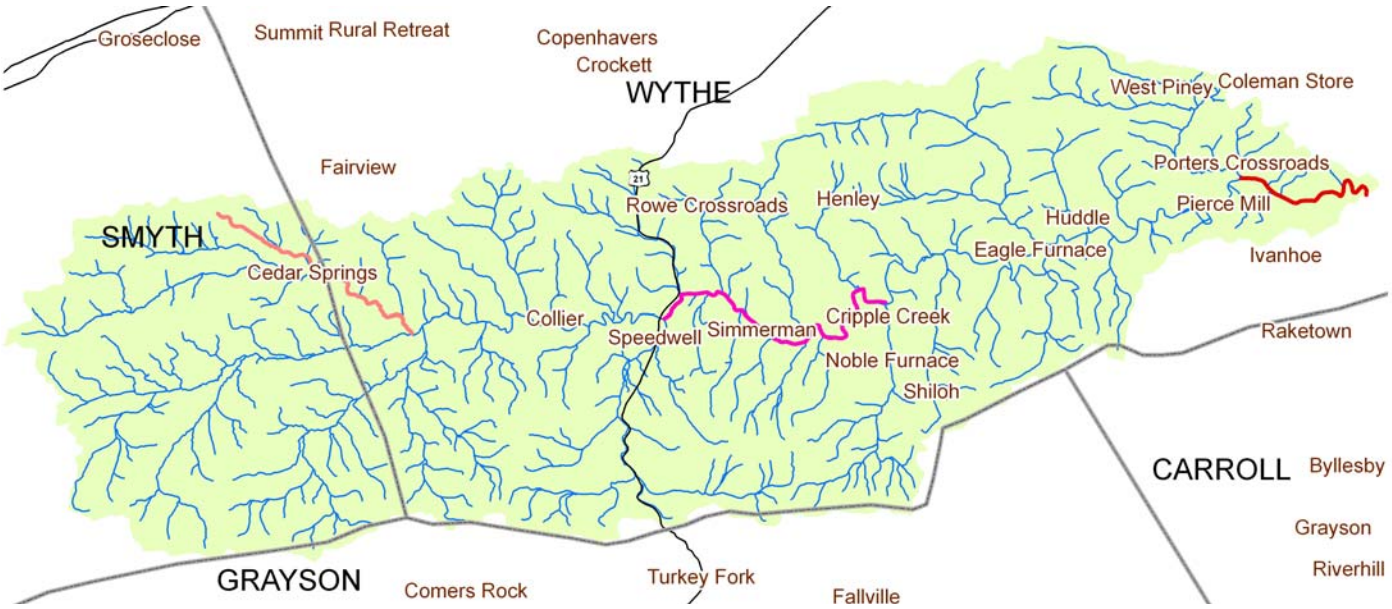
Bacteria
Total Maximum Daily Load (TMDL) Development for Cripple Creek



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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
BSE	Biological Systems Engineering
BST	Bacterial Source Tracking
E&S	Erosion and Sediment Control Program
GIS	Geographic Information Systems
HRU	Hydrologic Response Unit
HSPF	Hydrologic Simulation Program – Fortran
LA	Load Allocation
MOS	Margin of Safety
MPID	Monitoring Point Identification Number
MPN	Most Probable Number
MRLC	Multi-Resolution Land Characterization
MS4	Phase II Municipal Separate Storm Sewer System
NASA	National Aeronautics and Space Administration
NCDC	National Climatic Data Center
NLCD	National Land Cover Data
NPDES	National Pollutant Discharge Elimination System
NPS	Nonpoint Source
NRCS	Natural Resources Conservation Service
NWS	National Weather Service
SCS	Soil Conservation Service
SERCC	Southeast Regional Climate Center
SMC	Unsaturated Soil Moisture Capacity
SWCD	Soil and Water Conservation District
TMDL	Total Maximum Daily Load
UAA	Use Attainability Analysis
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
USLE	Universal Soil Loss Equation
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	Waste Load Allocation
WQMP	Water Quality Management Plan

Executive Summary

Background

Cripple Creek (VAS-N09R-01-BAC) was first listed as impaired streams in 2004 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2004) indicating that the recreational use goal and the aquatic life goal were not being met. These segments remained on the 2006 and 2008 Section 303(d) (VADEQ, 2006 & 2008) list due to water quality exceedances of the bacteria standard, but were de-listed for the benthic impairment. The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) delineated by VADEQ, beginning in the headwaters of Cripple Creek downstream to Blue Spring Creek near the intersection of Routes 749 and 692 in western Wythe County, is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL028.10.The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) delineated by VADEQ, beginning at Dean Branch near the community of Porters Crossroads to New River confluence just downstream of Ivanhoe. It is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL001.03.The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) delineated by VADEQ, begins at the confluence with Dry Run just above the community of Speedwell on Routes 21 and 749 and extends to Francis Mill Creek, near the community of Cripple Creek. The creek roughly paralleling Routes 749 and 619 in Wythe County is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL018.47.

The Cripple Creek (VAS-N09R-01-BAC) watershed is located predominately in Wythe County, Virginia, with portions in Smyth and Grayson Counties. About half of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment, located near Cedar Springs, is within Smyth County, while the other two impairment sections Cripple Creek (VAS-N09R-01-BAC_CPL01B04) and Cripple Creek (VAS-N09R-01-BAC_CPL02A98) are completely within Wythe County. The headwaters of Cripple Creek begin in Smyth County near Cedar Springs, Virginia and flows east approximately 32 miles before joining the New River east of Porter's Crossroads and Pierce Mill. The Cripple Creek watershed is approximately 88,885 acres, predominately forest, constituting approximately 60% of the total watershed area. The remaining land uses are divided between pasture (35%), residential (3.3%), and cropland (0.7%).

VADEQ personnel monitored pollutant concentrations throughout Cripple Creek watershed. Of the 12 water quality samples collected from January 2000 through December 2004 (2006 Section 303(d) 5-year listing period, VADEQ, 2006) at VADEQ stations 9-CPL028.10, 25% (3 of 12) of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Of the 12 samples collected from January 2000 through December 2004 at VADEQ station 9-CPL001.03, 33% (4 of 12) of the samples exceeded the water quality standard. Samples collected from VADEQ station CPL018.47 exceeded the water quality standard 25% (3 of 12) of the time. Consequently, three segments of Cripple Creek [Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04)] were determined as not

supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

Pollutant Sources

Currently, there is one active point source discharge with a VPDES permit to discharge within the Cripple Creek watershed; however, the facility is not permitted to discharge bacteria. Therefore, 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, 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 Cripple Creek watershed. To identify localized sources of fecal coliform, the watersheds were divided into subwatersheds. These subdivisions were based primarily on homogeneity of land use. The model was calibrated using observed flow values from USGS station #03166000 on Cripple Creek near Ivanhoe, VA for the period January 1, 2000 to December 31, 2004. 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 January 1, 1995 to December 31, 1999. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 9-CPL001.03, 9-CPL003.10, 9-CPL008.68, 9-CPL018.47, 9-CPL026.75, and 9-CPL028.10 within the Cripple Creek watershed were used to calibrate and validate the water quality component of HSPF. The period January 1, 2000 through December 31, 2004 was chosen for water quality calibration and January 1, 1995 through December 31, 1999 was chosen for water quality validation. 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 bacteria TMDL, 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.

