pairs)	325	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.2.4 Horses

The estimated number of horses in the South Anna River (VAN-F01R-01) watershed is included in Table 3.11. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the South Anna River (VAN-F01R-01) watershed is $2.85x10^{10}$ cfu/day ($1.04x10^{13}$ cfu/year).

Table 3.11. Horse population by subwatershed in the South Anna River (VAN-F01R-01) watershed.

Subwatershed	Horses
SAR-1	25
SAR-2	33
SAR-3	8
SAR-4	2
Total	**68**

3.2.5 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 South Anna River (VAN-F01R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.2.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.14. The total wildlife fecal coliform production each year in the South Anna River (VAN-F01R-01) watershed, is 4.21×10^{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 3.12).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.12). 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 3.12, 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 3.13.

Table 3.12. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the South Anna River (VAN-F01R-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	0.021	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	0.037[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	0.005[c]	0.00

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

Table 3.13. Distribution of wildlife among sub-watersheds in South Anna River (VAN-F01R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-1	64	24	95	2	12	4	5
SAR-2	60	30	50	3	19	5	4
SAR-3	28	19	18	2	9	3	5
SAR-4	5	7	7	1	2	1	1
Total	**157**	**80**	**170**	**8**	**42**	**13**	**15**

3.2.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the South Anna River (VAN-F01R-01) watershed along with average fecal coliform production rates are shown in Table 3.14. The total fecal coliform production by all sources in the South Anna River (VAN-F01R-01) watershed is 8.03×10^{15} cfu/yr.

Table 3.14. Potential fecal coliform sources and daily fecal coliform production by source in South Anna River (VAN-F01R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x106^6$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	240	25,000	6,004,110
Heifers	80	8,800	914,912
Beef Cattle (pairs)	325	33,000	14,500,420
Horses	68	420	28,580
Humans	482	1,950	254,902
Pets	206	450	120,565
Deer	157	350	54,988
Raccoon	80	50	4,003
Muskrat	170	25	4,253
Beaver	8	0.2	2
Wild Turkey	15	93	1,396
Duck	13	2,400	25,172
Goose	42	800	25,557

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.15. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.15.

From Table 3.15, it is clear in the South Anna River (VAN-F01R-01) watershed that nonpoint source loadings to the land surface are more than 484 times as large as direct loadings to the streams, with pastures receiving about 98% 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 3.15. Annual fecal coliform loadings to the stream and the various land use categories in the South Anna River (VAN-F01R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	319	0.04
Cattle in Stream	653	0.09
Wildlife in Stream	537	0.07
Loading to Land Surfaces		
Cropland	109	0.01
Pasture 1	480,956	65.67
Pasture 2	120,180	16.41
Pasture 3	113,676	15.52
Forest	2,515	0.34
Residential*	13,385	1.83
Total	732,331	100.00

*Includes loads received from failed septic systems and pets.

3.3 South Anna River (VAN-F02R-01) Sources

3.3.1 Humans and Pets

There are 315 homes served by municipal sanitary sewer in the South Anna River (VAN-F02R-01) watershed. Wastewater from 3,102 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The South Anna River (VAN-F02R-01) watershed has an estimated population of 7,746 people (3,417 households at an average of 2.27 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $1.51x10^{13}$ cfu/day ($5.51x10^{15}$ cfu/year) in South Anna River (VAN-F02R-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, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the South Anna River (VAN-F02R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.27 persons/household was 4.42×10^9 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 3.17.

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 18 houses that potentially could be classified as straight pipes in the South Anna River (VAN-F02R-01) watershed (Table 3.17).

3.3.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 5,326 acres; 1,505 acres; 969 acres; and 1,503 acres in 2000, 2001, 2002, and 2003, respectively, in Louisa County. Class B biosolids were applied to 1,108 acres and 734 acres in 2001 and 2003, respectively, in Albemarle County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the South Anna River (VAN-F02R-01) watershed were not available. To estimate biosolid applications within each South Anna River (VAN-F02R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 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. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.16 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.16. Estimated average annual biosolids application amount for each subwatershed in the South Anna River (VAN-F02R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-5	229
SAR-6	1,323
SAR-7	823
SAR-8	301
SAR-9	13
SAR-10	124
SAR-11	20
SAR-12	92
SAR-13	16
Total	**2,941**

3.3.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 1,811 dogs and 2,050 cats were projected to reside in the South Anna River (VAN-F02R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 3,416 for South Anna River (VAN-F02R-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 South Anna River (VAN-F02R-01) watershed is 1.5×10^{12} cfu/day (5.6×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.17. 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 3.17. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the South Anna River (VAN-F02R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-5	723	19	217	28	62	94	4	331
SAR-6	2,839	33	630	193	350	301	8	1,214
SAR-7	2,362	115	599	150	185	275	4	1,053
SAR-8	468	2	114	43	41	55	1	201
SAR-9	39	2	8	2	4	4	0	16
SAR-10	996	125	250	31	60	108	0	466
SAR-11	119	11	22	4	12	10	0	49
SAR-12	177	5	40	13	17	19	1	76
SAR-13	25	2	5	1	3	2	0	10
Total	**7,746**	**315**	**1,885**	**465**	**734**	**868**	**18**	**3,416**

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

3.3.3 Livestock Sources

In the South Anna River (VAN-F02R-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 South Anna River (VAN-F02R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.3.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the South Anna River (VAN-F01R-01) watershed. Based on information provided, it was determined that there were 160 milk cows, 80 dry cows, and 80 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 South Anna River (VAN-F02R-01) watershed (2,324 pairs) included cow/calf and feeder operations (Table 3.18).

Table 3.18. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in South Anna River (VAN-F02R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
SAR-5	0	0	344
SAR-6	320	1	962
SAR-7	0	0	600
SAR-8	0	0	224
SAR-9	0	0	10
SAR-10	0	0	90
SAR-11	0	0	15
SAR-12	0	0	67
SAR-13	0	0	12
Total	**320**	**1**	**2,324**

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

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

- Cows are confined according to the schedule given in Table 3.19.
- 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 3.19). 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 3.19. Time spent by cattle in confinement and in the stream in South Anna River (VAN-F02R-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 3.20 for dairy cattle and in Table 3.21 for beef cattle.

Table 3.20. Distribution of the dairy cattle[a] population in the South Anna River (VAN-F02R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	184.00	73.09	18.30	4.58	0.03	40.00
February	184.00	73.09	18.30	4.58	0.03	40.00
March	64.00	121.80	30.50	7.63	0.08	96.00
April	48.00	121.78	30.50	7.62	0.10	112.00
May	48.00	121.74	30.49	7.62	0.15	112.00
June	48.00	121.59	30.45	7.61	0.35	112.00
July	48.00	121.59	30.45	7.61	0.35	112.00
August	48.00	121.59	30.45	7.61	0.35	112.00
September	48.00	121.74	30.49	7.62	0.15	112.00
October	48.00	121.78	30.50	7.62	0.10	112.00
November	64.00	121.80	30.50	7.63	0.08	96.00
December	184.00	73.09	18.30	4.58	0.03	40.00

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

Table 3.21. Distribution of the beef cattle population (pairs) in the South Anna River (VAN-F02R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	2,034.78	509.59	127.40	0.84	0.00
February	0.00	2,388.66	598.21	149.55	0.98	0.00
March	0.00	2,459.05	615.84	153.96	1.51	0.00
April	0.00	2,529.42	633.46	158.37	2.08	0.00
May	0.00	2,599.36	650.98	162.74	3.20	0.00
June	0.00	2,666.75	667.85	166.96	7.68	0.00
July	0.00	2,737.39	685.55	171.39	7.88	0.00
August	0.00	2,808.03	703.24	175.81	8.08	0.00
September	0.00	2,882.28	721.83	180.46	3.55	0.00
October	0.00	1,768.82	442.98	110.75	1.45	0.00
November	0.00	1,857.55	465.20	116.30	1.14	0.00
December	0.00	1,946.31	487.43	121.86	0.80	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 both dairy (Table 3.20) and beef cattle (Table 3.21) 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 South Anna River (VAN-F02R-01) watersheds is 76,136 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.11×10^{11} cfu/day (4.05×10^{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

Dairy (Table 3.20) and beef (Table 3.21) 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 South Anna River (VAN-F02R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 4,936; 2,468; and 1,233 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 South Anna River (VAN-F02R-01), averaged over the year, are 2.65×10^{12}, 1.33×10^{12}, and 6.64×10^{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.

3.3.3.4 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 South Anna River (VAN-F02R-01) watershed is 425,102 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 64.4 acres of cropland and 0.0 acres of pasture 1 in the South Anna River (VAN-F02R-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 3.22. Dry cows and heifers were assumed to produce only solid manure.

Table 3.22. Schedule of cattle waste application in South Anna River (VAN-F02R-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.

3.3.3.5 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 3.27). 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 3.22. Based on availability of land and poultry litter, as well as the assumptions regarding application rate, 676.5 acres of the cropland and 73.0 acres of the pasture 1 in South Anna River (VAN-F02R-01) watershed received poultry litter application.

3.3.3.6 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 3.23.

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 3.23). 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 3.23). 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 3.22. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 0.0 acres of the cropland and 18.7 acres of the pasture 1 in South Anna River (VAN-F02R-01) received solid manure application.

Table 3.23. 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 South Anna River (VAN-F02R-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	80	1,400	115.0	2.17	5.23
Heifer	80	640	40.7	2.17	
Beef (pairs)	2,324	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.3.4 Horses

The estimated number of horses in the South Anna River (VAN-F02R-01) watershed is included in Table 3.24. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the South Anna River (VAN-F02R-01) watershed is $2.12x10^{11}$ cfu/day ($7.73x10^{13}$ cfu/year).

Table 3.24. Horse population by subwatershed in the South Anna River (VAN-F02R-01) watershed.

Subwatershed	Horses
SAR-5	130
SAR-6	181
SAR-7	113
SAR-8	43
SAR-9	2
SAR-10	17
SAR-11	3
SAR-12	13
SAR-13	2
Total	**504**

3.3.5 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 South Anna River (VAN-F02R-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 3.27 The total wildlife fecal coliform production each year in the South Anna River (VAN-F02R-01) watershed, is 5.66×10^{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 3.25).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.25). 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 3.25, 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 3.26.

Table 3.25. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the South Anna River (VAN-F02R-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	0.021	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	0.037[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	0.005[c]	0.00

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

Table 3.26. Distribution of wildlife among sub-watersheds in South Anna River (VAN-F02R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-5	316	174	348	18	157	27	30
SAR-6	667	605	629	63	206	72	103
SAR-7	486	565	707	60	150	52	82
SAR-8	174	218	123	23	57	19	29
SAR-9	10	10	2	1	3	1	2
SAR-10	133	111	56	12	41	14	27
SAR-11	20	27	2	3	6	2	4
SAR-12	56	57	45	6	17	6	9
SAR-13	5	9	4	1	1	0	1
Total	157	1776	1916	187	638	193	287

3.3.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the South Anna River (VAN-F02R-01) watershed along with average fecal coliform production rates are shown in Table 3.27. The total fecal coliform production by all sources in the South Anna River (VAN-F02R-01) watershed is 4.49×10^{16} cfu/yr.

Table 3.27. Potential fecal coliform sources and daily fecal coliform production by source in South Anna River (VAN-F02R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	240	25,000	600,411
Heifers	80	8,800	91,491
Beef Cattle (pairs)	2,324	33,000	10,368,916
Horses	504	420	21,182
Turkey	50,400		445,589
Humans	7,764	1,950	403,244
Pets	3,416	450	153,886
Deer	1,867	350	65,390
Raccoon	1,776	50	8,886
Muskrat	1,916	25	4,793
Beaver	187	0.2	4
Wild Turkey	287	93	2,671
Duck	193	2,400	34,858
Goose	638	800	38,331

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.28. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.28.

From Table 3.28, it is clear in the South Anna River (VAN-F02R-01) watershed that nonpoint source loadings to the land surface are more than 288 times as large as direct loadings to the streams, with pastures receiving about 94% 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 3.28. Annual fecal coliform loadings to the stream and the various land use categories in the South Anna River (VAN-F02R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	3,000	0.07
Cattle in Stream	4,053	0.10
Wildlife in Stream	7,689	0.18
Loading to Land Surfaces		
Cropland	11,849	0.28
Pasture 1	2,976,755	69.82
Pasture 2	748,272	17.55
Pasture 3	270,574	6.35
Forest	40,882	0.96
Residential*	200,352	4.70
Total	**4,263,426**	**100.00**

*Includes loads received from failed septic systems and pets.

3.4 South Anna River (VAP-F04R-01) Sources

3.4.1 Humans and Pets

There are 423 homes served by municipal sanitary sewer in the South Anna River (VAP-F04R-01) watershed. Wastewater from 6,143 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The South Anna River (VAP-F04R-01) watershed has an estimated population of 16,466 people (6,566 households at an average of 2.51 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $3.21x10^{13}$ cfu/day ($1.17x10^{16}$ cfu/year) in South Anna River (VAP-F04R-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.

3.4.1.1 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, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the South Anna River (VAP-F04R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.51 persons/household was 4.89×10^9 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 3.30.

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 37 houses that potentially could be classified as straight pipes in the South Anna River (VAP-F04R-01) watershed (Table 3.30.

3.4.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 147 acres; 844 acres; and 881 acres in 2001, 2002, and 2003, respectively, in Goochland County. Class B biosolids were applied 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively in Hanover County. In Louisa County, 5,326 acres; 1,505 acres; 969 acres; and 1,503 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the South Anna River (VAP-F04R-01) watershed were not available. To estimate biosolid applications within each South Anna River (VAP-F04R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 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. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.29 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.29. Estimated average annual biosolids application amount for each subwatershed in the South Anna River (VAP-F04R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-14	221
SAR-15	2,618
SAR-16	1,010
SAR-20	364
SAR-21	174
SAR-26	13
Total	**4,400**

3.4.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 3,480 dogs and 3,940 cats were projected to reside in the South Anna River (VAP-F04R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 6,566 for South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-01) watershed is 3.0×10^{12} cfu/day (1.1×10^{15} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.30. 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 3.30. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the South Anna River (VAP-F04R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-14	979	116	195	15	85	84	3	414
SAR-15	6,098	102	1,427	489	528	684	10	2,556
SAR-16	4,830	26	982	358	468	478	14	1,848
SAR-20	3,192	68	708	210	216	332	9	1,211
SAR-21	1,266	108	290	74	26	132	1	499
SAR-26	99	4	22	4	8	10	0	39
Total	**16,466**	**423**	**3,624**	**1,150**	**1,332**	**1,720**	**37**	**6,566**

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

3.4.3 Livestock Sources

In the South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-01) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.4.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the South Anna River (VAP-F04R-01) watershed. Based on information provided, it was determined that there were 350 milk cows, 175 dry cows, and 175 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.31). Beef cattle in the South Anna River (VAP-F04R-01) watershed (3,408 pairs) included cow/calf and feeder operations (Table 3.31).

Table 3.31. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in South Anna River (VAP-F04R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
SAR-14	0	0	160
SAR-15	0	0	1,935
SAR-16	0	0	847
SAR-20	700	1	308
SAR-21	0	0	147
SAR-26	0	0	11
Total	**700**	**1**	**3,408**

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

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

- Cows are confined according to the schedule given in Table 3.32.
- 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 3.32). 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 3.32. Time spent by cattle in confinement and in the stream in South Anna River (VAP-F04R-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 3.33 for dairy cattle and in Table 3.34 for beef cattle.

Table 3.33. Distribution of the dairy cattle[a] population in the South Anna River (VAP-F04R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	402.50	159.88	40.04	10.01	0.07	87.50
February	402.50	159.88	40.04	10.01	0.07	87.50
March	140.00	266.43	66.72	16.68	0.16	210.00
April	105.00	266.39	66.71	16.68	0.22	245.00
May	105.00	266.31	66.69	16.67	0.33	245.00
June	105.00	265.97	66.61	16.65	0.77	245.00
July	105.00	265.97	66.61	16.65	0.77	245.00
August	105.00	265.97	66.61	16.65	0.77	245.00
September	105.00	266.31	66.69	16.67	0.33	245.00
October	105.00	266.39	66.71	16.68	0.22	245.00
November	140.00	266.43	66.72	16.68	0.16	210.00
December	402.50	159.88	40.04	10.01	0.07	87.50

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

Table 3.34. Distribution of the beef cattle population (pairs) in the South Anna River (VAP-F04R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	2,983.88	747.28	186.82	1.22	0.00
February	0.00	3,502.82	877.24	219.31	1.44	0.00
March	0.00	3,606.04	903.09	225.77	2.22	0.00
April	0.00	3,709.23	928.93	232.23	3.05	0.00
May	0.00	3,811.79	954.62	238.65	4.70	0.00
June	0.00	3,910.62	979.37	244.84	11.26	0.00
July	0.00	4,014.21	1,005.31	251.33	11.56	0.00
August	0.00	4,117.80	1,031.25	257.81	11.85	0.00
September	0.00	4,226.68	1,058.52	264.63	5.21	0.00
October	0.00	2,593.87	649.60	162.40	2.13	0.00
November	0.00	2,723.99	682.19	170.55	1.68	0.00
December	0.00	2,854.15	714.79	178.70	1.17	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 both dairy (Table 3.33) and beef cattle (Table 3.34) 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 South Anna River (VAP-F04R-01) watersheds is 114,721 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.65×10^{11} cfu/day (6.01×10^{13} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.4.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.33) and beef (Table 3.34) 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 South Anna River (VAP-F04R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 4,580; 2,292; and 1,142 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 South Anna River (VAP-F04R-01), averaged over the year, are 2.47×10^{12}, 1.25×10^{12}, and 6.09×10^{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.

3.4.3.4 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 South Anna River (VAP-F04R-01) watershed is 929,911 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 140.9 acres of cropland and 0.0 acres of pasture 1 in the South Anna River (VAP-F04R-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 3.35. Dry cows and heifers were assumed to produce only solid manure.

Table 3.35. Schedule of cattle waste application in South Anna River (VAP-F04R-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.

3.4.3.5 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 3.40). 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 3.35. Based on availability of land and poultry litter, as well as the assumptions regarding application rate, 1,550.8 acres of the cropland and 437.0 acres of the pasture 1 in South Anna River (VAP-F04R-01) watershed received poultry litter application.

3.4.3.6 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 3.36.

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 3.36). 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 3.36). 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 3.35. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 41.0 acres of the cropland and 0.0 acres of the pasture 1 in South Anna River (VAP-F04R-01) received solid manure application.

Table 3.36. 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 South Anna River (VAP-F04R-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	175	1,400	115.0	2.17	5.11
Heifer	175	640	40.7	2.17	
Beef (pairs)	3,408	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.4.4 Horses

The estimated number of horses in the South Anna River (VAP-F04R-01) watershed is included in Table 3.37. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the South Anna River (VAP-F04R-01) watershed is $5.95x10^{11}$ cfu/day ($2.17x10^{14}$ cfu/year).

Table 3.37. Horse population by subwatershed in the South Anna River (VAP-F04R-01) watershed.

Subwatershed	Horses
SAR-14	30
SAR-15	386
SAR-16	534
SAR-20	308
SAR-21	147
SAR-26	11
Total	**1,416**

3.4.5 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 South Anna

River (VAP-F04R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.4.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.40. The total wildlife fecal coliform production each year in the South Anna River (VAP-F04R-01) watershed, is 1.12×10^{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 3.38).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.38). 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 3.38, 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 3.39.

Table 3.38. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the South Anna River (VAP-F04R-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	0.020	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	0.037[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	0.009[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

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

Table 3.39. Distribution of wildlife among sub-watersheds in South Anna River (VAP-F04R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-14	122	185	158	20	38	13	20
SAR-15	1,654	1235	628	178	542	171	388
SAR-16	705	812	601	86	609	93	105
SAR-20	370	490	325	53	417	57	66
SAR-21	177	203	85	22	200	27	32
SAR-26	15	15	0	2	16	2	3
Total	**3,043**	**2940**	**1797**	**361**	**1822**	**363**	**614**

3.4.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the South Anna River (VAP-F04R-01) watershed along with average fecal coliform production rates are shown in Table 3.40. The total fecal coliform production by all sources in the South Anna River (VAP-F04R-01) watershed is 8.75×10^{16} cfu/yr.

Table 3.40. Potential fecal coliform sources and daily fecal coliform production by source in South Anna River (VAP-F04R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	525	25,000	1,313,399
Heifers	175	8,800	200,137
Beef Cattle (pairs)	3,408	33,000	15,205,364
Horses	1,416	420	59,513
Chicken	207,800	89	5,292,132
Humans	16,466	1,950	883,042
Pets	6,566	450	295,684
Deer	3,043	350	106,578
Raccoon	2,940	50	14,710
Muskrat	1,797	25	4,496
Beaver	361	0.2	7
Wild Turkey	614	93	5,714
Duck	363	2,400	65,523
Goose	1,822	800	109,161

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.41. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.41.

From Table 3.41, it is clear in the South Anna River (VAP-F04R-01) watershed that nonpoint source loadings to the land surface are more than 225 times as large as direct loadings to the streams, with pastures receiving about 90% 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 3.41. Annual fecal coliform loadings to the stream and the various land use categories in the South Anna River (VAP-F04R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	6,853	0.10
Cattle in Stream	6,015	0.09
Wildlife in Stream	17,298	0.25
Loading to Land Surfaces		
Cropland	113,128	1.66
Pasture 1	4,555,604	66.90
Pasture 2	1,145,407	16.82
Pasture 3	461,771	6.78
Forest	80,467	1.18
Residential*	423,382	6.22
Total	**6,809,926**	**100.00**

*Includes loads received from failed septic systems and pets.

3.5 South Anna River (VAP-F04R-02) Sources

3.5.1 Humans and Pets

There are 373 homes served by municipal sanitary sewer in the South Anna River (VAP-F04R-02) watershed. Wastewater from 1,312 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The South Anna River (VAP-F04R-02) watershed has an estimated population of 5,230 people (1,685 households at an average of 3.10 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $1.02x10^{13}$ cfu/day ($3.72x10^{15}$ cfu/year) in South Anna River (VAP-F04R-02) watershed.

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

3.5.1.1 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, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the South Anna River (VAP-F04R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.10 persons/household was 6.05×10^9 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 3.43.

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 one house that potentially could be classified as straight pipes in the South Anna River (VAP-F04R-02) watershed (Table 3.43).

3.5.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively in Hanover County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the South Anna River (VAP-F04R-02) watershed were not available. To estimate biosolid applications within each South Anna River (VAP-F04R-02) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are

typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.42 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.42. Estimated average annual biosolids application amount for each subwatershed in the South Anna River (VAP-F04R-02) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-27	182
SAR-28	10
Total	**192**

3.5.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 893 dogs and 1,011 cats were projected to reside in the South Anna River (VAP-F04R-02) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,685 for South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-02) watershed is 7.6×10^{11} cfu/day (2.8×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.43. 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 3.43. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the South Anna River (VAP-F04R-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			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-27	4,969	354	418	187	641	224	1	1,600
SAR-28	262	19	22	10	34	12	0	85
Total	**5,230**	373	440	197	675	**236**	**1**	**1,685**

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

3.5.3 Livestock Sources

In the South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-02) watershed. Based on information provided, it was determined that there were 155 milk cows, 68 dry cows, and 68 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.44). Beef cattle in the South Anna River (VAP-F04R-02) watershed (162 pairs) included cow/calf and feeder operations (Table 3.44).

Table 3.44. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in South Anna River (VAP-F04R-02) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
SAR-27	311	1	154
SAR-28	0	0	8
Total	**311**	**1**	**162**

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

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

- Cows are confined according to the schedule given in Table 3.45.
- 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 3.45). 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 3.45. Time spent by cattle in confinement and in the stream in South Anna River (VAP-F04R-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 3.46 for dairy cattle and in Table 3.47 for beef cattle.

Table 3.46. Distribution of the dairy cattle[a] population in the South Anna River (VAP-F04R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	178.65	71.26	17.85	4.46	0.03	38.75
February	178.65	71.26	17.85	4.46	0.03	38.75
March	62.00	118.75	29.74	7.43	0.07	93.00
April	46.50	118.73	29.74	7.43	0.10	108.50
May	46.50	118.70	29.73	7.43	0.15	108.50
June	46.50	118.55	29.69	7.42	0.34	108.50
July	46.50	118.55	29.69	7.42	0.34	108.50
August	46.50	118.55	29.69	7.42	0.34	108.50
September	46.50	118.70	29.73	7.43	0.15	108.50
October	46.50	118.73	29.74	7.43	0.10	108.50
November	62.00	118.75	29.74	7.43	0.07	93.00
December	178.65	71.26	17.85	4.46	0.03	38.75

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

Table 3.47. Distribution of the beef cattle population (pairs) in the South Anna River (VAP-F04R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	141.84	35.52	8.88	0.06	0.00
February	0.00	166.51	41.70	10.42	0.07	0.00
March	0.00	171.41	42.93	10.73	0.11	0.00
April	0.00	176.32	44.16	11.04	0.14	0.00
May	0.00	181.19	45.38	11.34	0.22	0.00
June	0.00	185.89	46.55	11.64	0.54	0.00
July	0.00	190.82	47.79	11.95	0.55	0.00
August	0.00	195.74	49.02	12.26	0.56	0.00
September	0.00	200.92	50.32	12.58	0.25	0.00
October	0.00	123.30	30.88	7.72	0.10	0.00
November	0.00	129.49	32.43	8.11	0.08	0.00
December	0.00	135.67	33.98	8.49	0.06	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 3.46) and beef cattle (Table 3.47) 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 South Anna River (VAP-F04R-02) watersheds is 9,165 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.02×10^{10} cfu/day (3.73×10^{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.

3.5.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.46) and beef (Table 3.47) 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 South Anna River (VAP-F04R-02) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 4,183; 2,097; and 1,039 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 South Anna River (VAP-F04R-02), averaged over the year, are 1.84×10^{12}, 9.48×10^{11}, and 4.36×10^{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 South Anna River (VAP-F04R-02) watershed is 411,817 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 62.4 acres of cropland and 0.0 acres of pasture 1 in the South Anna River (VAP-F04R-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 3.48. Dry cows and heifers were assumed to produce only solid manure.

Table 3.48. Schedule of cattle waste application in South Anna River (VAP-F04R-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 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 3.49.

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 3.49). 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 3.49). 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 3.48. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 18.3 acres of the cropland and 0.0 acres of the pasture 1 in South Anna River (VAP-F04R-02) received solid manure application.

Table 3.49. 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 South Anna River (VAP-F04R-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	68	1,400	115.0	2.17	3.76
Heifer	68	640	40.7	2.17	
Beef (pairs)	162	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.5.4 Horses

The estimated number of horses in the South Anna River (VAP-F04R-02) watershed is included in Table 3.50. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the South Anna River (VAP-F04R-02) watershed is $6.82x10^{10}$ cfu/day ($2.49x10^{13}$ cfu/year).

Table 3.50. Horse population by subwatershed in the South Anna River (VAP-F04R-02) watershed.

Subwatershed	Horses
SAR-27	154
SAR-28	8
Total	**162**

3.5.5 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 South Anna River (VAP-F04R-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 3.53. The total wildlife fecal coliform production each year in the South Anna River (VAP-F04R-02) watershed, is 8.67×10^{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 3.51).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.51). 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 3.51, 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 3.52.

Table 3.51. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the South Anna River (VAP-F04R-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	0.019	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	0.037[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	0.021[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.006[c]	0.00

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

Table 3.52. Distribution of wildlife among sub-watersheds in South Anna River (VAP-F04R-02) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-27	157	206	42	22	186	25	25
SAR-28	8	11	2	1	10	1	1
Total	**165**	**217**	**44**	**23**	**196**	**26**	**26**

3.5.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the South Anna River (VAP-F04R-02) watershed along with average fecal coliform production rates are shown in Table 3.14. The total fecal coliform production by all sources in the South Anna River (VAP-F04R-02) watershed is 6.30×10^{15} cfu/yr.

Table 3.53. Potential fecal coliform sources and daily fecal coliform production by source in South Anna River (VAP-F04R-02) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($x106^6$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	233	25,000	5,828,990
Heifers	78	8,800	892,039
Beef Cattle (pairs)	162	33,000	7,227,902
Horses	162	420	68,087
Humans	5,230	1,950	1,466,454
Pets	1,685	450	758,617
Deer	165	350	57,790
Raccoon	217	50	10,857
Muskrat	44	25	1,101
Beaver	23	0.2	5
Wild Turkey	26	93	2,420
Duck	26	2,400	47,924
Goose	196	800	117,385

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.54. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.54.

From Table 3.54, it is clear in the South Anna River (VAP-F04R-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 3.54. Annual fecal coliform loadings to the stream and the various land use categories in the South Anna River (VAP-F04R-02) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	227	0.04
Cattle in Stream	373	0.07
Wildlife in Stream	1,580	0.28
Loading to Land Surfaces		
Cropland	2,522	0.45
Pasture 1	295,782	52.65
Pasture 2	76,444	13.61
Pasture 3	98,553	17.54
Forest	5,271	0.94
Residential*	80,988	14.42
Total	**561,740**	**100.00**

*Includes loads received from failed septic systems and pets.

3.6 Taylors Creek (VAN-F03R-01) Sources

3.6.1 Humans and Pets

There are no homes served by municipal sanitary sewer in the Taylors Creek (VAN-F03R-01) watershed. Wastewater from 1,252 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Taylors Creek (VAN-F03R-01) watershed has an estimated population of 3,118 people (1,252 households at an average of 2.49 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $6.08x10^{12}$ cfu/day ($2.22x10^{15}$ cfu/year) in Taylors Creek (VAN-F03R-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, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Taylors Creek (VAN-F03R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.49 persons/household was 4.86×10^9 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 3.56.

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 five houses that potentially could be classified as straight pipes in the Taylors Creek (VAN-F03R-01) watershed (Table 3.56).

3.6.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 147 acres; 844 acres; and 881 acres in 2001, 2002, and 2003, respectively, in Goochland County. In Louisa County, 5,326 acres; 1,505 acres; 969 acres; and 1,503 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Taylors Creek (VAN-F03R-01) watershed were not available. To estimate biosolid applications within each Taylors Creek (VAN-F03R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 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. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.55 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.55. Estimated average annual biosolids application amount for each subwatershed in the Taylors Creek (VAN-F03R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-17	205
SAR-18	280
SAR-19	62
Total	**547**

3.6.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 664 dogs and 751 cats were projected to reside in the Taylors Creek (VAN-F03R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,252 for Taylors Creek (VAN-F03R-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 Taylors Creek (VAN-F03R-01) watershed is 5.6×10^{11} cfu/day (2.1×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.56. 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 3.56. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Taylors Creek (VAN-F03R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-17	684	0	118	74	101	65	1	295
SAR-18	1,591	0	287	146	209	150	3	644
SAR-19	842	0	132	93	87	74	1	314
Total	**3,118**	**0**	**536**	**313**	**398**	**289**	**5**	**1,252**

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

3.6.3 Livestock Sources

In the Taylors Creek (VAN-F03R-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 Taylors Creek (VAN-F03R-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 is no dairy farms presently operating in the Taylors Creek (VAN-F03R-01) watershed. Beef cattle in the Taylors Creek (VAN-F03R-01) watershed (423 pairs) included cow/calf and feeder operations (Table 3.57).

Table 3.57. Distribution of beef cattle among subwatersheds in Taylors Creek (VAN-F03R-01) watersheds.

Subwatershed	Beef Cattle (pairs)
SAR-17	149
SAR-18	222
SAR-19	52
Total	**423**

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

- The beef cattle spend their time on pasture.

- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.58). 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 3.58. Time spent by cattle in the stream in Taylors Creek (VAN-F03R-01) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.59 for beef cattle.

Table 3.59. Distribution of the beef cattle population (pairs) in the Taylors Creek (VAN-F03R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	370.36	92.75	23.19	0.15	0.00
February	0.00	434.77	108.88	27.22	0.18	0.00
March	0.00	447.58	112.09	28.02	0.28	0.00
April	0.00	460.39	115.30	28.82	0.38	0.00
May	0.00	473.12	118.49	29.62	0.58	0.00
June	0.00	485.38	121.56	30.39	1.40	0.00
July	0.00	498.24	124.78	31.19	1.43	0.00
August	0.00	511.10	128.00	32.00	1.47	0.00
September	0.00	524.61	131.38	32.85	0.65	0.00
October	0.00	321.95	80.63	20.16	0.26	0.00
November	0.00	338.10	84.67	21.17	0.21	0.00
December	0.00	354.26	88.72	22.18	0.15	0.00

*Number of beef cattle defecating in stream.

3.6.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.59) 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 Taylors Creek (VAN-F03R-01) watersheds is 13,082 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.97×10^{10} cfu/day (7.20×10^{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.

3.6.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.59). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Taylors Creek (VAN-F03R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 3,619; 1,813; and 900 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 Taylors Creek (VAN-F03R-01), averaged over the year, are 2.08×10^{12}, 1.06×10^{12}, and 5.05×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.6.4 Horses

The estimated number of horses in the Taylors Creek (VAN-F03R-01) watershed is included in Table 3.60. 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 Taylors Creek (VAN-F03R-01) watershed is 9.53×10^{10} cfu/day (3.48×10^{13} cfu/year).

Table 3.60. Horse population by subwatershed in the Taylors Creek (VAN-F03R-01) watershed.

Subwatershed	Horses
SAR-17	28
SAR-18	147
SAR-19	52
Total	**227**

3.6.5 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 Taylors Creek (VAN-F03R-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 3.63. The total wildlife fecal coliform production each year in the Taylors Creek (VAN-F03R-01) watershed, is1.94×10^{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 3.61).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.61). 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 3.61, 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 3.62.

Table 3.61. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Taylors Creek (VAN-F03R-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	0.021	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	0.037[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	0.005[c]	0.00

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

Table 3.62. Distribution of wildlife among sub-watersheds in Taylors Creek (VAN-F03R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-17	110	110	25	12	33	12	19
SAR-18	256	297	107	32	238	36	48
SAR-19	88	124	14	14	100	14	19
Total	**454**	**531**	**146**	**58**	**371**	**62**	**86**

3.6.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Taylors Creek (VAN-F03R-01) watershed along with average fecal coliform production rates are shown in Table 3.63. The total fecal coliform production by all sources in the Taylors Creek (VAN-F03R-01) watershed is 8.18×10^{15} cfu/yr.

Table 3.63. Potential fecal coliform sources and daily fecal coliform production by source in Taylors Creek (VAN-F03R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x106^7$ cfu/ day)[b]
Beef Cattle (pairs)	423	33,000	1,887,285
Horses	227	420	9,541
Humans	3,118	1,950	147,175
Pets	1,252	450	56,395
Deer	454	350	15,901
Raccoon	531	50	2,657
Muskrat	146	25	365
Beaver	58	0.2	1
Wild Turkey	86	93	800
Duck	62	2,400	11,140
Goose	371	800	22,240

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.64. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.64.

From Table 3.64, it is clear in the Taylors Creek (VAN-F03R-01) watershed that nonpoint source loadings to the land surface are more than 167 times as large as direct loadings to the streams, with pastures receiving about 89% 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 3.64. Annual fecal coliform loadings to the stream and the various land use categories in the Taylors Creek (VAN-F03R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	907	0.11
Cattle in Stream	720	0.09
Wildlife in Stream	3,237	0.40
Loading to Land Surfaces		
Cropland	468	0.06
Pasture 1	550,474	67.33
Pasture 2	140,520	17.19
Pasture 3	33,498	4.10
Forest	14,365	1.76
Residential*	73,396	8.98
Total	**817,585**	**100.00**

*Includes loads received from failed septic systems and pets.

3.7 Newfound River (VAP-F05R-01) Sources

3.7.1 Humans and Pets

There are 21 homes served by municipal sanitary sewer in the Newfound River (VAP-F05R-01) watershed. Wastewater from 1,070 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Newfound River (VAP-F05R-01) watershed has an estimated population of 2,864 people (1,091 households at an average of 2.63 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $5.58x10^{12}$ cfu/day ($2.04x10^{15}$ cfu/year) in Newfound River (VAP-F05R-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, 1985-1995, and post-1995) based on 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Newfound River (VAP-F05R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 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 3.66.

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 five houses that potentially could be classified as straight pipes in the Newfound River (VAP-F05R-01) watershed (Table 3.66).

3.7.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 147 acres; 844 acres; and 881 acres in 2001, 2002, and 2003, respectively, in Goochland County. Class B biosolids were applied 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively in Hanover County. In Louisa County, 5,326 acres; 1,505 acres; 969 acres; and 1,503 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Newfound River (VAP-F05R-01) watershed were not available. To estimate biosolid applications within each Newfound River (VAP-F05R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 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. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.65 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.65. Estimated average annual biosolids application amount for each subwatershed in the Newfound River (VAP-F05R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
SAR-22	257
SAR-23	73
SAR-24	37
SAR-25	190
Total	**557**

3.7.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 578 dogs and 655 cats were projected to reside in the Newfound River (VAP-F05R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,091 for Newfound River (VAP-F05R-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 Newfound River (VAP-F05R-01) watershed is 4.9×10^{11} cfu/day (1.8×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.66. 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 3.66. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Newfound River (VAP-F05R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
SAR-22	2,001	19	406	142	189	197	2	758
SAR-23	604	1	124	47	59	61	1	233
SAR-24	172	0	34	13	17	17	2	67
SAR-25	86	0	18	7	8	9	0	33
Total	**2,864**	**21**	**583**	**209**	**273**	**284**	**5**	**1,091**

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

3.7.3 Livestock Sources

In the Newfound River (VAP-F05R-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 Newfound River (VAP-F05R-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 two dairy farms presently operating in the Newfound River (VAP-F05R-01) watershed. Based on information provided, it was determined that there were 250 milk cows, 125 dry cows, and 125 heifers distributed between the farms. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.67). Beef cattle in the Newfound River (VAP-F05R-01) watershed (466 pairs) included cow/calf and feeder operations (Table 3.68).

Table 3.67. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Newfound River (VAP-F05R-01) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
SAR-22	0	0	305
SAR-23	500	2	113
SAR-24	0	0	32
SAR-25	0	0	16
Total	**500**	**2**	**466**

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

Cattle spend varying amounts of time in confinement, loafing lots, streams, and pasture depending on the time of year and type of cattle (i.e., milk cow versus heifer). Accordingly, the

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

- Cows are confined according to the schedule given in Table 3.68.
- 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 3.68). 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 3.68. Time spent by cattle in confinement and in the stream in Newfound River (VAP-F05R-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 3.69 for dairy cattle and in Table 3.70 for beef cattle.

Table 3.69. Distribution of the dairy cattle[a] population in the Newfound River (VAP-F05R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	287.50	114.20	28.60	7.15	0.05	62.50
February	287.50	114.20	28.60	7.15	0.05	62.50
March	100.00	190.31	47.66	11.92	0.12	150.00
April	75.00	190.28	47.65	11.91	0.16	175.00
May	75.00	190.22	47.64	11.91	0.23	175.00
June	75.00	189.98	47.58	11.89	0.55	175.00
July	75.00	189.98	47.58	11.89	0.55	175.00
August	75.00	189.98	47.58	11.89	0.55	175.00
September	75.00	190.22	47.64	11.91	0.23	175.00
October	75.00	190.28	47.65	11.91	0.16	175.00
November	100.00	190.31	47.66	11.92	0.12	150.00
December	287.50	114.20	28.60	7.15	0.05	62.50

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

Table 3.70. Distribution of the beef cattle population (pairs) in the Newfound River (VAP-F05R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	408.01	102.18	25.55	0.17	0.00
February	0.00	478.96	119.95	29.99	0.20	0.00
March	0.00	493.08	123.49	30.87	0.30	0.00
April	0.00	507.19	127.02	31.75	0.42	0.00
May	0.00	521.21	130.53	32.63	0.64	0.00
June	0.00	534.73	133.92	33.48	1.54	0.00
July	0.00	548.89	137.46	34.37	1.58	0.00
August	0.00	563.06	141.01	35.25	1.62	0.00
September	0.00	577.94	144.74	36.18	0.71	0.00
October	0.00	354.68	88.82	22.21	0.29	0.00
November	0.00	372.47	93.28	23.32	0.23	0.00
December	0.00	390.27	97.74	24.43	0.16	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 3.69) and beef cattle (Table 3.70) 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 Newfound River (VAP-F05R-01) watersheds is 21,070 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 2.60×10^{10} cfu/day (9.48×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.7.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.69) and beef (Table 3.70) 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 Newfound River (VAP-F05R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 3,515; 1,762; and 873 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 Newfound River (VAP-F05R-01), averaged over the year, are 1.71×10^{12}, 8.83×10^{11}, and 4.04×10^{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.

3.7.3.4 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 Newfound River (VAP-F05R-01) watershed is 664,222 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 100.6 acres of cropland and 0.0 acres of pasture 1 in the Newfound River (VAP-F05R-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 3.71. Dry cows and heifers were assumed to produce only solid manure.

Table 3.71. Schedule of cattle waste application in Newfound River (VAP-F05R-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 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 3.72.

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 3.72). 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 3.72). 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 3.71. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 29.3 acres of the cropland and 0.0 acres of the pasture 1 in Newfound River (VAP-F05R-01) received solid manure application.

Table 3.72. 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 Newfound River (VAP-F05R-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	125	1,400	115.0	2.17	4.13
Heifer	125	640	40.7	2.17	
Beef (pairs)	466	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.7.4 Horses

The estimated number of horses in the Newfound River (VAP-F05R-01) watershed is included in Table 3.73. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Newfound River (VAP-F05R-01) watershed is $1.85x10^{11}$ cfu/day ($6.75x10^{13}$ cfu/year).

Table 3.73. Horse population by subwatershed in the Newfound River (VAP-F05R-01) watershed.

Subwatershed	Horses
SAR-22	279
SAR-23	113
SAR-24	32
SAR-25	16
Total	**440**

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 Newfound River (VAP-F05R-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 3.76. The total wildlife fecal coliform production each year in the Newfound River (VAP-F05R-01) watershed, is 2.50×10^{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 3.74).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.74). 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 3.74, 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 3.75.

Table 3.74. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Newfound River (VAP-F05R-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	0.020	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	0.037[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	0.012[b]	0.25
Wood Duck	300 feet buffer around main streams	0.002[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.005[c]	0.00

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

Table 3.75. Distribution of wildlife among sub-watersheds in Newfound River (VAP-F05R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
SAR-22	306	352	141	38	332	46	49
SAR-23	135	164	122	18	151	21	24
SAR-24	39	47	35	5	43	6	7
SAR-25	19	23	17	3	22	3	3
Total	**499**	**586**	**315**	**64**	**548**	**76**	**83**

3.7.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Newfound River (VAP-F05R-01) watershed along with average fecal coliform production rates are shown in Table 3.76. The total fecal coliform production by all sources in the Newfound River (VAP-F05R-01) watershed is 1.33×10^{16} cfu/yr.

Table 3.76. Potential fecal coliform sources and daily fecal coliform production by source in Newfound River (VAP-F05R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x106^7$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	375	25,000	938,142
Heifers	125	8,800	142,955
Beef Cattle (pairs)	466	33,000	2,079,137
Horses	440	420	18,493
Humans	2,864	1,950	151,852
Pets	1,091	450	49,116
Deer	499	350	17,477
Raccoon	586	50	2,932
Muskrat	315	25	788
Beaver	64	0.2	1
Wild Turkey	83	93	772
Duck	76	2,400	13,776
Goose	548	800	32,860

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.77. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.77.

From Table 3.77, it is clear in the Newfound River (VAP-F05R-01) watershed that nonpoint source loadings to the land surface are more than 190 times as large as direct loadings to the streams, with pastures receiving about 92% of the total fecal coliform load. It could be prematurely assumed that most of the fecal coliform loading in streams originates from upland sources, primarily from pastures. However, other factors such as precipitation (amount and pattern), manure application activities (time and method), type of waste (solid versus liquid manure), proximity to streams and environmental factors also impact the amount of fecal coliform from upland areas that reaches the stream. The HSPF model considers these factors when estimating fecal coliform loads to the receiving waters, as described in Chapter 4.

Table 3.77. Annual fecal coliform loadings to the stream and the various land use categories in the Newfound River (VAP-F05R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	954	0.08
Cattle in Stream	948	0.08
Wildlife in Stream	4,501	0.37
Loading to Land Surfaces		
Cropland	4,097	0.33
Pasture 1	753,729	61.57
Pasture 2	194,831	15.91
Pasture 3	175,184	14.31
Forest	17,557	1.43
Residential*	72,399	5.91
Total	**1,224,201**	**100.00**

*Includes loads received from failed septic systems and pets.

3.8 Northeast Creek (VAP-F09R-01) Sources

3.8.1 Humans and Pets

There are no homes served by municipal sanitary sewer in the Northeast Creek (VAP-F09R-01) watershed. Wastewater from 973 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Northeast Creek (VAP-F09R-01) watershed has an estimated population of 2,353 people (973 households at an average of 2.42 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $4.59x10^{12}$ cfu/day ($1.67x10^{15}$ cfu/year) in Northeast Creek (VAP-F09R-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.

3.8.1.1 Failing Septic Systems

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

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

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Northeast Creek (VAP-F09R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.42 persons/household was 4.72×10^9 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 3.79.

3.8.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded three houses that potentially could be classified as straight pipes in the Northeast Creek (VAP-F09R-01) watershed (Table 3.79).

3.8.1.3 Biosolids

According to VDH records, Class B biosolids were not applied in 2000 to 2003 in Spotsylvania County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Northeast Creek (VAP-F09R-01) watershed were not available. To estimate biosolid applications within each Northeast Creek (VAP-F09R-01) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are typically lower than this value. For this study, VDH

records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.78 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.78. Estimated average annual biosolids application amount for each subwatershed in the Northeast Creek (VAP-F09R-01) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
NEC-1	0
NEC-2	0
NEC-3	0
NEC-1	0
NEC-5	0
Total	**0**

3.8.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 516 dogs and 584 cats were projected to reside in the Northeast Creek (VAP-F09R-01) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 973 for Northeast Creek (VAP-F09R-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 Northeast Creek (VAP-F09R-01) watershed is 4.4×10^{11} cfu/day (1.61×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.79. 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 3.79. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Northeast Creek (VAP-F09R-01) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
NEC-1	913	0	189	93	76	96	1	359
NEC-2	626	0	108	71	94	60	1	275
NEC-3	519	0	90	55	74	49	1	220
NEC-4	236	0	41	20	29	21	0	90
NEC-5	59	0	10	8	11	6	0	29
Total	**2,353**	**0**	**438**	**248**	**284**	**232**	**3**	**973**

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

3.8.3 Livestock Sources

In the Northeast Creek (VAP-F09R-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 Northeast Creek (VAP-F09R-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.

3.8.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farms presently operating in the Northeast Creek (VAP-F09R-01) watershed. Beef cattle in the Northeast Creek (VAP-F09R-01) watershed (245 pairs) included cow/calf and feeder operations (Table 3.80).

Table 3.80. Distribution of beef cattle among subwatersheds in Northeast Creek (VAP-F09R-01) watersheds.

Subwatershed	Beef Cattle (pairs)
NEC-1	88
NEC-2	76
NEC-3	46
NEC-4	26
NEC-5	9
Total	**245**

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the

following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.81). 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 3.81. Time spent by cattle in the stream in Northeast Creek (VAP-F09R-01) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.82 for beef cattle.

Table 3.82. Distribution of the beef cattle population (pairs) in the Northeast Creek (VAP-F09R-01) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	214.51	53.72	13.43	0.09	0.00
February	0.00	251.82	63.06	15.77	0.10	0.00
March	0.00	259.24	64.92	16.23	0.16	0.00
April	0.00	266.66	66.78	16.70	0.22	0.00
May	0.00	274.03	68.63	17.16	0.34	0.00
June	0.00	281.13	70.41	17.60	0.81	0.00
July	0.00	288.58	72.27	18.07	0.83	0.00
August	0.00	296.03	74.14	18.53	0.85	0.00
September	0.00	303.85	76.10	19.02	0.37	0.00
October	0.00	186.47	46.70	11.67	0.15	0.00
November	0.00	195.83	49.04	12.26	0.12	0.00
December	0.00	205.18	51.39	12.85	0.08	0.00

*Number of beef cattle defecating in stream.

3.8.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.82) 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 Northeast Creek (VAP-F09R-01) watersheds is 7,577 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.14×10^{10} cfu/day (4.17×10^{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.

3.8.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.82). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Northeast Creek (VAP-F09R-01) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 3,167; 1,585; and 791 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 Northeast Creek (VAP-F09R-01), averaged over the year, are 1.79×10^{12}, 9.07×10^{11}, and 4.46×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.8.4 Horses

The estimated number of horses in the Northeast Creek (VAP-F09R-01) watershed is included in Table 3.83. 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 Northeast Creek (VAP-F09R-01) watershed is 6.3×10^{10} cfu/day (2.3×10^{13} cfu/year).

Table 3.83. Horse population by subwatershed in the Northeast Creek (VAP-F09R-01) watershed.

Subwatershed	Horses
NEC-1	54
NEC-2	47
NEC-3	28
NEC-4	16
NEC-5	5
Total	**150**

3.8.5 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 Northeast Creek (VAP-F09R-01) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.8.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.86. The total wildlife fecal coliform production each year in the Northeast Creek (VAP-F09R-01) watershed, is 1.84×10^{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 3.84).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.84). 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 3.84, 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 3.85.

Table 3.84. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Northeast Creek (VAP-F09R-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	0.021	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	0.037[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	0.014[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.004[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 3.85. Distribution of wildlife among sub-watersheds in Northeast Creek (VAP-F09R-01) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
NEC-1	203	203	95	22	137	24	25
NEC-2	122	112	31	12	82	15	15
NEC-3	102	91	9	10	68	12	13
NEC-4	47	45	20	5	31	6	6
NEC-5	11	10	12	1	8	1	1
Total	**485**	**461**	**167**	**50**	**326**	**58**	**60**

3.8.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Northeast Creek (VAP-F09R-01) watershed along with average fecal coliform production rates are shown in Table 3.86. The total fecal coliform production by all sources in the Northeast Creek (VAP-F09R-01) watershed is 4.87×10^{15} cfu/yr.

Table 3.86. Potential fecal coliform sources and daily fecal coliform production by source in Northeast Creek (VAP-F09R-01) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x106^7$ cfu/ day)[b]
Beef Cattle (pairs)	245	33,000	1,093,109
Horses	150	420	6,304
Humans	2,353	1,950	114,261
Pets	973	450	43,801
Deer	485	350	16,987
Raccoon	461	50	2,307
Muskrat	167	25	418
Beaver	50	0.2	1
Wild Turkey	60	93	558
Duck	58	2,400	10,542
Goose	326	800	19,565

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.87. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.87.

From Table 3.87, it is clear in the Northeast Creek (VAP-F09R-01) watershed that nonpoint source loadings to the land surface are more than 125 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 3.87. Annual fecal coliform loadings to the stream and the various land use categories in the Northeast Creek (VAP-F09R-01) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	525	0.11
Cattle in Stream	417	0.09
Wildlife in Stream	2,934	0.60
Loading to Land Surfaces		
Cropland	620	0.13
Pasture 1	312,653	64.20
Pasture 2	79,374	16.30
Pasture 3	19,476	4.00
Forest	13,843	2.84
Residential*	57,168	11.74
Total	**487,009**	**100.00**

*Includes loads received from failed septic systems and pets.

3.9 Totopotomoy Creek (VAP-F13R-02) Sources

3.9.1 Humans and Pets

There are 3,116 homes served by municipal sanitary sewer in the Totopotomoy Creek (VAP-F13R-02) watershed. Wastewater from 5,002 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Totopotomoy Creek (VAP-F13R-02) watershed has an estimated population of 24,940 people (8,118 households at an average of 3.07 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $4.86x10^{13}$ cfu/day ($1.78x10^{16}$ cfu/year) in Totopotomoy Creek (VAP-F13R-02) watershed.

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

3.9.1.1 Failing Septic Systems

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

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

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Totopotomoy Creek (VAP-F13R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 3.07 persons/household was 5.99×10^9 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 3.89.

3.9.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 25 houses that potentially could be classified as straight pipes in the Totopotomoy Creek (VAP-F13R-02) watershed (Table 3.89).

3.9.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively, in Hanover County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Totopotomoy Creek (VAP-F13R-02) watershed were not available. To estimate biosolid applications within each Totopotomoy Creek (VAP-F13R-02) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by treatment plants are

typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.88 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.88. Estimated average annual biosolids application amount for each subwatershed in the Totopotomoy Creek (VAP-F13R-02) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
TOC-1	41
TOC-2	77
TOC-3	105
TOC-1	46
TOC-5	77
Total	**346**

3.9.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 4,303 dogs and 4,871 cats were projected to reside in the Totopotomoy Creek (VAP-F13R-02) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 8,118 for Totopotomoy Creek (VAP-F13R-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 Totopotomoy Creek (VAP-F13R-02) watershed is 3.7×10^{12} cfu/day (1.3×10^{15} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.89. 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 3.89. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Totopotomoy Creek (VAP-F13R-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			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
TOC-1	16,460	2,477	555	647	1,323	391	6	5,008
TOC-2	5,568	386	1,048	290	349	488	8	2,081
TOC-3	2,058	243	247	215	0	142	5	710
TOC-4	337	7	73	22	21	34	3	126
TOC-5	518	3	108	40	39	52	3	194
Total	**24,940**	**3,116**	**2,030**	**1,215**	**1,733**	**1,107**	**25**	**8,118**

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

3.9.3 Livestock Sources

In the Totopotomoy Creek (VAP-F13R-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 Totopotomoy Creek (VAP-F13R-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.

3.9.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farms presently operating in the Totopotomoy Creek (VAP-F13R-02) watershed. Beef cattle in the Totopotomoy Creek (VAP-F13R-02) watershed (293 pairs) included cow/calf and feeder operations (Table 3.90).

Table 3.90. Distribution of beef cattle among subwatersheds in Totopotomoy Creek (VAP-F13R-02) watersheds.

Subwatershed	Beef Cattle (pairs)
TOC-1	35
TOC-2	65
TOC-3	89
TOC-4	39
TOC-5	65
Total	**293**

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the

following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.91). 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 3.91. Time spent by cattle in the stream in Totopotomoy Creek (VAP-F13R-02) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.92 for beef cattle.

Table 3.92. Distribution of the beef cattle population (pairs) in the Totopotomoy Creek (VAP-F13R-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	256.54	64.25	16.06	0.11	0.00
February	0.00	301.15	75.42	18.85	0.12	0.00
March	0.00	310.03	77.64	19.41	0.19	0.00
April	0.00	318.90	79.86	19.97	0.26	0.00
May	0.00	327.72	82.07	20.52	0.40	0.00
June	0.00	336.21	84.20	21.05	0.97	0.00
July	0.00	345.12	86.43	21.61	0.99	0.00
August	0.00	354.02	88.66	22.17	1.02	0.00
September	0.00	363.39	91.01	22.75	0.45	0.00
October	0.00	223.01	55.85	13.96	0.18	0.00
November	0.00	234.19	58.65	14.66	0.14	0.00
December	0.00	245.38	61.45	15.36	0.10	0.00

*Number of beef cattle defecating in stream.

3.9.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.92) 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 Totopotomoy Creek (VAP-F13R-02) watersheds is 9,062 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.36×10^{10} cfu/day (4.98×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.9.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.92). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Totopotomoy Creek (VAP-F13R-02) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 2,533; 1,272; and 626 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 Totopotomoy Creek (VAP-F13R-02), averaged over the year, are 1.54×10^{12}, 7.99×10^{11}, and 3.57×10^{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.

3.9.4 Horses

The estimated number of horses in the Totopotomoy Creek (VAP-F13R-02) watershed is included in Table 3.93. 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 Totopotomoy Creek (VAP-F13R-02) watershed is 1.2×10^{11} cfu/day (4.5×10^{13} cfu/year).

Table 3.93. Horse population by subwatershed in the Totopotomoy Creek (VAP-F13R-02) watershed.

Subwatershed	Horses
TOC-1	35
TOC-2	65
TOC-3	89
TOC-4	39
TOC-5	64
Total	**292**

3.9.5 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 Totopotomoy Creek (VAP-F13R-02) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.9.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.96. The total wildlife fecal coliform production each year in the Totopotomoy Creek (VAP-F13R-02) 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 3.94).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.94). 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 3.94, 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 3.95.

Table 3.94. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Totopotomoy Creek (VAP-F13R-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	0.019	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	0.037[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	0.021[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.006[c]	0.00

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

Table 3.95. Distribution of wildlife among sub-watersheds in Totopotomoy Creek (VAP-F13R-02) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
TOC-1	48	70	21	7	79	11	9
TOC-2	85	115	15	12	117	16	16
TOC-3	96	122	20	13	110	15	16
TOC-4	42	55	15	6	47	6	7
TOC-5	66	97	56	11	74	10	10
Total	**337**	**459**	**127**	**49**	**427**	**58**	**58**

3.9.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Totopotomoy Creek (VAP-F13R-02) watershed along with average fecal coliform production rates are shown in Table 3.96. The total fecal coliform production by all sources in the Totopotomoy Creek (VAP-F13R-02) watershed is 9.27×10^{15} cfu/yr.

Table 3.96. Potential fecal coliform sources and daily fecal coliform production by source in Totopotomoy Creek (VAP-F13R-02) 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]
Beef Cattle (pairs)	293	33,000	1,307,269
Horses	292	420	12,272
Humans	24,940	1,950	660,812
Pets	8118	450	365,564
Deer	337	350	11,803
Raccoon	459	50	2,297
Muskrat	127	25	318
Beaver	49	0.2	1
Wild Turkey	58	93	540
Duck	58	2,400	10,542
Goose	427	800	25,634

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.97. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.97.

From Table 3.97, it is clear in the Totopotomoy Creek (VAP-F13R-02) watershed that nonpoint source loadings to the land surface are more than 100 times as large as direct loadings to the streams, with pastures receiving about 58% 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 3.97. Annual fecal coliform loadings to the stream and the various land use categories in the Totopotomoy Creek (VAP-F13R-02) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	5,237	0.57
Cattle in Stream	498	0.05
Wildlife in Stream	3,459	0.37
Loading to Land Surfaces		
Cropland	521	0.06
Pasture 1	405,072	43.71
Pasture 2	105,505	11.39
Pasture 3	23,551	2.54
Forest	13,410	1.45
Residential*	369,391	39.86
Total	**926,643**	**100.00**

*Includes loads received from failed septic systems and pets.

3.10 Moncuin, Webb Creek (VAP-F13R-04) Sources

3.10.1 Humans and Pets

There are four homes served by municipal sanitary sewer in the Moncuin, Webb Creek (VAP-F13R-04) watershed. Wastewater from 485 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Moncuin, Webb Creek (VAP-F13R-04) watershed has an estimated population of 1,258 people (489 households at an average of 2.57 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $2.45x10^{12}$ cfu/day ($8.95x10^{14}$ cfu/year) in Moncuin, Webb Creek (VAP-F13R-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.

3.10.1.1 Failing Septic Systems

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

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

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Moncuin, Webb Creek (VAP-F13R-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.57 persons/household was 5.02×10^9 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 3.99.

3.10.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded seven houses that potentially could be classified as straight pipes in the Moncuin, Webb Creek (VAP-F13R-04) watershed (Table 3.99).

3.10.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 9,025 acres; 2,037 acres; 480 acres; and 401 acres in 2000, 2001, 2002, and 2003, respectively, in King William County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Moncuin, Webb Creek (VAP-F13R-04) watershed were not available. To estimate biosolid applications within each Moncuin, Webb Creek (VAP-F13R-04) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of $2.0\text{x}10^6$ cfu/g (VDH, 1997), values reported by

treatment plants are typically lower than this value. For this study, VDH records indicated that the primary source for biosolids was Blue Plains, a large wastewater treatment plant in the Washington D.C. metropolitan area. The fecal coliform density of biosolids from Blue Plains is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.98 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.98. Estimated average annual biosolids application amount for each subwatershed in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
PAR-3	96
PAR-4	237
PAR-5	90
PAR-6	124
PAR-7	45
Total	**592**

3.10.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 259 dogs and 293 cats were projected to reside in the Moncuin, Webb Creek (VAP-F13R-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 489 for Moncuin, Webb Creek (VAP-F13R-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 Moncuin, Webb Creek (VAP-F13R-04) watershed is 2.2×10^{11} cfu/day (8.0×10^{13} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.99. 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 3.99. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Sub-shed	Human Population	Sewered Houses	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
			Pre-1984	1985 - 1995	Post-1995			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
PAR-3	247	0	47	21	19	24	2	89
PAR-4	372	0	71	36	31	37	1	139
PAR-5	345	2	54	42	40	31	1	140
PAR-6	228	1	40	29	22	23	1	94
PAR-7	67	0	10	9	6	6	2	28
Total	**1,258**	**4**	**223**	**138**	**118**	**121**	**7**	**489**

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

3.10.3 Livestock Sources

In the Moncuin, Webb Creek (VAP-F13R-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 Moncuin, Webb Creek (VAP-F13R-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.

3.10.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is one dairy farm presently operating in the South Anna River (VAN-F01R-01) watershed. Based on information provided, it was determined that there were 100 milk cows, 50 dry cows, and 50 heifers on the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.100). Beef cattle in the Moncuin, Webb Creek (VAP-F13R-04) watershed (104 pairs) included cow/calf and feeder operations (Table 3.100).

Table 3.100. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Moncuin, Webb Creek (VAP-F13R-04) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
PAR-3	0	0	17
PAR-4	0	0	41
PAR-5	0	0	16
PAR-6	0	0	22
PAR-7	200	1	8
Total	**200**	**1**	**104**

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

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

- Cows are confined according to the schedule given in Table 3.101.
- 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 3.101). 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 3.101. Time spent by cattle in confinement and in the stream in Moncuin, Webb Creek (VAP-F13R-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 3.102 for dairy cattle and in Table 3.103 for beef cattle.

Table 3.102. Distribution of the dairy cattle[a] population in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	115.00	45.68	11.44	2.86	0.02	25.00
February	115.00	45.68	11.44	2.86	0.02	25.00
March	40.00	76.12	19.06	4.77	0.05	60.00
April	30.00	76.11	19.06	4.77	0.06	70.00
May	30.00	76.09	19.06	4.76	0.09	70.00
June	30.00	75.99	19.03	4.76	0.22	70.00
July	30.00	75.99	19.03	4.76	0.22	70.00
August	30.00	75.99	19.03	4.76	0.22	70.00
September	30.00	76.09	19.06	4.76	0.09	70.00
October	30.00	76.11	19.06	4.77	0.06	70.00
November	40.00	76.12	19.06	4.77	0.05	60.00
December	115.00	45.68	11.44	2.86	0.02	25.00

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

Table 3.103. Distribution of the beef cattle population (pairs) in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	91.06	22.80	5.70	0.04	0.00
February	0.00	106.89	26.77	6.69	0.04	0.00
March	0.00	110.04	27.56	6.89	0.07	0.00
April	0.00	113.19	28.35	7.09	0.09	0.00
May	0.00	116.32	29.13	7.28	0.14	0.00
June	0.00	119.34	29.89	7.47	0.34	0.00
July	0.00	122.50	30.68	7.67	0.35	0.00
August	0.00	125.66	31.47	7.87	0.36	0.00
September	0.00	128.98	32.30	8.08	0.16	0.00
October	0.00	79.16	19.82	4.96	0.07	0.00
November	0.00	83.13	20.82	5.20	0.05	0.00
December	0.00	87.10	21.81	5.45	0.04	0.00

*Number of beef cattle defecating in stream.

3.10.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy (Table 3.102) and beef cattle (Table 3.103) 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 Moncuin, Webb Creek (VAP-F13R-04) watersheds is 5,880 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 6.55×10^{09} cfu/day (2.39×10^{12} cfu/year). Part of the fecal coliform deposited in the stream stays in the dissolved form while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that dissolved fecal coliform bacteria are the primary form transported with the flow. Sediment-bound bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. For this TMDL, the dissolved form of bacteria was modeled and re-suspension of sediment-bound bacteria was accounted for through calibration (see Chapter 4). Die-off of fecal coliform in the stream results from sunlight, predation, turbidity, and other environmental factors.

3.10.3.3 Direct Manure Deposition on Pastures

Dairy (Table 3.102) and beef (Table 3.103) 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 Moncuin, Webb Creek (VAP-F13R-04) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 2,525; 1,262; and 631 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 Moncuin, Webb Creek (VAP-F13R-04), averaged over the year, are 1.03×10^{12}, 5.19×10^{11}, and 2.63×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.10.3.4 Land Application of Liquid Dairy Manure

A typical milk cow weighs 1,400 pounds and produces 17 gallons of liquid manure daily (ASAE, 1998). Based on the monthly confinement schedule and the number of milk cows, annual liquid dairy manure production in the Moncuin, Webb Creek (VAP-F13R-04) watershed is 265,689 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 40.2 acres of cropland and 0.0 acres of pasture 1 in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.104. Dry cows and heifers were assumed to produce only solid manure.

Table 3.104. Schedule of cattle waste application in Moncuin, Webb Creek (VAP-F13R-04) watershed.

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

* As percent of annual production.

3.10.3.5 Land Application of Solid Manure

Solid manure produced by dry cows, heifers, and beef cattle during confinement is collected for land application. It was assumed that milk cows produce only liquid manure while in confinement. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.105.

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 3.105). 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 3.105). 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 3.104. Based on availability of land and solid manure, as well as the assumptions regarding application rate, 11.7 acres of the cropland and 0.0 acres of the pasture 1 in Moncuin, Webb Creek (VAP-F13R-04) received solid manure application.

Table 3.105. 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 Moncuin, Webb Creek (VAP-F13R-04) watershed.

Type of Cattle	Population	Typical Weight (lb) [a]	Solid Manure Produced (lb/animal-day) [a]	Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) [a]	Weighted Average Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb)
Dry Cow	50	1,400	115.0	2.17	3.65
Heifer	50	640	40.7	2.17	
Beef (pairs)	104	1,000	60.0	5.50	

[a]Source: BSE (2003)

3.10.4 Horses

The estimated number of horses in the Moncuin, Webb Creek (VAP-F13R-04) watershed is included in Table 3.106. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002).

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

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Moncuin, Webb Creek (VAP-F13R-04) watershed is $7.97x10^{09}$ cfu/day ($2.91x10^{12}$ cfu/year).

Table 3.106. Horse population by subwatershed in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Subwatershed	Horses
PAR-3	3
PAR-4	8
PAR-5	3
PAR-6	4
PAR-7	1
Total	**19**

3.10.5 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 Moncuin, Webb Creek (VAP-F13R-04) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.10.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.109. The total wildlife fecal coliform production each year in the Moncuin, Webb Creek (VAP-F13R-04) watershed, is 1.98×10^{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 3.107).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.107). 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 3.107, 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 3.108.

Table 3.107. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Moncuin, Webb Creek (VAP-F13R-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	0.037	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	0.037[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	0.021[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.008[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 3.108. Distribution of wildlife among sub-watersheds in Moncuin, Webb Creek (VAP-F13R-04) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
PAR-3	134	72	3	8	77	5	20
PAR-4	202	99	8	11	116	8	24
PAR-5	127	70	8	7	74	5	19
PAR-6	116	86	12	10	67	5	14
PAR-7	36	26	0	3	21	2	2
Total	**615**	**353**	**31**	**39**	**355**	**25**	**79**

3.10.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Moncuin, Webb Creek (VAP-F13R-04) watershed along with average fecal coliform production rates are shown in Table 3.109. The total fecal coliform production by all sources in the Moncuin, Webb Creek (VAP-F13R-04) watershed is 3.79×10^{15} cfu/yr.

Table 3.109. Potential fecal coliform sources and daily fecal coliform production by source in Moncuin, Webb Creek (VAP-F13R-04) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($\times 10^6$ cfu/AU-day)[a]	Fecal Coliform Produced ($\times 106^6$ cfu/ day)[b]
Dairy Cattle			
Millk and Dry Cows	150	25,000	375,257
Heifers	50	8,800	57,182
Beef Cattle (pairs)	104	33,000	464,013
Horses	19	420	799
Humans	1,258	1,950	65,597
Pets	489	450	22,025
Deer	615	350	21,540
Raccoon	353	50	1,766
Muskrat	31	25	78
Beaver	39	0.2	1
Wild Turkey	79	93	735
Duck	25	2,400	8,745
Goose	355	800	21,322

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.110. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.110.

From Table 3.110, it is clear in the Moncuin, Webb Creek (VAP-F13R-04) watershed that nonpoint source loadings to the land surface are more than 74 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 3.110. Annual fecal coliform loadings to the stream and the various land use categories in the Moncuin, Webb Creek (VAP-F13R-04) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	1,313	0.39
Cattle in Stream	239	0.07
Wildlife in Stream	2,897	0.86
Loading to Land Surfaces		
Cropland	2,300	0.69
Pasture 1	175,534	52.40
Pasture 2	44,229	13.20
Pasture 3	63,432	18.94
Forest	14,366	4.29
Residential*	30,669	9.16
Total	**334,979**	**100.00**

*Includes loads received from failed septic systems and pets.

3.11 Black Creek (VAP-F13R-05) Sources

3.11.1 Humans and Pets

There are two homes served by municipal sanitary sewer in the Black Creek (VAP-F13R-05) watershed. Wastewater from 1,036 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Black Creek (VAP-F13R-05) watershed has an estimated population of 2,715 people (1,038 households at an average of 2.62 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $5.29x10^{12}$ cfu/day ($1.93x10^{15}$ cfu/year) in Black Creek (VAP-F13R-05) watershed.

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

3.11.1.1 Failing Septic Systems

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

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

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Black Creek (VAP-F13R-05) TMDL. The rates reported by Dr. Raymond B. Reneau, Jr. were a culmination of studies he performed throughout the state with numerous variables (e.g., soils) considered. These rates have been accepted by the Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, and United States Environmental Protection Agency in TMDLs throughout Virginia. Estimates of these failure rates were also supported by the Holmans Creek Watershed Study which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all (SAIC, 2001).

An average number of people per household and number of houses and people in each subwatershed in 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.62 persons/household was 5.10×10^9 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 3.112.

3.11.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded one house that potentially could be classified as a straight pipe in the Black Creek (VAP-F13R-05) watershed (Table 3.112).

3.11.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively, in Hanover County. In King William County, 9,025 acres; 2,037 acres; 480 acres; and 401 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Class B biosolids were applied to 0 acres; 352 acres; 0 acres; and 54 acres in 2000, 2001, 2002, and 2003, respectively, in New Kent County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Black Creek (VAP-F13R-05) watershed were not available. To estimate biosolid applications within each Black Creek (VAP-F13R-05) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by the total

pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 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 is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.111 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.111. Estimated average annual biosolids application amount for each subwatershed in the Black Creek (VAP-F13R-05) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
PAR-13	76
PAR-14	15
PAR-15	1
PAR-16	4
PAR-17	4
Total	**100**

3.11.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 550 dogs and 623 cats were projected to reside in the Black Creek (VAP-F13R-05) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 1,038 for Black Creek (VAP-F13R-05) 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 Black Creek (VAP-F13R-05) watershed is 4.7×10^{11} cfu/day (1.7×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.112. 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 3.112. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Black Creek (VAP-F13R-05) 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			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
PAR-13	1,968	2	341	192	231	182	0	766
PAR-14	585	0	64	64	83	41	0	211
PAR-15	22	0	3	2	3	2	0	8
PAR-16	70	0	9	7	9	5	1	26
PAR-17	69	0	12	7	8	6	0	27
Total	**2,715**	**2**	**428**	**273**	**334**	**236**	**1**	**1,038**

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

3.11.3 Livestock Sources

In the Black Creek (VAP-F13R-05) 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 Black Creek (VAP-F13R-05) watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCDs, NRCS, VADCR, VCE, watershed residents, and local producers.

3.11.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Black Creek (VAP-F13R-05) watershed. Beef cattle in the Black Creek (VAP-F13R-05) watershed (101 pairs) included cow/calf and feeder operations (Table 3.113).

Table 3.113. Distribution of beef cattle among subwatersheds in Black Creek (VAP-F13R-05) watersheds.

Subwatershed	Beef Cattle (pairs)
PAR-13	76
PAR-14	16
PAR-15	1
PAR-16	4
PAR-17	4
Total	**101**

Cattle spend varying amounts of time in streams and pasture depending on the time of year. Accordingly, the proportion of bacteria deposited in any given land area varies throughout the year. Based on discussions with SWCDs, NRCS, VADCR, VCE, and local producers, the

following assumptions and procedures were used to estimate the distribution of cattle (and thus their manure) among different land use types and in the stream:

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.114). 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 3.114. Time spent by cattle in the stream in Black Creek (VAP-F13R-05) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.115 for beef cattle.

Table 3.115. Distribution of the beef cattle population (pairs) in the Black Creek (VAP-F13R-05) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	88.43	22.15	5.54	0.04	0.00
February	0.00	103.81	26.00	6.50	0.04	0.00
March	0.00	106.87	26.76	6.69	0.07	0.00
April	0.00	109.93	27.53	6.88	0.09	0.00
May	0.00	112.97	28.29	7.07	0.14	0.00
June	0.00	115.90	29.02	7.26	0.33	0.00
July	0.00	118.97	29.79	7.45	0.34	0.00
August	0.00	122.04	30.56	7.64	0.35	0.00
September	0.00	125.26	31.37	7.84	0.15	0.00
October	0.00	76.87	19.25	4.81	0.06	0.00
November	0.00	80.73	20.22	5.05	0.05	0.00
December	0.00	84.59	21.18	5.30	0.03	0.00

*Number of beef cattle defecating in stream.

3.11.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.115) 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 Black Creek (VAP-F13R-05) watersheds is 3,124 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 4.71×10^{09} cfu/day (1.72×10^{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.

3.11.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.115). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Black Creek (VAP-F13R-05) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 1,620; 811; and 404 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 Black Creek (VAP-F13R-05), averaged over the year, are 9.17×10^{11}, 4.66×10^{11}, and 2.31×10^{11} cfu/ac-year for pastures 1, 2, and 3, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.11.4 Horses

The estimated number of horses in the Black Creek (VAP-F13R-05) watershed is included in Table 3.116. 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 Black Creek (VAP-F13R-05) watershed is 2.3×10^{10} cfu/day (8.4×10^{12} cfu/year).

Table 3.116. Horse population by subwatershed in the Black Creek (VAP-F13R-05) watershed.

Subwatershed	Horses
PAR-13	44
PAR-14	7
PAR-15	0
PAR-16	2
PAR-17	2
Total	**55**

3.11.5 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 Black Creek (VAP-F13R-05) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.11.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.119. The total wildlife fecal coliform production each year in the Black Creek (VAP-F13R-05) watershed, is 2.65×10^{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 3.117).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.117). 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 3.117, 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 3.118.

Table 3.117. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Black Creek (VAP-F13R-05) 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	0.037[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	0.021[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[b]	0.25
Wild Turkey	Entire watershed except urban areas	0.010[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 3.118. Distribution of wildlife among sub-watersheds in Black Creek (VAP-F13R-05) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
PAR-13	590	325	34	35	304	41	99
PAR-14	230	124	10	14	107	15	42
PAR-15	9	7	0	1	4	1	1
PAR-16	28	25	11	3	13	2	4
PAR-17	27	21	0	2	13	2	3
Total	**884**	**502**	**55**	**55**	**441**	**61**	**149**

3.11.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Black Creek (VAP-F13R-05) watershed along with average fecal coliform production rates are shown in Table 3.119. The total fecal coliform production by all sources in the Black Creek (VAP-F13R-05) watershed is 2.57×10^{15} cfu/yr.

Table 3.119. Potential fecal coliform sources and daily fecal coliform production by source in Black Creek (VAP-F13R-05) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Beef Cattle (pairs)	101	33,000	450,628
Horses	55	420	2,312
Humans	2,715	1,950	121,628
Pets	1,038	450	46,737
Deer	884	350	30,961
Raccoon	502	50	2,512
Muskrat	55	25	138
Beaver	55	0.2	1
Wild Turkey	149	93	1,387
Duck	61	2,400	11,141
Goose	441	800	26,472

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.120. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.120.

From Table 3.120, it is clear in the Black Creek (VAP-F13R-05) watershed that nonpoint source loadings to the land surface are more than 63 times as large as direct loadings to the streams, with pastures receiving about 66% 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 3.120. Annual fecal coliform loadings to the stream and the various land use categories in the Black Creek (VAP-F13R-05) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	195	0.08
Cattle in Stream	172	0.07
Wildlife in Stream	3,655	1.42
Loading to Land Surfaces		
Cropland	875	0.34
Pasture 1	129,097	50.27
Pasture 2	32,884	12.81
Pasture 3	8,169	3.18
Forest	20,481	7.98
Residential*	61,258	23.86
Total	**256,786**	**100.00**

*Includes loads received from failed septic systems and pets.

3.12 Pamunkey River (VAP-F13E-02) Sources

3.12.1 Humans and Pets

There are 58 homes served by municipal sanitary sewer in the Pamunkey River (VAP-F13E-02) watershed. Wastewater from 2,753 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Pamunkey River (VAP-F13E-02) watershed has an estimated population of 7,425 people (2,811 households at an average of 2.64 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95x10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $1.45x10^{13}$ cfu/day ($5.28x10^{15}$ cfu/year) in Pamunkey River (VAP-F13E-02) watershed.

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

3.12.1.1 Failing Septic Systems

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

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

Virginia Tech, a 40% failure rate for systems designed and installed prior to 1984, a 20% failure rate for systems designed and installed between 1985 and 1995, and a 3% failure rate on all systems designed and installed after 1995 was used in the development of the Pamunkey River (VAP-F13E-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 2005 were established using 1990 and 2000 U.S. Census Bureau demographics data (UCSB, 1990 and 2000). The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. Daily total fecal coliform load to the land from a failing septic system in a particular sub-watershed was determined by multiplying the average household occupancy rate for that subwatershed by the per capita fecal coliform production rate of 1.95×10^9 cfu/day (Geldreich et al., 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a subwatershed with an occupancy rate of 2.64 persons/household was 5.15×10^9 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 3.122.

3.12.1.2 Straight Pipes

Houses that deliver a waste load directly to the stream, or straight pipes, were estimated by identifying those houses located within 150 feet of streams in the pre-1967 and 1967-1987 age categories. Any houses within 150 feet of streams are considered potential straight pipe dischargers. Using the age categories (pre-1967, 1967 – 1987, post 1987), 10% of old houses (pre-1967) within 150 feet of streams and 2% of mid-age houses (1967 – 1987) within 150 feet of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 17 house that potentially could be classified as a straight pipe in the Pamunkey River (VAP-F13E-02) watershed (Table 3.122).

3.12.1.3 Biosolids

According to VDH records, Class B biosolids were applied to 859 acres; 2,261 acres; 475 acres; and 60 acres in 2000, 2001, 2002, and 2003, respectively, in Hanover County. In King William County, 9,025 acres; 2,037 acres; 480 acres; and 401 acres in 2000, 2001, 2002, and 2003, respectively, received Class B biosolids. Class B biosolids were applied to 0 acres; 352 acres; 0 acres; and 54 acres in 2000, 2001, 2002, and 2003, respectively, in New Kent County. Comprehensive application rates, bacteria concentrations, and spatial distribution of application sites within the Pamunkey River (VAP-F13E-02) watershed were not available. To estimate biosolid applications within each Pamunkey River (VAP-F13E-02) subwatershed, records of biosolid applications within the county were obtained from VDH. The average monthly biosolids application total mass data for the county from 2000 to 2003 were divided by

the total pasture and cropland acreage in the county. The resulting rates were distributed based on the crop and pasture areas in each subwatershed. Although Class B biosolids are permitted to contain fecal coliform concentrations of 2.0×10^6 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 is estimated to be less than 2,000 cfu/g (MapTech, 2002). Therefore, an average fecal coliform density of 2,000 cfu/g was used for bacteria loading calculations. Table 3.121 shows the estimated average annual biosolids application amount for each subwatershed (See Figure 4.1 through 4.4 for location of subwatersheds).

Table 3.121. Estimated average annual biosolids application amount for each subwatershed in the Pamunkey River (VAP-F13E-02) watershed.

Subwatershed	Biosolids Applied (dry tons / year)
PAR-1	32
PAR-2	389
PAR-8	3
PAR-9	271
PAR-10	285
PAR-11	168
PAR-12	28
PAR-18	10
PAR-19	502
PAR-20	7
Total	**1,695**

3.12.2 Pets

According to the American Veterinary Medical Association (AVMA), there are on average 0.53 dogs per household and 0.60 cats per household in the Unites States (AVMA, 1997). Based on theses densities and number of households in each watershed, 1,490 dogs and 1,687 cats were projected to reside in the Pamunkey River (VAP-F13E-02) impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 2,811 for Pamunkey River (VAP-F13E-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 Pamunkey River (VAP-F13E-02) watershed is 1.3×10^{12} cfu/day (4.6×10^{14} cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.122. 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 3.122. Estimated human population, number of sewered houses, number of unsewered houses by age category, number of failing septic systems, number of straight pipes, and pet population in the Pamunkey River (VAP-F13E-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			
	(#)	(#)	(#)	(#)	(#)	(#)	(#)	(#)
PAR-1	53	0	10	6	5	5	0	21
PAR-2	966	5	142	108	100	81	4	359
PAR-8	18	0	3	2	2	2	0	7
PAR-9	831	4	118	95	89	69	0	306
PAR-10	3,989	47	768	371	283	390	9	1,478
PAR-11	271	0	55	29	25	29	1	110
PAR-12	256	0	48	25	27	25	1	101
PAR-18	54	0	6	6	7	4	1	20
PAR-19	884	2	193	108	69	101	0	372
PAR-20	103	0	11	11	14	7	1	37
Total	**7,425**	**58**	**1,354**	**761**	**621**	**713**	**17**	**2,811**

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

3.12.3 Livestock Sources

In the Pamunkey River (VAP-F13E-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 Pamunkey River (VAP-F13E-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.

3.12.3.1 Cattle

Based on information obtained from VADCR and SWCDs, there is no dairy farm presently operating in the Pamunkey River (VAP-F13E-02) watershed. Beef cattle in the Pamunkey River (VAP-F13E-02) watershed (672 pairs) included cow/calf and feeder operations (Table 3.123).

Table 3.123. Distribution of beef cattle among subwatersheds in Pamunkey River (VAP-F13E-02) watersheds.

Subwatershed	Beef Cattle (pairs)
PAR-1	10
PAR-2	154
PAR-8	1
PAR-9	107
PAR-10	242
PAR-11	43
PAR-12	17
PAR-18	5
PAR-19	88
PAR-20	5
Total	**672**

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

- The beef cattle spend their time on pasture.
- Pasture 1 (improved pasture/hay land) stocks twice as many cows per unit area as pasture 2 (unimproved pasture/grazed woodlands), which stocks twice as many cows per unit area as pasture 3 (overgrazed pasture).
- Cows on pastures that are contiguous to streams have stream access.
- Cows with stream access spend varying amounts of time in the stream during different seasons (Table 3.124). 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 3.124. Time spent by cattle in the stream in Pamunkey River (VAP-F13E-02) watershed.

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

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

The time cattle spend each month in various land uses or a given stream reach was estimated based on typical agricultural practice, and adjusted to reflect feedback from TAC members and agricultural producers. Using these data describing where cattle spend their time, the cattle and their resulting bacteria loads were distributed among the land uses for modeling purposes. The resulting numbers of cattle in each land use type as well as in the stream for all subwatersheds are given in Table 3.125 for beef cattle.

Table 3.125. Distribution of the beef cattle population (pairs) in the Pamunkey River (VAP-F13E-02) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	0.00	588.37	147.35	36.84	0.24	0.00
February	0.00	690.70	172.98	43.24	0.28	0.00
March	0.00	711.05	178.07	44.52	0.44	0.00
April	0.00	731.40	183.17	45.79	0.60	0.00
May	0.00	751.62	188.23	47.06	0.93	0.00
June	0.00	771.11	193.11	48.28	2.22	0.00
July	0.00	791.53	198.23	49.56	2.28	0.00
August	0.00	811.96	203.35	50.84	2.34	0.00
September	0.00	833.43	208.72	52.18	1.03	0.00
October	0.00	511.47	128.09	32.02	0.42	0.00
November	0.00	537.12	134.52	33.63	0.33	0.00
December	0.00	562.79	140.94	35.24	0.23	0.00

*Number of beef cattle defecating in stream.

3.12.3.2 Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.115) 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 Pamunkey River (VAP-F13E-02) watersheds is 20,783 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 3.12×10^{10} cfu/day (1.14×10^{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.

3.12.3.3 Direct Manure Deposition on Pastures

Beef cattle that graze on pastures, but do not deposit in streams, contribute the majority of fecal coliform loading on pastures (Table 3.125). Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure it produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Since the confinement and calving schedule of the cattle changes throughout the year, manure and fecal coliform loading on pasture also change with season.

In the Pamunkey River (VAP-F13E-02) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 2,043; 1,024; and 507 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 Pamunkey River (VAP-F13E-02), averaged over the year, are 1.20×10^{12}, 6.18×10^{11}, and 2.89×10^{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.

3.12.4 Horses

The estimated number of horses in the Pamunkey River (VAP-F13E-02) watershed is included in Table 3.126. 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 Pamunkey River (VAP-F13E-02) watershed is 2.0×10^{11} cfu/day (7.4×10^{13} cfu/year).

Table 3.126. Horse population by subwatershed in the Pamunkey River (VAP-F13E-02) watershed.

Subwatershed	Horses
PAR-1	6
PAR-2	116
PAR-8	0
PAR-9	82
PAR-10	239
PAR-11	12
PAR-12	6
PAR-18	2
PAR-19	16
PAR-20	2
Total	**481**

3.12.5 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 Pamunkey River

(VAP-F13E-02) watershed. The potential bacteria load from these sources was accounted for during water quality calibration.

3.12.6 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Table 3.129. The total wildlife fecal coliform production each year in the Pamunkey River (VAP-F13E-02) watershed, is 6.72×10^{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 3.127).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.127). 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 3.127, 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 3.128.

Table 3.127. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Pamunkey River (VAP-F13E-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	0.033	0.10
Raccoon	Primary: 600 feet buffer around streams and impoundments Secondary: 601 feet -7,920 feet buffer from streams and impoundments	0.067	0.10
Muskrat	Primary: 66 feet buffer around streams and impoundments in forest and cropland Secondary: 67-300 feet buffer from same	0.035[a]	0.25
Beaver	300 feet buffer around streams and impoundments in forest and pasture	0.014	0.50
Geese	300 feet buffer around main streams	0.020[b]	0.25
Wood Duck	300 feet buffer around main streams	0.003[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 3.128. Distribution of wildlife among sub-watersheds in Pamunkey River (VAP-F13E-02) watershed.

Subwatershed	Deer	Raccoon	Muskrat	Beaver	Geese	Wood Duck	Wild Turkey
PAR-1	18	13	0	2	12	2	1
PAR-2	237	218	127	25	184	25	20
PAR-8	3	2	0	0	2	0	0
PAR-9	201	203	138	22	157	21	23
PAR-10	377	400	84	44	404	55	72
PAR-11	147	102	36	10	82	11	10
PAR-12	106	64	1	6	52	7	13
PAR-18	23	19	0	2	13	2	0
PAR-19	658	379	14	41	377	51	94
PAR-20	39	19	0	2	20	3	3
Total	**1,809**	**1,419**	**400**	**154**	**1,303**	**177**	**236**

3.12.7 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Pamunkey River (VAP-F13E-02) watershed along with average fecal coliform production rates are shown in Table 3.129. The total fecal coliform production by all sources in the Pamunkey River (VAP-F13E-02) watershed is 1.43×10^{16} cfu/yr.

Table 3.129. Potential fecal coliform sources and daily fecal coliform production by source in Pamunkey River (VAP-F13E-02) watershed.

Potential Source	Population in Watershed	Fecal Coliform Produced ($x10^7$ cfu/AU-day)[a]	Fecal Coliform Produced ($x10^7$ cfu/ day)[b]
Beef Cattle (pairs)	672	33,000	2,998,241
Horses	481	420	20,216
Humans	7,425	1,950	383,864
Pets	2,811	450	126,582
Deer	1,809	350	63,358
Raccoon	1,419	50	7,100
Muskrat	400	25	1,001
Beaver	154	0.2	3
Wild Turkey	236	93	2,196
Duck	177	2,400	32,225
Goose	1,303	800	78,098

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.130. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.130.

From Table 3.130, it is clear in the Pamunkey River (VAP-F13E-02) watershed that nonpoint source loadings to the land surface are more than 94 times as large as direct loadings to the streams, with pastures receiving about 83% 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 3.130. Annual fecal coliform loadings to the stream and the various land use categories in the Pamunkey River (VAP-F13E-02) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	3,324	0.23
Cattle in Stream	1,143	0.08
Wildlife in Stream	10,657	0.74
Loading to Land Surfaces		
Cropland	3,419	0.24
Pasture 1	896,596	62.67
Pasture 2	231,138	16.16
Pasture 3	54,006	3.78
Forest	47,318	3.31
Residential*	182,988	12.79
Total	1,430,590	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 nonpoint) 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 nonpoint 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds. In addition, the USEPA Water Quality Analysis Simulation Program (WASP) coupled with the USEPA Link-Node Tidal Hydrodynamic Model (DYNHYD) was selected as the modeling framework to simulate fecal coliform transport and fate in the Pamunkey River impairment. The ArcView 3.2 GIS program was used to display and analyze landscape information.

The HSPF model simulates nonpoint 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 South Anna River (VAN-F01R-01), South Anna River

(VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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.

Within DYNHYD the tidal impairment is simulated as a series of nodes connected by links. Time-variable outflow hydrographs from HSPF serve as upstream inputs to the model nodes and NOAA provided tide predictions for White House, Virginia are the downstream boundary condition. The model solves the equation of continuity at every node to provide in-stream heads and volumes. In addition, the model solves the equation of motion within each link to provide in-stream velocities and flow rates. These values are recorded at each simulation time step and are averaged over a longer period of time to be used by WASP for water quality calculations.

Within WASP the tidal impairment is simulated as a series of river reaches, known as segments. Time-variable pollutant loadings and in-stream pollutant concentrations from HSPF function as upstream model inputs. Due to the lack of extensive observed pollutant concentrations in the Pamunkey River, the downstream boundary condition was set equal to the geometric mean of all water quality samples taken in the lower Pamunkey River during the modeling time period. At each time step WASP solves the pollutant mass balance equation utilizing the volumes and velocities provided by the DYNHYD hydrodynamic linkage file.

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 South Anna River watershed is 298,300 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 28 subwatersheds as shown in Figure 4.1. Impaired segments of South Anna River (VAN-F01R-01) include SAR-1 through SAR-4. Unimpaired segments SAR-6 and SAR-7 drain to the impaired segments (SAR-9, SAR-11, SAR-12, and SAR-13) of South Anna River (VAN-F02R-01). Tributaries include Happy Creek (SAR-5), Roundabout Creek

(SAR-8), and Harris Creek (SAR-10). Beaver Creek (SAR-14) and unimpaired segments SAR-15 and SAR-16 drain into impaired segments SAR-20, SAR-21, and SAR-26 of South Anna River (VAP-F04R-01). Segments SAR-17, SAR-18, and SAR-19 constitute impaired segments of Taylors Creek (VAN-F03R-01). Unimpaired segment SAR-22 drains to impaired segments SAR-23, SAR-24, and SAR-25 of Newfound River (VAP-F05R-01). South Anna River (VAP-F04R-02) is comprised of impaired segments SAR-27 and SAR-28.

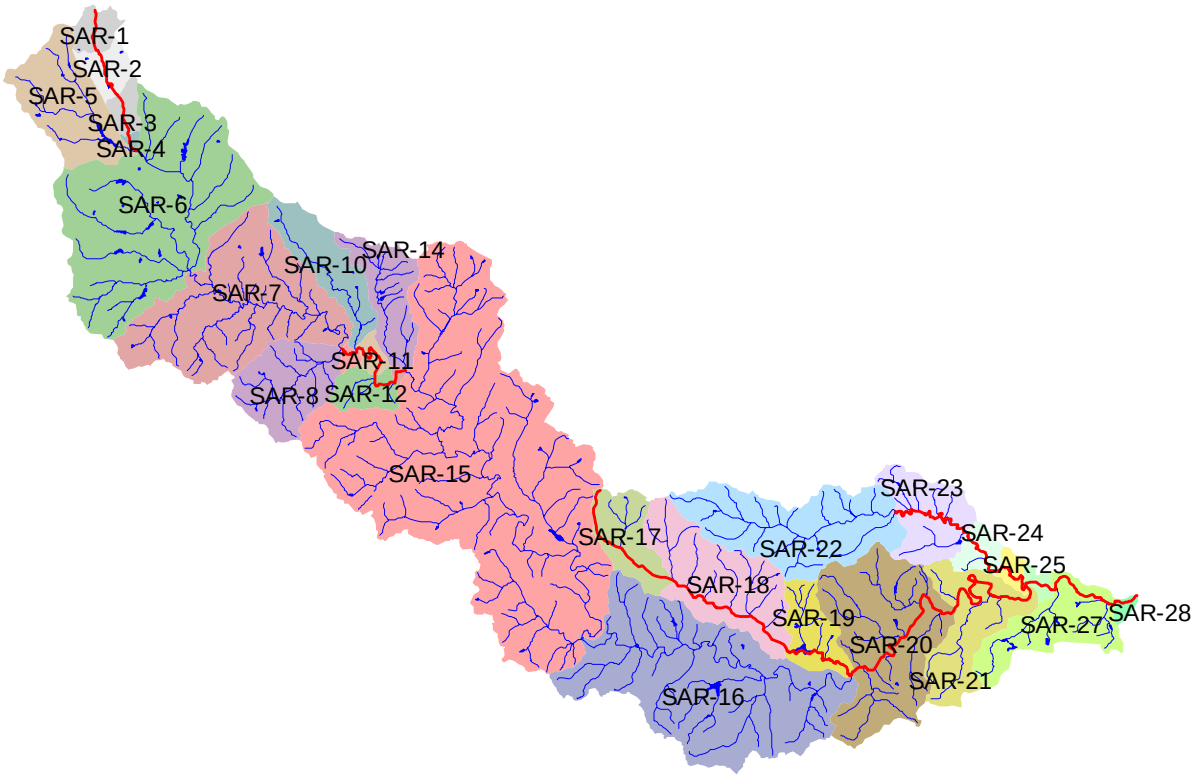

Figure 4.1. South Anna River subwatersheds.

The Northeast Creek (VAP-F09R-01) watershed is a moderately sized watershed (22,760 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 five subwatersheds as shown in Figure 4.2. An unnamed tributary (NEC-3) and unimpaired segment NEC-1, NEC-2, and NEC-3 drain to the impaired segment of Northeast Creek (NEC-5).

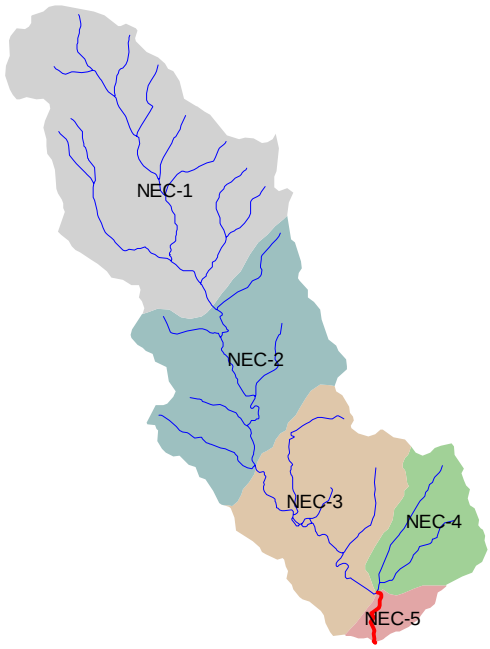

Figure 4.2. Northeast Creek subwatersheds.