TMDL Allocation Scenarios

One active point discharge in the Cripple Creek watershed currently has a VPDES permit. No municipalities with MS4 permits were identified within the Cripple Creek watershed. The waste load allocation was calculated at <1% of the TMDL. After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero exceedances. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality.

For the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairments, required reductions in fecal coliform loading from existing conditions for the selected TMDL allocation include a 100% reduction in straight pipes, 97% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 97% reduction in nonpoint source loadings to residential land use, a 97% reduction in nonpoint source loadings to pasture land use, a 97% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land use.

For the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairments, required reductions in fecal coliform loading from existing conditions for the selected TMDL allocation include 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 use.

Using equation [E.1], summaries of the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) bacteria TMDLs for the selected allocation scenario are shown in Tables E.1 through E.6.

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

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

Table E.1. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.94E+10	2.91E+12	N/A	2.94E+12

N/A – not applicable because MOS was implicit.

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

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

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

Table E.2. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	8.05E+07	4.17E+11	N/A	4.17E+11

N/A – not applicable because MOS was implicit.

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

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

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

Table E.3. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.87E+11	1.85E+13	N/A	1.87E+13

N/A – not applicable because MOS was implicit.

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

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

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

Table E.4. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.12E+08	2.87E+12	N/A	2.87E+12

N/A – not applicable because MOS was implicit.

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

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

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

Table E.5. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.82E+11	2.79E+13	N/A	2.82E+13

N/A – not applicable because MOS was implicit.

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

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

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

Table E.6. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	7.73E+08	5.32E+12	N/A	5.32E+12

N/A – not applicable because MOS was implicit.

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

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

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

TMDL Implementation and Reasonable Assurance

The goal of the TMDL program is to establish a three-step process that will enable the attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairment on Cripple Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and monitor stream water quality to determine if water quality standards are being attained. Watershed stakeholders will have the opportunity to participate in the development of the TMDL implementation plan. Specific goals for BMP implementation will be established as part of the implementation plan development.

Following the development of the TMDL, the VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring programs. 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. VADEQ staff, in cooperation with VADCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants, “water quality milestones” as established in the implementation plan, 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. Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the watershed.

Staged implementation is a key component to restoring water quality in Cripple Creek. An alternative scenario was evaluated to establish goals for the first implementation stage of the bacteria 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 bacteria Stage 1 implementation goal was to provide an instantaneous standard exceedance rate below 10%, a geometric mean standard exceedance rate of 0%, and 0% reduction in wildlife loads. These exceedance rate criteria mirror the new proposed bacteria standard meeting a 10% exceedance rate of the single sample maximum criterion (235 cfu/100ml) and a 0% exceedance rate of the geometric mean criterion (126 cfu/100 ml). After the proposed bacteria standard is adopted by the Virginia Water Control Board, the Stage I implementation scenario will become the TMDL allocation scenario, since it will meet the new revised standard.

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) bacteria impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 37% reduction in nonpoint source loadings to residential land use, a 37% reduction in nonpoint source loadings to pasture land use, a 37% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint

source loadings to forest land. This scenario resulted in a 9.91% instantaneous standard exceedance rate and a 0.0% geometric mean standard exceedance rate.

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) bacteria impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 47% reduction in nonpoint source loadings to residential land use, a 47% reduction in nonpoint source loadings to pasture land use, a 47% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.96% instantaneous standard exceedance rate and a 0.0% geometric mean standard exceedance rate.

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) bacteria impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 45% reduction in nonpoint source loadings to residential land use, a 45% reduction in nonpoint source loadings to pasture land use, a 45% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.96% instantaneous standard exceedance rate and a 0.0% geometric mean standard exceedance rate.

Public Participation

During development of the Cripple Creek Bacteria TMDL, public participation was encouraged through two public meetings and two Technical Advisory Committee (TAC) meetings. The first public meeting was held at the Speedwell Volunteer Fire Department on July 29, 2008, to discuss the need for a TMDL, and review the approach for TMDL development. The final public meeting was held at the Speedwell Volunteer Fire Department on July 23, 2009, to discuss the source allocations and reductions required to meet the TMDL. Copies of the draft TMDL report were available for public review and comment.

In addition to keeping the public apprised of progress in the development of the Cripple Creek Bacteria TMDL, a TMDL TAC was also established to help advise the TMDL developers. TAC meetings were held for this project on June 17, 2008 and July 20, 2009 at the Mount Rogers Planning District Commission in Marion, Virginia. The general public was solicited to participate on the TAC during the first public meeting in addition to agencies and groups already represented on the TAC. TheTAC membership for the Cripple Creek Bacteria TMDL included representatives from the following agencies and organizations: Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, Mount Rogers Planning District Commission, Evergreen Soil and Water Conservation District, Big Walker Soil and Water Conservation District, Smyth County, and Wythe County.

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.

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Chapter 1. Introduction

1.1 Background

1.1.1 TMDL Definition and Regulatory Information

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

1.1.2 Impairments Listing

Cripple Creek (VAS-N09R-01-BAC) was first listed as impaired streams in 2004 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2004) indicating that the recreational use goal and the aquatic life goal were not being met. These segments remained on the 2006 and 2008 Section 303(d) (VADEQ, 2006 & 2008) list due to water quality exceedances of the bacteria standard, but were de-listed for the benthic impairment.

The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) delineated by VADEQ, beginning in the headwaters of Cripple Creek downstream to Blue Spring Creek near the intersection of Routes 749 and 692 in western Wythe County, is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL028.10.

The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) delineated by VADEQ, beginning at Dean Branch near the community of Porters Crossroads to New River confluence just downstream of Ivanhoe. It is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL001.03.

The impaired portion of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) delineated by VADEQ, begins at the confluence with Dry Run just above the community of Speedwell on Routes 21 and 749 and extends to Francis Mill Creek, near the community of Cripple Creek. The creek roughly paralleling Routes 749 and 619 in Wythe County is listed as impaired on Virginia's 2008 list (VADEQ, 2008) due to water quality exceedances of the bacteria standard at station 9-CPL018.47.

1.1.3 Watershed Location and Description

The Cripple Creek (VAS-N09R-01-BAC) watershed is located predominately in Wythe County, Virginia, with portions in Smyth and Grayson Counties (Figure 1.1). About half of the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment, located near Cedar Springs, is

within Smyth County, while the other two impairment sections Cripple Creek (VAS-N09R-01-BAC_CPL01B04) and Cripple Creek (VAS-N09R-01-BAC_CPL02A98) are completely within Wythe County. The headwaters of Cripple Creek begin in Smyth County near Cedar Springs, Virginia and flows east approximately 32 miles before joining the New River east of Porter's Crossroads and Pierce Mill. The Cripple Creek watershed is approximately 88,885 acres, predominately forest, constituting approximately 60% of the total watershed area. The remaining land uses are divided between pasture (35%), residential (3.3%), and cropland (0.7%).