The Totopotomoy Creek (VAP-F13R-02) watershed is a moderately sized watershed (20,050 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 five subwatersheds as shown in Figure 4.3. Unimpaired segments of the Totopotomoy Creek (TOC-1 and TOC-2) drain to impaired segments TOC-3, TOC-4, and TOC-5.

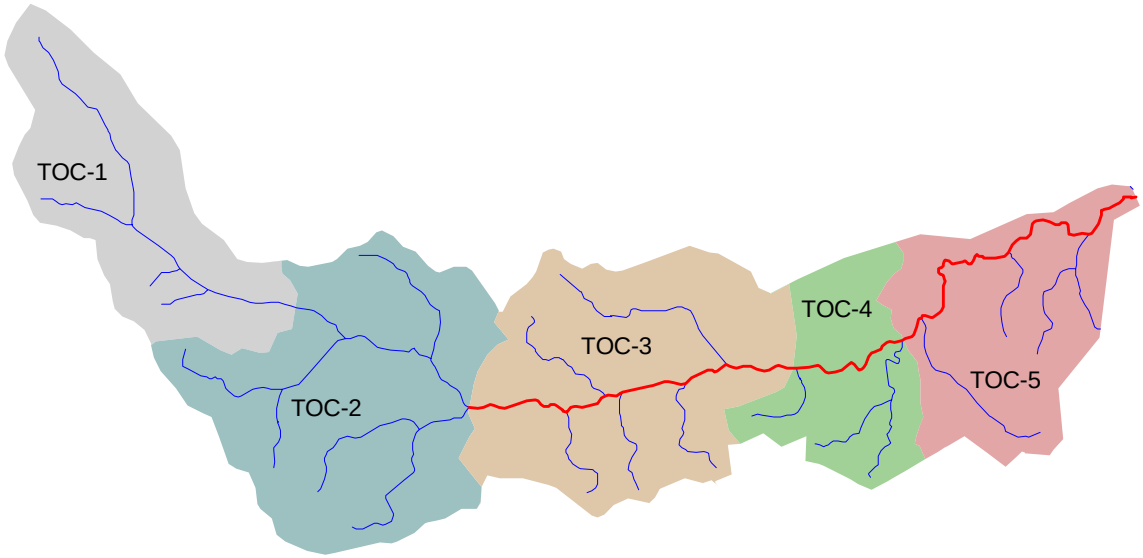

Figure 4.3. Totopotomoy Creek subwatersheds.

The Pamunkey River (VAP-F13E-02) watershed is 98,730 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 twenty subwatersheds as shown in Figure 4.4. Impaired segments of Moncuin/Webb Creek (VAP-F13R-04) include PAR-3 through PAR-7. Par-8 is an unimpaired segment of Moncuin Creek. Southern Branch (PAR-14) and the unimpaired segment PAR-13 drain into the impaired segments (PAR-15, PAR-16, and PAR-17) of Black Creek (VAP-F13R-05). Matedequin Creek (PAR-10), Jacks Creek (PAR-19), and unimpaired segments PAR-1 and PAR-2 drain into the impaired segments (PAR-9, PAR-11, PAR-12, PAR-18, and PAR-20) of Pamunkey River. For DYNHYD, the estuary portion of Pamunkey River was divided into six nodes and links based on location of HSPF subwatershed outlets and limitations of the DYNHYD model. Within WASP, the Pamunkey River was divided into six segments corresponding directly to the established DYNHYD nodes. The process was automated with the use of a DYNHYD to WASP hydrodynamic linkage file, which contains segment volumes, depths, velocities, and flows at every water quality model time step.

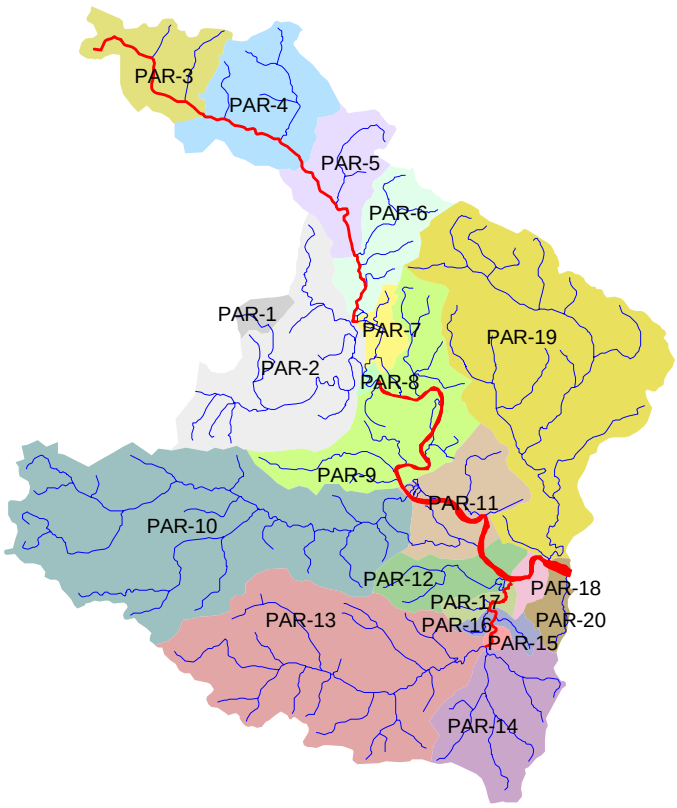

Figure 4.4. Pamunkey River subwatersheds.

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), 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 South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River 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 through Figure 4.4). Land use distribution in the subwatersheds as well as in the entire South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River watersheds is presented in Table 4.2 through Table 4.5.

Table 4.2. Land use distribution in South Anna River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
SAR-1	10.2	566.5	283.8	141.9	9.9	28.9	934.3	1,975.5
SAR-2	38.7	682.2	341.7	170.9	187.5	94.9	803.1	2,319.0
SAR-3	3.4	210.9	105.6	52.8	18.1	46.2	1,008.3	1,445.3
SAR-4	0.0	64.3	32.2	16.1	0.8	23.1	130.5	266.9
SAR-5	86.7	1,937.4	970.4	485.2	27.6	326.6	6,501.4	10,335.3
SAR-6	740.9	4,638.5	2,323.3	1,161.7	469.6	1,844.6	22,882.8	34,061.4
SAR-7	395.6	2,930.6	1,467.9	733.9	302.7	639.8	18,204.0	24,674.5
SAR-8	305.7	1,010.9	506.3	253.2	260.3	66.3	6,307.5	8,710.2
SAR-9	42.1	26.5	13.3	6.6	0.7	0.0	408.3	497.4
SAR-10	89.6	422.1	211.4	105.7	148.1	158.5	5,657.5	6,792.8
SAR-11	99.5	20.7	10.4	5.2	0.4	0.7	843.1	980.1
SAR-12	244.3	212.1	106.3	53.1	1.9	11.1	2,158.7	2,787.5
SAR-13	28.6	45.7	22.9	11.4	0.2	0.0	118.3	227.1
SAR-14	650.8	471.0	235.9	117.9	311.0	62.2	4,571.6	6,420.4
SAR-15	6,091.0	6,803.4	3,407.7	1,703.8	794.8	983.9	54,063.3	73,848.0
SAR-16	2,425.3	6,354.1	3,182.6	1,591.3	387.2	635.5	19,670.4	34,246.4
SAR-17	435.2	535.0	268.0	134.0	5.5	36.1	4,116.9	5,530.6
SAR-18	972.5	1,582.2	792.5	396.3	109.9	183.5	9,295.8	13,332.8
SAR-19	239.6	528.8	264.9	132.4	63.0	31.6	3,409.6	4,669.9
SAR-20	1,325.9	3,161.4	1,583.5	791.7	239.3	248.8	12,210.4	19,561.0
SAR-21	785.5	1,421.8	712.2	356.1	154.9	131.1	5,842.0	9,403.6
SAR-22	1,355.2	2,870.5	1,437.7	718.9	181.6	345.8	9,225.5	16,135.2
SAR-23	652.7	1,086.3	544.1	272.1	22.3	61.1	4,422.8	7,061.3
SAR-24	204.4	367.7	184.1	92.1	8.2	44.5	1,156.6	2,057.5
SAR-25	38.7	81.9	41.0	20.5	6.7	2.4	796.5	987.8
SAR-26	85.0	89.3	44.7	22.4	10.2	29.5	493.0	774.1
SAR-27	715.1	1,487.0	744.8	372.4	523.3	136.6	4,700.3	8,679.5
SAR-28	75.4	122.9	61.6	30.8	0.9	49.5	153.1	494.1
Total	**18,137.5**	**39,731.9**	**19,900.7**	**9,950.4**	**4,246.8**	**6,222.8**	**200,085.4**	**298,275.4**

Table 4.3. Land use distribution in Northeast Creek watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
NEC-1	780.4	565.1	283.0	141.5	71.6	159.6	7,546.3	9,547.6
NEC-2	489.5	595.3	298.2	149.1	34.5	63.2	4,105.2	5,734.9
NEC-3	336.2	340.5	170.5	85.3	3.9	109.4	3,716.7	4,762.4
NEC-4	192.1	193.8	97.1	48.5	1.2	18.5	1,625.4	2,176.7
NEC-5	88.7	51.9	26.0	13.0	0.0	4.7	351.5	535.9
Total	**1,886.9**	**1,746.6**	**874.8**	**437.4**	**111.3**	**355.4**	**17,345.1**	**22,757.5**

Table 4.4. Land use distribution in Totopotomoy Creek watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
TOC-1	201.1	324.8	162.7	81.3	1,175.2	79.8	1,676.0	3,700.8
TOC-2	436.3	579.6	290.3	145.1	1,073.5	65.3	2,892.1	5,482.3
TOC-3	625.9	775.5	388.4	194.2	123.5	170.4	2,871.3	5,149.2
TOC-4	220.6	365.3	183.0	91.5	54.2	41.8	1,260.9	2,217.3
TOC-5	407.5	590.8	295.9	148.0	56.8	110.2	1,888.0	3,497.2
Total	**1,891.5**	**2,635.9**	**1,320.2**	**660.1**	**2,483.3**	**467.5**	**10,588.3**	**20,046.7**

Table 4.5. Land use distribution in Pamunkey River watershed.

Sub-shed	Land Use (ac)							
	Cropland	Pasture1	Pasture2	Pasture3	Residential	Water/ Wetland	Forest	Total
PAR-1	25.9	169.6	85.0	42.5	8.3	108.0	147.5	586.8
PAR-2	1,778.3	1,556.2	779.5	389.7	80.8	878.4	3,197.8	8,660.7
PAR-3	291.7	275.3	137.9	69.0	27.0	59.1	2,753.3	3,613.3
PAR-4	669.4	703.7	352.5	176.2	14.7	147.9	3,379.0	5,443.3
PAR-5	275.1	254.8	127.6	63.8	90.9	91.4	2,590.0	3,493.6
PAR-6	471.8	297.7	149.1	74.6	47.4	132.7	1,987.1	3,160.4
PAR-7	68.8	168.9	84.6	42.3	0.8	282.8	322.8	971.0
PAR-8	31.2	12.0	6.0	3.0	0.1	65.3	51.1	168.8
PAR-9	1,497.0	939.7	470.7	235.3	1.3	644.1	3,589.9	7,377.9
PAR-10	1,567.4	2,233.4	1,118.7	559.3	261.1	484.6	12,765.2	18,989.6
PAR-11	865.9	599.6	300.3	150.2	0.9	732.9	1,200.9	3,850.7
PAR-12	200.2	294.6	147.6	73.8	0.4	363.8	1,377.0	2,457.5
PAR-13	1,031.5	1,019.7	510.7	255.4	28.6	575.5	10,871.6	14,293.0
PAR-14	218.0	270.3	135.4	67.7	9.2	132.6	4,212.6	5,045.7
PAR-15	23.8	6.4	3.2	1.6	0.0	65.2	89.9	190.2
PAR-16	72.7	58.6	29.4	14.7	0.1	42.4	390.1	608.0
PAR-17	86.3	52.8	26.5	13.2	0.0	74.4	339.6	592.8
PAR-18	51.2	84.1	42.1	21.1	0.0	346.5	51.5	596.5
PAR-19	1,366.5	1,523.5	763.1	381.5	30.3	850.0	12,763.5	17,678.5
PAR-20	138.1	52.2	26.1	13.1	0.0	371.2	350.8	951.4
Total	**10,730.7**	**10,573.2**	**5,295.9**	**2,647.9**	**602.1**	**6,448.9**	**62,431.1**	**98,729.8**

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 Table 4.6 through Table 4.9.

Table 4.6. Stream channel characteristics used to calculate F-Tables in the South Anna 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]
SAR-1	2.08	3	2	0.080	27	0.038	0.140
SAR-2	2.17	5	2	0.060	27	0.038	0.140
SAR-3	1.89	7	2	0.070	27	0.038	0.140
SAR-4	0.87	10	3	0.070	27	0.038	0.140
SAR-5	6.51	13	4	0.077	28	0.035	0.100
SAR-6	7.37	18	3	0.043	2	0.035	0.110
SAR-7	10.63	22	2	0.067	3	0.042	0.110
SAR-8	6.01	13	4	0.070	28	0.035	0.100
SAR-9	0.93	24	3	0.080	20	0.038	0.140
SAR-10	8.17	10	3	0.053	20	0.038	0.140
SAR-11	2.66	26	3	0.023	20	0.038	0.140
SAR-12	1.53	27	4	0.053	2	0.043	0.110
SAR-13	0.94	30	4	0.023	20	0.038	0.140
SAR-14	7.37	10	3	0.023	20	0.038	0.140
SAR-15	24.92	33	5	0.080	1	0.044	0.110
SAR-16	17.99	41	4	0.050	12	0.041	0.110
SAR-17	6.08	7	2	0.050	25	0.038	0.130
SAR-18	6.30	13	3	0.090	10	0.035	0.110
SAR-19	3.82	25	3	0.067	10	0.035	0.110
SAR-20	7.75	50	3	0.077	23	0.037	0.110
SAR-21	7.46	53	4	0.090	23	0.037	0.110
SAR-22	11.07	5	1	0.043	7	0.038	0.150
SAR-23	4.71	6	1	0.043	7	0.038	0.140
SAR-24	2.73	8	2	0.090	7	0.038	0.140
SAR-25	2.16	9	2	0.080	7	0.038	0.140
SAR-26	1.50	53	4	0.075	23	0.037	0.110
SAR-27	3.79	54	4	0.053	23	0.037	0.110
SAR-28	1.09	55	4	0.053	23	0.037	0.110

[a] Dimensionless.

Table 4.7. Stream channel characteristics used to calculate F-Tables in the Northeast Creek 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]
NEC-1	6.02	13	4	0.005	28	0.035	0.100
NEC-2	3.77	13	4	0.001	2	0.035	0.077
NEC-3	4.09	14	4	0.002	2	0.035	0.077
NEC-4	2.46	3	2	0.006	27	0.038	0.140
NEC-5	1.03	14	4	0.002	2	0.035	0.077

[a] Dimensionless.

Table 4.8. Stream channel characteristics used to calculate F-Tables in the Totopotomoy Creek 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]
TOC-1	4.70	5	2	0.002	2	0.035	0.077
TOC-2	2.49	8	2	0.003	2	0.035	0.077
TOC-3	3.96	11	3	0.002	2	0.035	0.077
TOC-4	1.52	15	3	0.002	2	0.035	0.077
TOC-5	4.13	18	4	0.001	2	0.035	0.077

[a] Dimensionless.

Table 4.9. Stream channel characteristics used to calculate F-Tables in the Pamunkey 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]
PAR-1	1.09	190	10	0.001	2	0.030	0.077
PAR-2	6.91	192	11	0.000	2	0.030	0.077
PAR-3	3.94	5	2	0.001	2	0.030	0.077
PAR-4	2.99	8	2	0.000	2	0.030	0.077
PAR-5	2.94	12	3	0.000	2	0.030	0.077
PAR-6	1.85	17	3	0.001	2	0.030	0.077
PAR-7	1.94	20	3	0.001	2	0.030	0.077
PAR-8	0.82	195	11	0.001	2	0.030	0.077
PAR-9	5.00	199	12	0.000	2	0.030	0.077
PAR-10	12.48	28	2	0.000	2	0.030	0.077
PAR-11	3.18	200	12	0.001	2	0.030	0.077
PAR-12	1.05	201	12	0.004	2	0.030	0.077
PAR-13	9.18	15	3	0.000	2	0.030	0.077
PAR-14	3.87	10	2	0.000	2	0.030	0.077
PAR-15	0.82	17	3	0.001	2	0.030	0.077
PAR-16	0.54	18	4	0.005	2	0.030	0.077
PAR-17	1.13	20	4	0.003	2	0.030	0.077
PAR-18	1.28	203	13	0.003	2	0.030	0.077
PAR-19	13.15	17	2	0.001	2	0.030	0.077
PAR-20	0.50	205	13	0.001	2	0.030	0.077

[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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), and Northeast Creek (VAP-F09R-01) watersheds used hourly weather data from the Piedmont Research Station (446712) and Culpeper (442159) weather stations. Daily precipitation from stations Piedmont Research Station (446712), Culpeper (442159), 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. Simulations performed for Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds used hourly weather data from the Richmond International AP (447201) weather station. Daily precipitation from stations Richmond International AP (447201), West Point 2 NW (449025), Ashland (440327), Crozier (442142), and Corbin (442009) was transformed to address discrepancies (i.e., missing data) between observed runoff and hourly precipitation records.

Using hourly precipitation data, frequency of precipitation events and precipitation amounts per hour were calculated. For daily precipitation amounts equal to or less than 0.3 inches, the daily amount was assigned to the hour with the highest likelihood of rainfall. For daily rainfall amounts greater than 0.3 inches, the daily amount was distributed over the day using the calculated hourly precipitation amount frequency distribution.

4.6 Accounting for Pollutant Sources

4.6.1 Overview

There are one, seven, 13, one, and one permitted point discharges located in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), and Moncuin/Webb Creek (VAP-F13R-04) watersheds, respectively, as identified in Section 3.1. This source was modeled using the permitted concentration and design discharge. Currently, MS4 permitted facilities exist in the South Anna River, Totopotomoy Creek, and Pamunkey River watersheds.

Fecal coliform loads that are directly deposited by straight pipes and cattle along with wildlife in streams were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct 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 nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams. Nonpoint source loading was applied as fecal coliform counts to the impervious fraction of each land use category in a subwatershed at a constant rate during the year. These constant application rates are a function of land use and are discussed in detail in Section 4.6.4. Fecal coliform die-off was simulated during periods when manure is stored, while on the land between runoff generating precipitation events, and while in streams.

4.6.2 Modeling Fecal Coliform Die-off

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

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

where: C_t = concentration or load at time t;

C_0 = starting concentration or load (cfu/ 100ml);

K = decay rate (day-1); and

t = time in days.

A review of literature provided estimates of decay rates that could be applied to waste storage and handling in the South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River watersheds (Table 4.10).

Table 4.10. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources in the South Anna River, Taylors Creek, Newfound River, Northeast Creek, Totopotomoy Creek, Moncuin/Webb Creek, Black Creek, and Pamunkey River 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 Nonpoint Sources

Fecal coliform loads from direct nonpoint 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 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 nonpoint sources in each watershed are described in detail in Chapter 3.

4.6.4 Modeling Land-based Nonpoint Sources

For modeling purposes, nonpoint fecal coliform loads were those that were deposited or applied to land and, hence, required surface runoff events for transport to streams. Fecal coliform loading by land use for all sources in each sub-watershed is presented in Chapter 3. The existing condition fecal coliform loads are based on best estimates of existing wildlife, livestock, 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 South Anna River

The South Anna River model containing was calibrated using observed flow values from USGS station #01672500 near Ashland, VA for the period October 1, 1992 to September 30, 1997. The model was validated for the period October 1, 1989 to September 30, 1992. 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.

Observed stream flow values were not available for Northeast Creek, therefore a “paired watershed” approach was used for hydrologic calibration and validation. The approach assumes that the paired watershed and Northeast Creek watershed have similar hydrologic responses based on physical, geologic, and hydrologic characteristics. The South Anna River watershed was chosen as the paired watershed due to similar physiographic and hydrologic characteristics. Hydrology calibration and validation were performed based on the physical,

hydrologic, and land use data for the South Anna River watershed. After calibration and validation completion, the parameterization for the South Anna River model was transferred to the Northeast Creek model. Parameters describing watershed characteristics such as land use, slope, infiltration rate, and F-Tables were updated to reflect the physical properties in Northeast Creek watershed.

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 4.11 and 4.12, respectively. All criteria were within the recommended ranges. As shown in Figures 4.5 and 4.6, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 4.7 and 4.8 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 4.9 and 4.10).

Table 4.11. Summary statistics for the calibration period (10/1/92 to 9/30/97) in South Anna River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Runoff (in)	10	73.91	77.58	5.0
Total of Highest 10% Flows (in)	15	33.75	37.68	11.6
Total of Lowest 50% Flows (in)	10	9.20	9.02	-2.0
Total Winter Runoff (in)	20	33.69	37.97	12.7
Total Summer Runoff (in)	20	7.54	6.43	-14.7
Total Storm Runoff (in)	20	70.21	75.13	7.0
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.78			

Table 4.12. Summary statistics for the validation period (10/1/89 to 9/30/92) in South Anna River watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Volume (in)	20	30.38	28.11	-7.5
Total of Highest 10% Flows (in)	25	13.28	11.30	-14.9
Total of Lowest 50% Flows (in)	20	4.23	4.53	7.0
Total Winter Flow (in)	30	11.89	12.07	1.5
Total Summer Flow Volume (in)	30	3.27	2.77	-15.2
Total Storm Volume (in)	30	27.99	25.70	-8.2
Groundwater Recession Coefficient	1	0.97	0.98	1.0
Coefficient of Determination, r^2	0.78			

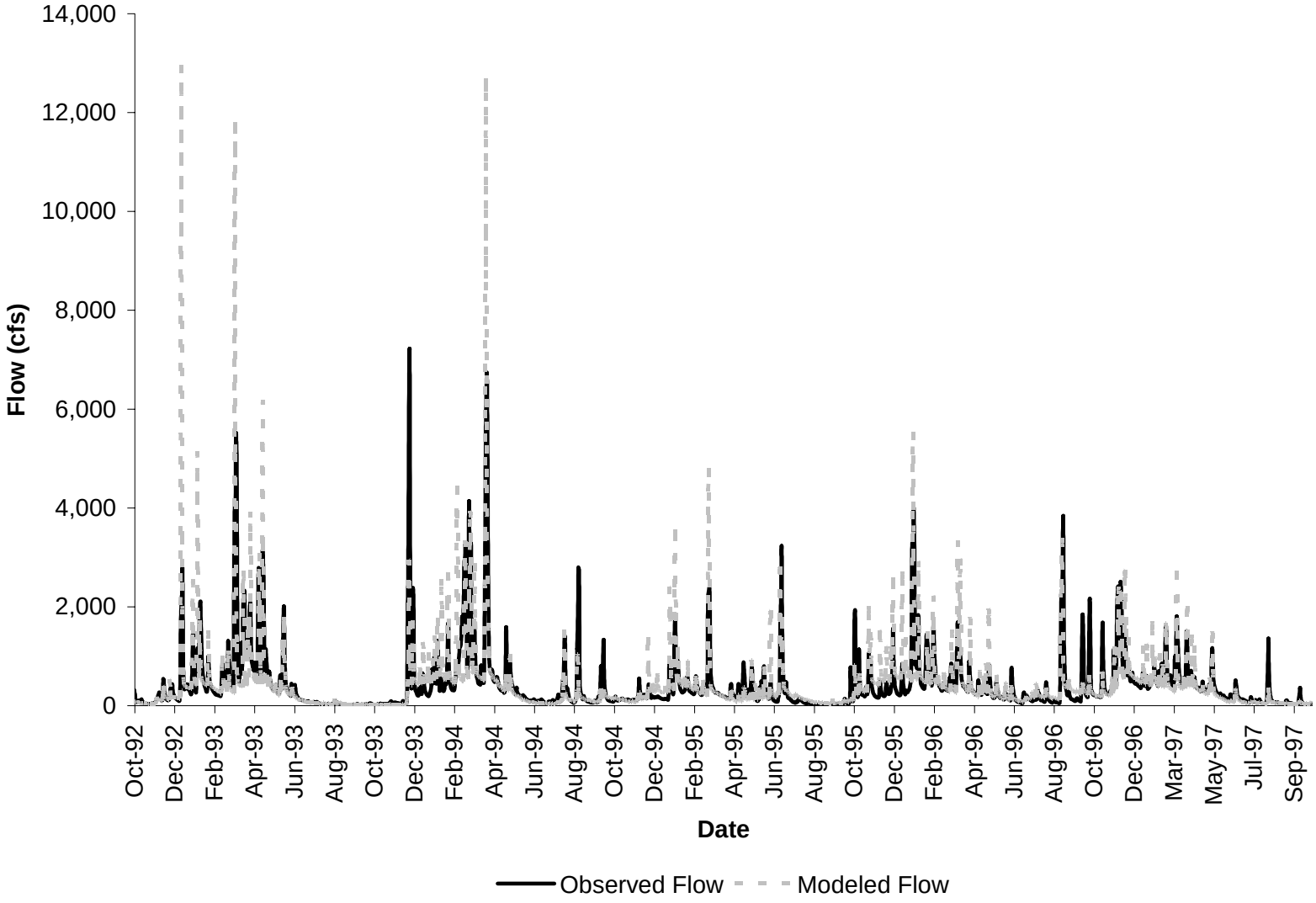

Figure 4.5. Observed and modeled flows for the calibration period 10/1/92 to 9/30/97 in South Anna River watershed.

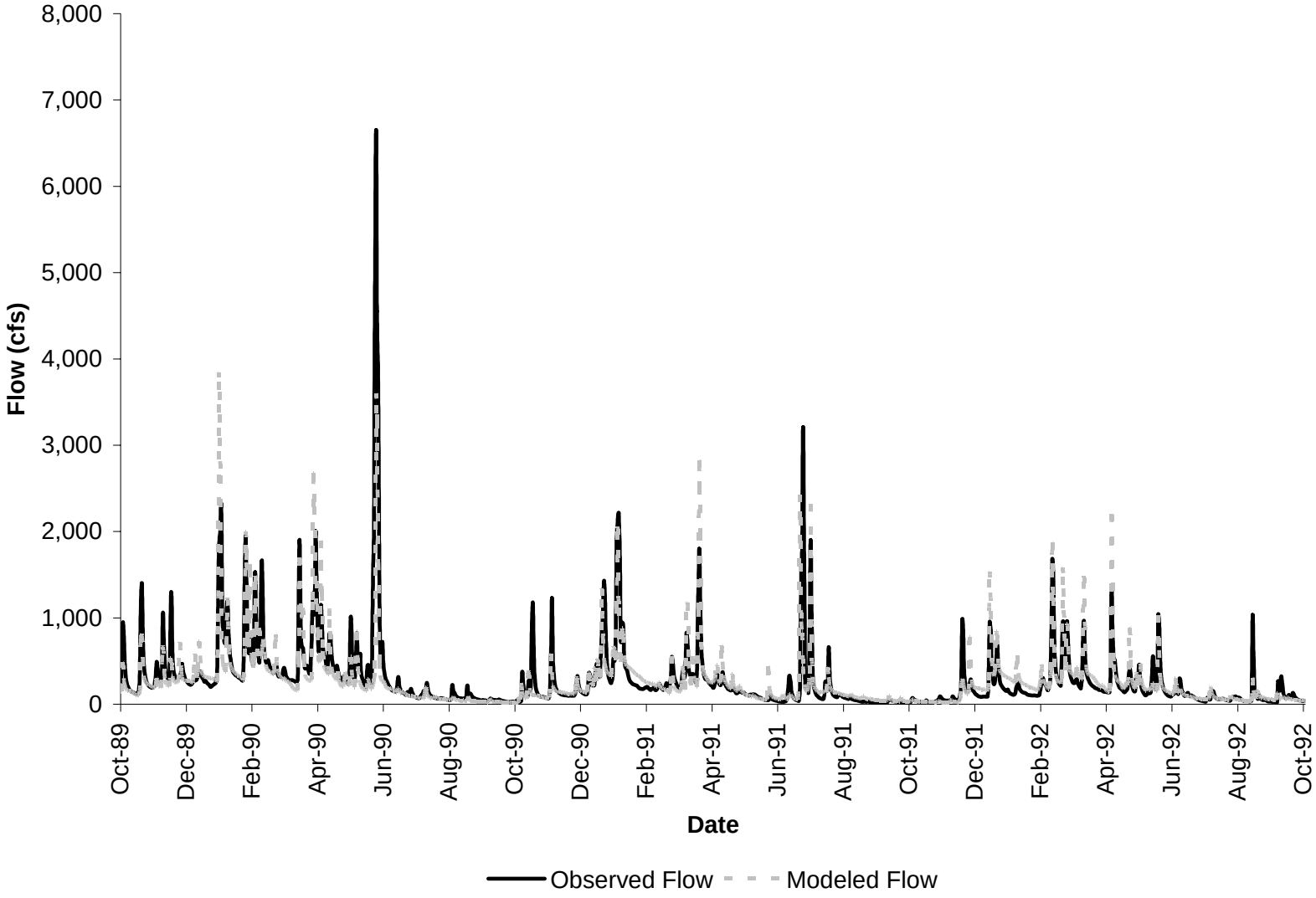

Figure 4.6. Observed and modeled flows for the validation period 10/1/89 to 9/30/92 in South Anna River watershed.

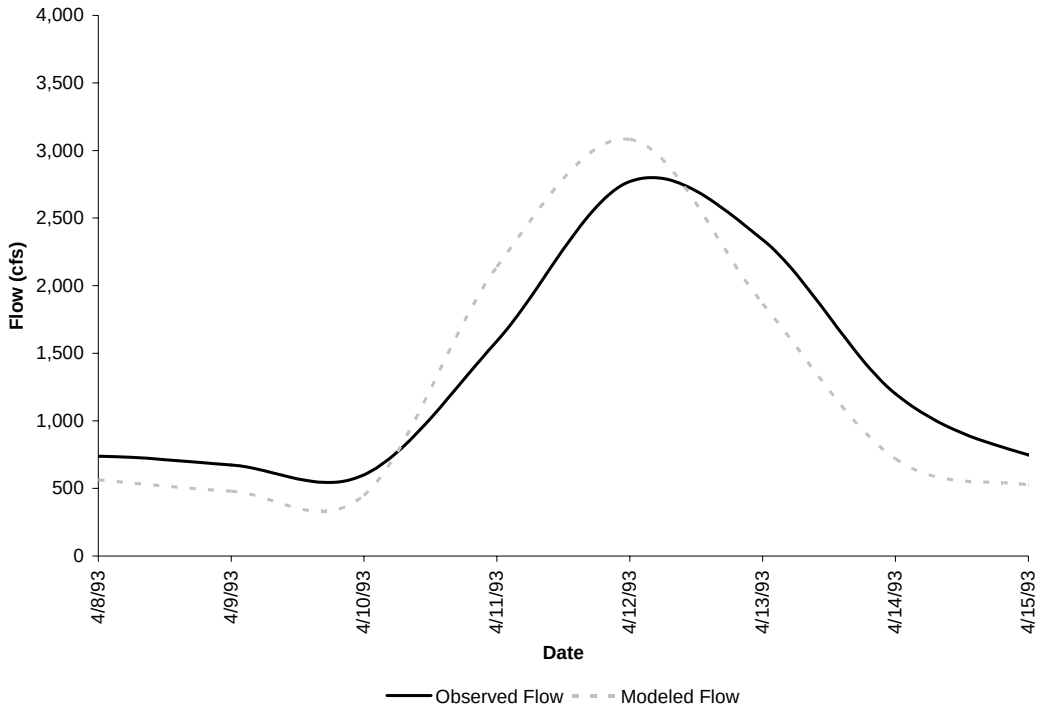

Figure 4.7. Observed and modeled flows for a representative storm (4/8/93-4/15/93) during the calibration period in South Anna River watershed.

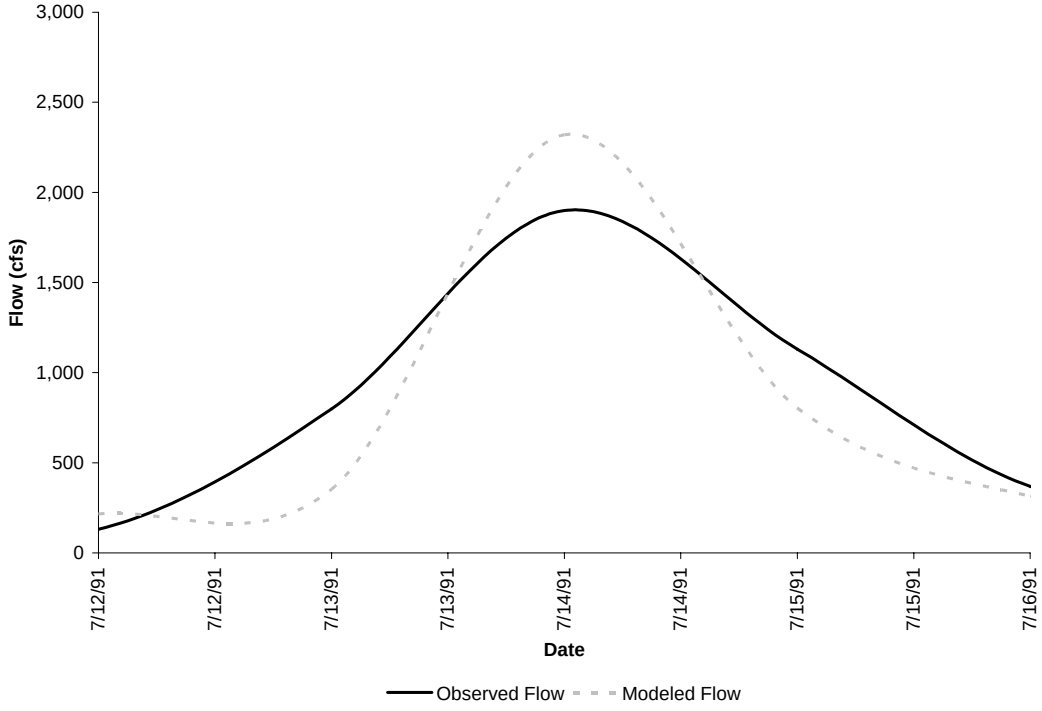

Figure 4.8. Observed and modeled flows for a representative storm (7/12/91-7/16/91) during the validation period in South Anna River watershed.

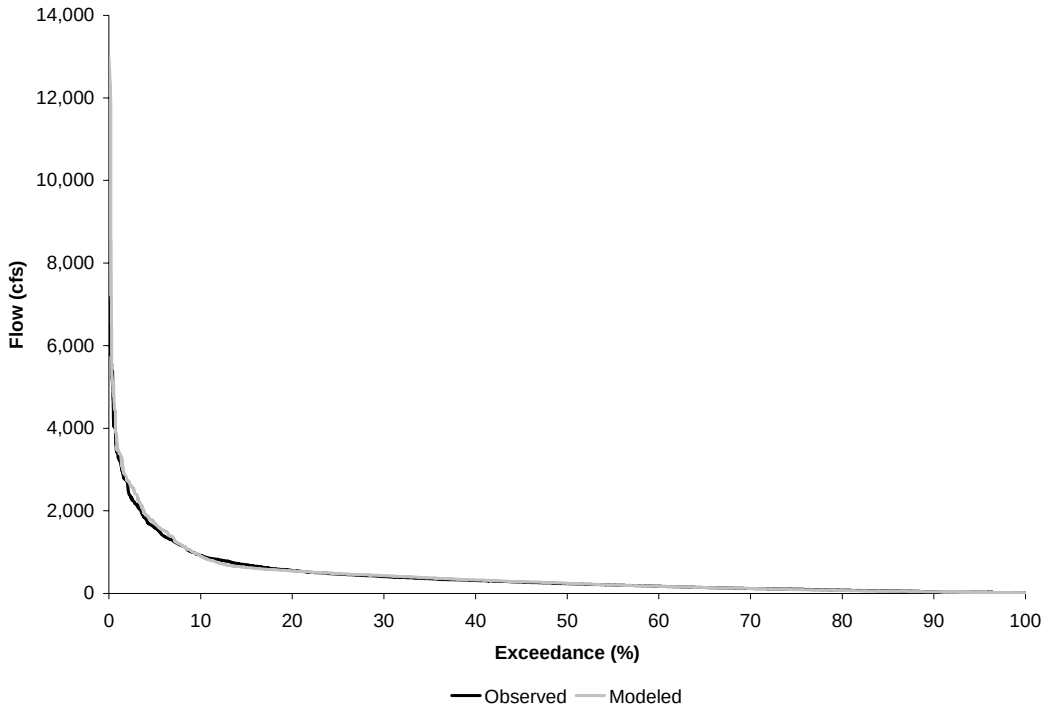

Figure 4.9. Cumulative frequency curves for the calibration period 10/1/92 to 9/30/97 in South Anna River watershed.

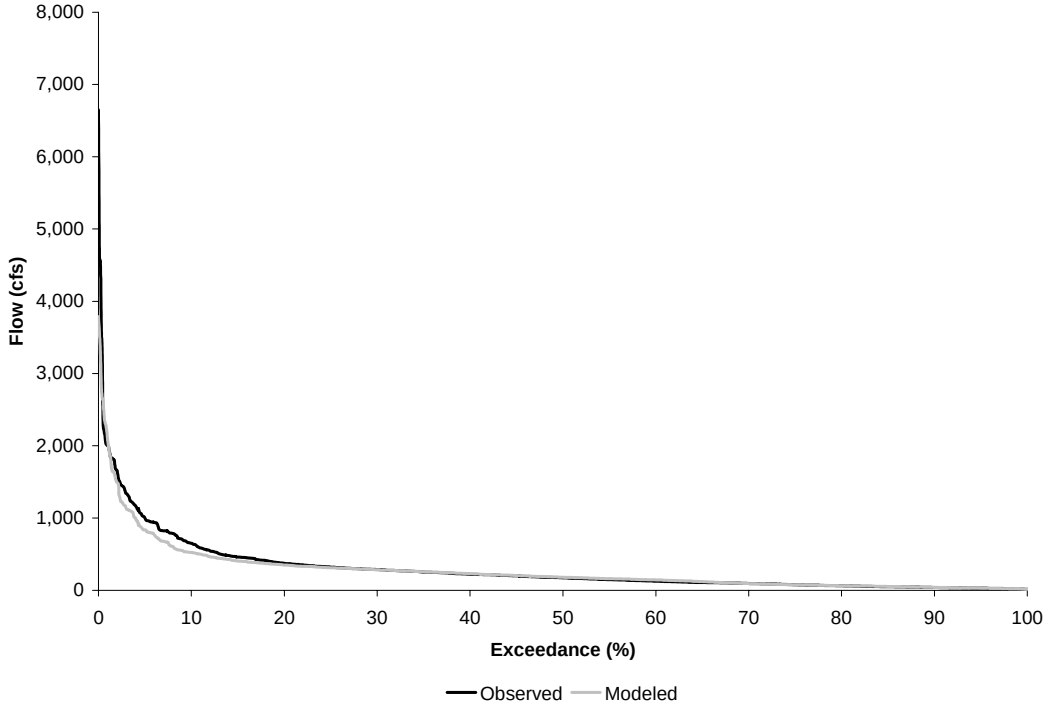

Figure 4.10. Cumulative frequency curves for the validation period 10/1/89 to 9/30/92 in South Anna River watershed.

Flow partitioning for South Anna River hydrologic model calibration and validation is shown in Table 4.13.

Table 4.13. Flow partitioning for the calibration and validation periods in South Anna River watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	90.9	32.9
Surface Runoff (in)	10.0 (11.0%)	4.7 (14.3%)
Interflow (in)	21.2 (23.3%)	8.5 (25.8%)
Baseflow (in)	59.7 (65.7%)	19.7 (59.9%)

A list of final calibration parameters for the hydrology calibration can be found in Tables 4.14 and 4.15.

Table 4.14. Calibrated hydrology HSPF parameters (PERLND) for South Anna 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	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.21	0.05 - 0.22	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	0.022	0.023-0.283	Determined by GIS
KVARY	Groundwater recession variable	1/in	0	3	0	5	0	0	Calibrate
AGWRC	Base groundwater recession	none	0.92	0.99	0.85	0.999	0.94	0.971	Calibrate
PWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW 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 W	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 – 0.279	Vegetation
UZSN	Upper zone nominal soil moisture storage	in	0.10	1	0.05	2	1.0	0.195 – 1.99	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	2.0	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	0.26 - 0.75	Vegetation

* USEPA, 2000.

Table 4.15. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for South Anna River watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	ft	200	500	100	700	100	100	Topography
SLSUR	Slope of overland flow	none	0.01	0.15	0.001	0.3	0.01	0.05 - 0.22	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 Totopotomoy Creek

The Totopotomoy Creek model was calibrated using observed flow values from USGS station #01673550 near Studley, Virginia for the period October 1, 1992 to September 30, 1997. The model was validated for the period October 1, 1987 to September 30, 1992. 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.

Observed stream flow values were not available for Moncuin/Webb Creek, Blacks Creek, and Pamunkey River, therefore a "paired watershed" approach was used for hydrologic calibration and validation. The approach assumes that the paired watershed and Moncuin/Webb Creek, Blacks Creek, and Pamunkey River watersheds have similar hydrologic responses based on physical, geologic, and hydrologic characteristics. The Totopotomoy Creek watershed was chosen as the paired watershed due to similar physiographic and hydrologic characteristics. Hydrology calibration and validation were performed based on the physical, hydrologic, and land use data for the Totopotomoy Creek watershed. After calibration and validation completion, the parameterization for the Totopotomoy Creek model was transferred to the Moncuin/Webb Creek, Blacks Creek, and Pamunkey River models. Parameters describing watershed characteristics such as land use, slope, infiltration rate, and F-Tables were updated

to reflect the physical properties in Moncuin/Webb Creek, Blacks Creek, and Pamunkey River watersheds.

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 4.16 and 4.17, respectively. All criteria were within the recommended ranges. As shown in Figures 4.11 and 4.12, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 4.13 and 4.14 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 4.15 and 4.16).

Table 4.16. Summary statistics for the calibration period (10/1/92 to 9/30/97) in Totopotomoy Creek watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Runoff (in)	10	52.34	53.46	2.1
Total of Highest 10% Flows (in)	15	18.58	16.37	-11.9
Total of Lowest 50% Flows (in)	10	9.55	8.79	-8.0
Total Winter Runoff (in)	20	22.18	22.98	3.6
Total Summer Runoff (in)	20	4.49	4.48	-0.3
Total Storm Runoff (in)	20	49.99	51.34	2.7
Groundwater Recession Coefficient	1	0.92	0.93	1.1
Coefficient of Determination, r^2	0.72			

Table 4.17. Summary statistics for the validation period (10/1/87 to 9/30/92) in Totopotomoy Creek watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Volume (in)	20	42.13	46.61	10.6
Total of Highest 10% Flows (in)	25	13.73	13.33	-2.9
Total of Lowest 50% Flows (in)	20	10.19	9.49	-6.8
Total Winter Flow (in)	30	14.29	16.95	18.6
Total Summer Flow Volume (in)	30	6.68	7.61	14.0
Total Storm Volume (in)	30	35.21	43.47	23.5
Groundwater Recession Coefficient	1	0.92	0.93	1.1
Coefficient of Determination, r^2	0.63			

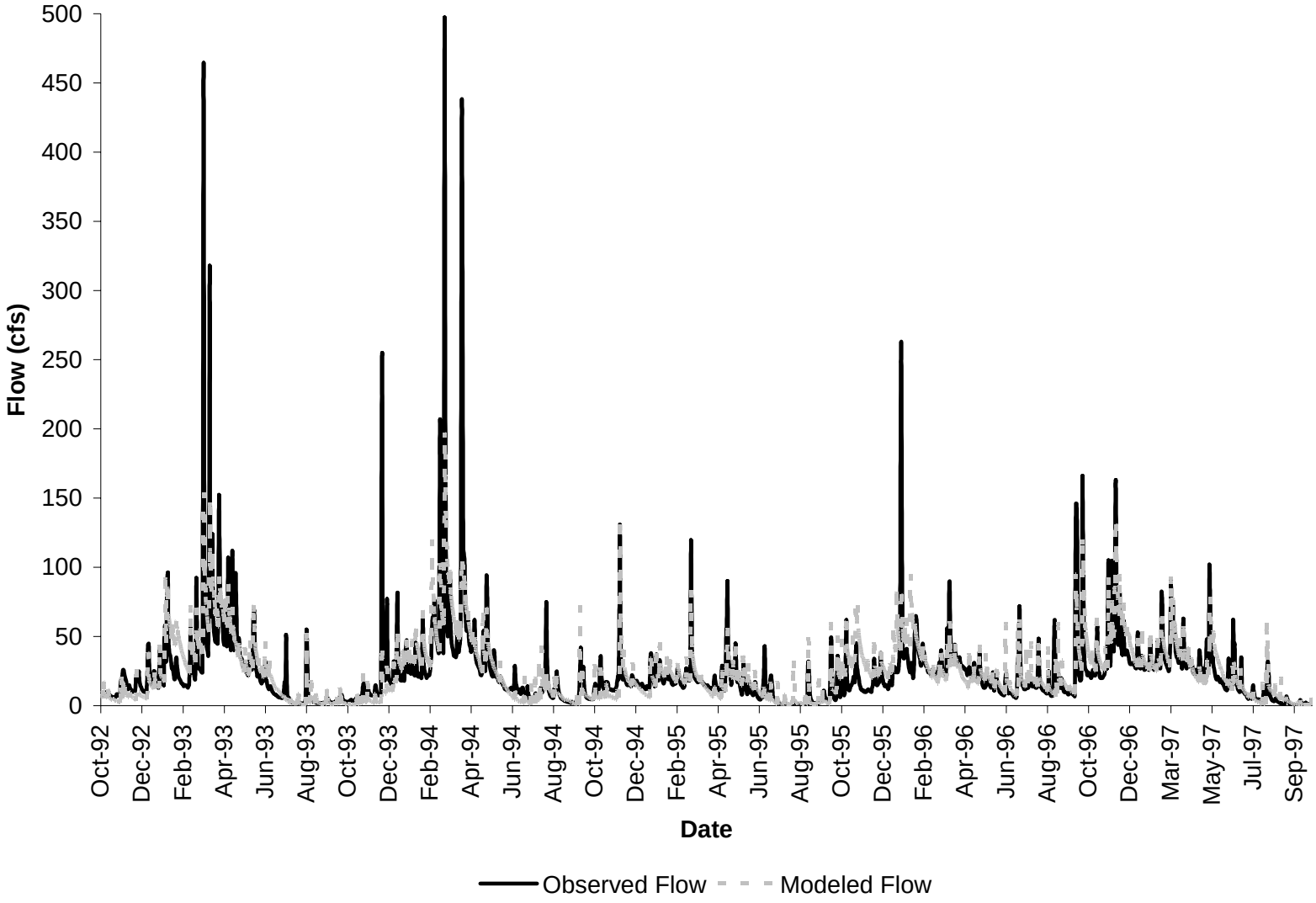

Figure 4.11. Observed and modeled flows for the calibration period 10/1/92 to 9/30/97 in Totopotomoy Creek watershed.

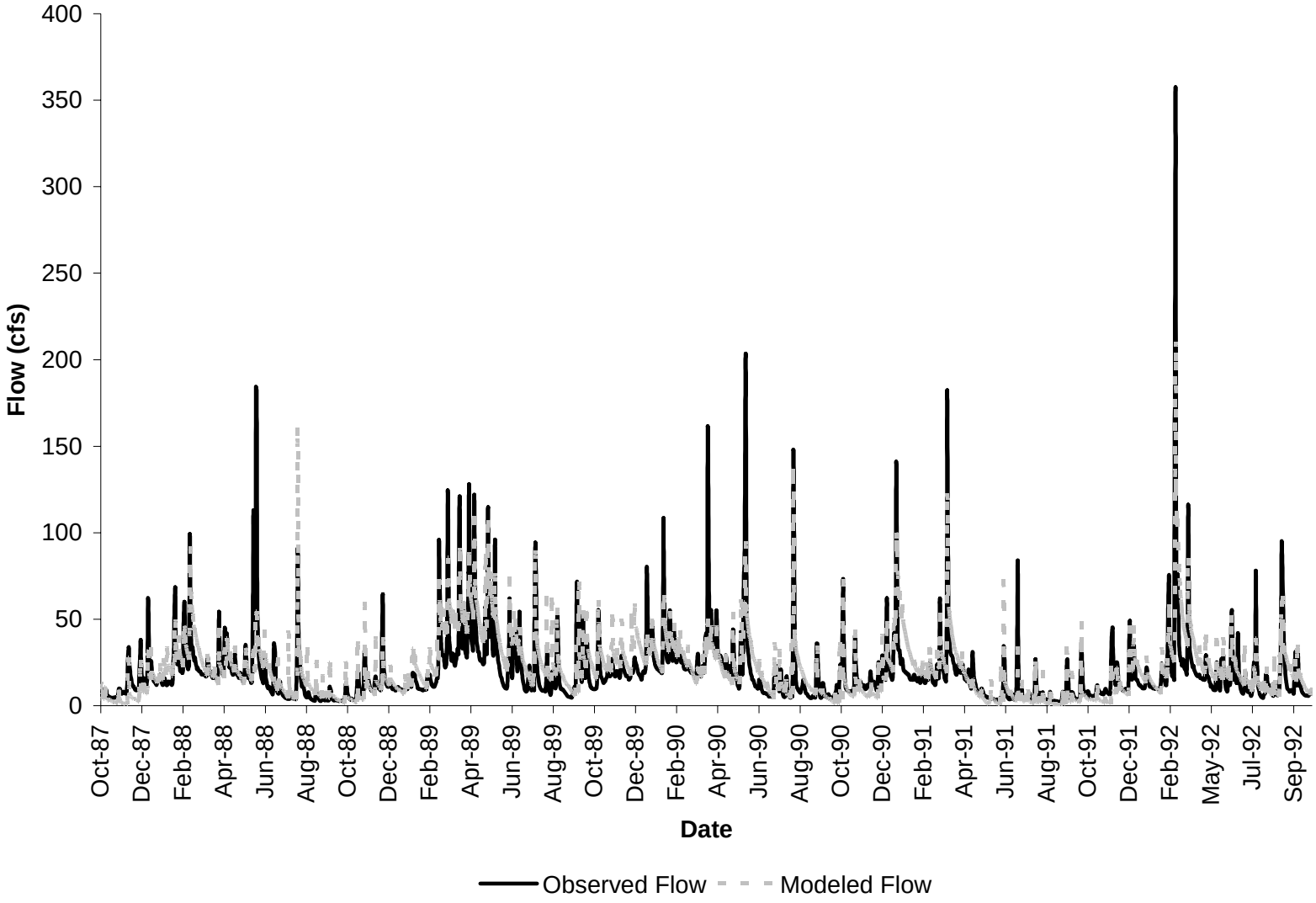

Figure 4.12. Observed and modeled flows for the validation period 10/1/87 to 9/30/92 in Totopotomoy Creek watershed.

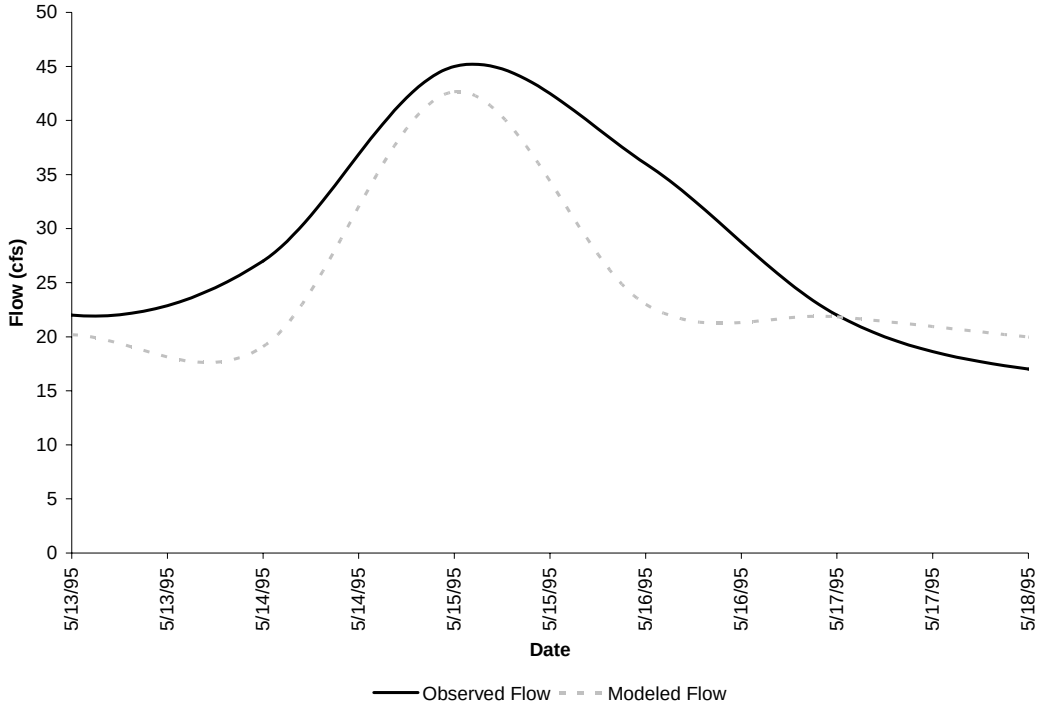

Figure 4.13. Observed and modeled flows for a representative storm (5/13/95-5/18/95) during the calibration period in Totopotomoy Creek watershed.

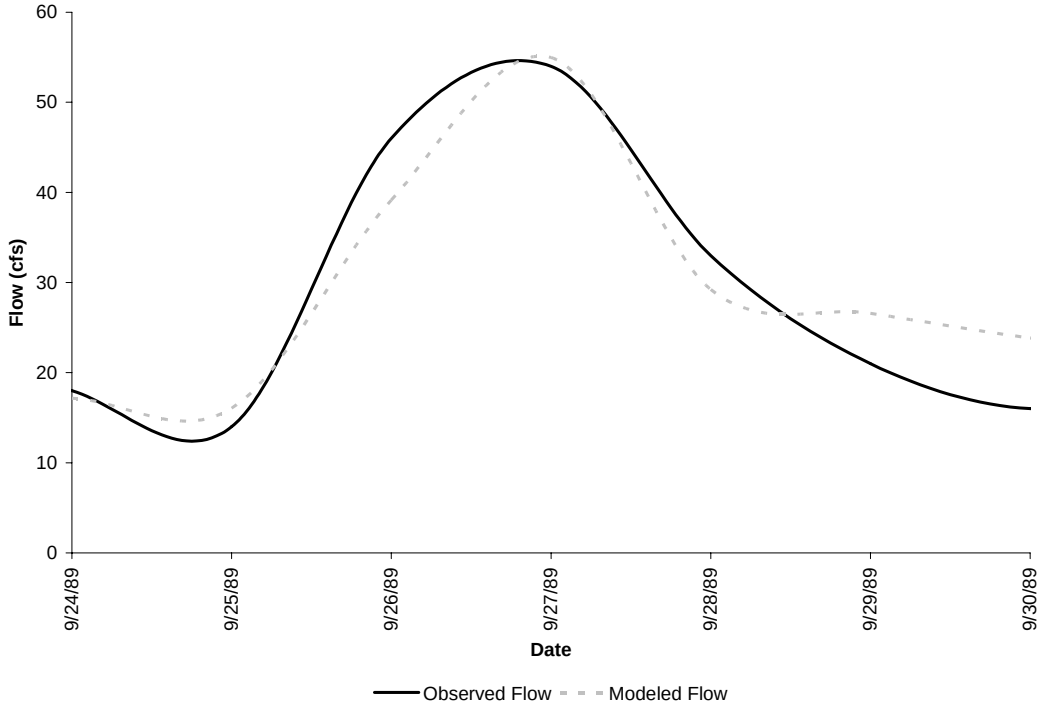

Figure 4.14. Observed and modeled flows for a representative storm (7/12/91-7/16/91) during the validation period in Totopotomoy Creek watershed.

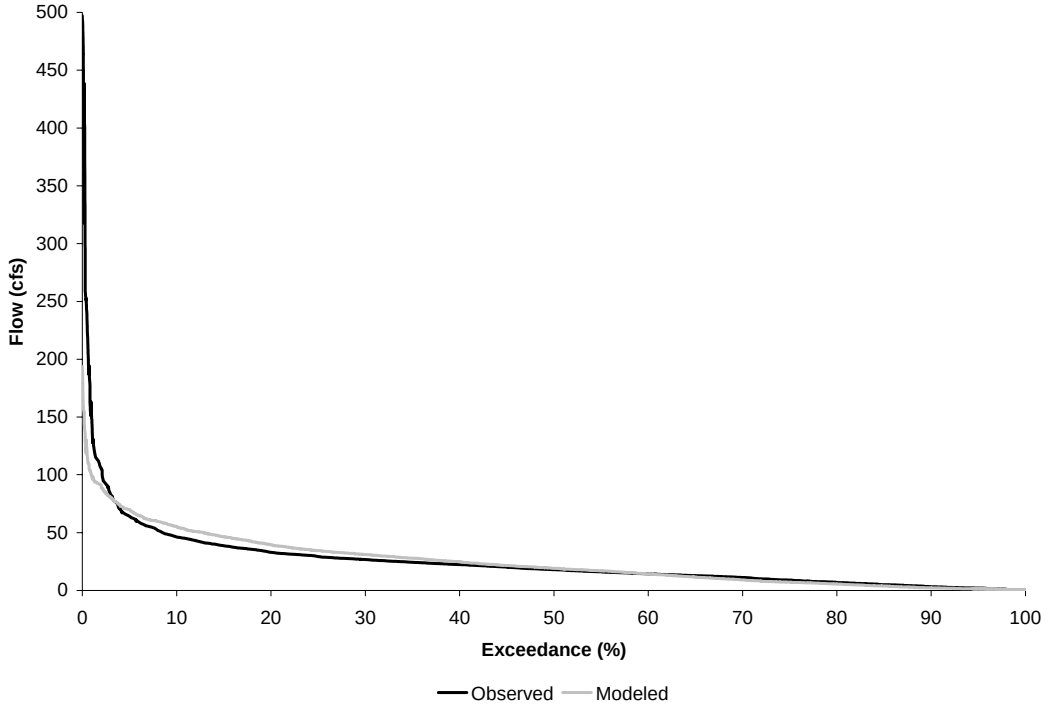

Figure 4.15. Cumulative frequency curves for the calibration period 10/1/92 to 9/30/97 in Totopotomoy Creek watershed.

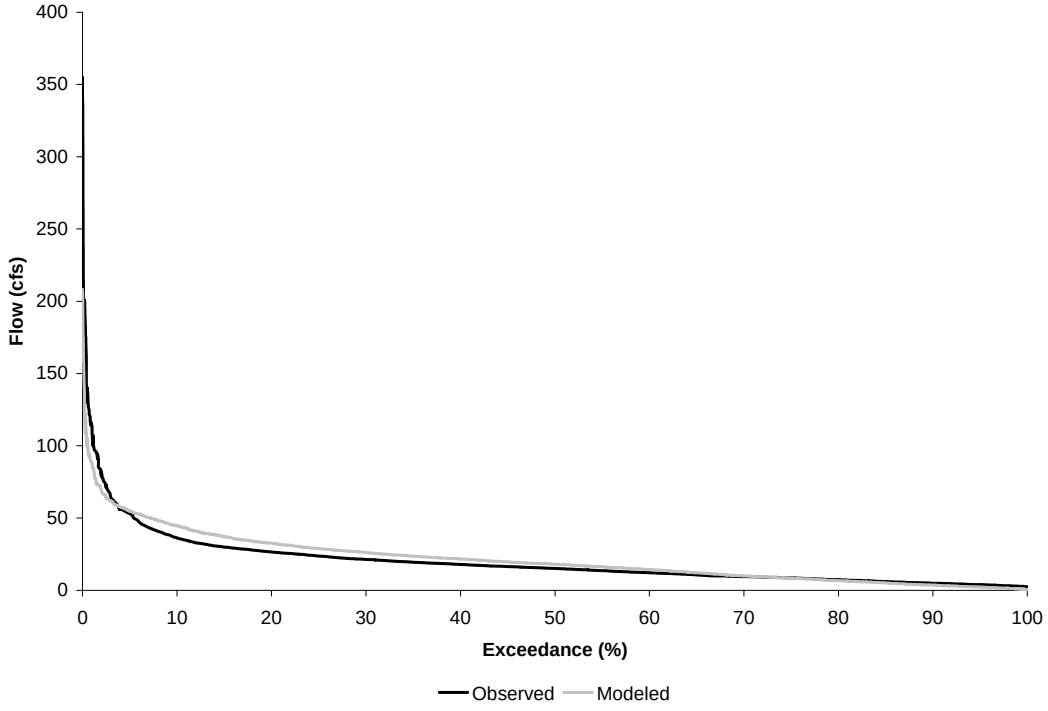

Figure 4.16. Cumulative frequency curves for the validation period 10/1/87 to 9/30/92 in Totopotomoy Creek watershed.

Flow partitioning for Totopotomoy Creek hydrologic model calibration and validation is shown in Table 4.18.

Table 4.18. Flow partitioning for the calibration and validation periods in Totopotomoy Creek watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	5.0	4.4
Surface Runoff (in)	0.5 (10.0%)	0.5 (11.4%)
Interflow (in)	0.3 (6.0%)	0.2 (4.5%)
Baseflow (in)	4.2 (84.0%)	3.7 (84.1%)

A list of final calibration parameters for the hydrology calibration can be found in Tables 4.19 and 4.20.

Table 4.19. Calibrated hydrology HSPF parameters (PERLND) for Totopotomoy Creek 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	4.9	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.21	0.20 - 0.25	Soil and cover condition
LSUR	Length of overland flow	ft	200	500	100	700	300	300	Topography
SLSUR	Slope of overland flowplane	none	0.01	0.15	0.001	0.3	0.022	0.033 - 0.053	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	0.955	Calibrate
PWAT-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
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of GW 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	0.025	Riparian vegetation
AGWETP	Fraction of remain ET from active W	none	0.0	0.05	0.0	0.2	0.0	0.0	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	in	0.03	0.2	0.01	0.4	0.1	0.01 – 0.25	Vegetation
UZSN	Upper zone nominal soil moisture storage	in	0.10	1	0.05	2	1.0	0.19 – 1.95	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	2.0	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.3	0.7	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.1-0.7	0.05 - 0.45	Vegetation

* USEPA, 2000.

Table 4.20. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for Totopotomoy Creek watershed.

Parameter	Definition	Units	Range of Values*				Start	Final	Function of…
			Typical		Possible				
			Min	Max	Min	Max			
IMPLND									
IWAT-PARM2									
LSUR	Length of overland flow	ft	200	500	100	700	100	100	Topography
SLSUR	Slope of overland flow	none	0.01	0.15	0.001	0.3	0.01	.01	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, the period of January 1, 1998 through December 31, 2002 was chosen for water quality calibration and January 1, 1993 through December 31, 1997 for water quality validation.

The PQUAL and IQUAL modules of HSPF were used to represent the build-up, die-off, and wash-off of fecal coliform bacteria from land surfaces. The modules are characterized by the following parameters: 1) Daily accumulation rate of bacteria on the soil surface (ACQOP); 2) Maximum bacteria build-up rate on the soil (SQOLIM); 3) Rate of surface runoff that removes 90% of the accumulated bacteria from the soil surface (WSQOP); and 4) Bacteria concentration in interflow, PQUAL only (IOQC). The GQUAL module in HSPF was used to represent the transport, settling, and die-off of dissolved bacteria in-stream. Settling and die-off were estimated using the first-order decay rate (FSTDEC). Additionally, F-Tables were adjusted to account for additional assimilative capacity in the watershed not represented by channel volumes derived for the reach section. Added assimilation can be achieved through three additional pathways. First, only the main channel of the impairment streams and the major tributaries are explicitly represented in HSPF. Stream channels not represented add additional

water volume available to dilute fecal coliform loads during low flow conditions and increase channel residence time, which increases settling and die-off of bacteria in transit. Second, dead water that occurs during minimal streamflow can provide added storage. Third, flow in the watershed drains through a multitude of farm ponds. Using GIS, ponds were estimated by separating water in the stream layer from water in the land use layer. Surface area of the ponds was multiplied by an estimated depth of four feet to calculate the total storage volume of all ponds in a subwatershed. To account for the three sources of additional storage, an additional storage volume was added to each line of the F-table. This storage has no effect on the functional relationship between volume of water stored in the channel and flow in the channel. The listed model parameters were adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established.

A number of factors, not inclusive to description below, complicate the water quality calibration. The difficulty in measuring bacteria concentrations is attributed to variability in bacteria density in feces, variability in location and timing of fecal deposition, variability in bacteria amount delivered to the stream, and environmental impacts on re-growth and die-off. The bacteria concentrations are highly dependent on flow conditions and variability associated with modeling stream flows compounds the variability in modeling the bacteria concentrations. The usually limited number of grab samples collected at each VADEQ station and the practice of censoring both high (over 8,000 cfu/100 ml or 16,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations hinder the water quality calibration process.

4.7.2.1 South Anna River (VAN-F01R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-SAR097.82 within the South Anna River (VAN-F01R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.21. Observations from the VADEQ station, 8-SAR097.82, were graphically compared to corresponding modeled concentrations at subwatershed SAR-3 (Figures 4.17 and 4.18). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. As expected, differences between modeled and observed bacteria concentrations were greater during the validation period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and violation 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 4.22 and 4.23 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.22 and 4.23. A difference of one violation could result in a difference of violation rate of 5-10%. The highest difference (48%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (50%) was recorded during the vaidation period. Ten observations were available for comparison during this period resulting in a 10% weighting when comparing the water quality standard violation rate. This translates into two model observations that were not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 South Anna River (VAN-F01R-01) watershed.

Table 4.21. Calibrated water quality HSPF parameters for South Anna River (VAN-F01R-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	84E05-29E09	84E05-29E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	84E06-29E10	76E06-26E10	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	52E07-27E09	52E07-27E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	52E08-27E10	47E08-24E10	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	2.3	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

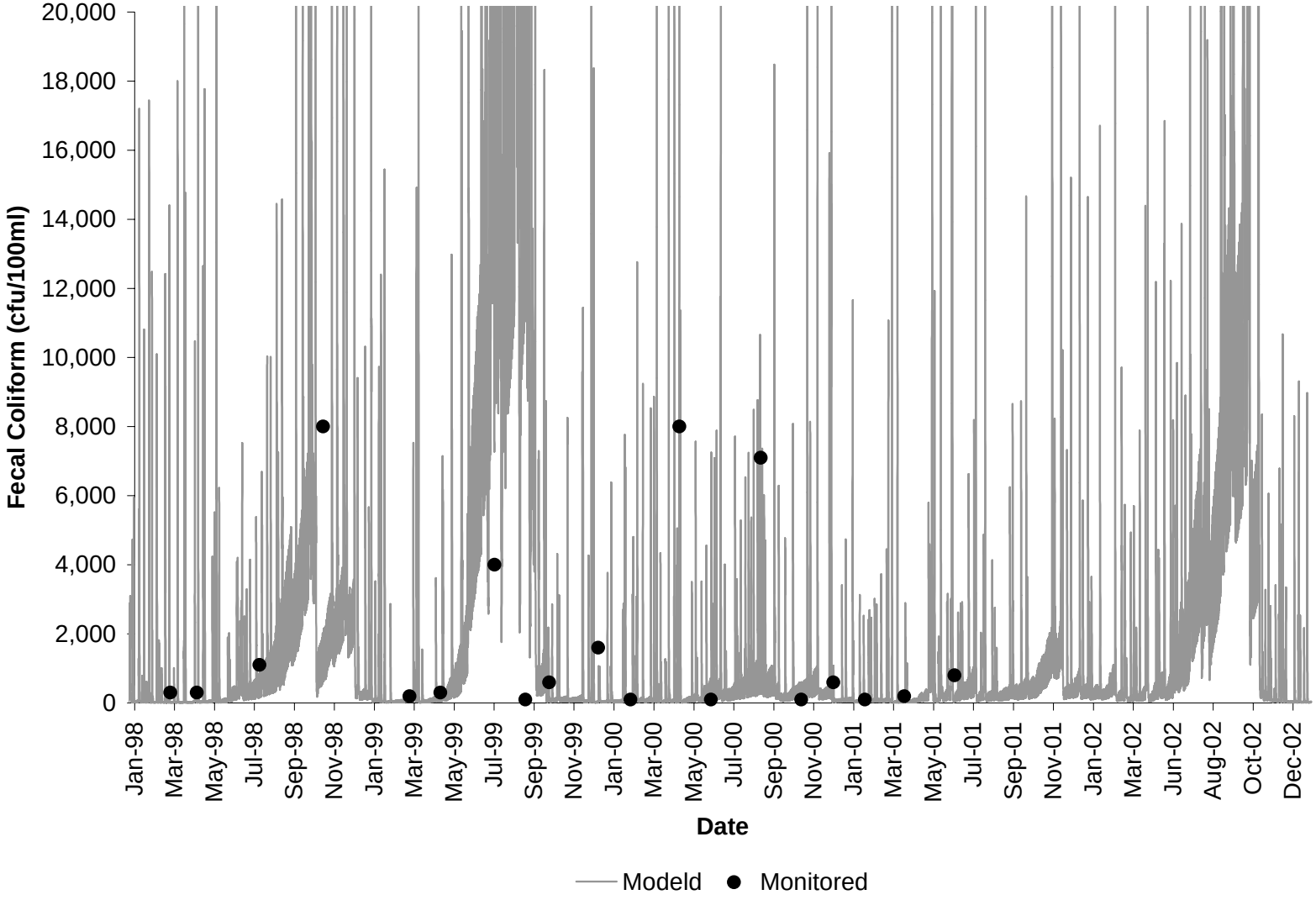

Figure 4.17. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-3 in South Anna River (VAN-F01R-01) impairment.

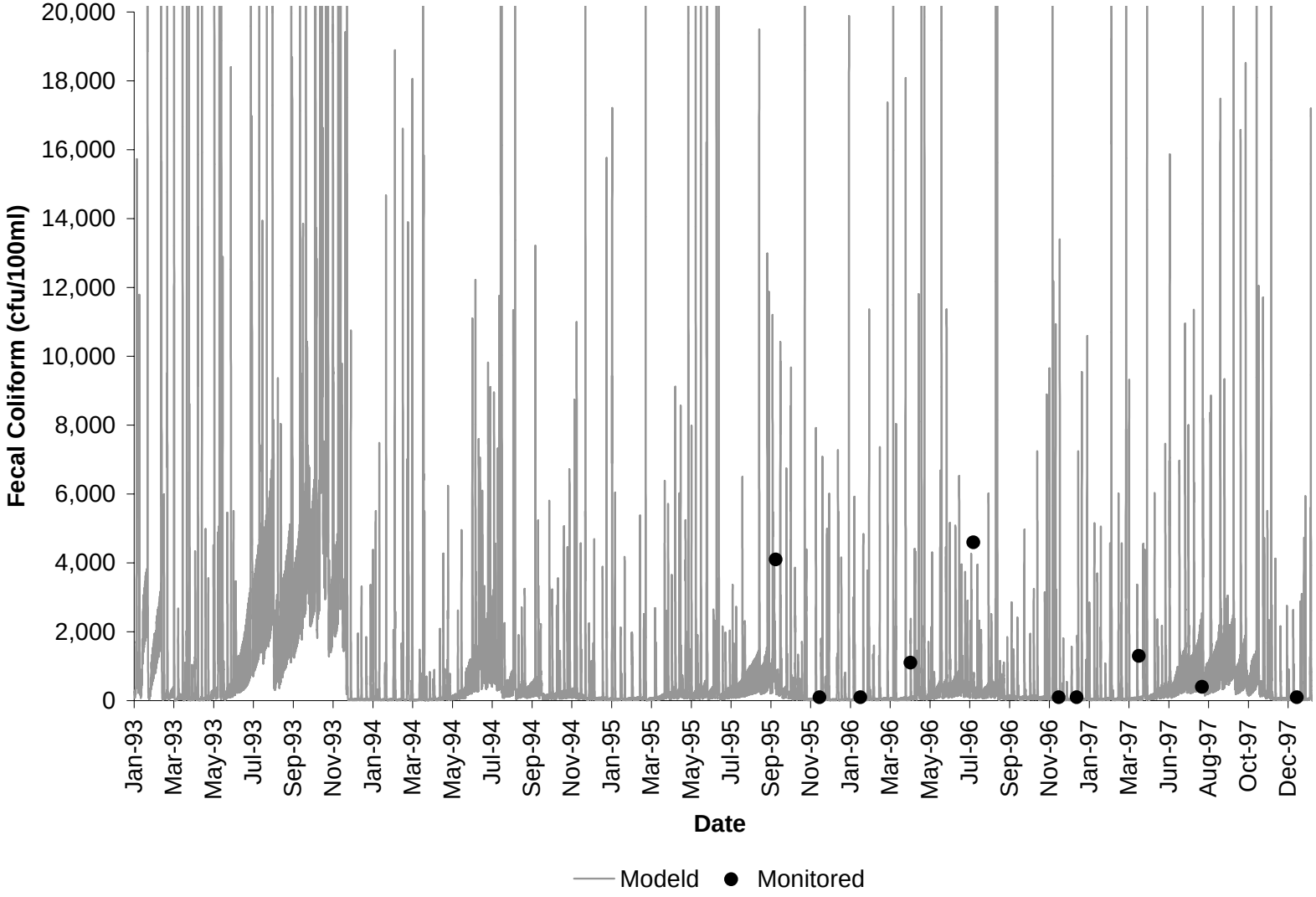

Figure 4.18. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-3 in South Anna River (VAN-F01R-01) impairment.

Table 4.22. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in South Anna River (VAN-F01R-01) watershed.

Parameter	Sub SAR-3
Geometric Mean of Observed Values (cfu/100mL)	545
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	566
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	32
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	32
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	47
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	47

Table 4.23. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in South Anna River (VAN-F01R-01) watershed.

Parameter	Sub SAR-3
Geometric Mean of Observed Values (cfu/100mL)	401
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	207
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	40
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	20
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	40
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	40

4.7.2.2 South Anna River (VAN-F02R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-SAR070.96 within the South Anna River (VAN-F02R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.24. Observations from the VADEQ station, 8-SAR070.96, were graphically compared to corresponding modeled concentrations at subwatershed SAR-12 (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 violation 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 violation 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 violation rates in Tables 4.25 and 4.26. A difference of one violation could result in a difference of violation rate of 6-10%. The highest difference (48%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (100%) was recorded during the validation period. Ten observations were available for comparison during this period resulting in a 10% weighting when comparing the water quality standard violation rate. This translates into one model observation that was not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 South Anna River (VAN-F02R-01) watershed.

Table 4.24. Calibrated water quality HSPF parameters for South Anna River (VAN-F02R-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	80E05-23E10	80E05-23E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	80E06-23E11	72E06-02E12	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	19E08-23E10	19E08-23E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	19E09-23E11	02E10-02E12	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	2.1	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

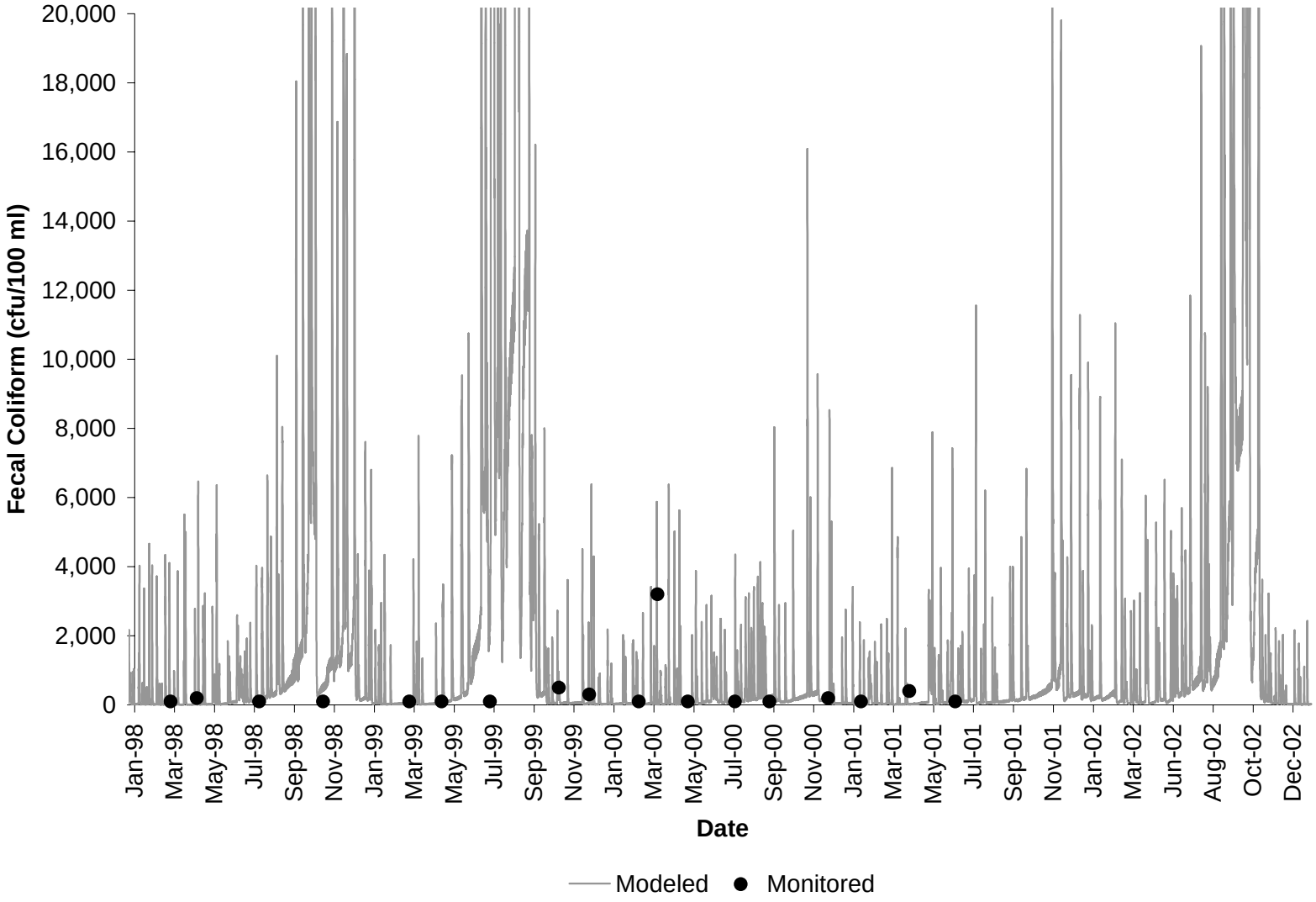

Figure 4.19. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-12 in South Anna River (VAN-F02R-01) impairment.

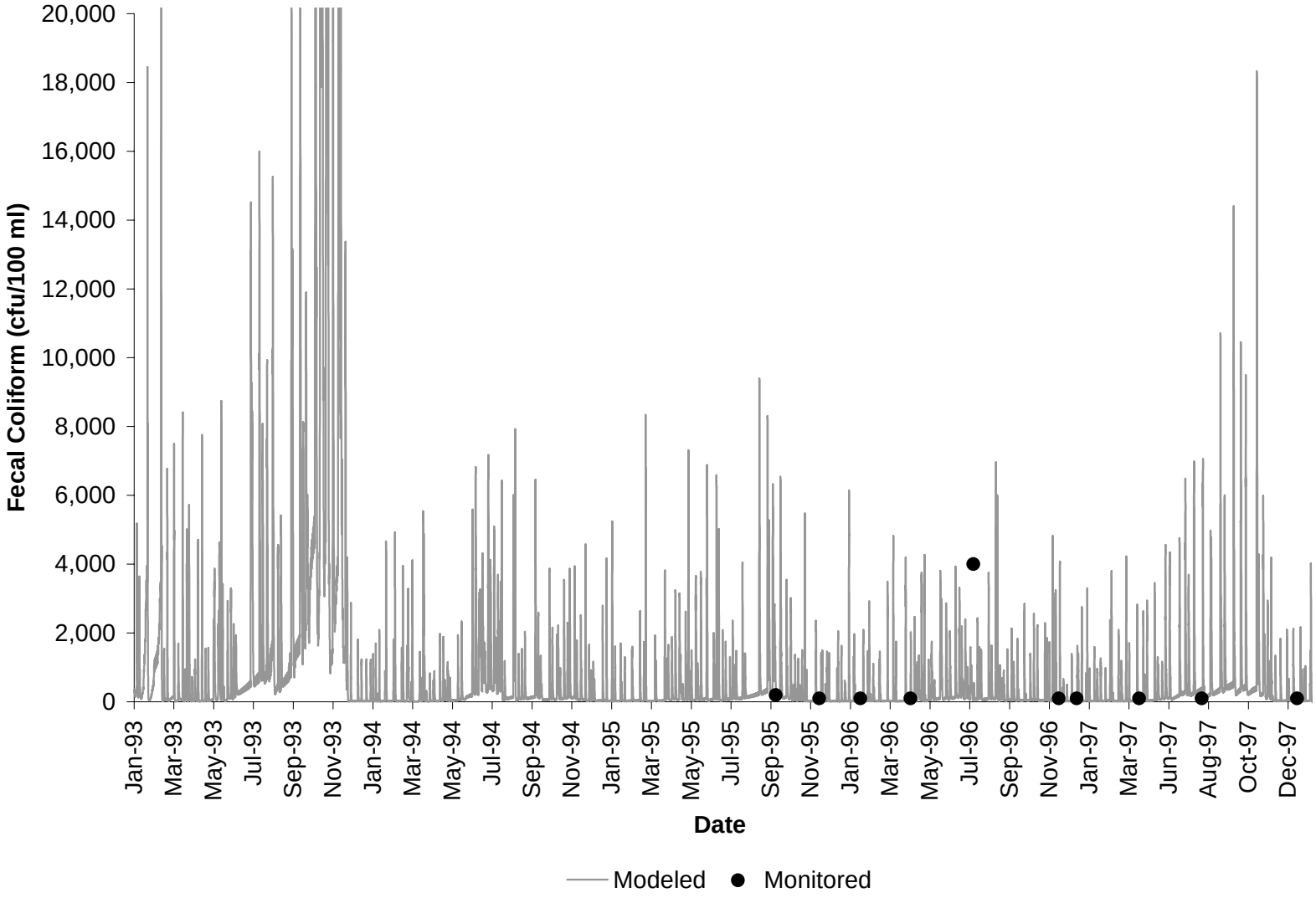

Figure 4.20. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-12 in South Anna River (VAN-F02R-01) impairment.

Table 4.25. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in South Anna River (VAN-F02R-01) watershed.

Parameter	Sub SAR-12
Geometric Mean of Observed Values (cfu/100mL)	164
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	160
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	6
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	11
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	17

Table 4.26. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in South Anna River (VAN-F02R-01) watershed.

Parameter	Sub SAR-12
Geometric Mean of Observed Values (cfu/100mL)	155
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	80
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	10
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	10
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	10

4.7.2.3 South Anna River (VAP-F04R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-SAR021.22 within the South Anna River (VAP-F04R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.27. Observations from the VADEQ station, 8-SAR021.22, were graphically compared to corresponding modeled concentrations at subwatershed SAR-16 (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 violation 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 violation 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 violation rates in Tables 4.28 and 4.29. A difference of one violation could result in a difference of violation rate of 5%. The highest difference (18%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard violation rates (5%) was recorded during the calibration period. Nineteen observations were available for comparison during this period resulting in a 5% weighting when comparing the water quality standard violation rate. This translates into one model observation that was above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 South Anna River (VAP-F04R-01) watershed.

Table 4.27. Calibrated water quality HSPF parameters for South Anna River (VAP-F04R-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	76E05-13E09	76E05-13E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	76E06-13E10	53E06-09E10	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	24E08-13E09	24E08 – 13E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	24E09-13E10	02E10-09E10	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	2.2 - 3.1	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

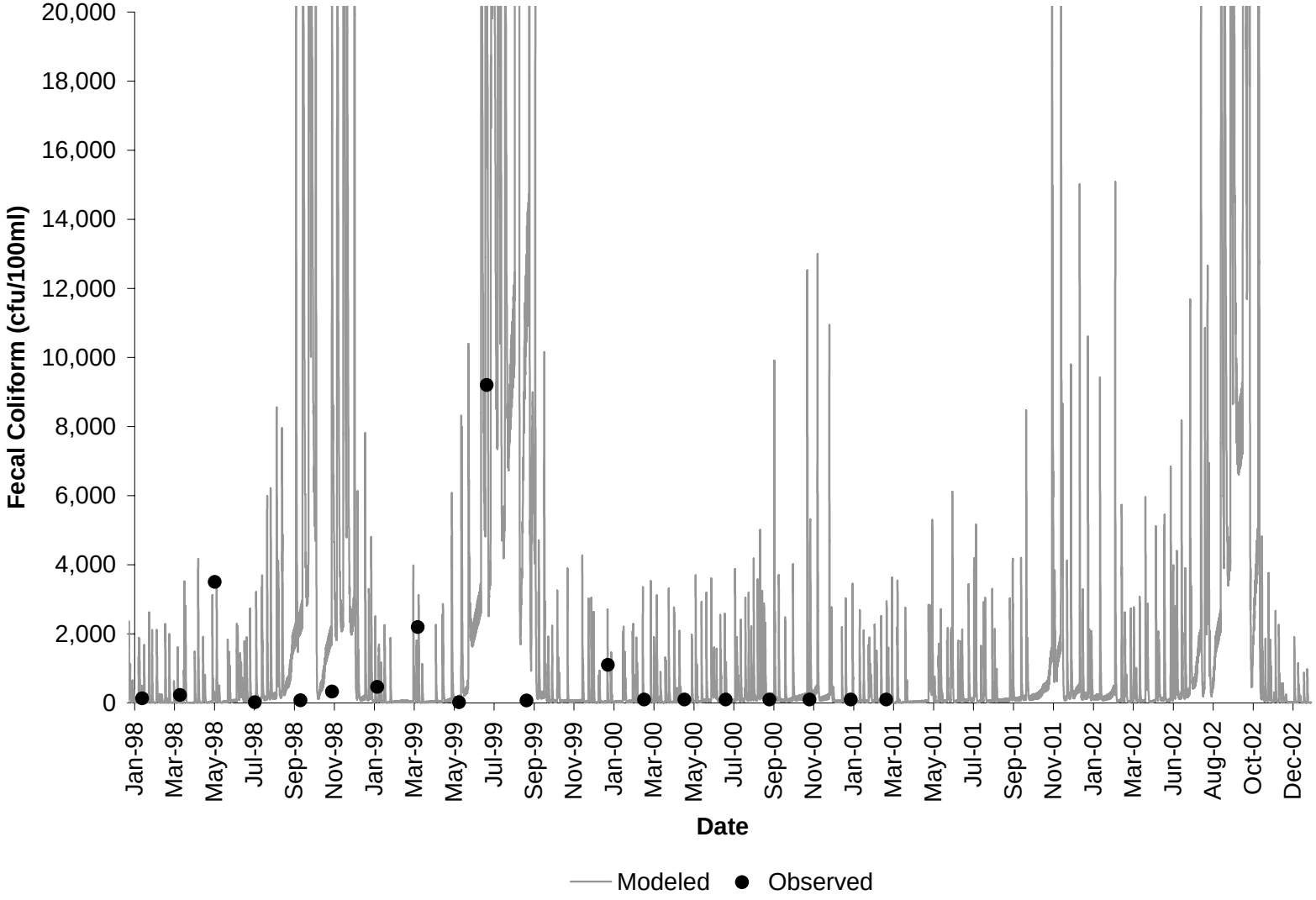

Figure 4.21. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-16 in South Anna River (VAP-F04R-01) impairment.

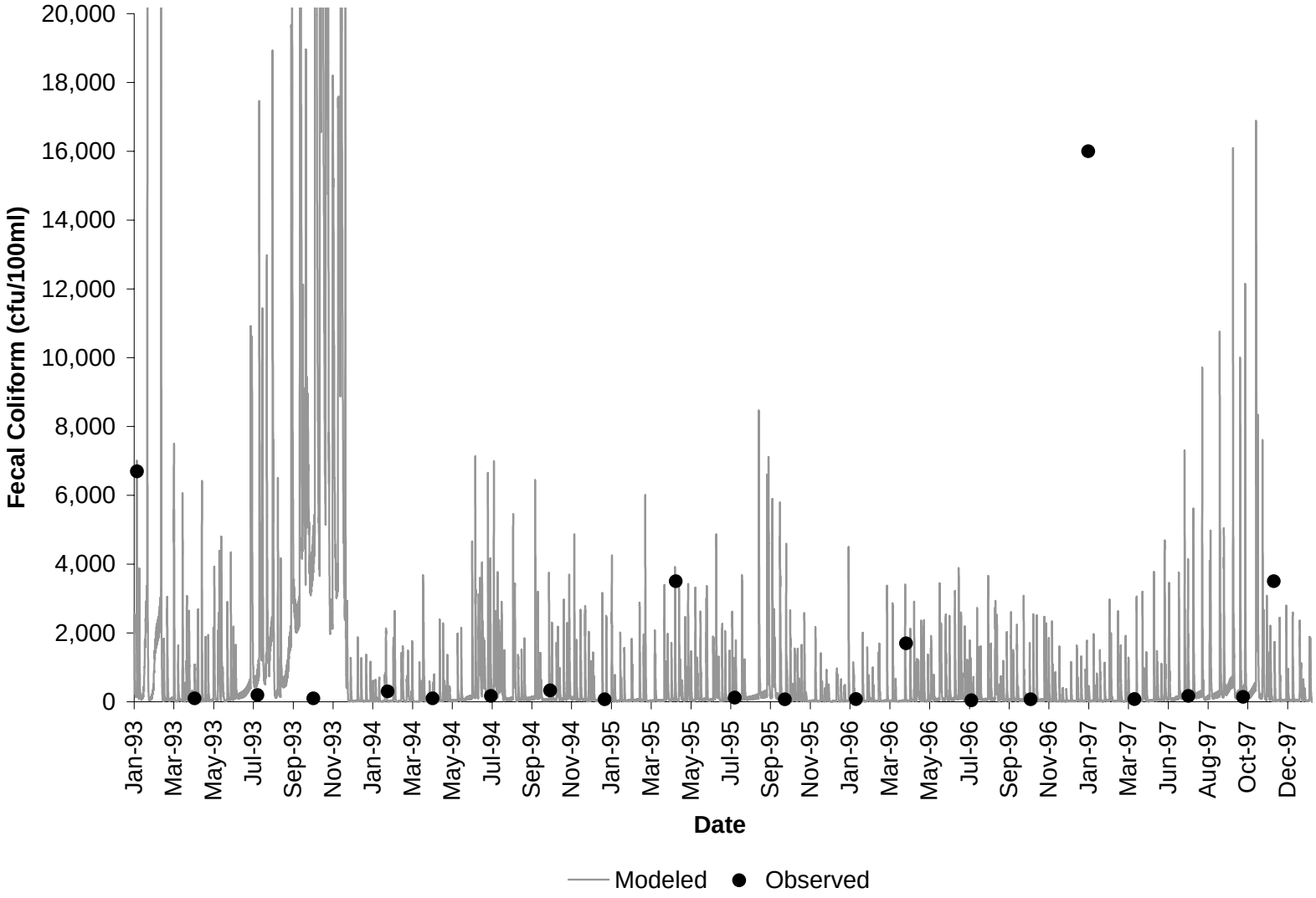

Figure 4.22. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-16 in South Anna River (VAP-F04R-01) impairment.

Table 4.28. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in South Anna River (VAP-F04R-01) watershed.

Parameter	Sub SAR-16
Geometric Mean of Observed Values (cfu/100mL)	203
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	239
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	21
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	26
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	26
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	31

Table 4.29. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in South Anna River (VAP-F04R-01) watershed.

Parameter	Sub SAR-16
Geometric Mean of Observed Values (cfu/100mL)	276
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	241
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	24
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	24
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	24
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	29

4.7.2.4 South Anna River (VAP-F04R-02)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-SAR001.11 within the South Anna River (VAP-F04R-02) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.30. Observations from the VADEQ station, 8-SAR001.11, were graphically compared to corresponding modeled concentrations at subwatershed SAR-27 (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 violation 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 violation 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 violation rates in Tables 4.31 and 4.32. A difference of one violation could result in a difference of violation rate of 2%. The highest difference (37%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (9%) was recorded during the calibration period. Forty-seven observations were available for comparison during this period resulting in a 2% weighting when comparing the water quality standard violation rate. This translates into four model observation that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 South Anna River (VAP-F04R-02) watershed.