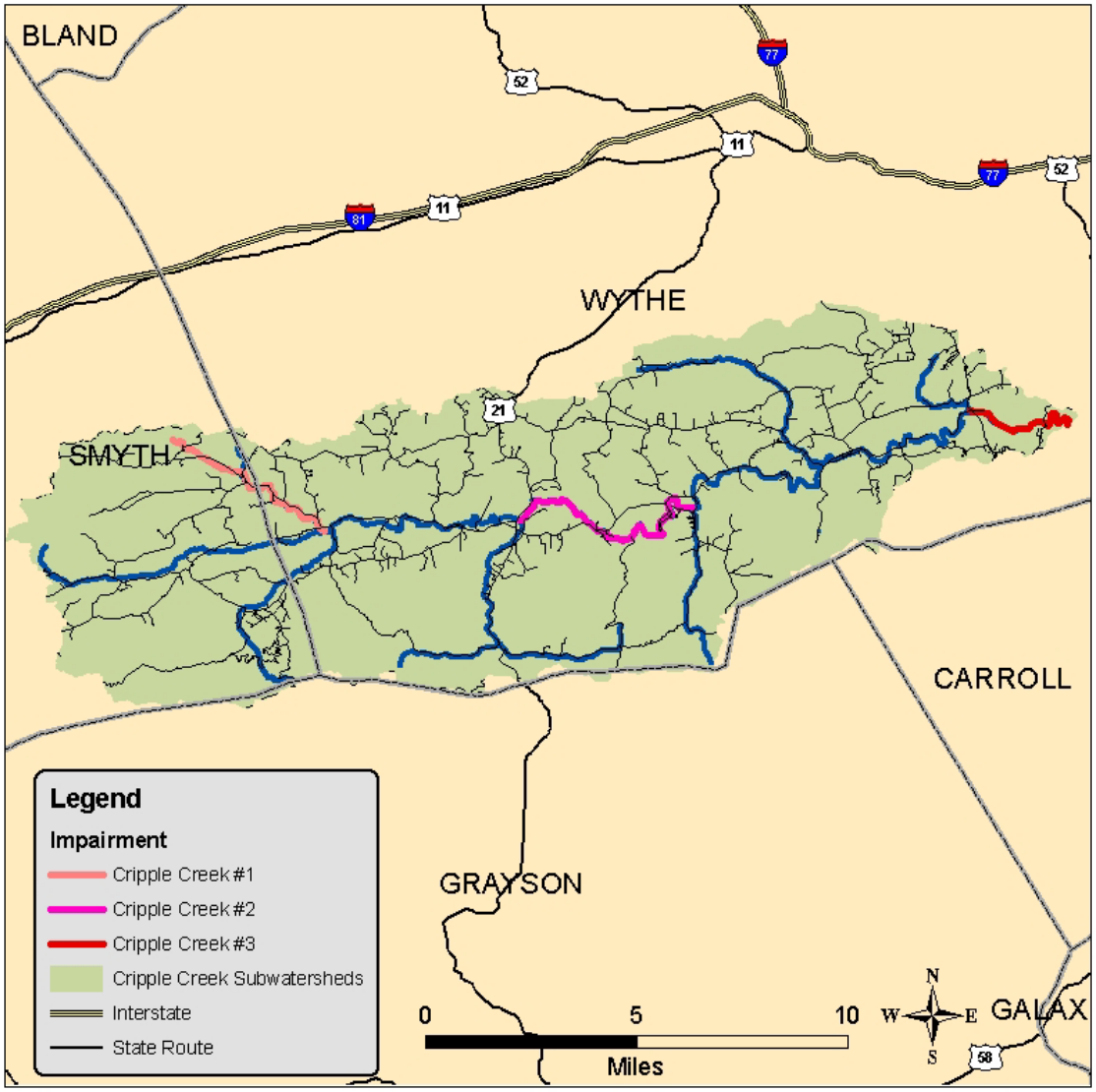

Figure 1.1. Location of Cripple Creek watershed.

1.1.4 Pollutant of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-

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

1.2 Designated Uses and Applicable Water Quality Standards

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

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

The goal of the Clean Water Act is that all streams should be suitable for recreational uses, including swimming and fishing. **Fecal coliform and *E. coli* bacteria** are used to indicate the presence of pathogens in streams supporting the **recreational use goal**. Bacteria in Cripple Creek (VAS-N09R-01-BAC) exceed the fecal coliform criterion.

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

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

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

- **Interim Fecal Coliform Standard:** Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more

samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

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

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

Chapter 2. Watershed Characterization

2.1 Water Resources

The Cripple Creek (VAS–N09R) watershed was subdivided into 19 subwatersheds for fecal coliform modeling purposes, as discussed in Section 4.2. Cripple Creek runs for approximately 33 miles from the headwaters to the confluence with the New River. Approximately 14.32 miles of which is impaired. Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment runs downstream from the headwaters to the confluence at Blue Spring Creek for 4.99 miles. Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment begins at the confluence with Dry Run near the community of Speedwell and extends to the confluence with Francis Mill Creek near the community of Cripple Creek over 6.24 miles. Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment begins at Dean Branch near Porters Crossroads and extends 3.09 miles to the confluence with the New River just beyond the community of Ivanhoe. Cripple Creek is a perennial stream with a trapezoidal channel cross-section.

2.2 Ecoregion

The Cripple Creek subwatersheds (See Figure 4.1 for subwatershed delineation) lie in the Northern Ridge and Valley Ecoregion of Virginia. The Northern Ridge and Valley Ecoregion is a northeast-southwest trending, relatively low-lying, but diverse ecoregion sandwiched between generally higher, more rugged mountainous regions with greater forest cover. As a result of extreme folding and faulting events, the region's roughly parallel ridges and valleys have a variety of widths, heights, and geologic materials, including limestone, dolomite, shale, siltstone, sandstone, chert, mudstone, and marble. Springs and caves are relatively numerous. Present-day forests cover about 50% of the region. The ecoregion has a diversity of aquatic habitats and species of fish.

2.2.1 Climate

The climate of the Cripple Creek (VAS-N09R-01-BAC) watershed is characterized based on the meteorological observations from 1/ 1/1893 to 12/31/2008 assembled by the Southeast Regional Climate Center for the Wytheville Post Office, Virginia (449301) station. Average annual precipitation is 40.1 inches with 55.3% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2009). Average annual snowfall is 17.2 inches with the highest snowfall occurring during January (SERCC, 2004). Average annual daily temperature is 64.1°F. The highest average daily temperature of 83.3°F occurs in July while the lowest average daily temperature of 22.8°F occurs in January (SERCC, 2009).

2.3 Land Use

Details of landuse used in this study are described in Section 4.3 with landuse per subwatershed listed in Table 4.2. For purposes of this study, it was assumed that residential development in the Cripple Creek watershed will continue at the overall average rate of less than 1.0% annually.