Table 4.30. Calibrated water quality HSPF parameters for South Anna River (VAP-F04R-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	80E05-17E10	80E05-17E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	80E06-17E11	56E06-01E12	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	53E08-17E10	53E08-17E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	53E09-17E11	04E10-01E12	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	3.1	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

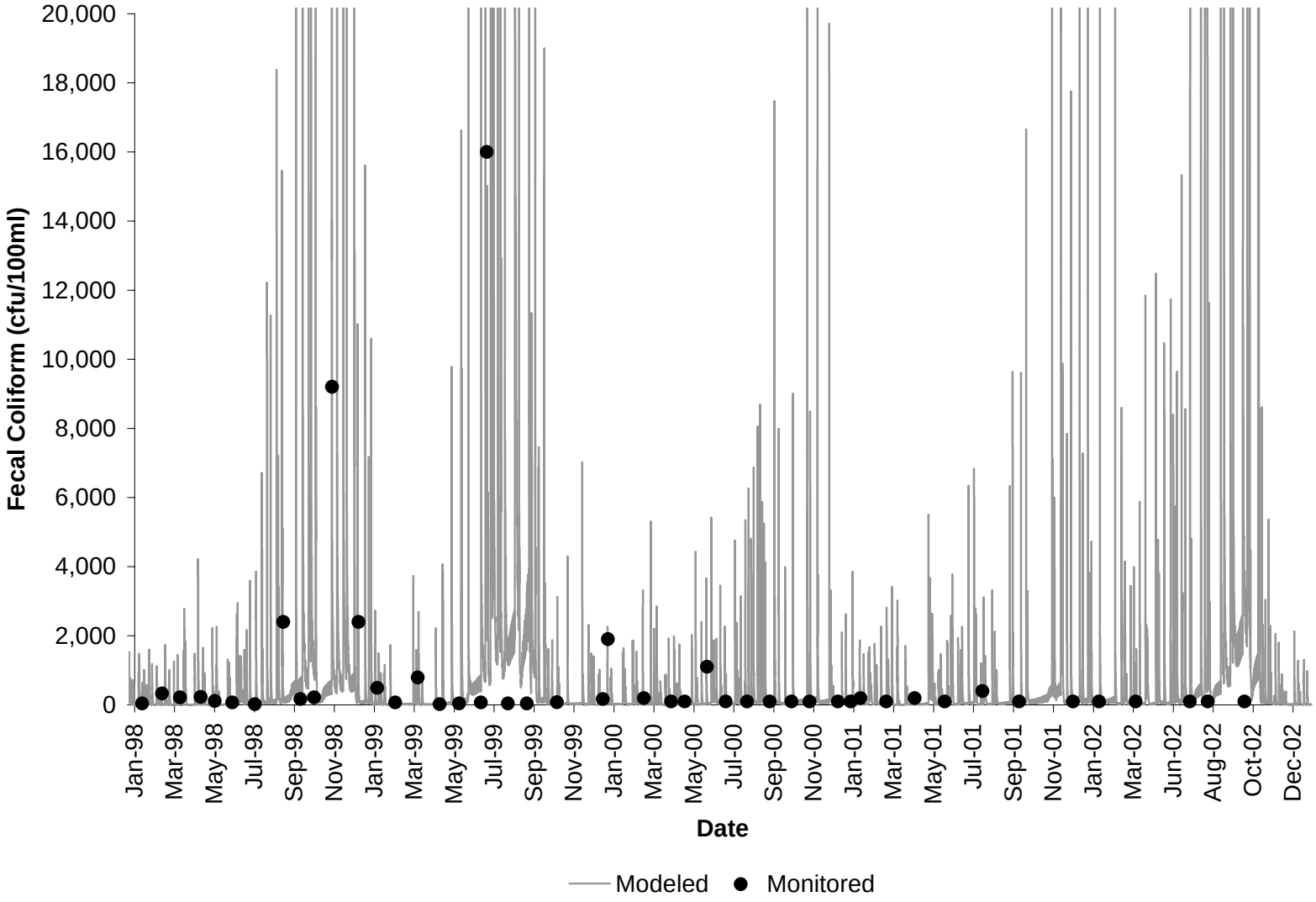

Figure 4.23. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-27 in South Anna River (VAP-F04R-02) impairment.

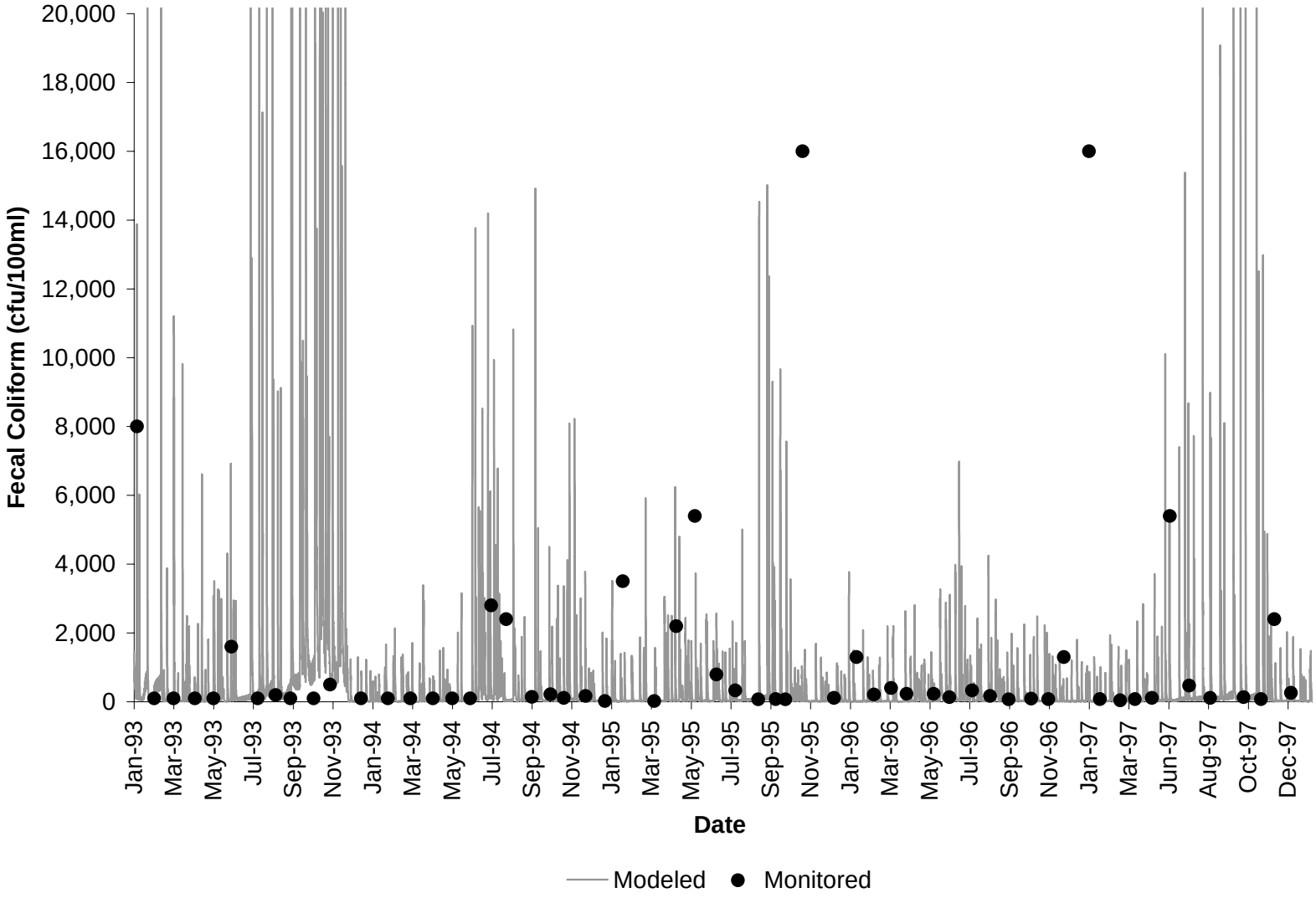

Figure 4.24. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-27 in South Anna River (VAP-F04R-02) impairment.

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Table 4.31. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in South Anna River (VAP-F04R-02) watershed.

Parameter	Sub SAR-27
Geometric Mean of Observed Values (cfu/100mL)	170
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	175
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	13
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	19
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	17
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	26

Table 4.32. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in South Anna River (VAP-F04R-02) watershed.

Parameter	Sub SAR-27
Geometric Mean of Observed Values (cfu/100mL)	260
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	164
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	22
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	14
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	27
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	24

4.7.2.5 Taylors Creek (VAN-F03R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-TLR002.54 within the Taylors Creek (VAN-F03R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.33. Observations from the VADEQ station, 8-TLR002.54, were graphically compared to corresponding modeled concentrations at subwatershed SAR-19 (Figures 4.25 and 4.26). 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.

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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 violation 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 4.34 and 4.35 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.34 and 4.35. A difference of one violation could result in a difference of violation rate of 5-33%. The highest differences between observed and modeled geometric mean concentrations (27%) and the water quality standard violation rates (15%) was recorded during the calibration period. Nineteen observations were available for comparison during this period resulting in a 5% weighting when comparing the water quality standard violation rate. This translates into three model observation that were above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Taylors Creek (VAN-F03R-01) watershed.

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Table 4.33. Calibrated water quality HSPF parameters for Taylors Creek (VAN-F03R-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	23E05-11E10	23E05-11E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	23E06-11E11	11E06-17E10	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	12E09-11E10	12E09-11E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	12E10-11E11	02E10-12E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	8.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

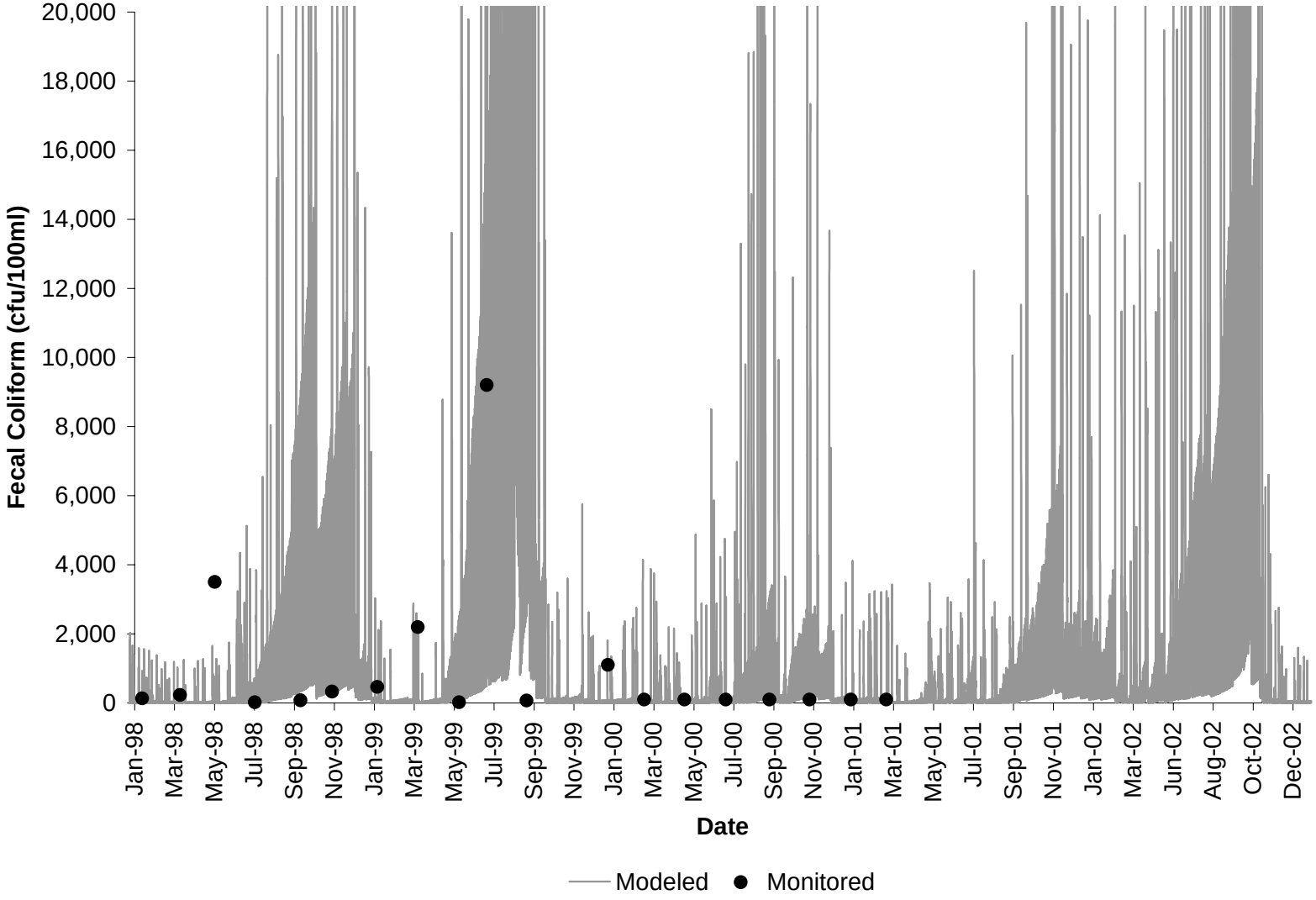

Figure 4.25. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-19 in Taylors Creek (VAN-F03R-01) impairment.

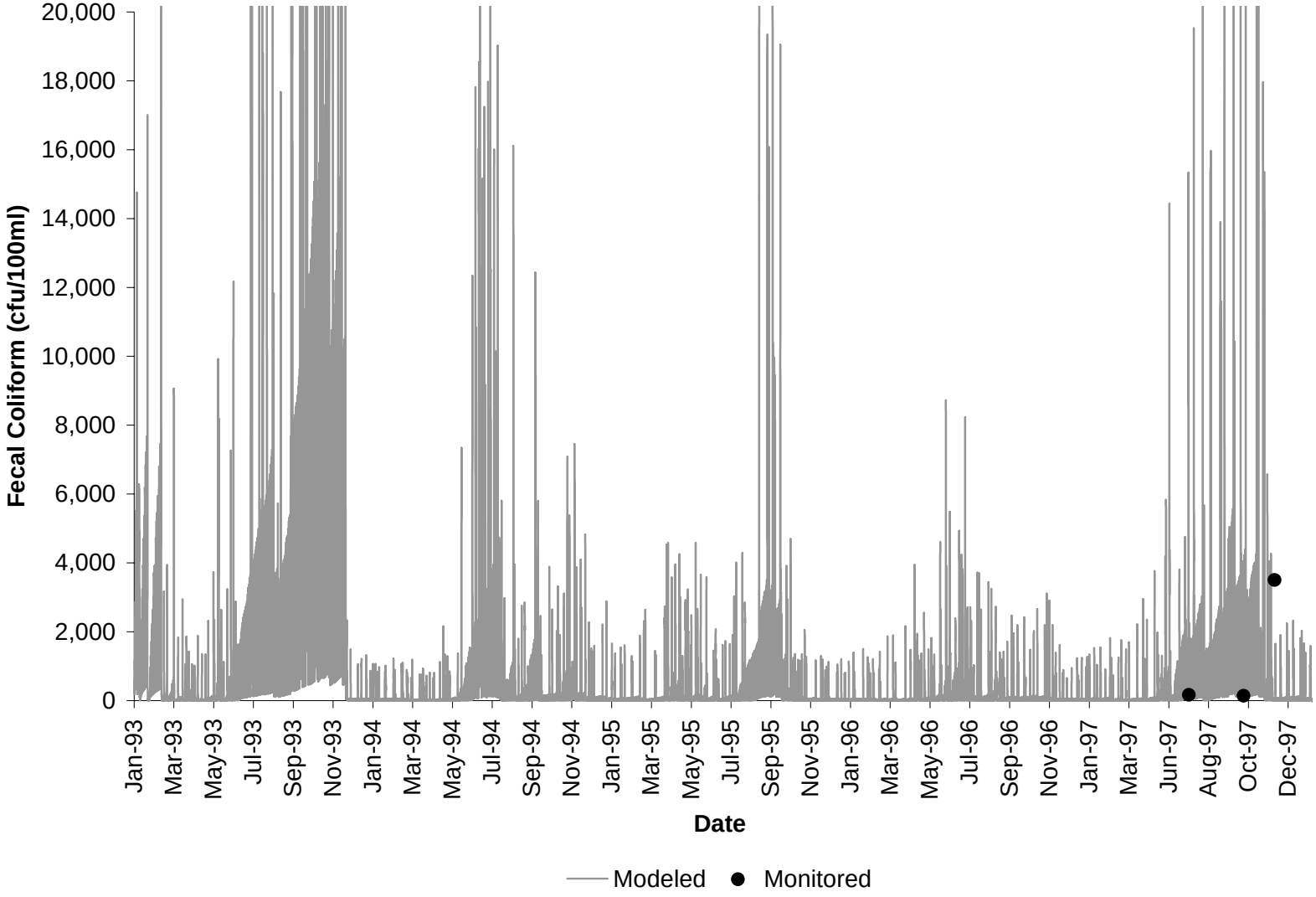

Figure 4.26. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-19 in Taylors Creek (VAN-F03R-01) impairment.

Table 4.34. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Taylors Creek (VAN-F03R-01) watershed.

Parameter	Sub SAR-19
Geometric Mean of Observed Values (cfu/100mL)	156
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	214
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	16
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	26

Table 4.35. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Taylors Creek (VAN-F03R-01) watershed.

Parameter	Sub SAR-19
Geometric Mean of Observed Values (cfu/100mL)	296
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	350
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	33
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	33
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	33
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	33

4.7.2.6 Newfound River (VAP-F05R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-NFD002.26 within the Newfound River (VAP-F05R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.36. Observations from the VADEQ station, 8-NFD002.26, were graphically compared to corresponding modeled concentrations at subwatershed SAR-24 (Figures 4.27 and 4.28). 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 violation 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 4.37 and 4.38 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.37 and 4.38. A difference of one violation could result in a difference of violation rate of 5-7%. The highest difference (21%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (7%) was recorded during the validation period. Fifteen observations were available for comparison during this period resulting in a 7% weighting when comparing the water quality standard violation rate. This translates into one model observation that was not above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Newfound River (VAP-F05R-01) watershed.

Table 4.36. Calibrated water quality HSPF parameters for Newfound River (VAP-F05R-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	76E05-27E09	76E05-27E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	76E06-27E10	30E06-11E10	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	11E09-27E09	11E09-27E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	11E10-27E10	04E10-11E10	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.

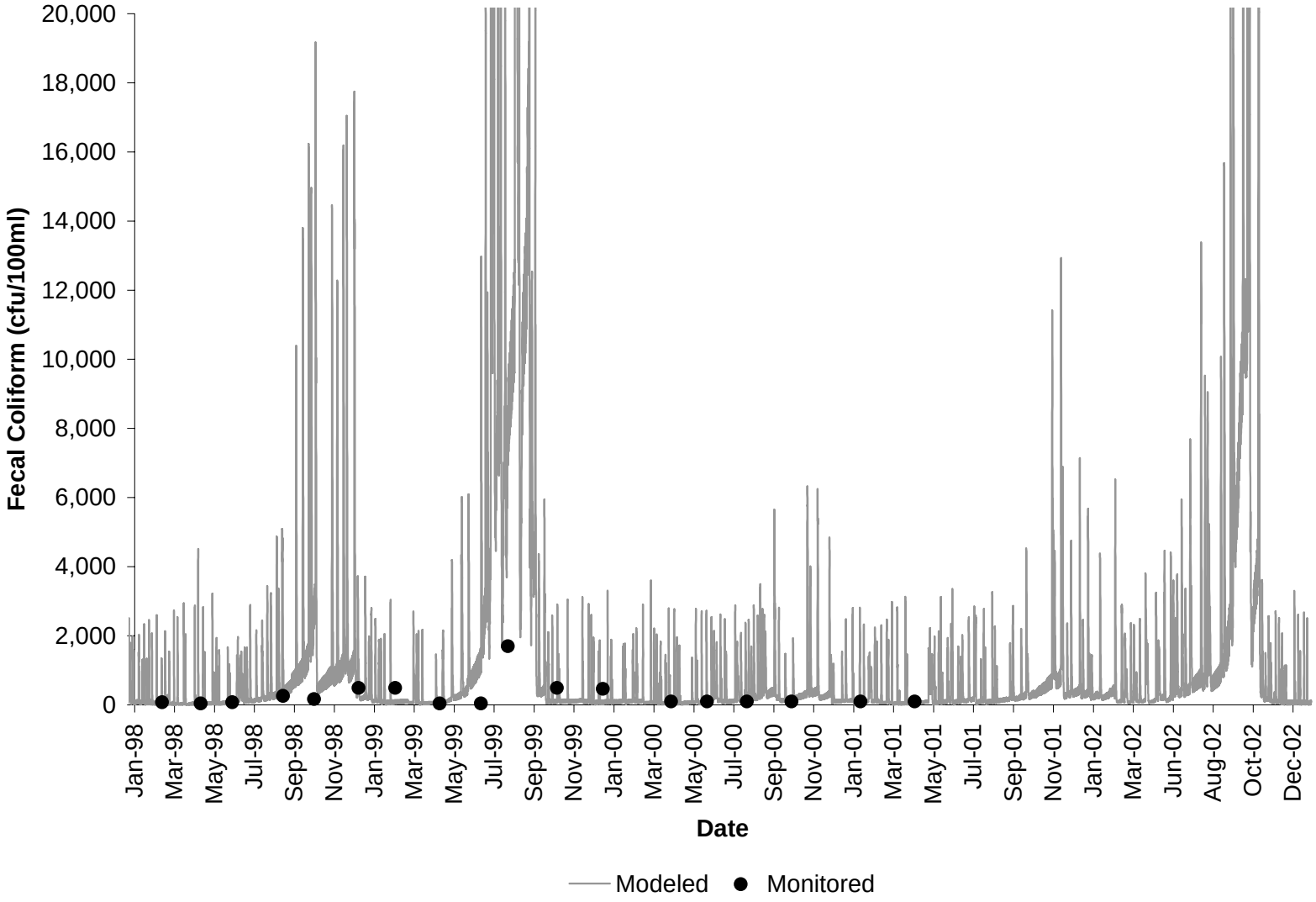

Figure 4.27. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed SAR-24 in Newfound River (VAP-F05R-01) impairment.

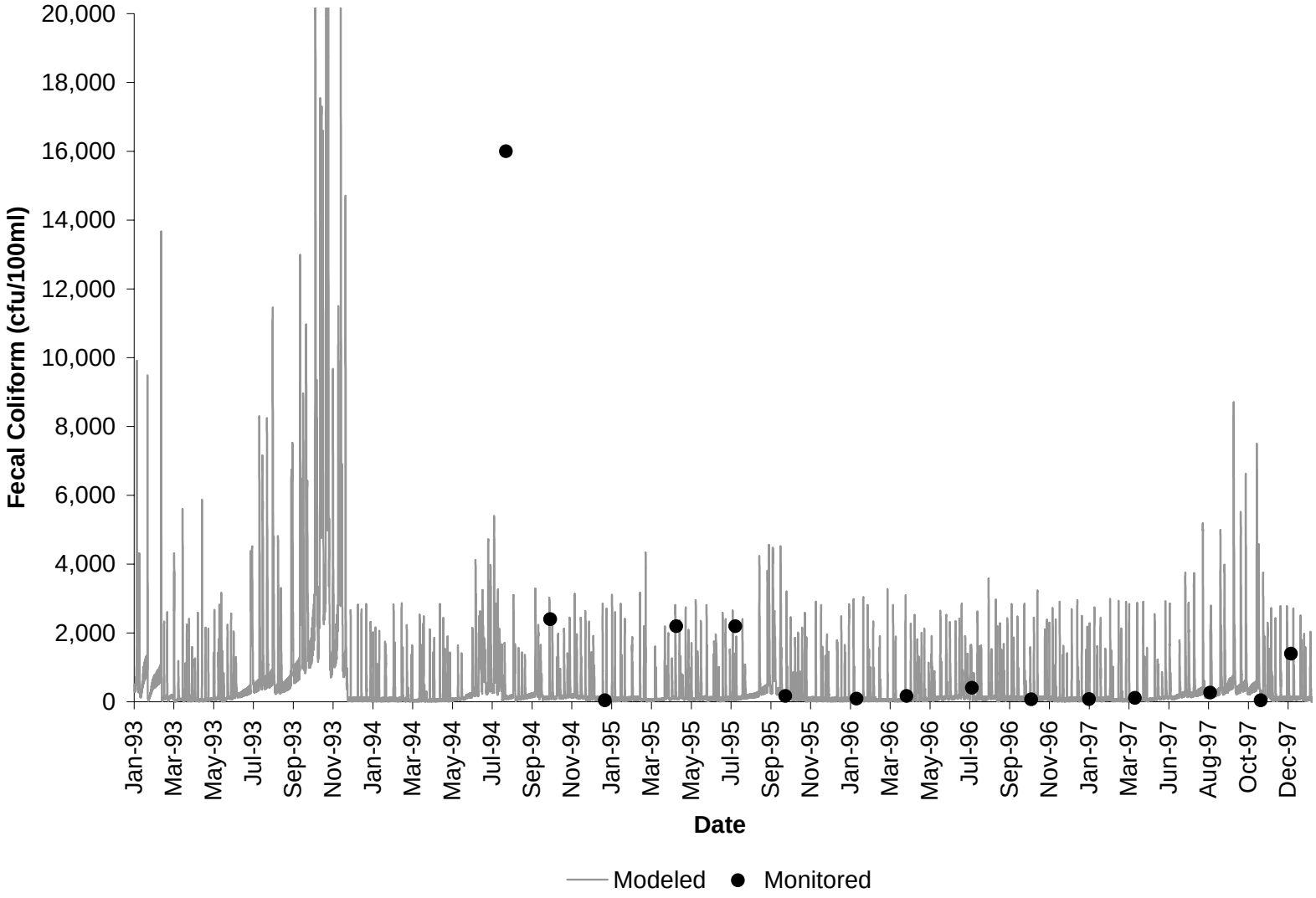

Figure 4.28. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed SAR-24 in Newfound River (VAP-F05R-01) impairment.

Table 4.37. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Newfound River (VAP-F05R-01) watershed.

Parameter	Sub SAR-24
Geometric Mean of Observed Values (cfu/100mL)	154
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	187
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	6
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	11
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	28
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	28

Table 4.38. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Newfound River (VAP-F05R-01) watershed.

Parameter	Sub SAR-24
Geometric Mean of Observed Values (cfu/100mL)	339
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	266
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	33
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	27
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	40
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	33

4.7.2.7 Northeast Creek (VAP-F09R-01)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-NST003.46 within the Northeast Creek (VAP-F09R-01) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.39. Observations from the VADEQ station, 8-NST003.46, were graphically compared to corresponding modeled concentrations at subwatershed NEC-3 (Figures 4.29 and 4.30). 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 violation rate of the previous 1,000 cfu/100mL fecal coliform instantaneous standard and the interim 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 4.40 and 4.41 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.40 and 4.41. A difference of one violation could result in a difference of violation rate of 3-7%. The highest difference (23%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard violation rates (7%) was recorded during the validation period. Thirteen observations were available for comparison during this period resulting in a 7% weighting when comparing the water quality standard violation rate. This translates into one model observation that was above 400 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Northeast Creek (VAP-F09R-01) watershed.

Table 4.39. Calibrated water quality HSPF parameters for Northeast Creek (VAP-F09R-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	83E05-18E10	83E05-18E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	83E05-18E10	33E06-72E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	2.0	0.75	Land use
IOQC	Constituent concentration in interflow	#/ft^3	0	1E6	0	1E10	1E03	1E03	Land use
AOQC	Constituent concentration in active groundwater	#/ft^3	0	1E6	0	1E10	0E00	0E00	Land use
IMPLND									
QUAL-INPUT									
SQO	Initial storage of constituent	#/ac	0	1E20	0	1E30	1E09	1E09	Land use
ACQOP	Rate of accumulation of constituent	#/day	0	1E20	0	1E30	00E00-18E10	00E00-18E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	00E00-18E11	00E00-72E10	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	0.1	0.1	Land use
RCHRES									
GQ-GENDECAY									
FSTDEC	First order decay rate of the constituent	1/day	0.01	10.0	0.01	30.0	2.0	6.2	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

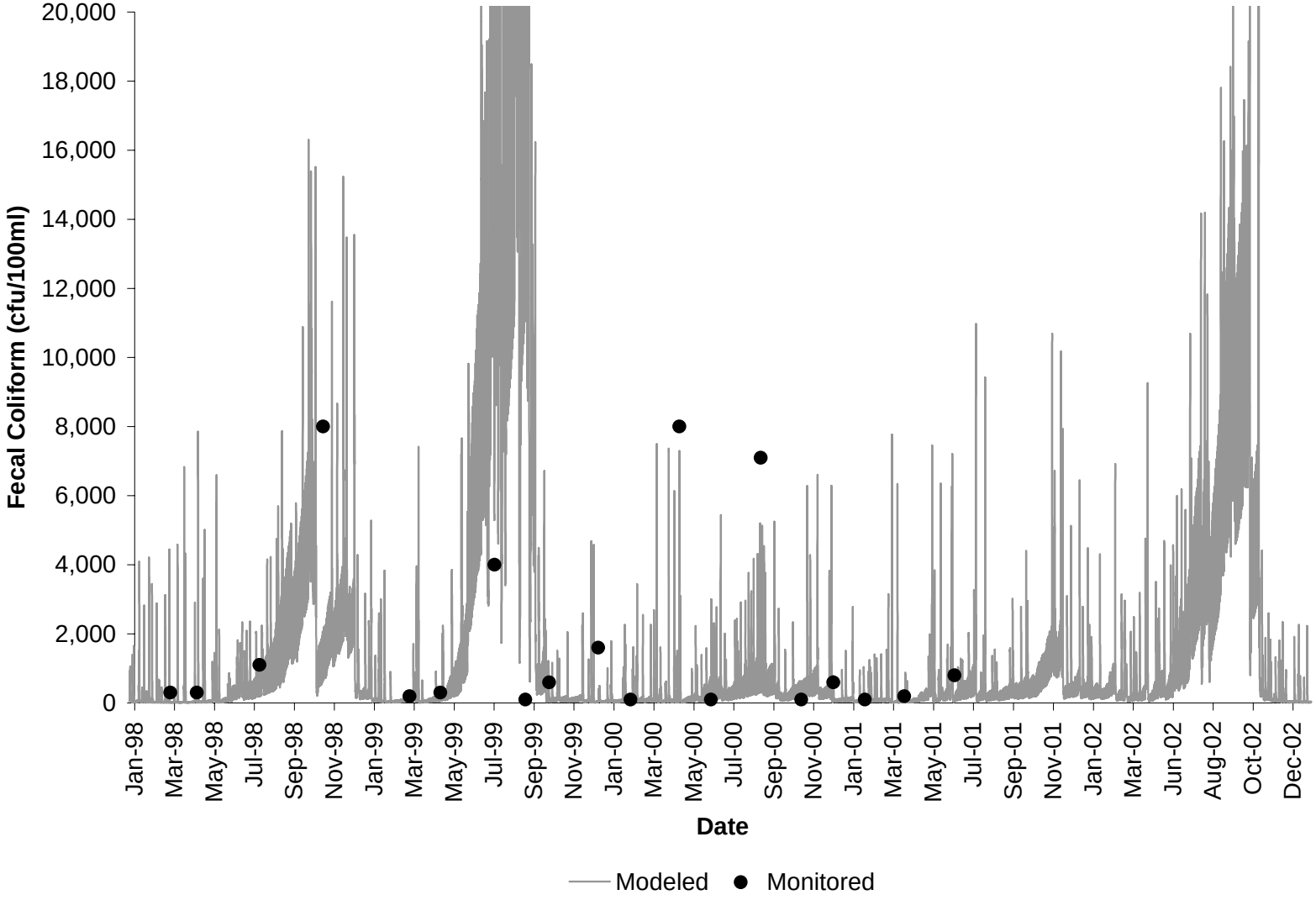

Figure 4.29. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed NEC-3 in Northeast Creek (VAP-F09R-01) impairment.

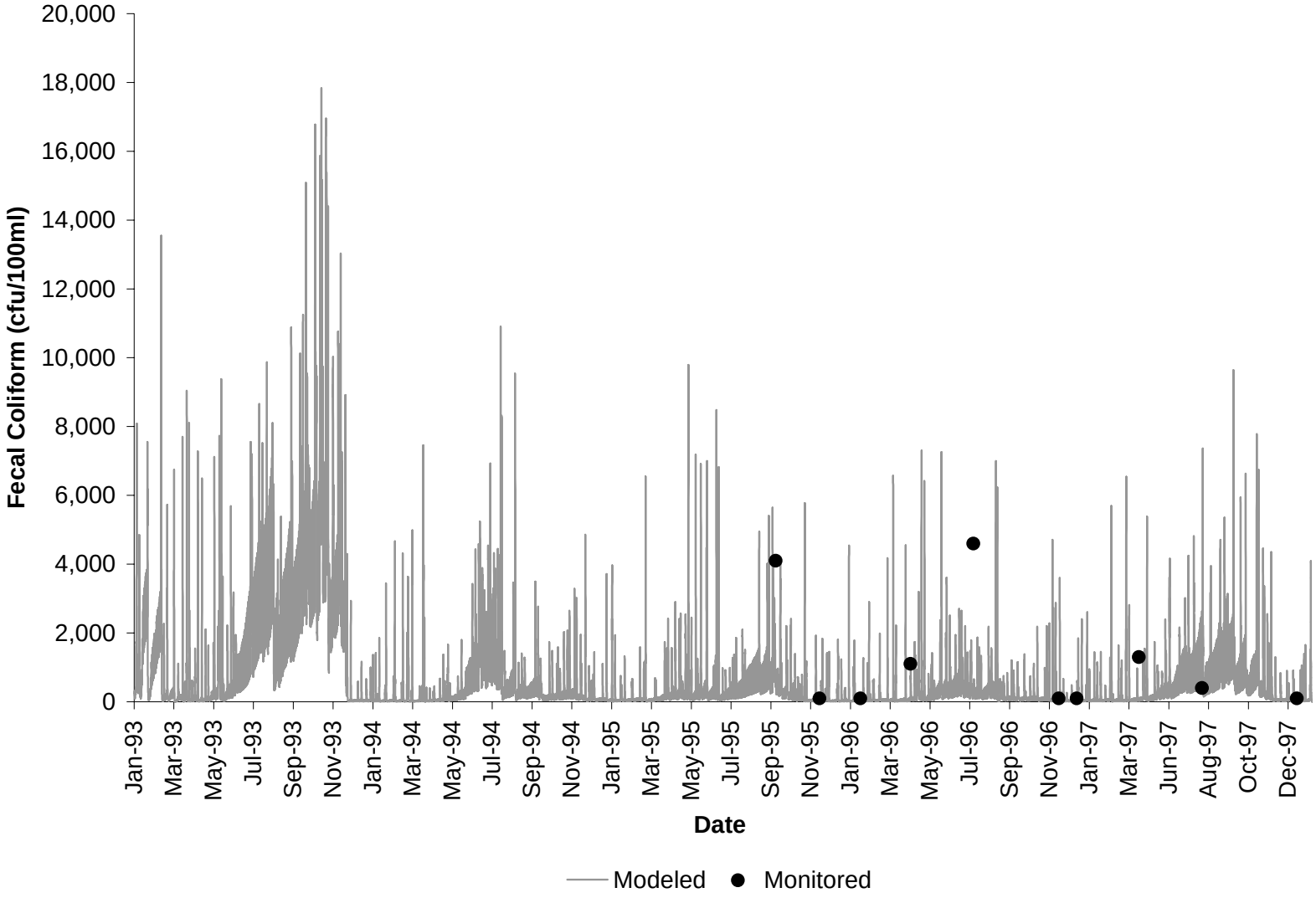

Figure 4.30. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed NEC-3 in Northeast Creek (VAP-F09R-01) impairment.

Table 4.40. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Northeast Creek (VAP-F09R-01) watershed.

Parameter	Sub NEC-3
Geometric Mean of Observed Values (cfu/100mL)	166
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	215
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	10
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	17
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	20
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	27

Table 4.41. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Northeast Creek (VAP-F09R-01) watershed.

Parameter	Sub NEC-3
Geometric Mean of Observed Values (cfu/100mL)	135
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	150
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	0
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	8
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	15

4.7.2.8 Totopotomoy Creek (VAP-F13R-02)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-TPT004.37 within the Totopotomoy Creek (VAP-F13R-02) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.42. Observations from the VADEQ station, 8-TPT004.37, were graphically compared to corresponding modeled concentrations at subwatershed TOC-4 (Figure 4.31). There were no observations during the validation period. It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the

variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period. 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 violation 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 4.43 shows the observed and modeled comparisons of the geometric mean and violation rates for the calibration period. It should be noted that a limited number of observed values were available for comparison when determining violation rates in Table 4.43. A difference of one violation could result in a difference of violation rate of 4%. The highest difference (2%) between observed and modeled geometric mean concentrations was recorded during the calibration period. The highest difference in the water quality standard violation rates (4%) was recorded during the calibration period. Twenty-three observations were available for comparison during this period resulting in a 4% weighting when comparing the water quality standard violation rate. This translates into one model observation that was not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Totopotomoy Creek (VAP-F13R-02) watershed.

Table 4.42. Calibrated water quality HSPF parameters for Totopotomoy Creek (VAP-F13R-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	74E05-12E09	74E05-12E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	74E06-12E10	66E06-11E10	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	45E08-12E09	45E08-12E09	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	45E09-12E10	40E09-11E10	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	5.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

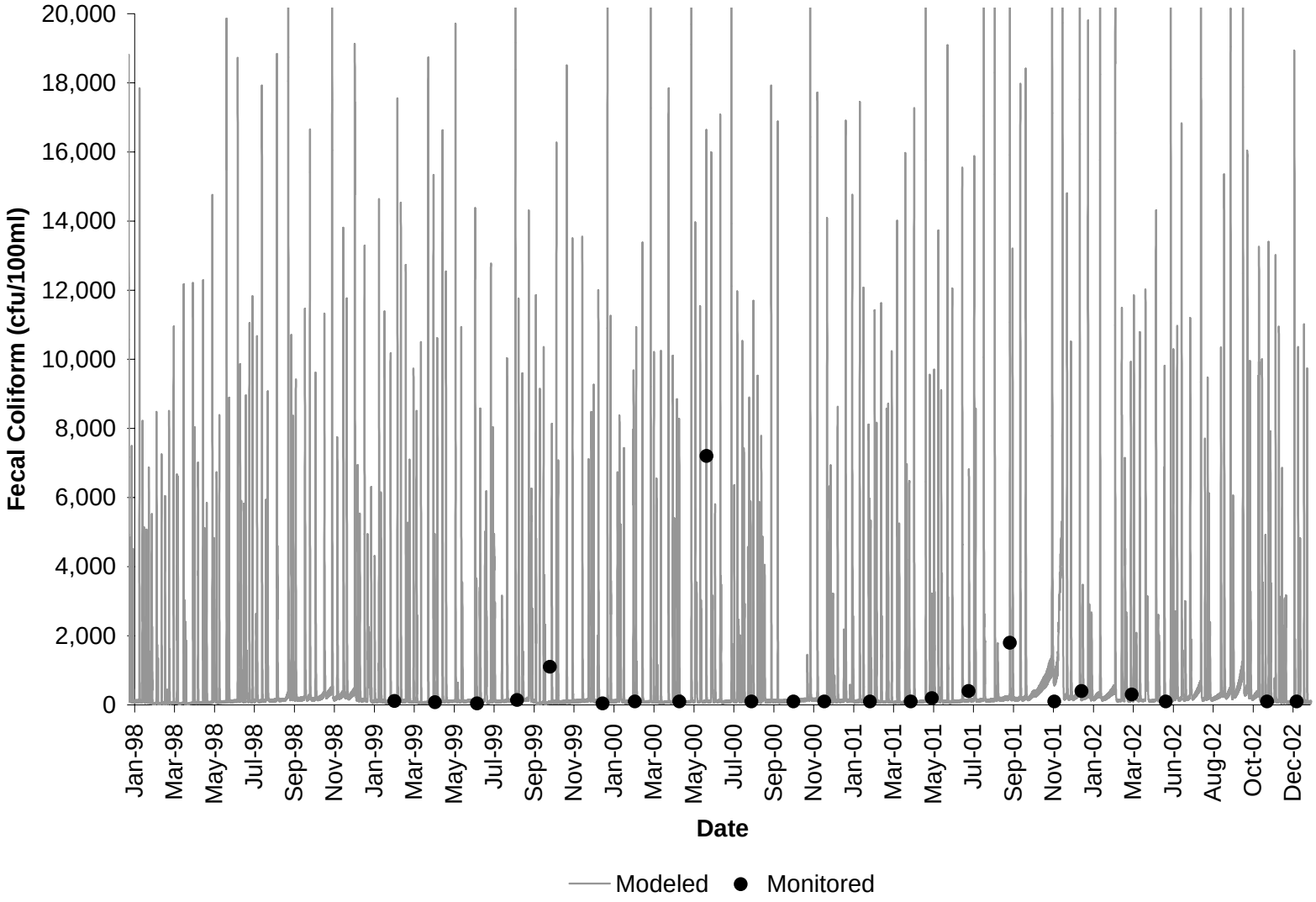

Figure 4.31. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed TOC-4 in Totopotomoy Creek (VAP-F13R-02) impairment.

Table 4.43. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Totopotomoy Creek (VAP-F13R-02) watershed.

Parameter	Sub TOC-4
Geometric Mean of Observed Values (cfu/100mL)	173
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	170
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	13
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	9
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	13
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	13

4.7.2.9 Moncuin/Webb Creek (VAP-F13R-04)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-MNQ004.19 within the Moncuin/Webb Creek (VAP-F13R-04) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.44. Observations from the VADEQ station, 8-MNQ004.19, were graphically compared to corresponding modeled concentrations at subwatershed PAR-5 (Figures 4.32 and 4.33). 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 violation 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 4.45 and 4.46 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.45 and 4.46. A difference of one violation could result in a difference of violation rate of 6-13%. The highest difference (30%) between observed and

modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (13%) was recorded during the validation period. Eight observations were available for comparison during this period resulting in a 13% weighting when comparing the water quality standard violation rate. This translates into one model observation that was not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Moncuin/Webb Creek (VAP-F13R-04) watershed.

Table 4.44. Calibrated water quality HSPF parameters for Moncuin/Webb Creek (VAP-F13R-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	14E06-07E10	14E06-07E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	14E07-07E11	01E08-23E10	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	34E08-07E10	34E08-07E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	34E09-07E11	03E10-67E10	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	1.2	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

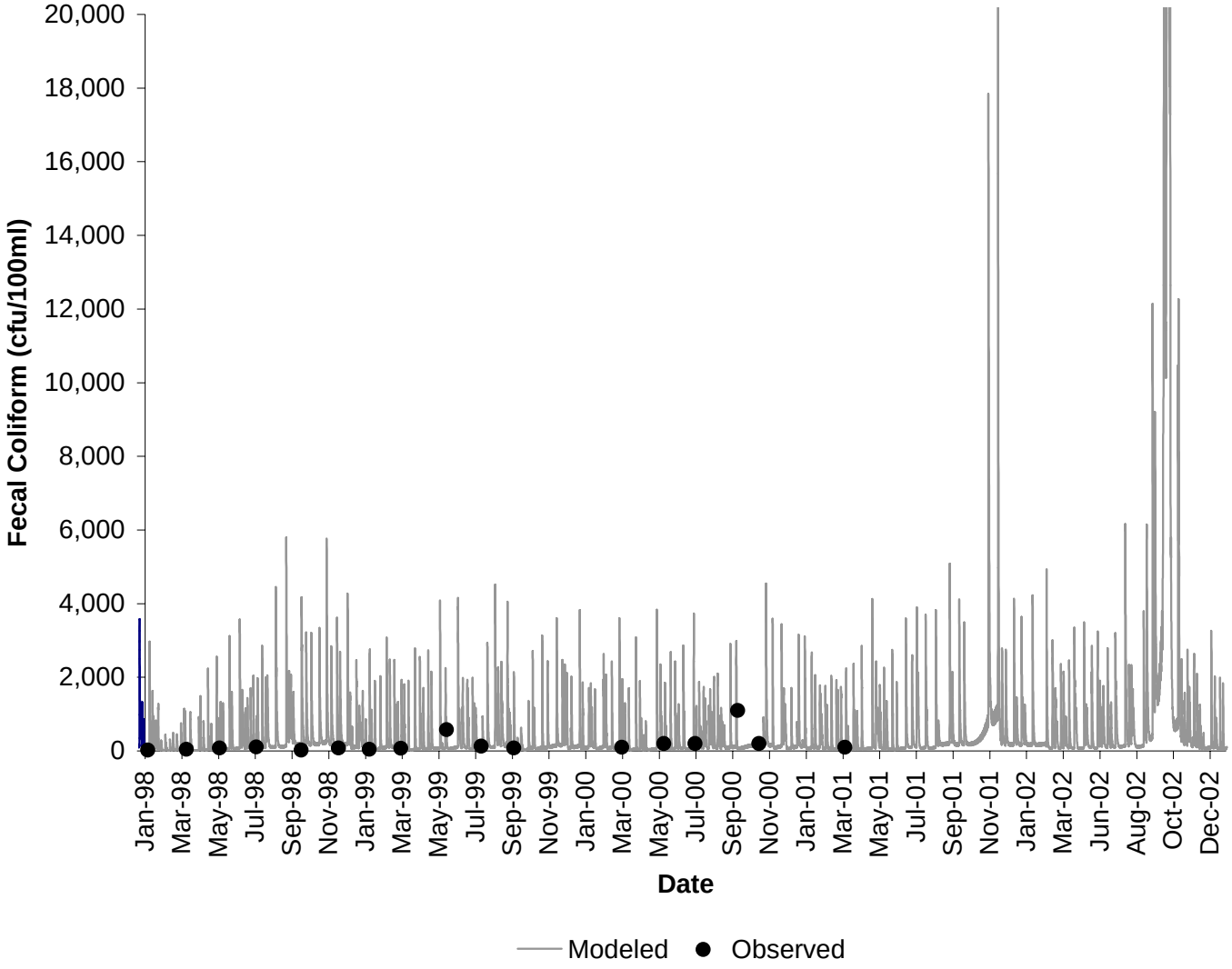

Figure 4.32. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed PAR-5 in Moncuin/Webb Creek (VAP-F13R-04) impairment.

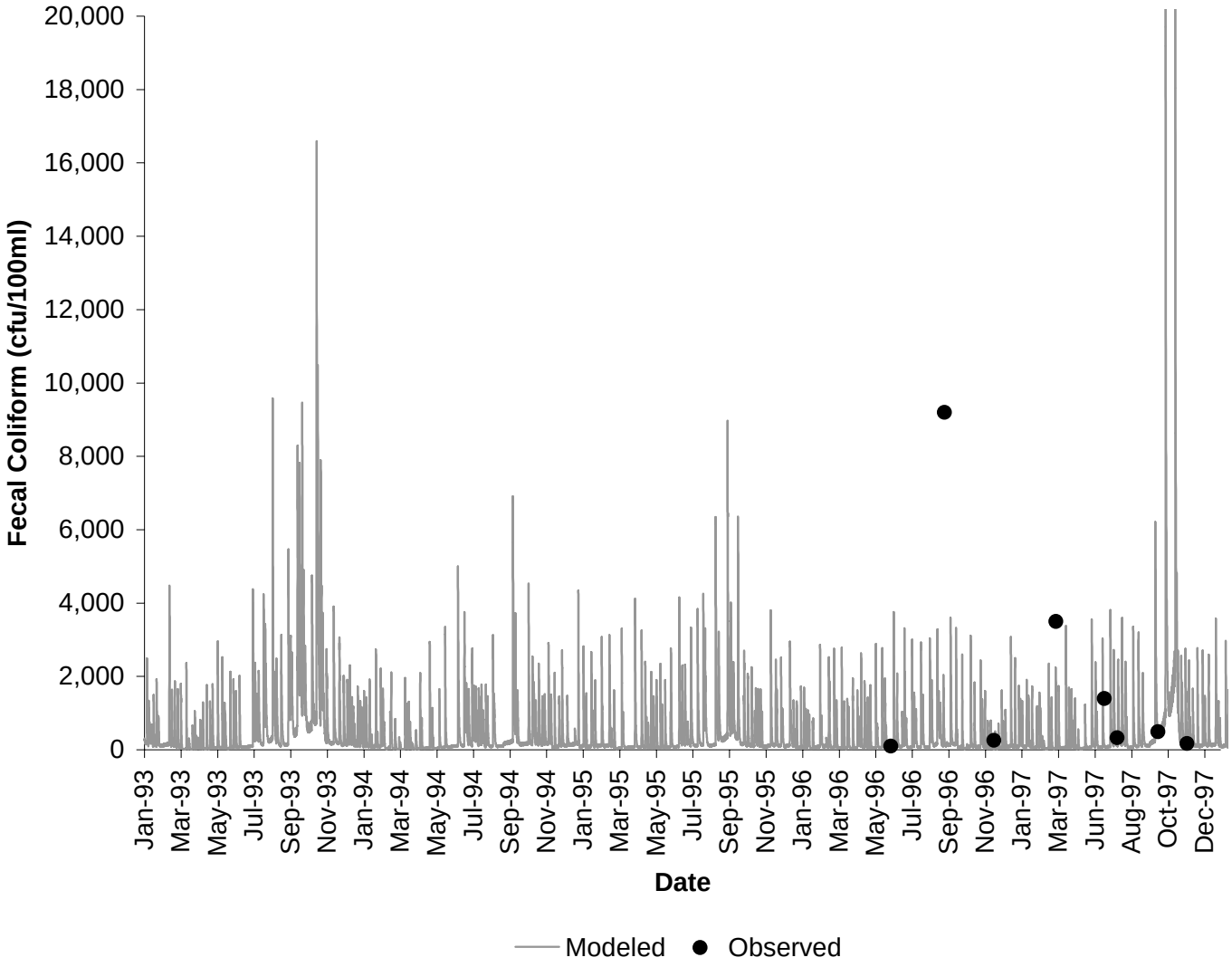

Figure 4.33. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed PAR-5 in Moncuin/Webb Creek (VAP-F13R-04) impairment.

Table 4.45. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Moncuin/Webb Creek (VAP-F13R-04) watershed.

Parameter	Sub PAR-5
Geometric Mean of Observed Values (cfu/100mL)	103
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	125
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	6
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	6
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	12
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	12

Table 4.46. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Moncuin/Webb Creek (VAP-F13R-04) watershed.

Parameter	Sub PAR-5
Geometric Mean of Observed Values (cfu/100mL)	651
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	456
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	38
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	25
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	50
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	50

4.7.2.10 Black Creek (VAP-F13R-05)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-BLC001.77 within the Black Creek (VAP-F13R-05) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.47. Observations from the VADEQ station, 8-BLC001.77, were graphically compared to corresponding modeled concentrations at subwatershed PAR-15 (Figures 4.34 and 4.35). 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 violation 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 4.48 and 4.49 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.48 and 4.49. A difference of one violation could result in a difference of violation rate of 6-13%. The highest difference (30%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (13%) was recorded during the validation period. Eight observations were available for comparison during this period resulting in a 13% weighting when comparing the water quality standard violation rate. This translates into one model observation that was not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Black Creek (VAP-F13R-05) watershed.

Table 4.47. Calibrated water quality HSPF parameters for Black Creek (VAP-F13R-05) 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	00E00-47E10	00E00-47E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	00E00-47E11	00E00-04E12	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	00E00-47E10	00E00-47E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	00E00-47E11	00E00-58E10	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	1.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

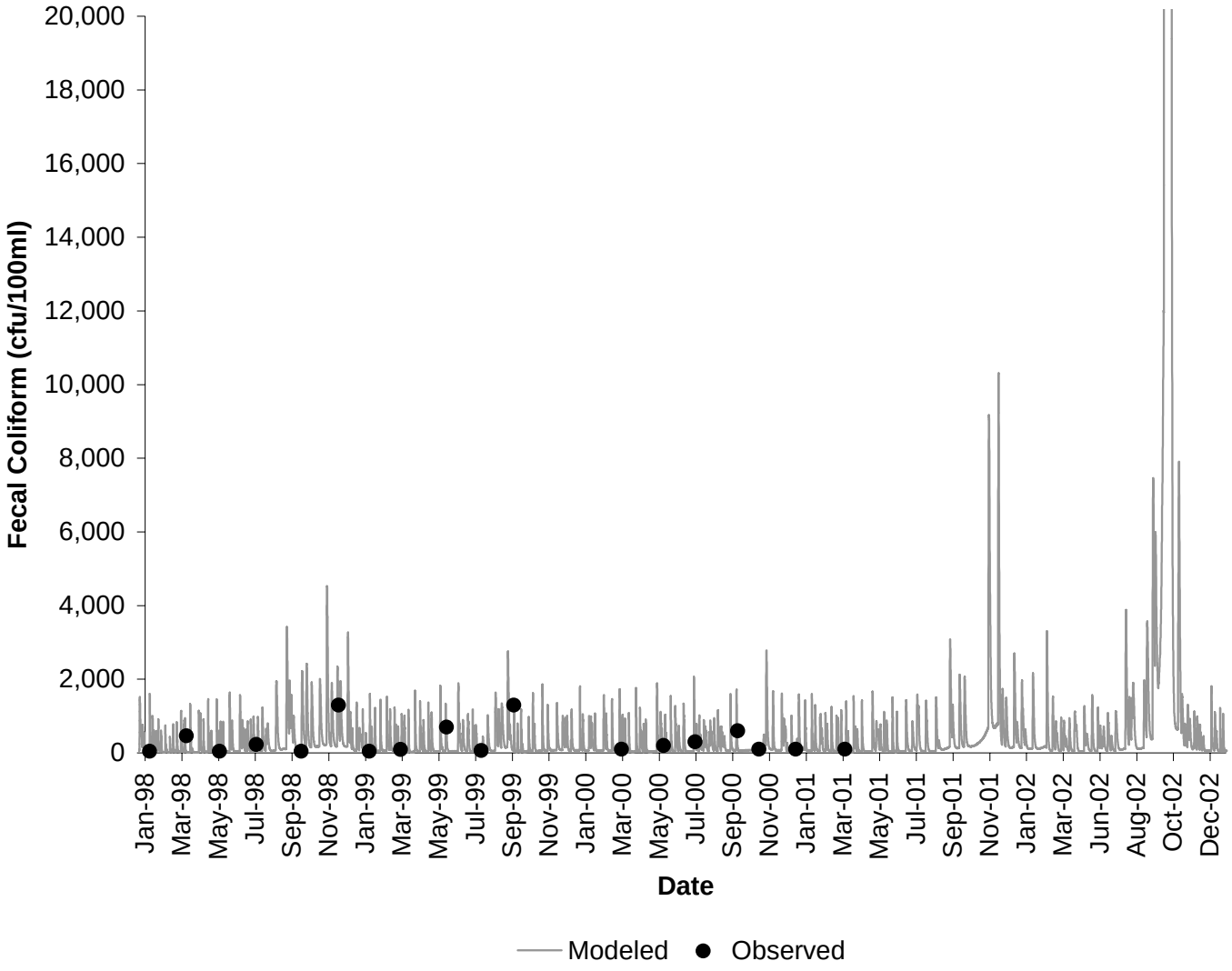

Figure 4.34. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed PAR-15 in Black Creek (VAP-F13R-05) impairment.

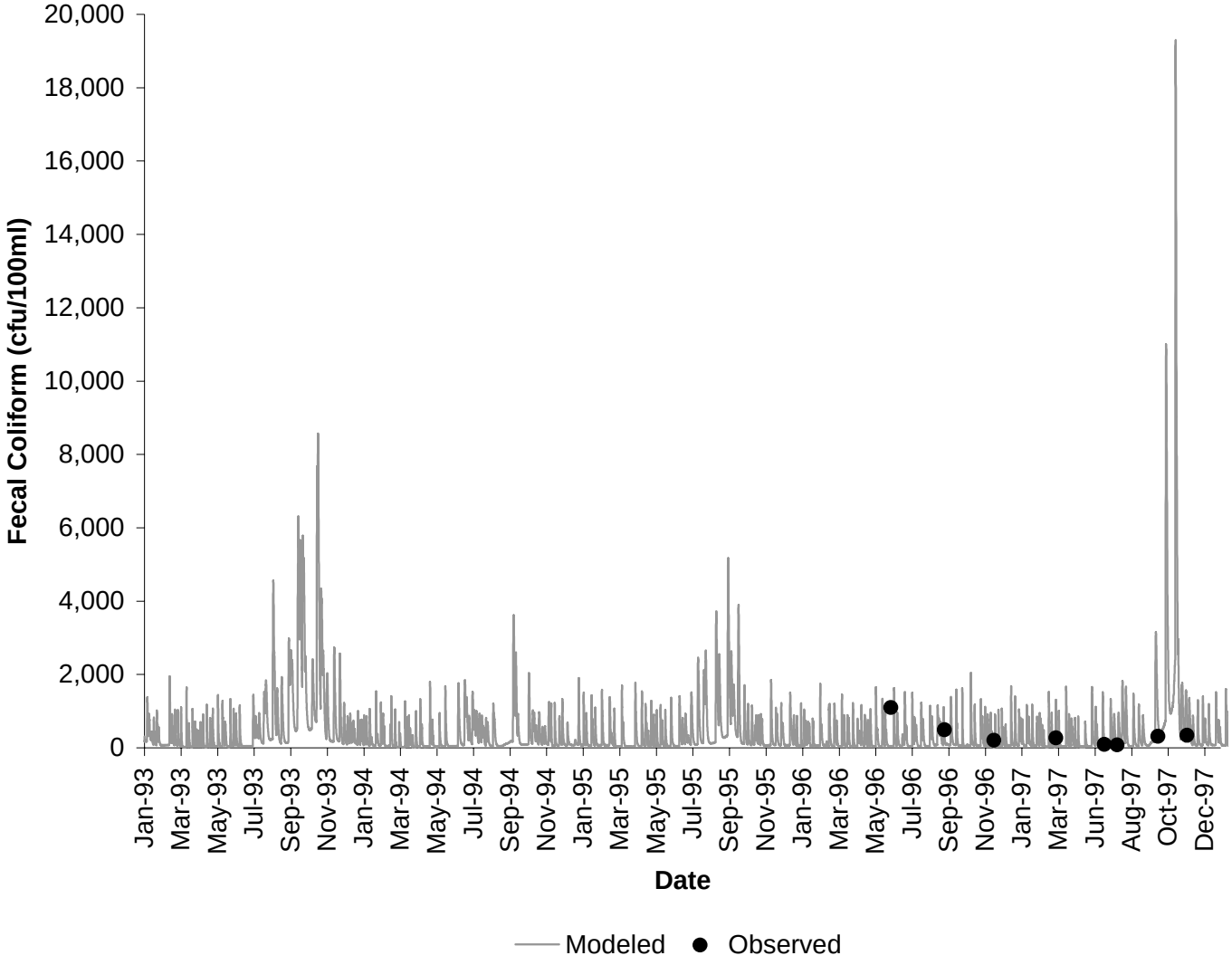

Figure 4.35. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed PAR-15 in Black Creek (VAP-F13R-05) impairment.

Table 4.48. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Black Creek (VAP-F13R-05) watershed.

Parameter	Sub PAR-15
Geometric Mean of Observed Values (cfu/100mL)	167
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	167
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	11
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	28
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	28

Table 4.49. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Black Creek (VAP-F13R-05) watershed.

Parameter	Sub PAR-15
Geometric Mean of Observed Values (cfu/100mL)	263
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	178
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	13
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	0
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	25
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	25

4.7.2.11 Pamunkey River (VAP-F13E-02)

Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring station 8-PMK048.80 within the Pamunkey River (VAP-F13E-02) impairment were used to calibrate the water quality component of HSPF. The final water calibration parameters are shown in Table 4.50. Observations from the VADEQ station, 8-PMK048.80, were graphically compared to corresponding modeled concentrations at subwatershed PAR-8 (Figures 4.36 and 4.37). 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 violation 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 4.51 and 4.52 show the observed and modeled comparisons of the geometric mean and violation 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 violation rates in Tables 4.51 and 4.52. A difference of one violation could result in a difference of violation rate of 2%. The highest difference (12%) between observed and modeled geometric mean concentrations was recorded during the validation period. The highest difference in the water quality standard violation rates (6%) was recorded during the validation period. Forty-eight observations were available for comparison during this period resulting in a 2% weighting when comparing the water quality standard violation rate. This translates into three model observations that were not above 1,000 cfu/100ml. The modeled versus observed geometric mean concentrations and violation 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 Pamunkey River (VAP-F13E-02) watershed.

Table 4.50. Calibrated water quality HSPF parameters for Pamunkey River (VAP-F13E-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	00E00-62E10	00E00-62E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	00E00-62E11	00E00-06E12	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	00E00-62E10	00E00-62E10	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	00E00-62E11	00E00-06E12	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	1.0 – 6.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

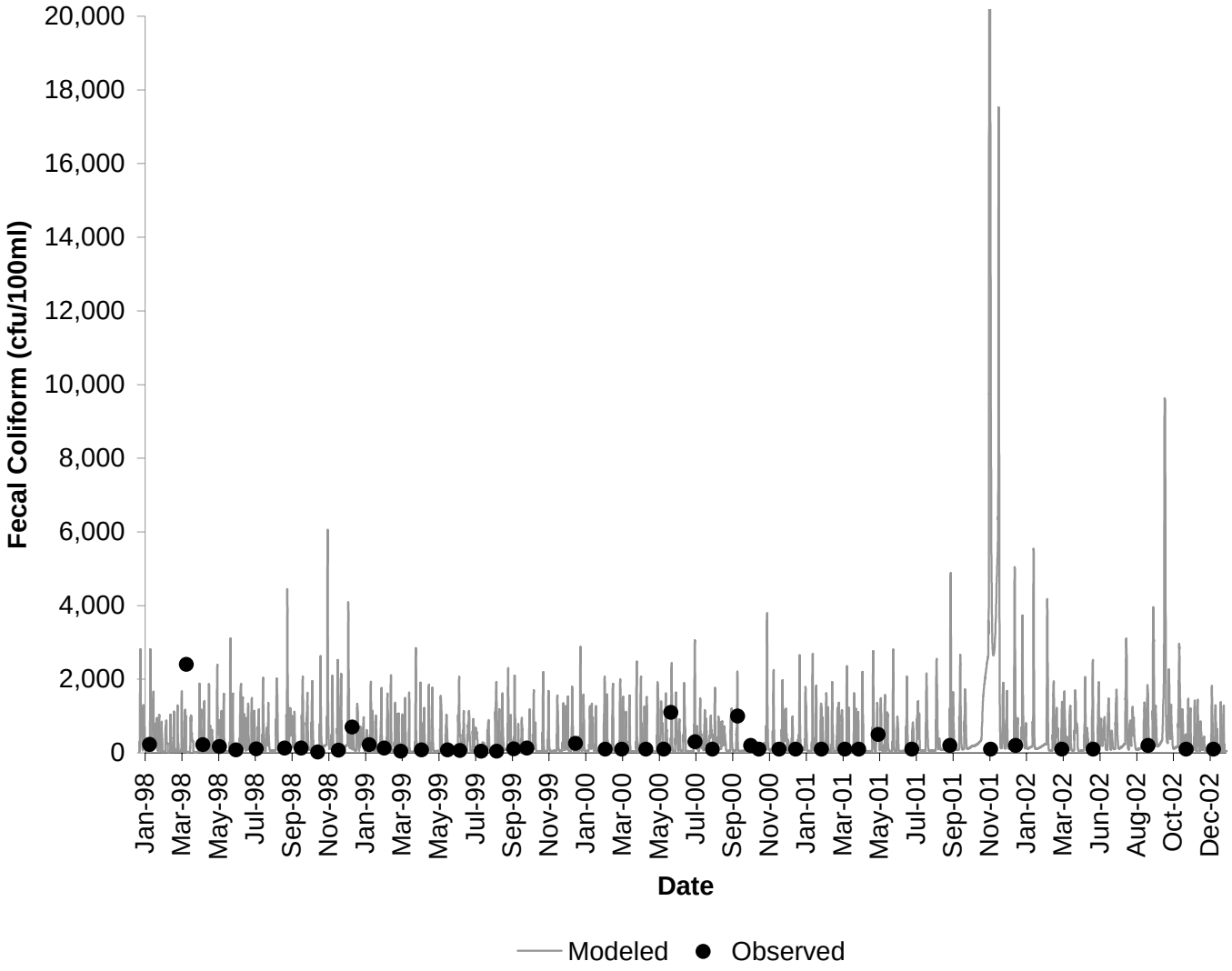

Figure 4.36. Water quality calibration results with observed and modeled fecal coliform concentrations for subwatershed PAR-8 in Pamunkey River (VAP-F13E-02) impairment.

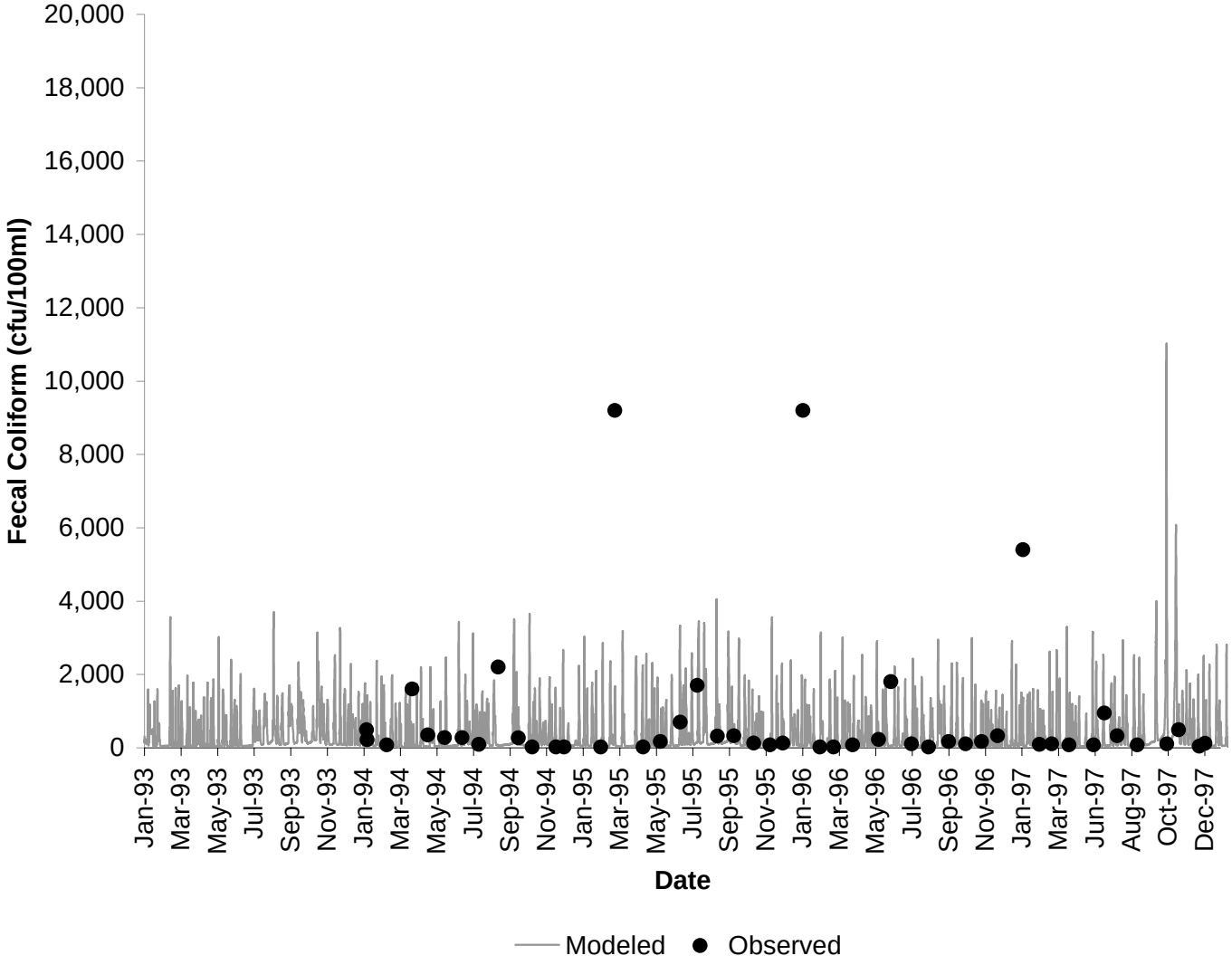

Figure 4.37. Water quality validation results with observed and modeled fecal coliform concentrations for subwatershed PAR-8 in Pamunkey River (VAP-F13E-02) impairment.

Table 4.51. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the calibration period in Pamunkey River (VAP-F13E-02) watershed.

Parameter	Sub PAR-8
Geometric Mean of Observed Values (cfu/100mL)	137
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	142
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	4
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	8
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	11
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	13

Table 4.52. Observed and modeled geometric mean concentrations and violation rates of instantaneous standards for the validation period in Pamunkey River (VAP-F13E-02) watershed.

Parameter	Sub PAR-8
Geometric Mean of Observed Values (cfu/100mL)	185
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	162
Observed Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	14
Modeled Fecal Coliform Instantaneous Standard, 1,000 cfu/100mL, Violation Rate (%)	8
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	23
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Violation Rate (%)	21

Chapter 5. Load Allocations

5.1 Background

The objective of a TMDL is to allocate allowable loads among different pollutant sources so that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991). The goal for the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02). 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:

$$TMDL = WLA + LA + MOS \qquad [5.1]$$

where: WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

While developing allocation scenarios to implement the bacteria TMDL, an implicit MOS was used by formulating conservative estimates of all factors that would affect the bacteria loadings in the watershed (e.g., animal numbers, production rates, and contributions to streams). These factors were estimated in such a way as to represent the worst-case scenario; i.e., these factors would describe the highest in-stream bacteria conditions that could exist in the watershed. Creating a TMDL with these conservative estimates ensures that the worst-case scenario has been considered and that no water quality standard violations will occur if the TMDL plan is followed.

Bacteria loadings were updated to reflect 2005 conditions for the existing conditions and allocation runs. The simulation period selected for the load allocation study was January 1993 to December 1997. This period incorporates average rainfall, low rainfall, and high rainfall years allowing the representation of both low and high flow conditions.

The calendar-month geometric mean values used in this report are geometric means of the daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric

mean from the hourly HSPF output, the arithmetic mean of the hourly values was computed on a daily basis, and then the geometric mean was calculated from these average daily values.

The guidance for developing an *E. coli* TMDL put forth by the VADEQ is to develop input for the model using fecal coliform loadings as the bacteria source in the watershed. Then, the model output of average fecal coliform concentrations is converted to daily average *E. coli* concentrations through the use of the following translator equation derived by the VADEQ:

$$\log_2(EC) = -0.0172 + 0.91905*\log_2(FC) \qquad [5.2]$$

where: EC = *E. coli* concentration (cfu/100mL); and
FC = fecal coliform concentration (cfu/100mL)

Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Average annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

5.2 Existing Conditions

Bacteria loadings for 2005 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 instantaneous standard of 235 cfu/100 mL. Subwatershed outlets were used for comparison of modeled concentrations to water quality standards for the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) impairments. Appendix C contains tables with monthly land-based and direct bacteria loadings for existing conditions.

5.2.1 South Anna River (VAN-F01R-01)

Figure 5.1 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the 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 South Anna River (VAN-F01R-01) impairment was subwatershed SAR-4.

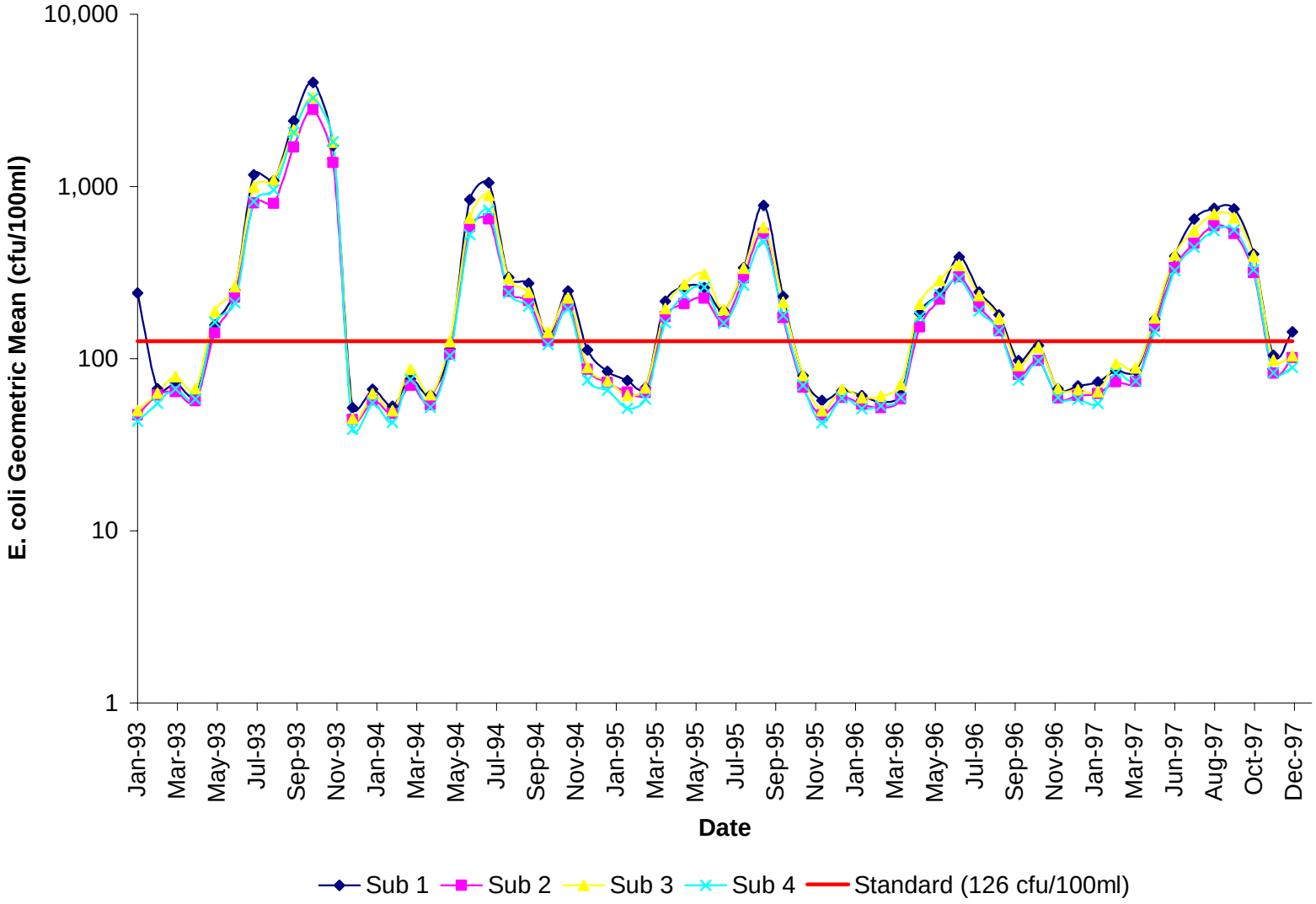

Figure 5.1. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-1 to SAR-4 in South Anna River (VAN-F01R-01) watershed.

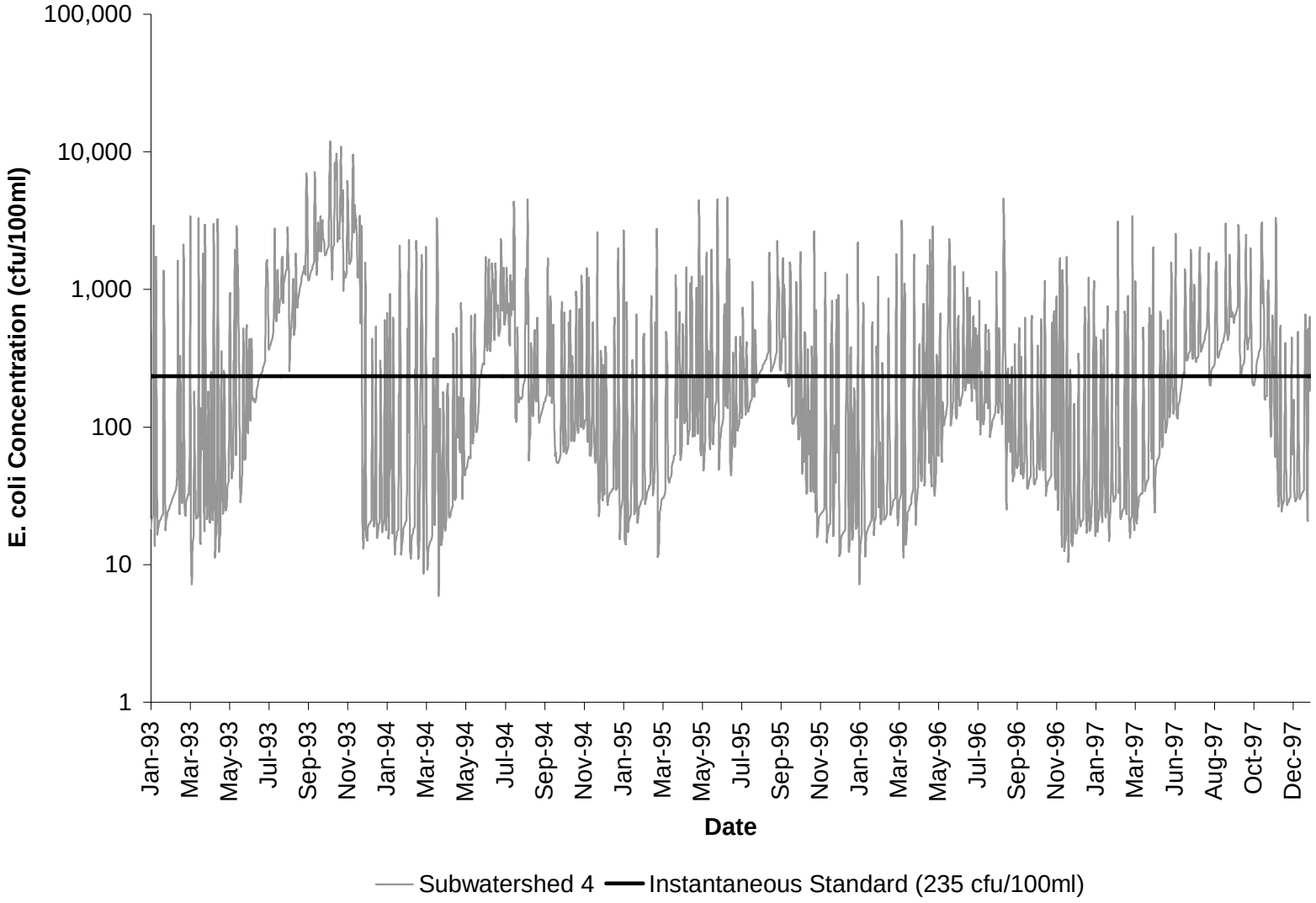

Figure 5.2. Daily average *E. coli* concentrations for subwatershed SAR-4 in South Anna River (VAN-F01R-01) watershed.

5.2.2 South Anna River (VAN-F02R-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 South Anna River (VAN-F02R-01) impairment was subwatershed SAR-13.

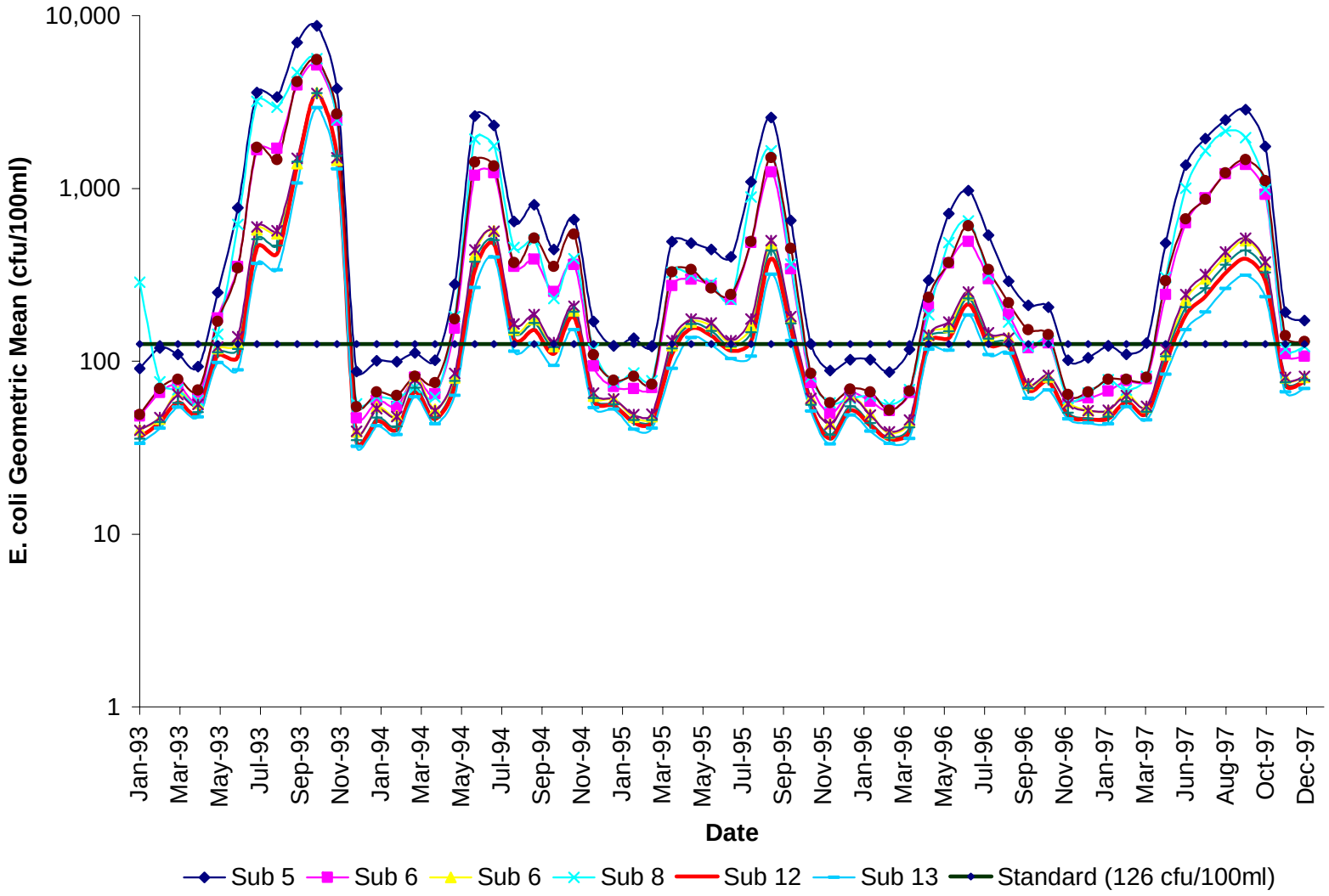

Figure 5.3. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-5 to SAR-13 in South Anna River (VAN-F02R-01) watershed.

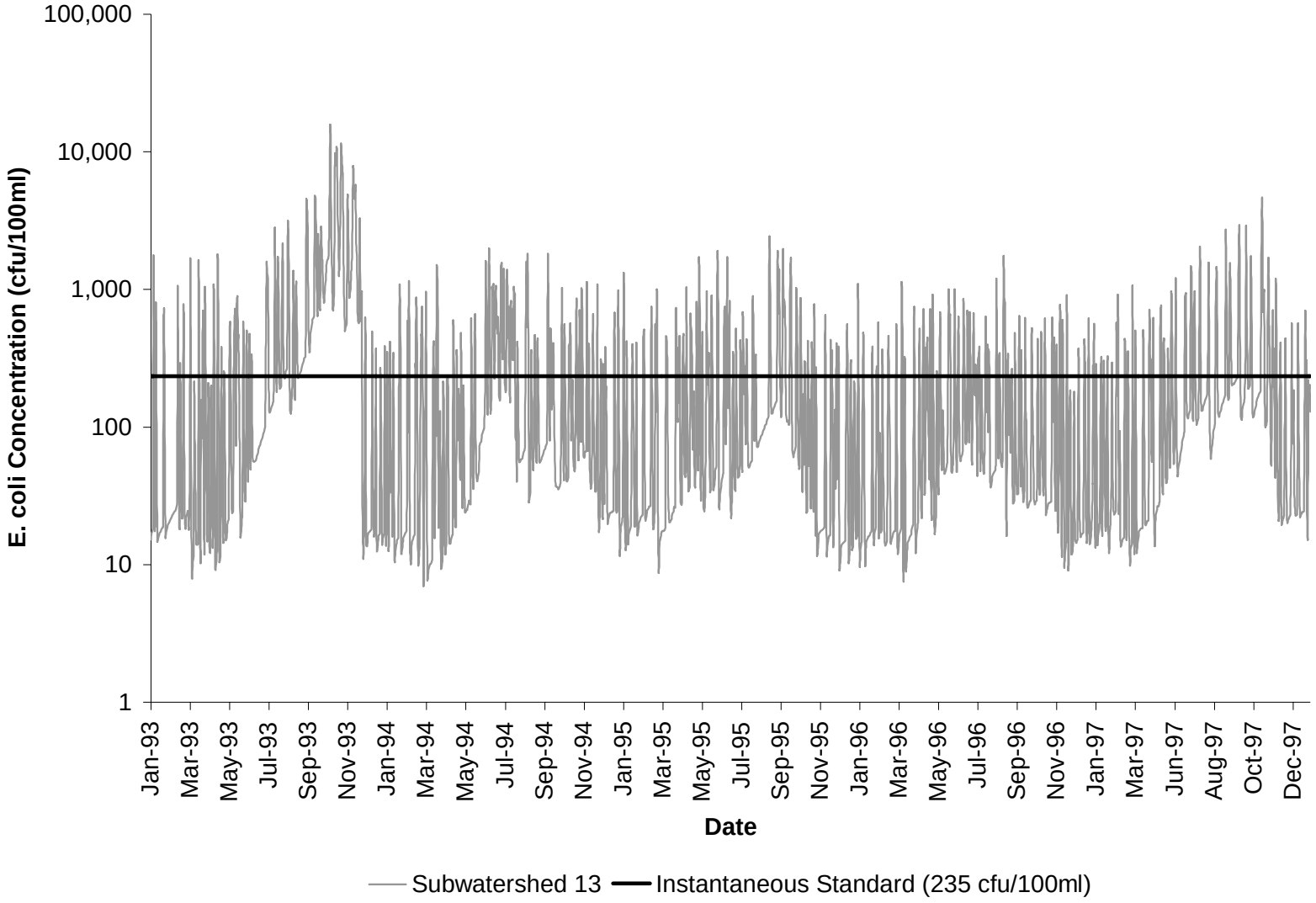

Figure 5.4. Daily average *E. coli* concentrations for subwatershed SAR-13 in South Anna River (VAN-F02R-01) watershed.

5.2.3 South Anna River (VAP-F04R-01)

Figure 5.5 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the 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 South Anna River (VAP-F04R-01) impairment was subwatershed SAR-26.

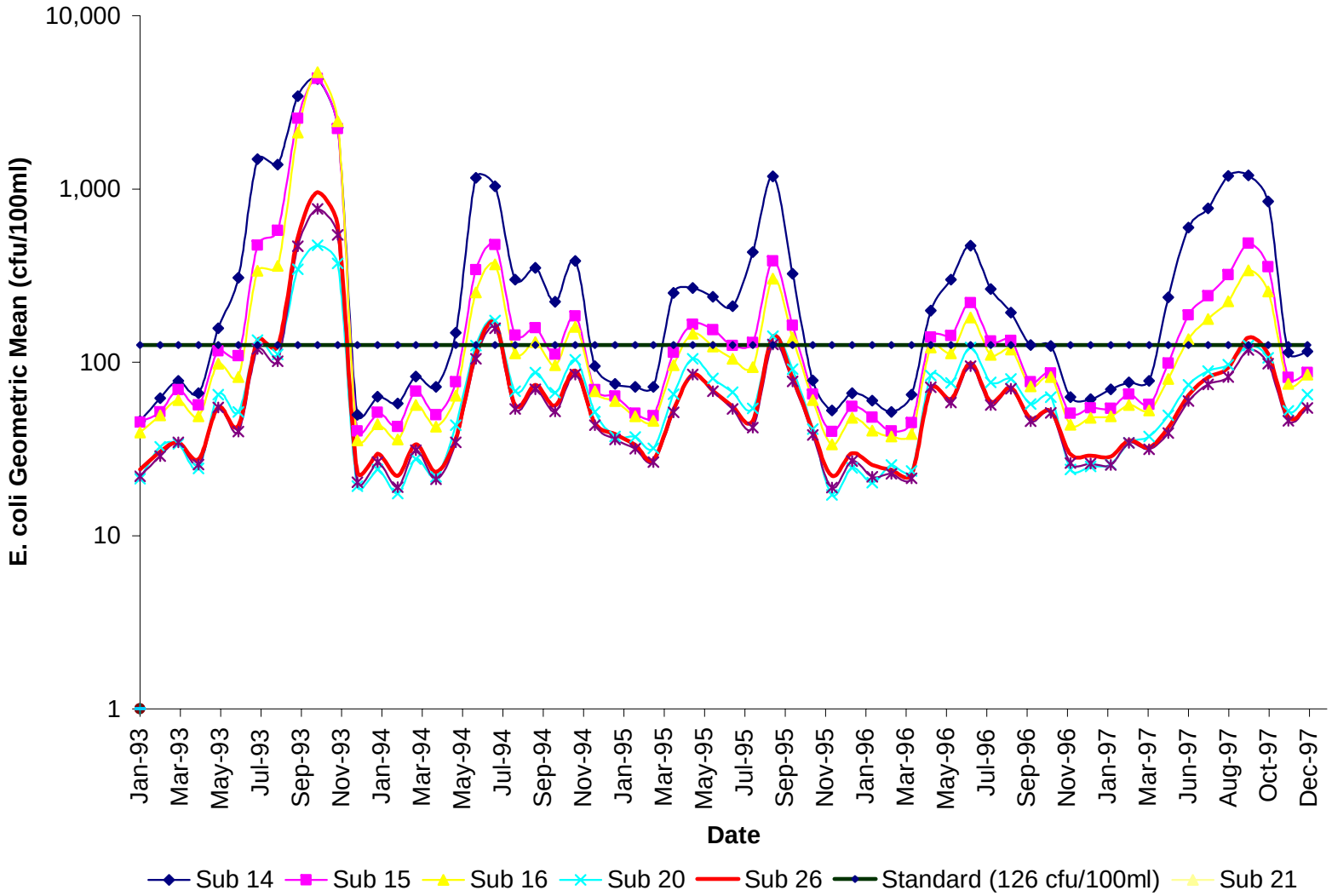

Figure 5.5. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-14 to SAR-16, SAR-20 to SAR-21, and SAR-26 in South Anna River (VAP-F04R-01) watershed.

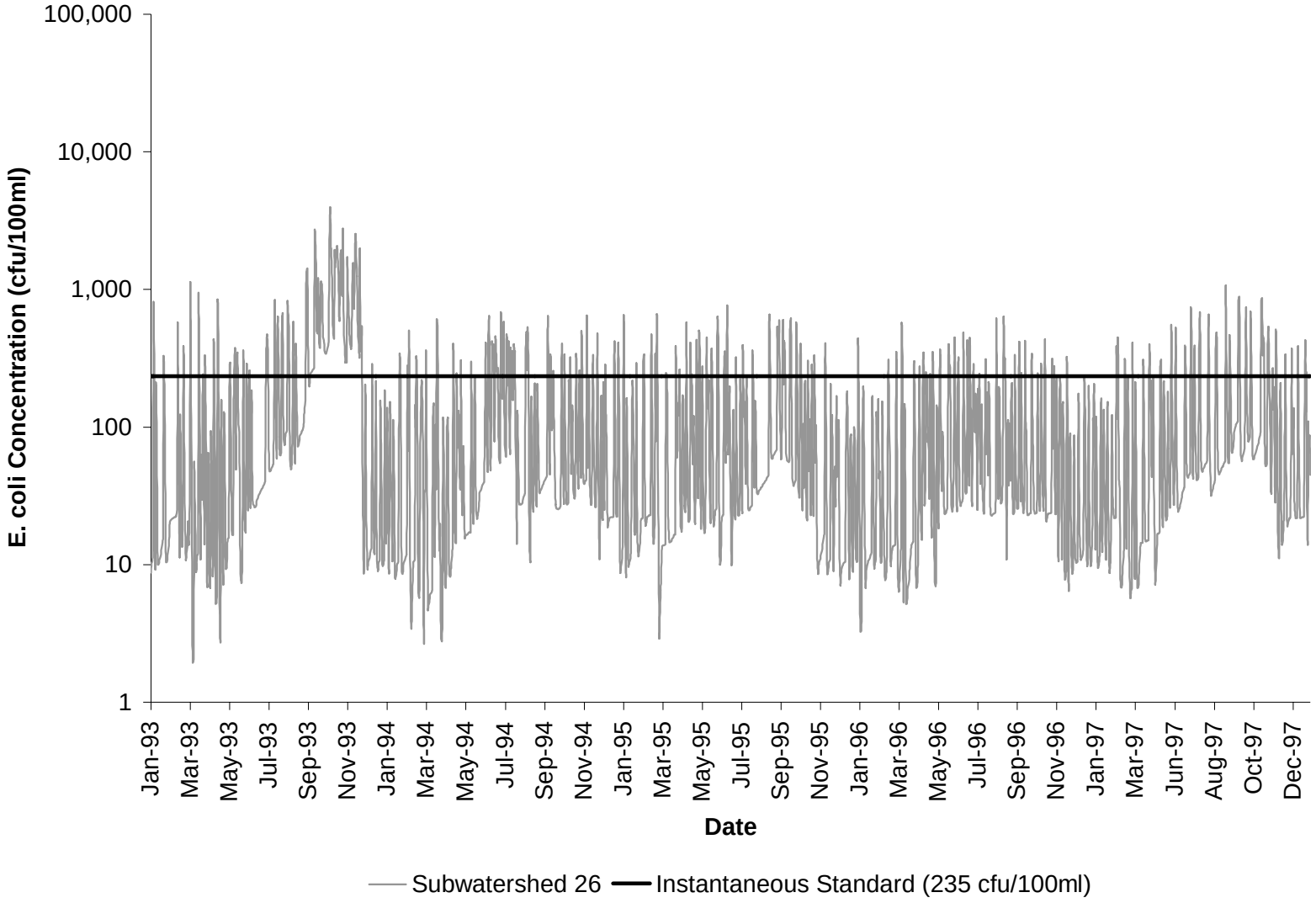

Figure 5.6. Daily average *E. coli* concentrations for subwatershed SAR-26 in South Anna River (VAP-F04R-01) watershed.

5.2.4 South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-02) impairment was subwatershed SAR-28.

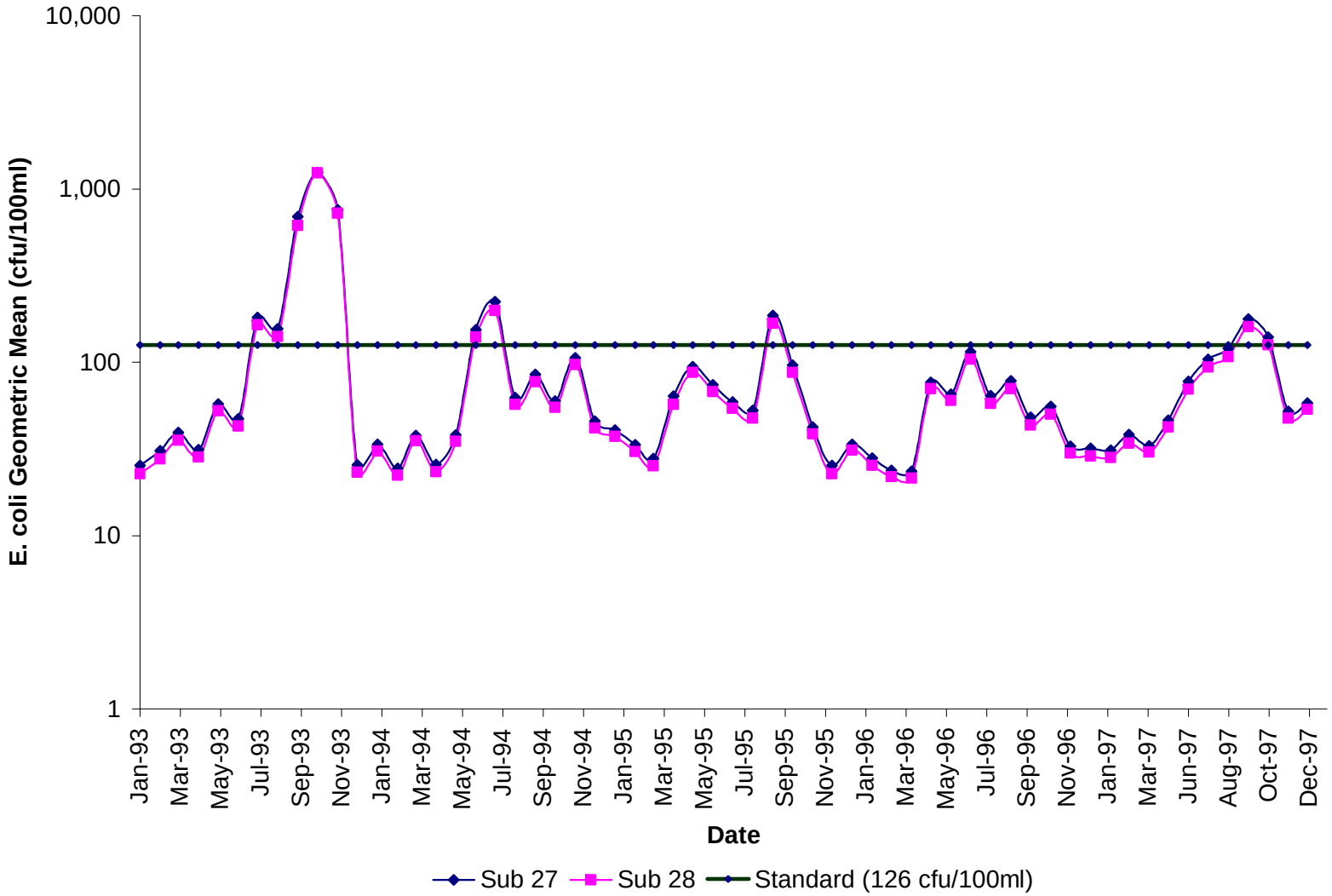

Figure 5.7. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-27 and SAR-28 in South Anna River (VAP-F04R-02) watershed.