2.4 Water Quality Data

2.4.1 Historic Data for Fecal Coliform

Of the 12 water quality samples collected from January 2000 through December 2004 (2006 Section 303(d) 5-year listing period, VADEQ, 2006) at VADEQ stations 9-CPL028.10, 25% (3 of 12) of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Of the 12 samples collected from January 2000 through December 2004 at VADEQ station 9-CPL001.03, 33% (4 of 12) of the samples exceeded the water quality standard. Samples collected from VADEQ station 9-CPL018.47 exceeded the water quality standard 25% (3 of 12) of the time. Consequently, three segments of Cripple Creek [Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04)] were determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

VADEQ personnel monitored pollutant concentrations throughout Cripple Creek watershed. 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 collected at VADEQ stations 9-CPL001.03, 9-CPL002.82, 9-CPL003.10, 9-CPL008.68, 9-CPL018.47, 9-CPL026.75, and 9-CPL028.10 from 1990 through 2007 are plotted in Figures 2.1 through 2.7, respectively. The Most Probable Number (MPN) and membrane filtration methods were used for analyzing water samples for fecal coliform concentration.

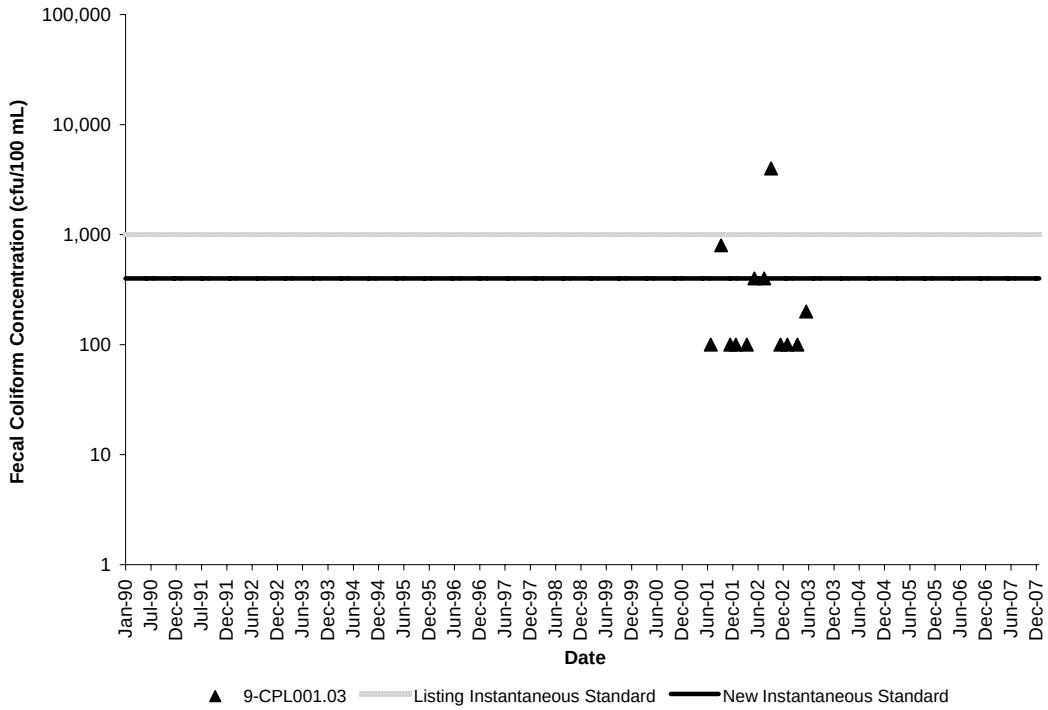

Figure 2.1. Fecal coliform concentrations at VADEQ station 9-CPL01.03 in Cripple Creek watershed.

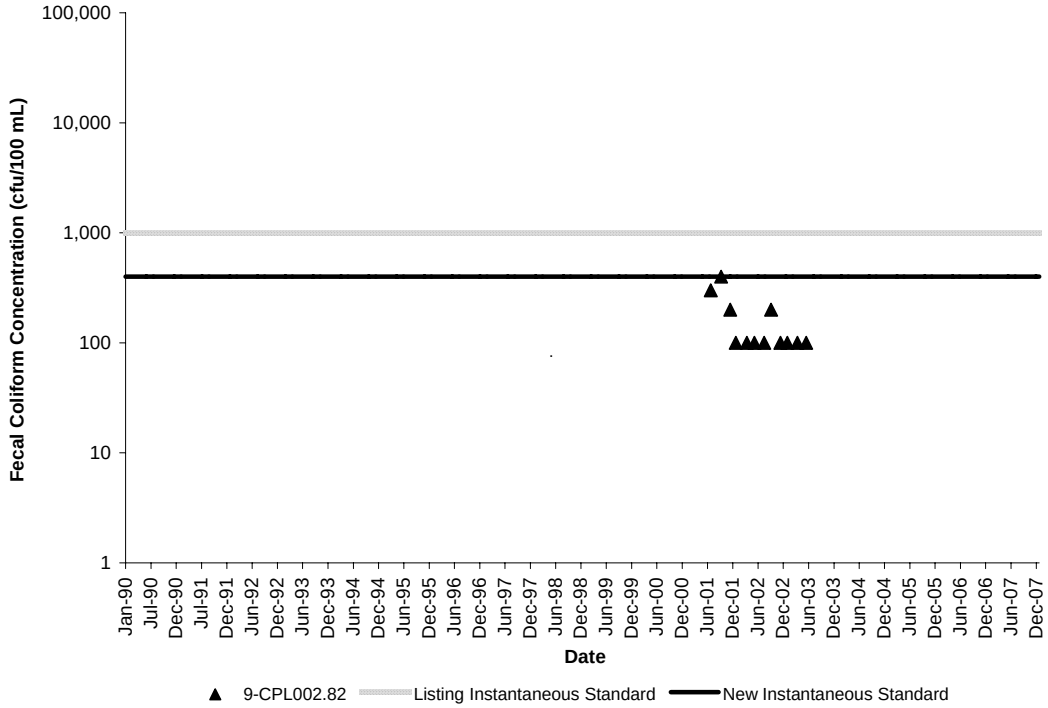

Figure 2.2. Fecal coliform concentrations at VADEQ station 9-CPL002.82 in Cripple Creek watershed.