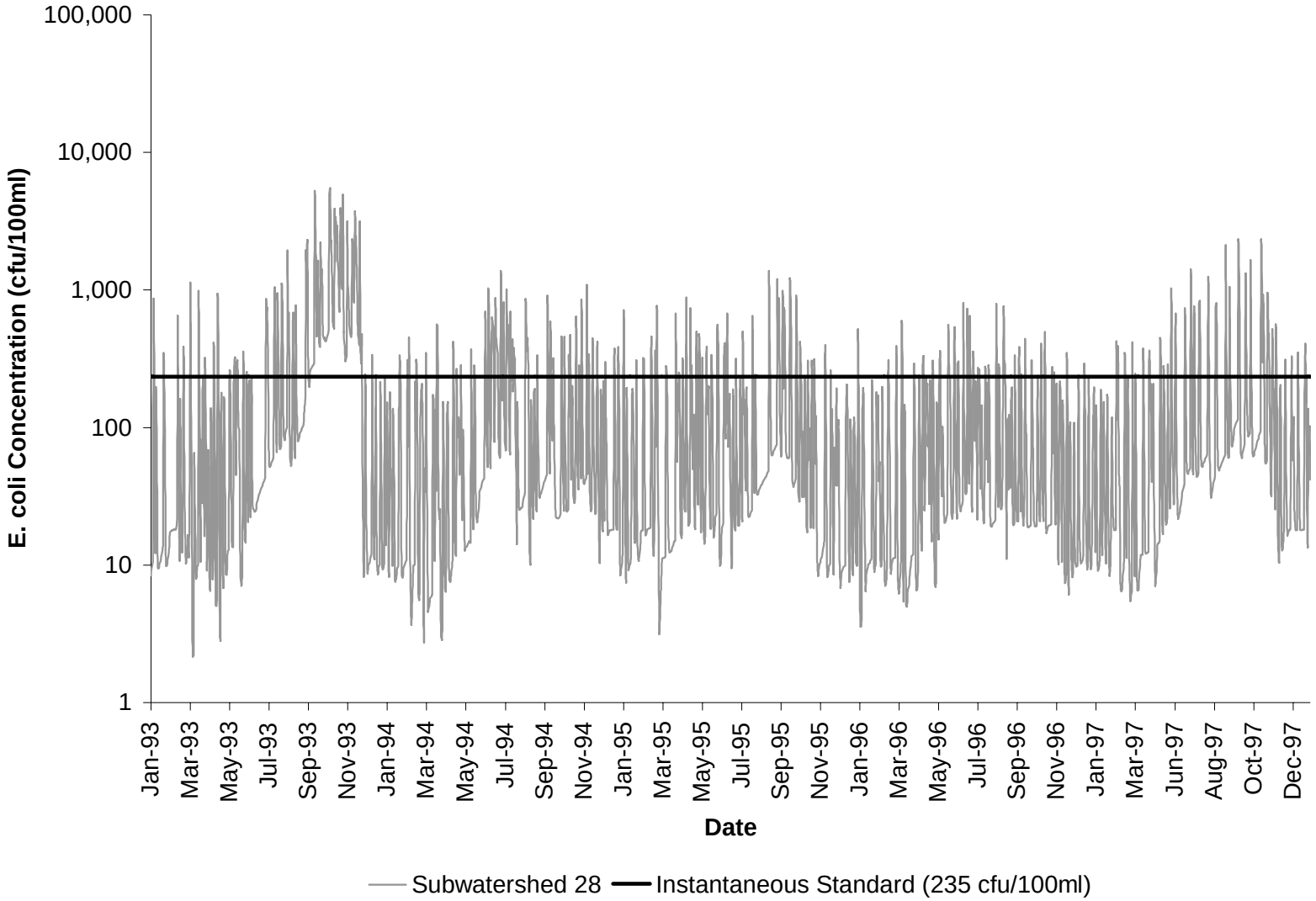

Figure 5.8. Daily average *E. coli* concentrations for subwatershed SAR-28 in South Anna River (VAP-F04R-02) watershed.

5.2.5 Taylors Creek (VAN-F03R-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 Taylors Creek (VAN-F03R-01)impairment was subwatershed SAR-19.

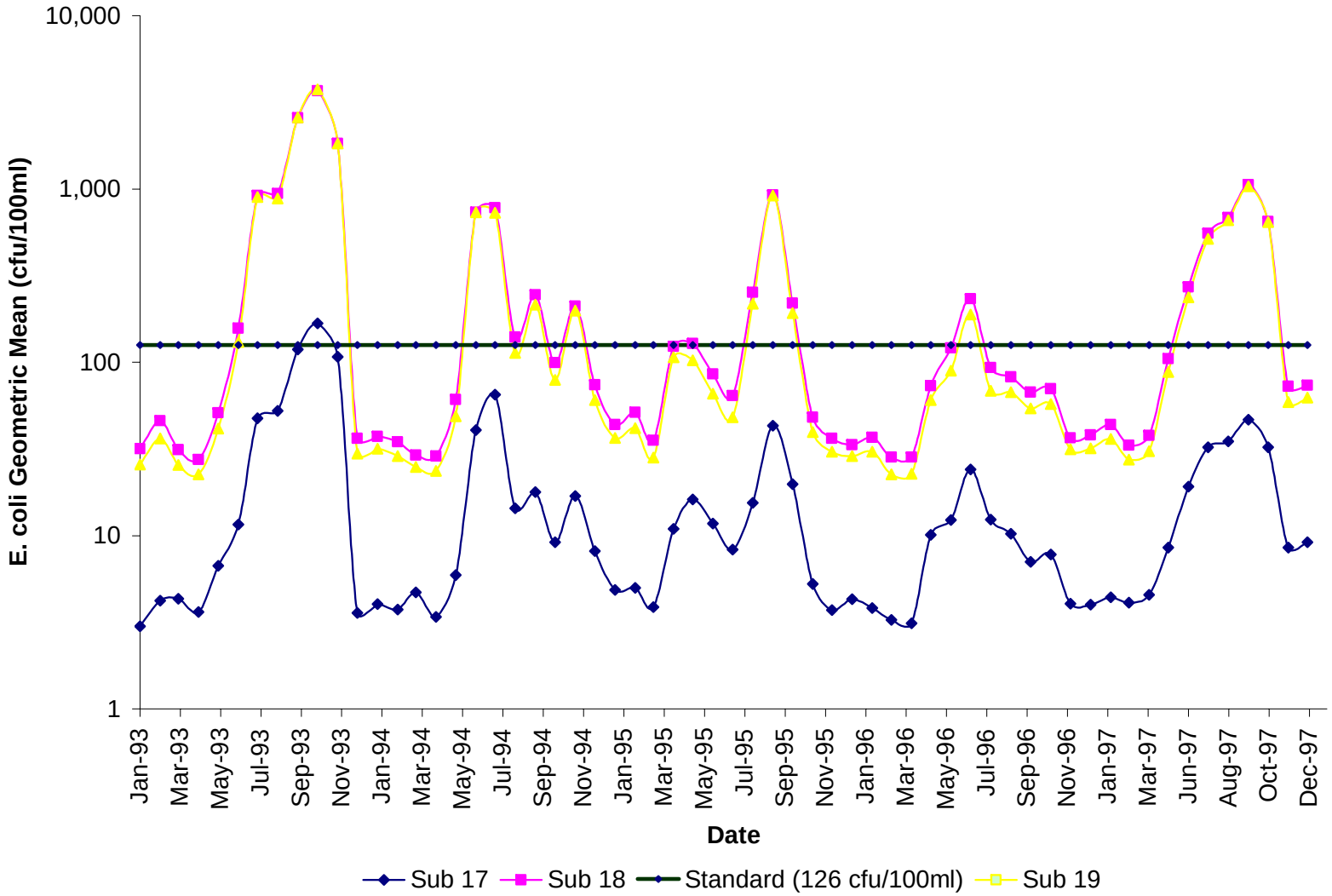

Figure 5.9. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-17 to SAR-19 in Taylors Creek (VAN-F03R-01) watershed.

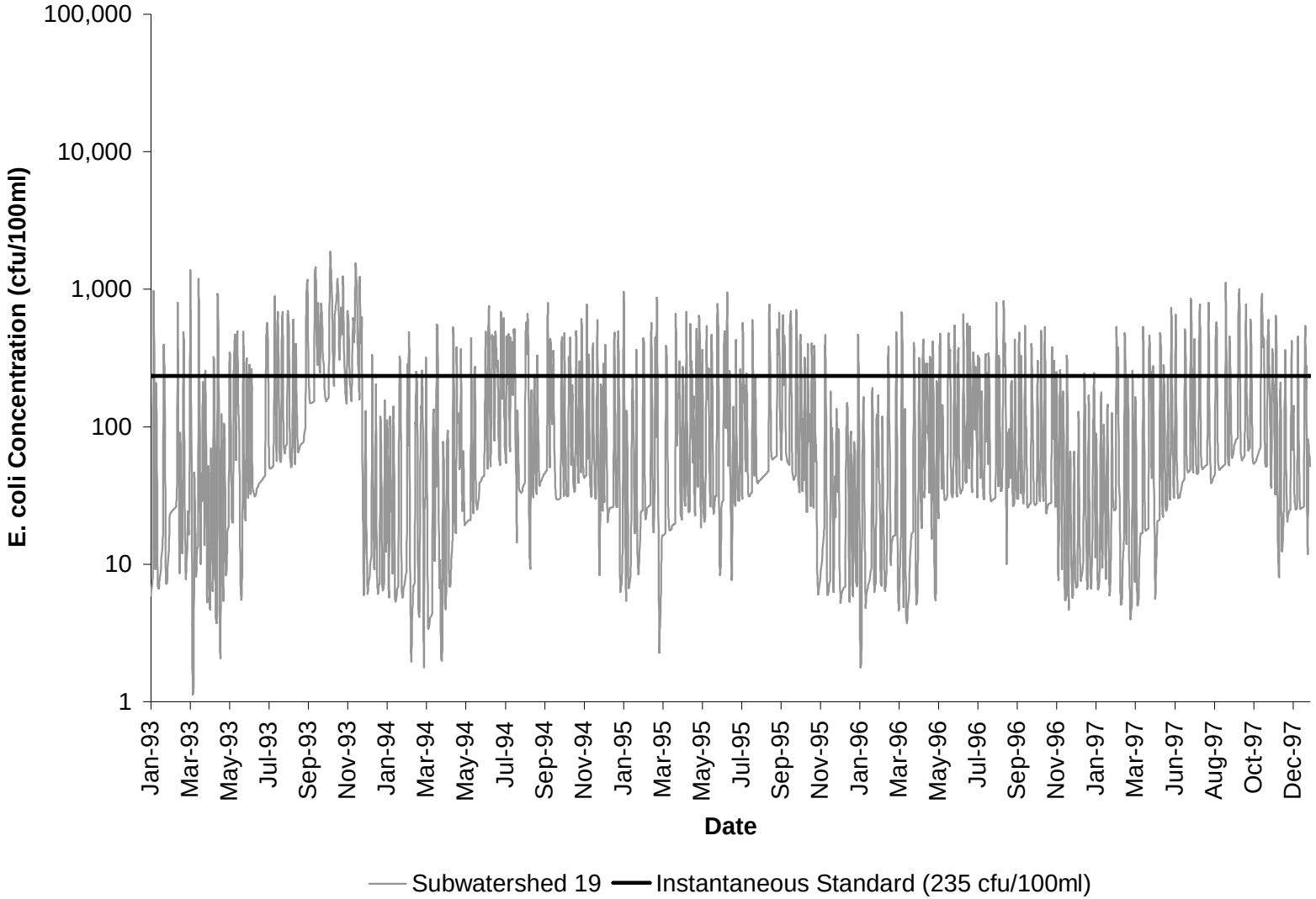

Figure 5.10. Daily average *E. coli* concentrations for subwatershed SAR-19 in Taylors Creek (VAN-F03R-01) watershed.

5.2.6 Newfound River (VAP-F05R-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 Newfound River (VAP-F05R-01) impairment was subwatershed SAR-25.

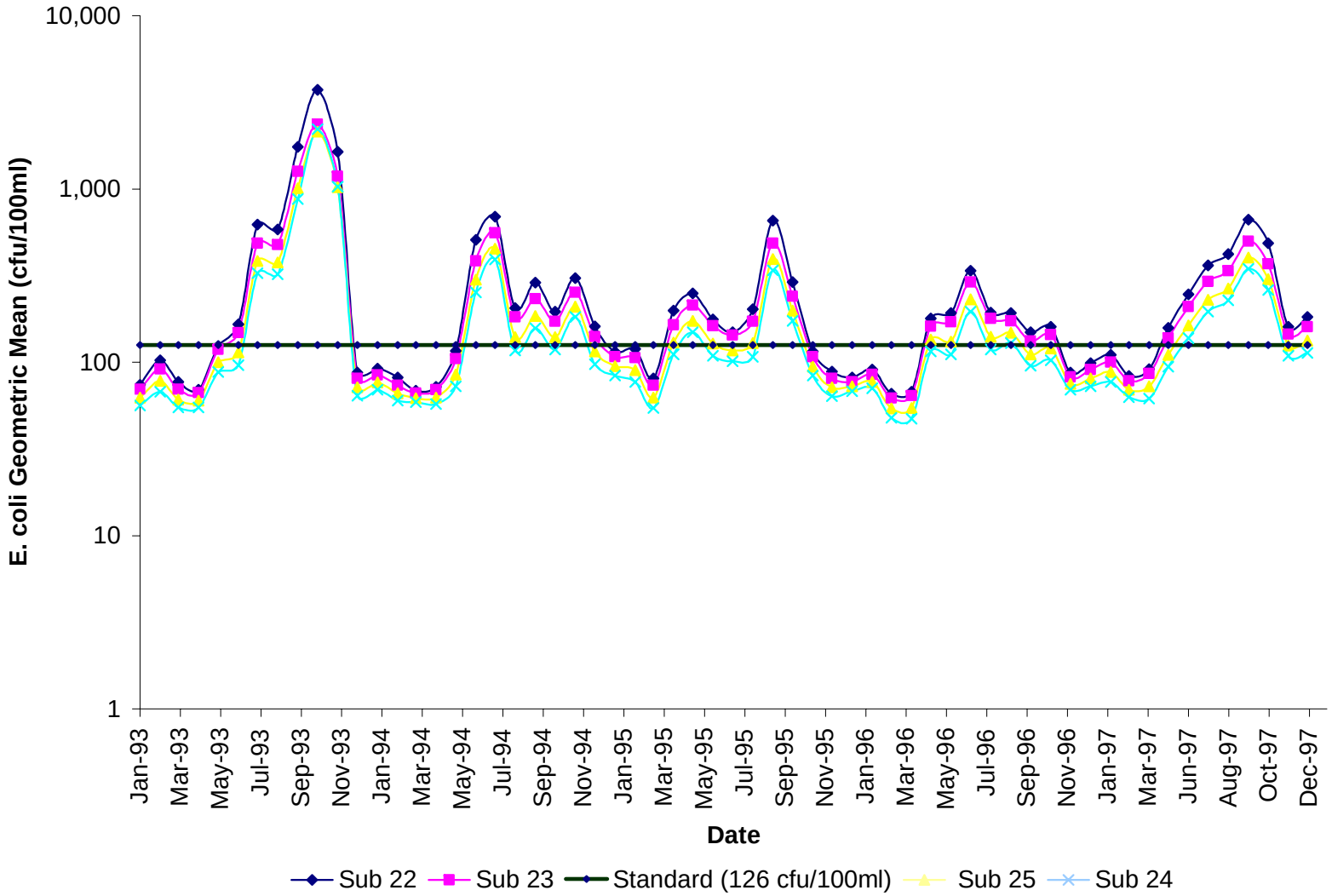

Figure 5.11. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds SAR-22 to SAR-25 in Newfound River (VAP-F05R-01) watershed.

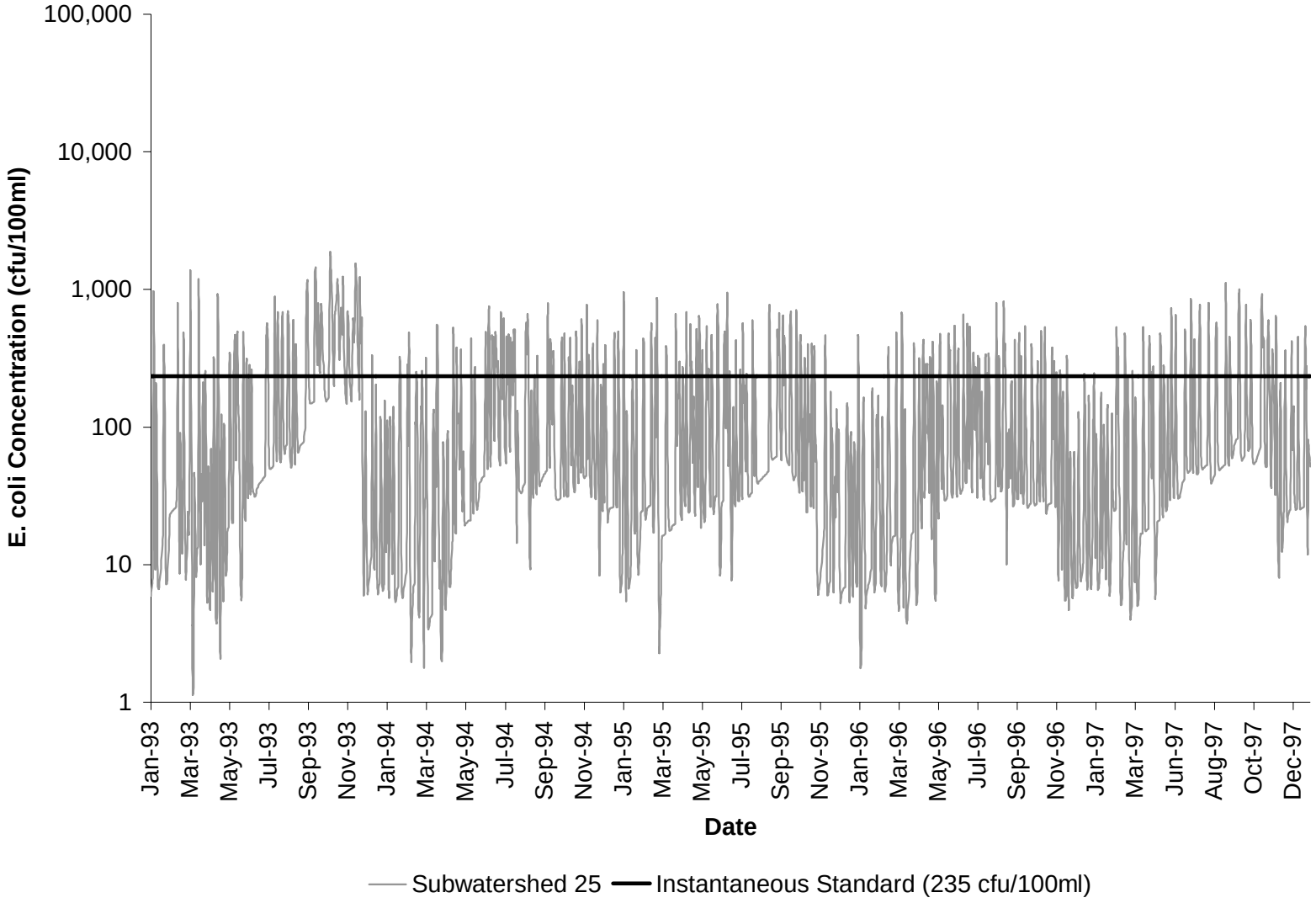

Figure 5.12. Daily average *E. coli* concentrations for subwatershed SAR-25 in Newfound River (VAP-F05R-01) watershed.

5.2.7 Northeast Creek (VAP-F09R-01)

Figure 5.13 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the instantaneous standard of 235 cfu/100 mL (Figure 5.14). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Northeast Creek (VAP-F09R-01) impairment was subwatershed NEC-5.

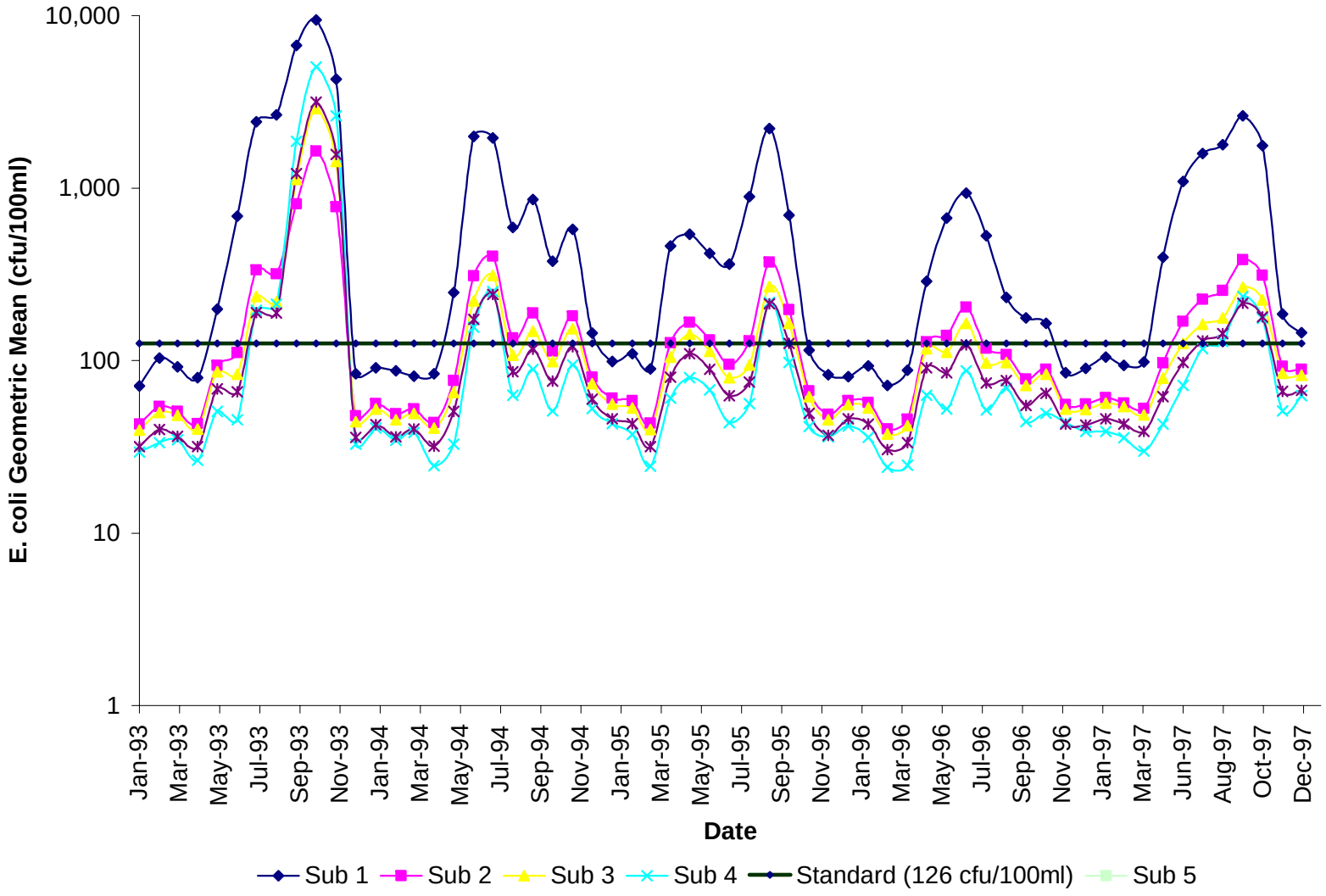

Figure 5.13. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds NEC-1 to NEC-5 in Northeast Creek (VAP-F09R-01) watershed.

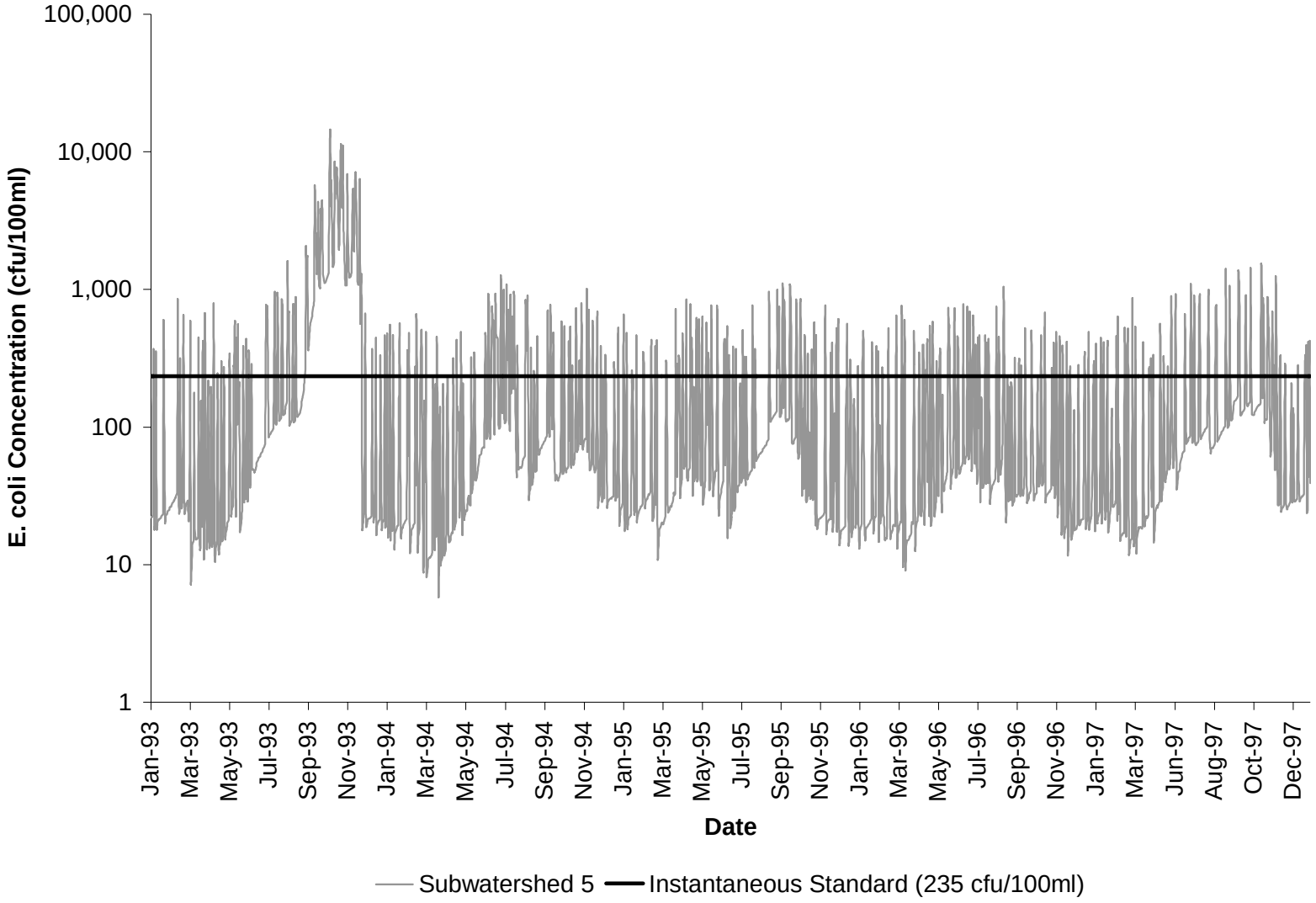

Figure 5.14. Daily average *E. coli* concentrations for subwatershed NEC-5 in Northeast Creek (VAP-F09R-01) watershed.

5.2.8 Totopotomoy Creek (VAP-F13R-02)

Figure 5.15 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the instantaneous standard of 235 cfu/100 mL (Figure 5.16). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Totopotomoy Creek (VAP-F13R-02) impairment was subwatershed TOC-5.

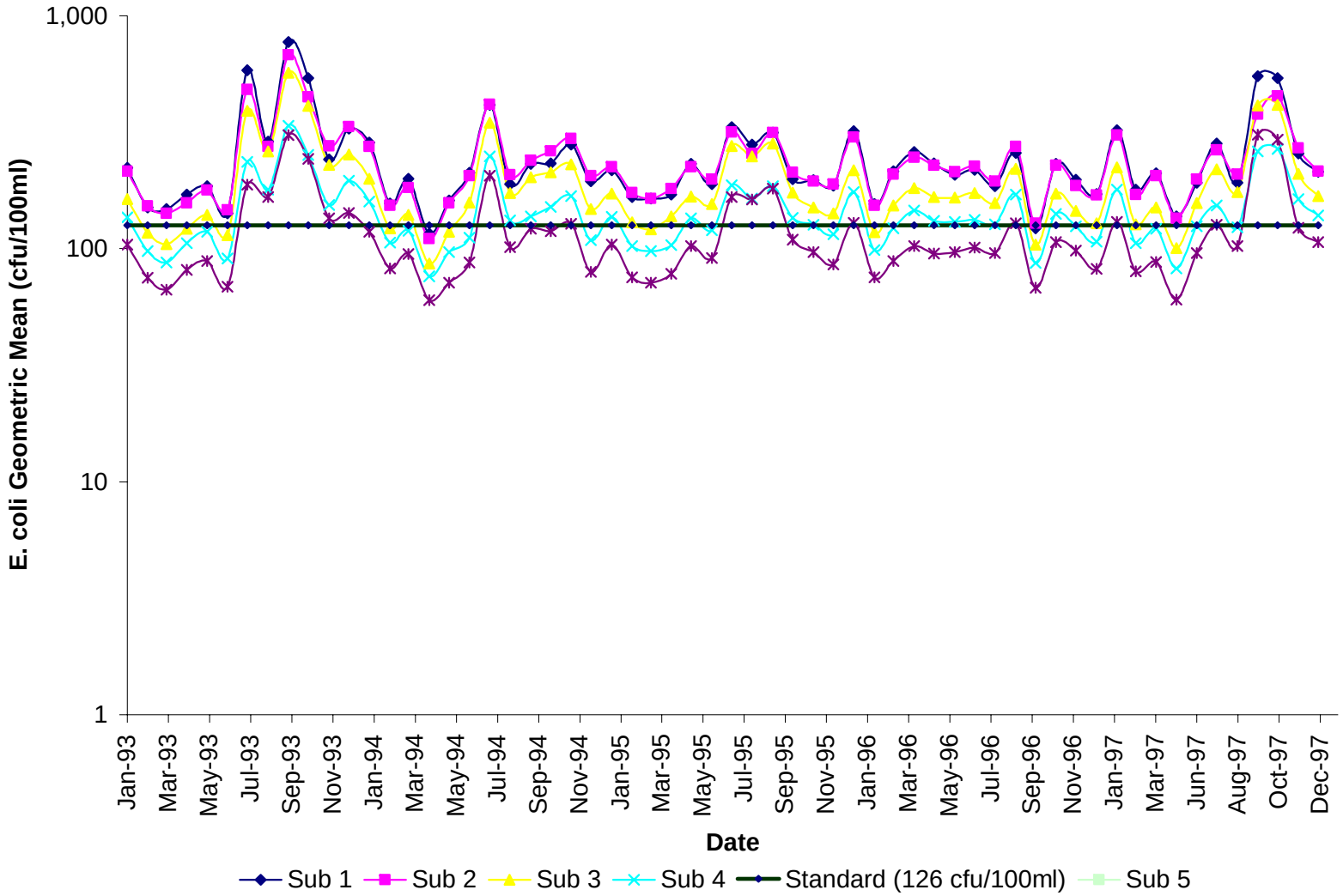

Figure 5.15. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds TOC-1 to TOC-5 in Totopotomoy Creek (VAP-F13R-02) watershed.

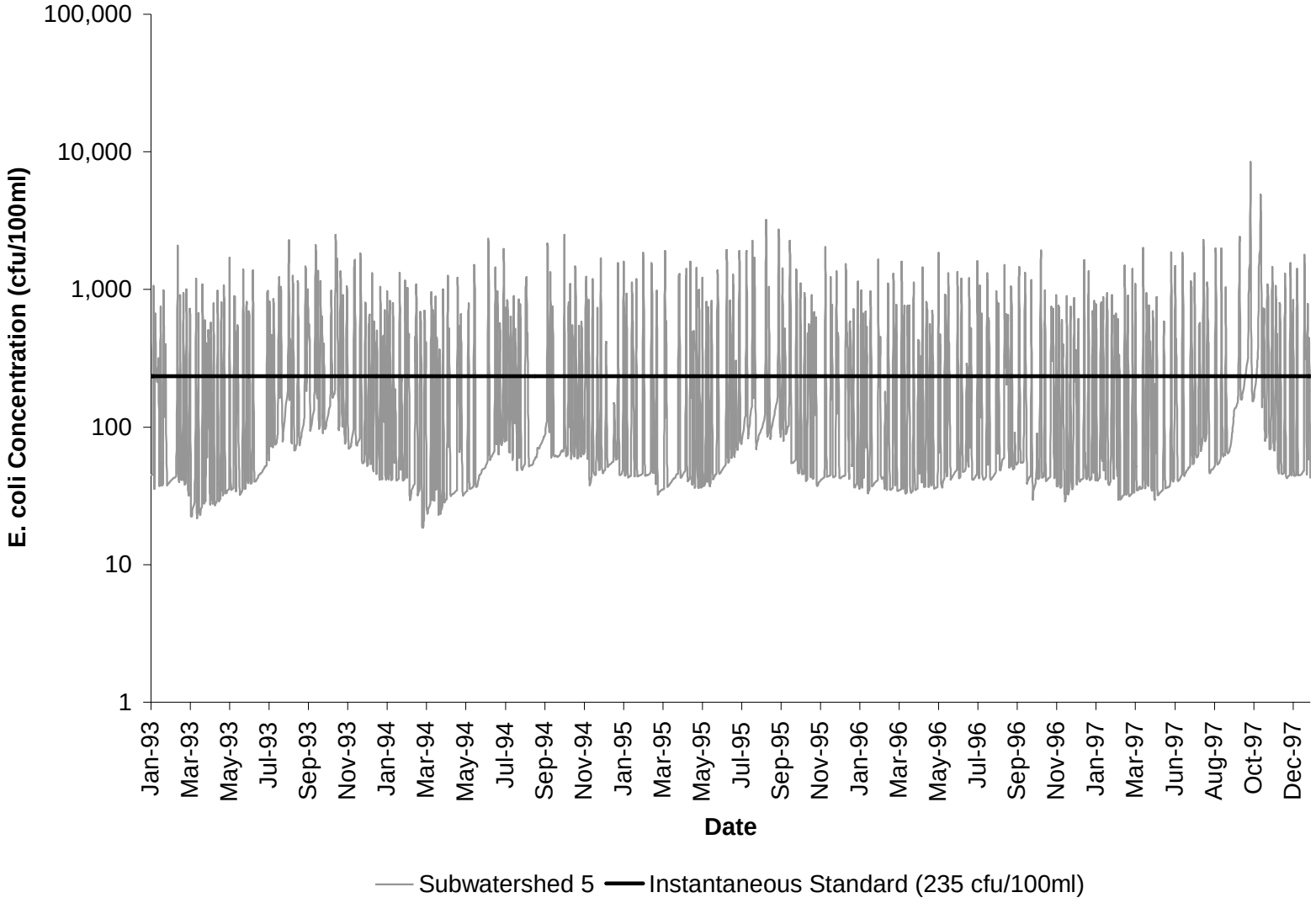

Figure 5.16. Daily average *E. coli* concentrations for subwatershed TOC-5 in Totopotomoy Creek (VAP-F13R-02) watershed.

5.2.9 Moncuin/Webb Creek (VAP-F13R-04)

Figure 5.17 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the instantaneous standard of 235 cfu/100 mL (Figure 5.18). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Moncuin/Webb Creek (VAP-F13R-04) impairment was subwatershed PAR-7.

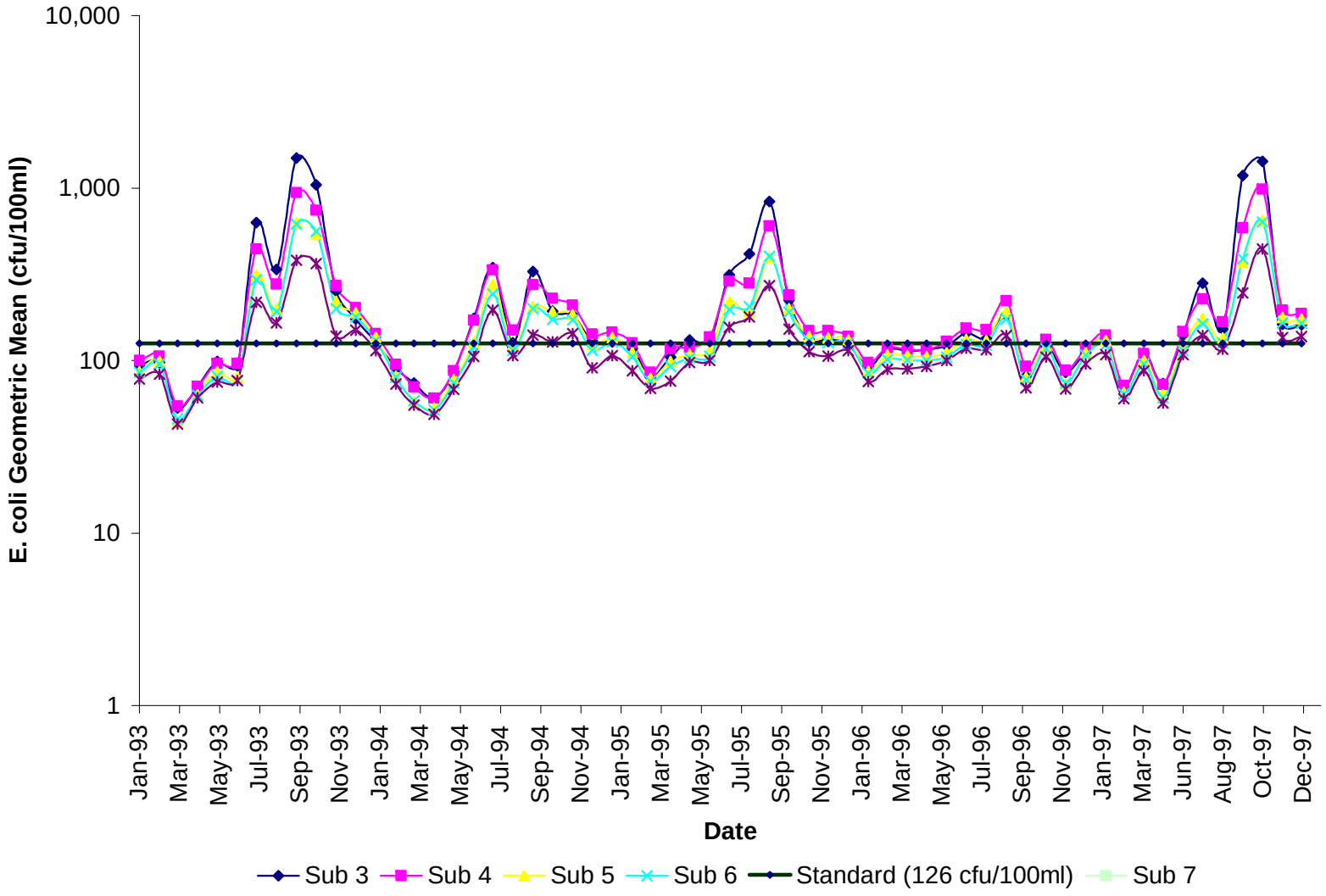

Figure 5.17. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds PAR-3 to PAR-7 in Moncuin/Webb Creek (VAP-F13R-04) watershed.

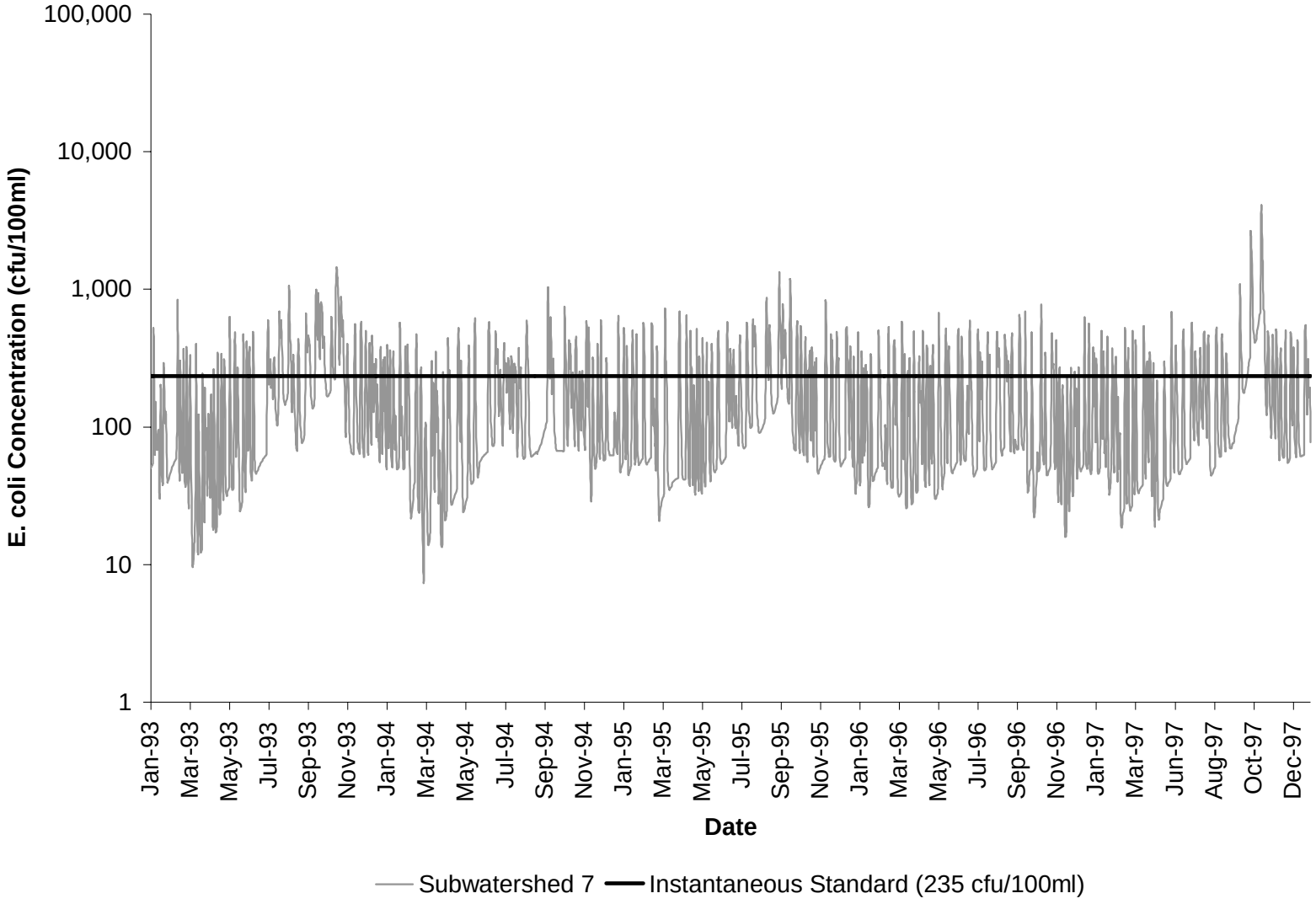

Figure 5.18. Daily average *E. coli* concentrations for subwatershed PAR-7 in Moncuin/Webb Creek (VAP-F13R-04) watershed.

5.2.10 Black Creek (VAP-F13R-05)

Figure 5.19 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the instantaneous standard of 235 cfu/100 mL (Figure 5.20). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Black Creek (VAP-F13R-05) impairment was subwatershed PAR-17.

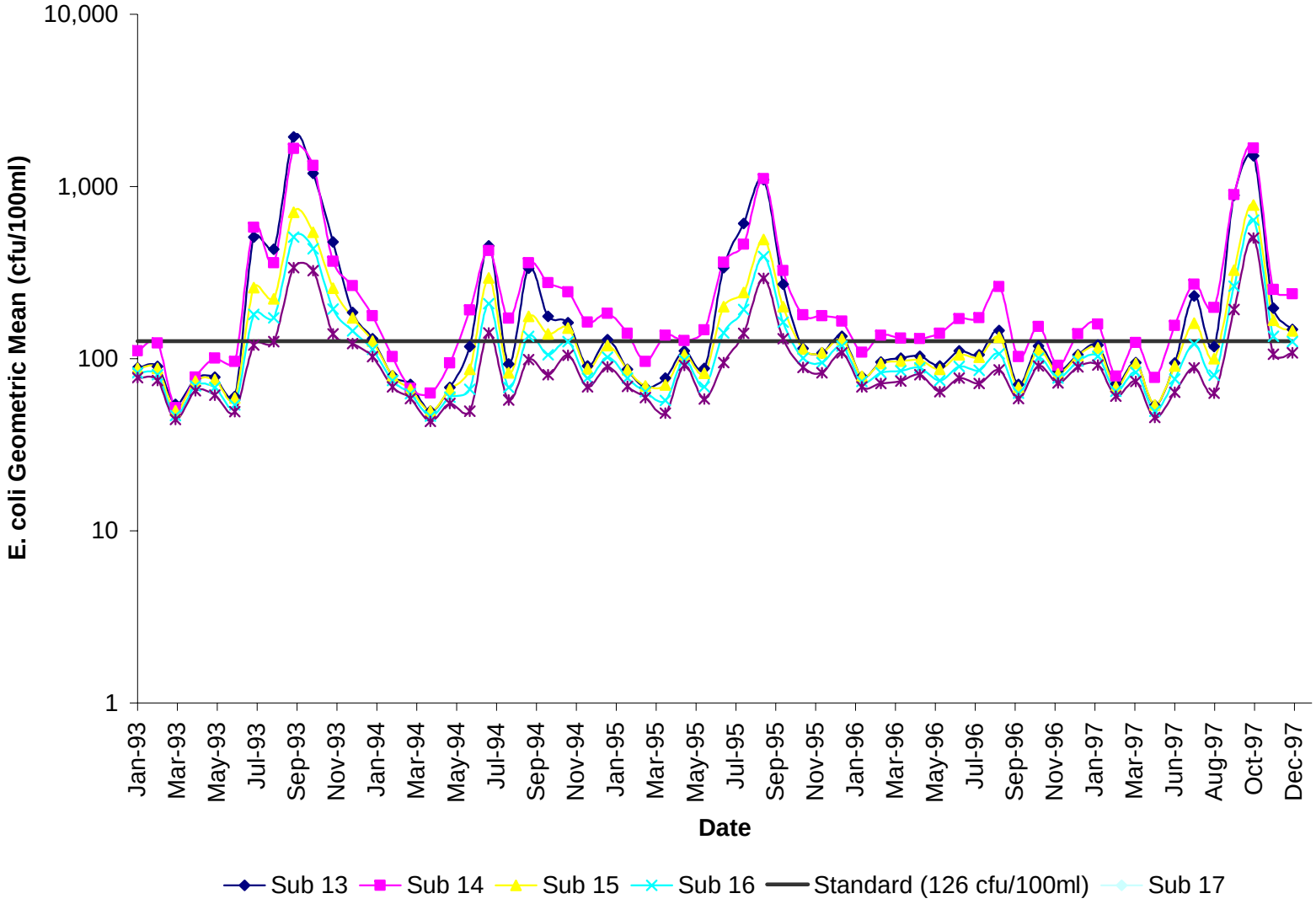

Figure 5.19. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds PAR-13 to PAR-17 in Black Creek (VAP-F13R-05) watershed.

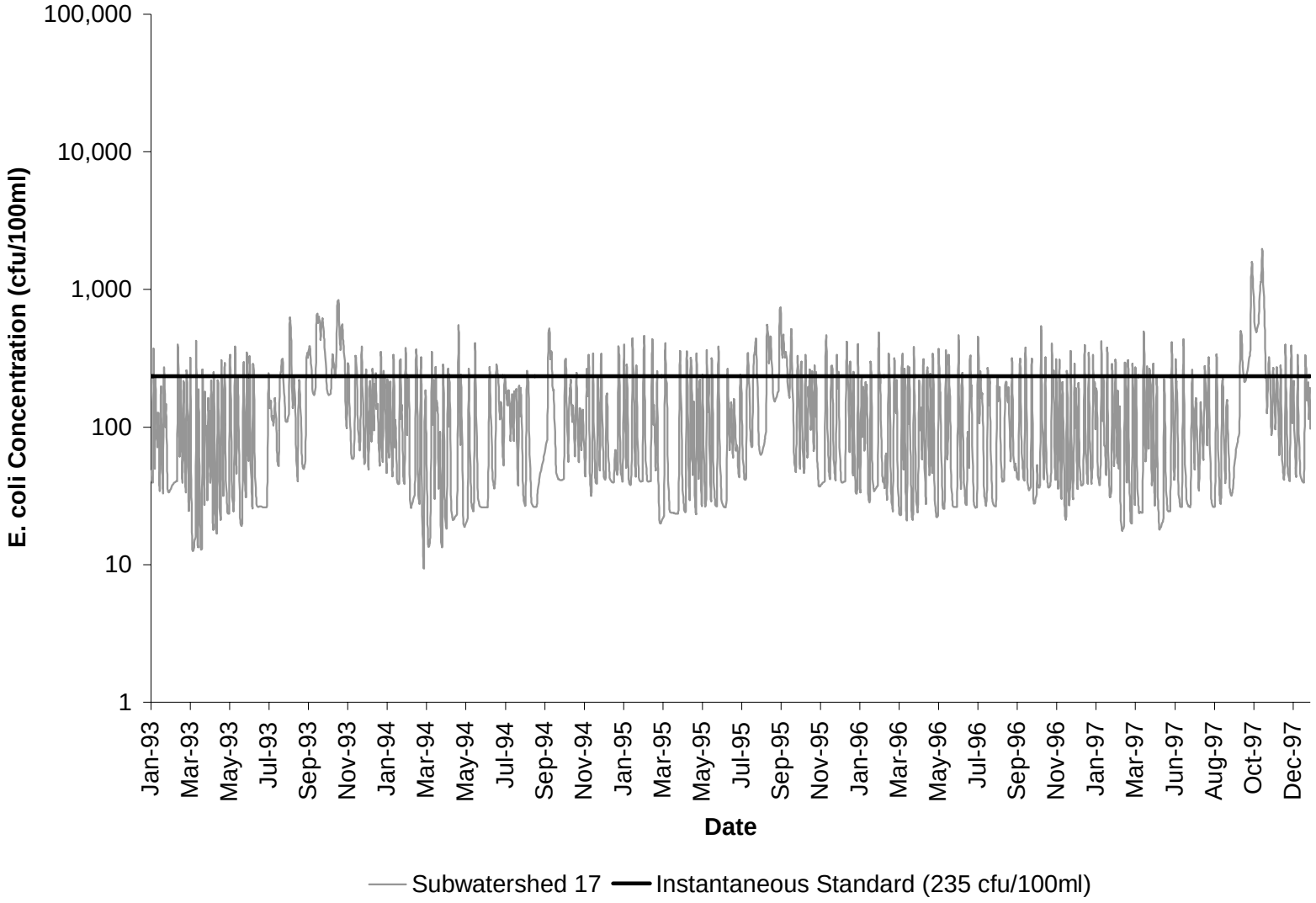

Figure 5.20. Daily average *E. coli* concentrations for subwatershed PAR-17 in Black Creek (VAP-F13R-05) watershed.

5.2.11 Pamunkey River (VAP-F13E-02)

Figure 5.21 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 5.22). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Pamunkey River (VAP-F13E-02) impairment was subwatershed PAR-20.

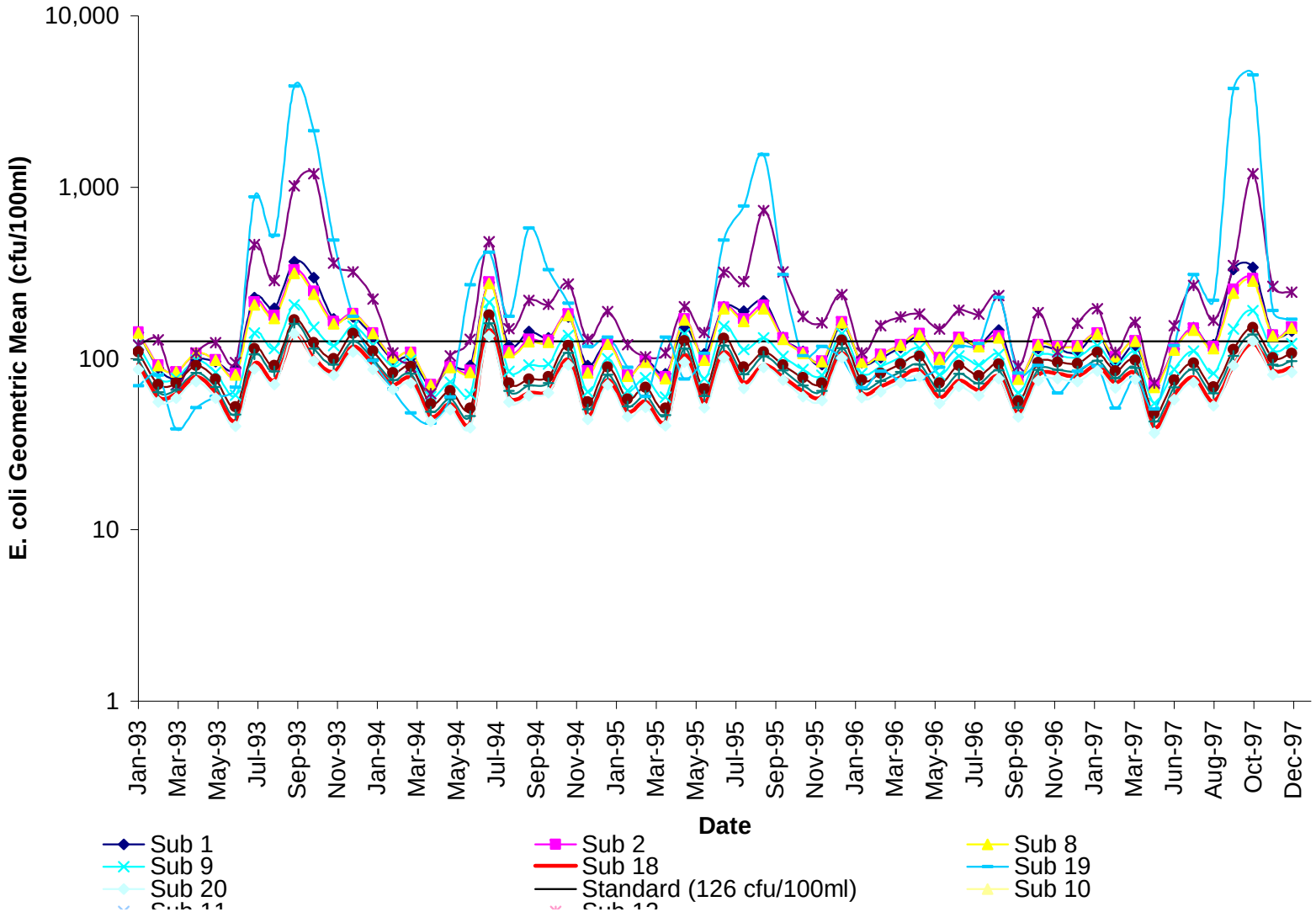

Figure 5.21. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds PAR-1, PAR-2, PAR-8 to PAR-12, and PAR-18 to PAR-20 in Pamunkey River (VAP-F13E-02) watershed.

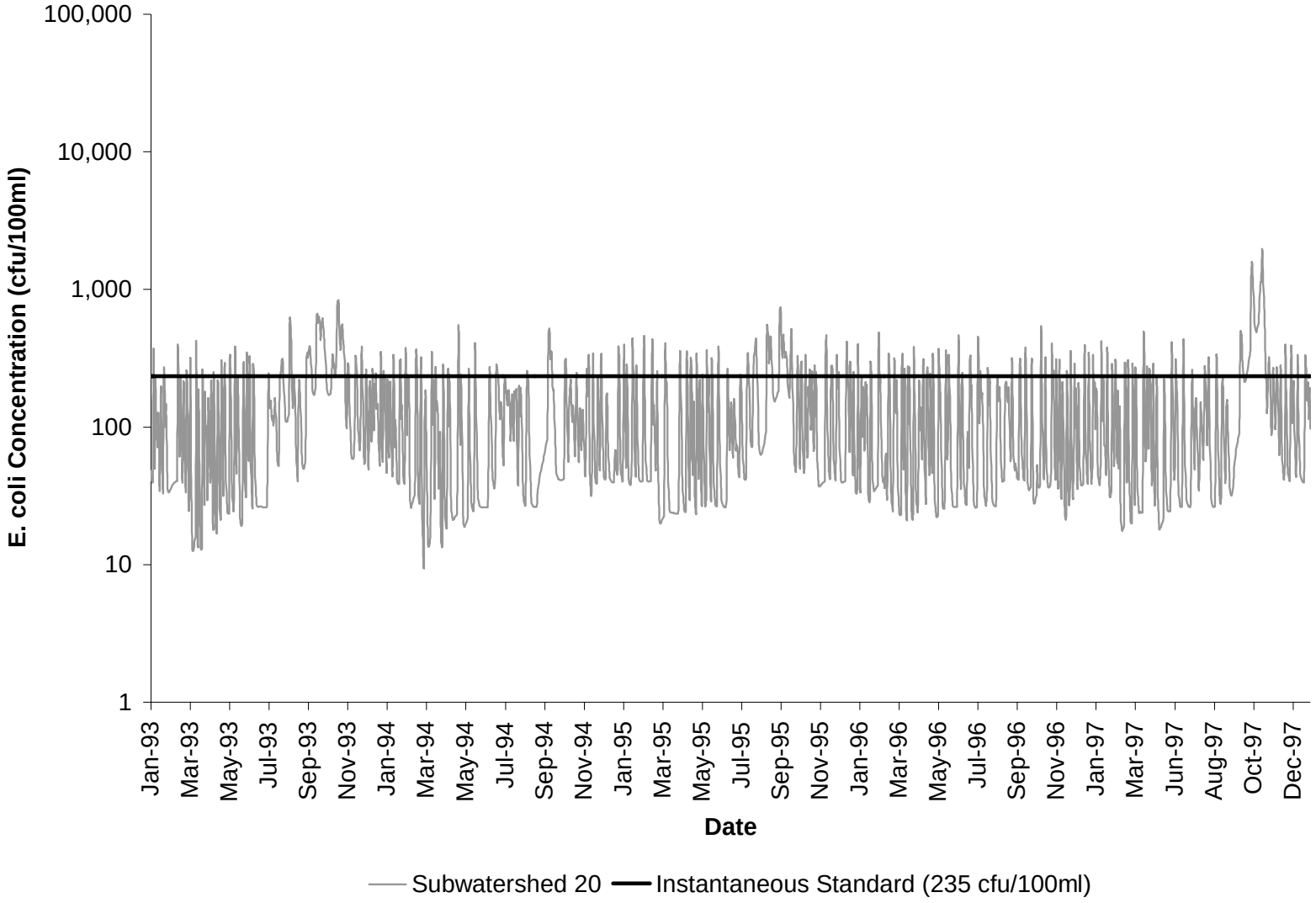

Figure 5.22. Daily average *E. coli* concentrations for subwatershed PAR-20 in Pamunkey River (VAP-F13E-02) watershed.

5.3 Impact Analysis

Analyses were conducted to assess the impact of unknown variability in source allocations on changes in direct and land-based loads. Model output from existing conditions was set as the comparative base to adjustments in direct and land-based loads of +100%, +10%, -10%, and -100% of the base value. Model simulations were made for the period January 1993 to December 1997, corresponding with the period used in the allocation scenarios. Percent difference in monthly geometric mean *E. coli* concentration and maximum daily average *E. coli* concentration per month for each direct and land-based load change to base value was calculated and plotted. Analysis results were used to assess the affects of future growth on the rate of water quality standards exceedance.

5.3.1 South Anna River (VAN-F01R-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 5.23 and 5.24, respectively. Figures 5.25 and 5.26, 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 5.23 with Figure 5.24 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.25 to Figure 5.26 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.

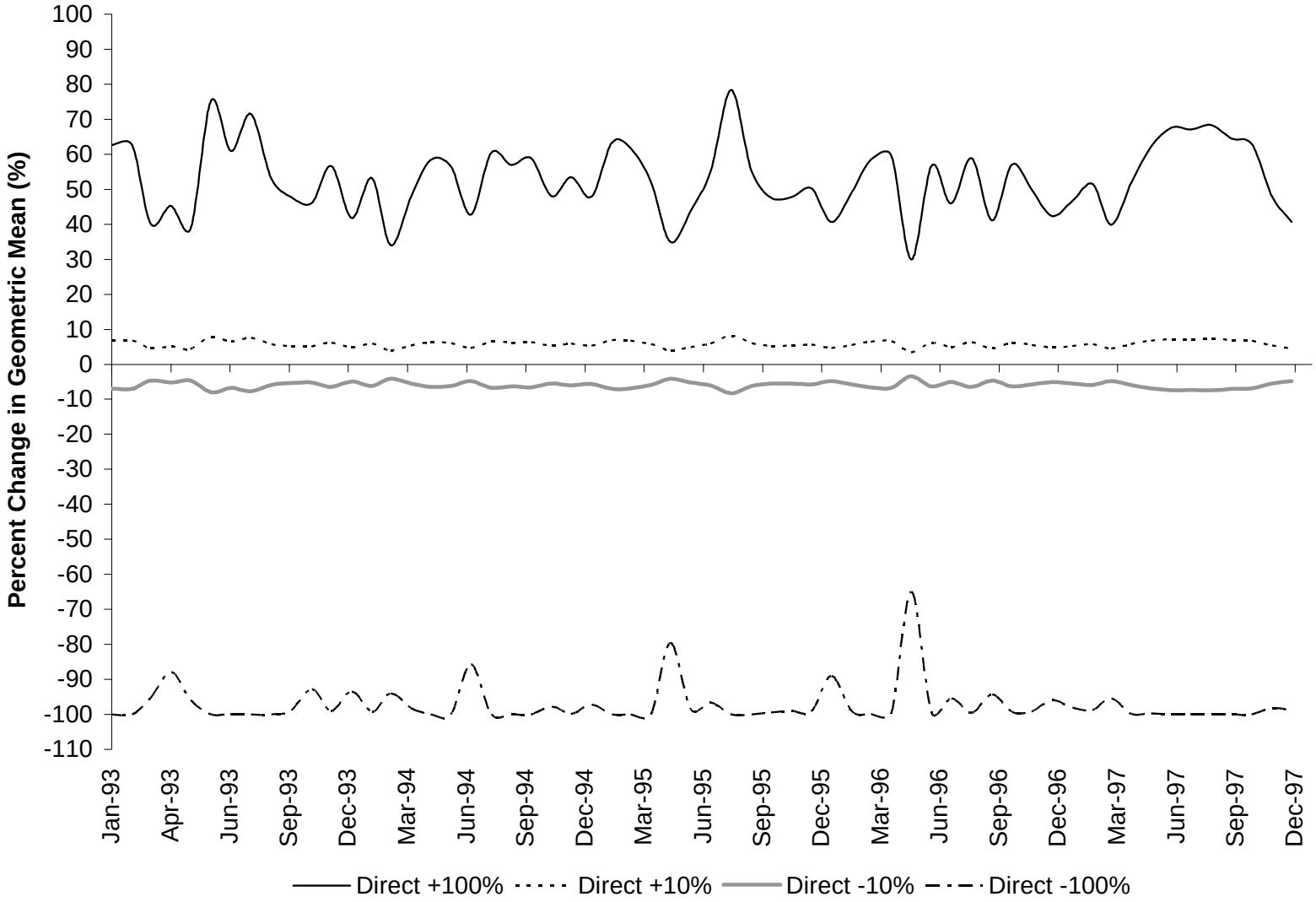

Figure 5.23. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-4) of South Anna River (VAN-F01R-01) watershed, as affected by direct load changes.

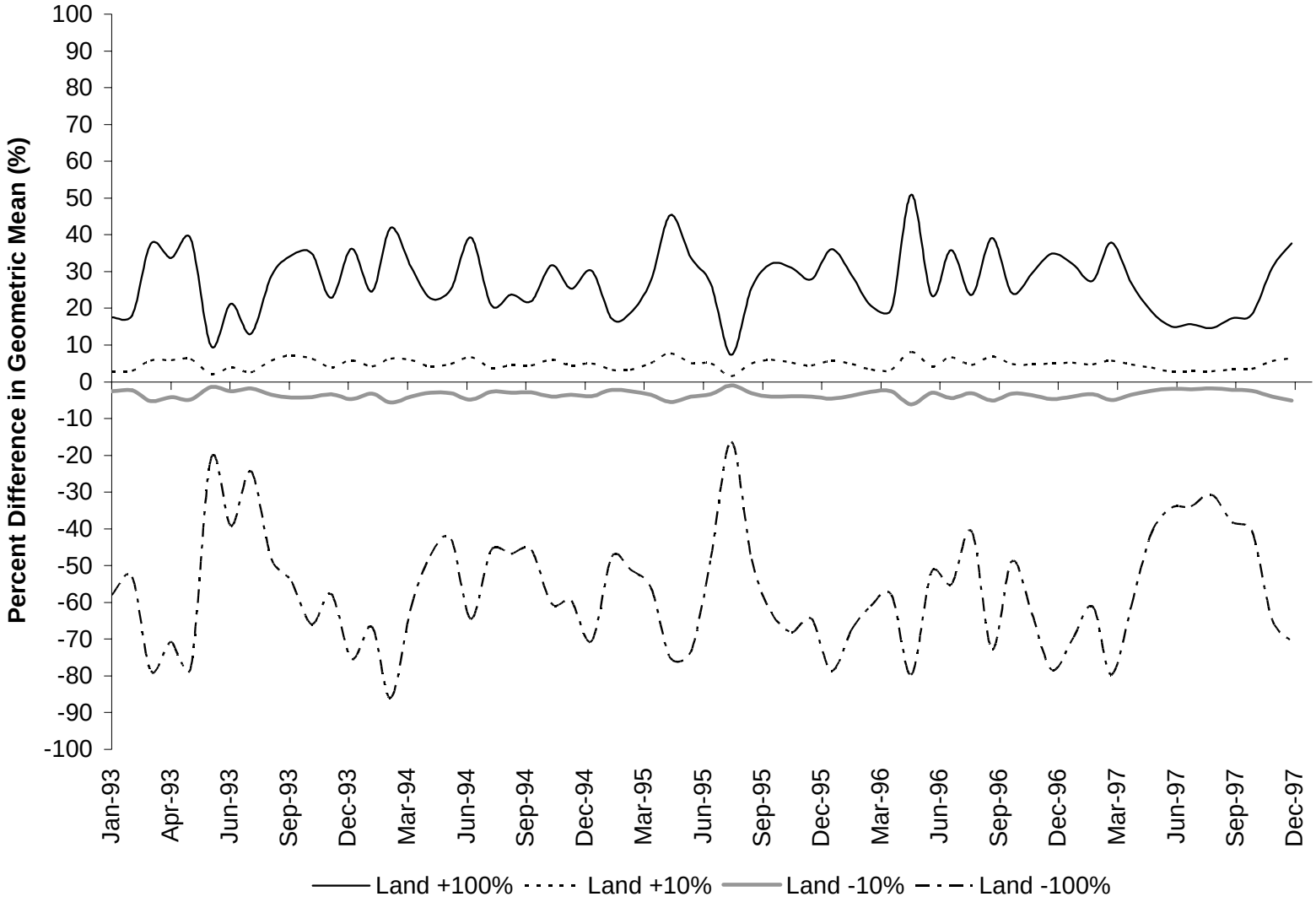

Figure 5.24. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-4) of South Anna River (VAN-F01R-01) watershed, as affected by land-based load changes.

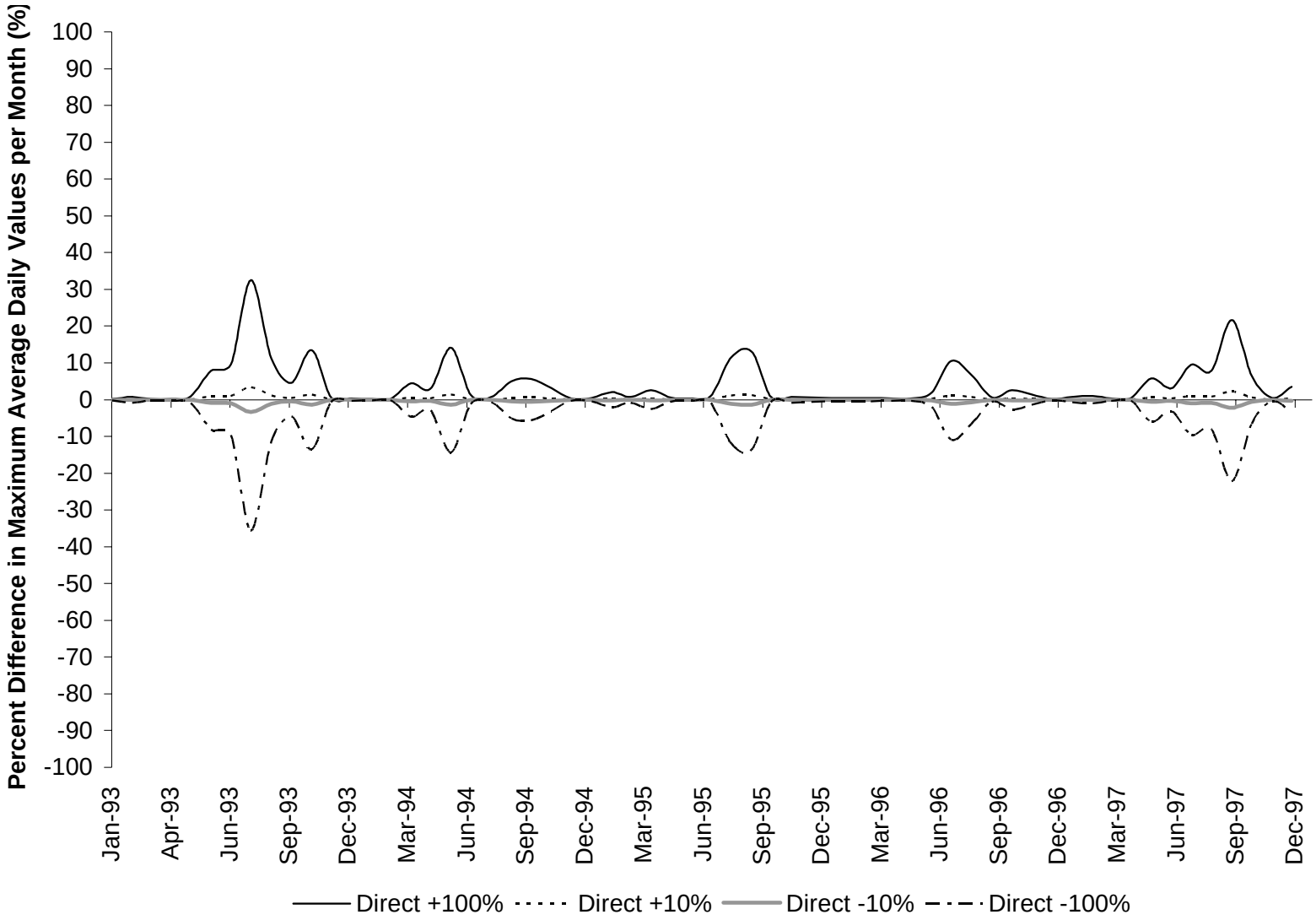

Figure 5.25. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-4) of South Anna River (VAN-F01R-01) watershed, as affected by direct load changes.

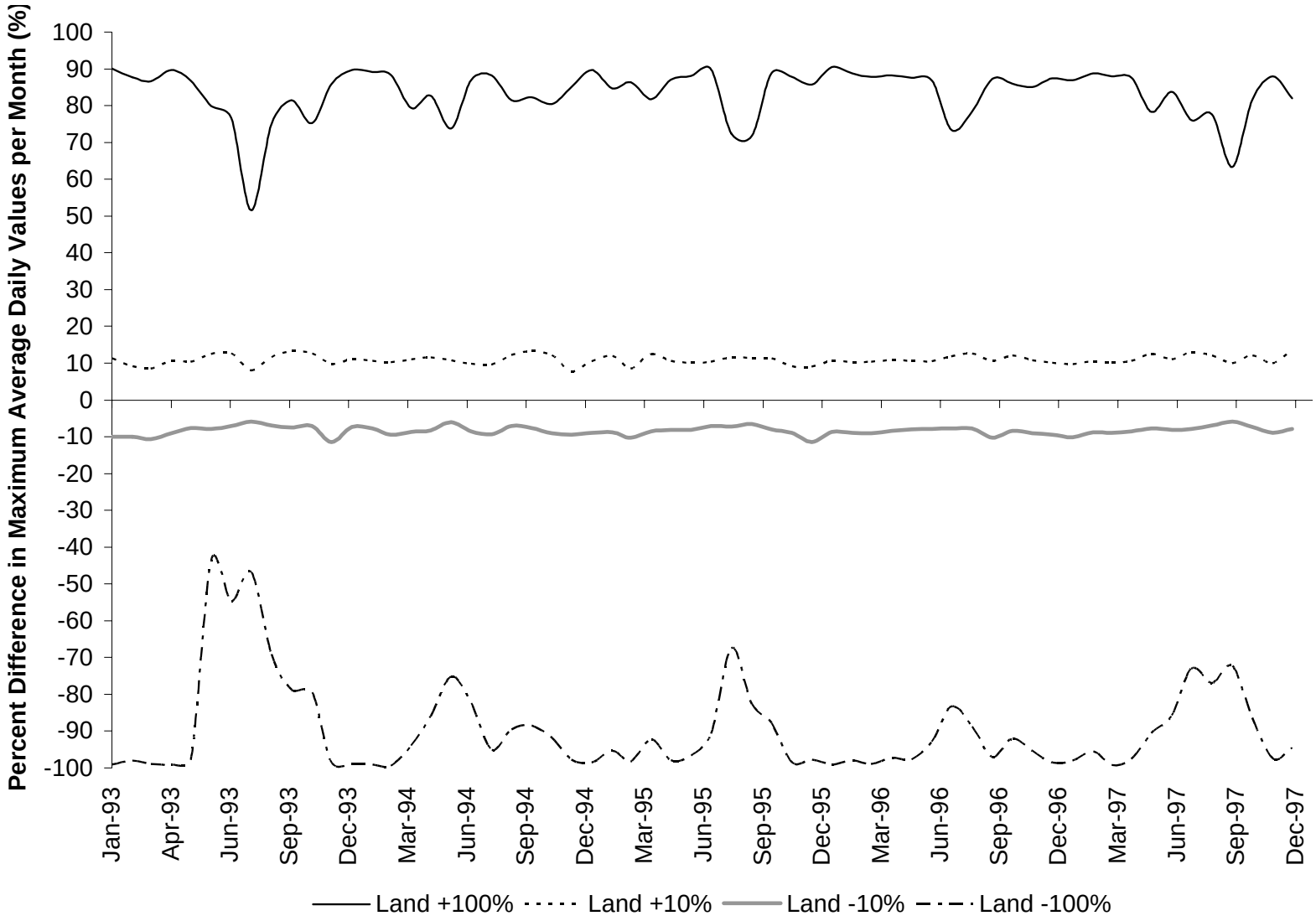

Figure 5.26. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-4) of South Anna River (VAN-F01R-01) watershed, as affected by land-based load changes.

5.3.2 South Anna River (VAN-F02R-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 5.27 and 5.28, respectively. Figures 5.29 and 5.30, 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 5.27 with Figure 5.28 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.29 to Figure 5.30 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.

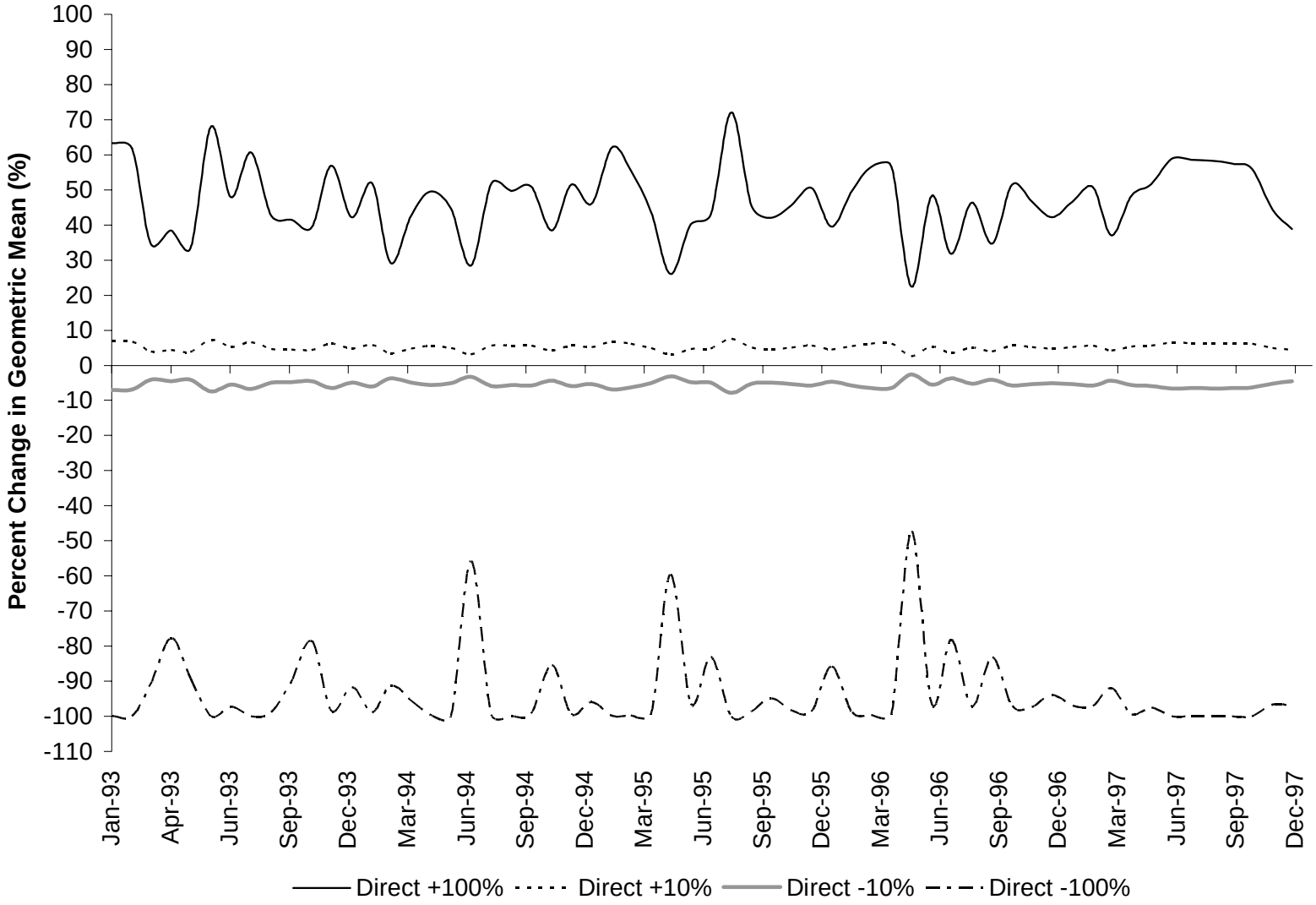

Figure 5.27. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-13) of South Anna River (VAN-F02R-01) watershed, as affected by direct load changes.

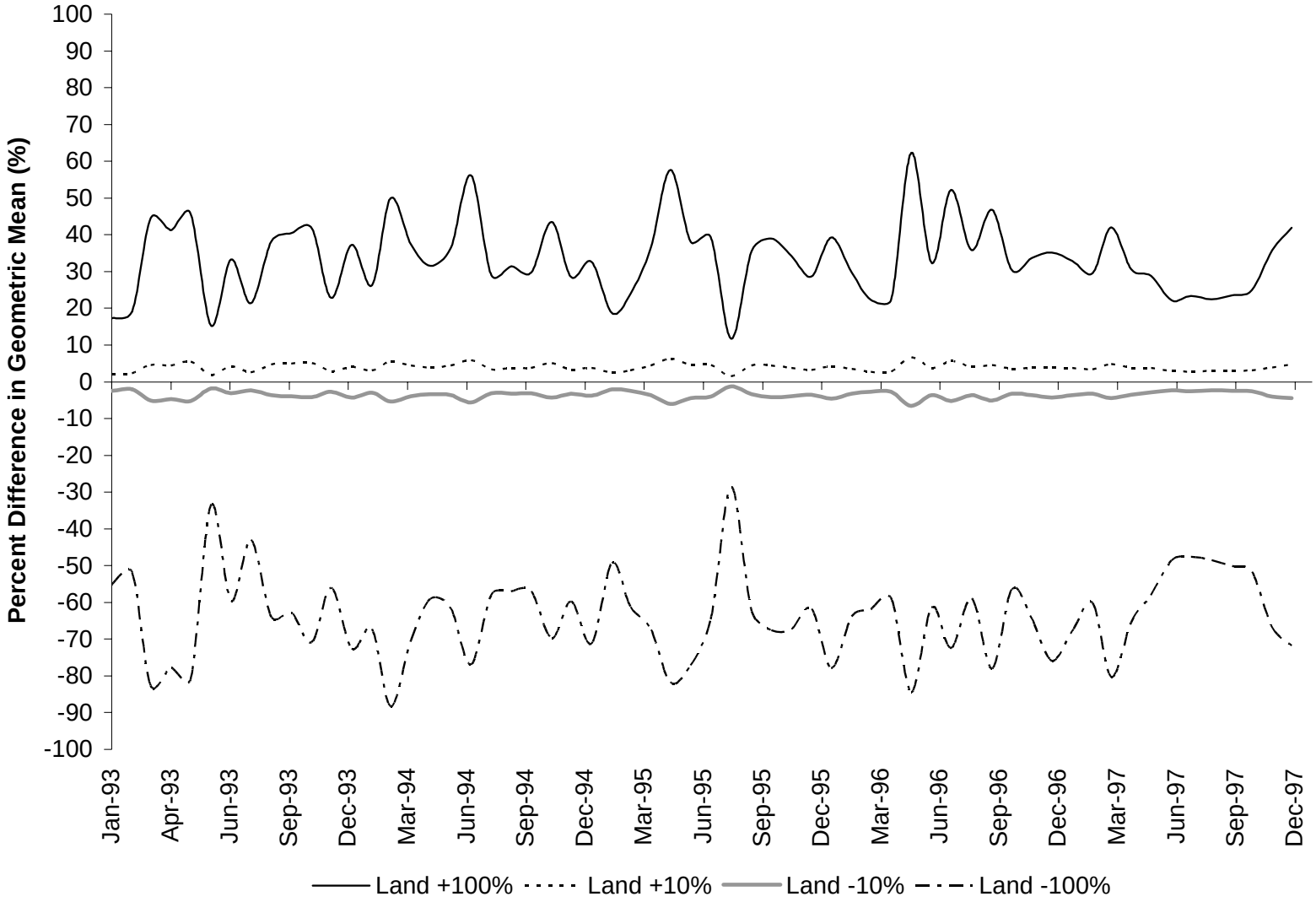

Figure 5.28. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-13) of South Anna River (VAN-F02R-01) watershed, as affected by land-based load changes.

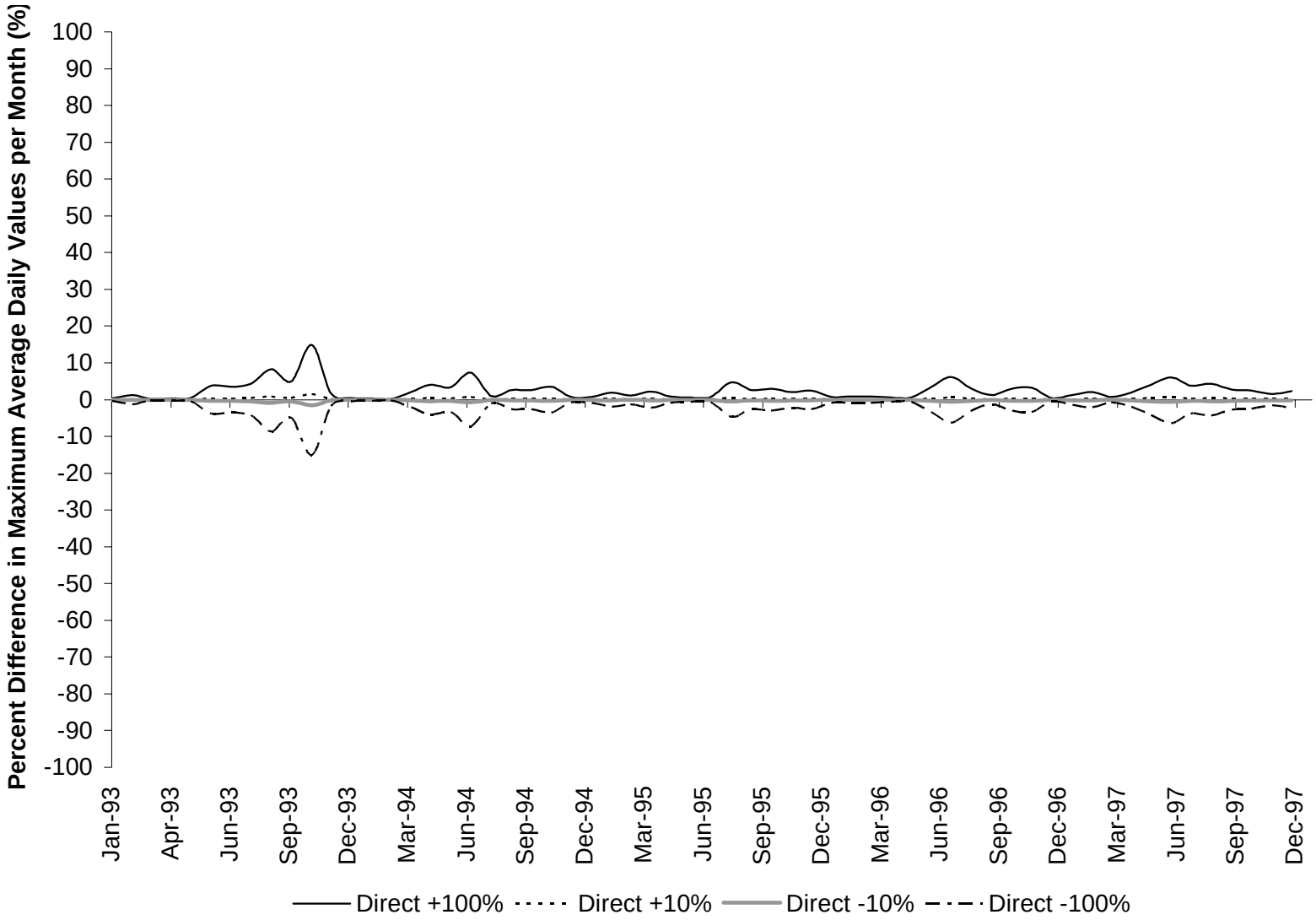

Figure 5.29. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-13) of South Anna River (VAN-F02R-01) watershed, as affected by direct load changes.

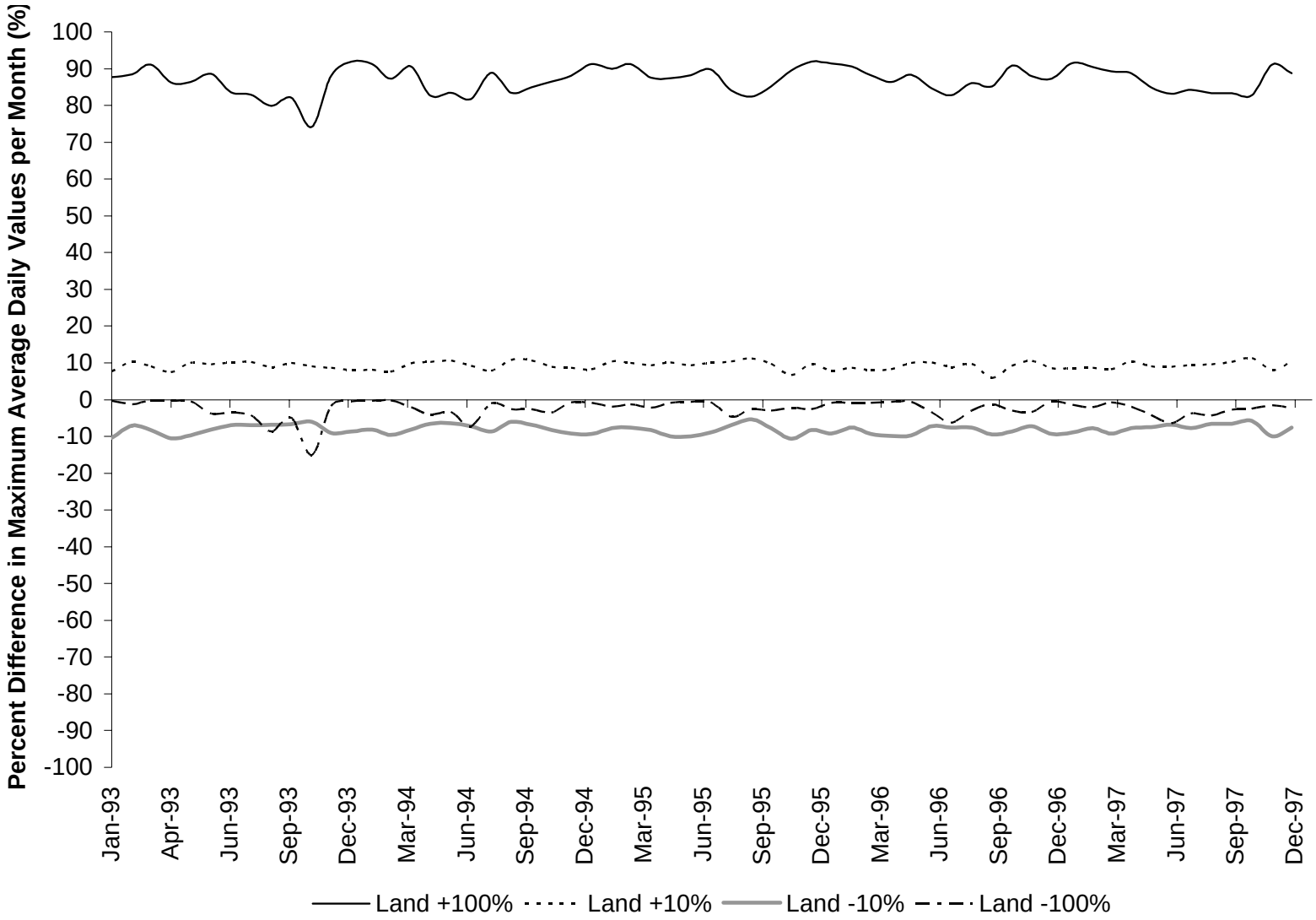

Figure 5.30. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-13) of South Anna River (VAN-F02R-01) watershed, as affected by land-based load changes.

5.3.3 South Anna River (VAP-F04R-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 5.31 and 5.32, respectively. Figures 5.33 and 5.34, 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 5.31 with Figure 5.32 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.33 to Figure 5.34 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.

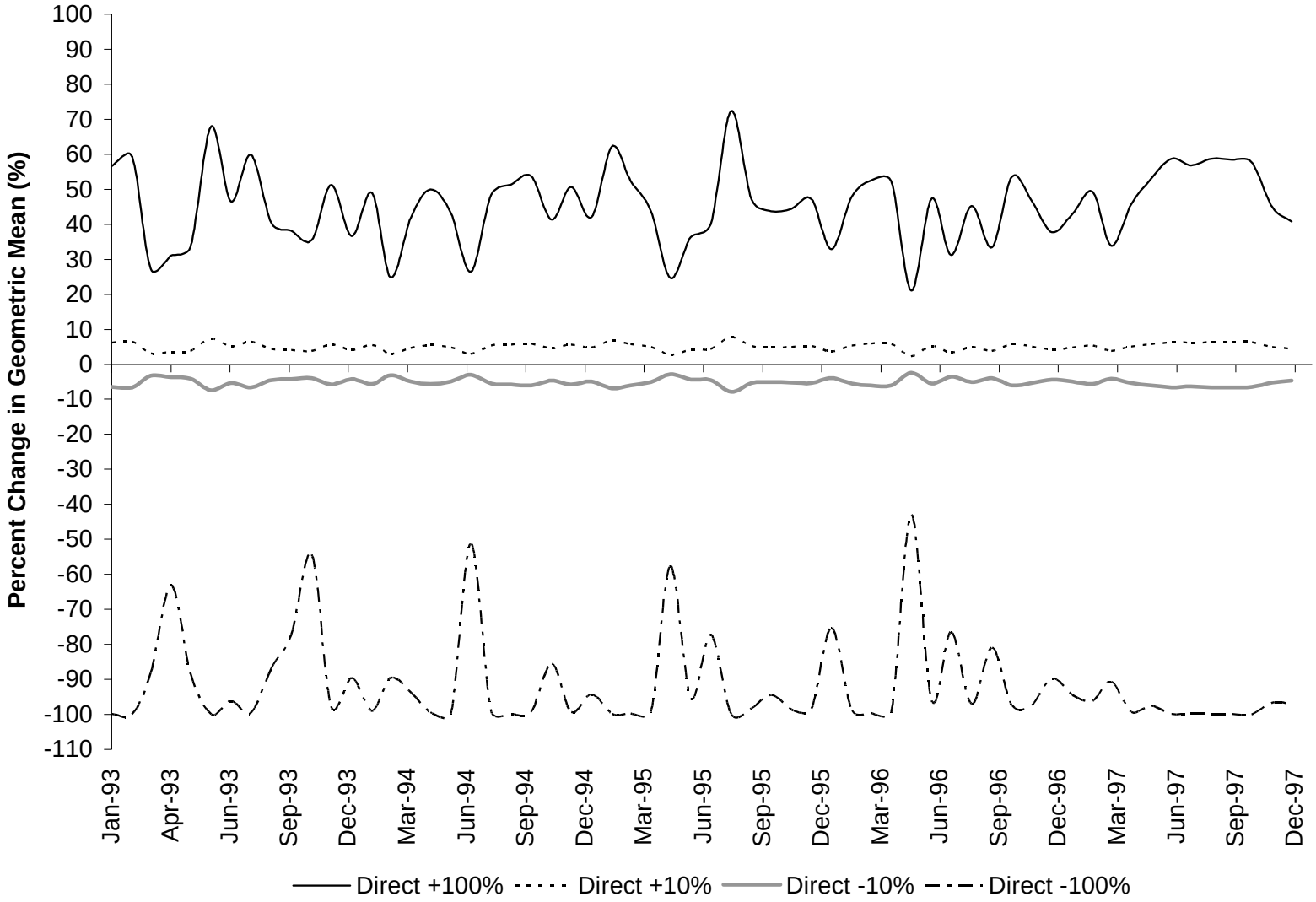

Figure 5.31. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-26) of South Anna River (VAP-F04R-01) watershed, as affected by direct load changes.

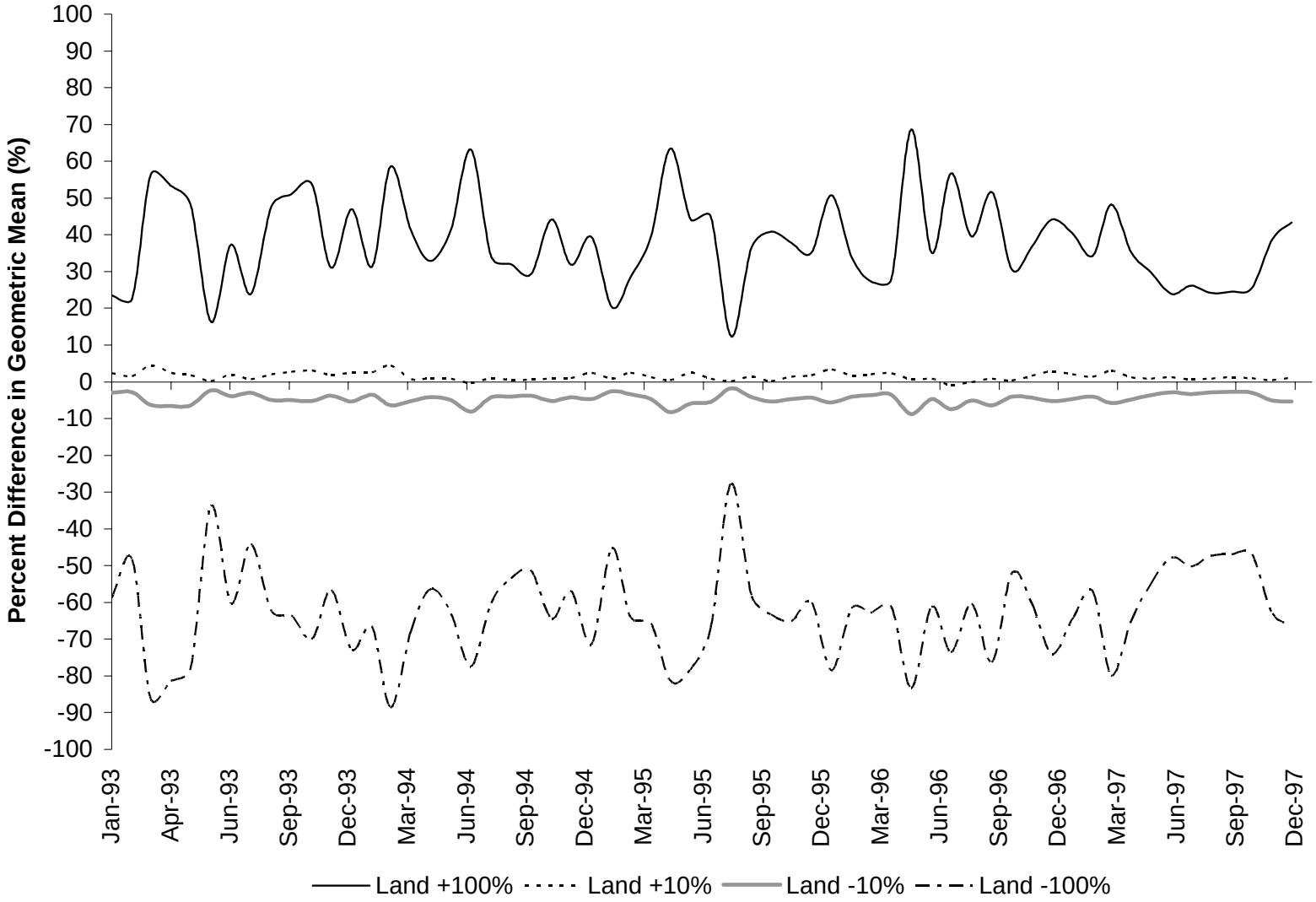

Figure 5.32. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-26) of South Anna River (VAP-F04R-01) watershed, as affected by land-based load changes.

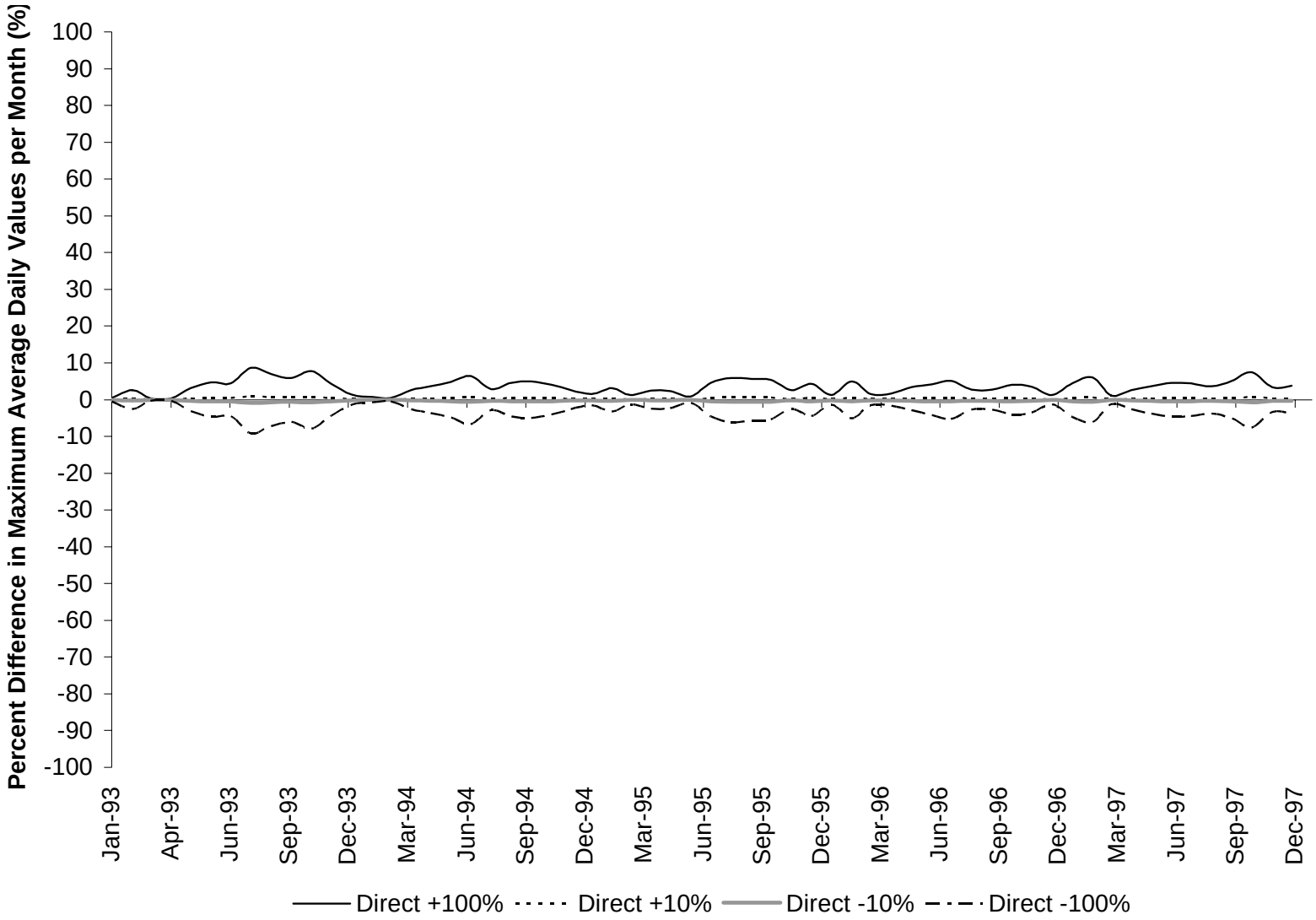

Figure 5.33. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-26) of South Anna River (VAP-F04R-01) watershed, as affected by direct load changes.

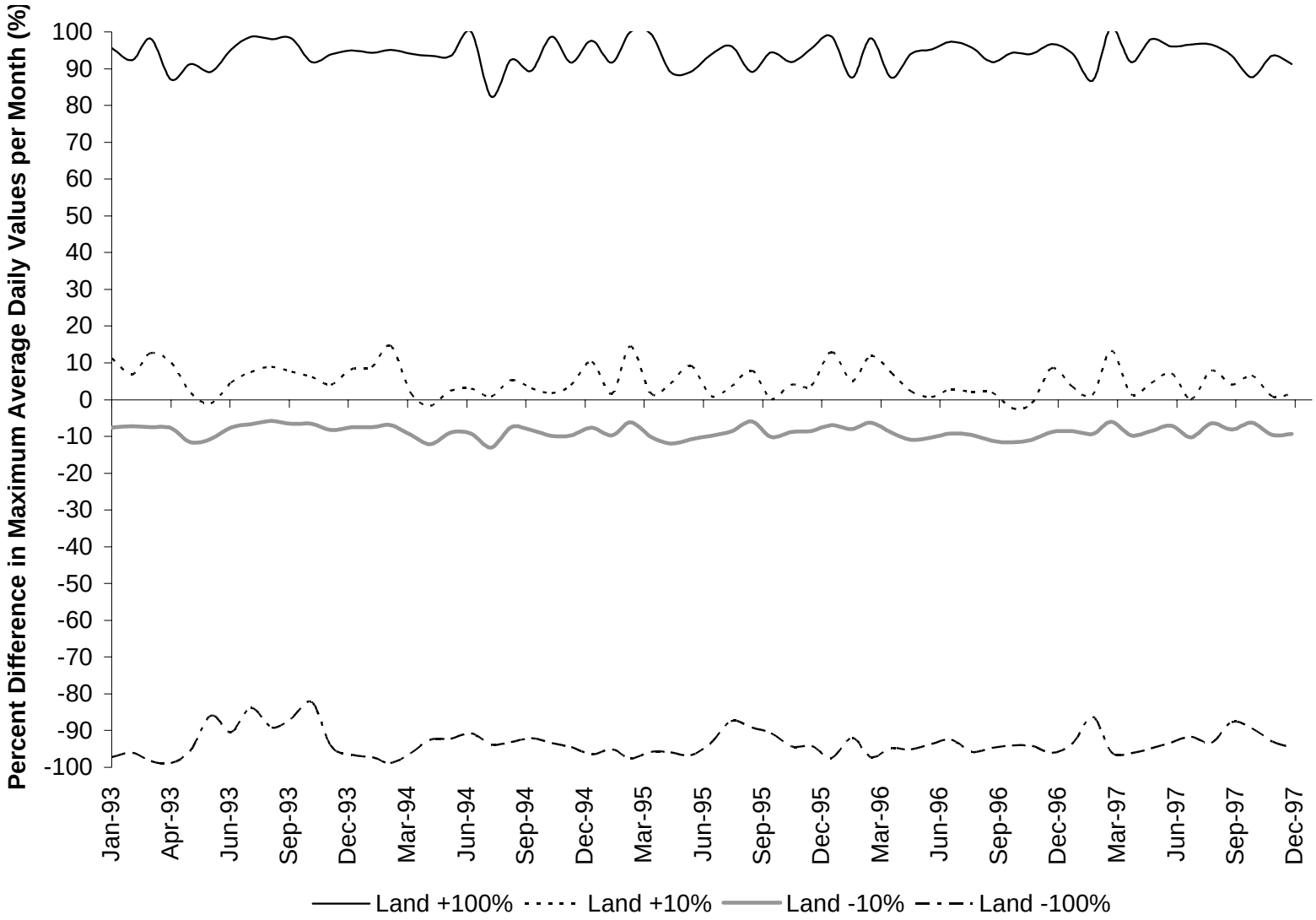

Figure 5.34. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-26) of South Anna River (VAP-F04R-01) watershed, as affected by land-based load changes.

5.3.4 South Anna River (VAP-F04R-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 5.35 and 5.36, respectively. Figures 5.37 and 5.38, 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 5.35 with Figure 5.36 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.37 to Figure 5.38 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.

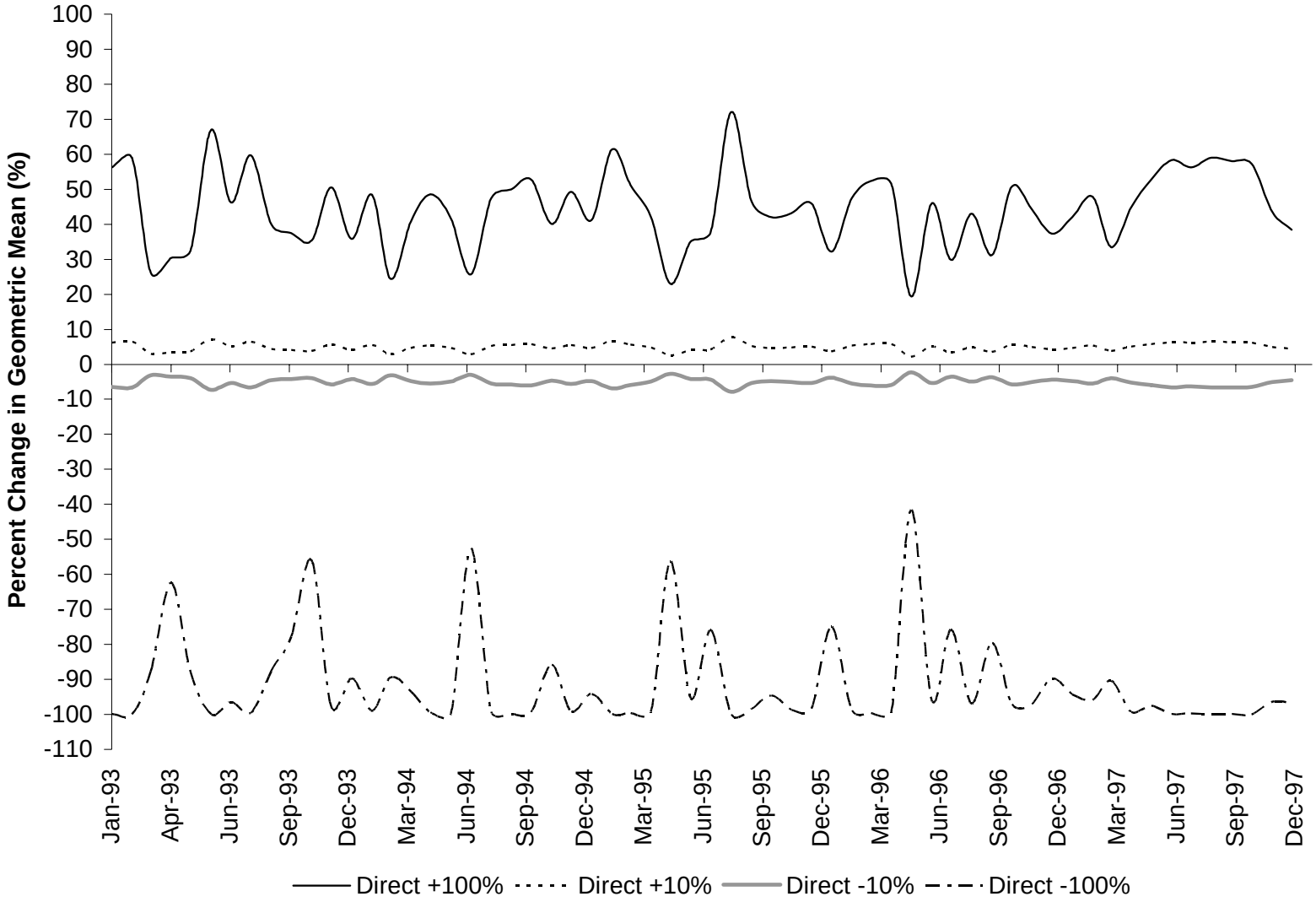

Figure 5.35. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-28) of South Anna River (VAP-F04R-02) watershed, as affected by direct load changes.

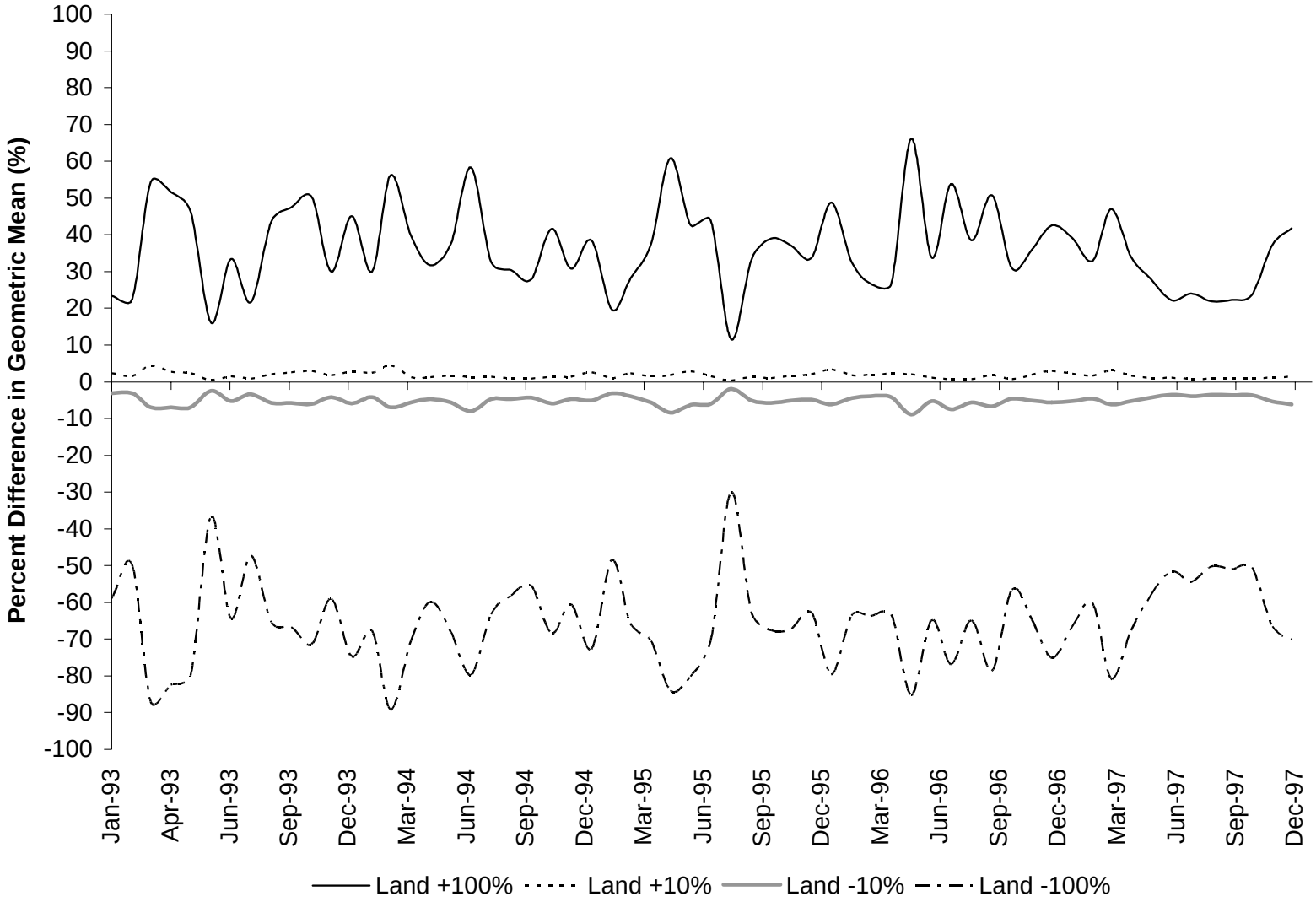

Figure 5.36. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-28) of South Anna River (VAP-F04R-02) watershed, as affected by land-based load changes.

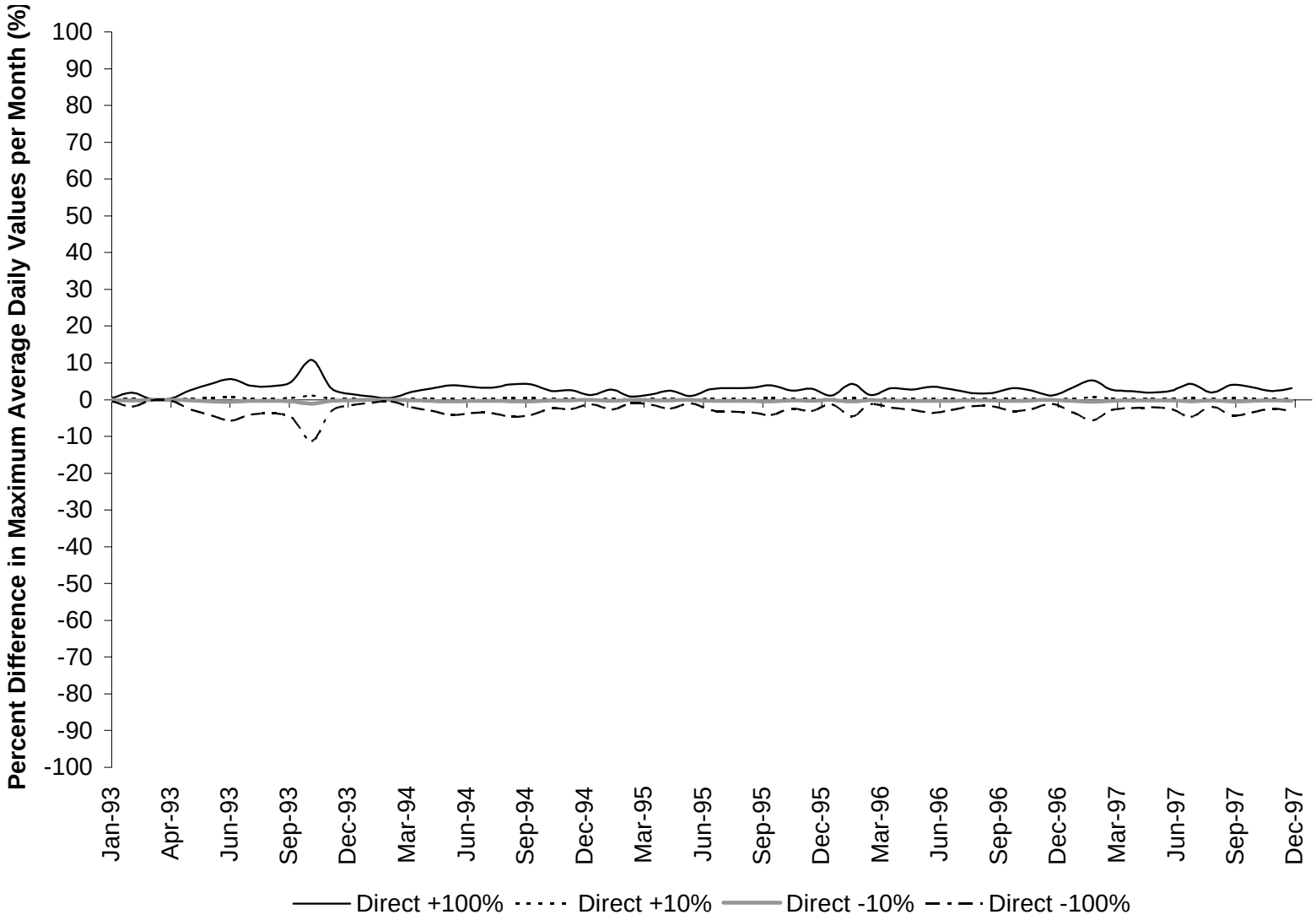

Figure 5.37. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-28) of South Anna River (VAP-F04R-02) watershed, as affected by direct load changes.

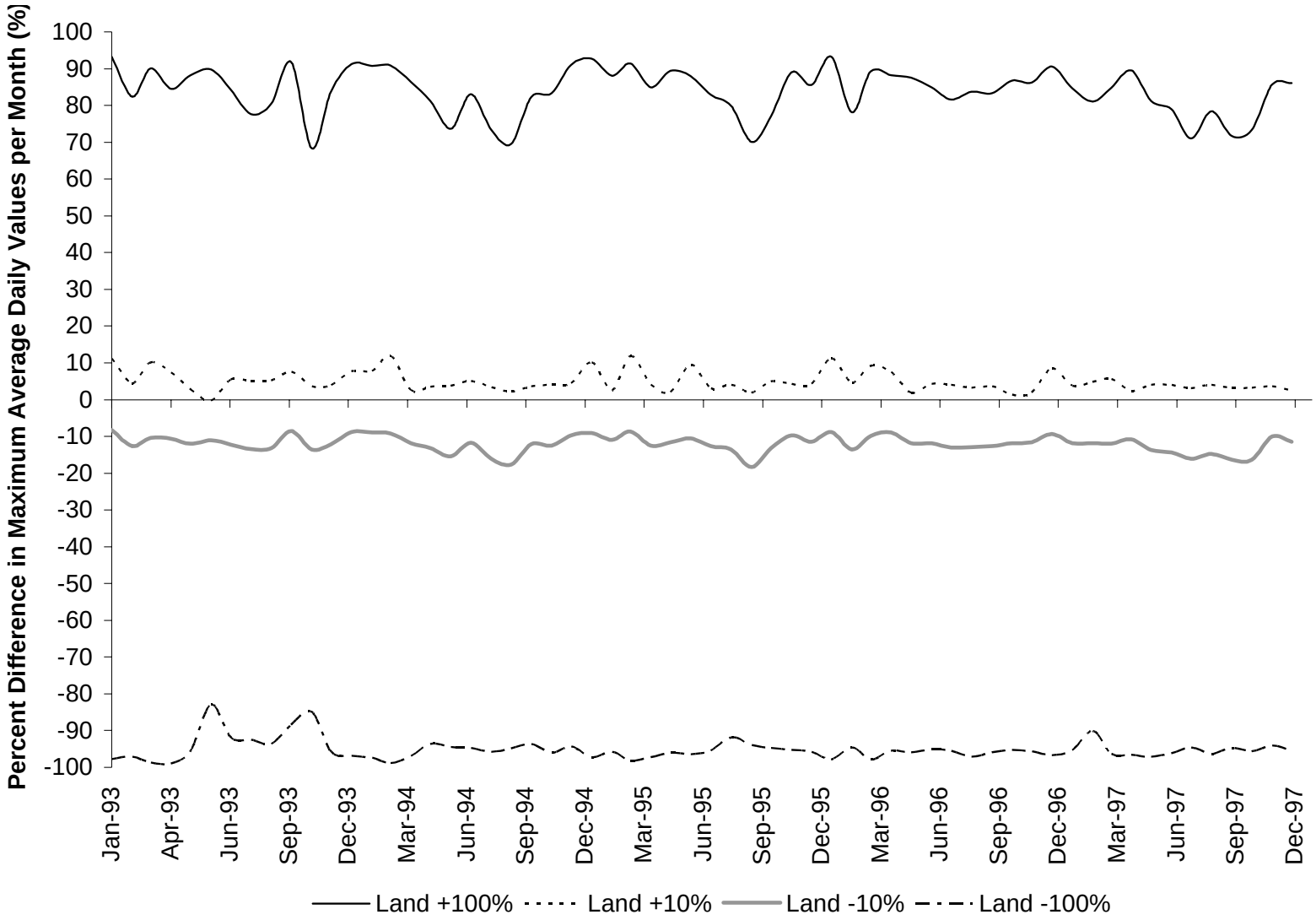

Figure 5.38. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-28) of South Anna River (VAP-F04R-02) watershed, as affected by land-based load changes.

5.3.5 Taylors Creek (VAN-F03R-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 5.39 and 5.40, respectively. Figures 5.41 and 5.42, 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 5.39 with Figure 5.40 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.41 to Figure 5.42 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.

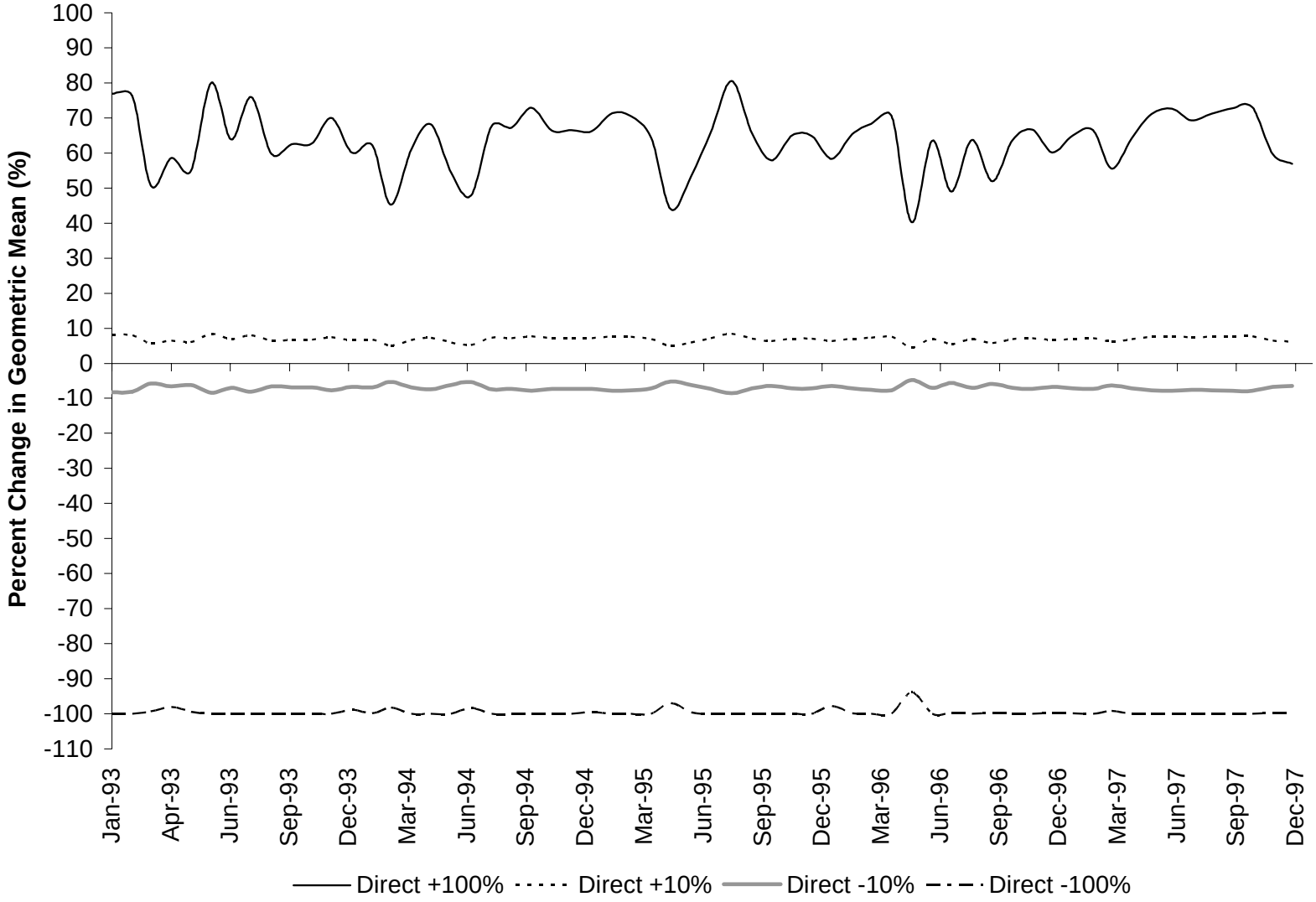

Figure 5.39. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-19) of Taylors Creek (VAN-F03R-01) watershed, as affected by direct load changes.

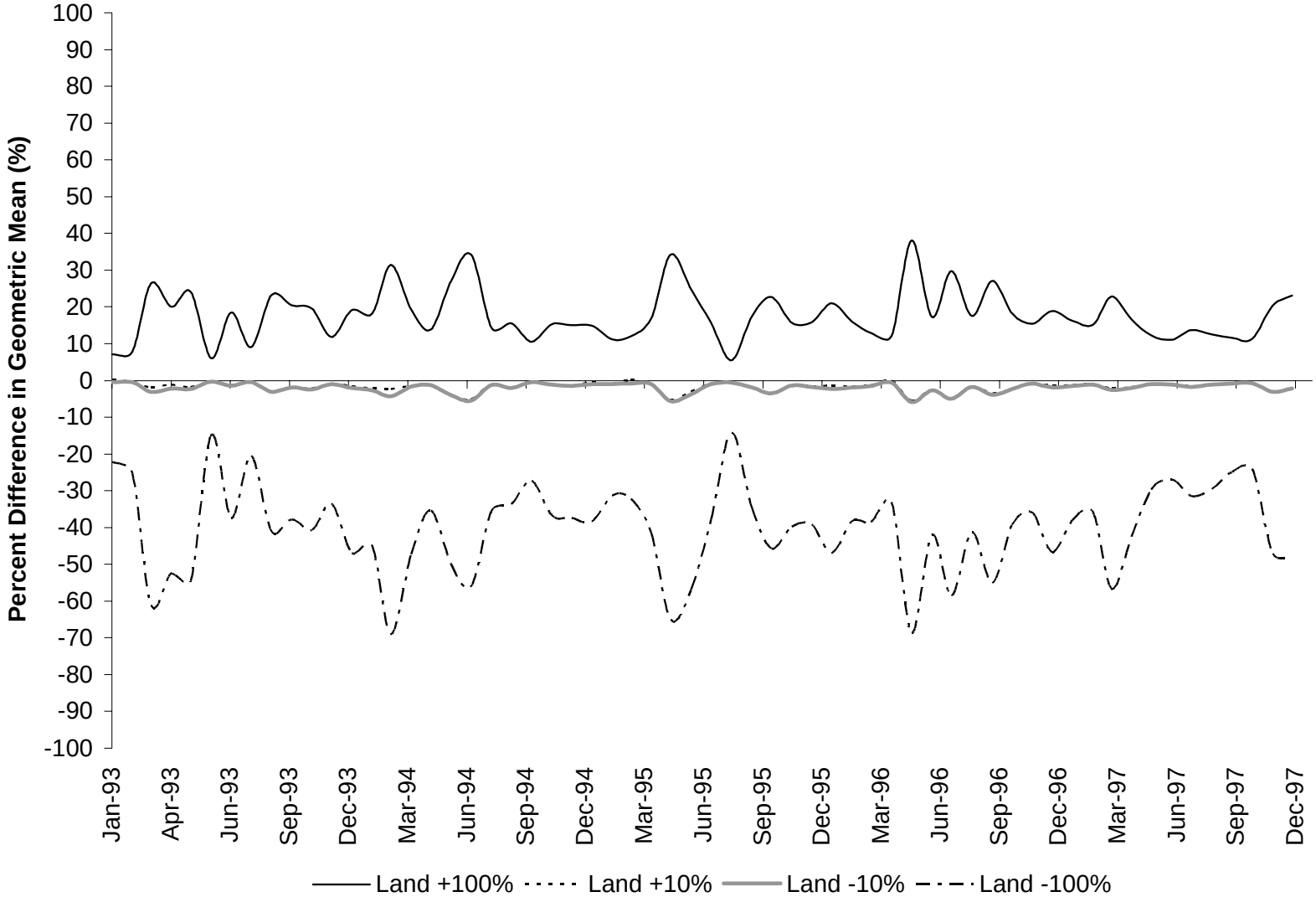

Figure 5.40. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-19) of Taylors Creek (VAN-F03R-01) watershed, as affected by land-based load changes.

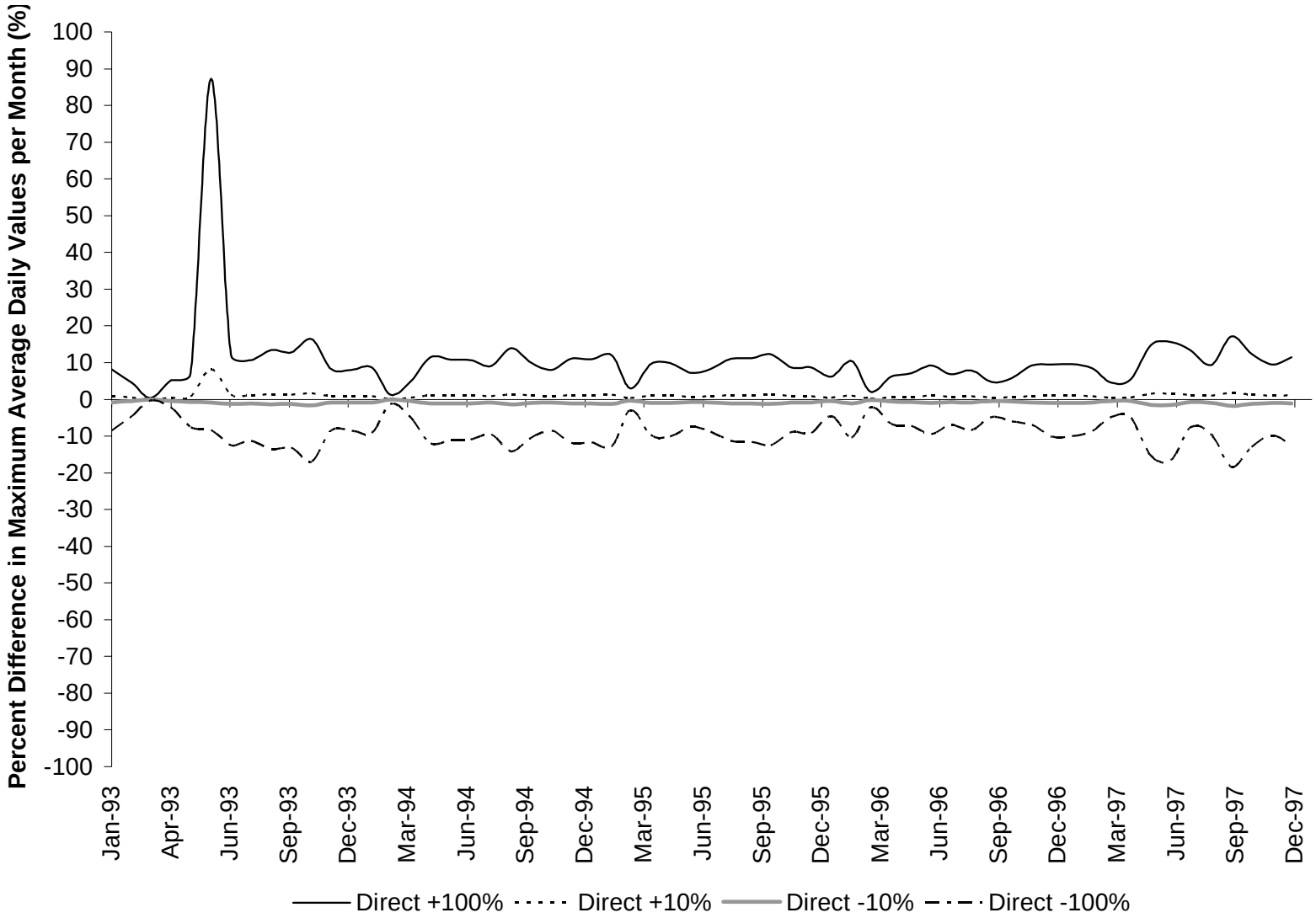

Figure 5.41. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-19) of Taylors Creek (VAN-F03R-01) watershed, as affected by direct load changes.

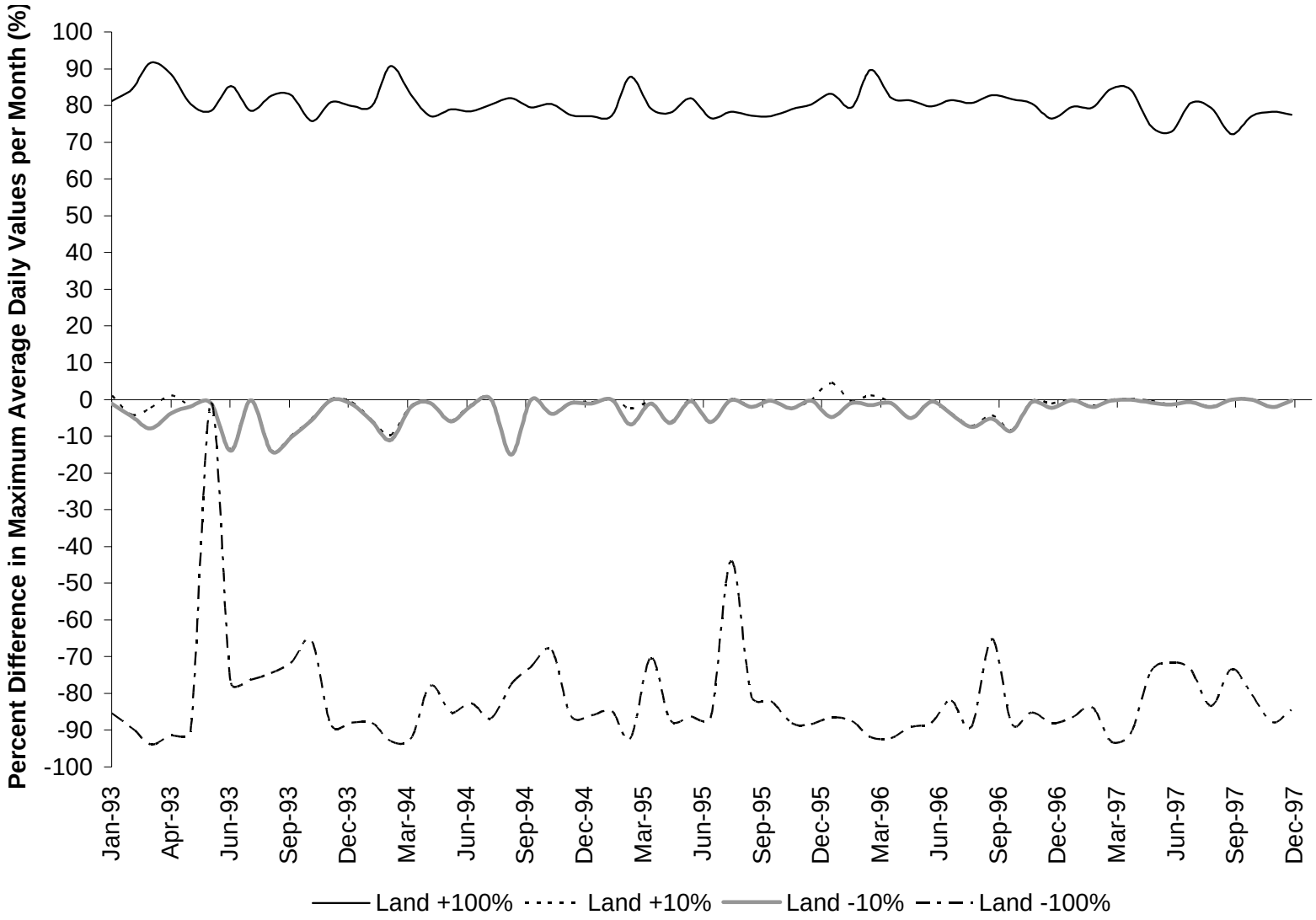

Figure 5.42. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-19) of Taylors Creek (VAN-F03R-01) watershed, as affected by land-based load changes.

5.3.6 Newfound River (VAP-F05R-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 5.43 and 5.44, respectively. Figures 5.45 and 5.46, 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 5.43 with Figure 5.44 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.45 to Figure 5.46 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.

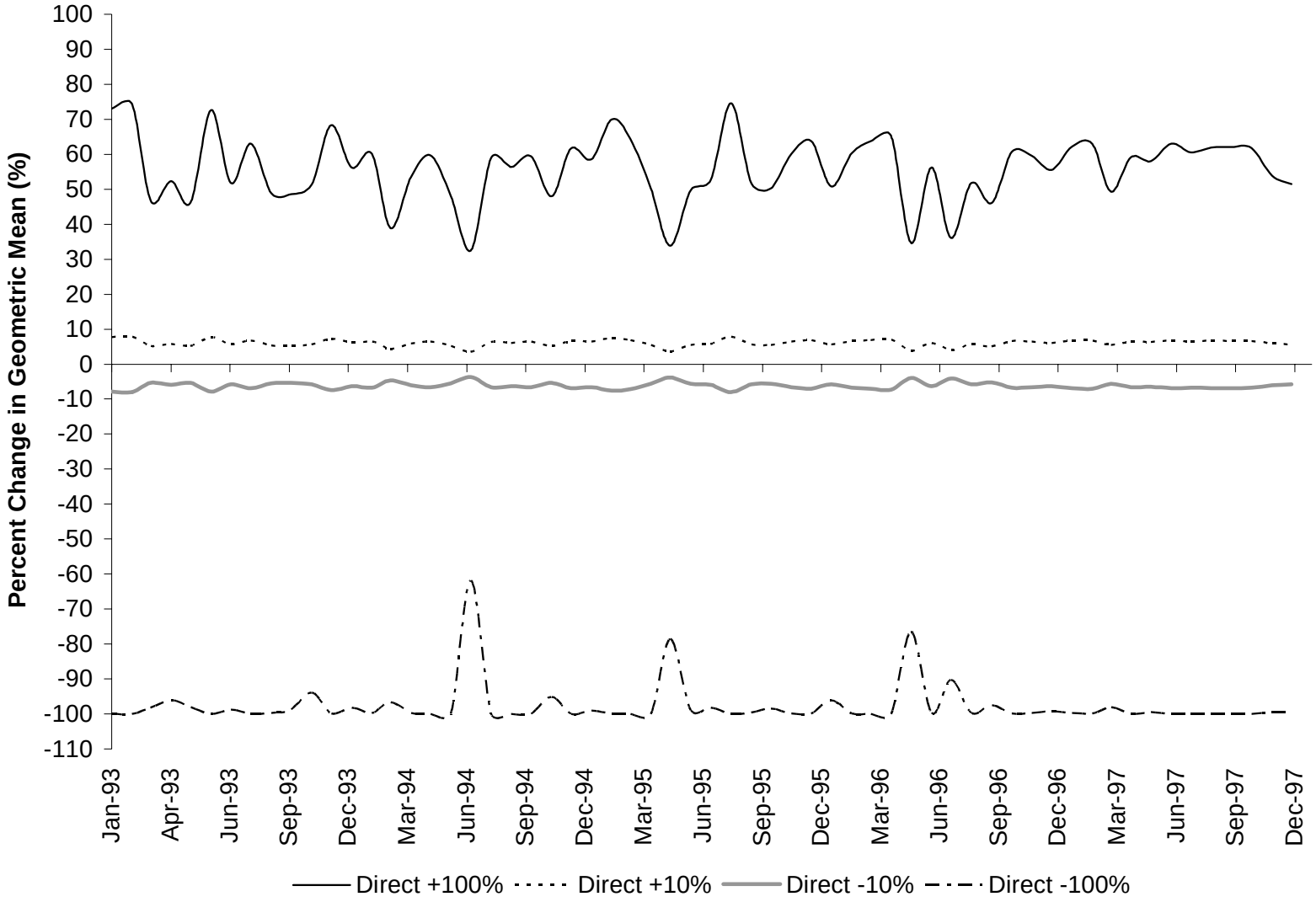

Figure 5.43. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-25) of Newfound River (VAP-F05R-01) watershed, as affected by direct load changes.

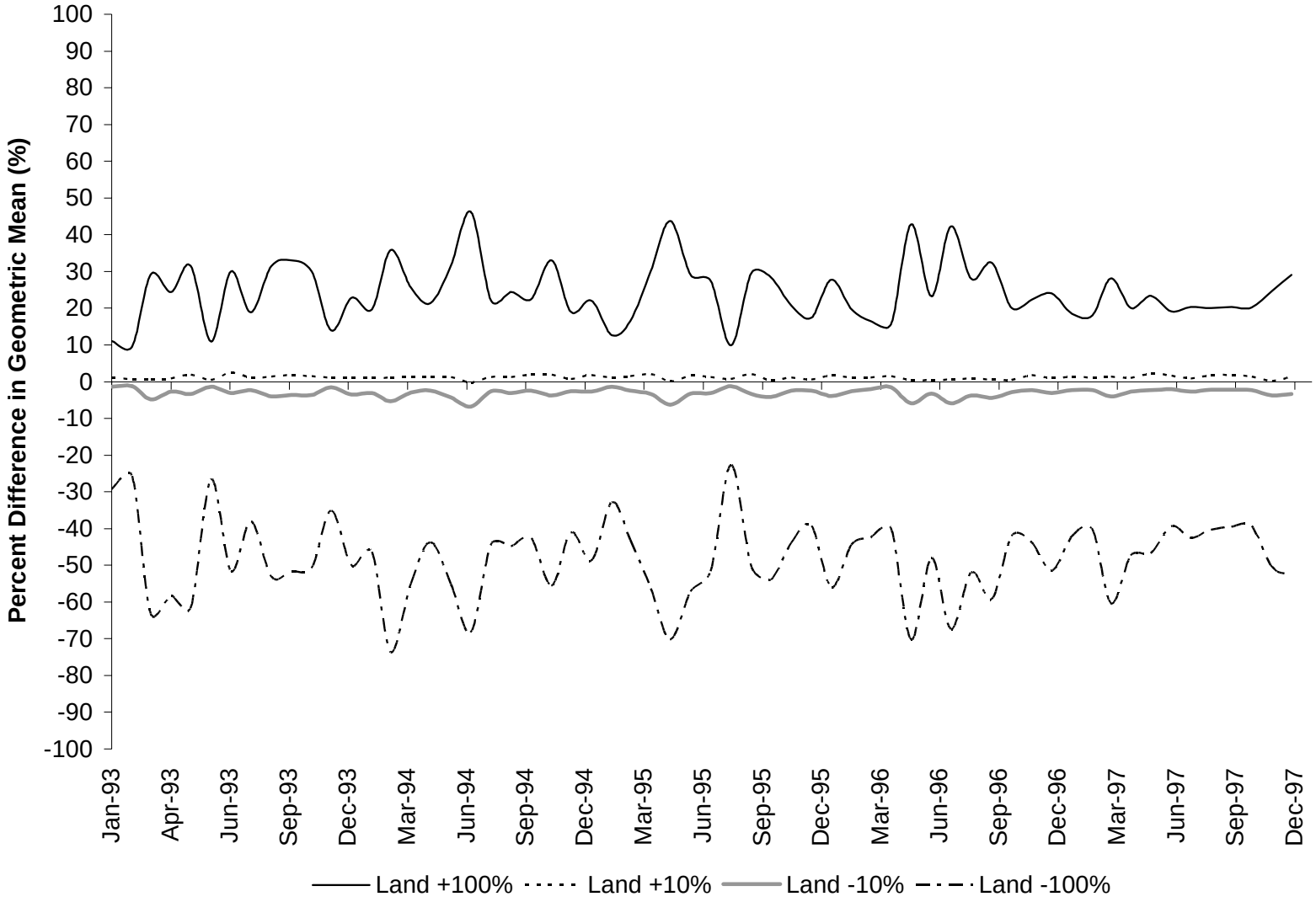

Figure 5.44. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed SAR-25) of Newfound River (VAP-F05R-01) watershed, as affected by land-based load changes.

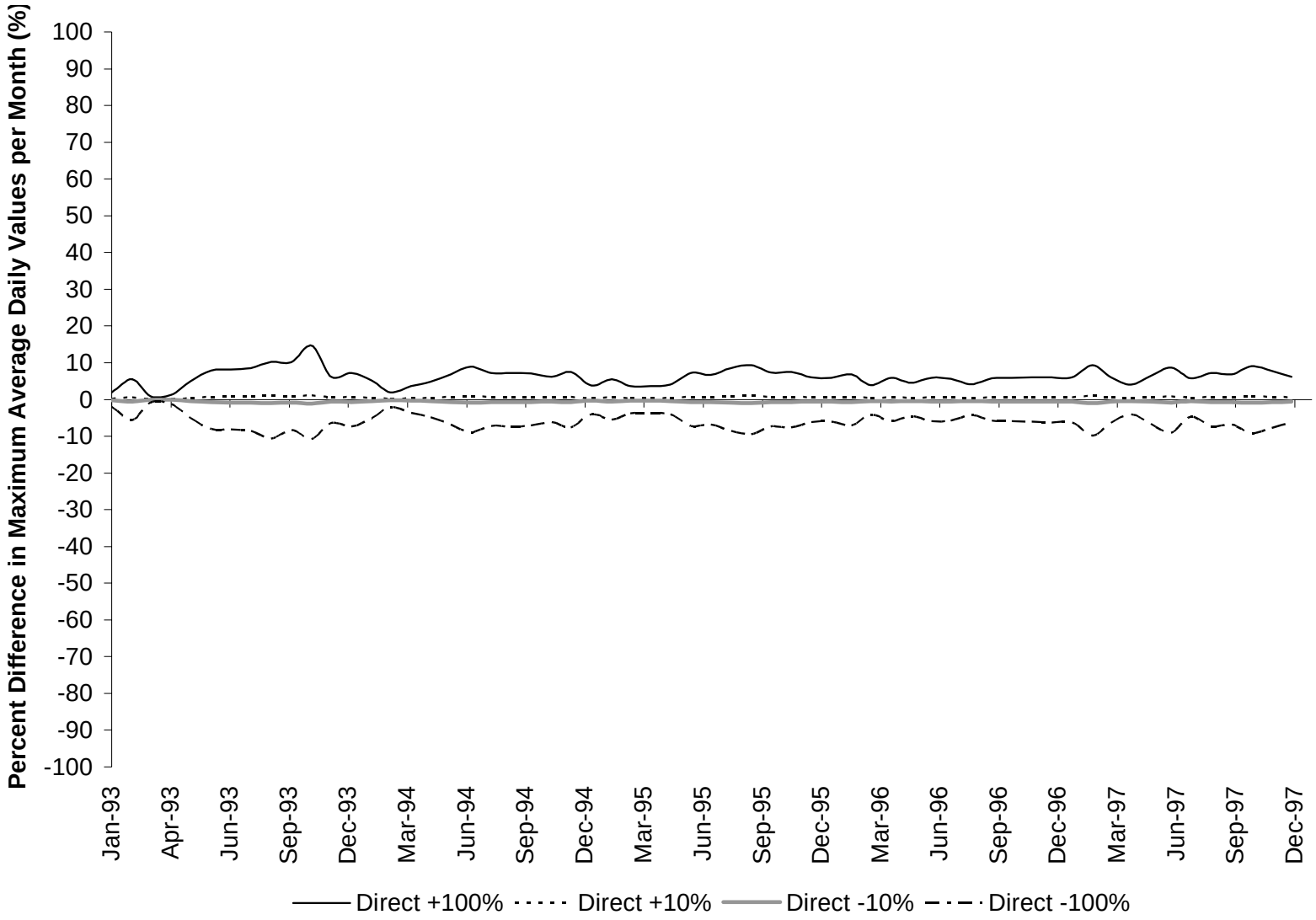

Figure 5.45. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-25) of Newfound River (VAP-F05R-01) watershed, as affected by direct load changes.

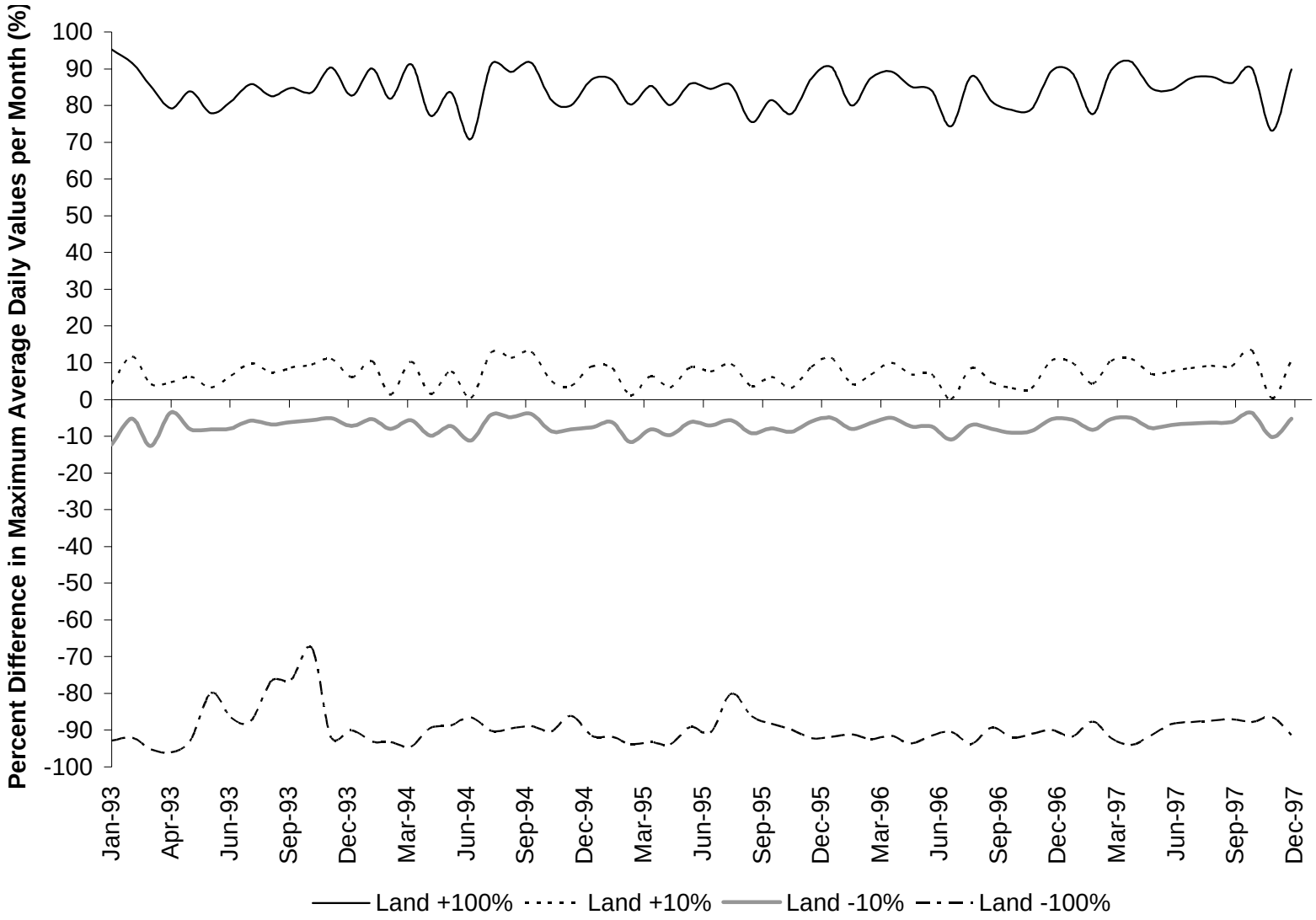

Figure 5.46. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed SAR-25) of Newfound River (VAP-F05R-01) watershed, as affected by land-based load changes.

5.3.7 Northeast Creek (VAP-F09R-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 5.47 and 5.48, respectively. Figures 5.49 and 5.50, 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 5.47 with Figure 5.48 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.49 to Figure 5.50 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.

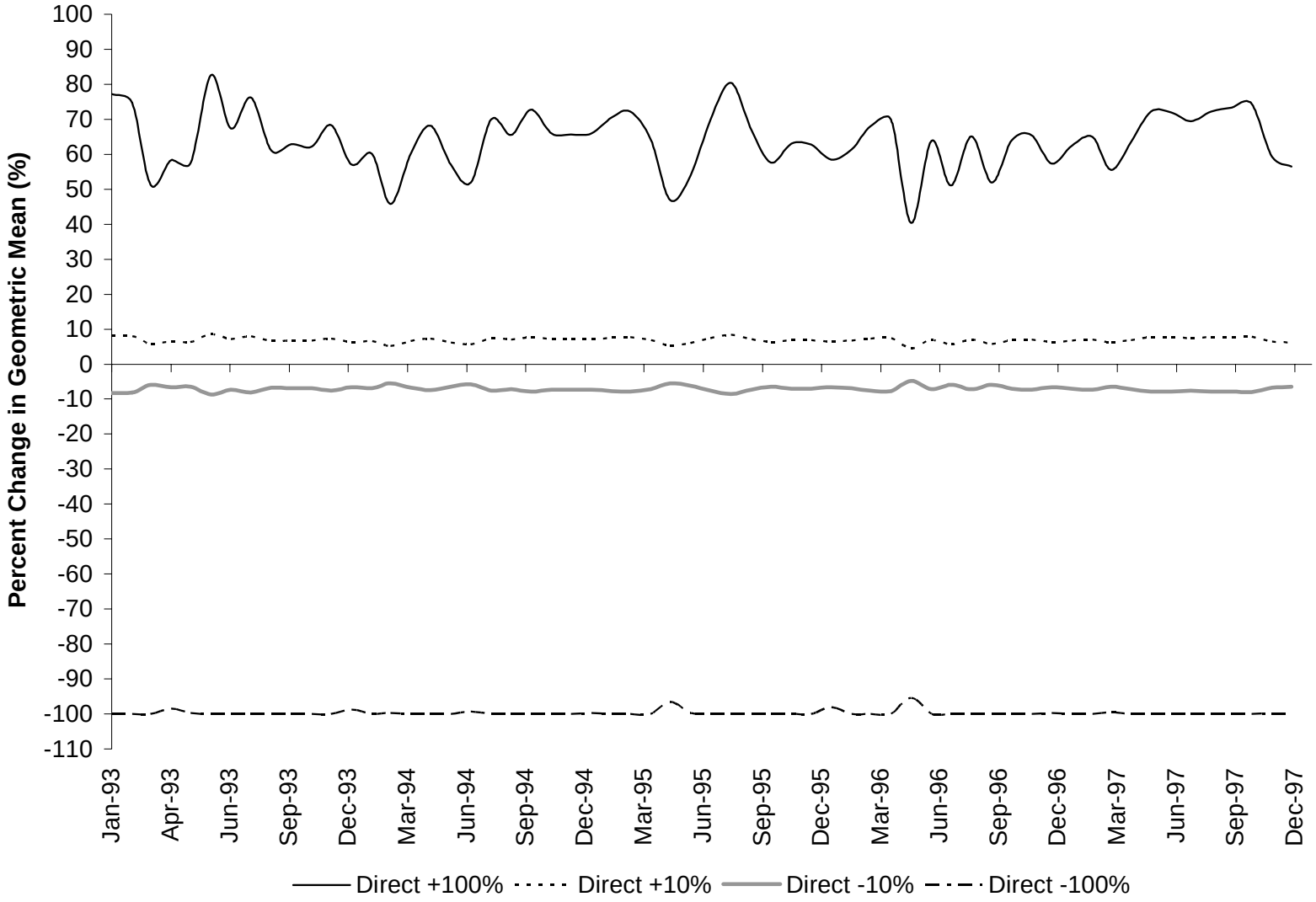

Figure 5.47. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed NEC-5) of Northeast Creek (VAP-F09R-01) watershed, as affected by direct load changes.

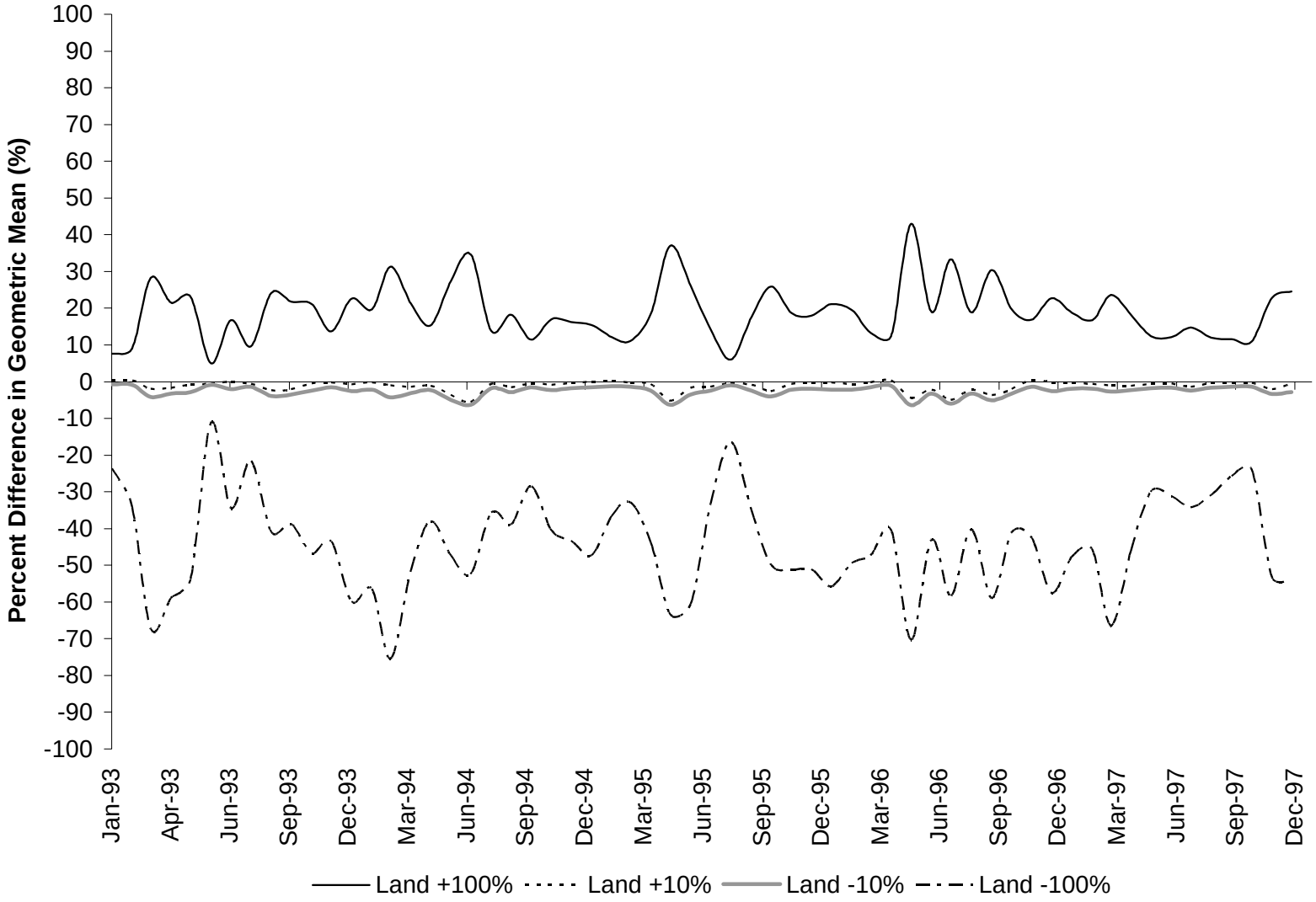

Figure 5.48. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed NEC-5) of Northeast Creek (VAP-F09R-01) watershed, as affected by land-based load changes.

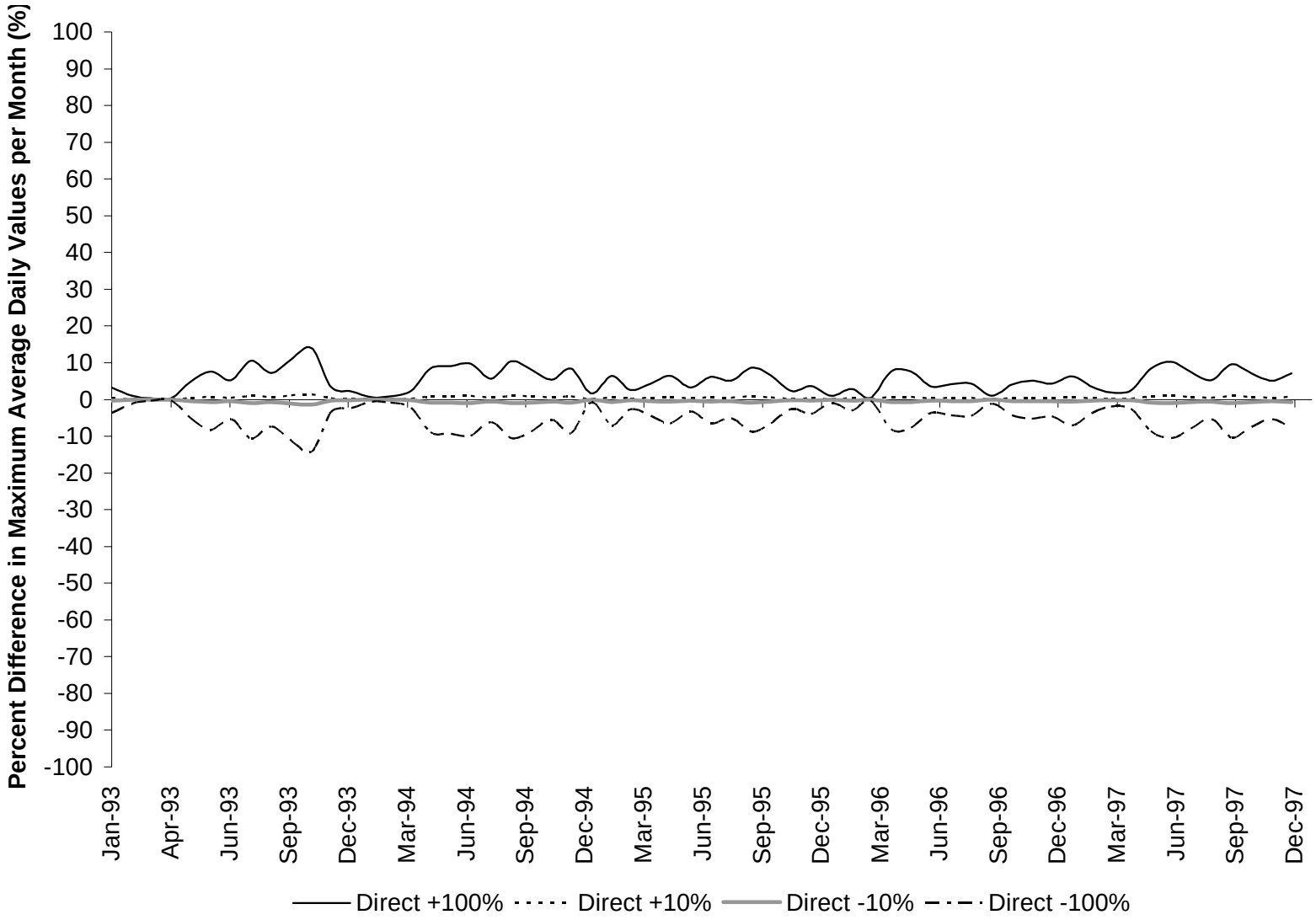

Figure 5.49. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed NEC-5) of Northeast Creek (VAP-F09R-01) watershed, as affected by direct load changes.

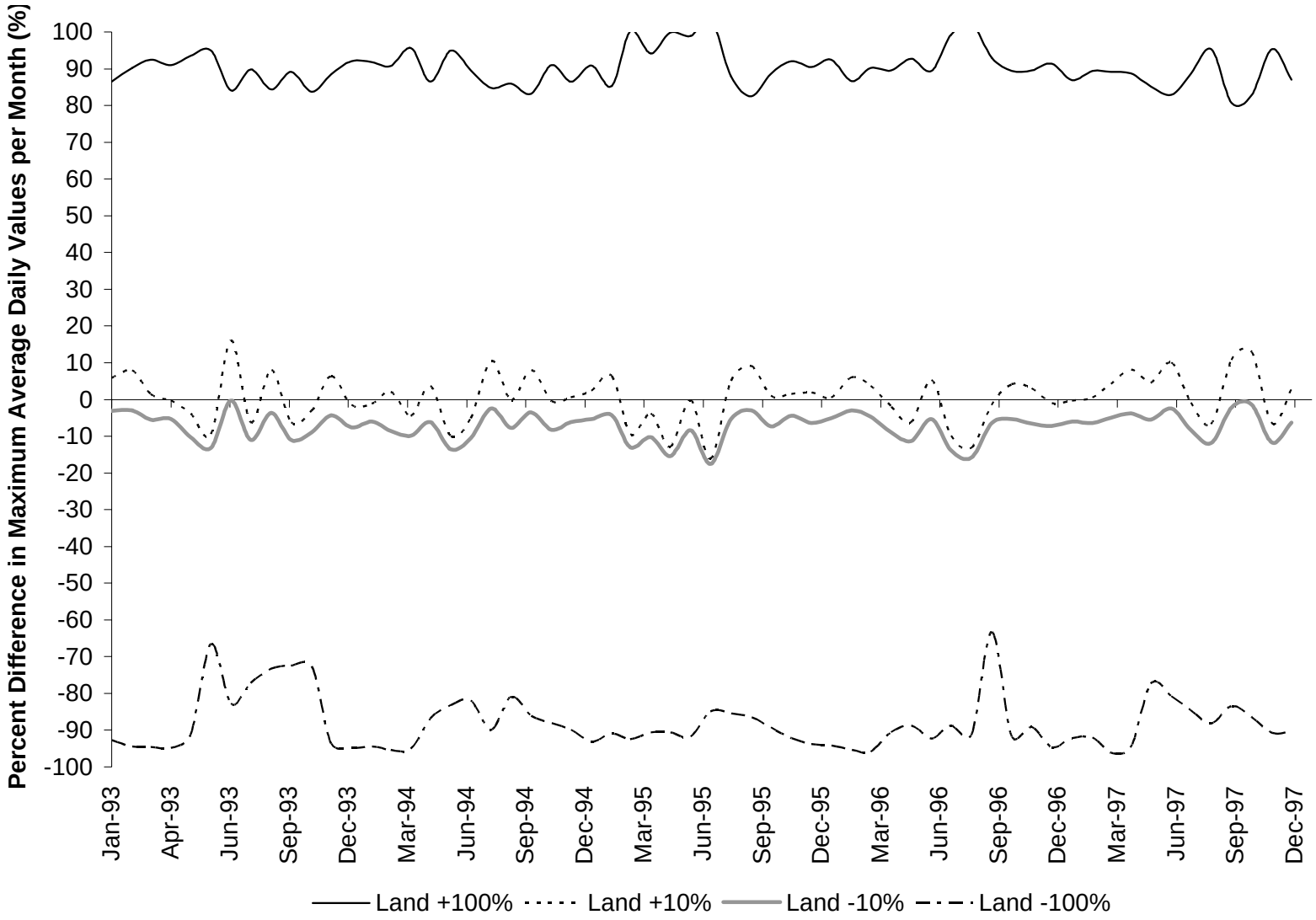

Figure 5.50. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed NEC-5) of Northeast Creek (VAP-F09R-01) watershed, as affected by land-based load changes.

5.3.8 Totopotomoy Creek (VAP-F13R-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 5.51 and 5.52, respectively. Figures 5.53 and 5.54, 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 5.51 with Figure 5.52 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.53 to Figure 5.54 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.

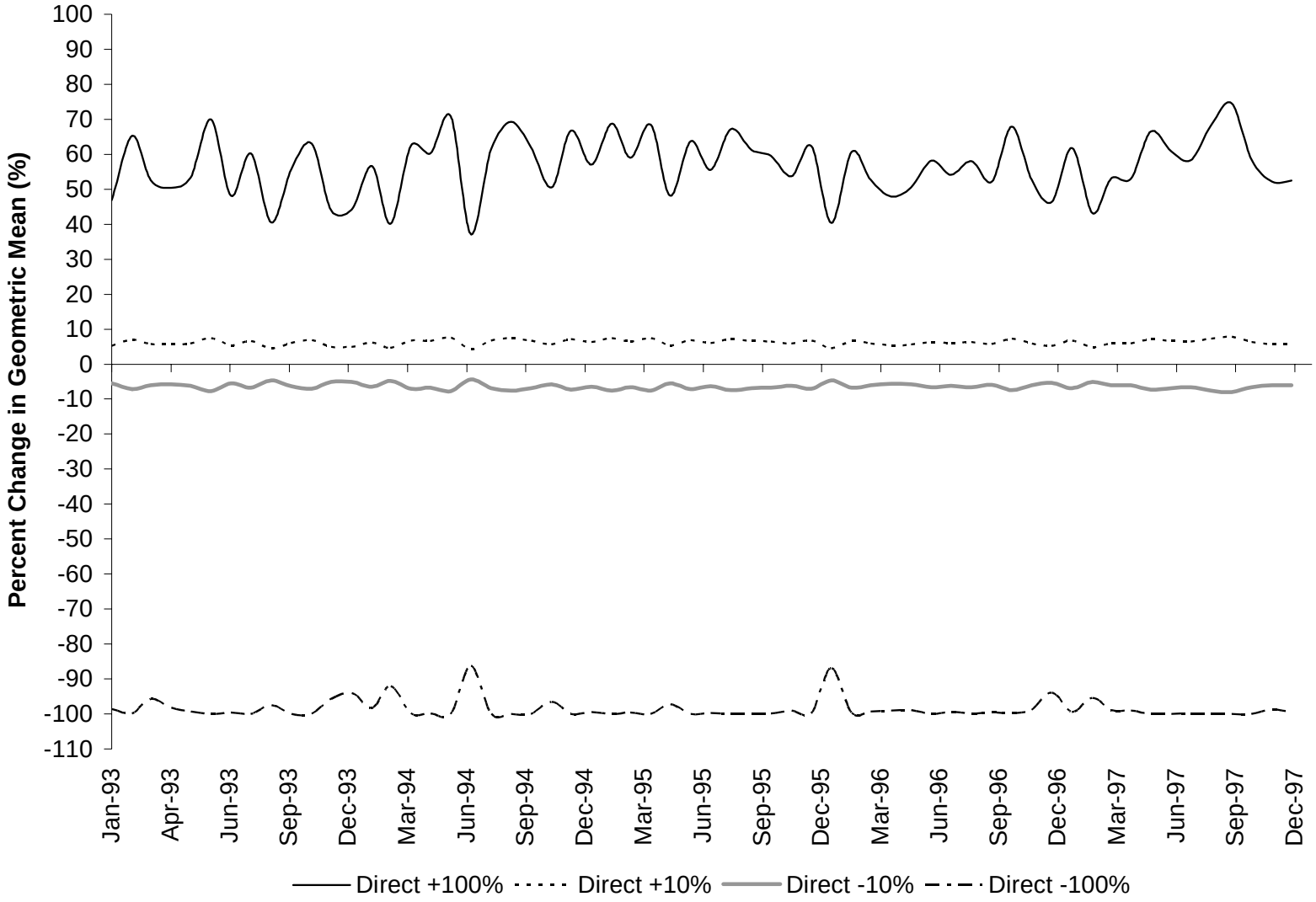

Figure 5.51. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed TOC-5) of Totopotomoy Creek (VAP-F13R-02) watershed, as affected by direct load changes.

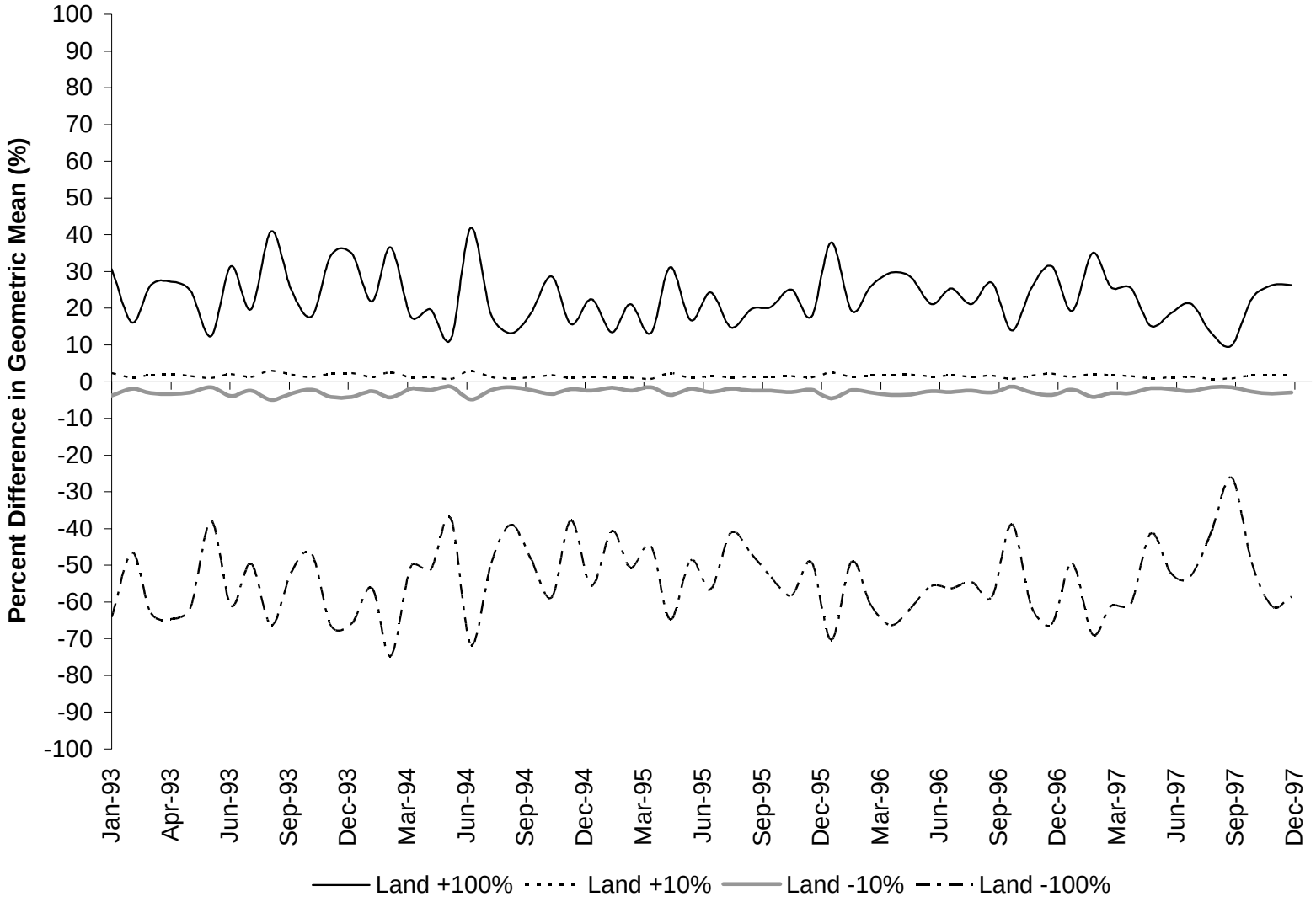

Figure 5.52. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed TOC-5) of Totopotomoy Creek (VAP-F13R-02) watershed, as affected by land-based load changes.

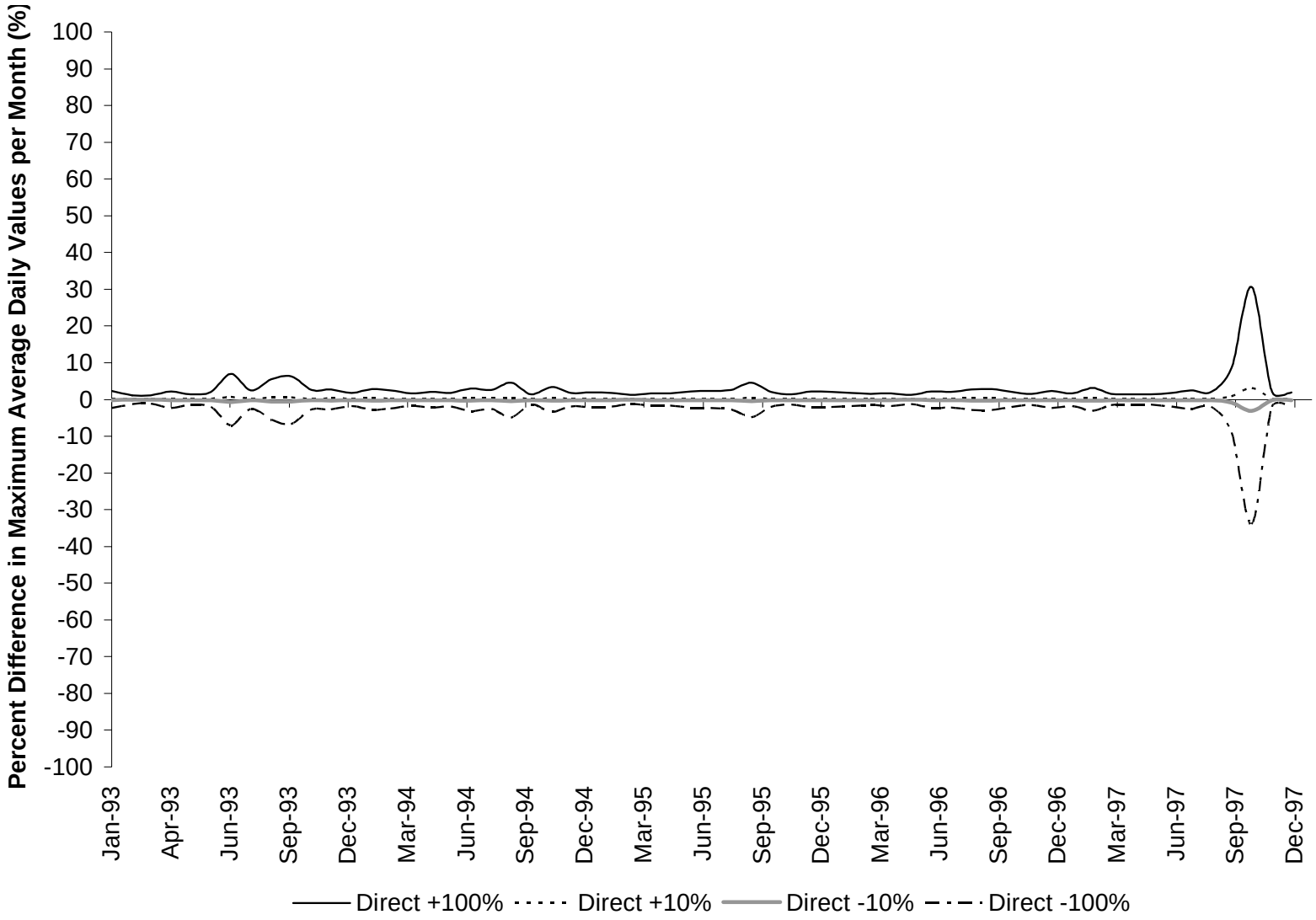

Figure 5.53. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed TOC-5) of Totopotomoy Creek (VAP-F13R-02) watershed, as affected by direct load changes.

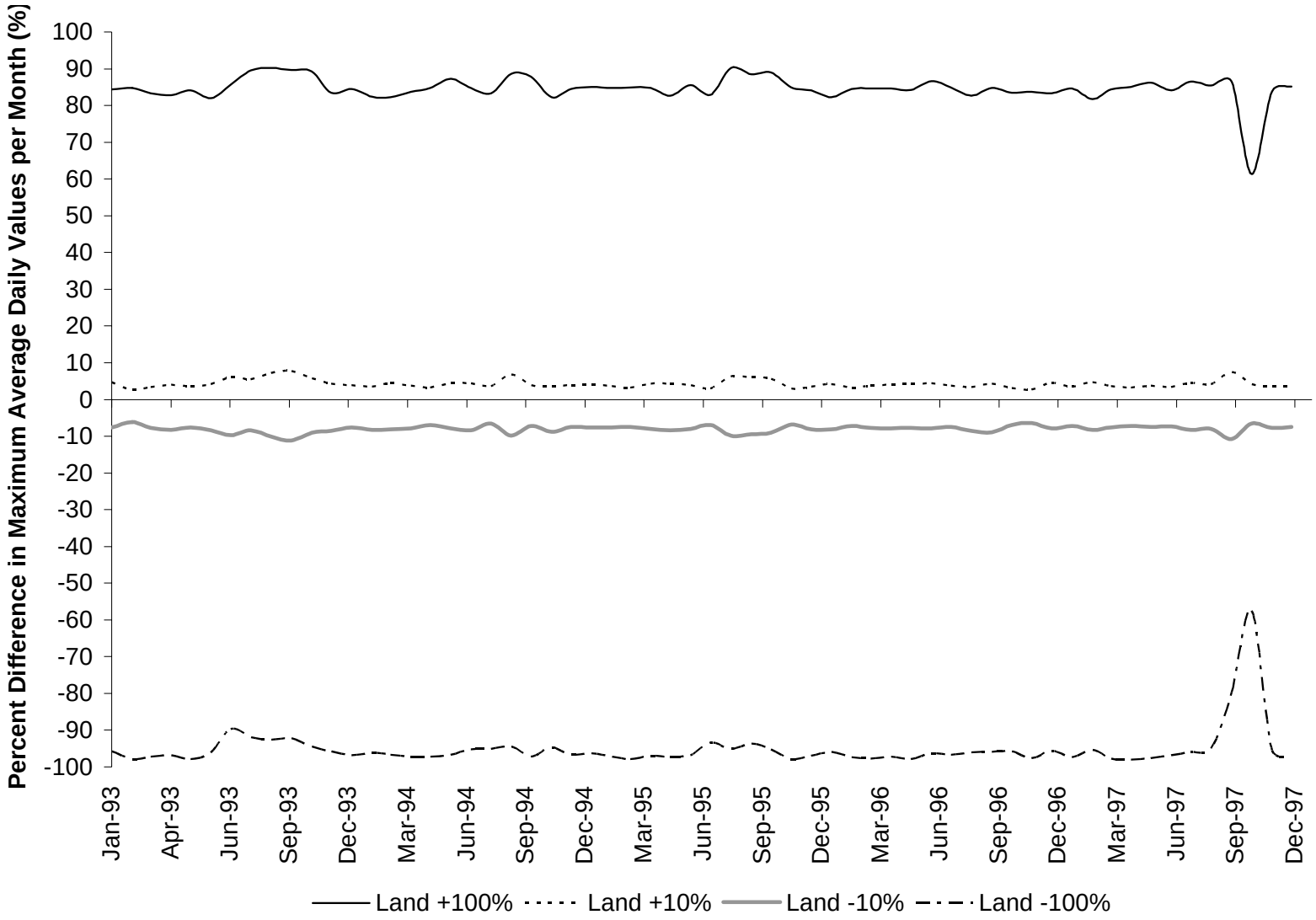

Figure 5.54. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed TOC-5) of Totopotomoy Creek (VAP-F13R-02) watershed, as affected by land-based load changes.

5.3.9 Moncuin/Webb Creek (VAP-F13R-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 5.55 and 5.56, respectively. Figures 5.57 and 5.58, 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 5.55 with Figure 5.56 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.57 to Figure 5.58 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.

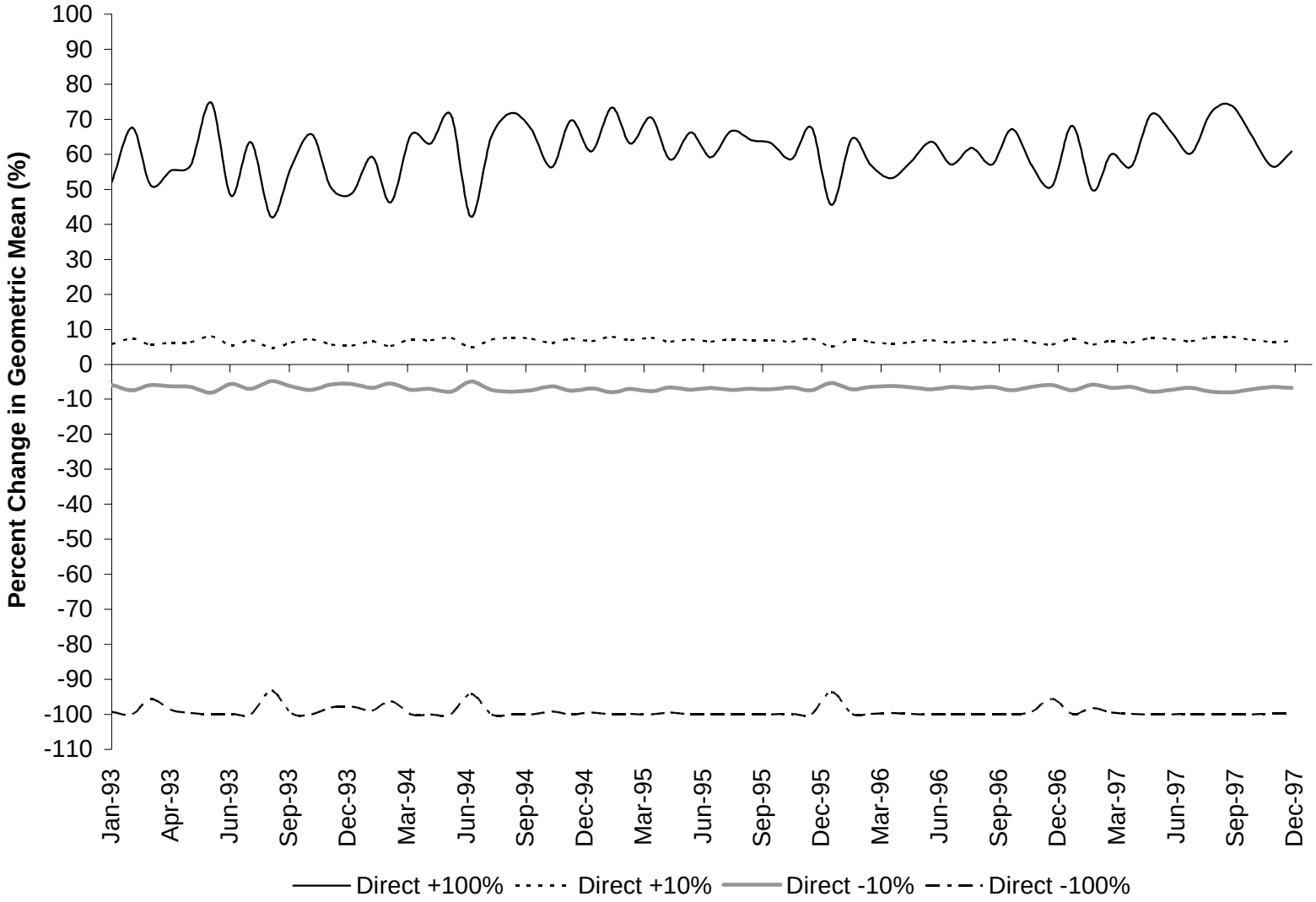

Figure 5.55. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-7) of Moncuin/Webb Creek (VAP-F13R-04) watershed, as affected by direct load changes.