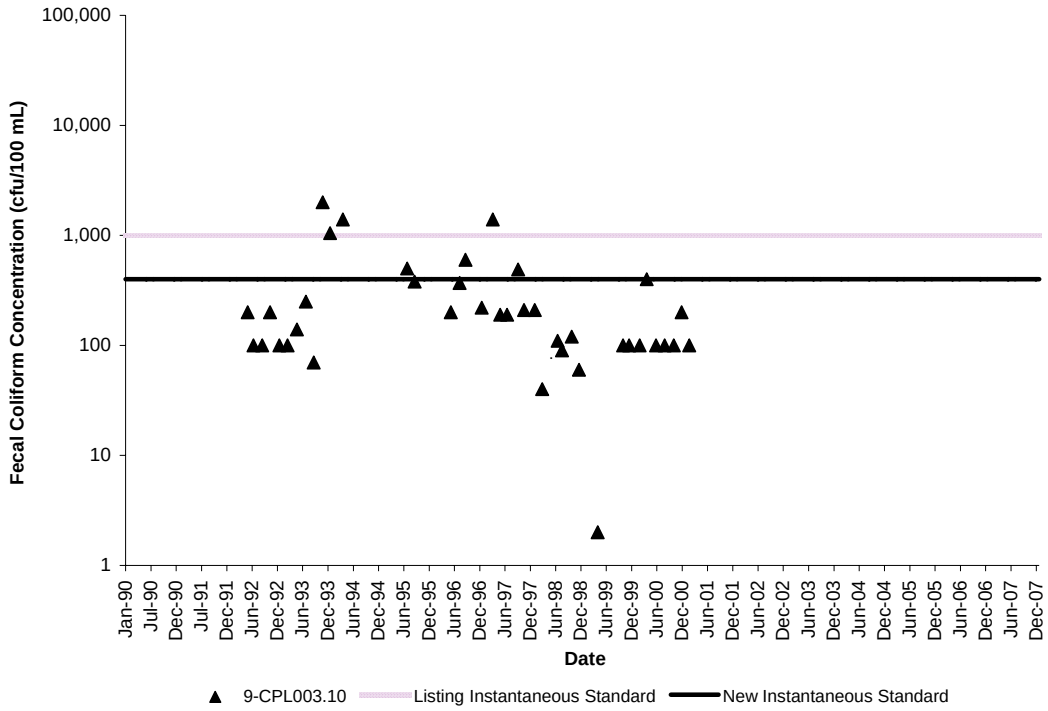

Figure 2.3. Fecal coliform concentrations at VADEQ station 9-CPL003.10 in Cripple Creek watershed.

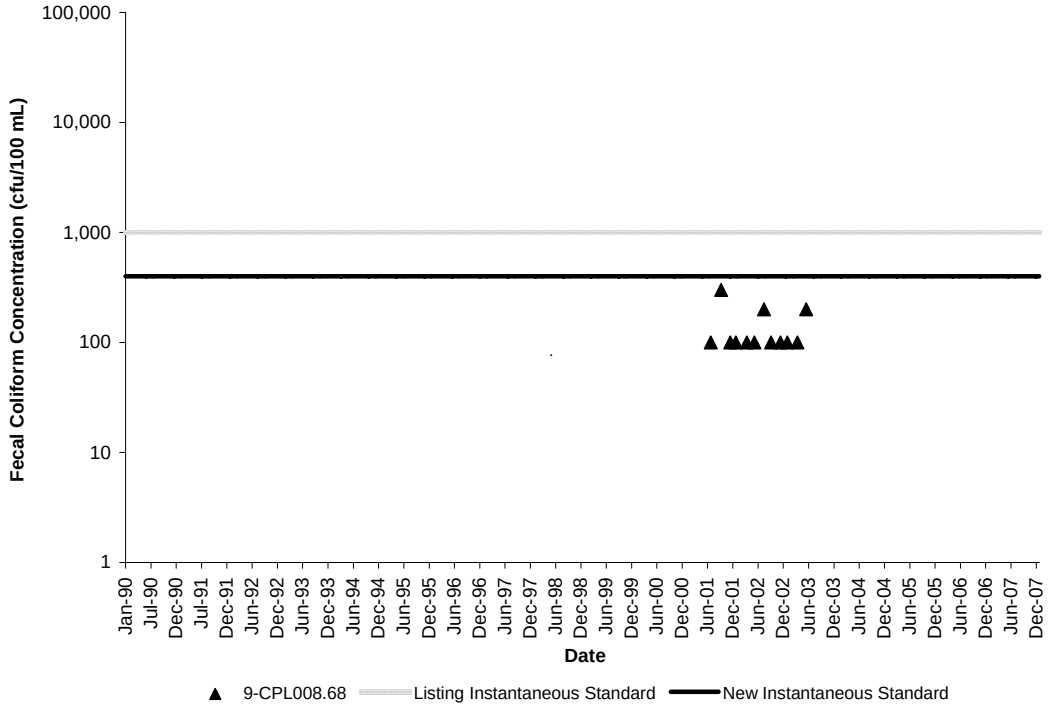

Figure 2.4. Fecal coliform concentrations at VADEQ station 9-CPL008.68 in Cripple Creek watershed.

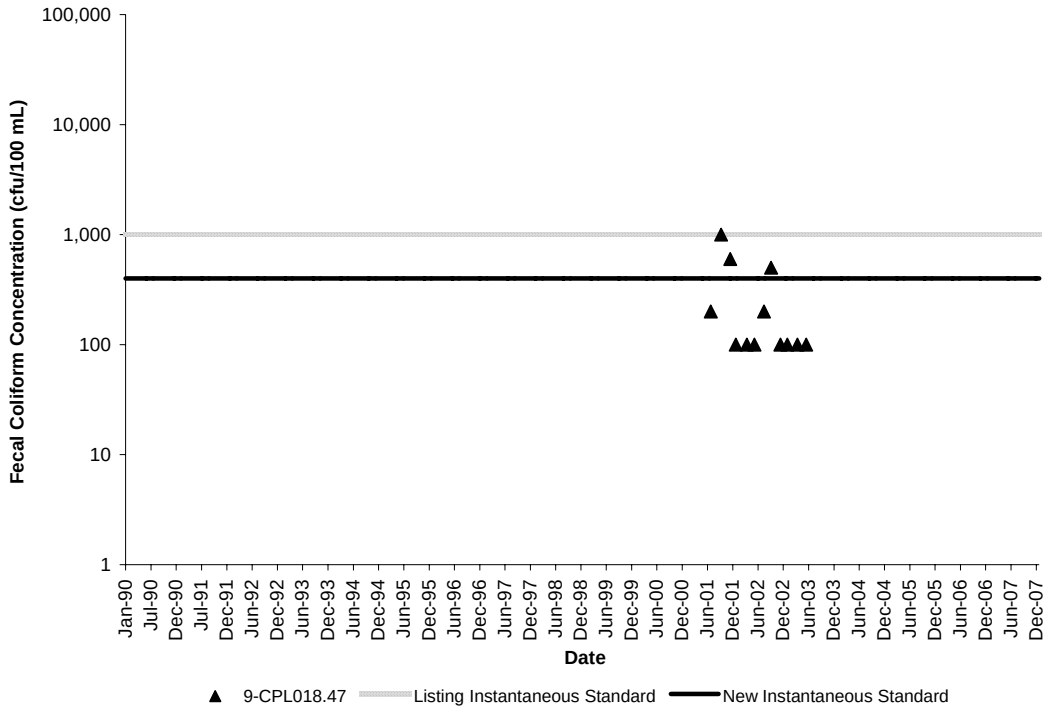

Figure 2.5. Fecal coliform concentrations at VADEQ station 9-CPL018.47 in Cripple Creek watershed.

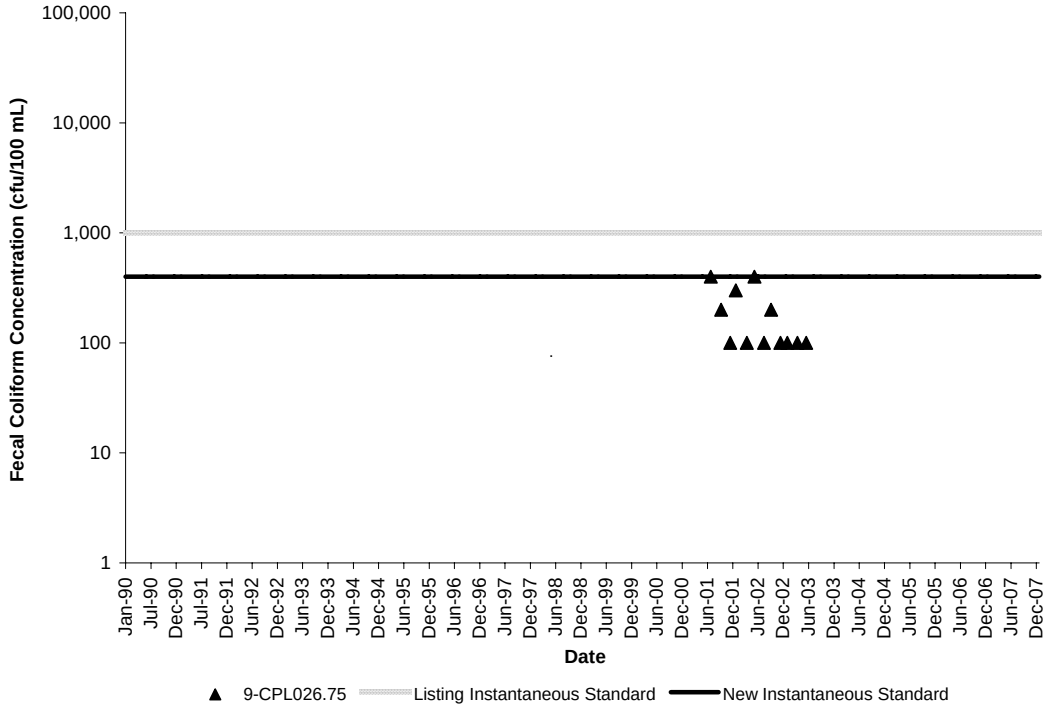

Figure 2.6. Fecal coliform concentrations at VADEQ station 9-CPL026.75 in Cripple Creek watershed.

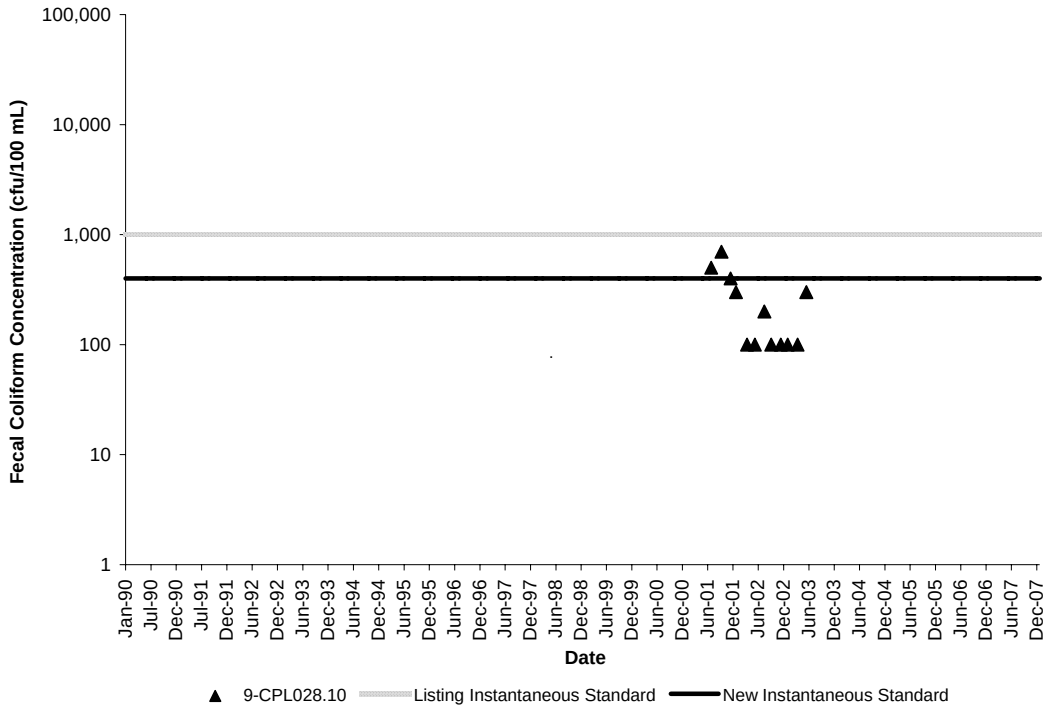

Figure 2.7. Fecal coliform concentrations at VADEQ station 9-CPL028.10 in Cripple Creek watershed.

Seasonal variability of fecal coliform concentrations in the stream network was evaluated by plotting the mean monthly fecal coliform concentration values. Mean monthly fecal coliform concentration values were determined as the average of zero to six values for each month; the number of values varied according to the available number of samples for each month in the 1990 to 2007 period of record (Tables 2.1 and 2.2). Mean monthly fecal coliform bacteria concentrations were plotted for stations 9-CPL001.03, 9-CPL002.82, 9-CPL003.10, 9-CPL008.68, 9-CPL018.47, 9-CPL026.75, and 9-CPL028.10 (Figures 2.8 - 2.14). It should be noted that due to the upper cap (8,000 cfu/100 mL or 16,000 cfu/100 mL) and lower cap (100 cfu/100ml or 18 cfu/100ml) imposed on the fecal coliform count, the actual counts could be higher or lower in cases where fecal coliform levels are equal to these level limits, therefore changing the averages shown in Figure 2.8 through 2.14. Station 9-CPL003.10 was the only station with values for all months (Figure 2.9). The highest average in-stream fecal coliform concentrations occurred in the spring and fall. The highest averages occurred in November followed by April, March, and January with the remaining monthly values uniform (Figure 2.9).

Table 2.1. Number of samples collected per month from 01/1/1990 to 12/31/2007 in the Cripple Creek stations 9-CPL001.03, 9-CPL002.82, 9-CPL003.10, and 9-CPL008.68.

Month	Samples Collected at			
	9-CPL001.03 (#)	***9-CPL002.82 (#)***	***9-CPL003.10 (#)***	***9-CPL008.68 (#)***
January	2	2	4	2
February	0	0	3	0
March	2	2	3	2
April	0	0	3	0
May	2	2	4	2
June	0	0	2	0
July	2	2	6	2
August	0	0	2	0
September	2	2	5	2
October	0	0	3	0
November	2	2	3	2
December	0	0	3	0
TOTAL	**12**	**12**	**41**	**12**

Table 2.2. Number of samples collected per month from 01/1/1990 to 12/31/2007 in Cripple Creek stations 9-CPL018.47, 9-CPL026.75, and 9-CPL028.10.