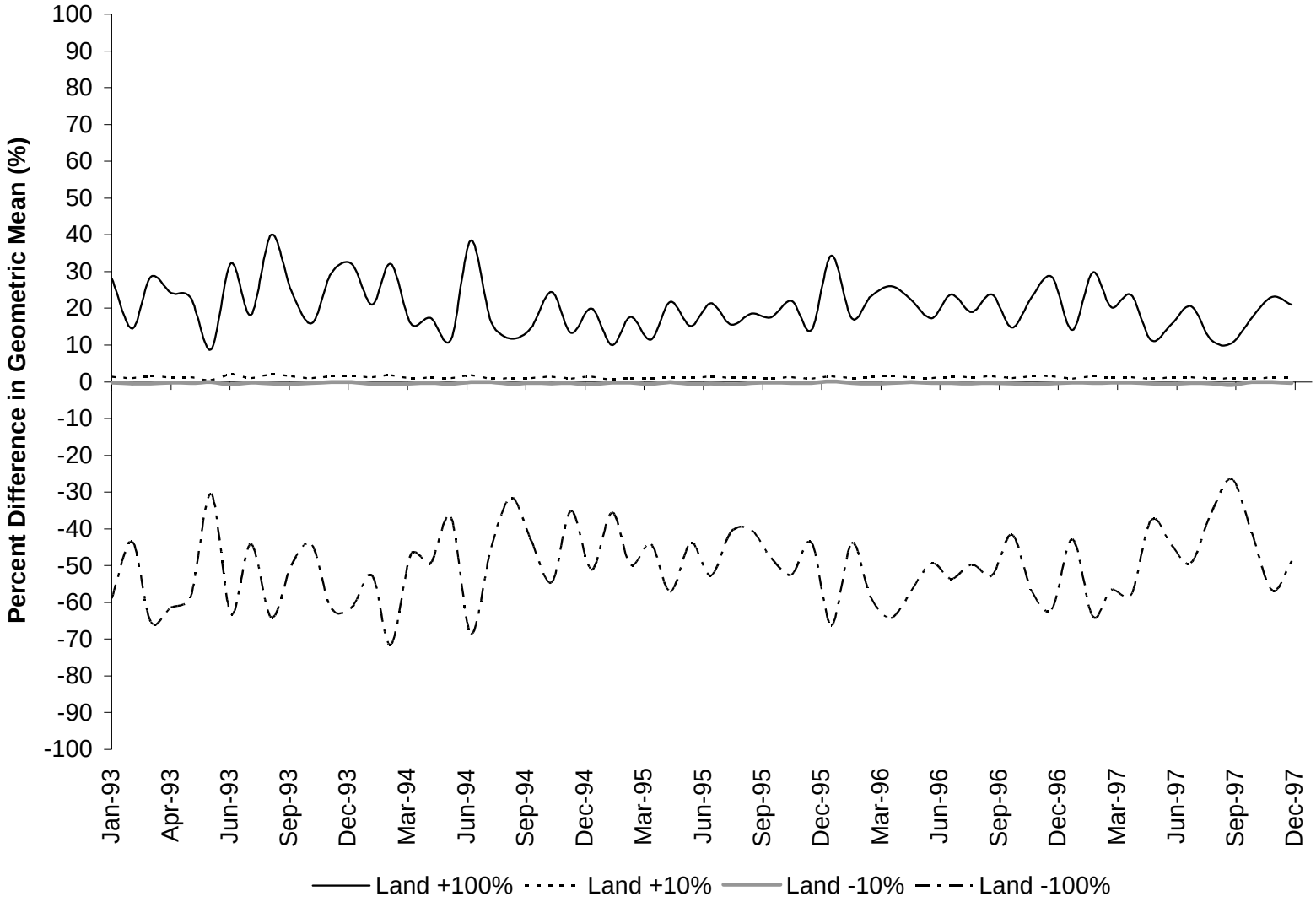

Figure 5.56. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-7) of Moncuin/Webb Creek (VAP-F13R-04) watershed, as affected by land-based load changes.

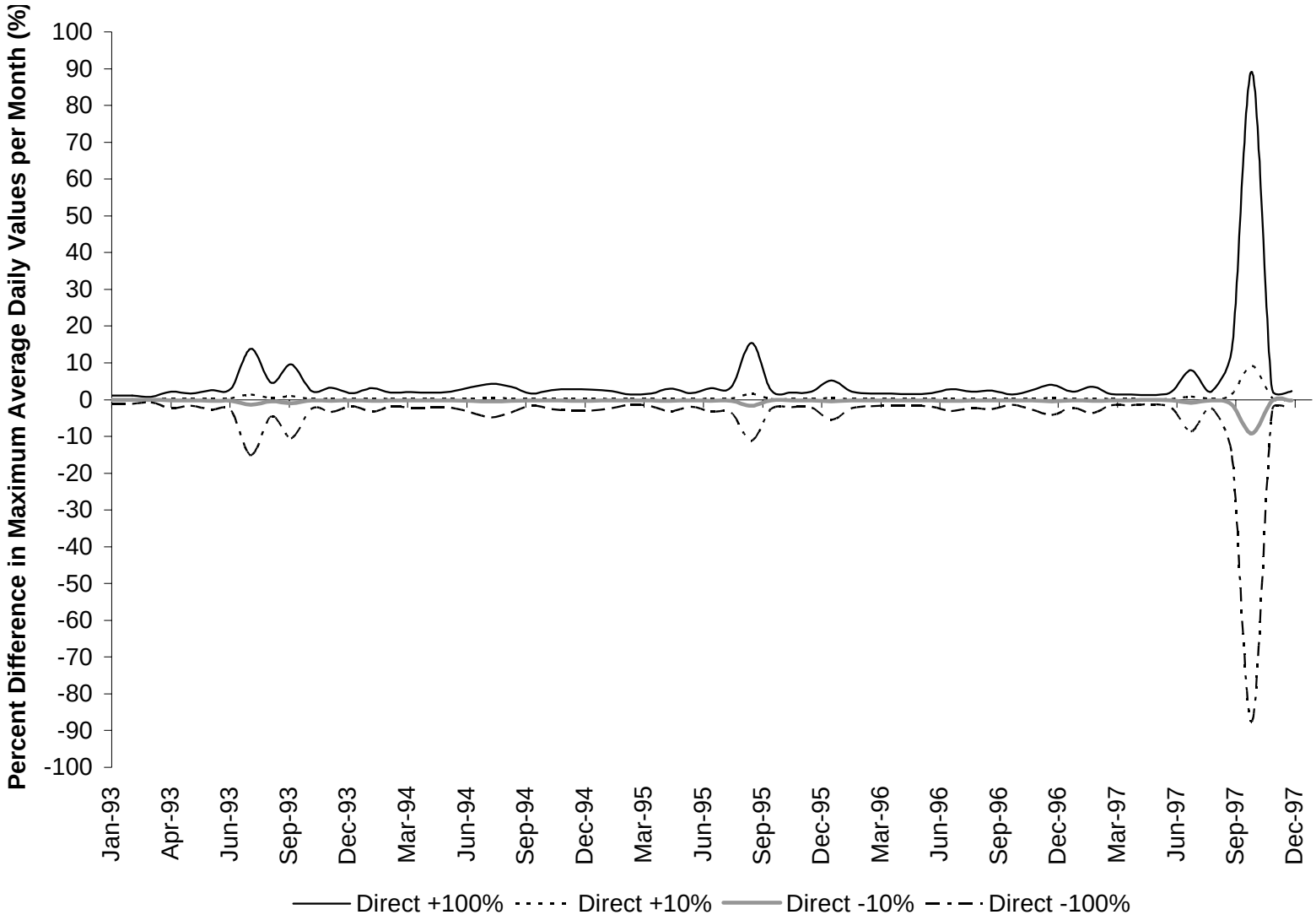

Figure 5.57. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-7) of Moncuin/Webb Creek (VAP-F13R-04) watershed, as affected by direct load changes.

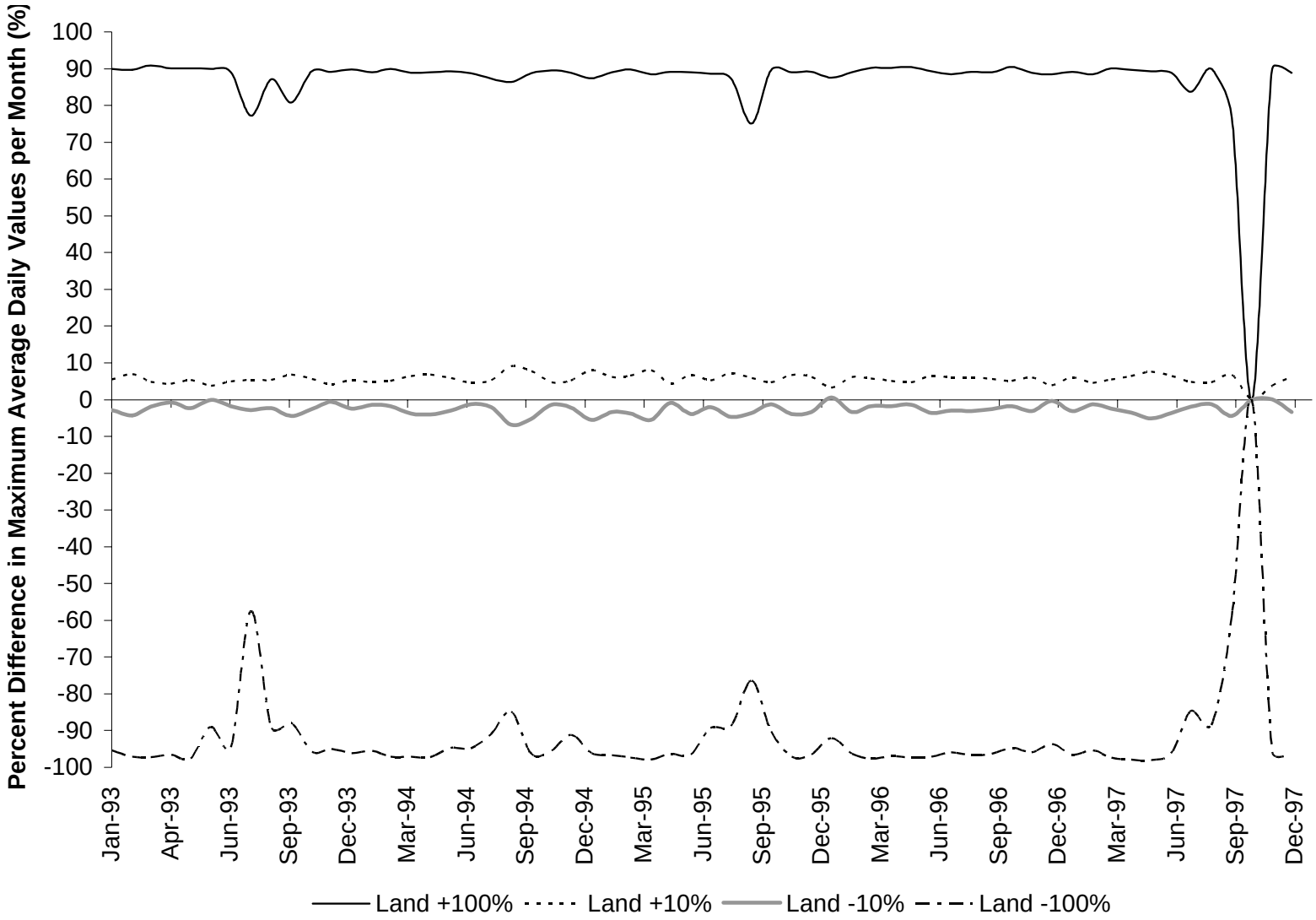

Figure 5.58. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-7) of Moncuin/Webb Creek (VAP-F13R-04) watershed, as affected by land-based load changes.

5.3.10 Black Creek (VAP-F13R-05)

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 5.59 and 5.60, respectively. Figures 5.61 and 5.62, 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 5.59 with Figure 5.60 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.61 to Figure 5.62 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.

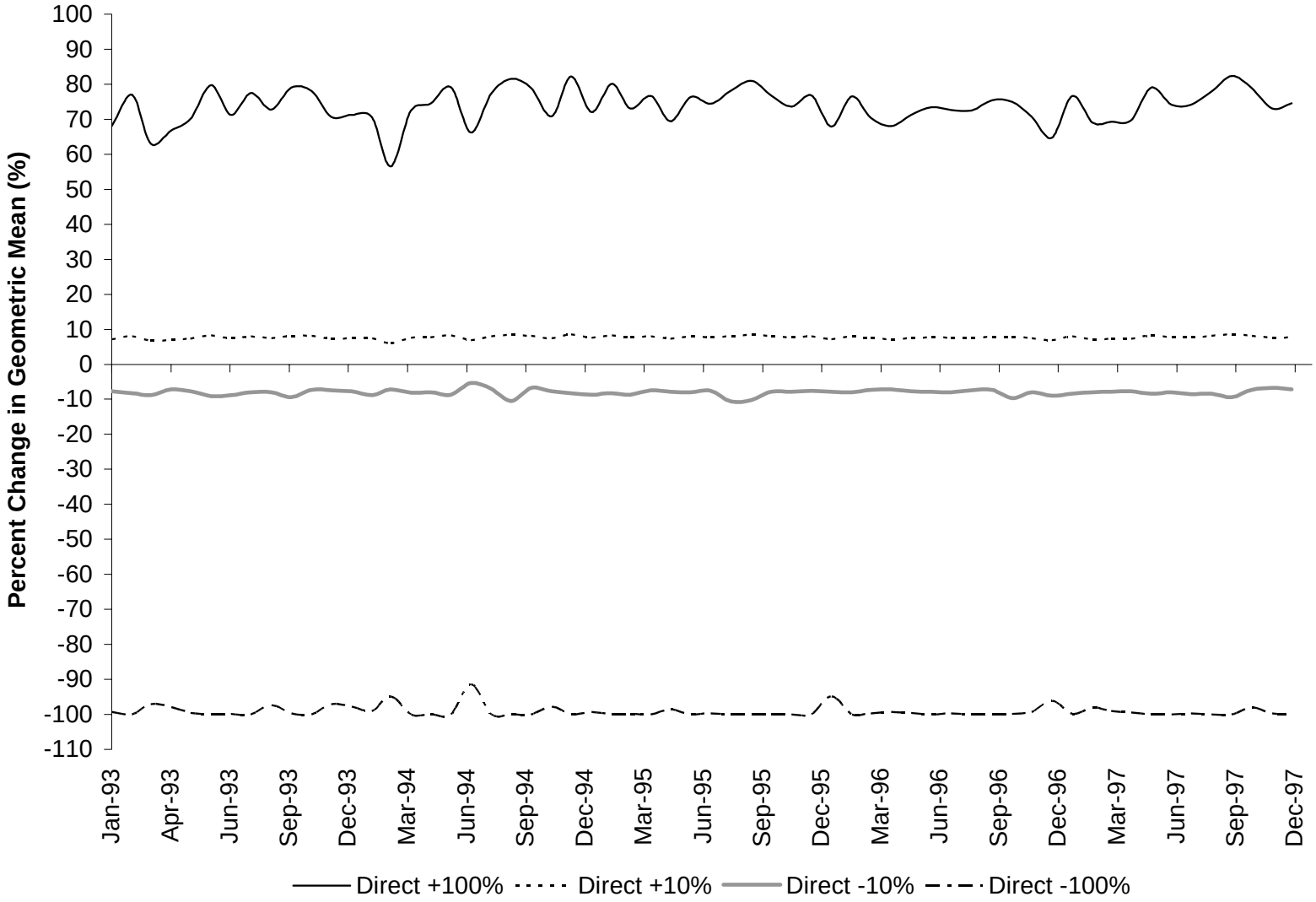

Figure 5.59. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-17) of Black Creek (VAP-F13R-05) watershed, as affected by direct load changes.

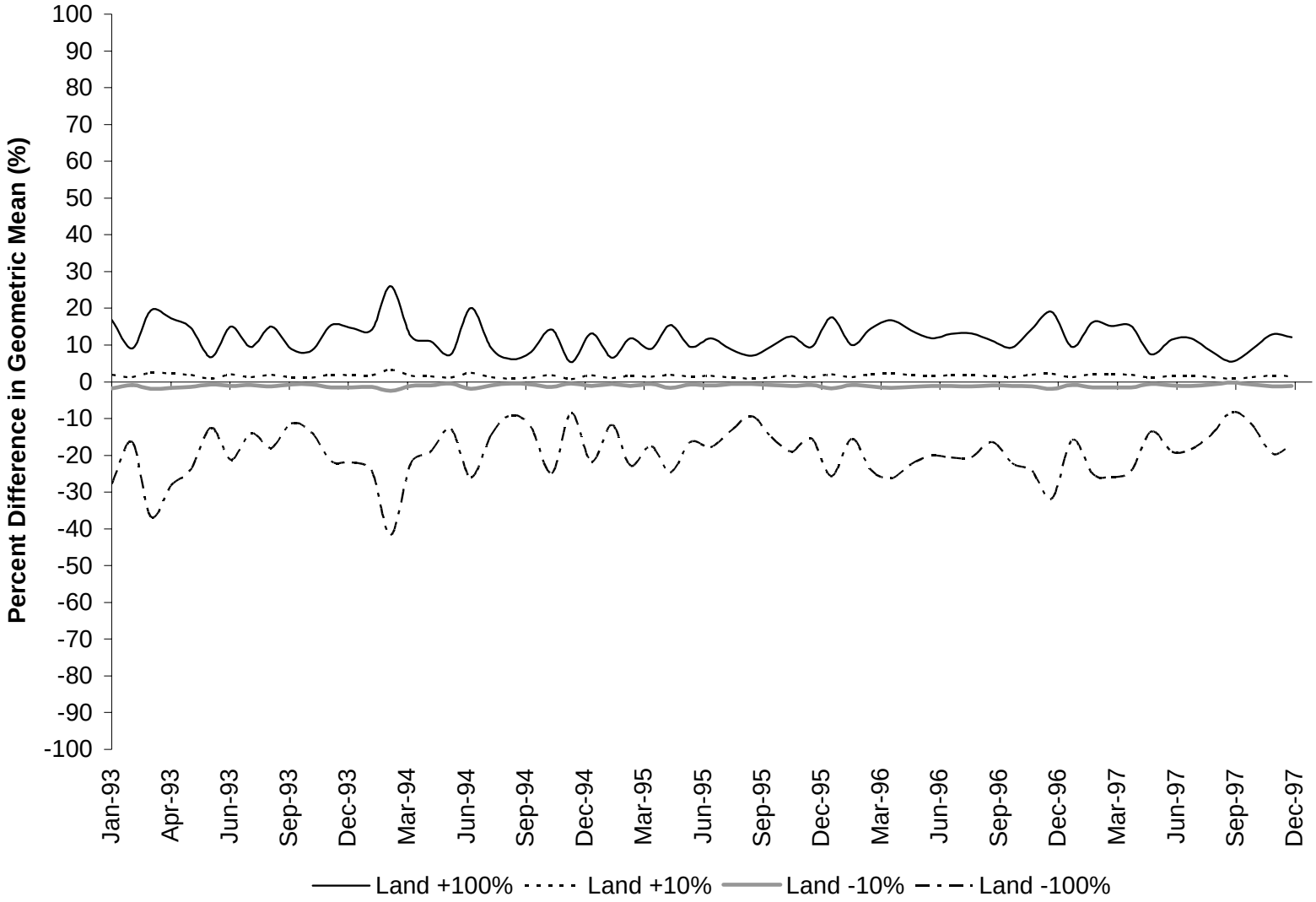

Figure 5.60. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-17) of Black Creek (VAP-F13R-05) watershed, as affected by land-based load changes.

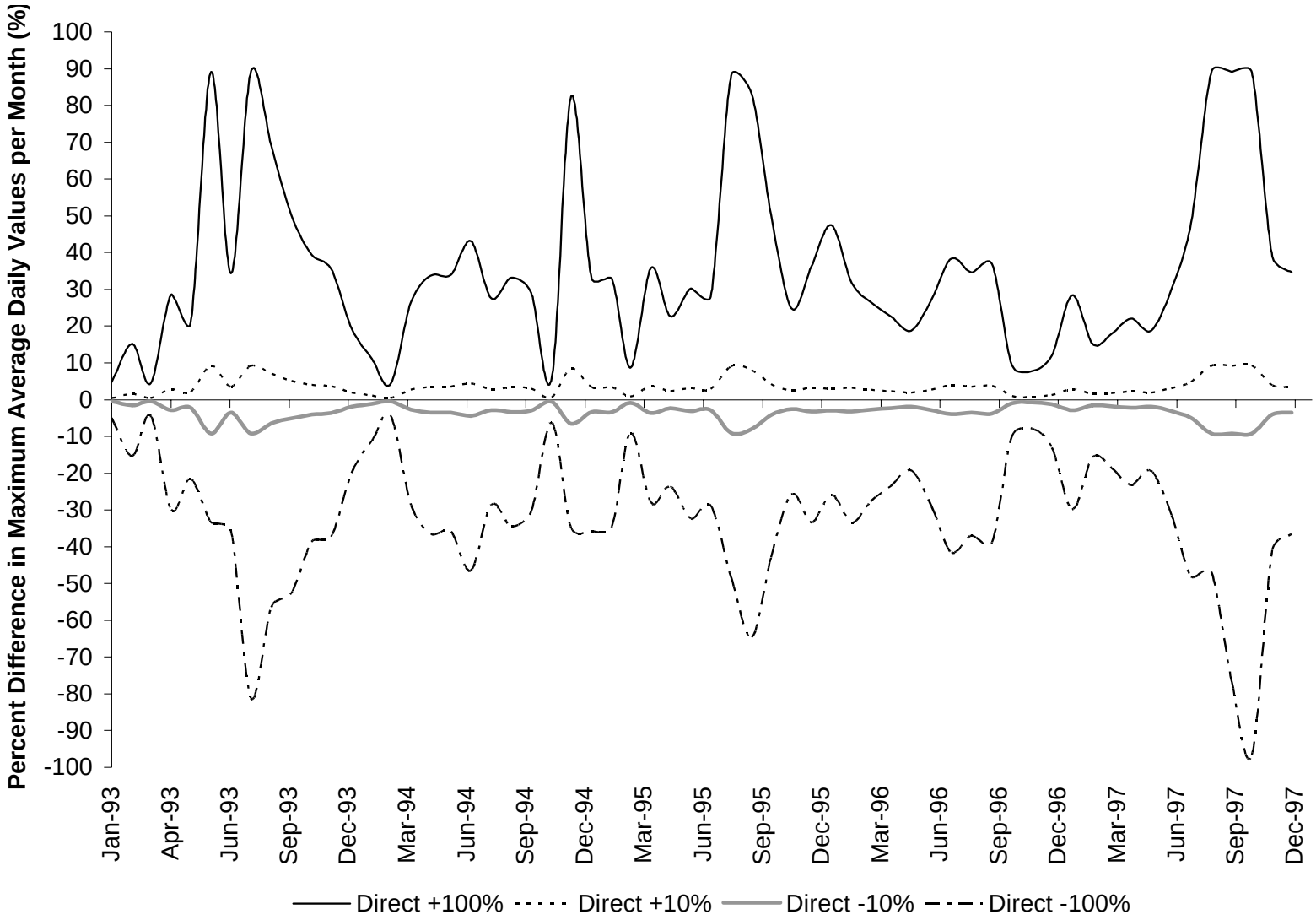

Figure 5.61. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-17) of Black Creek (VAP-F13R-05) watershed, as affected by direct load changes.

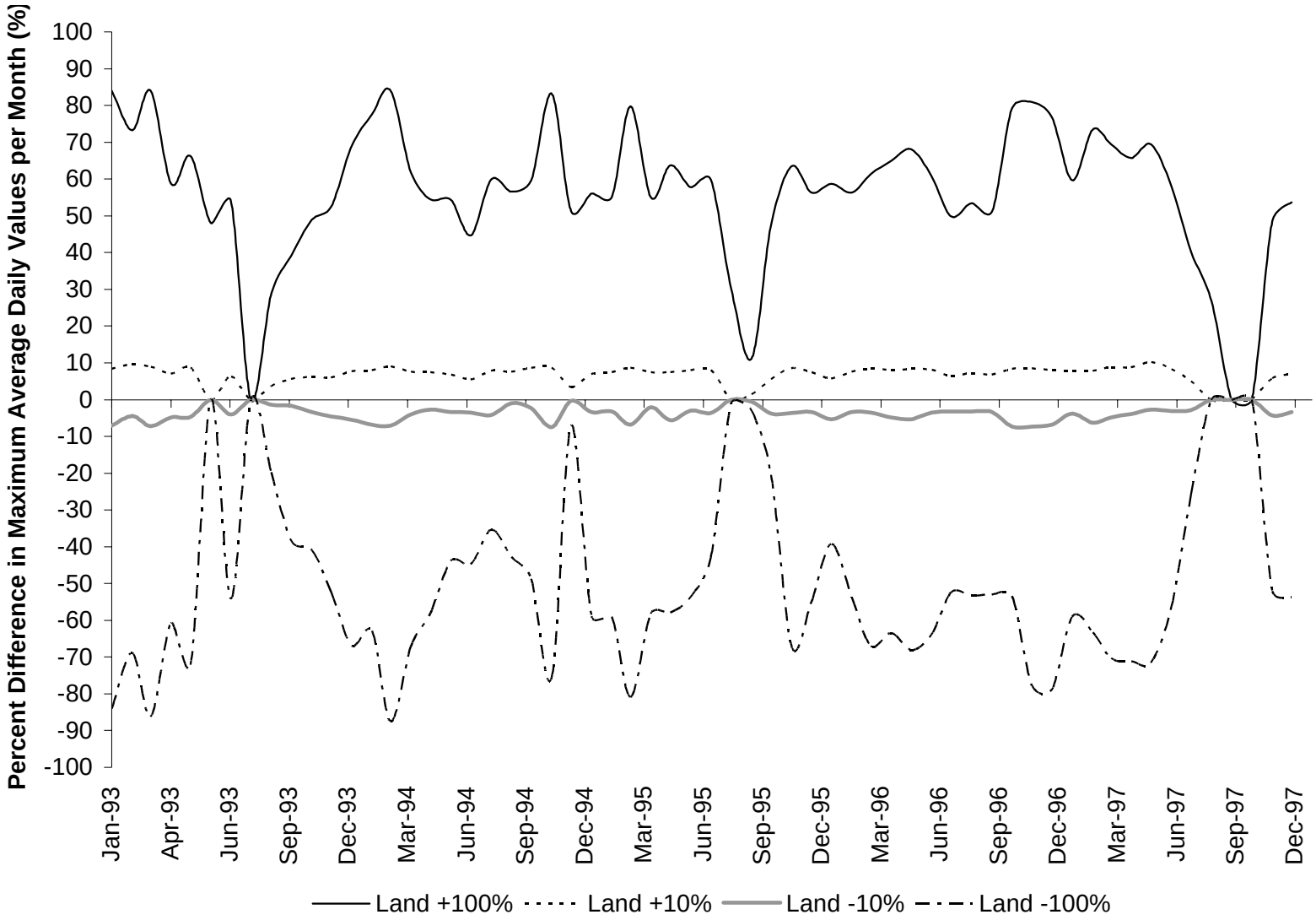

Figure 5.62. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-17) of Black Creek (VAP-F13R-05) watershed, as affected by land-based load changes.

5.3.11 Pamunkey River (VAP-F13E-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 5.63 and 5.64, respectively. Figures 5.65 and 5.66, 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 5.63 with Figure 5.64 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.65 to Figure 5.66 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.

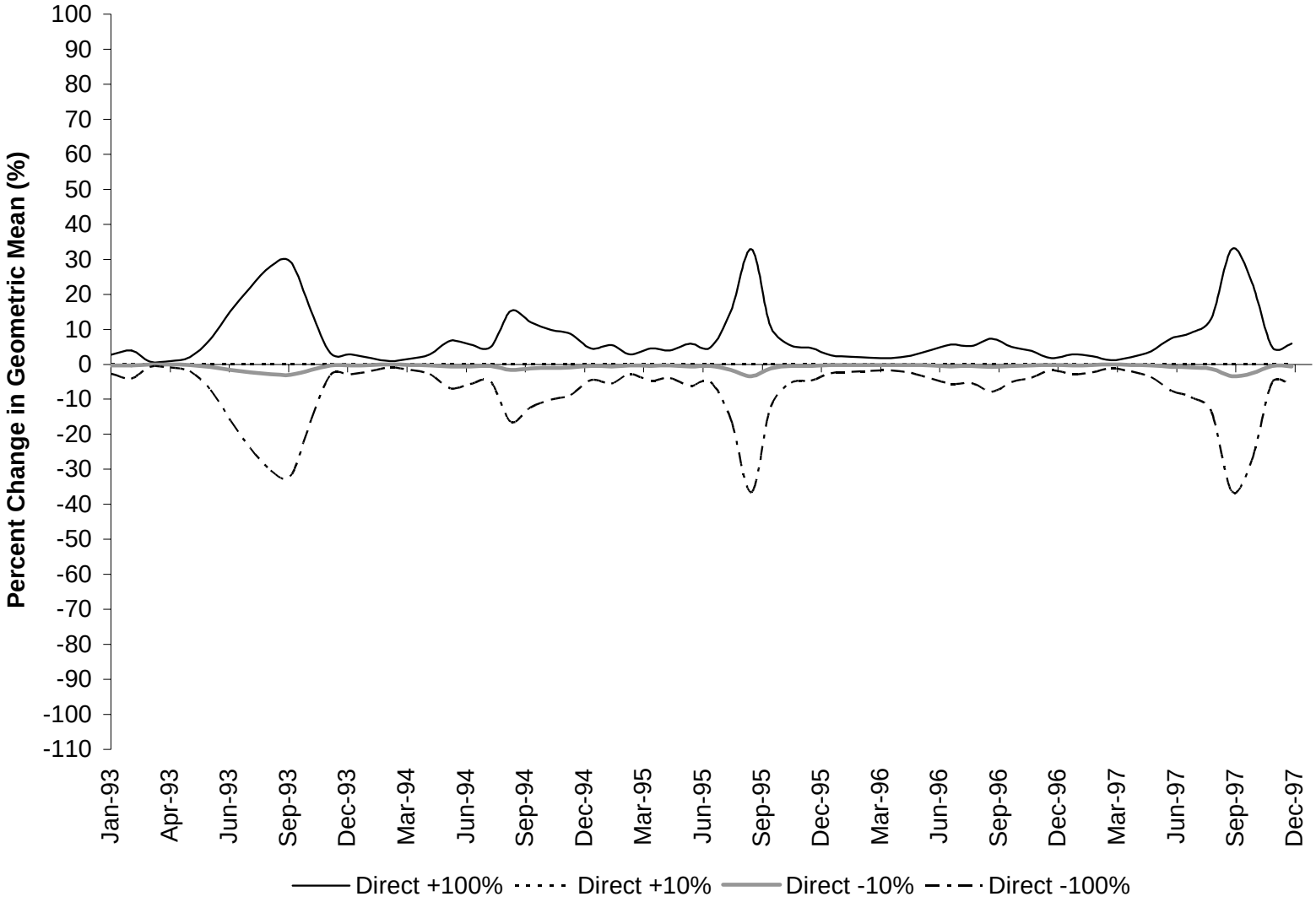

Figure 5.63. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-20) of Pamunkey River (VAP-F13E-02) watershed, as affected by direct load changes.

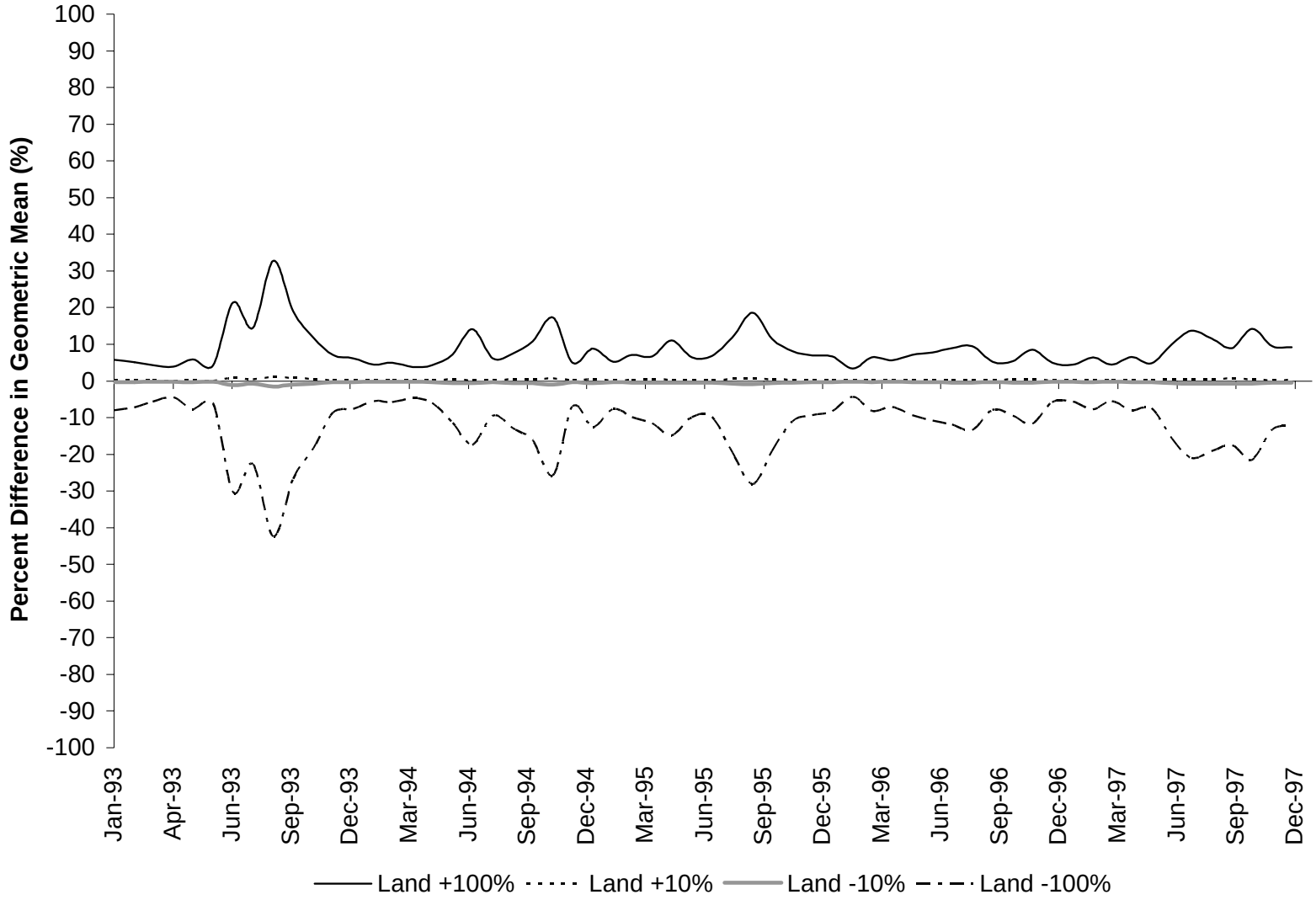

Figure 5.64. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed PAR-20) of Pamunkey River (VAP-F13E-02) watershed, as affected by land-based load changes.

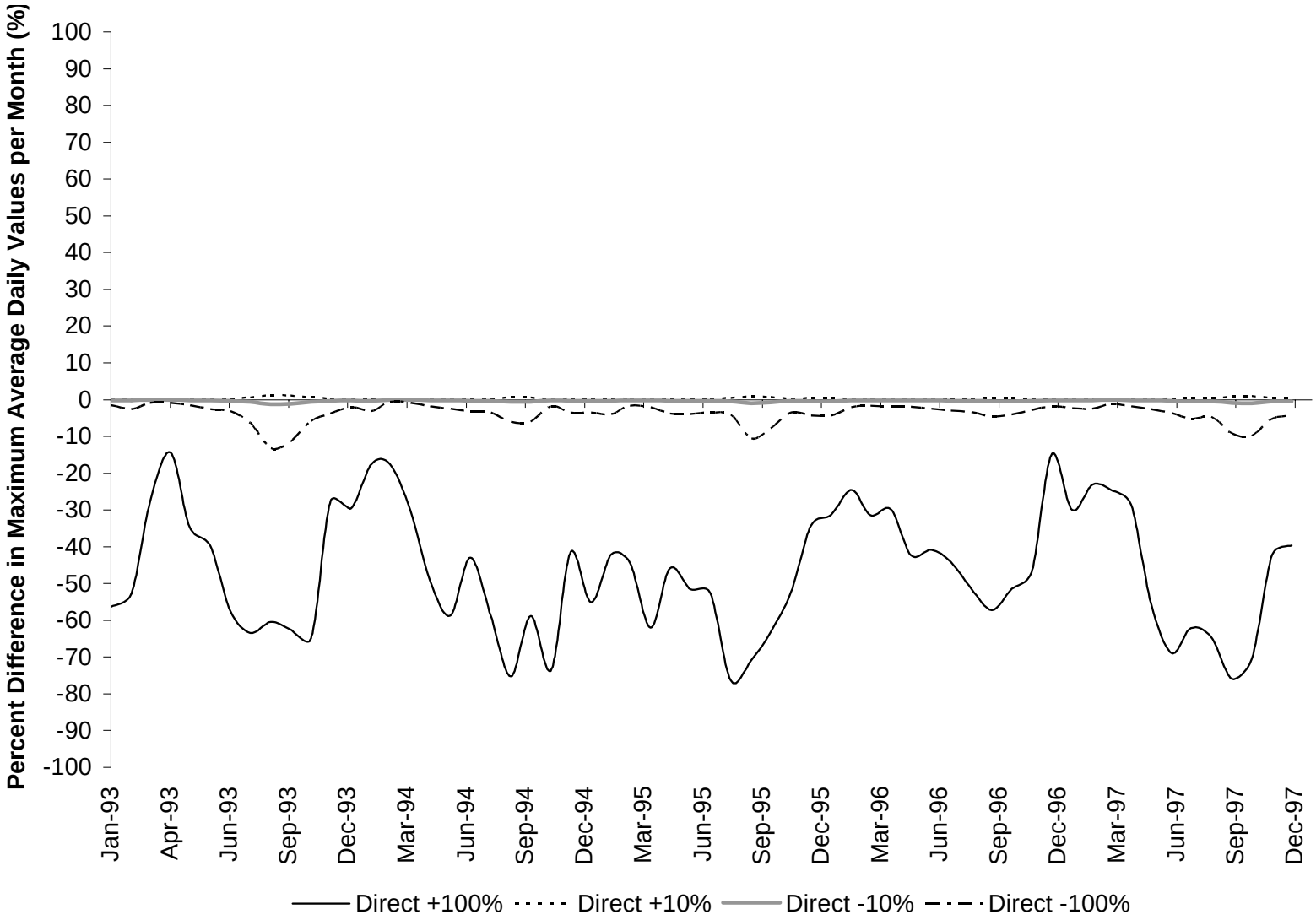

Figure 5.65. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-20) of Pamunkey River (VAP-F13E-02) watershed, as affected by direct load changes.

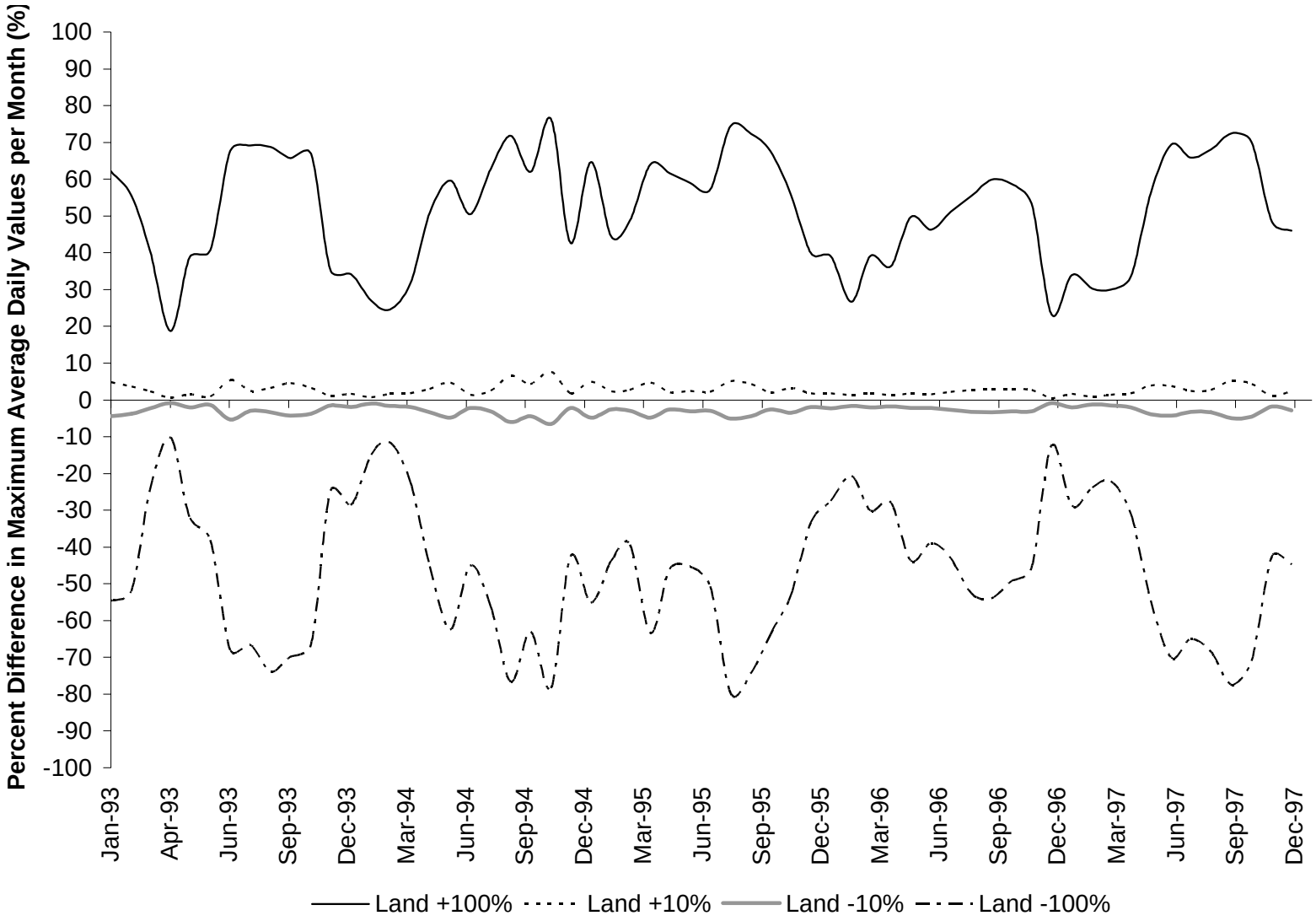

Figure 5.66. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed PAR-20) of Pamunkey River (VAP-F13E-02) watershed, as affected by land-based load changes.

5.4 TMDL Allocation Scenarios

Direct and land-based loads representing existing conditions were reduced in a variety of allocation scenarios (addressing anthropogenic sources first) until the *E. coli* TMDL goals of a calendar-month geometric mean of 126 cfu/100mL and the instantaneous 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 one, seven, 13, one, and one active point discharges with a VPDES permit within the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), and Moncuin/Webb Creek (VAP-F13R-04) watersheds, respectively. Municipalities with MS4 permits were identified within the South Anna River, Northeast Creek, Totopotomoy Creek, Black Creek, and Pamunkey River 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 2003-2004 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) impairments and their results are summarized in Sections 5.4.1 through 5.4.11.

The general approach used to determine the TMDL allocation was very similar among the six watersheds. The first scenario represents existing conditions. Scenarios numbered 1 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. Scenario 5 represents reducing all anthropogenic sources by 100% while reducing directly deposited wildlife loads by 75%. The results of Scenarios 1 through 5 were then used to formulate additional scenarios that led to the TMDL allocation. These additional scenarios were designed to first determine non-anthropogenic source reductions required to meet bacteria water quality standards, if any. Subsequent scenarios were used to determine required reductions in anthropogenic sources. Details of Scenarios 6 through 10 are discussed in Sections 5.4.1 through 5.4.11. (Further discussion of wildlife reduction allocations can be found in Section 6.5.4.)

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Discharge from the permitted point sources in the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Moncuin/Webb Creek (VAP-F13R-04) watersheds were increased by two and five times the existing permit levels to determine the effect of possible facility expansion, which is discussed in Sections 5.4.1, 5.4.2, 5.4.3, 5.4.4, and 5.4.9, respectively. These increases did not result in violations of the water quality standard. Future growth in discharges from permitted point sources in the Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) watersheds was accounted for by developing WLAs at <1% of the TMDL. These WLAs did not result in violations 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 Pamunkey 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-

02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 instantaneous 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) are seasonal. The TMDL accounts for these seasonal effects.
- The violation rates listed in the allocation scenario tables indicate violation rates for the watershed outlet only. Some scenarios resulted in bacteria water quality standard violations in subwatersheds upstream of the outlet but within the impaired reach watershed.

5.4.1 South Anna River (VAN-F01R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.1. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the South Anna River (VAN-F01R-01) watershed. It was determined that meeting the bacteria water quality standards required a 90% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in one violation of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load. Scenario 9 represents the lowest reduction in livestock direct deposition (99%) and an attempt to lower the reduction of pasture and cropland land-based loads, which resulted in a 0.2% violation rate of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios

intended to determine the required reduction in pasture and cropland land-based loads, which was 97%. Scenario 10 met the 0% violation criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.67 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.2 presents the existing and allocated direct and land-applied fecal coliform loads that result in in-stream *E. coli* concentrations to meet the applicable *E. coli* water quality standards after application of the VADEQ translator for fecal coliform to *E. coli* concentration. Table 5.3 presents the final allocated in-stream *E. coli* loads for the South Anna River (VAN-F01R-01) impairment.

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 South Anna River (VAN-F01R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.4). The increases did not result in additional violations of the water quality standards.

Table 5.1. TMDL allocation scenarios for South Anna River (VAN-F01R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	50.0 (30)	40.7 (744)
1	100	0	100	0	0	0	0	28.3 (17)	30.0 (548)
2	100	50	100	50	50	0	0	18.3 (11)	23.3 (425)
3	100	75	100	75	75	0	0	15.0 (9)	15.6 (285)
4	100	100	100	100	100	0	0	8.3 (5)	5.8 (105)
5	100	100	100	100	100	75	0	5.0 (3)	12.9 (235)
6	100	100	100	100	100	90	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	90	0	1.7 (1)	0.2 (44)
8	100	100	98	100	100	90	0	1.7 (1)	0.0 (0)
9	100	100	99	96	96	90	0	0.0 (0)	0.2 (1)
10	100	100	99	97	97	90	0	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 South Anna River (VAN-F01R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.19E+12	0.00E+00	100
Livestock	6.52E+12	6.52E+10	99
Wildlife	5.37E+12	5.37E+11	90
Total	*1.51E+13*	*6.02E+11*	*96*
Land-based			
Residential	1.34E+14	0.00E+00	100
Cropland	1.09E+12	3.27E+10	97
Pasture	7.15E+15	2.15E+14	97
Forest	2.52E+13	2.52E+13	0
Total	*7.31E+15*	*2.40E+14*	*97*

Table 5.3. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F01R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.64E+12	3.67E+12	N/A	5.31E+12

N/A – not applicable because MOS was implicit.

Table 5.4. Expansion matrix for WLA in the South Anna River (VAN-F01R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0021105	SAR-2	0.940	126	1.64E12
Existing WLA		0.940	126	1.64E12
Expansion Scenario: 2 x Existing WLA		1.880	126	3.28E12
Expansion Scenario: 5 x Existing WLA		4.700	126	8.20E12

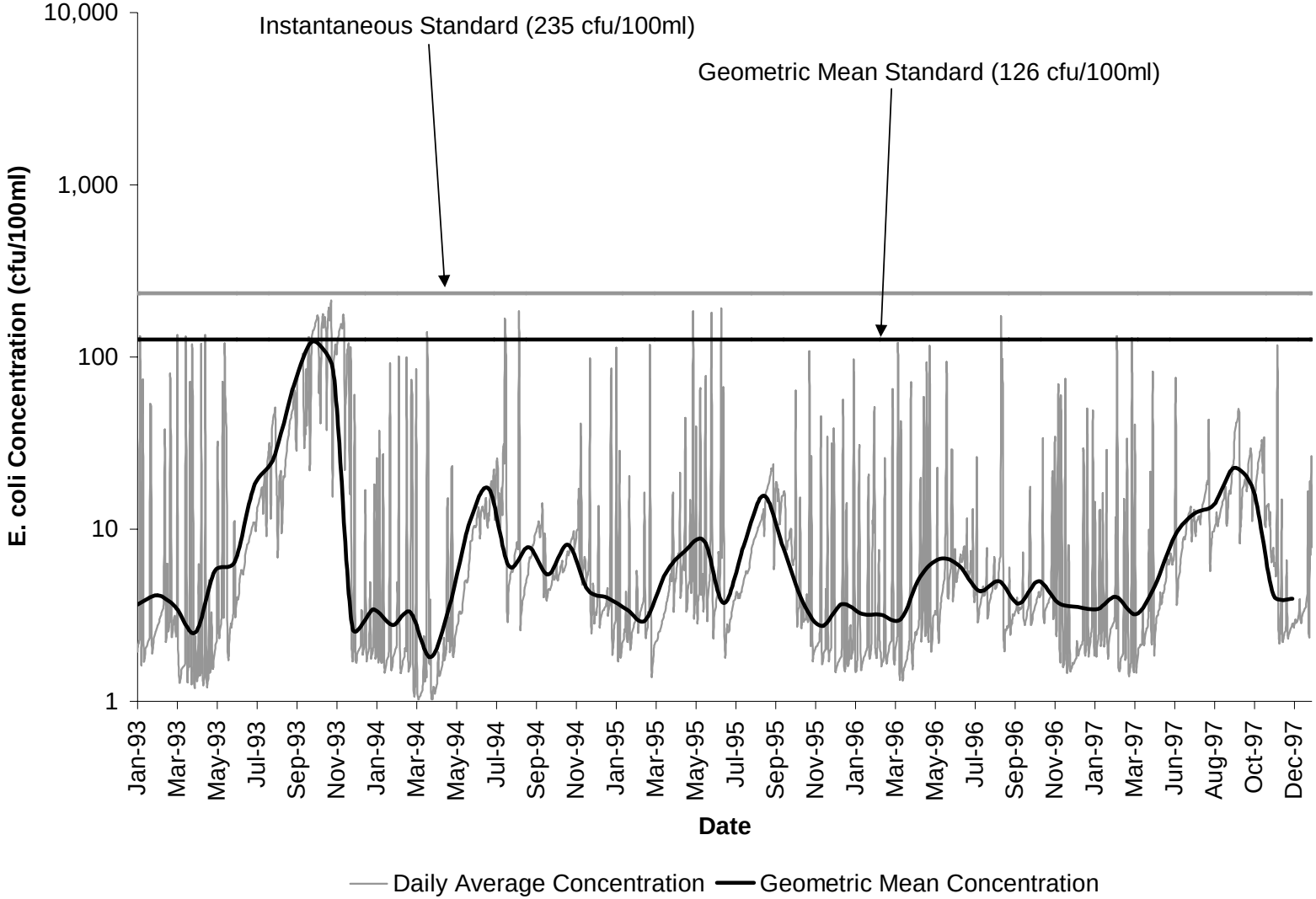

Figure 5.67. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.1) in South Anna River (VAN-F01R-01) impairment.

5.4.2 South Anna River (VAN-F02R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.5. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the South Anna River (VAN-F02R-01) watershed. It was determined that meeting the bacteria water quality standards required a 92% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in one violation of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load. Scenario 9 an attempt to lower the reduction of pasture and cropland land-based loads to 98%, which resulted in a 0.1% violation rate of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 99%. Scenario 10 met the 0% violation criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.68 for the final TMDL allocation (Scenario 10), 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 South Anna River (VAN-F02R-01) impairment.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the six study watersheds are discussed in Section 5.3. Discharges from the permitted point sources in the South Anna River (VAN-F02R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.8). The increases did not result in additional violations of the water quality standards.

Table 5.5. TMDL allocation scenarios for South Anna River (VAN-F02R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	30.0 (18)	29.7 (542)
1	100	0	100	0	0	0	0	21.7 (13)	28.2 (515)
2	100	50	100	50	50	0	0	15.0 (9)	19.3 (352)
3	100	75	100	75	75	0	0	11.7 (7)	10.8 (198)
4	100	100	100	100	100	0	0	5.0 (3)	3.6 (66)
5	100	100	100	100	100	75	0	5.0 (3)	8.2 (144)
6	100	100	100	100	100	92	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	92	0	1.7 (1)	0.9 (2)
8	100	100	99	100	100	92	0	1.7 (1)	0.4 (2)
9	100	100	100	98	98	92	0	0.0 (0)	0.1 (1)
10	100	100	100	99	99	92	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.6. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in South Anna River (VAN-F02R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.00E+13	0.00E+00	100
Livestock	4.05E+13	0.00E+00	100
Wildlife	7.69E+13	6.15E+12	92
Total	*1.47E+14*	*6.15E+12*	*96*
Land-based			
Residential	2.00E+15	0.00E+00	100
Cropland	1.18E+14	1.18E+12	99
Pasture	3.91E+16	3.91E+14	99
Forest	4.09E+14	4.09E+14	0
Total	*4.16E+16*	*8.01E+14*	*98*

Table 5.7. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F02R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.48E+12	7.96E+12	N/A	9.44E+12

N/A – not applicable because MOS was implicit.

Table 5.8. Expansion matrix for WLA in the South Anna River (VAN-F02R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0088706	SAR-6	0.039	126	6.87E10
VA0090743	SAR-6	0.700	126	1.22E12
VA0076678	SAR-6	0.100	126	1.74E11
VAG116048	SAR-06	0.001	126	1.69E09
VAG251002	SAR-06	0.001	126	1.69E09
VAG406073	SAR-06	0.001	126	1.69E09
VA0088421	SAR-12	0.010	126	1.74E10
Existing WLA		0.853	126	1.48E12
Expansion Scenario: 2 x Existing WLA		1.706	126	2.96E12
Expansion Scenario: 5 x Existing WLA		4.265	126	7.40E12

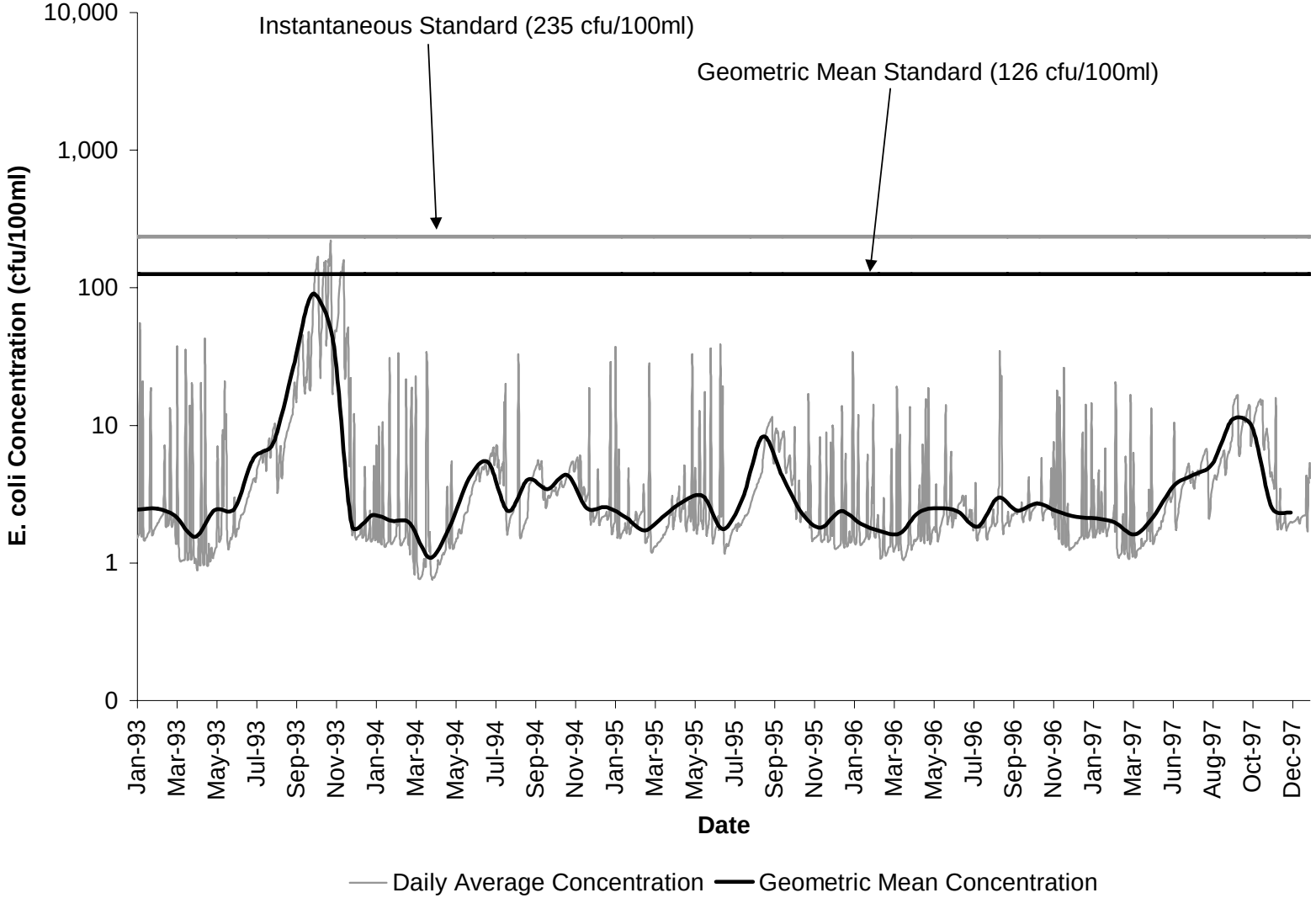

Figure 5.68. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.5) in South Anna River (VAN-F02R-01) impairment.

5.4.3 South Anna River (VAP-F04R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.9. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the South Anna River (VAN-F01R-01) watershed. It was determined that meeting the bacteria water quality standards required a 41% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in three violations of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load. Scenario 9 represents the lowest reduction in livestock direct deposition (98%) and an attempt to lower the reduction of pasture and cropland land-based loads to 94%, which resulted in a 0.1% violation rate of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 95%. Scenario 10 met the 0% violation criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.69 or the final TMDL allocation (Scenario 10), 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 South Anna River (VAN-F01R-01) impairment.

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 South Anna River (VAN-F01R-01) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.12). The increases did not result in additional violations of the water quality standards.

Table 5.9. TMDL allocation scenarios for South Anna River (VAP-F04R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	11.7 (7)	18.0 (329)
1	100	0	100	0	0	0	0	8.3 (5)	17.4 (150)
2	100	50	100	50	50	0	0	5.0 (3)	8.2 (78)
3	100	75	100	75	75	0	0	5.0 (3)	4.3 (47)
4	100	100	100	100	100	0	0	5.0 (3)	2.6 (38)
5	100	100	100	100	100	75	0	5.0 (3)	2.1 (30)
6	100	100	100	100	100	41	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	41	0	0.0 (0)	0.2 (3)
8	100	100	97	100	100	41	0	1.7 (1)	0.0 (0)
9	100	100	98	94	94	41	0	0.0 (0)	0.1 (1)
10	100	100	98	95	95	41	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.10. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in South Anna River (VAP-F04R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	6.85E+13	0.00E+00	100
Livestock	6.01E+13	1.20E+12	98
Wildlife	1.73E+14	1.02E+14	41
Total	*3.02E+14*	*1.03E+14*	*66*
Land-based			
Residential	4.23E+15	0.00E+00	100
Cropland	1.13E+15	5.65E+13	95
Pasture	6.16E+16	3.08E+15	95
Forest	8.05E+14	8.05E+14	0
Total	*6.78E+16*	*3.94E+15*	*94*

Table 5.11. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.02E+12	2.98E+13	N/A	3.08E+13

N/A – not applicable because MOS was implicit.

Table 5.12. Expansion matrix for WLA in the South Anna River (VAP-F04R-01) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0067954	SAR-14	0.400	126	6.96E11
VA0090409	SAR-15	0.016	126	2.79E10
VA0090140	SAR-15	0.040	126	6.96E10
VA0067105	SAR-16	0.025	126	4.35E10
VAG404000	SAR-20	0.0005	126	7.88E08
VAG404200	SAR-20	0.0005	126	9.00E08
VAG404205	SAR-20	0.001	126	1.69E09
VAG404210	SAR-20	0.0005	126	7.88E08
VAG404217	SAR-20	0.0006	126	1.01E09
VA0022641	SAR-21	0.040	126	6.96E10
VA0060232	SAR-21	0.060	126	1.04E11
VAG404222	SAR-21	0.0005	126	7.88E08
VAG404066	SAR-21	0.001	126	1.69E09
Existing WLA		0.585	126	1.02E12
Expansion Scenario: 2 x Existing WLA		1.170	126	2.04E12
Expansion Scenario: 5 x Existing WLA		2.925	126	5.10E12

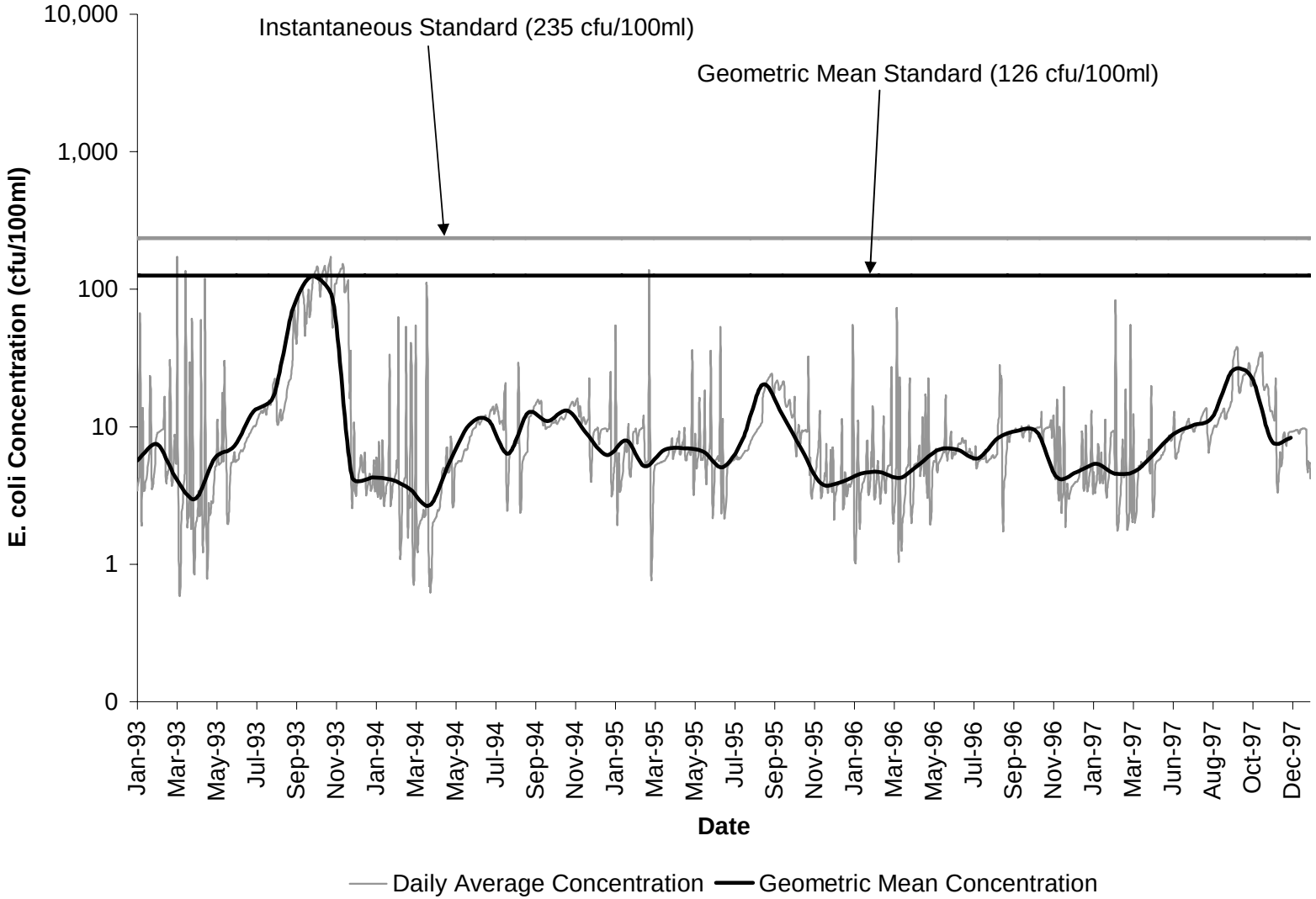

Figure 5.69. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.9) in South Anna River (VAP-F04R-01) impairment.

5.4.4 South Anna River (VAP-F04R-02)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.13. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the South Anna River (VAP-F04R-02) watershed. It was determined that meeting the bacteria water quality standards required a 94% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in four violations of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 8 represents livestock direct deposition load at 94% resulting in zero violations. Scenario 9 represents an attempt to lower the reduction of pasture and cropland land-based loads to 94%, which resulted in a 0% violation rate of the instantaneous bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 94%. Scenario 10 met the 0% violation criteria of both standards and was selected as the final TMDL allocation. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.70 or the final TMDL allocation (Scenario 10), 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 South Anna River (VAP-F04R-02) impairment.

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 South Anna River (VAP-F04R-02) watershed were increased by two and five times the existing permit levels to determine the effect of possible facility expansion (Table 5.16). The increases did not result in additional violations of the water quality standards.

Table 5.13. TMDL allocation scenarios for South Anna River (VAP-F04R-02) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	15.0 (9)	19.5 (356)
1	100	0	100	0	0	0	0	10.0 (6)	19.0 (196)
2	100	50	100	50	50	0	0	5.0 (3)	10.7 (110)
3	100	75	100	75	75	0	0	5.0 (3)	6.0 (52)
4	100	100	100	100	100	0	0	5.0 (3)	2.8 (66)
5	100	100	100	100	100	75	0	5.0 (3)	1.6 (32)
6	100	100	100	100	100	94	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	94	0	1.7 (1)	0.2 (4)
8	100	100	94	100	100	94	0	0.0 (0)	0.0 (0)
9	100	100	94	94	94	94	0	0.0 (0)	0.0 (0)
10	100	100	94	94	94	94	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.14. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in South Anna River (VAP-F04R-02) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.27E+12	0.00E+00	100
Livestock	3.73E+12	2.24E+11	94
Wildlife	1.58E+13	9.48E+11	94
Total	*2.18E+13*	*1.17E+12*	*95*
Land-based			
Residential	8.10E+14	0.00E+00	100
Cropland	2.52E+13	1.51E+12	94
Pasture	4.71E+15	2.83E+14	94
Forest	5.27E+13	5.27E+13	0
Total	*5.60E+15*	*3.37E+14*	*94*

Table 5.15. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-02) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	3.48E+12	3.13E+13	N/A	3.48E+13

N/A – not applicable because MOS was implicit.

Table 5.16. Expansion matrix for WLA in the South Anna River (VAP-F04R-02) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0024899	SAR-27	2.000	126	3.48E12
Existing WLA		2.000	126	3.48E12
Expansion Scenario: 2 x Existing WLA		4.000	126	6.96E12
Expansion Scenario: 5 x Existing WLA		10.000	126	1.74E13

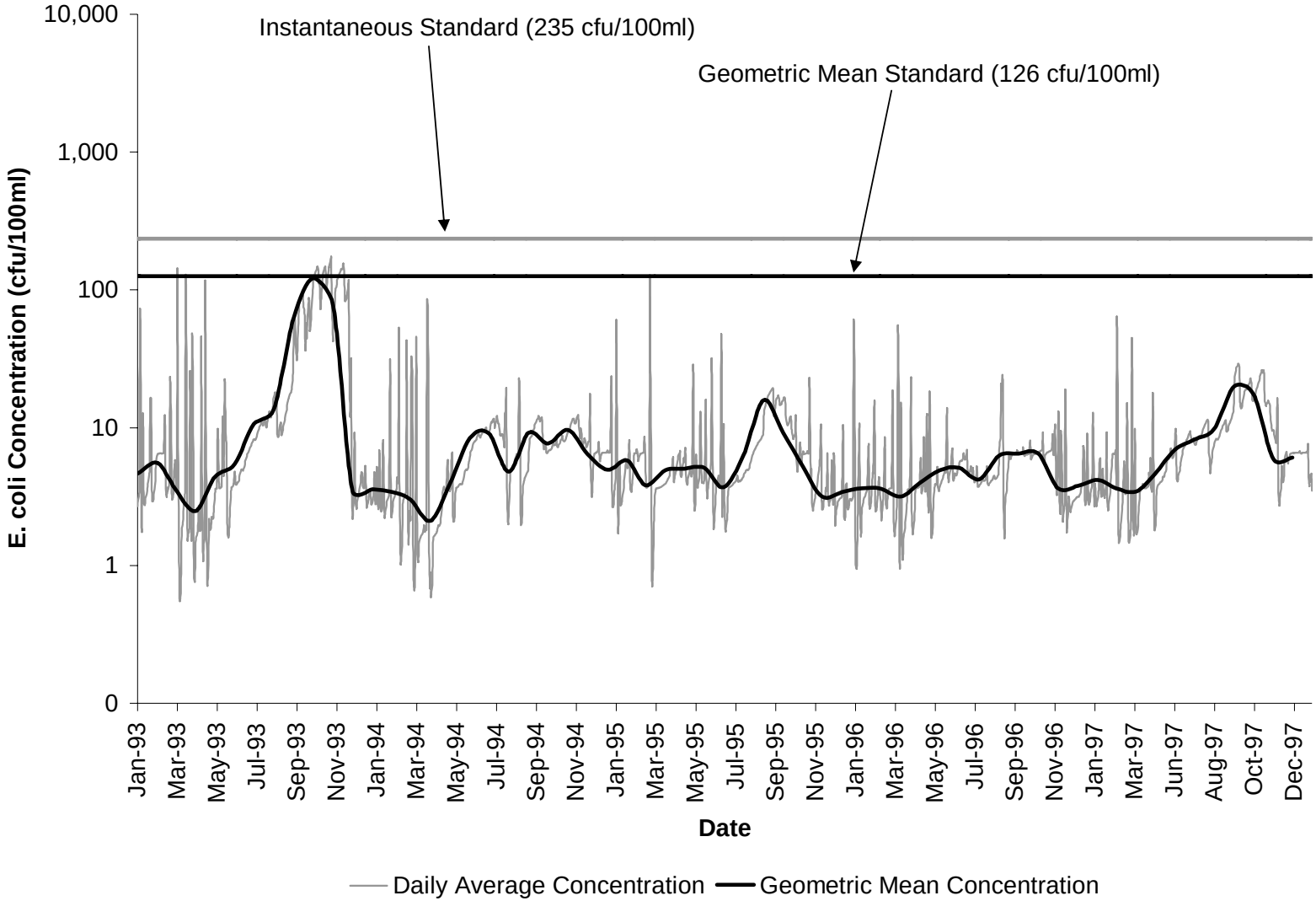

Figure 5.70. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.13) in South Anna River (VAP-F04R-02) impairment.

5.4.5 Taylors Creek (VAN-F03R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.17. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Taylors Creek (VAN-F03R-01) watershed. It was determined that meeting the bacteria water quality standards required a 97% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in a violation of the geometric mean bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 96%. Scenario 9 represents the lowest reduction in livestock direct deposition (97%) and an attempt to lower the reduction of pasture and cropland land-based loads, which resulted in a 1.7% violation rate of the geometric mean bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 100% and 97%, respectively. Scenario 10 met the 0% violation 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 5.71 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.18 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 5.19 presents the final allocated in-stream *E. coli* loads for the Taylors Creek (VAN-F03R-01) impairment.

Table 5.17. TMDL allocation scenarios for Taylors Creek (VAN-F03R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean*	Instantaneous*
Existing Conditions	0	0	0	0	0	0	0	31.7 (19)	30.3 (553)
1	100	0	100	0	0	0	0	30.0 (18)	27.3 (499)
2	100	50	100	50	50	0	0	28.3 (17)	22.8 (417)
3	100	75	100	75	75	0	0	28.3 (17)	20.9 (381)
4	100	100	100	100	100	0	0	21.7 (13)	19.0 (347)
5	100	100	100	100	100	75	0	18.3 (11)	9.3 (170)
6	100	100	100	100	100	97	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	97	0	1.7 (1)	0.0 (0)
8	100	100	96	100	100	97	0	1.7 (1)	0.0 (0)
9	100	100	97	99	99	97	0	1.7 (1)	0.0 (0)
10	100	100	97	99	100	97	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.18. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Taylors Creek (VAN-F03R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.07E+12	0.00E+00	100
Livestock	7.20E+12	2.16E+11	97
Wildlife	3.24E+13	9.72E+11	97
Total	*4.87E+13*	*1.19E+12*	*98*
Land-based			
Residential	7.34E+14	0.00E+00	100
Cropland	4.68E+12	4.68E+10	99
Pasture	7.24E+15	0.00E+00	100
Forest	1.44E+14	1.44E+14	0
Total	*8.12E+15*	*1.44E+14*	*98*

Table 5.19. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.89E+09	1.89E+11	N/A	1.91E+11

N/A – not applicable because MOS was implicit.

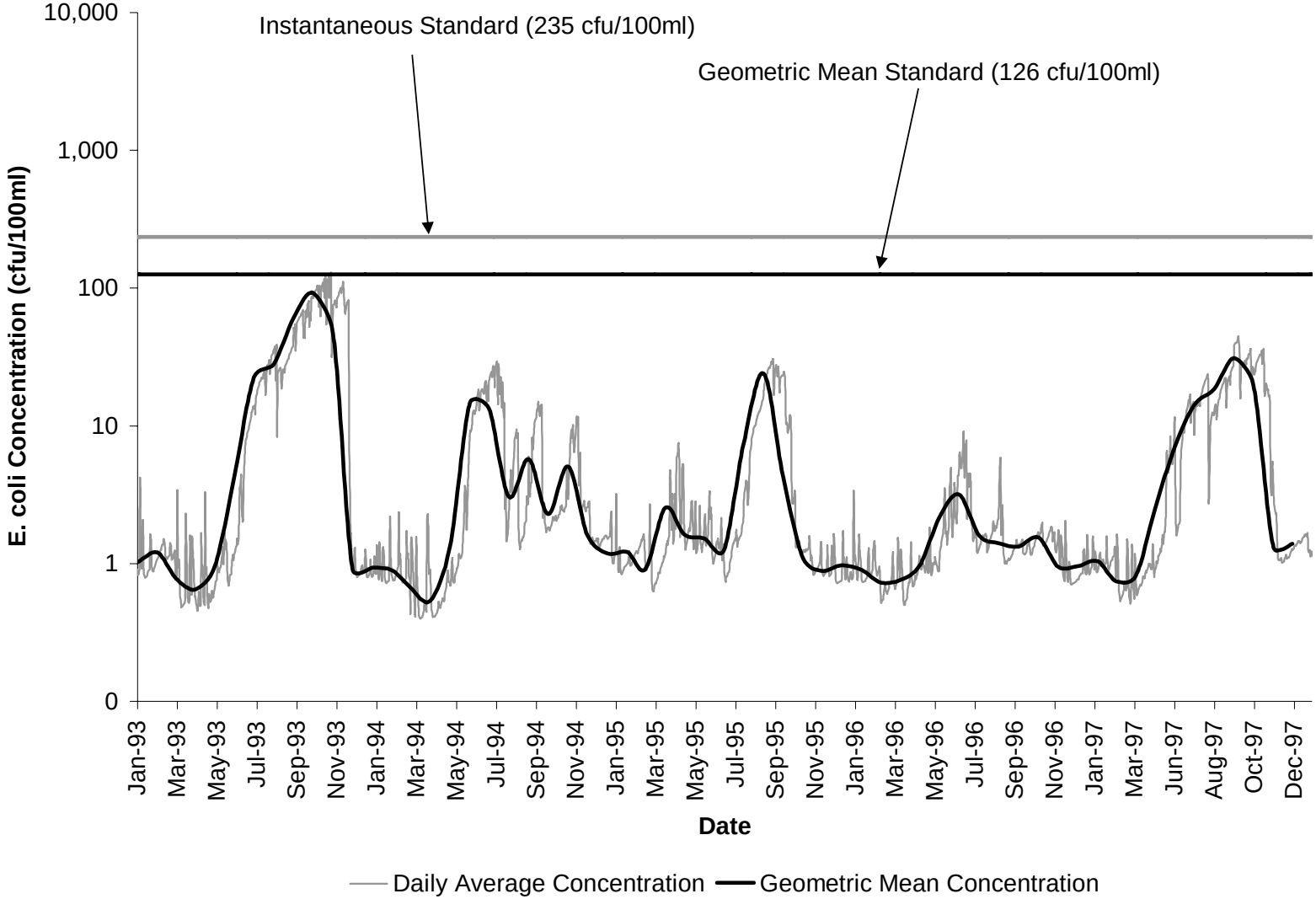

Figure 5.71. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.17) in Taylors Creek (VAN-F03R-01) impairment.

5.4.6 Newfound River (VAP-F05R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.20. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Newfound River (VAP-F05R-01) watershed. It was determined that meeting the bacteria water quality standards required a 90% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 98%. Scenario 9 represents the lowest reduction in livestock direct deposition (99%) and an attempt to lower the reduction of pasture and cropland land-based loads to 89%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 90%. Scenario 10 met the 0% violation 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 5.72 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.21 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 5.22 presents the final allocated in-stream *E. coli* loads for the Newfound River (VAP-F05R-01) impairment.

Table 5.20. TMDL allocation scenarios for Newfound River (VAP-F05R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean*	Instantaneous*
Existing Conditions	0	0	0	0	0	0	0	31.7 (19)	29.0 (530)
1	100	0	100	0	0	0	0	28.3 (17)	27.2 (497)
2	100	50	100	50	50	0	0	20.0 (12)	16.5 (301)
3	100	75	100	75	75	0	0	15.0 (9)	9.4 (172)
4	100	100	100	100	100	0	0	10.0 (6)	4.8 (88)
5	100	100	100	100	100	75	0	5.0 (3)	5.4 (99)
6	100	100	100	100	100	90	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	90	0	1.7 (1)	0.1 (3)
8	100	100	98	100	100	90	0	1.7 (1)	0.0 (0)
9	100	100	99	89	89	90	0	0.0 (0)	0.1 (1)
10	100	100	99	90	90	90	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.21. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Newfound River (VAP-F05R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.54E+12	0.00E+00	100
Livestock	9.48E+12	9.48E+10	99
Wildlife	4.50E+13	4.50E+12	90
Total	*6.40E+13*	*4.59E+12*	*93*
Land-based			
Residential	7.24E+14	0.00E+00	100
Cropland	4.10E+13	4.10E+12	90
Pasture	1.12E+16	1.12E+15	90
Forest	1.76E+14	1.76E+14	0
Total	*1.21E+16*	*1.30E+15*	*89*

Table 5.22. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Newfound River (VAP-F05R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	2.89E+10	2.89E+12	N/A	2.92E+12

N/A – not applicable because MOS was implicit.

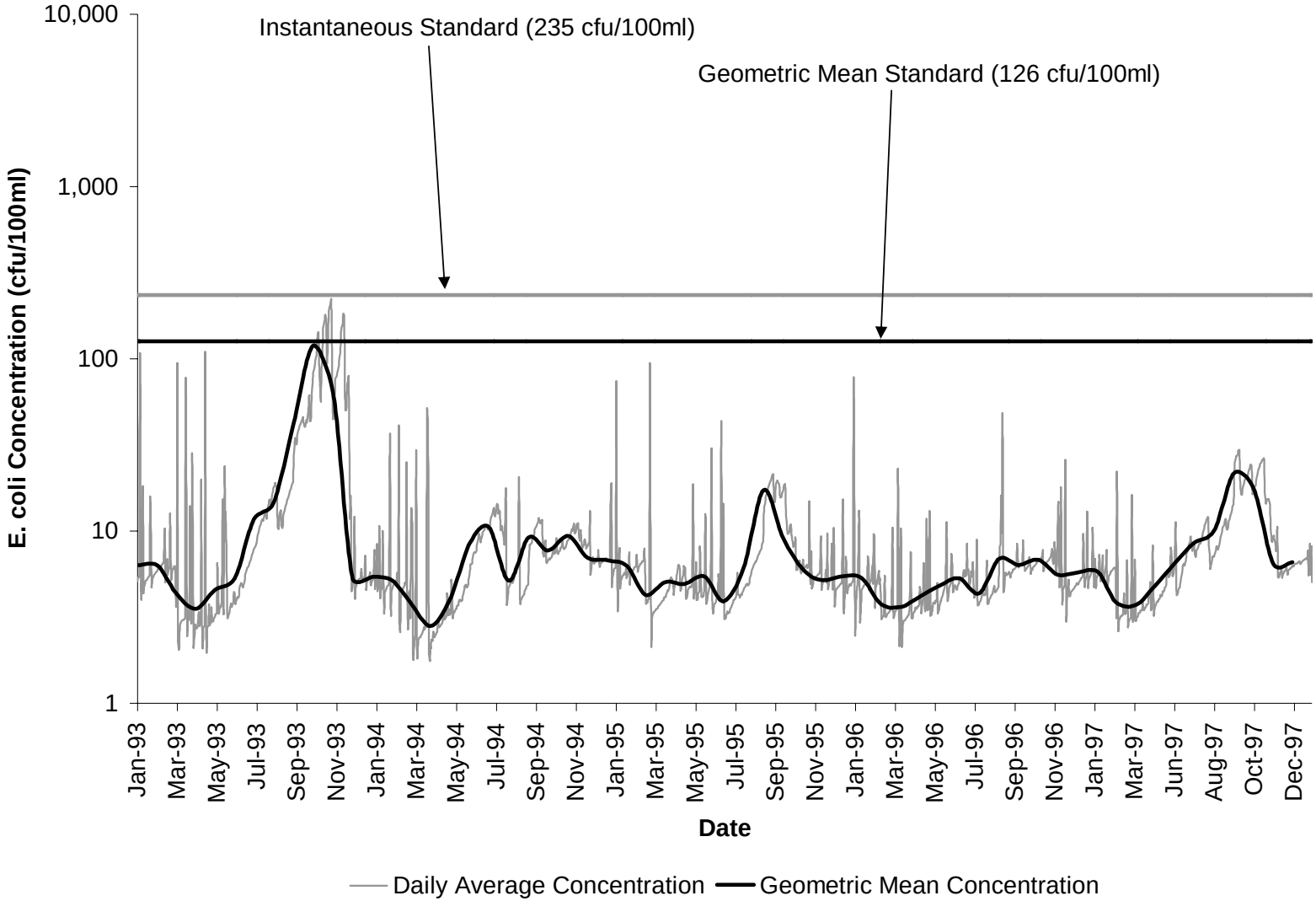

Figure 5.72. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.20) in Newfound River (VAP-F05R-01) impairment.

5.4.7 Northeast Creek (VAP-F09R-01)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.23. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Northeast Creek (VAP-F09R-01) watershed. It was determined that meeting the bacteria water quality standards required a 94% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 93%. Scenario 9 represents the lowest reduction in livestock direct deposition (94%) and an attempt to lower the reduction of pasture and cropland land-based loads to 93%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 94%. Scenario 10 met the 0% violation 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 5.73 for the final TMDL allocation (Scenario 10), 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 Northeast Creek (VAP-F09R-01) impairment.

Table 5.23. TMDL allocation scenarios for Northeast Creek (VAP-F09R-01) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	20.0 (12)	23.7 (432)
1	0	100	0	0	0	0	0	15.0 (9)	23.3 (425)
2	50	100	50	50	50	0	0	11.7 (7)	18.1 (330)
3	75	100	75	75	75	0	0	10.0 (6)	10.1 (184)
4	100	100	100	100	100	0	0	5.0 (3)	4.60 (84)
5	100	100	100	100	100	75	0	1.7 (1)	0.2 (4)
6	100	100	100	100	100	94	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	94	0	0.0 (0)	0.1 (1)
8	100	100	93	100	100	94	0	0.0 (0)	0.1 (1)
9	100	100	94	93	93	94	0	0.0 (0)	0.1 (1)
10	100	100	94	94	94	94	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.24. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Northeast Creek (VAP-F09R-01) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.25E+12	0.00E+00	100
Livestock	4.17E+12	2.50E+11	94
Wildlife	2.93E+13	1.76E+12	94
Total	*3.87E+13*	*2.01E+12*	*95*
Land-based			
Residential	5.72E+14	0.00E+00	100
Cropland	6.20E+12	3.72E+11	94
Pasture	4.12E+15	2.47E+14	94
Forest	1.38E+14	1.38E+14	0
Total	*4.84E+15*	*3.86E+14*	*92*

Table 5.25. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Northeast Creek (VAP-F09R-01) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	2.30E+10	2.30E+12	N/A	2.32E+12

N/A – not applicable because MOS was implicit.

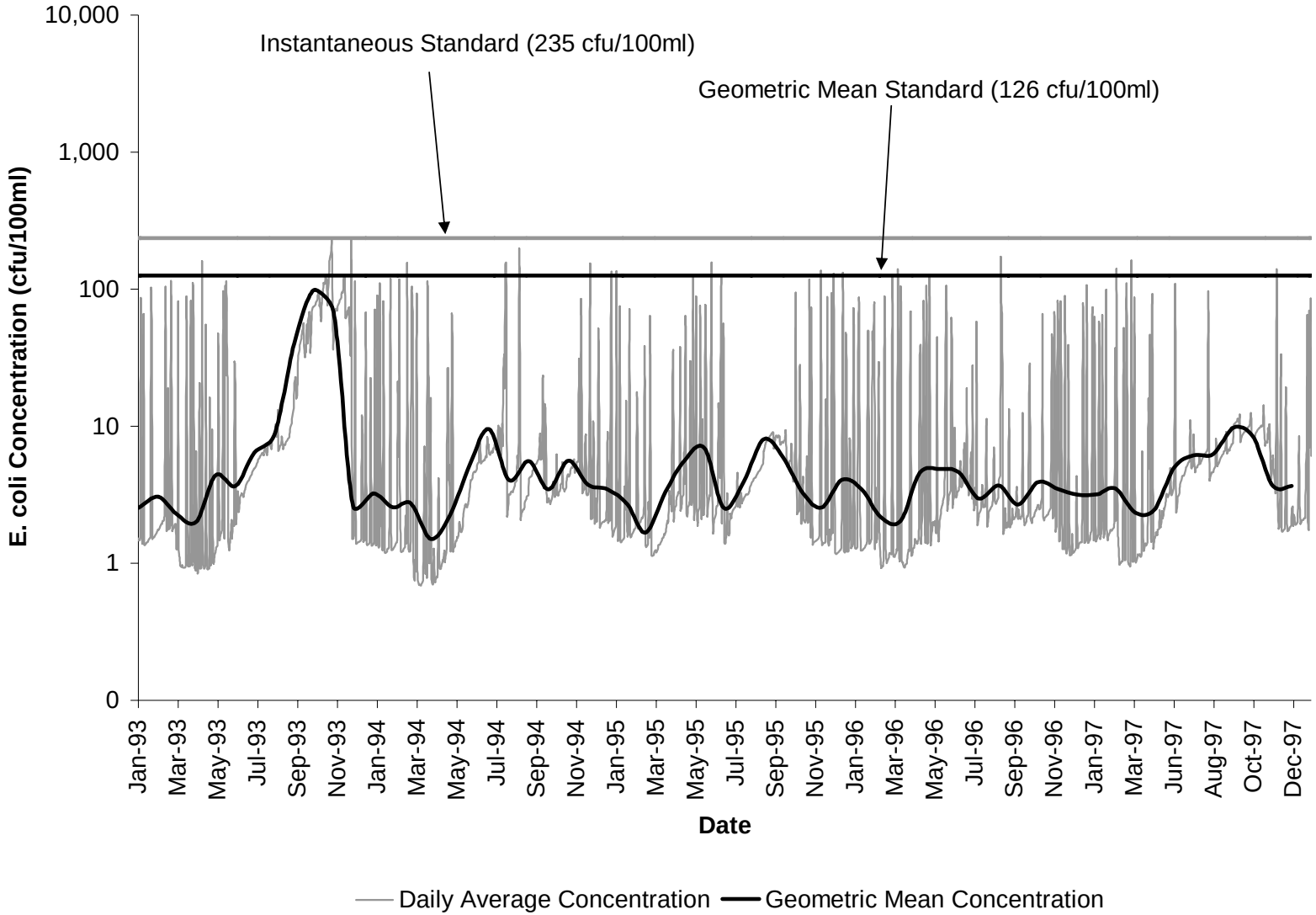

Figure 5.73. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.23) in Northeast Creek (VAP-F09R-01) impairment.

5.4.8 Totopotomoy Creek (VAP-F13R-02)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.26. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Totopotomoy Creek (VAP-F13R-02) watershed. It was determined that meeting the bacteria water quality standards required a 83% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load to 98%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 99%. Scenario 9 represents the lowest reduction in livestock direct deposition (99%) and an attempt to lower the reduction of pasture and cropland land-based loads to 82%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 83%. Scenario 10 met the 0% violation 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 5.74 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.27 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 5.28 presents the final allocated in-stream *E. coli* loads for the Totopotomoy Creek (VAP-F13R-02) impairment.

Table 5.26. TMDL allocation scenarios for Totopotomoy Creek (VAP-F13R-02) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations of E. coli Standard	
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest	Geometric Mean*	Instantaneous*
Existing Conditions	0	0	0	0	0	0	0	28.3 (17)	25.6 (467)
1	100	0	100	0	0	0	0	8.3 (5)	24.3 (444)
2	100	50	100	50	50	0	0	6.7 (4)	19.1 (349)
3	100	75	100	75	75	0	0	5.0 (3)	17.3 (315)
4	100	100	100	100	100	0	0	0.0 (0)	0.5 (9)
5	100	100	100	100	100	75	0	0.0 (0)	0.3 (5)
6	100	100	100	100	100	83	0	0.0 (0)	0.0 (0)
7	100	98	100	100	100	83	0	0.0 (0)	0.2 (4)
8	100	99	98	100	100	83	0	0.0 (0)	0.1 (1)
9	100	99	99	82	82	83	0	0.0 (0)	0.1 (1)
10	100	99	99	83	83	83	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.27. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Totopotomoy Creek (VAP-F13R-02) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.24E+13	0.00E+00	100
Livestock	4.98E+12	2.99E+11	94
Wildlife	3.46E+13	2.08E+12	94
Total	*9.20E+13*	*2.37E+12*	*97*
Land-based			
Residential	3.69E+15	0.00E+00	100
Cropland	5.21E+12	3.13E+11	94
Pasture	5.34E+15	3.20E+14	94
Forest	1.34E+14	1.34E+14	0
Total	*9.17E+15*	*4.55E+14*	*95*

Table 5.28. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Totopotomoy Creek (VAP-F13R-02) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.62E+10	1.62E+12	N/A	1.64E+12

N/A – not applicable because MOS was implicit.

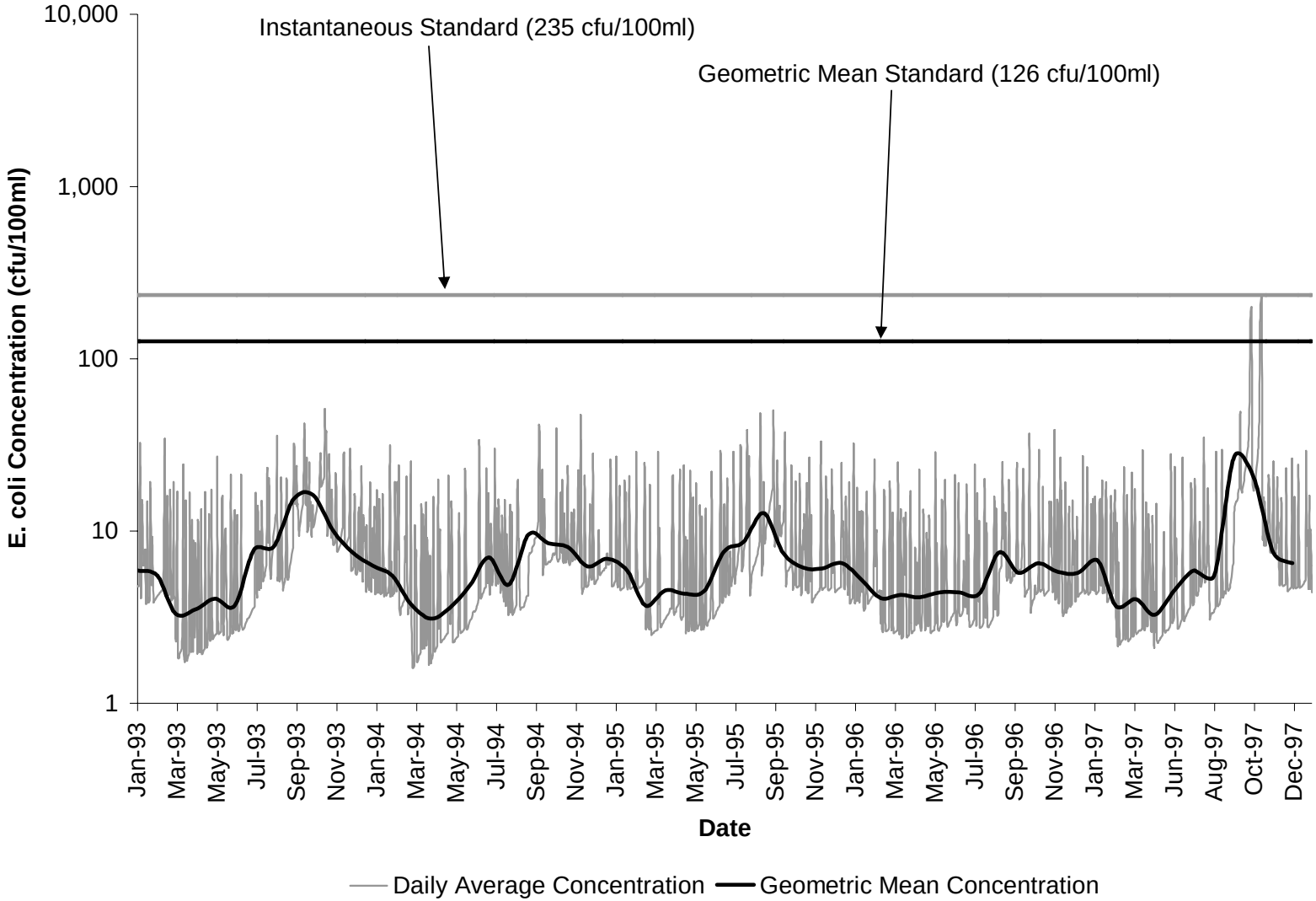

Figure 5.74. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.26) in Totopotomoy Creek (VAP-F13R-02) impairment.