Month	Samples Collected at		
	9-CPL018.47 (#)	***9-CPL026.75 (#)***	***9-CPL028.10 (#)***
January	2	2	2
February	0	0	0
March	2	2	2
April	0	0	0
May	2	2	2
June	0	0	0
July	2	2	2
August	0	0	0
September	2	2	2
October	0	0	0
November	2	2	2
December	0	0	0
TOTAL	**12**	**12**	**12**

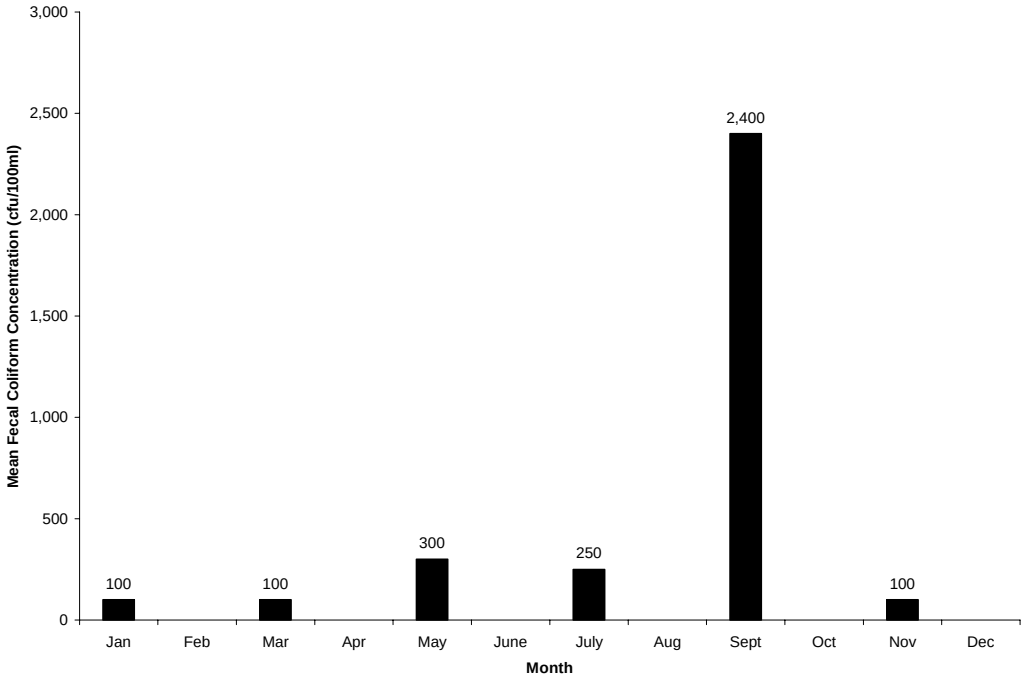

Figure 2.8. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL001.03 from January 2000 through December 2007 in Cripple Creek watershed.

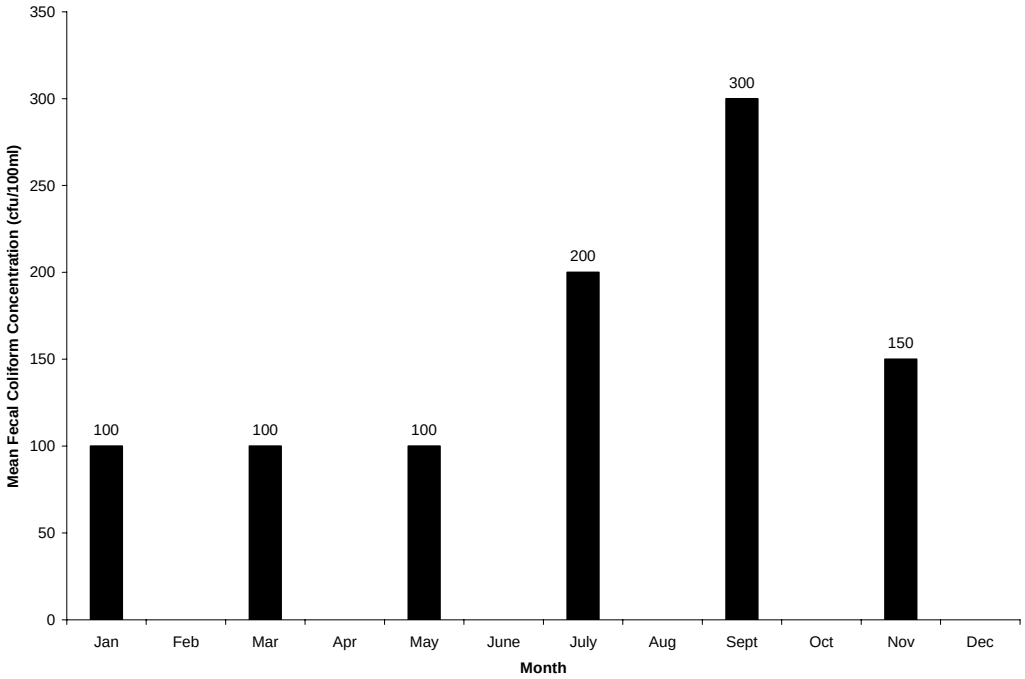

Figure 2.9. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL002.82 from January 2000 through December 2007 in Cripple Creek watershed.

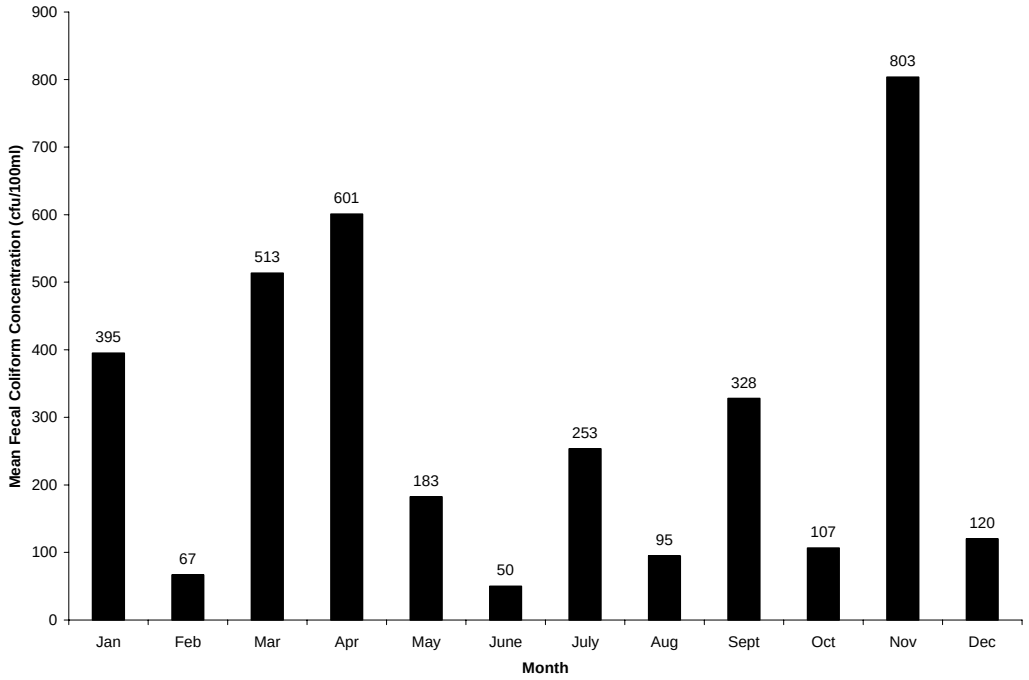

Figure 2.10. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL003.10 from January 2000 through December 2007 in Cripple Creek watershed.