5.4.9 Moncuin/Webb Creek (VAP-F13R-04)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.29. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Moncuin/Webb Creek (VAP-F13R-04) watershed. It was determined that meeting the bacteria water quality standards required a 99% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 98%. Scenario 9 represents the lowest reduction in livestock direct deposition (99%) and an attempt to lower the reduction of pasture and cropland land-based loads to 98%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 99%. Scenario 10 met the 0% violation 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 5.75 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.30 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 5.31 presents the final allocated in-stream *E. coli* loads for the Moncuin/Webb Creek (VAP-F13R-04) impairment.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Potential increases in all sources and the effect on the TMDLs for the study watersheds are discussed in Section 5.3. Discharge from the permitted point source in the Moncuin/Webb Creek (VAP-F13R-04) watershed was increased by two and five times the existing permit level to determine the effect of possible facility expansion (Table 5.32). The increases did not result in additional violations of the water quality standards.

Table 5.29. TMDL allocation scenarios for Moncuin/Webb Creek (VAP-F13R-04) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	56.7 (34)	36.0 (657)
1	100	0	100	0	0	0	0	51.7 (31)	35.5 (648)
2	100	50	100	50	50	0	0	35.0 (21)	26.1 (477)
3	100	75	100	75	75	0	0	26.7 (16)	17.2 (314)
4	100	100	100	100	100	0	0	16.7 (10)	9.6 (175)
5	100	100	100	100	100	75	0	6.7 (4)	1.9 (35)
6	100	100	100	100	100	99	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	99	0	0.0 (0)	0.1 (2)
8	100	100	98	100	100	99	0	0.0 (0)	0.1 (1)
9	100	100	99	98	98	99	0	0.0 (0)	0.2 (4)
10	100	100	99	99	99	99	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.30. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Moncuin/Webb Creek (VAP-F13R-04) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.31E+13	0.00E+00	100
Livestock	2.97E+12	2.97E+10	99
Wildlife	2.90E+13	2.90E+11	99
Total	*4.51E+13*	*3.20E+11*	*99*
Land-based			
Residential	3.07E+14	0.00E+00	100
Cropland	2.30E+13	2.30E+11	99
Pasture	2.83E+15	2.83E+13	99
Forest	1.44E+14	1.44E+14	0
Total	*3.30E+15*	*1.73E+14*	*95*

Table 5.31. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Moncuin/Webb Creek (VAP-F13R-04) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	8.71E+10	1.81E+11	N/A	2.68E+11

N/A – not applicable because MOS was implicit.

Table 5.32. Expansion matrix for WLA in the Moncuin/Webb Creek (VAP-F13R-04) watershed.

Permit Number	Sub-shed	Design Flow (MGD)	Effluent Limit (cfu/100ml)	Wasteload Allocation (cfu/yr)
VA0088102	PAR-6	0.050	126	8.71E10
Existing WLA		0.050	126	8.71E10
Expansion Scenario: 2 x Existing WLA		0.100	126	1.74E11
Expansion Scenario: 5 x Existing WLA		0.250	126	4.35E11

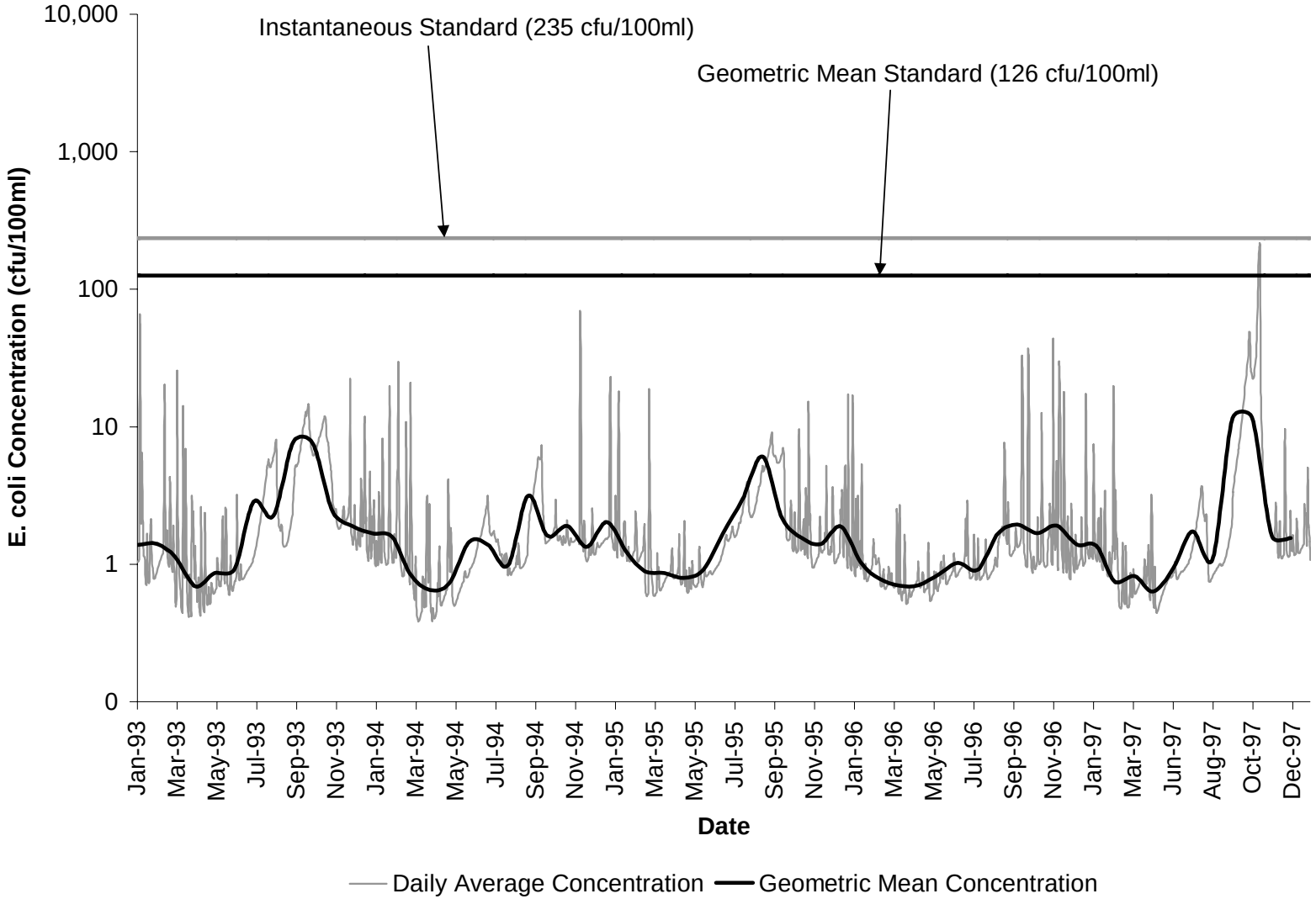

Figure 5.75. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.29) in Moncuin/Webb Creek (VAP-F13R-04) impairment.

5.4.10 Black Creek (VAP-F13R-05)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.33. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Black Creek (VAP-F13R-05) watershed. It was determined that meeting the bacteria water quality standards required a 83% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 82%. Scenario 9 represents the lowest reduction in livestock direct deposition (83%) and an attempt to lower the reduction of pasture and cropland land-based loads to 82%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 83%. Scenario 10 met the 0% violation 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 5.76 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.34 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 5.35 presents the final allocated in-stream *E. coli* loads for the Black Creek (VAP-F13R-05) impairment.

Table 5.33. TMDL allocation scenarios for Black Creek (VAP-F13R-05) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	36.7 (22)	30.9 (565)
1	100	0	100	0	0	0	0	35.0 (21)	30.9 (564)
2	100	50	100	50	50	0	0	21.7 (13)	16.2 (296)
3	100	75	100	75	75	0	0	16.7 (10)	8.9 (164)
4	100	100	100	100	100	0	0	8.3 (5)	2.5 (45)
5	100	100	100	100	100	75	0	0.0 (0)	0.2 (4)
6	100	100	100	100	100	83	0	0.0 (0)	0.0 (0)
7	100	99	100	100	100	83	0	0.0 (0)	0.1 (2)
8	100	100	82	100	100	83	0	0.0 (0)	0.1 (1)
9	100	100	83	82	82	83	0	0.0 (0)	0.1 (1)
10	100	100	83	83	83	83	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.34. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Black Creek (VAP-F13R-05) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.95E+12	0.00E+00	100
Livestock	1.72E+12	2.92E+11	83
Wildlife	3.65E+13	6.21E+12	83
Total	*4.02E+13*	*6.50E+12*	*84*
Land-based			
Residential	6.13E+14	0.00E+00	100
Cropland	8.75E+12	1.49E+12	83
Pasture	1.70E+15	2.89E+14	83
Forest	2.05E+14	2.05E+14	0
Total	*2.53E+15*	*4.95E+14*	*80*

Table 5.35. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Black Creek (VAP-F13R-05) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	1.26E+10	1.26E+12	N/A	1.27E+12

N/A – not applicable because MOS was implicit.

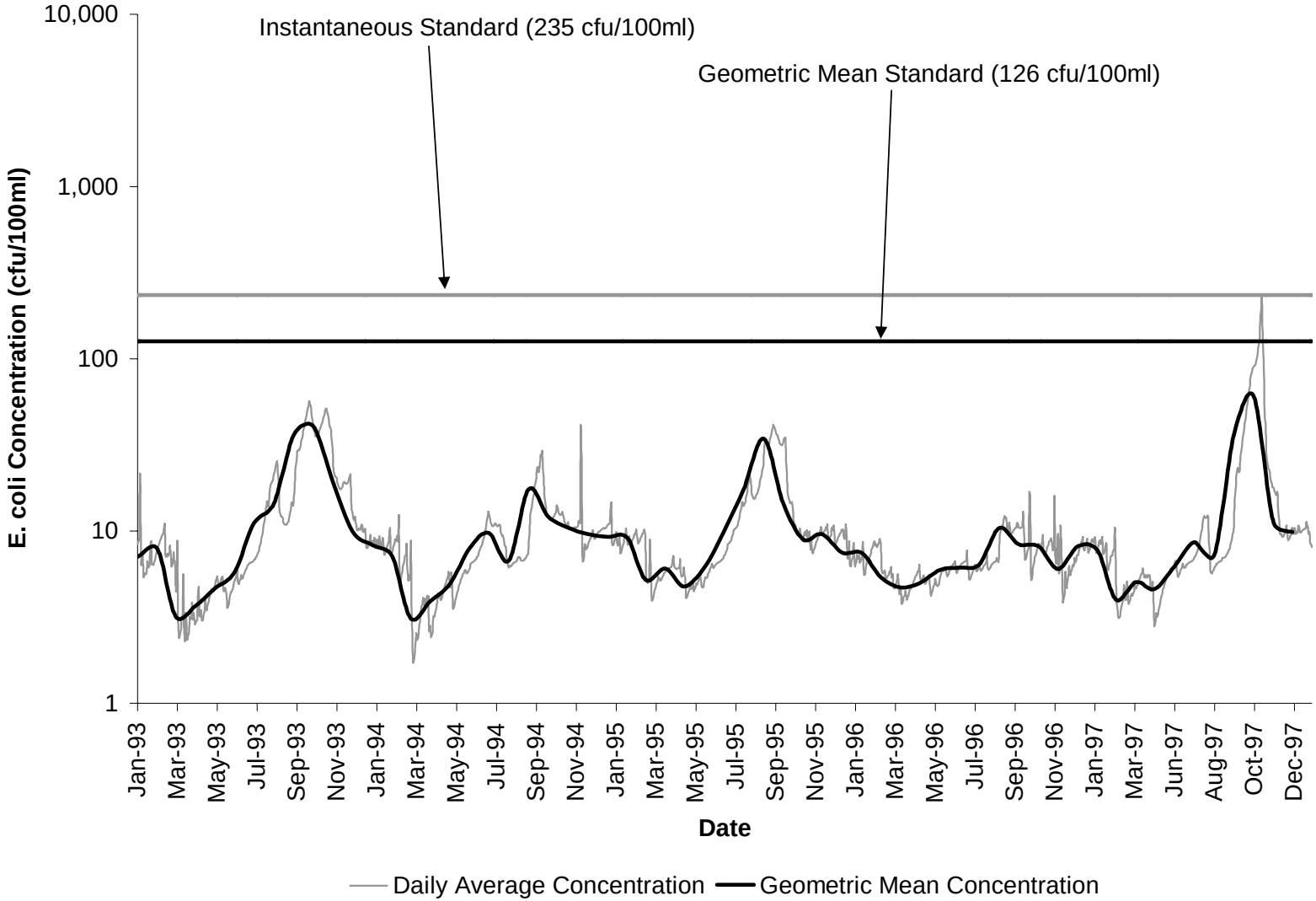

Figure 5.76. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.32) in Black Creek (VAP-F13R-05) impairment.

5.4.11 Pamunkey River (VAP-F13E-02)

Formulations of Scenarios 1 through 5 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.36. Scenario 6 represents the determination of required reductions in wildlife loads (directly deposited and forest land-based) in the Pamunkey River (VAP-F13E-02) watershed. It was determined that meeting the bacteria water quality standards required a 83% reduction of directly deposited wildlife load, but no reduction in forest land-based load. Scenario 7 represents an attempt to lower the reduction of residential land based load, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 8 represents attempts to lower the livestock direct deposition load to 82%. Scenario 9 represents the lowest reduction in livestock direct deposition (83%) and an attempt to lower the reduction of pasture and cropland land-based loads to 82%, which resulted in violations of the bacteria water quality standard at the watershed outlet. Scenario 10 represents the last in a series of scenarios intended to determine the required reduction in pasture and cropland land-based loads, which was 83%. Scenario 10 met the 0% violation 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 5.77 for the final TMDL allocation (Scenario 10), along with the geometric mean and instantaneous standards. Table 5.37 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 5.38 presents the final allocated in-stream *E. coli* loads for the Pamunkey River (VAP-F13E-02) impairment.

Table 5.36. TMDL allocation scenarios for Pamunkey River (VAP-F13E-02) impairment.

Scenario Number	Percent Reduction in Fecal Coliform Loading from Existing Conditions							% Violations 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	25.0 (15)	34.7 (633)
1	100	0	100	0	0	0	0	13.3 (8)	33.2 (606)
2	100	50	100	50	50	0	0	10.0 (6)	29.1 (531)
3	100	75	100	75	75	0	0	5.0 (3)	13.3 (243)
4	100	100	100	100	100	0	0	1.7 (1)	0.5 (9)
5	100	100	100	100	100	75	0	0.0 (0)	0.3 (5)
6	100	100	100	100	100	83	0	0.0 (0)	0.0 (0)
7	100	98	100	100	100	83	0	0.0 (0)	0.2 (4)
8	100	99	98	100	100	83	0	0.0 (0)	0.1 (1)
9	100	99	99	82	82	83	0	0.0 (0)	0.1 (1)
10	100	99	99	83	83	83	0	0.0 (0)	0.0 (0)

* Number of violations is in parentheses.

Table 5.37. Annual nonpoint source fecal coliform loads for existing conditions and final allocation along with corresponding reductions in Pamunkey River (VAP-F13E-02) impairment.

Source	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.32E+13	0.00E+00	100
Livestock	1.14E+13	1.94E+12	83
Wildlife	1.07E+14	1.82E+13	83
Total	*1.52E+14*	*2.01E+13*	*87*
Land-based			
Residential	1.83E+15	0.00E+00	100
Cropland	3.42E+13	5.81E+12	83
Pasture	1.18E+16	2.01E+15	83
Forest	4.73E+14	4.73E+14	0
Total	*1.41E+16*	*2.48E+15*	*82*

Table 5.38. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Pamunkey River (VAP-F13E-02) impairment.

Pollutant	WLA (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
E. coli	7.40E+12	7.40E+14	N/A	7.47E+14

N/A – not applicable because MOS was implicit.

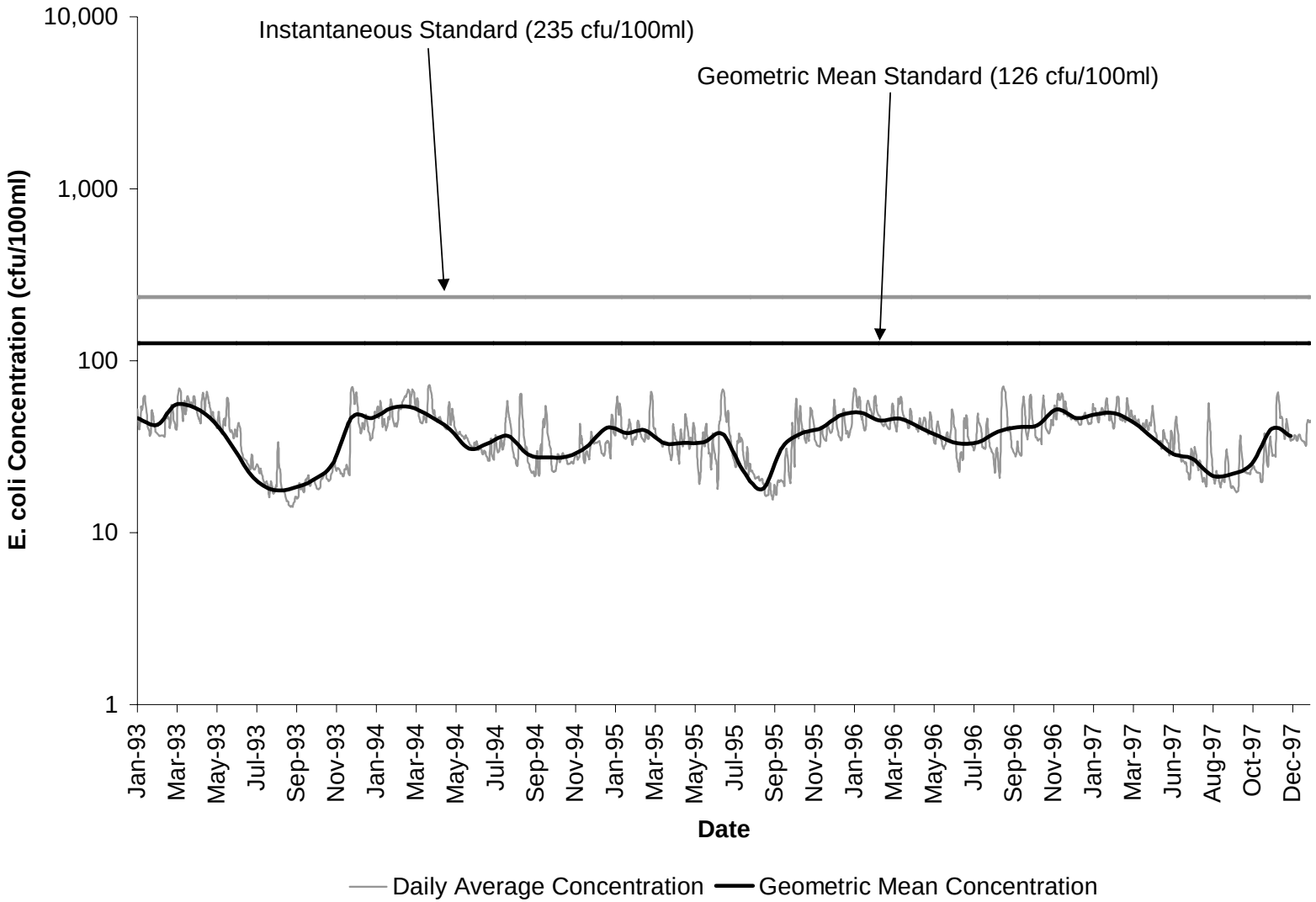

Figure 5.77. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 10 from Table 5.35) in Pamunkey River (VAP-F13E-02) impairment.

Chapter 6. TMDL Implementation and Reasonable Assurance

Once a TMDL has been approved by USEPA, measures must be taken to reduce pollution levels from both point and non point sources in the stream (see section 7.4.2). 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 violations 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 violation rate is a conservative estimate of the extent of implementation needed to have each impaired segment de-listed, currently; a less than 10.5% violation 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 6.2.11.

6.2.1 South Anna River (VAN-F01R-01)

The Stage 1 allocation for the South Anna River (VAN-F01R-01) impairment requires a 100% reduction in straight pipes, 95% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 95% reduction in nonpoint source loadings to residential land use, a 95% reduction in nonpoint source loadings to pasture land use, a 95% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.58% instantaneous standard violation 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 South Anna River (VAN-F01R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.1.

Table 6.1. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in South Anna River (VAN-F01R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.19E+12	0.00E+00	100
Livestock	6.52E+12	3.26E+11	95
Wildlife	5.37E+12	5.37E+12	0
Total	*1.51E+13*	*5.70E+12*	*62*
Land-based			
Residential	1.34E+14	6.70E+12	95
Cropland	1.09E+12	5.45E+10	95
Pasture	7.15E+15	3.58E+14	95
Forest	2.52E+13	2.52E+13	0
Total	*7.31E+15*	*3.89E+14*	*95*

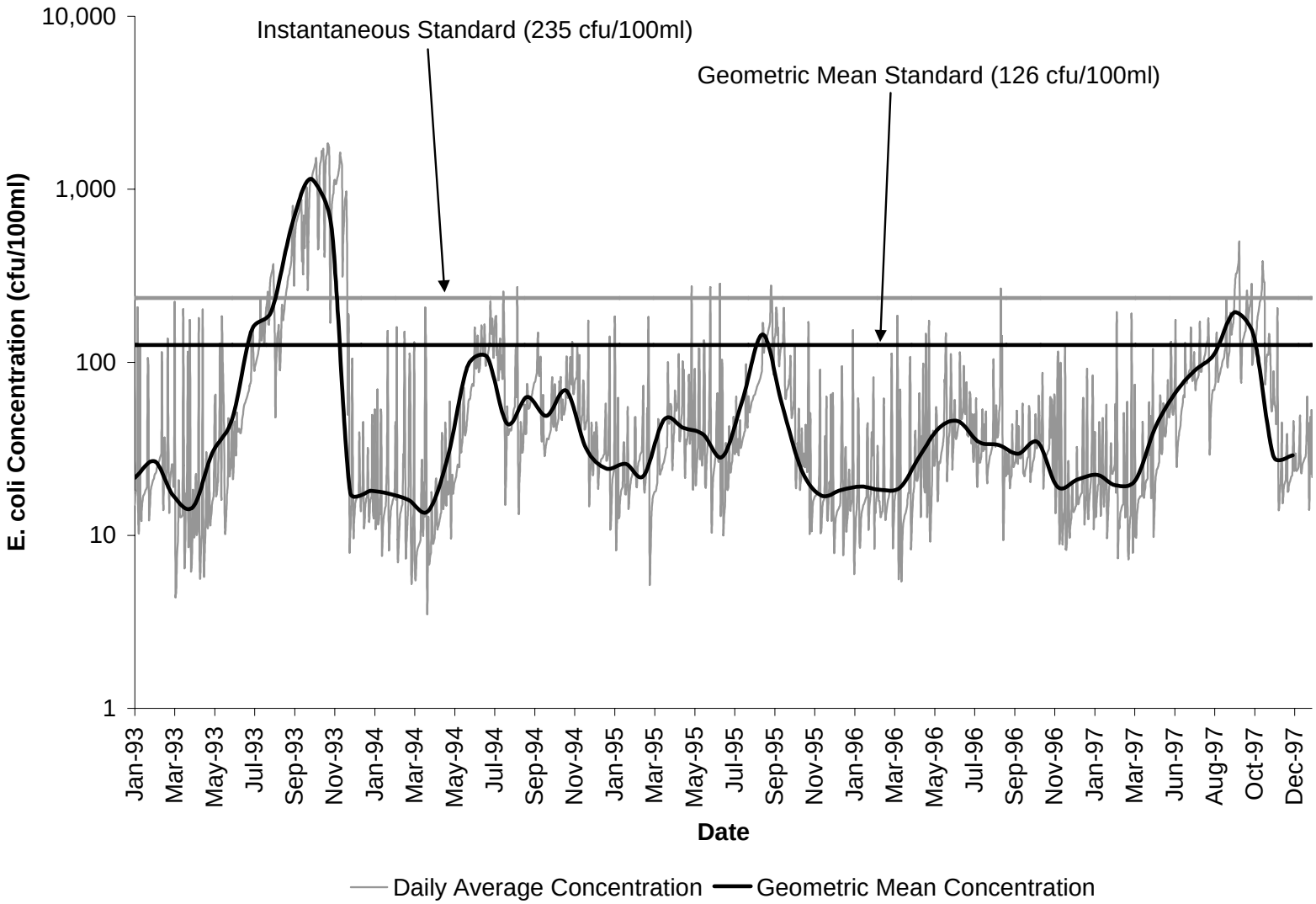

Figure 6.1. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in South Anna River (VAN-F01R-01) impairment.

6.2.2 South Anna River (VAN-F02R-01)

The Stage 1 allocation for the South Anna River (VAN-F02R-01) impairment requires a 100% reduction in straight pipes, 89% reduction in livestock direct deposition, a 0% reduction in wildlife direct deposition, a 89% 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 violation 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 South Anna River (VAN-F02R-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 South Anna River (VAN-F02R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.00E+13	0.00E+00	100
Livestock	4.05E+13	4.46E+12	89
Wildlife	7.69E+13	7.69E+13	0
Total	*1.47E+14*	*8.14E+13*	*45*
Land-based			
Residential	2.00E+15	2.20E+14	89
Cropland	1.18E+14	1.30E+13	89
Pasture	3.91E+16	4.30E+15	89
Forest	4.09E+14	4.09E+14	0
Total	*4.16E+16*	*4.94E+15*	*88*

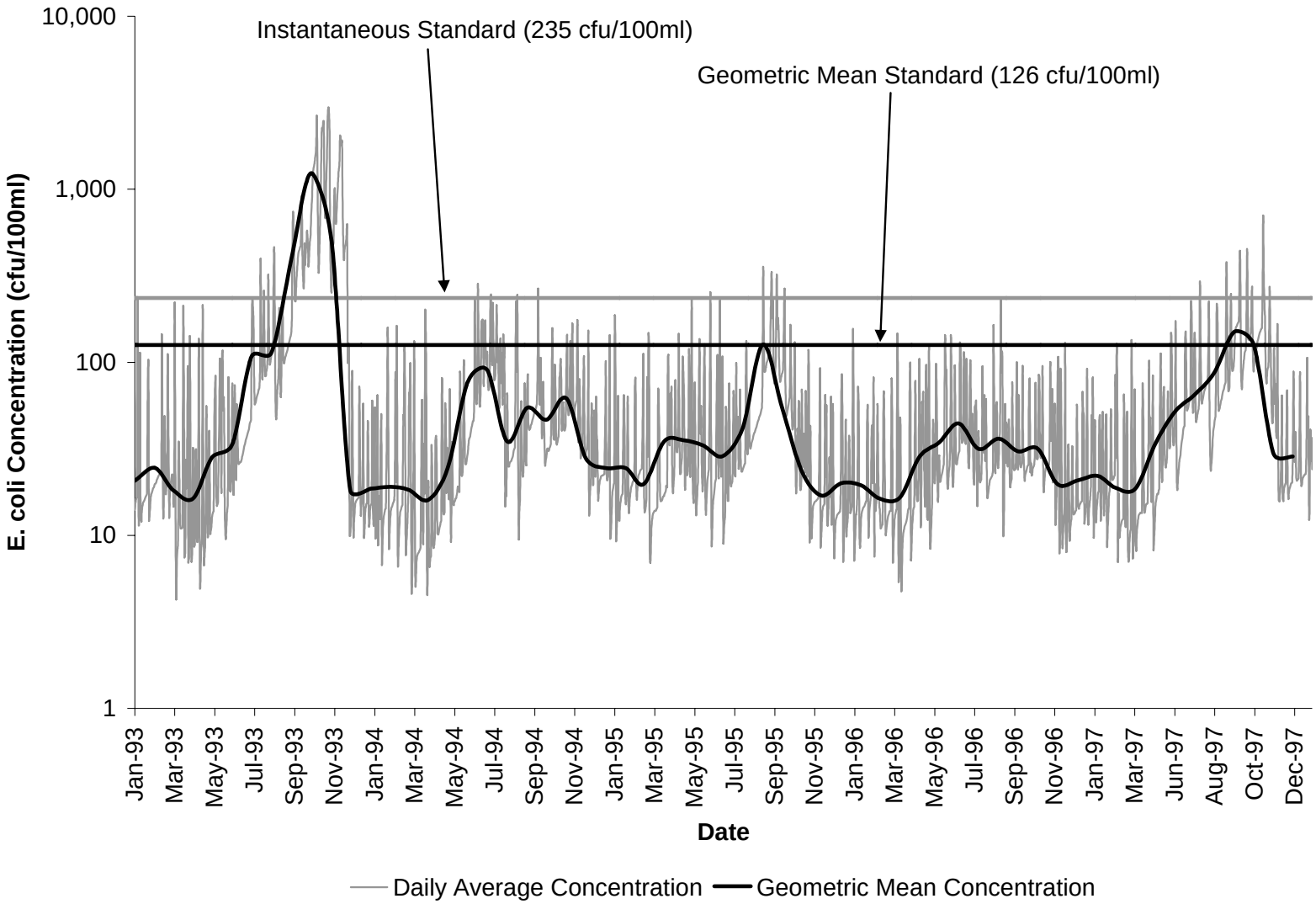

Figure 6.2. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in South Anna River (VAN-F02R-01)impairment.

6.2.3 South Anna River (VAP-F04R-01)

The Stage 1 allocation for the South Anna River (VAP-F04R-01) impairment requires a 100% reduction in straight pipes, 60% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 60% reduction in nonpoint source loadings to residential land use, a 60% reduction in nonpoint source loadings to pasture land use, a 60% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.97% instantaneous standard violation 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 South Anna River (VAP-F04R-01) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.3.

Table 6.3. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in South Anna River (VAP-F04R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	6.85E+13	0.00E+00	100
Livestock	6.01E+13	2.40E+13	60
Wildlife	1.73E+14	1.73E+14	0
Total	*3.02E+14*	*1.97E+14*	*35*
Land-based			
Residential	4.23E+15	1.69E+15	60
Cropland	1.13E+15	4.52E+14	60
Pasture	6.16E+16	2.46E+16	60
Forest	8.05E+14	8.05E+14	0
Total	*6.78E+16*	*2.76E+16*	*59*

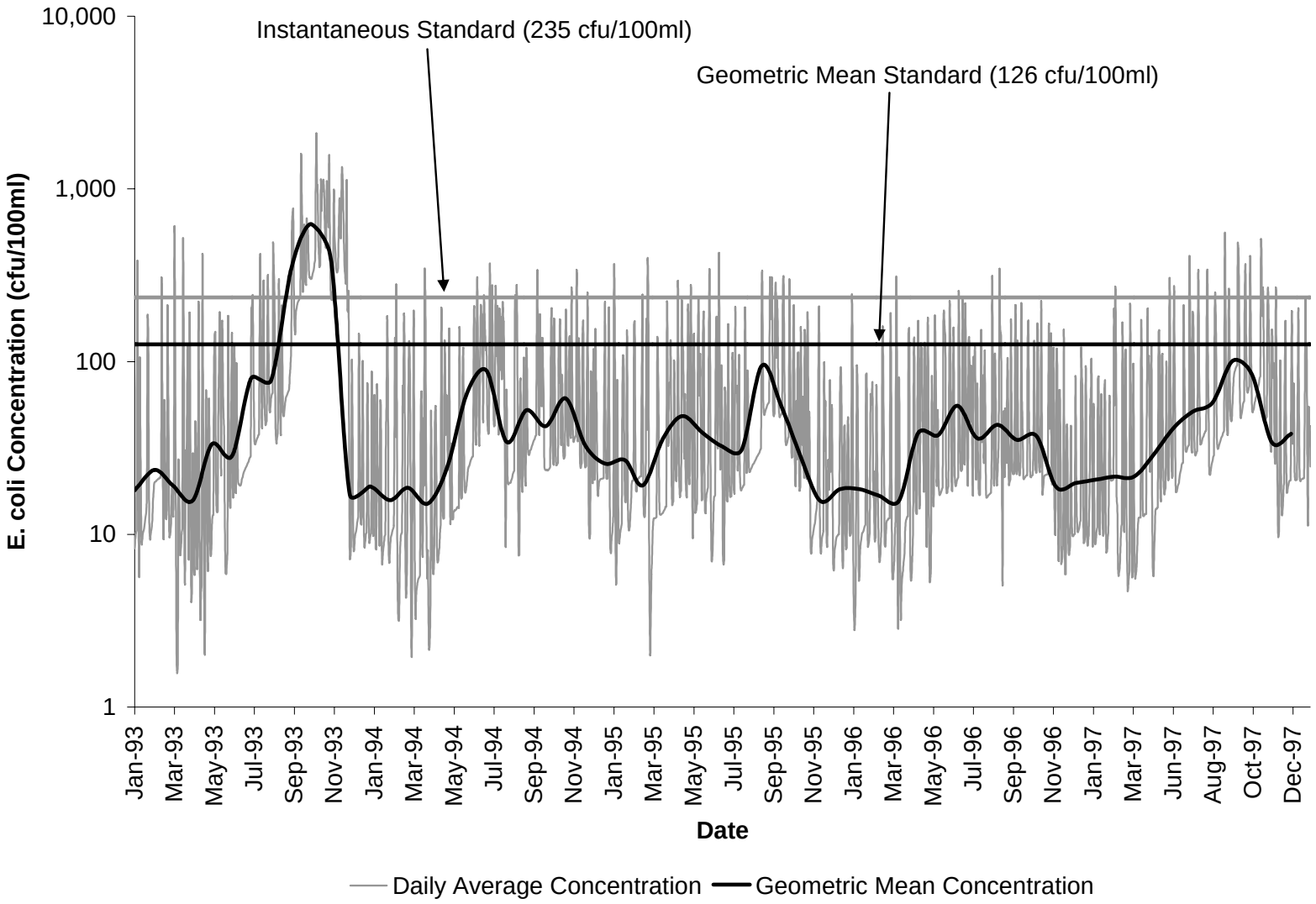

Figure 6.3. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in South Anna River (VAP-F04R-01) impairment.

6.2.4 South Anna River (VAP-F04R-02)

The Stage 1 allocation for the South Anna River (VAP-F04R-02) impairment requires a 100% reduction in straight pipes, 70% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 70% reduction in nonpoint source loadings to residential land use, a 70% reduction in nonpoint source loadings to pasture land use, a 70% 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 violation 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 South Anna River (VAP-F04R-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 South Anna River (VAP-F04R-02) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.27E+12	0.00E+00	100
Livestock	3.73E+12	1.12E+12	70
Wildlife	1.58E+13	1.58E+13	0
Total	*2.18E+13*	*1.69E+13*	*22*
Land-based			
Residential	8.10E+14	2.43E+14	70
Cropland	2.52E+13	7.56E+12	70
Pasture	4.71E+15	1.41E+15	70
Forest	5.27E+13	5.27E+13	0
Total	*5.60E+15*	*1.72E+15*	*69*

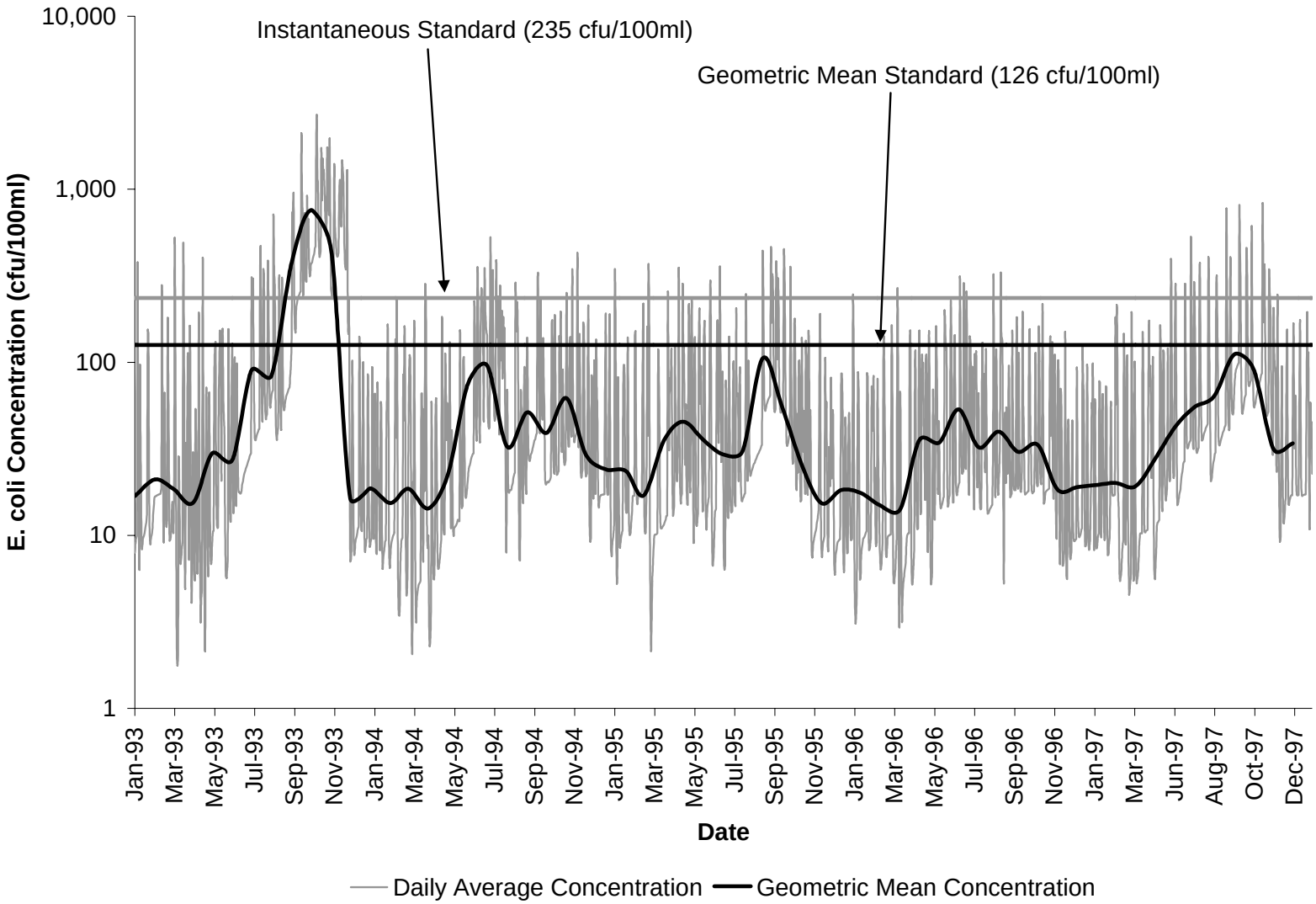

Figure 6.4. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in South Anna River (VAP-F04R-02) impairment.

6.2.5 Taylors Creek (VAN-F03R-01)

The Stage 1 allocation for the Taylors Creek (VAN-F03R-01) impairment requires a 100% reduction in straight pipes, 97% reduction in livestock direct deposition, 58% reduction in wildlife direct deposition, a 100% reduction in nonpoint source loadings to residential and pasture land uses, a 99% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.86% instantaneous standard violation 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 Taylors Creek (VAN-F03R-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 Taylors Creek (VAN-F03R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.07E+12	0.00E+00	100
Livestock	7.20E+12	2.16E+11	97
Wildlife	3.24E+13	1.36E+13	58
Total	*4.87E+13*	*1.38E+13*	*72*
Land-based			
Residential	7.34E+14	0.00E+00	100
Cropland	4.68E+12	4.68E+10	99
Pasture	7.24E+15	0.00E+00	100
Forest	1.44E+14	1.44E+14	0
Total	*8.12E+15*	*1.44E+14*	*98*

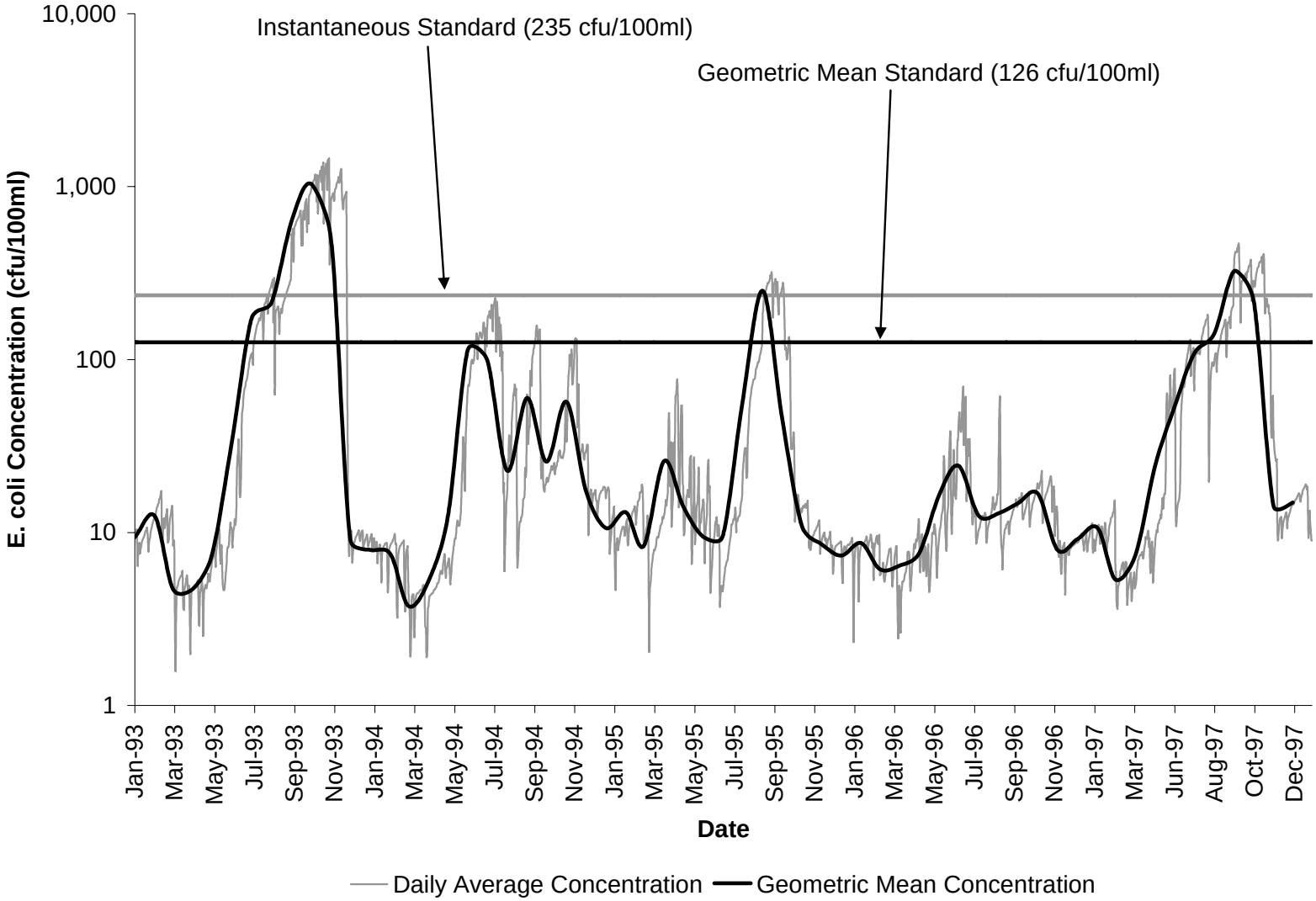

Figure 6.5. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Taylors Creek (VAN-F03R-01) impairment.

6.2.6 Newfound River (VAP-F05R-01)

The Stage 1 allocation for the Newfound River (VAP-F05R-01) impairment requires a 100% reduction in straight pipes, 91% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 91% 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 9.36% instantaneous standard violation 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 Newfound River (VAP-F05R-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 Newfound River (VAP-F05R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	9.54E+12	0.00E+00	100
Livestock	9.48E+12	8.53E+11	91
Wildlife	4.50E+13	4.50E+13	0
Total	*6.40E+13*	*4.59E+13*	*28*
Land-based			
Residential	7.24E+14	6.52E+13	91
Cropland	4.10E+13	3.69E+12	91
Pasture	1.12E+16	1.01E+15	91
Forest	1.76E+14	1.76E+14	0
Total	*1.21E+16*	*1.25E+15*	*90*

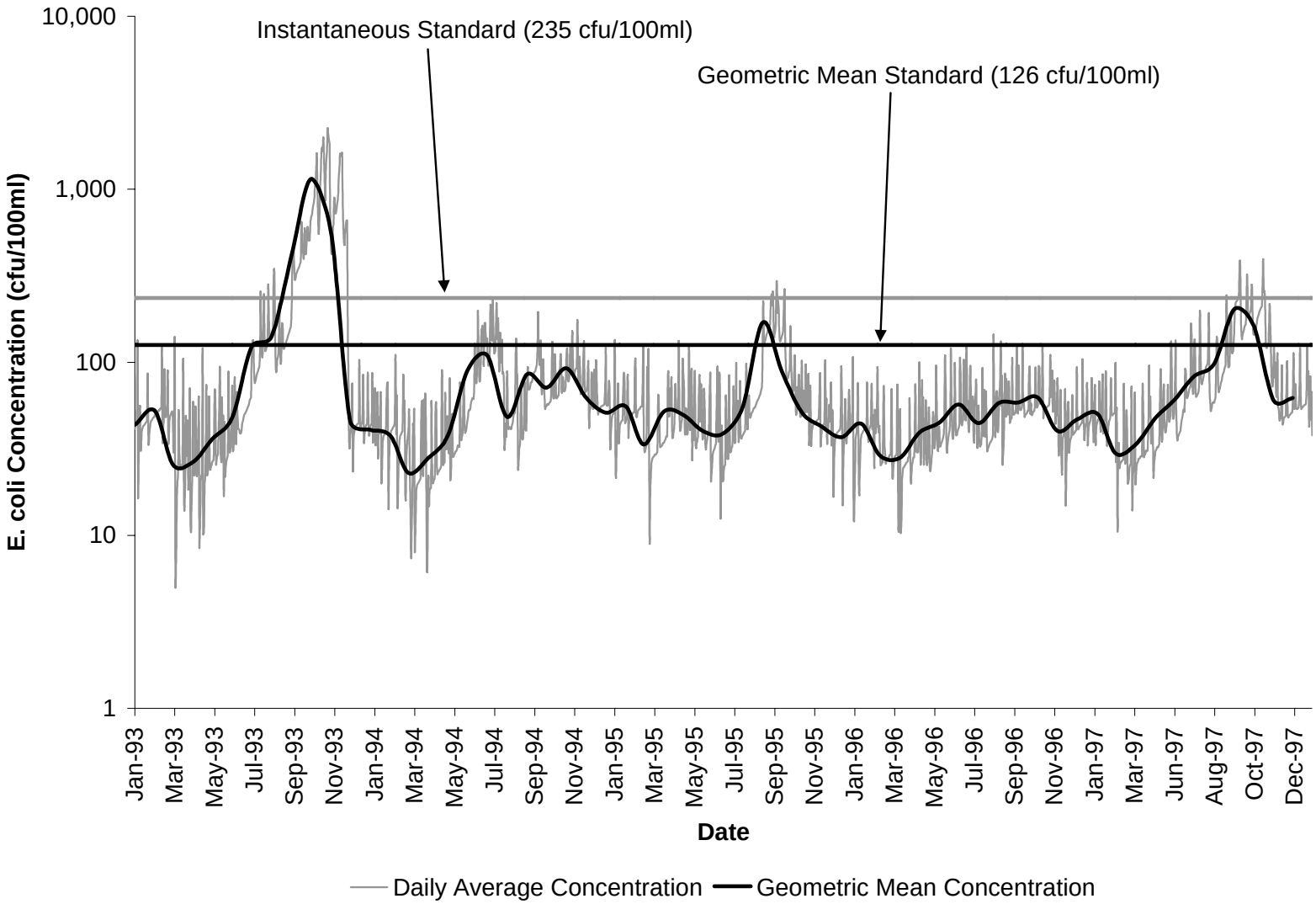

Figure 6.6. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Newfound River (VAP-F05R-01) impairment.

6.2.7 Northeast Creek (VAP-F09R-01)

The Stage 1 allocation for the Northeast Creek (VAP-F09R-01) impairment requires a 100% reduction in straight pipes, 76% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 76% reduction in nonpoint source loadings to residential land use, a 76% reduction in nonpoint source loadings to pasture land use, a 76% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.86% instantaneous standard violation rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.7 for the Northeast Creek (VAP-F09R-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 6.7.

Table 6.7. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Northeast Creek (VAP-F09R-01) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.25E+12	0.00E+00	100
Livestock	4.17E+12	1.00E+12	76
Wildlife	2.93E+13	2.93E+13	0
Total	*3.87E+13*	*3.03E+13*	*22*
Land-based			
Residential	5.72E+14	1.37E+14	76
Cropland	6.20E+12	1.49E+12	76
Pasture	4.12E+15	9.89E+14	76
Forest	1.38E+14	1.38E+14	0
Total	*4.84E+15*	*1.27E+15*	*74*

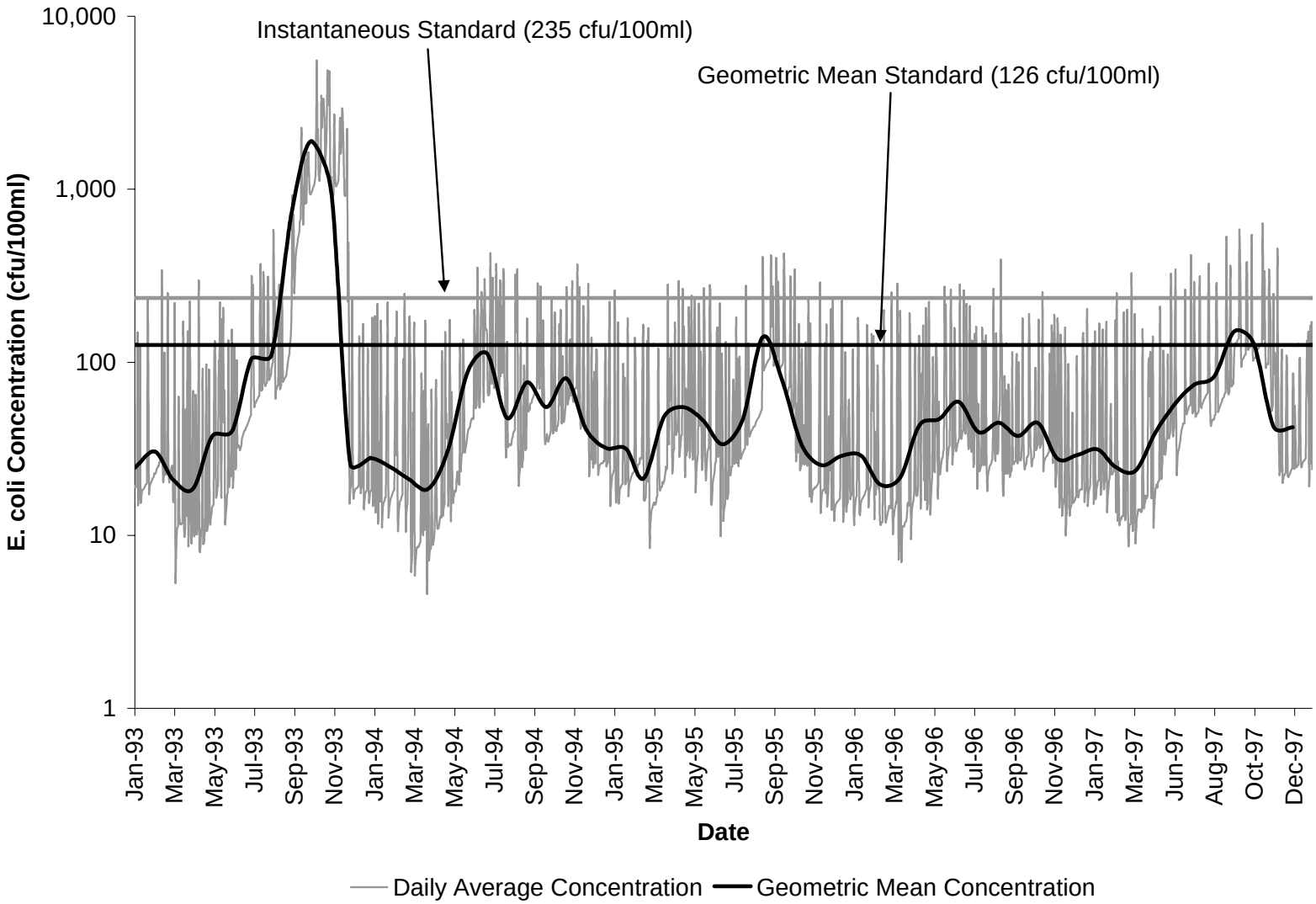

Figure 6.7. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Northeast Creek (VAP-F09R-01) impairment.

6.2.8 Totopotomoy Creek (VAP-F13R-02)

The Stage 1 allocation for the Totopotomoy Creek (VAP-F13R-02) impairment requires a 100% reduction in straight pipes, 94% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 90% reduction in nonpoint source loadings to residential land use, a 90% reduction in nonpoint source loadings to pasture land use, a 90% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.97% instantaneous standard violation rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.8 for the Totopotomoy Creek (VAP-F13R-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 6.8.

Table 6.8. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Totopotomoy Creek (VAP-F13R-02) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	5.24E+13	0.00E+00	100
Livestock	4.98E+12	2.99E+11	94
Wildlife	3.46E+13	3.46E+13	0
Total	*9.20E+13*	*3.49E+13*	*62*
Land-based			
Residential	3.69E+15	3.69E+14	90
Cropland	5.21E+12	5.21E+11	90
Pasture	5.34E+15	5.34E+14	90
Forest	1.34E+14	1.34E+14	0
Total	*9.17E+15*	*1.04E+15*	*89*

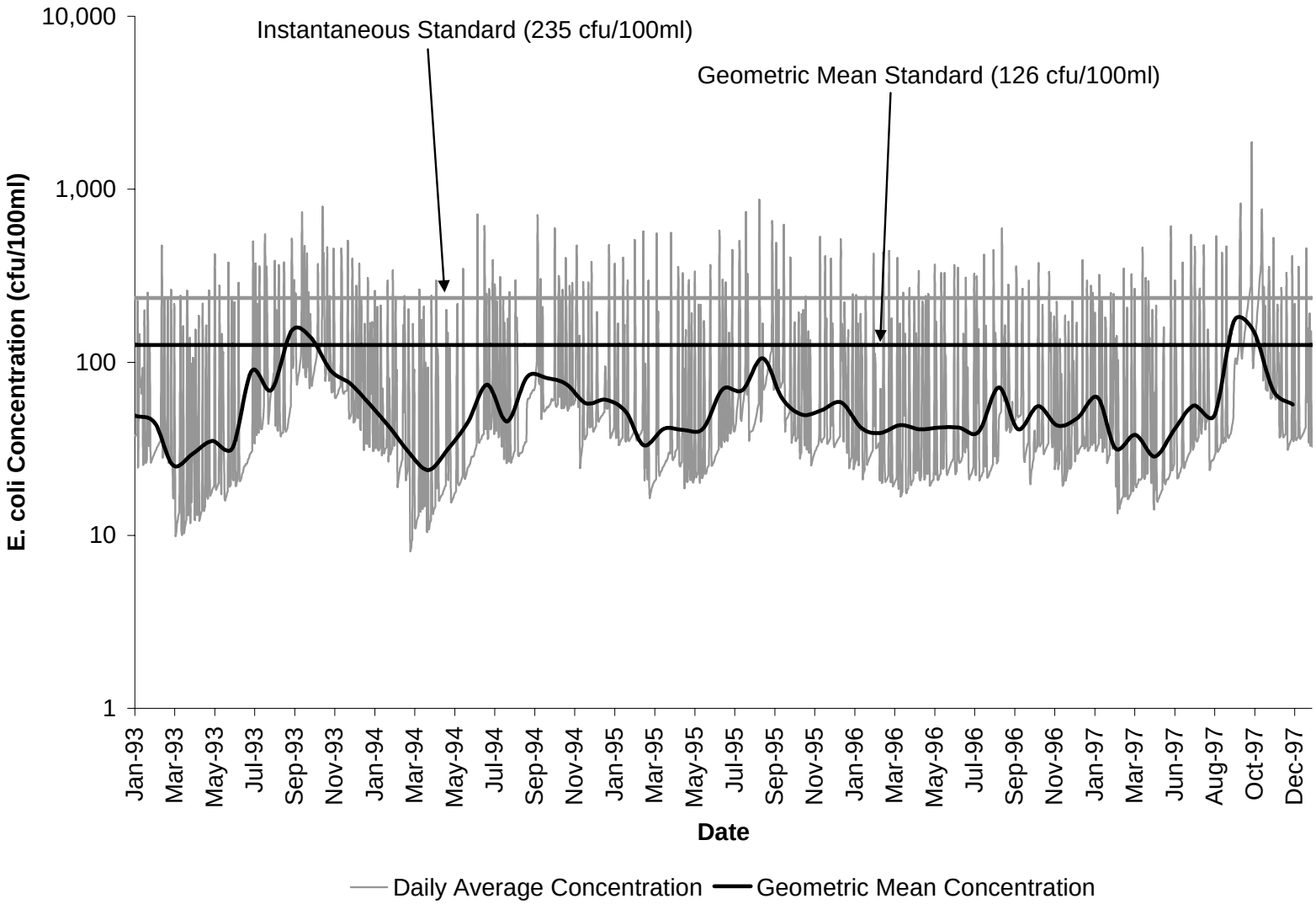

Figure 6.8. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Totopotomoy Creek (VAP-F13R-02) impairment.

6.2.9 Moncuin/Webb Creek (VAP-F13R-04)

The Stage 1 allocation for the Moncuin/Webb Creek (VAP-F13R-04) impairment requires a 100% reduction in straight pipes, 98% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 98% reduction in nonpoint source loadings to residential land use, a 98% reduction in nonpoint source loadings to pasture land use, a 98% 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 violation rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.9 for the Moncuin/Webb Creek (VAP-F13R-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 6.9.

Table 6.9. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Moncuin/Webb Creek (VAP-F13R-04) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.31E+13	0.00E+00	100
Livestock	2.39E+12	4.78E+10	98
Wildlife	2.90E+13	2.90E+13	0
Total	*4.45E+13*	*2.90E+13*	*35*
Land-based			
Residential	3.07E+14	6.14E+12	98
Cropland	2.30E+13	4.60E+11	98
Pasture	2.83E+15	5.66E+13	98
Forest	1.44E+14	1.44E+14	0
Total	*3.30E+15*	*2.07E+14*	*94*

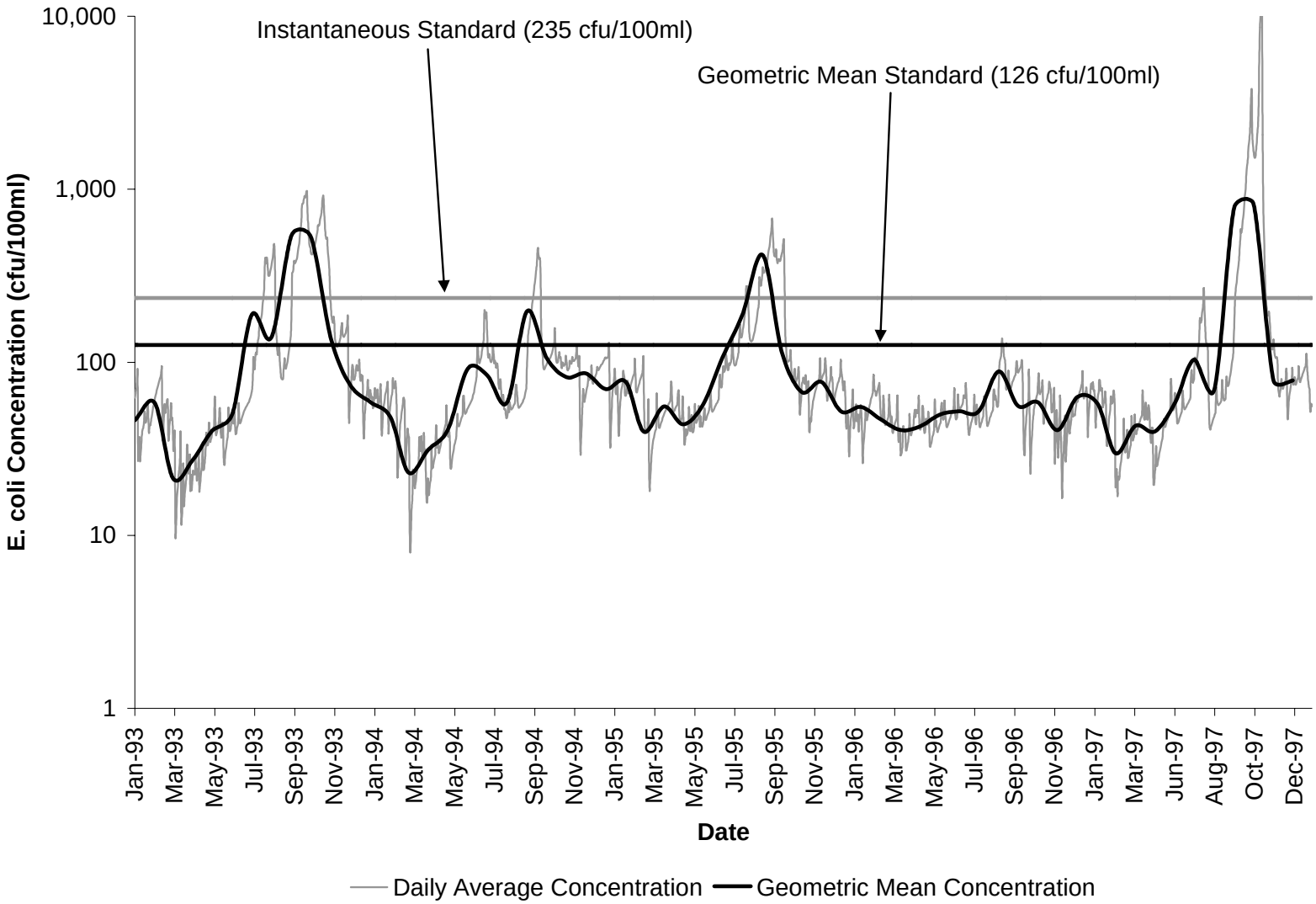

Figure 6.9. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Moncuin/Webb Creek (VAP-F13R-04) impairment.

6.2.10 Black Creek (VAP-F13R-05)

The Stage 1 allocation for the Black Creek (VAP-F13R-05) impairment requires a 100% reduction in straight pipes, 70% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 70% reduction in nonpoint source loadings to residential land use, a 70% reduction in nonpoint source loadings to pasture land use, a 70% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.47% instantaneous standard violation rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.10 for the Black Creek (VAP-F13R-05) impairment. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform loads from the Stage 1 scenario are presented graphically in Figure 6.10.

Table 6.10. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Black Creek (VAP-F13R-05) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	1.95E+12	0.00E+00	100
Livestock	1.72E+12	5.16E+11	70
Wildlife	3.65E+13	3.65E+13	0
Total	*4.02E+13*	*3.70E+13*	*8*
Land-based			
Residential	6.13E+14	1.84E+14	70
Cropland	8.75E+12	2.63E+12	70
Pasture	1.70E+15	5.10E+14	70
Forest	2.05E+14	2.05E+14	0
Total	*2.53E+15*	*9.02E+14*	*64*

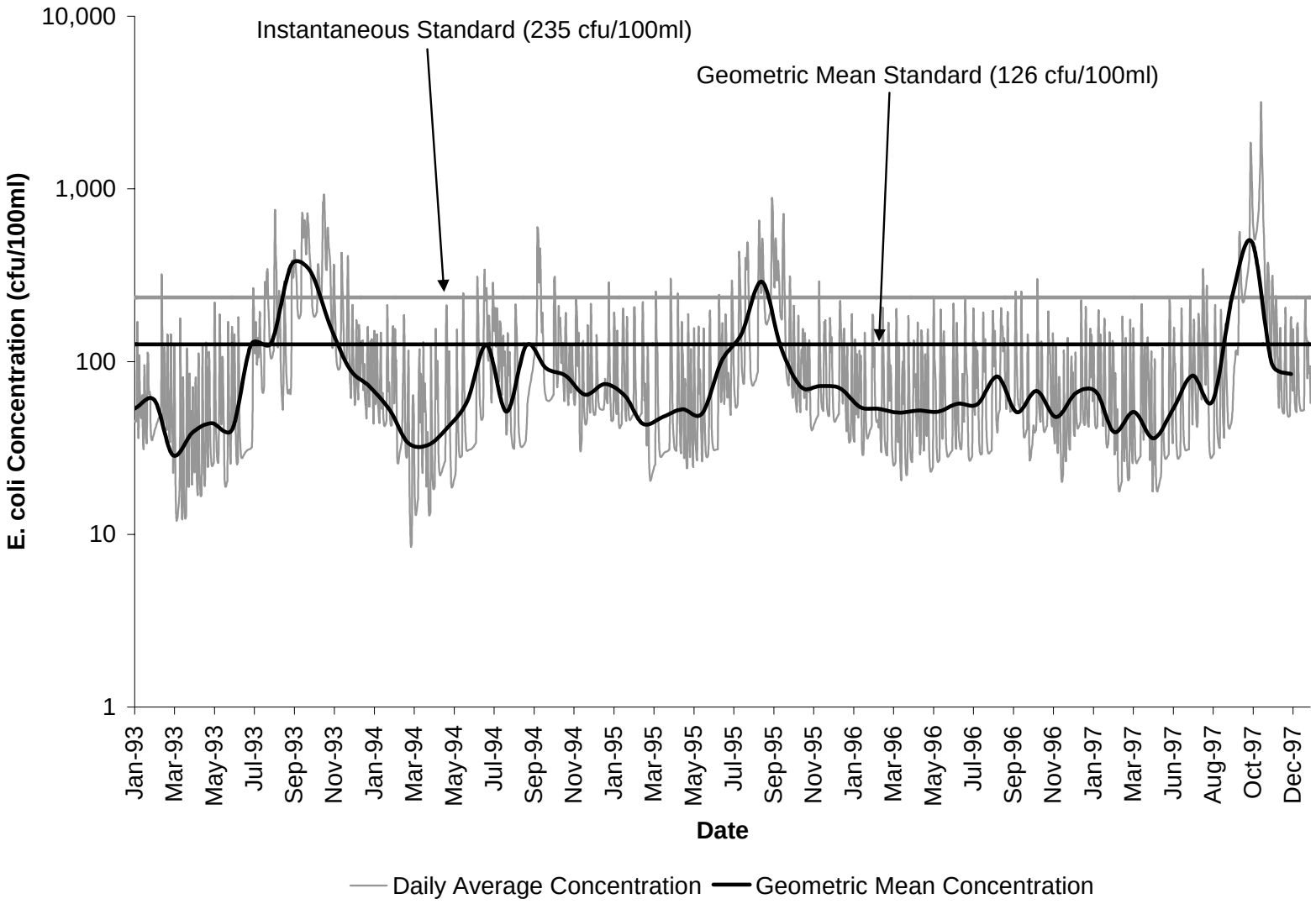

Figure 6.10. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Black Creek (VAP-F13R-05) impairment.

6.2.11 Pamunkey River (VAP-F13E-02)

The Stage 1 allocation for the Pamunkey River (VAP-F13E-02) impairment requires a 100% reduction in straight pipes, 70% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 70% reduction in nonpoint source loadings to residential land use, a 70% reduction in nonpoint source loadings to pasture land use, a 70% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.47% instantaneous standard violation 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 6.11 for the Pamunkey River (VAP-F13E-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 6.11.

Table 6.11. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Pamunkey River (VAP-F13E-02) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	3.32E+13	0.00E+00	100
Livestock	1.14E+13	3.42E+12	70
Wildlife	1.07E+14	1.07E+14	0
Total	*1.52E+14*	*1.10E+14*	*27*
Land-based			
Residential	1.83E+15	5.49E+14	70
Cropland	3.42E+13	1.03E+13	70
Pasture	1.18E+16	3.54E+15	70
Forest	4.73E+14	4.73E+14	0
Total	*1.41E+16*	*4.57E+15*	*68*

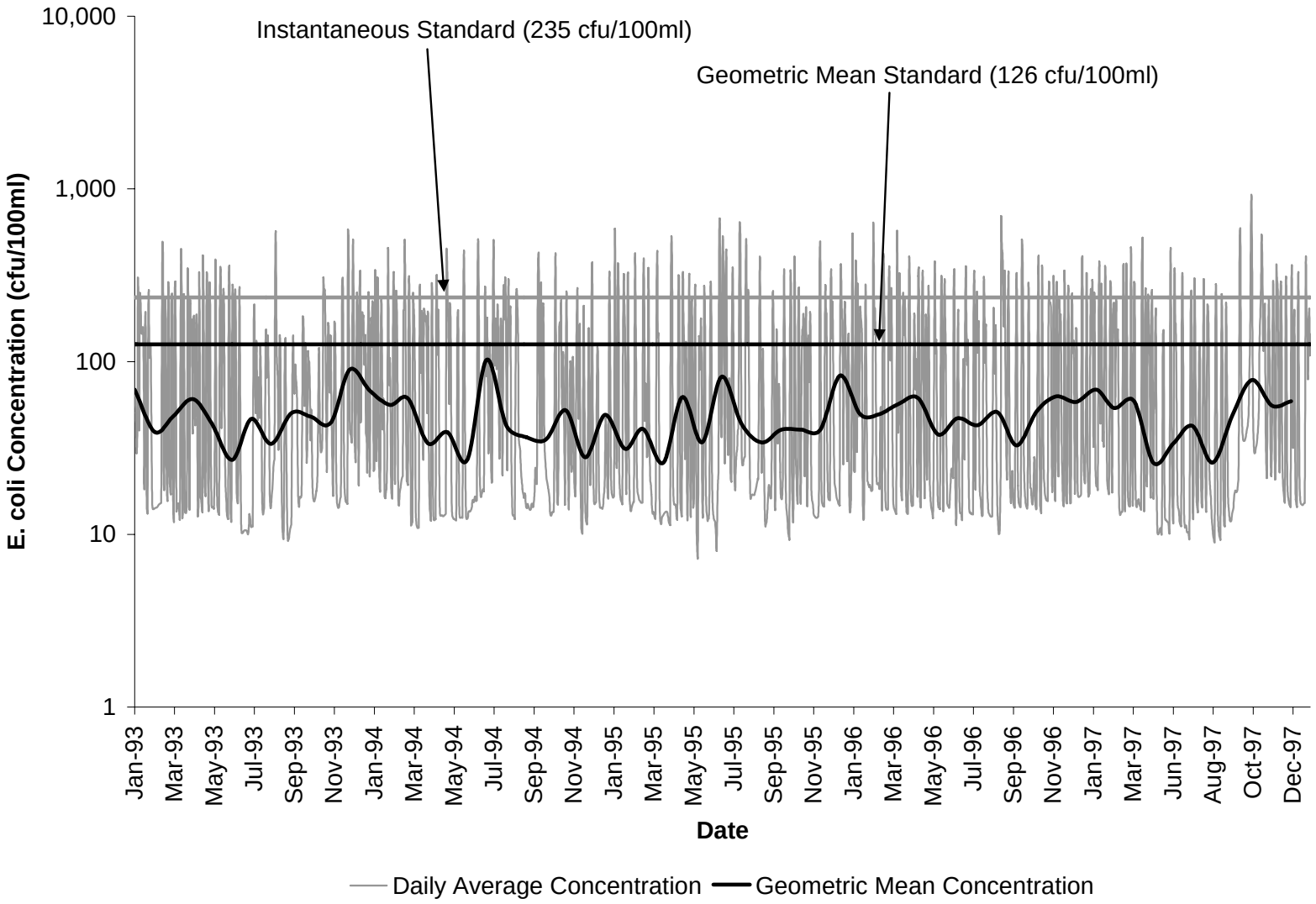

Figure 6.11. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Pamunkey River (VAP-F13E-02) impairment.

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 York River and Lower York Coastal Basins. 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 York River and Lower York Coastal Basins). 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/TributaryStrategies/FinalizedTribStrats/york.pdf

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-up Monitoring

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

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, 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 or the VADEQ Central Office Citizens Monitoring Coordinator.

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 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 VADEQ's standard monitoring plan. Ancillary monitoring by citizens', watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request 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 EPA 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/sw/vsmp

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,…".

Part of the Northeast Creek watershed is covered by permit # VAR040005 for small municipal separate storm sewer systems (MS4s) owned by theSpotsylvania County. Part of theSouth Anna River, Totopotomoy Creek, Black Creek, and Pamunkey River watersheds are covered bypermit # VAR040012 for small municipal separate storm sewer systems (MS4s) owned by theHanover County. Part of the South Anna River watershed is covered by permit # VAR040011 for small municipal separate storm sewer systems (MS4s) owned by the Town of Ashland. The permits state, under Part II.A., that the "permittee must develop, implement, and enforce a stormwater management program designed to reduce the discharge of pollutants from the MS4 to the maximum extent practicable (MEP), to protect water quality, and to satisfy the appropriate water quality requirements of the Clean Water Act and the State Water Control Law."

The permit also contains a TMDL clause that states: "If a TMDL is approved for any waterbody into which the small MS4 discharges, the Board will review the TMDL to determine whether the TMDL includes requirements for control of stormwater discharges. If discharges from the MS4 are not meeting the TMDL allocations, the Board will notify the permittee of that finding and may require that the Stormwater Management Program required in Part II be modified to implement the TMDL within a timeframe consistent with the TMDL." "Board" means the Soil and Water Conservation Board.

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 a violation of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 6.4.5 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 South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy

Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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/sw/stormwat.htm

6.4.4 Implementation Funding Sources

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

6.4.5 Attainability of Primary Contact Recreation Use

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

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

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

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This and other information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/WQS03AUG.pdf

The process to address potentially unattainable reductions based on the above is as follows: First is the development of a stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the stage 1 scenario are targeted primarily at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife. During the implementation of the stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in Section 6.2 above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct. If water quality standards are not being met, and no additional cost-effective and reasonable best management practices can be identified, a UAA may be initiated with the goal of re-designating the stream for secondary contact recreation.

Chapter 7. Public Participation

The development of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) TMDLs would not have been possible without public participation. The first public meetings were held at the Louisa County Government Center in Louisa, Virginia and King William High Scholl in King William, Virginia on April 13, 2005 and April 20, 2005, respectively, to discuss the need for a TMDL and the process for TMDL development. Seven people attended the Louisa meeting and 13 people attended the King William meeting. Copies of the presentation materials were available for public distribution. Public notice of the meeting was printed in the Virginia Register. In addition, the meeting was advertised on the VADEQ website. There was a 30-day public comment period and no written comment was received.

The second public meetings were held at the Louisa County Government Center in Louisa, Virginia and Eastern Hanover Volunteer Company in Mechanicsville, Virginia on December 7, 2005 and December 8, 2005, respectively, to discuss the draft watershed source assessment and to review the approach for TMDL development. Sixteen people attended the Louisa meeting and two people attended the Mechanicsville meeting. Public notice of the meeting was printed in the Virginia Register. The meeting was advertised on the VADEQ website. Notification regarding the meeting was sent to area appointed and elected officials, Technical Advisory Committee (TAC) members, and prior public meeting attendees. There was a 30-day public comment period and no written comment was received.

The third and final public meetings were held at the Eastern Hanover Volunteer Company in Mechanicsville, Virginia and Louisa County Government Center in Louisa, Virginia on March 22, 2006 and March 23, 2006, respectively, to discuss the source allocations and reductions required to meet the TMDL. One person attended the Mechanicsville meeting and five people attended the Louisa 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. The meeting was advertised on the VADEQ website. Notification regarding the meeting was sent to area appointed and elected officials, TAC members, and prior public meeting attendees. There was a 30-day public comment period and two written comments were received.

In addition to keeping the public apprised of progress in the development of the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) TMDLs, a TMDL TAC was also established to help advise the TMDL developers. TAC meetings were held two to three weeks prior to public meetings. The TAC membership for the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-

F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) 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 Cooperative Extension
- Colonial, Culpeper, Hanover-Caroline, Thomas Jefferson SWCDs
- Hampton Roads Sanitation District
- Hanover County Government
- Randolph-Macon College
- Richmond Regional PDC
- South Anna Monitoring Project
- Town of Ashland

The TMDL TAC met on November 16, 2005 and March 9, 2005 at the Ashland Council Chmabers in Ashland, Virginia to discuss the South Anna River (VAN-F01R-01), South Anna River (VAN-F02R-01), South Anna River (VAP-F04R-01), South Anna River (VAP-F04R-02), Taylors Creek (VAN-F03R-01), Newfound River (VAP-F05R-01), Northeast Creek (VAP-F09R-01), Totopotomoy Creek (VAP-F13R-02), Moncuin/Webb Creek (VAP-F13R-04), Black Creek (VAP-F13R-05), and Pamunkey River (VAP-F13E-02) bacteria TMDLs. Fifteen and six people attended the November and March meetings, respectively. TAC meetings were used as a forum to review data and assumptions used in the modeling, and to provide local government agencies an opportunity to raise concerns about the implications of the TMDL for their jurisdictions. The generous assistance of the staff of these agencies is gratefully acknowledged.

Glossary

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

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

Background levels
Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering and dissolution. A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

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

Bacterial Source Tracking (BST)
A collection of scientific methods used to track sources of fecal coliform.

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

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

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

E-911 digital data
Emergency response database prepared by the county that contains graphical data on road centerlines and buildings. The database contains approximate outlines of buildings, including dwellings and poultry houses.

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

Fecal coliform
A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms.

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

Mathematically the geometric mean, $\bar{x}_g$, is expressed as: $\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$ where n is the number of samples, and x_i is the value of sample i.

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

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

Instantaneous criterion
The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

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

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). 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 8-SAR097.82 in South Anna watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR097.82	09/27/95	4100		0.56
8-SAR097.82	12/04/95	100		2.42
8-SAR097.82	02/06/96	100		1.05
8-SAR097.82	04/24/96	1100		0.00
8-SAR097.82	07/31/96	4600		1.87
8-SAR097.82	12/11/96	100		0.03
8-SAR097.82	01/08/97	100		11.8
8-SAR097.82	04/15/97	1300		N/A
8-SAR097.82	07/22/97	400		1.16
8-SAR097.82	12/17/97	100		0.02
8-SAR097.82	02/25/98	300		0.85
8-SAR097.82	04/07/98	300		0.61
8-SAR097.82	07/13/98	1100		0.04
8-SAR097.82	10/20/98	8000		0.00
8-SAR097.82	03/03/99	200		4.14
8-SAR097.82	04/20/99	300		1.45
8-SAR097.82	07/13/99	4000		0.83
8-SAR097.82	08/30/99	100		0.05
8-SAR097.82	10/06/99	600		0.00
8-SAR097.82	12/21/99	1600		0.46
8-SAR097.82	02/09/00	100		0.55
8-SAR097.82	04/25/00	8000		0.12
8-SAR097.82	06/13/00	100		1.73
8-SAR097.82	08/29/00	7100		1.54
8-SAR097.82	10/31/00	100		1.35
8-SAR097.82	12/20/00	600		1.26
8-SAR097.82	02/07/01	100		0.19
8-SAR097.82	04/09/01	200		0.95
8-SAR097.82	06/26/01	800		0.90
8-SAR097.82	07/29/03	9900	1900	3.54
8-SAR097.82	08/18/03	3300	430	0.01
8-SAR097.82	09/03/03	6700	1600	2.41
8-SAR097.82	10/01/03	160	118	N/A
8-SAR097.82	11/03/03	220	154	0.02

N/A – Data not available

Table A.2. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR070.96 in South Anna watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR070.96	09/27/95	200		0.56
8-SAR070.96	12/04/95	100		2.42
8-SAR070.96	02/06/96	100		1.05
8-SAR070.96	04/24/96	100		0.00
8-SAR070.96	07/31/96	4000		1.87
8-SAR070.96	12/11/96	100		0.03
8-SAR070.96	01/08/97	100		11.8
8-SAR070.96	04/15/97	100		N/A
8-SAR070.96	07/22/97	100		1.16
8-SAR070.96	12/17/97	100		0.02
8-SAR070.96	02/25/98	100		0.85
8-SAR070.96	04/07/98	200		0.61
8-SAR070.96	07/13/98	100		0.04
8-SAR070.96	10/20/98	100		0.00
8-SAR070.96	03/03/99	100		4.14
8-SAR070.96	04/22/99	100		1.45
8-SAR070.96	07/06/99	100		0.02
8-SAR070.96	10/21/99	500		1.75
8-SAR070.96	12/07/99	300		1.02
8-SAR070.96	02/22/00	100		0.40
8-SAR070.96	03/22/00	3200		0.00
8-SAR070.96	05/08/00	100		0.30
8-SAR070.96	07/20/00	100		0.95
8-SAR070.96	09/12/00	100		1.12
8-SAR070.96	12/12/00	200		0.68
8-SAR070.96	02/01/01	100		0.62
8-SAR070.96	04/17/01	400		0.65
8-SAR070.96	06/27/01	100		0.90

N/A – Data not available

Table A.3. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR021.22 in South Anna watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR021.22	07/17/90	100		0.93
8-SAR021.22	10/15/90	600		2.81
8-SAR021.22	10/15/90	600		2.81
8-SAR021.22	01/15/91	600		0.85
8-SAR021.22	04/10/91	100		0.10
8-SAR021.22	04/10/91	100		0.10
8-SAR021.22	09/30/91	200		0.91
8-SAR021.22	01/06/92	400		N/A
8-SAR021.22	04/13/92	100		2.43
8-SAR021.22	07/07/92	700		0.18
8-SAR021.22	10/01/92	100		1.93
8-SAR021.22	01/05/93	6700		0.42
8-SAR021.22	04/05/93	100		1.37
8-SAR021.22	07/12/93	200		0.69
8-SAR021.22	10/07/93	100		0.57
8-SAR021.22	01/31/94	300		2.41
8-SAR021.22	04/11/94	100		0.47
8-SAR021.22	07/11/94	170		0.12
8-SAR021.22	10/11/94	330		1.96
8-SAR021.22	01/04/95	68		0.17
8-SAR021.22	04/25/95	3500		2.51
8-SAR021.22	07/26/95	120		0.51
8-SAR021.22	10/12/95	68		1.73
8-SAR021.22	01/31/96	78		4.51
8-SAR021.22	04/18/96	1700		3.44
8-SAR021.22	07/29/96	45		0.30
8-SAR021.22	10/29/96	68		0.65
8-SAR021.22	01/27/97	16000		0.48
8-SAR021.22	04/09/97	78		N/A
8-SAR021.22	07/02/97	170		0.00
8-SAR021.22	09/25/97	140		0.88
8-SAR021.22	11/12/97	3500		0.30
8-SAR021.22	01/12/98	130		N/A
8-SAR021.22	03/12/98	230		0.92
8-SAR021.22	05/05/98	3500		0.07
8-SAR021.22	07/06/98	18		3.06
8-SAR021.22	09/15/98	78		2.20

Table A.3. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR021.22 in South Anna watershed (Continued).

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR021.22	11/03/98	330		0.43
8-SAR021.22	01/12/99	460		0.00
8-SAR021.22	03/16/99	2200		2.37
8-SAR021.22	05/19/99	20		0.33
8-SAR021.22	07/01/99	9200		0.41
8-SAR021.22	09/01/99	68		0.10
8-SAR021.22	01/05/00	1100		0.20
8-SAR021.22	03/01/00	100		0.03
8-SAR021.22	05/03/00	100		0.18
8-SAR021.22	07/06/00	100		2.22
8-SAR021.22	09/12/00	100		1.12
8-SAR021.22	11/13/00	100		0.00
8-SAR021.22	01/16/01	100		0.00
8-SAR021.22	03/12/01	100		0.00
8-SAR021.22	07/08/03	340	64	4.28
8-SAR021.22	08/12/03	3000	120	1.78
8-SAR021.22	09/09/03	220	76	0.40
8-SAR021.22	10/07/03	100	40	0.03
8-SAR021.22	11/04/03			0.10

N/A – Data not available

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR001.11 in South Anna watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR001.11	01/10/90	300		0.02
8-SAR001.11	02/07/90	500		1.77
8-SAR001.11	03/01/90	100		0.37
8-SAR001.11	03/07/90			1.62
8-SAR001.11	04/12/90	100		0.58
8-SAR001.11	05/15/90	100		0.63
8-SAR001.11	06/12/90	100		0.74
8-SAR001.11	07/17/90	100		0.93
8-SAR001.11	09/17/90	100		0.42
8-SAR001.11	10/15/90	700		2.81
8-SAR001.11	10/15/90	700		2.81
8-SAR001.11	11/28/90			0.06
8-SAR001.11	11/28/90			0.06
8-SAR001.11	12/17/90			0.00
8-SAR001.11	01/15/91	100		0.85
8-SAR001.11	03/13/91	100		0.65
8-SAR001.11	04/10/91	100		0.10
8-SAR001.11	04/10/91	100		0.10
8-SAR001.11	05/08/91	100		0.15
8-SAR001.11	06/10/91	100		2.10
8-SAR001.11	08/05/91	100		0.59
8-SAR001.11	09/04/91	100		0.80
8-SAR001.11	09/30/91	100		0.91
8-SAR001.11	12/03/91	300		0.34
8-SAR001.11	01/06/92	400		0.38
8-SAR001.11	02/18/92	200		0.30
8-SAR001.11	03/04/92	200		0.07
8-SAR001.11	04/13/92	100		2.43
8-SAR001.11	05/11/92	100		0.00
8-SAR001.11	06/10/92			0.44
8-SAR001.11	07/07/92	300		0.18
8-SAR001.11	08/17/92	100		0.17
8-SAR001.11	09/02/92	100		N/A
8-SAR001.11	10/01/92	100		1.93
8-SAR001.11	11/03/92	100		0.60
8-SAR001.11	12/02/92	100		0.56
8-SAR001.11	01/05/93	8000		0.42

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR001.11 in South Anna watershed. (Continued).

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR001.11	02/01/93	100		0.30
8-SAR001.11	03/03/93	100		1.76
8-SAR001.11	04/05/93	100		1.37
8-SAR001.11	05/04/93	100		0.43
8-SAR001.11	06/01/93	1600		0.50
8-SAR001.11	07/12/93	100		0.69
8-SAR001.11	08/09/93	200		1.92
8-SAR001.11	09/01/93	100		0.33
8-SAR001.11	10/07/93	100		0.57
8-SAR001.11	11/02/93	500		0.06
8-SAR001.11	12/20/93	100		0.25
8-SAR001.11	01/31/94	100		2.41
8-SAR001.11	02/10/94			0.80
8-SAR001.11	03/07/94	100		0.00
8-SAR001.11	04/11/94	100		0.47
8-SAR001.11	05/11/94	100		1.00
8-SAR001.11	06/08/94	100		0.53
8-SAR001.11	07/11/94	2800		0.12
8-SAR001.11	08/03/94	2400		0.98
8-SAR001.11	09/12/94	140		0.00
8-SAR001.11	10/11/94	220		1.96
8-SAR001.11	11/01/94	110		0.22
8-SAR001.11	12/05/94	170		1.94
8-SAR001.11	01/04/95	20		0.17
8-SAR001.11	02/01/95	3500		0.34
8-SAR001.11	03/22/95	20		0.32
8-SAR001.11	04/25/95	2200		2.51
8-SAR001.11	05/24/95	5400		1.55
8-SAR001.11	06/27/95	790		1.37
8-SAR001.11	07/26/95	330		0.51
8-SAR001.11	08/31/95	68		2.67
8-SAR001.11	09/27/95	78		0.56
8-SAR001.11	10/12/95	68		1.73
8-SAR001.11	11/08/95	16000		1.03
8-SAR001.11	12/27/95	110		0.65
8-SAR001.11	01/31/96	1300		4.51

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR001.11 in South Anna watershed. (Continued).

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR001.11	02/27/96	210		0.11
8-SAR001.11	03/25/96	400		0.02
8-SAR001.11	04/18/96	230		3.44
8-SAR001.11	05/30/96	230		0.13
8-SAR001.11	06/24/96	130		0.42
8-SAR001.11	07/29/96	330		0.3
8-SAR001.11	08/26/96	170		0.01
8-SAR001.11	09/24/96	68		3.93
8-SAR001.11	10/29/96	92		0.65
8-SAR001.11	11/25/96	78		0.15
8-SAR001.11	12/19/96	1300		0.68
8-SAR001.11	01/27/97	16000		0.48
8-SAR001.11	02/13/97	78		0.45
8-SAR001.11	03/17/97	45		0.10
8-SAR001.11	04/09/97	78		N/A
8-SAR001.11	05/05/97	110		0.69
8-SAR001.11	06/02/97	5400		0.19
8-SAR001.11	07/02/97	470		0.00
8-SAR001.11	08/04/97	110		0.00
8-SAR001.11	09/25/97	130		0.88
8-SAR001.11	10/22/97	78		1.24
8-SAR001.11	11/12/97	2400		0.30
8-SAR001.11	12/08/97	260		0.50
8-SAR001.11	01/12/98	45		0.53
8-SAR001.11	02/12/98	330		0.93
8-SAR001.11	03/12/98	220		0.92
8-SAR001.11	04/13/98	230		0.11
8-SAR001.11	05/05/98	110		0.07
8-SAR001.11	06/01/98	68		1.32
8-SAR001.11	07/06/98	20		3.06
8-SAR001.11	08/19/98	2400		1.59
8-SAR001.11	09/15/98	170		2.20
8-SAR001.11	10/06/98	220		0.05
8-SAR001.11	11/03/98	9200		0.43
8-SAR001.11	12/14/98	2400		2.14
8-SAR001.11	01/12/99	490		0.00

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR001.11 in South Anna watershed. (Continued).

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR001.11	02/09/99	68		0.13
8-SAR001.11	03/16/99	790		2.37
8-SAR001.11	04/19/99	18		0.25
8-SAR001.11	05/19/99	45		0.33
8-SAR001.11	06/22/99	68		0.20
8-SAR001.11	07/01/99	16000		0.41
8-SAR001.11	08/03/99	40		0.08
8-SAR001.11	09/01/99	40		0.10
8-SAR001.11	10/18/99	78		0.64
8-SAR001.11	12/28/99	170		1.15
8-SAR001.11	01/05/00	1900		0.20
8-SAR001.11	02/03/00			0.02
8-SAR001.11	03/01/00	200		0.03
8-SAR001.11	04/12/00	100		0.33
8-SAR001.11	05/03/00	100		0.18
8-SAR001.11	06/07/00	1100		2.95
8-SAR001.11	07/06/00	100		2.22
8-SAR001.11	08/08/00	100		1.03
8-SAR001.11	09/12/00	100		1.12
8-SAR001.11	10/16/00	100		2.00
8-SAR001.11	11/13/00	100		0.00
8-SAR001.11	12/27/00	100		0.00
8-SAR001.11	01/16/01	100		0.00
8-SAR001.11	01/31/01	200		0.62
8-SAR001.11	03/12/01	100		0.00
8-SAR001.11	04/25/01	200		0.50
8-SAR001.11	06/11/01	100		0.17
8-SAR001.11	08/08/01	400		0.37
8-SAR001.11	10/04/01	100		1.53
8-SAR001.11	12/27/01	100		0.41
8-SAR001.11	02/05/02	100		0.15
8-SAR001.11	04/03/02	100		2.20
8-SAR001.11	06/26/02	100		0.03
8-SAR001.11	07/24/02	100		0.56
8-SAR001.11	09/19/02	100		0.00
8-SAR001.11	11/13/02			0.46

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-SAR001.11 in South Anna watershed. (Continued).

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-SAR001.11	01/02/03	2700		0.00
8-SAR001.11	03/11/03	100		1.40
8-SAR001.11	05/21/03	1700		0.23
8-SAR001.11	07/08/03	530	120	4.28
8-SAR001.11	07/10/03	280	70	4.14
8-SAR001.11	08/12/03	700	160	1.78
8-SAR001.11	09/09/03	200	70	0.40
8-SAR001.11	09/16/03	180	110	1.67
8-SAR001.11	10/07/03	100	100	0.03
8-SAR001.11	11/04/03	130	82	0.10
8-SAR001.11	11/13/03	250	10	1.52

N/A – Data not available

Table A.5. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-TLR002.54 in Taylor's Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-TLR002.54	07/02/97	5400		0.00
8-TLR002.54	09/25/97	40		0.88
8-TLR002.54	11/12/97	120		0.30
8-TLR002.54	01/12/98	78		0.53
8-TLR002.54	03/12/98	20		0.92
8-TLR002.54	05/05/98	230		0.07
8-TLR002.54	07/06/98	78		3.06
8-TLR002.54	09/15/98	210		N/A
8-TLR002.54	11/03/98	170		0.43
8-TLR002.54	01/12/99	130		0.00
8-TLR002.54	03/16/99	220		2.37
8-TLR002.54	05/19/99	45		0.33
8-TLR002.54	07/01/99	16000		0.41
8-TLR002.54	09/01/99	68		0.10
8-TLR002.54	01/05/00	1100		0.20
8-TLR002.54	03/01/00	100		0.03
8-TLR002.54	05/03/00	300		0.18
8-TLR002.54	07/06/00	100		2.22
8-TLR002.54	09/12/00	100		1.12
8-TLR002.54	11/13/00	100		0.00
8-TLR002.54	01/16/01	100		0.00
8-TLR002.54	03/12/01	100		0.00
8-TLR002.54	07/08/03	25	10	4.28
8-TLR002.54	08/12/03	280	60	1.78
8-TLR002.54	09/09/03	75	100	0.40
8-TLR002.54	10/07/03	75	20	0.03
8-TLR002.54	11/04/03	75	60	0.10

N/A – Data not available

Table A.6. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-NFD002.26 in Newfound River watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-NFD002.26	08/03/94	16000		0.98
8-NFD002.26	10/11/94	2400		1.96
8-NFD002.26	01/04/95	45		0.17
8-NFD002.26	04/25/95	2200		2.51
8-NFD002.26	07/26/95	2200		0.51
8-NFD002.26	10/12/95	170		1.73
8-NFD002.26	01/31/96	93		4.51
8-NFD002.26	04/18/96	170		N/A
8-NFD002.26	07/29/96	410		0.30
8-NFD002.26	10/29/96	68		0.65
8-NFD002.26	01/27/97	78		0.48
8-NFD002.26	04/09/97	110		N/A
8-NFD002.26	08/04/97	270		0.00
8-NFD002.26	10/22/97	45		1.24
8-NFD002.26	12/08/97	1400		0.50
8-NFD002.26	02/12/98	78		0.93
8-NFD002.26	04/13/98	45		0.11
8-NFD002.26	06/01/98	78		1.32
8-NFD002.26	08/19/98	260		1.59
8-NFD002.26	10/06/98	170		0.05
8-NFD002.26	12/14/98	490		2.14
8-NFD002.26	02/09/99	490		0.13
8-NFD002.26	04/19/99	45		0.25
8-NFD002.26	06/22/99	45		0.20
8-NFD002.26	08/03/99	1700		0.08
8-NFD002.26	10/18/99	490		0.64
8-NFD002.26	12/28/99	460		1.15
8-NFD002.27	04/12/00	100		0.33
8-NFD002.28	06/07/00	100		2.95
8-NFD002.29	08/08/00	100		1.03
8-NFD002.30	10/16/00	100		2.00
8-NFD002.31	01/31/01	100		0.62
8-NFD002.32	04/25/01	100		N/A

N/A – Data not available

Table A.4. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-NST003.46 in Northeast Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-NST003.46	10/15/74	100		0.10
8-NST003.46	12/19/74	100		0.88
8-NST003.46	02/20/75	100		0.00
8-NST003.46	04/28/75	100		0.70
8-NST003.46	06/19/75	100		0.90
8-NST003.46	07/31/75	100		0.49
8-NST003.46	10/22/75	100		0.74
8-NST003.46	02/04/76	100		N/A
8-NST003.46	07/09/87	1700		0.00
8-NST003.46	08/06/87	100		0.83
8-NST003.46	09/22/87	100		0.56
8-NST003.46	10/22/87	100		0.00
8-NST003.46	11/19/87	100		3.52
8-NST003.46	12/10/87	300		4.15
8-NST003.46	01/25/88	100		0.02
8-NST003.46	02/25/88	100		0.43
8-NST003.46	04/14/88	100		0.07
8-NST003.46	10/06/88	100		0.84
8-NST003.46	11/03/88	100		1.45
8-NST003.46	12/07/88	100		0.19
8-NST003.46	01/10/89	200		8.57
8-NST003.46	02/07/89	900		0.39
8-NST003.46	03/23/89	100		2.64
8-NST003.46	06/18/91	130		2.54
8-NST003.46	09/26/91	16000		3.16
8-NST003.46	12/23/91	330		0.34
8-NST003.46	03/16/92	170		0.10
8-NST003.46	09/22/92	100		0.16
8-NST003.46	03/30/93	100		0.08
8-NST003.46	09/20/93	100		0.36
8-NST003.46	06/29/94	100		0.55
8-NST003.46	09/27/94	300		0.20
8-NST003.46	12/27/94	100		N/A
8-NST003.46	03/27/95	100		0.12
8-NST003.46	09/21/95	100		1.44
8-NST003.46	12/19/95	100		0.04
8-NST003.46	03/04/96	100		0.98

Table A.7. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-NST003.46 in Northeast Creek watershed. (continued)

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-NST003.46	06/12/96	200		0.04
8-NST003.46	10/31/96	100		0.16
8-NST003.46	04/28/97	800		N/A
8-NST003.46	10/30/97	100		0.25
8-NST003.46	04/02/98	100		0.72
8-NST003.46	10/27/98	100		0.00
8-NST003.46	01/21/99	100		0.13
8-NST003.46	03/17/99	100		2.00
8-NST003.46	06/03/99	100		0.05
8-NST003.46	08/25/99	100		1.16
8-NST003.46	10/28/99	100		0.91
8-NST003.46	12/15/99	700		0.27
8-NST003.46	02/29/00	100		0.00
8-NST003.46	04/17/00	2000		0.70
8-NST003.46	06/22/00	100		0.11
8-NST003.46	08/23/00	100		2.70
8-NST003.46	10/19/00	8000		1.59
8-NST003.46	12/14/00	100		0.68
8-NST003.46	02/13/01	500		0.93
8-NST003.46	03/29/01	100		0.62
8-NST003.46	05/17/01	100		0.06
8-NST003.46	06/11/01	100		0.17
8-NST003.46	08/08/01	100		0.37
8-NST003.46	10/04/01	100		1.53
8-NST003.46	12/26/01	100		0.41
8-NST003.46	02/05/02	100		0.15
8-NST003.46	02/05/02	100		0.15
8-NST003.46	02/05/02	100		0.15
8-NST003.46	02/05/02	100		0.15
8-NST003.46	04/03/02	100		2.20
8-NST003.46	06/26/02	100		0.03
8-NST003.46	07/24/02	600		0.56
8-NST003.46	09/19/02	100		0.00
8-NST003.46	11/13/02	1200		0.46
8-NST003.46	01/02/03	100		0.00
8-NST003.46	03/11/03	100		1.40

Table A.8. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-TPT004.37 in Totopotomoy Creek watershed

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-TPT004.37	02/08/99	110		0.02
8-TPT004.37	04/12/99	78		0.40
8-TPT004.37	06/16/99	40		0.16
8-TPT004.37	08/17/99	140		0.97
8-TPT004.37	10/07/99	1100		0.00
8-TPT004.37	12/28/99	45		1.15
8-TPT004.37	02/16/00	100		0.10
8-TPT004.37	04/25/00	100		N/A
8-TPT004.37	06/06/00	7200		3.15
8-TPT004.37	08/15/00	100		1.63
8-TPT004.37	10/19/00	100		1.59
8-TPT004.37	12/06/00	100		0.00
8-TPT004.37	02/15/01	100		0.53
8-TPT004.37	04/19/01	100		1.24
8-TPT004.37	05/22/01	200		0.58
8-TPT004.37	07/18/01	400		0.68
8-TPT004.37	09/20/01	1800		0.07
8-TPT004.37	11/28/01	100		0.00
8-TPT004.37	01/09/02	400		0.14
8-TPT004.37	03/28/02	300		0.02
8-TPT004.37	05/20/02	100		0.00
8-TPT004.37	10/24/02	100		0.42
8-TPT004.37	12/09/02	100		0.00
8-TPT004.37	02/20/03	100		6.43
8-TPT004.37	04/24/03	100		0.61
8-TPT004.37	06/18/03	100		1.31
8-TPT004.37	07/08/03	2900	54	4.28
8-TPT004.37	08/12/03	520	55	1.78
8-TPT004.37	09/09/03	580	54	0.40
8-TPT004.37	10/07/03	80	52	0.03
8-TPT004.37	11/04/03	140	52	0.10

N/A – Data not available

Table A.5. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-8-MNQ004.19 in Monquin, Webb watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-MNQ004.19	06/19/96	4300		0.62
8-MNQ004.19	09/18/96	9200		0.00
8-MNQ004.19	12/11/96	260		0.03
8-MNQ004.19	03/26/97	3500		0.66
8-MNQ004.19	06/16/97	1400		1.97
8-MNQ004.19	07/08/97	330		1.22
8-MNQ004.19	09/15/97	490		1.81
8-MNQ004.19	11/03/97	170		N/A
8-MNQ004.19	01/05/98	20		0.04
8-MNQ004.19	03/11/98	40		0.61
8-MNQ004.19	05/06/98	78		0.02
8-MNQ004.19	07/07/98	110		3.03
8-MNQ004.19	09/21/98	20		0.26
8-MNQ004.19	11/23/98	78		1.09
8-MNQ004.19	01/14/99	45		0.00
8-MNQ004.19	03/08/99	68		0.28
8-MNQ004.19	05/24/99	580		0.27
8-MNQ004.19	07/22/99	130		0.30
8-MNQ004.19	09/15/99	78		0.00
8-MNQ004.19	03/15/00	100		0.02
8-MNQ004.19	05/25/00	200		1.79
8-MNQ004.19	07/17/00	200		1.85
8-MNQ004.19	09/27/00	1100		0.02
8-MNQ004.19	11/02/00	200		1.37
8-MNQ004.19	03/27/01	100		0.46
8-MNQ004.19	07/08/03	620	400	4.28
8-MNQ004.19	08/12/03	530	150	1.78
8-MNQ004.19	08/28/03		180	0.42
8-MNQ004.19	09/09/03	25	70	0.40
8-MNQ004.19	10/07/03	75	10	0.03
8-MNQ004.19	10/23/03		25	0.45
8-MNQ004.19	11/04/03	75	120	0.10

Table A.10. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-BLC001.77 in Black Creek watershed

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-BLC001.77	06/19/96	1100		0.62
8-BLC001.77	09/18/96	490		0.00
8-BLC001.77	12/11/96	210		0.03
8-BLC001.77	03/26/97	270		0.66
8-BLC001.77	06/16/97	92		1.97
8-BLC001.77	07/08/97	78		1.22
8-BLC001.77	09/15/97	310		1.81
8-BLC001.77	11/03/97	340		N/A
8-BLC001.77	01/08/98	45		0.02
8-BLC001.77	03/11/98	460		0.61
8-BLC001.77	05/06/98	45		0.02
8-BLC001.77	07/07/98	230		3.03
8-BLC001.77	09/21/98	45		0.26
8-BLC001.77	11/23/98	1300		1.09
8-BLC001.77	01/14/99	45		0.00
8-BLC001.77	03/08/99	93		0.28
8-BLC001.77	05/24/99	700		0.27
8-BLC001.77	07/22/99	61		0.30
8-BLC001.77	09/15/99	1300		0.00
8-BLC001.77	03/15/00	100		0.02
8-BLC001.77	05/25/00	200		1.79
8-BLC001.77	07/17/00	300		1.85
8-BLC001.77	09/27/00	600		0.02
8-BLC001.77	11/02/00	100		1.37
8-BLC001.77	01/03/01	100		0.11
8-BLC001.77	03/27/01	100		0.46
8-BLC001.77	07/08/03	280	10	4.28
8-BLC001.77	08/12/03	75	10	1.78
8-BLC001.77	08/28/03		100	0.42
8-BLC001.77	09/09/03	25	20	0.40
8-BLC001.77	10/07/03	75	50	0.03
8-BLC001.77	10/23/03		25	0.45
8-BLC001.77	11/04/03	75	70	N/A

N/A – Data not available

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-PMK048.80 in Pamunkey River watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-PMK048.80	01/12/94	490		0.41
8-PMK048.80	01/13/94	220		0.41
8-PMK048.80	01/13/94			0.41
8-PMK048.80	02/15/94	79		2.15
8-PMK048.80	02/15/94			2.15
8-PMK048.80	03/30/94	1600		0.16
8-PMK048.80	03/30/94			0.16
8-PMK048.80	04/26/94	350		N/A
8-PMK048.80	04/26/94			0.31
8-PMK048.80	05/24/94	280		0.16
8-PMK048.80	05/24/94			0.16
8-PMK048.80	06/23/94	280		3.26
8-PMK048.80	06/23/94			3.26
8-PMK048.80	07/21/94	93		2.65
8-PMK048.80	07/21/94			2.65
8-PMK048.80	08/23/94	2200		4.39
8-PMK048.80	08/23/94			4.39
8-PMK048.80	09/26/94			0.20
8-PMK048.80	09/26/94	270		0.20
8-PMK048.80	10/20/94			0.36
8-PMK048.80	10/20/94	20		0.36
8-PMK048.80	11/29/94			0.07
8-PMK048.80	11/29/94	18		0.07
8-PMK048.80	12/13/94			6.78
8-PMK048.80	12/13/94	20		6.78
8-PMK048.80	02/13/95	18		2.84
8-PMK048.80	03/09/95	9200		0.07
8-PMK048.80	04/26/95	20		2.71
8-PMK048.80	05/25/95	170		1.88
8-PMK048.80	06/28/95	700		1.38
8-PMK048.80	07/27/95	1700		0.64
8-PMK048.80	08/30/95	320		1.05
8-PMK048.80	09/27/95	330		N/A
8-PMK048.80	10/31/95	130		0.25
8-PMK048.80	11/27/95	78		0.00
8-PMK048.80	12/19/95	130		0.04
8-PMK048.80	01/22/96	9200		0.99

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-PMK048.80 in Pamunkey River watershed. (continued)

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-PMK048.80	02/20/96	20		0.28
8-PMK048.80	03/14/96	18		0.05
8-PMK048.80	04/15/96	78		3.44
8-PMK048.80	05/29/96	230		0.37
8-PMK048.80	06/19/96	1800		0.62
8-PMK048.80	07/24/96	110		1.12
8-PMK048.80	08/22/96	20		0.08
8-PMK048.80	09/25/96	170		4.20
8-PMK048.80	10/24/96	110		0.99
8-PMK048.80	11/20/96	170		0.00
8-PMK048.80	12/17/96	330		0.21
8-PMK048.80	01/29/97	5400		1.29
8-PMK048.80	02/26/97	92		0.24
8-PMK048.80	03/19/97	110		0.10
8-PMK048.80	04/17/97	78		N/A
8-PMK048.80	05/29/97	78		0.90
8-PMK048.80	06/16/97	950		1.97
8-PMK048.80	07/08/97	330		1.22
8-PMK048.80	08/11/97	78		0.00
8-PMK048.80	09/30/97	110		2.72
8-PMK048.80	10/20/97	490		0.90
8-PMK048.80	11/24/97	40		2.09
8-PMK048.80	12/04/97	120		1.21
8-PMK048.80	01/08/98	230		0.02
8-PMK048.80	03/11/98	2400		0.61
8-PMK048.80	04/08/98	220		0.01
8-PMK048.80	05/06/98	170		0.02
8-PMK048.80	06/03/98	78		1.34
8-PMK048.80	07/07/98	110		3.03
8-PMK048.80	08/24/98	130		1.35
8-PMK048.80	09/21/98	130		0.26
8-PMK048.80	10/19/98	18		0.09
8-PMK048.80	11/23/98	68		1.09
8-PMK048.80	12/16/98	700		1.71
8-PMK048.80	01/14/99	220		0.00
8-PMK048.80	02/08/99	130		0.02

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-PMK048.80 in Pamunkey River watershed. (continued)

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-PMK048.80	03/08/99	45		0.28
8-PMK048.80	04/12/99	78		0.40
8-PMK048.80	05/26/99	78		0.31
8-PMK048.80	06/16/99	61		0.16
8-PMK048.80	07/22/99	45		0.30
8-PMK048.80	08/17/99	45		0.97
8-PMK048.80	09/15/99	110		0.00
8-PMK048.80	10/07/99	130		0.00
8-PMK048.80	12/28/99	260		1.15
8-PMK048.80	02/16/00	100		0.10
8-PMK048.80	03/15/00	100		0.02
8-PMK048.80	04/25/00	100		0.12
8-PMK048.80	05/25/00	100		1.79
8-PMK048.80	06/06/00	1100		3.15
8-PMK048.80	07/17/00	300		1.85
8-PMK048.80	08/15/00	100		1.63
8-PMK048.80	09/27/00	1000		0.02
8-PMK048.80	10/19/00	200		1.59
8-PMK048.80	11/02/00	100		1.37
8-PMK048.80	12/06/00	100		0.00
8-PMK048.80	01/03/01	100		0.11
8-PMK048.80	02/15/01	100		0.53
8-PMK048.80	03/27/01	100		0.46
8-PMK048.80	04/19/01	100		1.24
8-PMK048.80	05/22/01	500		0.58
8-PMK048.80	07/18/01	100		0.68
8-PMK048.80	09/20/01	200		0.07
8-PMK048.80	11/28/01	100		0.00
8-PMK048.80	01/09/02	200		0.14
8-PMK048.80	03/28/02	100		0.02
8-PMK048.80	05/20/02	100		0.00
8-PMK048.80	08/21/02	200		0.60
8-PMK048.80	10/24/02	100		0.42
8-PMK048.80	12/09/02	100		0.00
8-PMK048.80	02/20/03	100		6.43
8-PMK048.80	04/24/03	100		0.61

Table A.11. Observed fecal coliform concentration, *E. coli* concentration, and antecedent rainfall for VADEQ station 8-PMK048.80 in Pamunkey River watershed. (continued)

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Observed *E. coli* Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
8-PMK048.80	06/18/03	100		1.31
8-PMK048.80	07/08/03	280	42	4.28
8-PMK048.80	08/12/03	600	64	1.78
8-PMK048.80	08/28/03	480	130	0.42
8-PMK048.80	09/09/03	230	110	0.40
8-PMK048.80	10/07/03	50	28	0.03
8-PMK048.80	10/23/03	75	20	0.45
8-PMK048.80	11/04/03	320	270	0.10

N/A – Data not available

Appendix B – Bacteria Source Tracking Report

The bacterial source tracking (BST) data were generated in a separate study for VADEQ performed by MapTech, Inc. and New River Highlands RC&D. The reader should refer to data and analyses for stations 8-SAR097.82, 8-SAR021.22, 8-SAR001.11, 8-NST003.46, 8-TPT004.37, and 8-PMK048.80.

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/bst04.pdf

or contact VDEQ-NRO or VDEQ-PRO

Appendix C – Fecal Coliform Loading in Subwatersheds

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	11,686	2,937	740	82	561	0
Fe.	0	12,495	3,139	790	74	512	0
Mar.	0	14,114	3,545	892	59	561	0
Apr.	0	14,049	3,529	887	57	543	0
May.	0	14,917	3,746	942	59	561	0
Jun.	0	14,809	3,719	935	57	543	0
Jul.	0	15,707	3,944	991	59	561	0
Aug.	0	16,111	4,045	1,017	59	561	0
Sep.	0	16,003	4,018	1,010	79	543	0
Oct.	0	10,164	2,556	644	82	561	0
Nov.	0	10,328	2,597	654	79	543	0
Dec.	0	11,180	2,811	708	82	561	0
Total	5	161,564	40,587	10,209	828	6,614	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	12,968	3,269	814	92	300	0
Fe.	1	13,848	3,488	869	84	273	0
Mar.	1	15,639	3,938	981	65	300	0
Apr.	1	15,563	3,918	976	62	290	0
May.	1	16,522	4,159	1,037	65	300	0
Jun.	1	16,400	4,128	1,029	62	290	0
Jul.	1	17,391	4,377	1,091	65	300	0
Aug.	1	17,836	4,488	1,119	65	300	0
Sep.	1	17,713	4,457	1,111	89	290	0
Oct.	1	11,294	2,850	709	92	300	0
Nov.	1	11,471	2,893	720	89	290	0
Dec.	1	12,412	3,130	779	92	300	0
Total	16	179,057	45,096	11,236	924	3,535	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	7,721	1,937	486	59	233	3,100
Fe.	0	7,604	1,907	478	54	213	2,825
Mar.	0	11,218	2,812	705	46	233	7,440
Apr.	0	10,975	2,751	689	44	226	8,400
May.	0	11,462	2,873	720	46	233	8,680
Jun.	0	11,199	2,807	703	44	226	8,400
Jul.	0	11,697	2,932	734	46	233	8,680
Aug.	0	11,821	2,963	742	46	233	8,680
Sep.	0	11,575	2,901	727	57	226	8,400
Oct.	0	10,002	2,508	628	59	233	8,680
Nov.	0	9,832	2,465	618	57	226	7,200
Dec.	0	7,565	1,898	476	59	233	3,100
Total	1	122,672	30,755	7,706	617	2,750	83,585

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	0	1,078	271	68	13	41	0
Fe.	0	1,153	289	73	12	38	0
Mar.	0	1,302	327	82	11	41	0
Apr.	0	1,296	325	82	11	40	0
May.	0	1,376	345	87	11	41	0
Jun.	0	1,366	343	86	11	40	0
Jul.	0	1,449	364	91	11	41	0
Aug.	0	1,486	373	94	11	41	0
Sep.	0	1,476	371	93	13	40	0
Oct.	0	938	236	59	13	41	0
Nov.	0	953	239	60	13	40	0
Dec.	0	1,031	259	65	13	41	0
Total	0	14,905	3,742	940	146	487	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	32,159	8,196	1,973	693	1,748	0
Fe.	3	34,189	8,691	2,104	632	1,593	0
Mar.	4	38,583	9,804	2,375	476	1,748	0
Apr.	3	38,370	9,746	2,363	460	1,691	0
May.	4	40,708	10,337	2,508	476	1,748	0
Jun.	3	40,382	10,250	2,489	460	1,691	0
Jul.	4	42,798	10,860	2,639	476	1,748	0
Aug.	4	43,868	11,128	2,706	476	1,748	0
Sep.	3	43,541	11,041	2,687	671	1,691	0
Oct.	4	28,131	7,187	1,721	693	1,748	0
Nov.	3	28,524	7,281	1,747	671	1,691	0
Dec.	4	30,819	7,860	1,889	693	1,748	0
Total	42	442,072	112,382	27,203	6,875	20,593	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	21	90,560	22,747	5,720	1,397	6,057	3,100
Fe.	19	96,183	24,149	6,068	1,273	5,520	2,825
Mar.	21	111,277	27,935	7,017	1,004	6,057	7,440
Apr.	21	110,570	27,756	6,971	972	5,862	8,400
May.	21	117,215	29,422	7,389	1,004	6,057	8,680
Jun.	21	116,187	29,163	7,323	972	5,862	8,400
Jul.	21	123,051	30,884	7,755	1,004	6,057	8,680
Aug.	21	126,043	31,633	7,942	1,004	6,057	8,680
Sep.	21	125,028	31,377	7,877	1,352	5,862	8,400
Oct.	21	82,047	20,615	5,187	1,397	6,057	8,680
Nov.	21	83,038	20,861	5,248	1,352	5,862	7,200
Dec.	21	86,814	21,809	5,486	1,397	6,057	3,100
Total	251	1,268,012	318,349	79,983	14,127	71,364	83,585

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	12	53,918	13,547	3,409	1,060	5,307	0
Fe.	11	57,652	14,479	3,640	966	4,836	0
Mar.	12	65,123	16,354	4,110	776	5,307	0
Apr.	12	64,821	16,276	4,090	750	5,136	0
May.	12	68,829	17,282	4,342	776	5,307	0
Jun.	12	68,331	17,155	4,310	750	5,136	0
Jul.	12	72,475	18,195	4,571	776	5,307	0
Aug.	12	74,340	18,662	4,688	776	5,307	0
Sep.	12	73,840	18,535	4,655	1,026	5,136	0
Oct.	12	46,893	11,788	2,969	1,060	5,307	0
Nov.	12	47,649	11,976	3,015	1,026	5,136	0
Dec.	12	51,581	12,962	3,263	1,060	5,307	0
Total	147	745,453	187,210	47,063	10,801	62,532	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	8	20,123	5,055	1,271	388	1,088	0
Fe.	8	21,518	5,402	1,357	354	991	0
Mar.	8	24,306	6,102	1,533	286	1,088	0
Apr.	8	24,194	6,074	1,526	276	1,053	0
May.	8	25,690	6,449	1,620	286	1,088	0
Jun.	8	25,504	6,402	1,608	276	1,053	0
Jul.	8	27,051	6,790	1,705	286	1,088	0
Aug.	8	27,748	6,964	1,748	286	1,088	0
Sep.	8	27,561	6,917	1,736	375	1,053	0
Oct.	8	17,501	4,398	1,107	388	1,088	0
Nov.	8	17,783	4,468	1,124	375	1,053	0
Dec.	8	19,251	4,836	1,216	388	1,088	0
Total	99	278,229	69,855	17,552	3,964	12,817	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	898	225	57	22	67	0
Fe.	1	960	241	60	20	61	0
Mar.	1	1,085	272	68	20	67	0
Apr.	1	1,080	271	68	19	65	0
May.	1	1,146	288	72	20	67	0
Jun.	1	1,138	286	72	19	65	0
Jul.	1	1,207	303	76	20	67	0
Aug.	1	1,238	311	78	20	67	0
Sep.	1	1,230	309	77	21	65	0
Oct.	1	781	196	49	22	67	0
Nov.	1	793	199	50	21	65	0
Dec.	1	859	216	54	22	67	0
Total	13	12,415	3,116	782	245	787	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	8,085	2,031	511	301	2,080	0
Fe.	2	8,646	2,171	545	274	1,896	0
Mar.	2	9,766	2,452	616	225	2,080	0
Apr.	2	9,721	2,440	613	218	2,013	0
May.	2	10,322	2,591	651	225	2,080	0
Jun.	2	10,247	2,572	646	218	2,013	0
Jul.	2	10,869	2,728	685	225	2,080	0
Aug.	2	11,149	2,798	703	225	2,080	0
Sep.	2	11,074	2,779	698	291	2,013	0
Oct.	2	7,032	1,767	445	301	2,080	0
Nov.	2	7,145	1,795	452	291	2,013	0
Dec.	2	7,735	1,943	489	301	2,080	0
Total	29	111,791	28,068	7,053	3,094	24,512	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	1,346	338	85	45	218	0
Fe.	2	1,440	361	91	41	199	0
Mar.	2	1,626	408	102	34	218	0
Apr.	2	1,619	406	102	33	211	0
May.	2	1,719	431	108	34	218	0
Jun.	2	1,707	428	107	33	211	0
Jul.	2	1,810	454	114	34	218	0
Aug.	2	1,857	466	117	34	218	0
Sep.	2	1,844	463	116	44	211	0
Oct.	2	1,171	294	74	45	218	0
Nov.	2	1,190	299	75	44	211	0
Dec.	2	1,288	323	81	45	218	0
Total	29	18,617	4,670	1,172	470	2,571	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	7	6,017	1,511	380	121	395	0
Fe.	6	6,434	1,615	406	110	360	0
Mar.	7	7,268	1,824	458	89	395	0
Apr.	7	7,235	1,816	456	86	383	0
May.	7	7,682	1,928	484	89	395	0
Jun.	7	7,626	1,914	480	86	383	0
Jul.	7	8,089	2,030	509	89	395	0
Aug.	7	8,297	2,082	522	89	395	0
Sep.	7	8,242	2,068	519	117	383	0
Oct.	7	5,232	1,314	331	121	395	0
Nov.	7	5,317	1,335	336	117	383	0
Dec.	7	5,756	1,445	363	121	395	0
Total	82	83,195	20,882	5,244	1,235	4,658	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	1,078	271	68	6	44	0
Fe.	1	1,152	289	73	5	40	0
Mar.	1	1,302	327	82	6	44	0
Apr.	1	1,296	325	82	6	43	0
May.	1	1,376	345	87	6	44	0
Jun.	1	1,366	343	86	6	43	0
Jul.	1	1,449	363	91	6	44	0
Aug.	1	1,486	373	94	6	44	0
Sep.	1	1,476	370	93	6	43	0
Oct.	1	937	235	59	6	44	0
Nov.	1	952	239	60	6	43	0
Dec.	1	1,031	259	65	6	44	0
Total	9	14,900	3,740	939	71	519	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	20	14,368	3,607	906	270	1,810	0
Fe.	18	15,364	3,856	968	246	1,649	0
Mar.	20	17,356	4,356	1,094	201	1,810	0
Apr.	19	17,275	4,335	1,088	195	1,752	0
May.	20	18,344	4,603	1,155	201	1,810	0
Jun.	19	18,212	4,570	1,147	195	1,752	0
Jul.	20	19,316	4,847	1,216	201	1,810	0
Aug.	20	19,814	4,971	1,247	201	1,810	0
Sep.	19	19,681	4,938	1,239	261	1,752	0
Oct.	20	12,494	3,138	789	270	1,810	0
Nov.	19	12,696	3,188	802	261	1,752	0
Dec.	20	13,745	3,451	867	270	1,810	0
Total	233	198,664	49,861	12,519	2,775	21,325	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	176	173,800	43,647	10,972	3,537	13,697	0
Fe.	161	185,850	46,654	11,719	3,223	12,482	0
Mar.	176	209,937	52,698	13,235	2,559	13,697	0
Apr.	171	208,966	52,450	13,171	2,476	13,255	0
May.	176	221,888	55,690	13,983	2,559	13,697	0
Jun.	171	220,286	55,285	13,880	2,476	13,255	0
Jul.	176	233,646	58,635	14,719	2,559	13,697	0
Aug.	176	239,663	60,142	15,096	2,559	13,697	0
Sep.	171	238,052	59,735	14,992	3,423	13,255	0
Oct.	176	151,146	37,974	9,554	3,537	13,697	0
Nov.	171	153,585	38,581	9,704	3,423	13,255	0
Dec.	176	166,264	41,760	10,501	3,537	13,697	0
Total	2,079	2,403,083	603,251	151,527	35,865	161,383	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	65	81,117	20,848	4,892	2,225	10,341	0
Fe.	59	85,944	22,009	5,211	2,028	9,423	0
Mar.	65	96,935	24,809	5,882	1,403	10,341	0
Apr.	63	96,347	24,645	5,851	1,358	10,007	0
May.	65	102,166	26,119	6,210	1,403	10,341	0
Jun.	63	101,302	25,886	6,162	1,358	10,007	0
Jul.	65	107,313	27,408	6,532	1,403	10,341	0
Aug.	65	109,947	28,068	6,697	1,403	10,341	0
Sep.	63	109,079	27,833	6,649	2,153	10,007	0
Oct.	65	71,201	18,364	4,271	2,225	10,341	0
Nov.	63	72,106	18,574	4,334	2,153	10,007	0
Dec.	65	77,818	20,022	4,685	2,225	10,341	0
Total	763	1,111,275	284,586	67,374	21,336	121,837	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	13,379	3,359	844	236	1,347	0
Fe.	10	14,308	3,591	902	215	1,227	0
Mar.	10	16,162	4,056	1,018	172	1,347	0
Apr.	10	16,087	4,037	1,013	167	1,303	0
May.	10	17,082	4,287	1,076	172	1,347	0
Jun.	10	16,959	4,255	1,068	167	1,303	0
Jul.	10	17,988	4,513	1,133	172	1,347	0
Aug.	10	18,451	4,629	1,162	172	1,347	0
Sep.	10	18,327	4,598	1,154	228	1,303	0
Oct.	10	11,635	2,922	735	236	1,347	0
Nov.	10	11,823	2,969	746	228	1,303	0
Dec.	10	12,799	3,214	808	236	1,347	0
Total	124	185,002	46,431	11,657	2,401	15,869	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	24	21,482	5,538	1,282	888	3,196	0
Fe.	22	22,728	5,836	1,366	810	2,913	0
Mar.	24	25,628	6,576	1,542	567	3,196	0
Apr.	23	25,467	6,531	1,534	548	3,093	0
May.	24	27,000	6,920	1,627	567	3,196	0
Jun.	23	26,766	6,856	1,615	548	3,093	0
Jul.	24	28,348	7,258	1,712	567	3,196	0
Aug.	24	29,039	7,431	1,755	567	3,196	0
Sep.	23	28,804	7,367	1,742	860	3,093	0
Oct.	24	18,883	4,887	1,119	888	3,196	0
Nov.	23	19,113	4,940	1,136	860	3,093	0
Dec.	24	20,618	5,322	1,228	888	3,196	0
Total	280	293,878	75,461	17,657	8,557	37,658	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	5,266	1,378	304	356	1,686	0
Fe.	5	5,537	1,441	324	324	1,537	0
Mar.	5	6,237	1,621	365	224	1,686	0
Apr.	5	6,192	1,608	363	216	1,632	0
May.	5	6,558	1,702	385	224	1,686	0
Jun.	5	6,496	1,684	382	216	1,632	0
Jul.	5	6,874	1,781	405	224	1,686	0
Aug.	5	7,036	1,821	415	224	1,686	0
Sep.	5	6,973	1,804	412	344	1,632	0
Oct.	5	4,657	1,226	266	356	1,686	0
Nov.	5	4,704	1,235	270	344	1,632	0
Dec.	5	5,064	1,327	292	356	1,686	0
Total	64	71,594	18,628	4,183	3,407	19,869	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	33	40,380	10,478	2,369	1,428	7,098	6,781
Fe.	30	41,170	10,644	2,433	1,301	6,468	6,180
Mar.	33	52,148	13,426	3,106	884	7,098	16,275
Apr.	32	51,387	13,223	3,064	856	6,869	18,375
May.	33	54,044	13,900	3,225	884	7,098	18,988
Jun.	32	53,166	13,669	3,175	856	6,869	18,375
Jul.	33	55,896	14,364	3,341	884	7,098	18,988
Aug.	33	56,854	14,604	3,401	884	7,098	18,988
Sep.	32	56,012	14,381	3,353	1,381	6,869	18,375
Oct.	33	42,788	11,081	2,520	1,428	7,098	18,988
Nov.	32	42,574	11,016	2,512	1,381	6,869	15,750
Dec.	33	39,181	10,178	2,294	1,428	7,098	6,781
Total	386	585,602	150,964	34,793	13,596	83,630	182,842

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	18	14,927	3,909	860	678	2,774	0
Fe.	17	15,689	4,085	914	618	2,528	0
Mar.	18	17,672	4,597	1,032	420	2,774	0
Apr.	18	17,543	4,559	1,026	406	2,685	0
May.	18	18,580	4,824	1,089	420	2,774	0
Jun.	18	18,403	4,774	1,080	406	2,685	0
Jul.	18	19,473	5,048	1,145	420	2,774	0
Aug.	18	19,930	5,162	1,173	420	2,774	0
Sep.	18	19,752	5,112	1,165	656	2,685	0
Oct.	18	13,206	3,478	752	678	2,774	0
Nov.	18	13,335	3,505	763	656	2,685	0
Dec.	18	14,354	3,766	824	678	2,774	0
Total	217	202,865	52,817	11,824	6,458	32,689	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	32	30,661	8,004	1,779	1,124	4,282	0
Fe.	29	32,271	8,378	1,893	1,024	3,902	0
Mar.	32	36,357	9,430	2,136	687	4,282	0
Apr.	31	36,099	9,355	2,124	665	4,144	0
May.	32	38,241	9,902	2,254	687	4,282	0
Jun.	31	37,883	9,802	2,236	665	4,144	0
Jul.	32	40,094	10,366	2,370	687	4,282	0
Aug.	32	41,043	10,604	2,429	687	4,282	0
Sep.	31	40,683	10,503	2,411	1,088	4,144	0
Oct.	32	27,090	7,109	1,556	1,124	4,282	0
Nov.	31	27,369	7,169	1,578	1,088	4,144	0
Dec.	32	29,473	7,706	1,705	1,124	4,282	0
Total	376	417,266	108,328	24,470	10,648	50,454	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	16	17,963	4,634	1,065	517	1,305	4,844
Fe.	15	17,974	4,624	1,071	471	1,190	4,414
Mar.	16	24,371	6,238	1,466	321	1,305	11,625
Apr.	16	23,922	6,121	1,440	311	1,263	13,125
May.	16	25,064	6,412	1,510	321	1,305	13,563
Jun.	16	24,567	6,283	1,481	311	1,263	13,125
Jul.	16	25,737	6,580	1,552	321	1,305	13,563
Aug.	16	26,088	6,668	1,574	321	1,305	13,563
Sep.	16	25,617	6,546	1,546	500	1,263	13,125
Oct.	16	20,936	5,378	1,251	517	1,305	13,563
Nov.	16	20,689	5,312	1,238	500	1,263	11,250
Dec.	16	17,523	4,523	1,038	517	1,305	4,844
Total	190	270,452	69,320	16,232	4,928	15,381	130,602

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	3,234	846	188	145	382	0
Fe.	5	3,401	885	199	132	348	0
Mar.	5	3,831	996	225	89	382	0
Apr.	5	3,804	988	224	86	370	0
May.	5	4,029	1,045	237	89	382	0
Jun.	5	3,991	1,035	236	86	370	0
Jul.	5	4,224	1,094	250	89	382	0
Aug.	5	4,323	1,119	256	89	382	0
Sep.	5	4,285	1,108	254	140	370	0
Oct.	5	2,859	752	164	145	382	0
Nov.	5	2,888	758	167	140	370	0
Dec.	5	3,109	815	180	145	382	0
Total	60	43,978	11,440	2,579	1,375	4,503	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	1,621	425	95	65	175	0
Fe.	4	1,704	444	101	59	159	0
Mar.	4	1,919	500	113	39	175	0
Apr.	4	1,906	496	113	37	169	0
May.	4	2,018	524	120	39	175	0
Jun.	4	1,999	519	119	37	169	0
Jul.	4	2,116	549	126	39	175	0
Aug.	4	2,165	561	129	39	175	0
Sep.	4	2,146	556	128	63	169	0
Oct.	4	1,433	378	83	65	175	0
Nov.	4	1,448	381	84	63	169	0
Dec.	4	1,558	409	91	65	175	0
Total	46	22,033	5,742	1,301	607	2,062	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	1,110	290	65	47	214	0
Fe.	4	1,167	304	69	43	195	0
Mar.	4	1,315	342	78	27	214	0
Apr.	4	1,306	339	77	26	207	0
May.	4	1,383	359	82	27	214	0
Jun.	4	1,370	355	81	26	207	0
Jul.	4	1,450	376	86	27	214	0
Aug.	4	1,484	384	88	27	214	0
Sep.	4	1,471	381	88	46	207	0
Oct.	4	981	258	57	47	214	0
Nov.	4	991	260	58	46	207	0
Dec.	4	1,067	280	62	47	214	0
Total	52	15,094	3,928	891	437	2,518	0

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	32	19,727	5,130	1,161	545	6,525	3,003
Fe.	29	20,163	5,222	1,195	497	5,946	2,737
Mar.	32	25,284	6,522	1,509	305	6,525	7,208
Apr.	31	24,929	6,427	1,489	296	6,315	8,138
May.	32	26,232	6,759	1,568	305	6,525	8,409
Jun.	31	25,820	6,650	1,545	296	6,315	8,138
Jul.	32	27,160	6,991	1,626	305	6,525	8,409
Aug.	32	27,639	7,111	1,656	305	6,525	8,409
Sep.	31	27,242	7,006	1,634	528	6,315	8,138
Oct.	32	20,604	5,350	1,216	545	6,525	8,409
Nov.	31	20,523	5,323	1,213	528	6,315	6,975
Dec.	32	19,127	4,980	1,123	545	6,525	3,003
Total	373	284,450	73,470	16,933	5,001	76,882	80,973

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	837	221	47	28	348	0
Fe.	2	876	230	50	25	318	0
Mar.	2	986	259	56	18	348	0
Apr.	2	979	256	56	18	337	0
May.	2	1,036	271	60	18	348	0
Jun.	2	1,025	268	59	18	337	0
Jul.	2	1,085	283	63	18	348	0
Aug.	2	1,109	289	64	18	348	0
Sep.	2	1,099	286	64	27	337	0
Oct.	2	743	198	41	28	348	0
Nov.	2	750	199	42	27	337	0
Dec.	2	806	213	45	28	348	0
Total	22	11,332	2,974	647	269	4,106	0

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

Table C.29. Monthly nonpoint fecal coliform loadings in sub-watershed NEC-1.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	23	8,162	2,077	508	595	2,013	0
Fe.	21	8,687	2,206	541	542	1,835	0
Mar.	23	9,806	2,489	611	402	2,013	0
Apr.	23	9,753	2,474	607	389	1,949	0
May.	23	10,349	2,625	645	402	2,013	0
Jun.	23	10,268	2,603	640	389	1,949	0
Jul.	23	10,884	2,759	678	402	2,013	0
Aug.	23	11,157	2,827	695	402	2,013	0
Sep.	23	11,076	2,806	690	576	1,949	0
Oct.	23	7,132	1,819	443	595	2,013	0
Nov.	23	7,235	1,844	450	576	1,949	0
Dec.	23	7,819	1,991	486	595	2,013	0
Total	274	112,328	28,519	6,994	5,862	23,723	0

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

Table C.30. Monthly nonpoint fecal coliform loadings in sub-watershed NEC-2.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	13	7,081	1,804	439	349	1,232	0
Fe.	12	7,531	1,915	467	318	1,122	0
Mar.	13	8,500	2,160	528	234	1,232	0
Apr.	12	8,454	2,147	525	227	1,192	0
May.	13	8,969	2,277	557	234	1,232	0
Jun.	12	8,898	2,259	553	227	1,192	0
Jul.	13	9,431	2,393	586	234	1,232	0
Aug.	13	9,668	2,452	601	234	1,232	0
Sep.	12	9,596	2,433	596	338	1,192	0
Oct.	13	6,191	1,582	383	349	1,232	0
Nov.	12	6,278	1,603	389	338	1,192	0
Dec.	13	6,785	1,730	420	349	1,232	0
Total	149	97,382	24,756	6,044	3,433	14,511	0

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

Table C.31. Monthly nonpoint fecal coliform loadings in sub-watershed NEC-3.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	9	4,261	1,084	265	296	1,024	0
Fe.	8	4,536	1,151	283	269	933	0
Mar.	9	5,120	1,299	319	199	1,024	0
Apr.	8	5,093	1,292	318	193	991	0
May.	9	5,405	1,370	337	199	1,024	0
Jun.	8	5,362	1,359	334	193	991	0
Jul.	9	5,684	1,440	354	199	1,024	0
Aug.	9	5,827	1,476	363	199	1,024	0
Sep.	8	5,785	1,465	361	286	991	0
Oct.	9	3,723	949	232	296	1,024	0
Nov.	8	3,777	962	235	286	991	0
Dec.	9	4,082	1,039	254	296	1,024	0
Total	103	58,656	14,887	3,656	2,910	12,062	0

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

Table C.32. Monthly nonpoint fecal coliform loadings in sub-watershed NEC-4.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	2,402	611	150	136	467	0
Fe.	5	2,558	649	160	124	426	0
Mar.	5	2,888	732	181	91	467	0
Apr.	5	2,872	728	180	88	452	0
May.	5	3,048	772	191	91	467	0
Jun.	5	3,024	766	189	88	452	0
Jul.	5	3,206	812	200	91	467	0
Aug.	5	3,287	832	206	91	467	0
Sep.	5	3,263	826	204	131	452	0
Oct.	5	2,098	534	131	136	467	0
Nov.	5	2,128	542	133	131	452	0
Dec.	5	2,301	585	144	136	467	0
Total	64	33,075	8,389	2,068	1,335	5,506	0

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

Table C.33. Monthly nonpoint fecal coliform loadings in sub-watershed NEC-5.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	3	811	204	52	29	116	0
Fe.	2	867	218	55	27	106	0
Mar.	3	979	247	62	22	116	0
Apr.	2	975	245	62	21	112	0
May.	3	1,035	261	66	22	116	0
Jun.	2	1,027	259	65	21	112	0
Jul.	3	1,090	274	69	22	116	0
Aug.	3	1,118	281	71	22	116	0
Sep.	2	1,110	279	70	29	112	0
Oct.	3	706	178	45	29	116	0
Nov.	2	717	181	46	29	112	0
Dec.	3	776	196	50	29	116	0
Total	30	11,212	2,823	714	303	1,366	0

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

Table C.34. Monthly nonpoint fecal coliform loadings in sub-watershed TOC-1.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	3,559	932	205	255	14,954	0
Fe.	4	3,740	974	218	232	13,627	0
Mar.	5	4,213	1,096	246	154	14,954	0
Apr.	5	4,182	1,087	244	149	14,471	0
May.	5	4,429	1,150	259	154	14,954	0
Jun.	5	4,387	1,138	257	149	14,471	0
Jul.	5	4,642	1,204	273	154	14,954	0
Aug.	5	4,751	1,231	279	154	14,954	0
Sep.	5	4,708	1,219	277	247	14,471	0
Oct.	5	3,149	830	179	255	14,954	0
Nov.	5	3,180	836	182	247	14,471	0
Dec.	5	3,423	898	196	255	14,954	0
Total	57	48,363	12,596	2,815	2,407	176,188	0

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

Table C.35. Monthly nonpoint fecal coliform loadings in sub-watershed TOC-2.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	6,609	1,731	380	387	10,982	0
Fe.	9	6,945	1,809	404	352	10,008	0
Mar.	10	7,823	2,035	456	234	10,982	0
Apr.	10	7,765	2,018	453	227	10,628	0
May.	10	8,224	2,136	481	234	10,982	0
Jun.	10	8,145	2,113	477	227	10,628	0
Jul.	10	8,619	2,234	506	234	10,982	0
Aug.	10	8,821	2,285	518	234	10,982	0
Sep.	10	8,742	2,263	515	374	10,628	0
Oct.	10	5,848	1,540	332	387	10,982	0
Nov.	10	5,905	1,552	337	374	10,628	0
Dec.	10	6,355	1,668	364	387	10,982	0
Total	117	89,800	23,384	5,224	3,650	129,397	0

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

Table C.36. Monthly nonpoint fecal coliform loadings in sub-watershed TOC-3.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	14	9,059	2,374	520	369	3,543	0
Fe.	13	9,519	2,479	553	336	3,228	0
Mar.	14	10,722	2,790	624	228	3,543	0
Apr.	14	10,643	2,767	621	220	3,428	0
May.	14	11,271	2,928	659	228	3,543	0
Jun.	14	11,163	2,897	653	220	3,428	0
Jul.	14	11,812	3,063	692	228	3,543	0
Aug.	14	12,089	3,132	710	228	3,543	0
Sep.	14	11,980	3,102	704	357	3,428	0
Oct.	14	8,018	2,113	455	369	3,543	0
Nov.	14	8,095	2,129	461	357	3,428	0
Dec.	14	8,713	2,287	498	369	3,543	0
Total	168	123,084	32,060	7,151	3,507	41,741	0

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

Table C.37. Monthly nonpoint fecal coliform loadings in sub-watershed TOC-4.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	3,977	1,043	228	156	741	0
Fe.	5	4,178	1,089	243	143	675	0
Mar.	5	4,705	1,225	274	97	741	0
Apr.	5	4,670	1,215	272	94	717	0
May.	5	4,946	1,285	289	97	741	0
Jun.	5	4,899	1,272	286	94	717	0
Jul.	5	5,183	1,345	304	97	741	0
Aug.	5	5,304	1,375	311	97	741	0
Sep.	5	5,257	1,362	309	151	717	0
Oct.	5	3,520	928	200	156	741	0
Nov.	5	3,554	935	202	151	717	0
Dec.	5	3,825	1,005	219	156	741	0
Total	61	54,019	14,078	3,136	1,491	8,727	0

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

Table C.38. Monthly nonpoint fecal coliform loadings in sub-watershed TOC-5.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	6,609	1,731	380	249	1,132	0
Fe.	9	6,946	1,809	404	227	1,032	0
Mar.	10	7,823	2,035	456	152	1,132	0
Apr.	10	7,766	2,018	454	147	1,096	0
May.	10	8,224	2,136	481	152	1,132	0
Jun.	10	8,146	2,114	477	147	1,096	0
Jul.	10	8,619	2,235	506	152	1,132	0
Aug.	10	8,822	2,285	519	152	1,132	0
Sep.	10	8,743	2,263	515	241	1,096	0
Oct.	10	5,848	1,541	332	249	1,132	0
Nov.	10	5,905	1,552	337	241	1,096	0
Dec.	10	6,356	1,668	364	249	1,132	0
Total	118	89,806	23,387	5,225	2,356	13,338	0

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

Table C.39. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-1.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	963	249	59	41	108	0
Fe.	1	1,020	262	63	38	98	0
Mar.	1	1,150	295	71	25	108	0
Apr.	1	1,143	293	70	24	104	0
May.	1	1,212	311	75	25	108	0
Jun.	1	1,201	308	74	24	104	0
Jul.	1	1,272	326	78	25	108	0
Aug.	1	1,303	334	80	25	108	0
Sep.	1	1,293	331	80	40	104	0
Oct.	1	846	219	52	41	108	0
Nov.	1	856	222	52	40	104	0
Dec.	1	924	239	57	41	108	0
Total	13	13,183	3,390	810	389	1,269	0

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

Table C.40. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-2.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	63	15,162	3,935	899	620	1,870	0
Fe.	58	16,003	4,133	956	565	1,704	0
Mar.	63	18,038	4,655	1,079	382	1,870	0
Apr.	61	17,918	4,621	1,073	369	1,809	0
May.	63	18,989	4,894	1,139	382	1,870	0
Jun.	61	18,819	4,846	1,130	369	1,809	0
Jul.	63	19,925	5,128	1,197	382	1,870	0
Aug.	63	20,404	5,248	1,227	382	1,870	0
Sep.	61	20,233	5,200	1,218	600	1,809	0
Oct.	63	13,359	3,484	786	620	1,870	0
Nov.	61	13,510	3,517	797	600	1,809	0
Dec.	63	14,562	3,785	862	620	1,870	0
Total	744	206,924	53,446	12,363	5,891	22,030	0

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

Table C.41. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-3.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	13	1,537	388	99	326	536	0
Fe.	11	1,642	414	105	297	488	0
Mar.	13	1,854	468	119	227	536	0
Apr.	12	1,845	466	118	220	519	0
May.	13	1,959	494	125	227	536	0
Jun.	12	1,945	490	124	220	519	0
Jul.	13	2,063	520	132	227	536	0
Aug.	13	2,115	533	135	227	536	0
Sep.	12	2,101	530	134	315	519	0
Oct.	13	1,338	339	86	326	536	0
Nov.	12	1,359	344	88	315	519	0
Dec.	13	1,471	372	95	326	536	0
Total	148	21,228	5,358	1,360	3,251	6,313	0

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

Table C.42. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-4.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	29	3,709	938	239	460	791	0
Fe.	27	3,962	1,001	254	419	721	0
Mar.	29	4,475	1,130	287	308	791	0
Apr.	28	4,453	1,124	285	298	766	0
May.	29	4,728	1,193	303	308	791	0
Jun.	28	4,693	1,184	300	298	766	0
Jul.	29	4,977	1,256	318	308	791	0
Aug.	29	5,105	1,288	326	308	791	0
Sep.	28	5,070	1,278	324	445	766	0
Oct.	29	3,229	818	209	460	791	0
Nov.	28	3,280	830	212	445	766	0
Dec.	29	3,549	898	229	460	791	0
Total	344	51,229	12,938	3,289	4,516	9,321	0

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

Table C.43. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-5.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	12	1,446	366	93	314	669	0
Fe.	11	1,545	390	99	286	610	0
Mar.	12	1,745	440	112	217	669	0
Apr.	12	1,737	438	111	210	648	0
May.	12	1,844	465	118	217	669	0
Jun.	12	1,831	462	117	210	648	0
Jul.	12	1,941	490	124	217	669	0
Aug.	12	1,991	502	127	217	669	0
Sep.	12	1,977	498	126	304	648	0
Oct.	12	1,259	319	81	314	669	0
Nov.	12	1,279	324	83	304	648	0
Dec.	12	1,384	350	89	314	669	0
Total	142	19,981	5,043	1,281	3,125	7,884	0

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

Table C.44. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-6.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	21	1,987	502	127	271	478	0
Fe.	19	2,123	535	136	247	436	0
Mar.	21	2,398	605	153	188	478	0
Apr.	21	2,386	602	152	182	463	0
May.	21	2,534	639	162	188	478	0
Jun.	21	2,515	634	160	182	463	0
Jul.	21	2,667	672	170	188	478	0
Aug.	21	2,736	689	174	188	478	0
Sep.	21	2,717	684	173	263	463	0
Oct.	21	1,729	437	111	271	478	0
Nov.	21	1,757	444	113	263	463	0
Dec.	21	1,901	480	122	271	478	0
Total	250	27,450	6,923	1,755	2,702	5,632	0

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

Table C.45. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-7.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	3,306	831	209	78	129	1,938
Fe.	4	3,127	785	198	71	117	1,766
Mar.	4	5,175	1,299	326	54	129	4,650
Apr.	4	5,031	1,262	317	52	125	5,250
May.	4	5,222	1,310	329	54	129	5,425
Jun.	4	5,071	1,273	319	52	125	5,250
Jul.	4	5,265	1,321	332	54	129	5,425
Aug.	4	5,290	1,327	333	54	129	5,425
Sep.	4	5,150	1,292	324	75	125	5,250
Oct.	4	4,931	1,237	311	78	129	5,425
Nov.	4	4,803	1,205	303	75	125	4,500
Dec.	4	3,275	823	207	78	129	1,938
Total	47	55,646	13,967	3,507	773	1,519	52,241

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

Table C.46. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-8.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	1	90	23	6	6	26	0
Fe.	1	96	24	6	5	24	0
Mar.	1	109	27	7	4	26	0
Apr.	1	108	27	7	4	26	0
May.	1	115	29	7	4	26	0
Jun.	1	114	29	7	4	26	0
Jul.	1	121	30	8	4	26	0
Aug.	1	124	31	8	4	26	0
Sep.	1	123	31	8	5	26	0
Oct.	1	78	20	5	6	26	0
Nov.	1	79	20	5	5	26	0
Dec.	1	86	22	5	6	26	0
Total	11	1,243	312	79	55	311	0

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

Table C.47. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-9.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	54	10,515	2,727	624	556	1,587	0
Fe.	49	11,101	2,865	663	506	1,446	0
Mar.	54	12,513	3,227	749	355	1,587	0
Apr.	52	12,430	3,204	745	343	1,536	0
May.	54	13,174	3,393	790	355	1,587	0
Jun.	52	13,056	3,360	784	343	1,536	0
Jul.	54	13,824	3,556	831	355	1,587	0
Aug.	54	14,157	3,639	852	355	1,587	0
Sep.	52	14,039	3,606	845	538	1,536	0
Oct.	54	9,262	2,413	545	556	1,587	0
Nov.	52	9,368	2,437	553	538	1,536	0
Dec.	54	10,098	2,623	598	556	1,587	0
Total	631	143,540	37,050	8,579	5,355	18,701	0

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

Table C.48. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-10.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	38	24,585	6,439	1,415	1,412	8,570	0
Fe.	35	25,839	6,728	1,505	1,286	7,810	0
Mar.	38	29,104	7,570	1,698	885	8,570	0
Apr.	37	28,891	7,508	1,689	857	8,294	0
May.	38	30,599	7,945	1,792	885	8,570	0
Jun.	37	30,307	7,862	1,777	857	8,294	0
Jul.	38	32,069	8,313	1,884	885	8,570	0
Aug.	38	32,822	8,501	1,931	885	8,570	0
Sep.	37	32,529	8,419	1,917	1,366	8,294	0
Oct.	38	21,752	5,729	1,238	1,412	8,570	0
Nov.	37	21,965	5,773	1,255	1,366	8,294	0
Dec.	38	23,642	6,203	1,356	1,412	8,570	0
Total	448	334,103	86,990	19,456	13,507	100,976	0

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

Table C.49. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-11.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	46	3,892	985	251	289	596	0
Fe.	42	4,157	1,050	267	264	543	0
Mar.	46	4,695	1,186	302	185	596	0
Apr.	44	4,673	1,180	300	179	577	0
May.	46	4,961	1,253	318	185	596	0
Jun.	44	4,924	1,243	316	179	577	0
Jul.	46	5,222	1,318	335	185	596	0
Aug.	46	5,356	1,351	343	185	596	0
Sep.	44	5,319	1,342	340	280	577	0
Oct.	46	3,389	859	220	289	596	0
Nov.	44	3,442	872	223	280	577	0
Dec.	46	3,725	943	241	289	596	0
Total	540	53,754	13,582	3,456	2,793	7,025	0

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

Table C.50. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-12.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	11	1,544	392	101	222	534	0
Fe.	10	1,648	418	107	202	487	0
Mar.	11	1,861	471	120	157	534	0
Apr.	11	1,852	469	120	152	517	0
May.	11	1,966	498	127	157	534	0
Jun.	11	1,952	494	126	152	517	0
Jul.	11	2,070	524	134	157	534	0
Aug.	11	2,122	537	137	157	534	0
Sep.	11	2,108	533	136	215	517	0
Oct.	11	1,345	342	88	222	534	0
Nov.	11	1,366	347	89	215	517	0
Dec.	11	1,478	375	96	222	534	0
Total	133	21,311	5,399	1,381	2,228	6,297	0

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

Table C.51. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-13.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	51	7,114	1,821	447	1,363	3,952	0
Fe.	47	7,562	1,930	475	1,242	3,601	0
Mar.	51	8,533	2,177	536	969	3,952	0
Apr.	50	8,486	2,163	533	938	3,824	0
May.	51	9,003	2,294	565	969	3,952	0
Jun.	50	8,930	2,275	561	938	3,824	0
Jul.	51	9,464	2,410	594	969	3,952	0
Aug.	51	9,701	2,469	609	969	3,952	0
Sep.	50	9,628	2,450	604	1,319	3,824	0
Oct.	51	6,224	1,598	391	1,363	3,952	0
Nov.	50	6,311	1,619	397	1,319	3,824	0
Dec.	51	6,818	1,747	429	1,363	3,952	0
Total	606	97,773	24,952	6,142	13,721	46,561	0

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

Table C.52. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-14.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	12	1,453	369	95	523	983	0
Fe.	11	1,551	393	100	476	896	0
Mar.	12	1,752	444	113	385	983	0
Apr.	11	1,743	441	113	372	951	0
May.	12	1,850	468	120	385	983	0
Jun.	11	1,837	465	119	372	951	0
Jul.	12	1,948	493	126	385	983	0
Aug.	12	1,997	505	129	385	983	0
Sep.	11	1,984	502	128	506	951	0
Oct.	12	1,266	322	83	523	983	0
Nov.	11	1,285	327	84	506	951	0
Dec.	12	1,391	353	91	523	983	0
Total	138	20,056	5,081	1,299	5,339	11,580	0

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

Table C.53. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-15.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	2	90	23	6	21	28	0
Fe.	2	96	24	6	19	26	0
Mar.	2	109	27	7	17	28	0
Apr.	2	108	27	7	17	27	0
May.	2	115	29	7	17	28	0
Jun.	2	114	29	7	17	27	0
Jul.	2	121	30	8	17	28	0
Aug.	2	124	31	8	17	28	0
Sep.	2	123	31	8	20	27	0
Oct.	2	78	20	5	21	28	0
Nov.	2	80	20	5	20	27	0
Dec.	2	86	22	5	21	28	0
Total	22	1,245	313	79	227	330	0

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

Table C.54. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-16.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	4	363	92	24	60	103	0
Fe.	4	388	98	25	55	94	0
Mar.	4	438	111	28	44	103	0
Apr.	4	436	110	28	42	100	0
May.	4	463	117	30	44	103	0
Jun.	4	459	116	30	42	100	0
Jul.	4	487	123	31	44	103	0
Aug.	4	499	126	32	44	103	0
Sep.	4	496	125	32	58	100	0
Oct.	4	316	80	21	60	103	0
Nov.	4	321	82	21	58	100	0
Dec.	4	348	88	23	60	103	0
Total	50	5,014	1,270	325	612	1,212	0

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

Table C.55. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-17.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	363	92	24	58	134	0
Fe.	5	387	98	25	53	122	0
Mar.	5	438	111	28	41	134	0
Apr.	5	435	110	28	40	129	0
May.	5	462	117	30	41	134	0
Jun.	5	459	116	30	40	129	0
Jul.	5	487	123	31	41	134	0
Aug.	5	499	126	32	41	134	0
Sep.	5	496	125	32	56	129	0
Oct.	5	316	80	21	58	134	0
Nov.	5	321	81	21	56	129	0
Dec.	5	347	88	23	58	134	0
Total	59	5,009	1,268	324	582	1,575	0

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

Table C.56. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-18.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	5	458	117	30	43	78	0
Fe.	5	488	124	32	39	71	0
Mar.	5	551	140	36	26	78	0
Apr.	5	548	140	36	25	75	0
May.	5	582	148	38	26	78	0
Jun.	5	577	147	38	25	75	0
Jul.	5	612	156	40	26	78	0
Aug.	5	628	160	41	26	78	0
Sep.	5	623	159	41	42	75	0
Oct.	5	399	102	27	43	78	0
Nov.	5	405	104	27	42	75	0
Dec.	5	438	112	29	43	78	0
Total	60	6,310	1,609	417	408	919	0

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

Table C.57. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-19.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	61	7,962	2,014	514	1,593	2,007	0
Fe.	56	8,505	2,148	546	1,452	1,829	0
Mar.	61	9,605	2,426	616	1,104	2,007	0
Apr.	59	9,559	2,413	613	1,068	1,942	0
May.	61	10,149	2,562	650	1,104	2,007	0
Jun.	59	10,074	2,542	645	1,068	1,942	0
Jul.	61	10,684	2,696	684	1,104	2,007	0
Aug.	61	10,957	2,764	701	1,104	2,007	0
Sep.	59	10,882	2,745	696	1,542	1,942	0
Oct.	61	6,932	1,756	449	1,593	2,007	0
Nov.	59	7,041	1,783	455	1,542	1,942	0
Dec.	61	7,619	1,928	492	1,593	2,007	0
Total	719	109,970	27,776	7,062	15,865	23,643	0

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

Table C.58. Monthly nonpoint fecal coliform loadings in sub-watershed PAR-20.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)						
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]	Loafing Lot
Jan.	10	453	115	29	82	154	0
Fe.	9	484	122	31	75	140	0
Mar.	10	547	138	35	58	154	0
Apr.	10	544	138	35	56	149	0
May.	10	577	146	37	58	154	0
Jun.	10	573	145	37	56	149	0
Jul.	10	608	154	39	58	154	0
Aug.	10	623	157	40	58	154	0
Sep.	10	619	156	40	80	149	0
Oct.	10	395	100	26	82	154	0
Nov.	10	401	102	26	80	149	0
Dec.	10	434	110	28	82	154	0
Total	120	6,258	1,583	404	828	1,817	0

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

Appendix D – Required Reductions in Fecal Coliform Loads by Subwatershed – Allocation Scenario

Table D.1. Required annual reductions in nonpoint sources in sub-watershed SAR-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	506	0%	15	97%
Pasture	21,236,034	97%	637,080	97%
Loafing Lots	0	0%	0	97%
Forest	82,791	0.4%	82,791	0%
Residential	661,357	3%	0	100%
Total	21,980,687	100%	719,887	97%

Table D.2. Required annual reductions in direct nonpoint sources in sub-watershed SAR-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	22,113	41%	221	99%
Wildlife in Streams	16,559	31%	1,656	90%
Straight Pipes	15,489	29%	0	100%
Total	54,161	100%	1,877	97%

Table D.3. Required annual reductions in nonpoint sources in sub-watershed SAR-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,606	0%	48	97%
Pasture	23,538,871	98%	706,165	97%
Loafing Lots	0	0%	0	97%
Forest	92,405	0.4%	92,405	0%
Residential	353,478	1%	0	100%
Total	23,986,360	100%	798,619	97%

Table D.4. Required annual reductions in direct nonpoint sources in sub-watershed SAR-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	24,324	39%	243	99%
Wildlife in Streams	21,788	35%	2,179	90%
Straight Pipes	16,436	26%	0	100%
Total	62,549	100%	2,422	96%

Table D.5. Required annual reductions in nonpoint sources in sub-watershed SAR-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	105	0%	3	97%
Pasture	16,113,266	65%	483,398	97%
Loafing Lots	8,358,500	34%	250,755	97%
Forest	61,728	0.2%	61,728	0%
Residential	275,042	1%	0	100%
Total	24,808,641	100%	795,884	97%

Table D.6. Required annual reductions in direct nonpoint sources in sub-watershed SAR-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	16,773	59%	168	99%
Wildlife in Streams	11,707	41%	1,171	90%
Straight Pipes	0	0%	0	100%
Total	28,480	100%	1,338	95%

Table D.7. Required annual reductions in nonpoint sources in sub-watershed SAR-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	0	0%	0	97%
Pasture	1,958,804	97%	58,764	97%
Loafing Lots	0	0%	0	97%
Forest	14,582	0.7%	14,582	0%
Residential	48,654	2%	0	100%
Total	2,022,040	100%	73,346	96%

Table D.8. Required annual reductions in direct nonpoint sources in sub-watershed SAR-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,041	36%	20	99%
Wildlife in Streams	3,640	64%	364	90%
Straight Pipes	0	0%	0	100%
Total	5,681	100%	384	93%

Table D.9. Required annual reductions in nonpoint sources in sub-watershed SAR-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,170	0%	42	99%
Pasture	58,165,677	95%	581,656	99%
Loafing Lots	0	0%	0	99%
Forest	687,489	1%	687,489	0%
Residential	2,059,264	3%	0	100%
Total	60,916,600	100%	1,269,186	98%

Table D.10. Required annual reductions in direct nonpoint sources in sub-watershed SAR-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	58,515	22%	0	100%
Wildlife in Streams	146,073	54%	11,686	92%
Straight Pipes	63,807	24%	0	100%
Total	268,395	100%	11,686	96%

Table D.11. Required annual reductions in nonpoint sources in sub-watershed SAR-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	25,113	0%	251	99%
Pasture	166,634,317	91%	1,666,342	99%
Loafing Lots	8,358,500	5%	83,585	99%
Forest	1,412,735	0.8%	1,412,735	0%
Residential	7,136,432	4%	0	100%
Total	183,567,097	100%	3,162,912	98%

Table D.12. Required annual reductions in direct nonpoint sources in sub-watershed SAR-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	173,606	30%	0	100%
Wildlife in Streams	264,930	46%	21,194	92%
Straight Pipes	136,630	24%	0	100%
Total	575,166	100%	21,194	96%

Table D.13. Required annual reductions in nonpoint sources in sub-watershed SAR-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,709	0%	147	99%
Pasture	97,972,636	93%	979,725	99%
Loafing Lots	0	0%	0	99%
Forest	1,080,112	1%	1,080,112	0%
Residential	6,253,159	6%	0	100%
Total	105,320,616	100%	2,059,985	98%

Table D.14. Required annual reductions in direct nonpoint sources in sub-watershed SAR-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	102,060	28%	0	100%
Wildlife in Streams	200,200	54%	16,016	92%
Straight Pipes	65,543	18%	0	100%
Total	367,804	100%	16,016	96%

Table D.15. Required annual reductions in nonpoint sources in sub-watershed SAR-8.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	9,864	0%	99	99%
Pasture	36,563,580	96%	365,635	99%
Loafing Lots	0	0%	0	99%
Forest	396,352	1%	396,352	0%
Residential	1,281,655	3%	0	100%
Total	38,251,452	100%	762,086	98%

Table D.16. Required annual reductions in direct nonpoint sources in sub-watershed SAR-8.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	38,103	30%	0	100%
Wildlife in Streams	72,157	57%	5,773	92%
Straight Pipes	16,979	13%	0	100%
Total	127,239	100%	5,773	95%

Table D.17. Required annual reductions in nonpoint sources in sub-watershed SAR-9.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,267	0.1%	13	99%
Pasture	1,631,273	94%	16,313	99%
Loafing Lots	0	0%	0	99%
Forest	24,491	1%	24,491	0%
Residential	78,697	5%	0	100%
Total	1,735,727	100%	40,816	98%

Table D.18. Required annual reductions in direct nonpoint sources in sub-watershed SAR-9.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,701	28%	0	100%
Wildlife in Streams	4,378	72%	350	92%
Straight Pipes	0	0%	0	100%
Total	6,079	100%	350	94%

Table D.19. Required annual reductions in nonpoint sources in sub-watershed SAR-10.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,888	0%	29	99%
Pasture	14,691,174	84%	146,912	99%
Loafing Lots	0	0%	0	99%
Forest	309,404	2%	309,404	0%
Residential	2,451,156	14%	0	100%
Total	17,454,622	100%	456,345	97%

Table D.20. Required annual reductions in direct nonpoint sources in sub-watershed SAR-10.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	15,309	23%	0	100%
Wildlife in Streams	50,645	77%	4,052	92%
Straight Pipes	0	0%	0	100%
Total	65,954	100%	4,052	94%

Table D.21. Required annual reductions in nonpoint sources in sub-watershed SAR-11.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,896	0.1%	29	99%
Pasture	2,445,870	89%	24,459	99%
Loafing Lots	0	0%	0	99%
Forest	46,954	2%	46,954	0%
Residential	257,112	9%	0	100%
Total	2,752,833	100%	71,441	97%

Table D.22. Required annual reductions in direct nonpoint sources in sub-watershed SAR-11.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,552	26%	0	100%
Wildlife in Streams	7,367	74%	589	92%
Straight Pipes	0	0%	0	100%
Total	9,919	100%	589	94%

Table D.23. Required annual reductions in nonpoint sources in sub-watershed SAR-12.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	8,239	0.1%	82	99%
Pasture	10,932,083	95%	109,321	99%
Loafing Lots	0	0%	0	99%
Forest	123,520	1%	123,520	0%
Residential	465,766	4%	0	100%
Total	11,529,607	100%	232,923	98%

Table D.24. Required annual reductions in direct nonpoint sources in sub-watershed SAR-12.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	11,397	23%	0	100%
Wildlife in Streams	22,128	44%	1,770	92%
Straight Pipes	17,068	34%	0	100%
Total	50,593	100%	1,770	97%

Table D.25. Required annual reductions in nonpoint sources in sub-watershed SAR-13.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	923	0%	9	99%
Pasture	1,957,815	97%	19,578	99%
Loafing Lots	0	0%	0	99%
Forest	7,109	0.4%	7,109	0%
Residential	51,944	3%	0	100%
Total	2,017,791	100%	26,696	99%

Table D.26. Required annual reductions in direct nonpoint sources in sub-watershed SAR-13.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,041	66%	0	100%
Wildlife in Streams	1,054	34%	84	92%
Straight Pipes	0	0%	0	100%
Total	3,095	100%	84	97%

Table D.27. Required annual reductions in nonpoint sources in sub-watershed SAR-14.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	23,272	0.1%	1,164	95%
Pasture	26,104,439	91%	1,305,222	95%
Loafing Lots	0	0%	0	95%
Forest	277,495	1.0%	277,495	0%
Residential	2,132,502	7%	0	100%
Total	28,537,707	100%	1,583,881	94%

Table D.28. Required annual reductions in direct nonpoint sources in sub-watershed SAR-14.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	27,216	21%	544	98%
Wildlife in Streams	51,253	39%	30,239	41%
Straight Pipes	51,874	40%	0	100%
Total	130,343	100%	30,783	76%

Table D.29. Required annual reductions in nonpoint sources in sub-watershed SAR-15.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	207,919	0.1%	10,396	95%
Pasture	315,786,162	94%	15,789,312	95%
Loafing Lots	0	0%	0	95%
Forest	3,586,516	1%	3,586,516	0%
Residential	16,138,308	5%	0	100%
Total	335,718,905	100%	19,386,224	94%

Table D.30. Required annual reductions in direct nonpoint sources in sub-watershed SAR-15.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	329,145	29%	6,583	98%
Wildlife in Streams	636,527	56%	375,551	41%
Straight Pipes	174,256	15%	0	100%
Total	1,139,928	100%	382,134	66%

Table D.31. Required annual reductions in nonpoint sources in sub-watershed SAR-16.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	76,345	0%	3,817	95%
Pasture	146,323,533	91%	7,316,178	95%
Loafing Lots	0	0%	0	95%
Forest	2,133,649	1%	2,133,649	0%
Residential	12,183,672	8%	0	100%
Total	160,717,199	100%	9,453,645	94%

Table D.32. Required annual reductions in direct nonpoint sources in sub-watershed SAR-16.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	144,075	15%	2,882	98%
Wildlife in Streams	523,977	56%	309,147	41%
Straight Pipes	267,328	29%	0	100%
Total	935,381	100%	312,028	67%

Table D.33. Required annual reductions in nonpoint sources in sub-watershed SAR-17.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	12,356	0%	124	99%
Pasture	24,308,990	93%	0	100%
Loafing Lots	0	0%	0	100%
Forest	240,121	0.9%	240,121	0%
Residential	1,586,873	6%	0	100%
Total	26,148,340	100%	240,244	99%

Table D.34. Required annual reductions in direct nonpoint sources in sub-watershed SAR-17.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	25,345	30%	760	97%
Wildlife in Streams	41,947	50%	1,258	97%
Straight Pipes	16,963	20%	0	100%
Total	84,255	100%	2,019	98%

Table D.35. Required annual reductions in nonpoint sources in sub-watershed SAR-18.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	28,015	0.1%	280	99%
Pasture	38,699,623	89%	0	100%
Loafing Lots	0	0%	0	100%
Forest	855,714	2%	855,714	0%
Residential	3,765,781	9%	0	100%
Total	43,349,133	100%	855,995	98%

Table D.36. Required annual reductions in direct nonpoint sources in sub-watershed SAR-18.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	37,762	13%	1,133	97%
Wildlife in Streams	200,403	69%	6,012	97%
Straight Pipes	54,139	19%	0	100%
Total	292,304	100%	7,145	98%

Table D.37. Required annual reductions in nonpoint sources in sub-watershed SAR-19.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,417	0.1%	64	99%
Pasture	9,440,575	80%	0	100%
Loafing Lots	0	0%	0	100%
Forest	340,695	3%	340,695	0%
Residential	1,986,914	17%	0	100%
Total	11,774,600	100%	340,759	97%

Table D.38. Required annual reductions in direct nonpoint sources in sub-watershed SAR-19.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	8,845	8%	265	97%
Wildlife in Streams	81,382	74%	2,441	97%
Straight Pipes	19,622	18%	0	100%
Total	109,849	100%	2,707	98%

Table D.39. Required annual reductions in nonpoint sources in sub-watershed SAR-20.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	38,631	0%	1,932	95%
Pasture	77,135,905	73%	3,856,796	95%
Loafing Lots	18,284,219	17%	914,211	95%
Forest	1,359,566	1%	1,359,566	0%
Residential	8,362,980	8%	0	100%
Total	105,181,302	100%	6,132,505	94%

Table D.40. Required annual reductions in direct nonpoint sources in sub-watershed SAR-20.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	74,199	13%	1,484	98%
Wildlife in Streams	343,419	58%	202,617	41%
Straight Pipes	173,264	29%	0	100%
Total	590,882	100%	204,101	65%

Table D.41. Required annual reductions in nonpoint sources in sub-watershed SAR-21.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	21,716	0.1%	1,086	95%
Pasture	26,750,562	87%	1,337,528	95%
Loafing Lots	0	0%	0	95%
Forest	645,762	2%	645,762	0%
Residential	3,268,929	11%	0	100%
Total	30,686,969	100%	1,984,376	94%

Table D.42. Required annual reductions in direct nonpoint sources in sub-watershed SAR-21.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	25,005	12%	500	98%
Wildlife in Streams	162,146	79%	95,666	41%
Straight Pipes	18,557	9%	0	100%
Total	205,708	100%	96,166	53%

Table D.43. Required annual reductions in nonpoint sources in sub-watershed SAR-22.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	37,602	0.1%	3,760	90%
Pasture	55,006,422	90%	5,500,644	90%
Loafing Lots	0	0%	0	90%
Forest	1,064,751	2%	1,064,751	0%
Residential	5,045,395	8%	0	100%
Total	61,154,170	100%	6,569,155	89%

Table D.44. Required annual reductions in direct nonpoint sources in sub-watershed SAR-22.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	51,881	14%	519	99%
Wildlife in Streams	270,594	75%	27,059	90%
Straight Pipes	38,572	11%	0	100%
Total	361,047	100%	27,578	92%

Table D.45. Required annual reductions in nonpoint sources in sub-watershed SAR-23.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	19,027	0%	1,903	90%
Pasture	35,600,420	70%	3,560,043	90%
Loafing Lots	13,060,156	26%	1,306,016	90%
Forest	492,815	1.0%	492,815	0%
Residential	1,538,070	3%	0	100%
Total	50,710,489	100%	5,360,777	89%

Table D.46. Required annual reductions in direct nonpoint sources in sub-watershed SAR-23.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	34,798	19%	348	99%
Wildlife in Streams	125,281	70%	12,528	90%
Straight Pipes	18,941	11%	0	100%
Total	179,020	100%	12,876	93%

Table D.47. Required annual reductions in nonpoint sources in sub-watershed SAR-24.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,999	0.1%	600	90%
Pasture	5,799,732	91%	579,973	90%
Loafing Lots	0	0%	0	90%
Forest	137,501	2%	137,501	0%
Residential	450,272	7%	0	100%
Total	6,393,504	100%	718,074	89%

Table D.48. Required annual reductions in direct nonpoint sources in sub-watershed SAR-24.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	5,443	7%	54	99%
Wildlife in Streams	35,702	45%	3,570	90%
Straight Pipes	37,882	48%	0	100%
Total	79,027	100%	3,625	95%

Table D.49. Required annual reductions in nonpoint sources in sub-watershed SAR-25.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,640	0.1%	464	90%
Pasture	2,907,604	91%	290,760	90%
Loafing Lots	0	0%	0	90%
Forest	60,655	2%	60,655	0%
Residential	206,195	6%	0	100%
Total	3,179,094	100%	351,879	89%

Table D.50. Required annual reductions in direct nonpoint sources in sub-watershed SAR-25.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,722	13%	27	99%
Wildlife in Streams	18,556	87%	1,856	90%
Straight Pipes	0	0%	0	100%
Total	21,277	100%	1,883	91%

Table D.51. Required annual reductions in nonpoint sources in sub-watershed SAR-26.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,206	0.2%	260	95%
Pasture	1,991,263	87%	99,563	95%
Loafing Lots	0	0%	0	95%
Forest	43,742	2%	43,742	0%
Residential	251,835	11%	0	100%
Total	2,292,046	100%	143,565	94%

Table D.52. Required annual reductions in direct nonpoint sources in sub-watershed SAR-26.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,871	13%	37	98%
Wildlife in Streams	12,500	87%	7,375	41%
Straight Pipes	0	0%	0	100%
Total	14,371	100%	7,412	48%

Table D.53. Required annual reductions in nonpoint sources in sub-watershed SAR-27.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	37,331	0.1%	2,240	94%
Pasture	37,485,324	70%	2,249,120	94%
Loafing Lots	8,097,297	15%	485,838	94%
Forest	500,144	0.9%	500,144	0%
Residential	7,688,218	14%	0	100%
Total	53,808,314	100%	3,237,341	94%

Table D.54. Required annual reductions in direct nonpoint sources in sub-watershed SAR-27.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	35,915	17%	2,155	94%
Wildlife in Streams	150,009	72%	9,001	94%
Straight Pipes	22,680	11%	0	100%
Total	208,605	100%	11,155	95%

Table D.55. Required annual reductions in nonpoint sources in sub-watershed SAR-28.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,190	0.1%	131	94%
Pasture	1,495,293	77%	89,718	94%
Loafing Lots	0	0%	0	94%
Forest	26,932	1%	26,932	0%
Residential	410,612	21%	0	100%
Total	1,935,026	100%	116,781	94%

Table D.56. Required annual reductions in direct nonpoint sources in sub-watershed SAR-28.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,361	15%	82	94%
Wildlife in Streams	8,009	85%	481	94%
Straight Pipes	0	0%	0	100%
Total	9,370	100%	562	94%

Table D.57. Required annual reductions in nonpoint sources in sub-watershed NEC-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	27,432	0.2%	1,646	94%
Pasture	14,784,175	83%	887,051	94%
Loafing Lots	0	0%	0	94%
Forest	586,189	3%	586,189	0%
Residential	2,372,306	13%	0	100%
Total	17,770,102	100%	1,474,886	92%

Table D.58. Required annual reductions in direct nonpoint sources in sub-watershed NEC-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	14,969	10%	898	94%
Wildlife in Streams	122,967	79%	7,378	94%
Straight Pipes	18,560	12%	0	100%
Total	156,496	100%	8,276	95%

Table D.59. Required annual reductions in nonpoint sources in sub-watershed NEC-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,886	0.1%	893	94%
Pasture	12,818,183	88%	769,091	94%
Loafing Lots	0	0%	0	94%
Forest	343,265	2%	343,265	0%
Residential	1,451,128	10%	0	100%
Total	14,627,462	100%	1,113,250	92%

Table D.60. Required annual reductions in direct nonpoint sources in sub-watershed NEC-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	12,928	12%	776	94%
Wildlife in Streams	74,326	72%	4,460	94%
Straight Pipes	16,666	16%	0	100%
Total	103,919	100%	5,235	95%

Table D.61. Required annual reductions in nonpoint sources in sub-watershed NEC-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	10,294	0.1%	618	94%
Pasture	7,719,847	84%	463,191	94%
Loafing Lots	0	0%	0	94%
Forest	290,995	3%	290,995	0%
Residential	1,206,165	13%	0	100%
Total	9,227,301	100%	754,803	92%

Table D.62. Required annual reductions in direct nonpoint sources in sub-watershed NEC-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	7,825	9%	469	94%
Wildlife in Streams	60,055	71%	3,603	94%
Straight Pipes	17,245	20%	0	100%
Total	85,124	100%	4,073	95%

Table D.63. Required annual reductions in nonpoint sources in sub-watershed NEC-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,388	0.1%	383	94%
Pasture	4,353,194	86%	261,192	94%
Loafing Lots	0	0%	0	94%
Forest	133,479	3%	133,479	0%
Residential	550,639	11%	0	100%
Total	5,043,700	100%	395,054	92%

Table D.64. Required annual reductions in direct nonpoint sources in sub-watershed NEC-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	4,423	13%	265	94%
Wildlife in Streams	28,864	87%	1,732	94%
Straight Pipes	0	0%	0	100%
Total	33,287	100%	1,997	94%

Table D.65. Required annual reductions in nonpoint sources in sub-watershed NEC-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,003	0.2%	180	94%
Pasture	1,474,874	90%	88,492	94%
Loafing Lots	0	0%	0	94%
Forest	30,334	2%	30,334	0%
Residential	136,557	8%	0	100%
Total	1,644,769	100%	119,007	93%

Table D.66. Required annual reductions in direct nonpoint sources in sub-watershed NEC-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,531	18%	92	94%
Wildlife in Streams	7,164	82%	430	94%
Straight Pipes	0	0%	0	100%
Total	8,695	100%	522	94%

Table D.67. Required annual reductions in nonpoint sources in sub-watershed TOC-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,718	0%	972	83%
Pasture	6,377,311	26%	1,084,143	83%
Loafing Lots	0	0%	0	83%
Forest	240,663	1.0%	240,663	0%
Residential	17,618,802	73%	176,188	99%
Total	24,242,494	100%	1,501,966	94%

Table D.68. Required annual reductions in direct nonpoint sources in sub-watershed TOC-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	5,954	3%	60	99%
Wildlife in Streams	64,349	30%	10,939	83%
Straight Pipes	144,053	67%	0	100%
Total	214,355	100%	10,999	95%

Table D.69. Required annual reductions in nonpoint sources in sub-watershed TOC-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	11,718	0%	1,992	83%
Pasture	11,840,805	47%	2,012,937	83%
Loafing Lots	0	0%	0	83%
Forest	364,979	1%	364,979	0%
Residential	12,939,706	51%	129,397	99%
Total	25,157,209	100%	2,509,305	90%

Table D.70. Required annual reductions in direct nonpoint sources in sub-watershed TOC-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	11,057	4%	111	99%
Wildlife in Streams	93,944	36%	15,971	83%
Straight Pipes	156,383	60%	0	100%
Total	261,384	100%	16,081	94%

Table D.71. Required annual reductions in nonpoint sources in sub-watershed TOC-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	16,838	0.1%	2,863	83%
Pasture	16,229,536	78%	2,759,021	83%
Loafing Lots	0	0%	0	83%
Forest	350,708	2%	350,708	0%
Residential	4,174,079	20%	41,741	99%
Total	20,771,161	100%	3,154,332	85%

Table D.72. Required annual reductions in direct nonpoint sources in sub-watershed TOC-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	15,139	7%	151	99%
Wildlife in Streams	89,230	42%	15,169	83%
Straight Pipes	105,894	50%	0	100%
Total	210,263	100%	15,321	93%

Table D.73. Required annual reductions in nonpoint sources in sub-watershed TOC-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,060	0.1%	1,030	83%
Pasture	7,123,232	87%	1,210,950	83%
Loafing Lots	0	0%	0	83%
Forest	149,064	2%	149,064	0%
Residential	872,661	11%	8,727	99%
Total	8,151,017	100%	1,369,770	83%

Table D.74. Required annual reductions in direct nonpoint sources in sub-watershed TOC-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	6,634	6%	66	99%
Wildlife in Streams	37,616	37%	6,395	83%
Straight Pipes	58,762	57%	0	100%
Total	103,013	100%	6,461	94%

Table D.75. Required annual reductions in nonpoint sources in sub-watershed TOC-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	11,755	0.1%	1,998	83%
Pasture	11,841,853	88%	2,013,115	83%
Loafing Lots	0	0%	0	83%
Forest	235,584	2%	235,584	0%
Residential	1,333,810	10%	13,338	99%
Total	13,423,001	100%	2,264,035	83%

Table D.76. Required annual reductions in direct nonpoint sources in sub-watershed TOC-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	11,057	8%	111	99%
Wildlife in Streams	60,768	47%	10,330	83%
Straight Pipes	58,580	45%	0	100%
Total	130,404	100%	10,441	92%

Table D.77. Required annual reductions in nonpoint sources in sub-watershed PAR-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,273	0.1%	216	83%
Pasture	1,738,269	91%	295,506	83%
Loafing Lots	0	0%	0	83%
Forest	38,896	2%	38,896	0%
Residential	126,912	7%	0	100%
Total	1,905,350	100%	334,618	82%

Table D.78. Required annual reductions in direct nonpoint sources in sub-watershed PAR-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	1,701	14%	289	83%
Wildlife in Streams	10,309	86%	1,752	83%
Straight Pipes	0	0%	0	100%
Total	12,010	100%	2,042	83%

Table D.79. Required annual reductions in nonpoint sources in sub-watershed PAR-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	74,406	0.2%	12,649	83%
Pasture	27,273,342	90%	4,636,469	83%
Loafing Lots	0	0%	0	83%
Forest	589,056	2%	589,056	0%
Residential	2,202,961	7%	0	100%
Total	30,139,765	100%	5,238,173	83%

Table D.80. Required annual reductions in direct nonpoint sources in sub-watershed PAR-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	26,196	10%	4,453	83%
Wildlife in Streams	152,083	59%	25,854	83%
Straight Pipes	78,678	31%	0	100%
Total	256,956	100%	30,307	88%

Table D.81. Required annual reductions in nonpoint sources in sub-watershed PAR-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,798	0.4%	148	99%
Pasture	2,794,638	74%	27,946	99%
Loafing Lots	0	0%	0	99%
Forest	325,076	9%	325,076	0%
Residential	631,298	17%	0	100%
Total	3,765,810	100%	353,170	91%

Table D.82. Required annual reductions in direct nonpoint sources in sub-watershed PAR-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,892	3%	29	99%
Wildlife in Streams	61,827	59%	618	99%
Straight Pipes	40,366	38%	0	100%
Total	105,084	100%	647	99%

Table D.83. Required annual reductions in nonpoint sources in sub-watershed PAR-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	34,436	0.4%	344	99%
Pasture	6,745,583	83%	67,456	99%
Loafing Lots	0	0%	0	99%
Forest	451,587	6%	451,587	0%
Residential	932,074	11%	0	100%
Total	8,163,680	100%	519,387	94%

Table D.84. Required annual reductions in direct nonpoint sources in sub-watershed PAR-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	6,974	6%	70	99%
Wildlife in Streams	94,284	78%	943	99%
Straight Pipes	19,546	16%	0	100%
Total	120,805	100%	1,013	99%

Table D.85. Required annual reductions in nonpoint sources in sub-watershed PAR-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,180	0.4%	142	99%
Pasture	2,630,494	70%	26,305	99%
Loafing Lots	0	0%	0	99%
Forest	312,504	8%	312,504	0%
Residential	788,427	21%	0	100%
Total	3,745,605	100%	338,951	91%

Table D.86. Required annual reductions in direct nonpoint sources in sub-watershed PAR-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,722	3%	27	99%
Wildlife in Streams	59,988	74%	600	99%
Straight Pipes	18,028	22%	0	100%
Total	80,737	100%	627	99%

Table D.87. Required annual reductions in nonpoint sources in sub-watershed PAR-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	24,994	0.6%	250	99%
Pasture	3,612,735	81%	36,127	99%
Loafing Lots	0	0%	0	99%
Forest	270,183	6%	270,183	0%
Residential	563,247	13%	0	100%
Total	4,471,159	100%	306,560	93%

Table D.88. Required annual reductions in direct nonpoint sources in sub-watershed PAR-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	3,742	5%	37	99%
Wildlife in Streams	55,486	72%	555	99%
Straight Pipes	17,802	23%	0	100%
Total	77,029	100%	592	99%

Table D.89. Required annual reductions in nonpoint sources in sub-watershed PAR-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,650	0%	47	99%
Pasture	7,311,976	57%	73,120	99%
Loafing Lots	5,224,063	41%	52,241	99%
Forest	77,257	0.6%	77,257	0%
Residential	151,861	1%	0	100%
Total	12,769,807	100%	202,664	98%

Table D.90. Required annual reductions in direct nonpoint sources in sub-watershed PAR-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	7,592	12%	76	99%
Wildlife in Streams	18,074	30%	181	99%
Straight Pipes	35,550	58%	0	100%
Total	61,216	100%	257	100%

Table D.91. Required annual reductions in nonpoint sources in sub-watershed PAR-8.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,147	0.6%	195	83%
Pasture	163,453	81%	27,787	83%
Loafing Lots	0	0%	0	83%
Forest	5,486	3%	5,486	0%
Residential	31,115	15%	0	100%
Total	201,200	100%	33,468	83%

Table D.92. Required annual reductions in direct nonpoint sources in sub-watershed PAR-8.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	170	13%	29	83%
Wildlife in Streams	1,168	87%	199	83%
Straight Pipes	0	0%	0	100%
Total	1,338	100%	227	83%

Table D.93. Required annual reductions in nonpoint sources in sub-watershed PAR-9.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	63,055	0.3%	10,719	83%
Pasture	18,916,854	88%	3,215,865	83%
Loafing Lots	0	0%	0	83%
Forest	535,467	3%	535,467	0%
Residential	1,870,133	9%	0	100%
Total	21,385,509	100%	3,762,051	82%

Table D.94. Required annual reductions in direct nonpoint sources in sub-watershed PAR-9.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	18,201	12%	3,094	83%
Wildlife in Streams	130,479	88%	22,181	83%
Straight Pipes	0	0%	0	100%
Total	148,680	100%	25,276	83%

Table D.95. Required annual reductions in nonpoint sources in sub-watershed PAR-10.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	44,826	0.1%	7,620	83%
Pasture	44,054,928	79%	7,489,338	83%
Loafing Lots	0	0%	0	83%
Forest	1,350,697	2%	1,350,697	0%
Residential	10,097,633	18%	0	100%
Total	55,548,084	100%	8,847,656	84%

Table D.96. Required annual reductions in direct nonpoint sources in sub-watershed PAR-10.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	41,164	8%	6,998	83%
Wildlife in Streams	325,813	60%	55,388	83%
Straight Pipes	177,417	33%	0	100%
Total	544,395	100%	62,386	89%

Table D.97. Required annual reductions in nonpoint sources in sub-watershed PAR-11.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	54,041	0.7%	9,187	83%
Pasture	7,079,219	87%	1,203,467	83%
Loafing Lots	0	0%	0	83%
Forest	279,258	3%	279,258	0%
Residential	702,527	9%	0	100%
Total	8,115,046	100%	1,491,913	82%

Table D.98. Required annual reductions in direct nonpoint sources in sub-watershed PAR-11.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	7,314	8%	1,243	83%
Wildlife in Streams	68,001	73%	11,560	83%
Straight Pipes	17,991	19%	0	100%
Total	93,306	100%	12,804	86%

Table D.99. Required annual reductions in nonpoint sources in sub-watershed PAR-12.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13,322	0.4%	2,265	83%
Pasture	2,809,114	76%	477,549	83%
Loafing Lots	0	0%	0	83%
Forest	222,795	6%	222,795	0%
Residential	629,674	17%	0	100%
Total	3,674,905	100%	702,609	81%

Table D.100. Required annual reductions in direct nonpoint sources in sub-watershed PAR-12.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,892	4%	492	83%
Wildlife in Streams	43,040	67%	7,317	83%
Straight Pipes	18,547	29%	0	100%
Total	64,478	100%	7,808	88%

Table D.101. Required annual reductions in nonpoint sources in sub-watershed PAR-13.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	60,558	0.3%	10,295	83%
Pasture	12,886,720	68%	2,190,743	83%
Loafing Lots	0	0%	0	83%
Forest	1,372,072	7%	1,372,072	0%
Residential	4,656,133	25%	0	100%
Total	18,975,482	100%	3,573,109	81%

Table D.102. Required annual reductions in direct nonpoint sources in sub-watershed PAR-13.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	12,928	5%	2,198	83%
Wildlife in Streams	248,510	95%	42,247	83%
Straight Pipes	0	0%	0	100%
Total	261,438	100%	44,444	83%

Table D.103. Required annual reductions in nonpoint sources in sub-watershed PAR-14.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13,796	0.3%	2,345	83%
Pasture	2,643,590	61%	449,410	83%
Loafing Lots	0	0%	0	83%
Forest	533,937	12%	533,937	0%
Residential	1,158,025	27%	0	100%
Total	4,349,349	100%	985,693	77%

Table D.104. Required annual reductions in direct nonpoint sources in sub-watershed PAR-14.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	2,722	3%	463	83%
Wildlife in Streams	89,385	97%	15,195	83%
Straight Pipes	0	0%	0	100%
Total	92,106	100%	15,658	83%

Table D.105. Required annual reductions in nonpoint sources in sub-watershed PAR-15.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	2,233	1%	380	83%
Pasture	163,741	74%	27,836	83%
Loafing Lots	0	0%	0	83%
Forest	22,717	10%	22,717	0%
Residential	33,045	15%	0	100%
Total	221,736	100%	50,933	77%

Table D.106. Required annual reductions in direct nonpoint sources in sub-watershed PAR-15.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	170	4%	29	83%
Wildlife in Streams	4,624	96%	786	83%
Straight Pipes	0	0%	0	100%
Total	4,794	100%	815	83%

Table D.107. Required annual reductions in nonpoint sources in sub-watershed PAR-16.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,042	0.6%	857	83%
Pasture	660,913	78%	112,355	83%
Loafing Lots	0	0%	0	83%
Forest	61,184	7%	61,184	0%
Residential	121,170	14%	0	100%
Total	848,308	100%	174,396	79%

Table D.108. Required annual reductions in direct nonpoint sources in sub-watershed PAR-16.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	680	2%	116	83%
Wildlife in Streams	11,648	37%	1,980	83%
Straight Pipes	19,495	61%	0	100%
Total	31,824	100%	2,096	93%

Table D.109. Required annual reductions in nonpoint sources in sub-watershed PAR-17.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,857	0.7%	996	83%
Pasture	660,068	75%	112,212	83%
Loafing Lots	0	0%	0	83%
Forest	58,201	7%	58,201	0%
Residential	157,458	18%	0	100%
Total	881,584	100%	171,408	81%

Table D.110. Required annual reductions in direct nonpoint sources in sub-watershed PAR-17.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	680	6%	116	83%
Wildlife in Streams	11,307	94%	1,922	83%
Straight Pipes	0	0%	0	100%
Total	11,987	100%	2,038	83%

Table D.111. Required annual reductions in nonpoint sources in sub-watershed PAR-18.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,971	0.6%	1,015	83%
Pasture	833,650	86%	141,721	83%
Loafing Lots	0	0%	0	83%
Forest	40,785	4%	40,785	0%
Residential	91,896	9%	0	100%
Total	972,302	100%	183,521	81%

Table D.112. Required annual reductions in direct nonpoint sources in sub-watershed PAR-18.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	851	3%	145	83%
Wildlife in Streams	11,209	35%	1,906	83%
Straight Pipes	19,674	62%	0	100%
Total	31,734	100%	2,050	94%

Table D.113. Required annual reductions in nonpoint sources in sub-watershed PAR-19.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	71,885	0.4%	12,220	83%
Pasture	14,480,809	78%	2,461,738	83%
Loafing Lots	0	0%	0	83%
Forest	1,586,539	9%	1,586,539	0%
Residential	2,364,317	13%	0	100%
Total	18,503,550	100%	4,060,497	78%

Table D.114. Required annual reductions in direct nonpoint sources in sub-watershed PAR-19.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	14,969	5%	2,545	83%
Wildlife in Streams	306,368	95%	52,083	83%
Straight Pipes	0	0%	0	100%
Total	321,337	100%	54,627	83%

Table D.115. Required annual reductions in nonpoint sources in sub-watershed PAR-20.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	11,988	1%	2,038	83%
Pasture	824,398	75%	140,148	83%
Loafing Lots	0	0%	0	83%
Forest	82,778	8%	82,778	0%
Residential	181,651	17%	0	100%
Total	1,100,815	100%	224,964	80%

Table D.116. Required annual reductions in direct nonpoint sources in sub-watershed PAR-20.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	851	2%	145	83%
Wildlife in Streams	17,257	45%	2,934	83%
Straight Pipes	20,139	53%	0	100%
Total	38,247	100%	3,078	92%