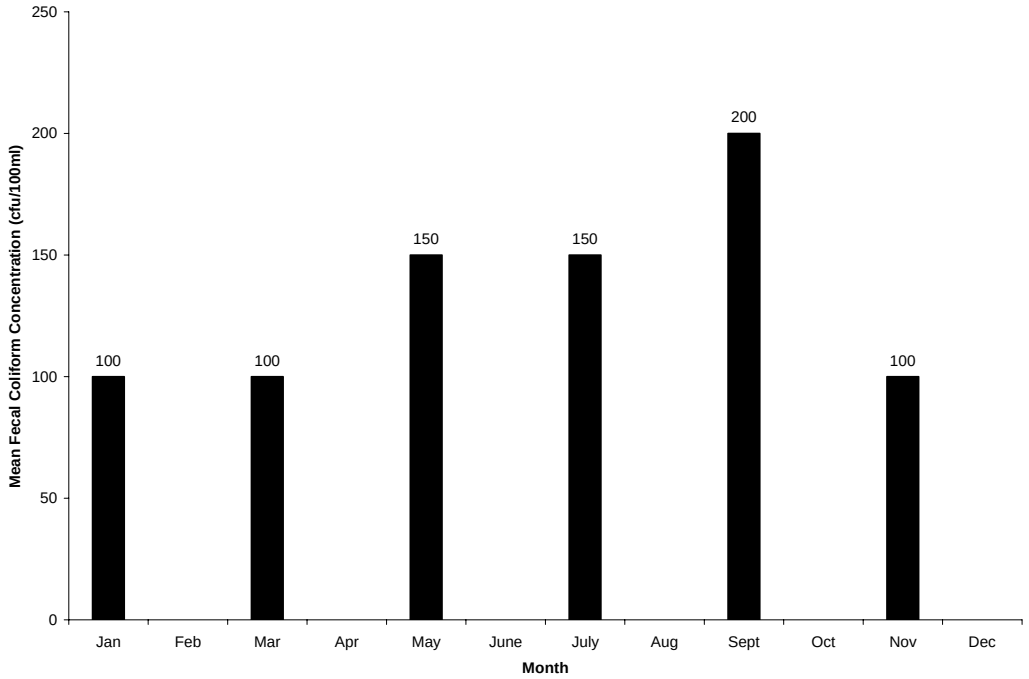

Figure 2.11. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL008.68 from January 2000 through December 2007 in Cripple Creek watershed.

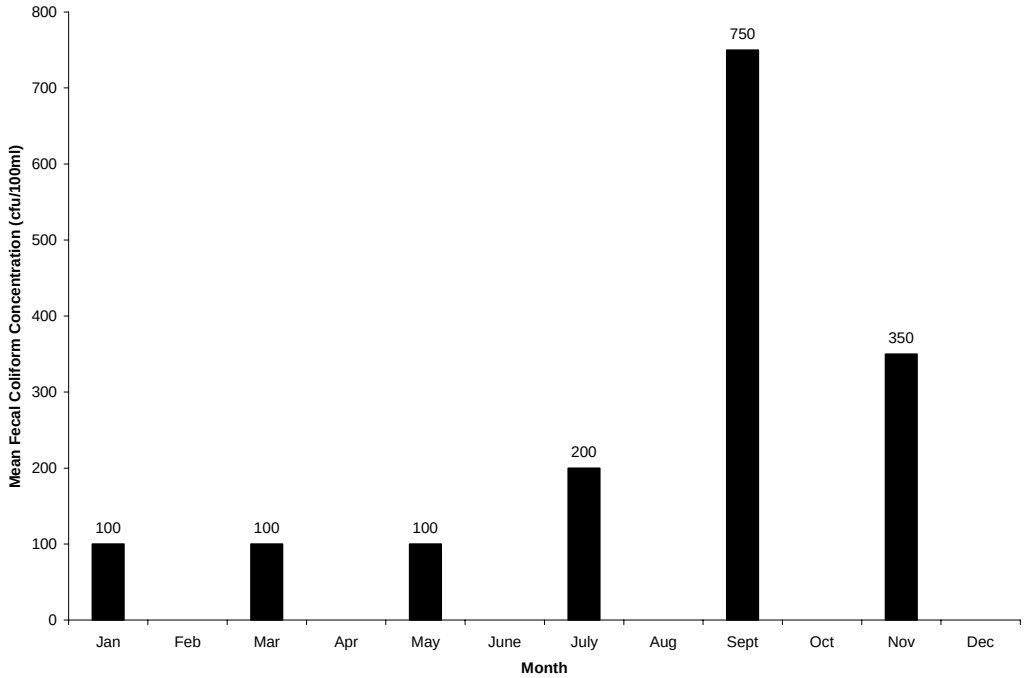

Figure 2.12. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL018.47 from January 2000 through December 2007 in Cripple Creek watershed.

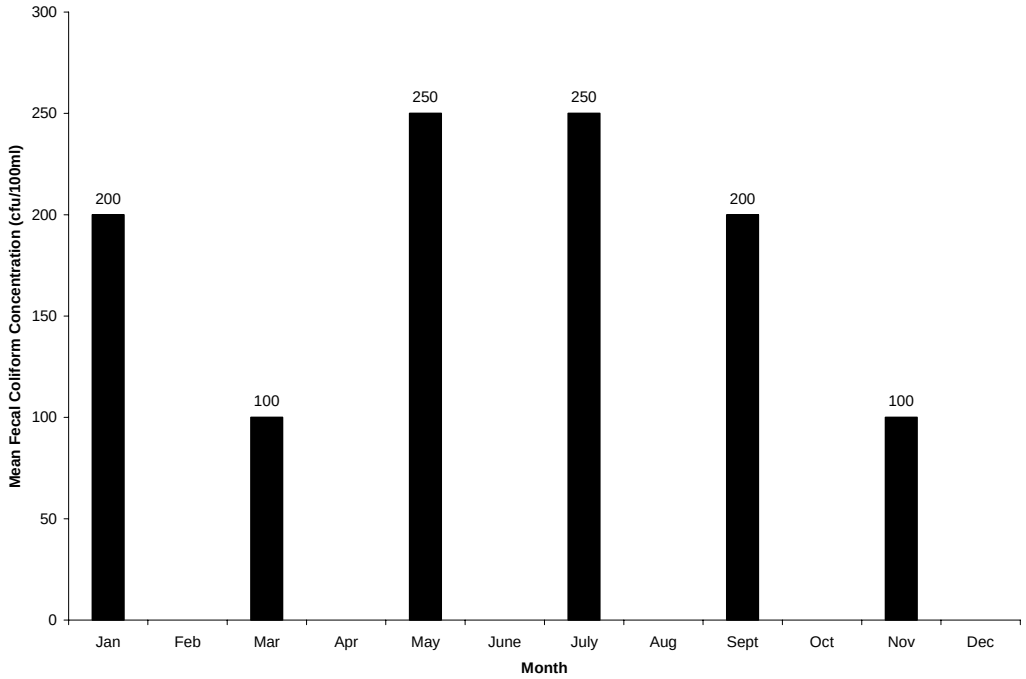

Figure 2.13. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL026.75 from January 2000 through December 2007 in Cripple Creek watershed.

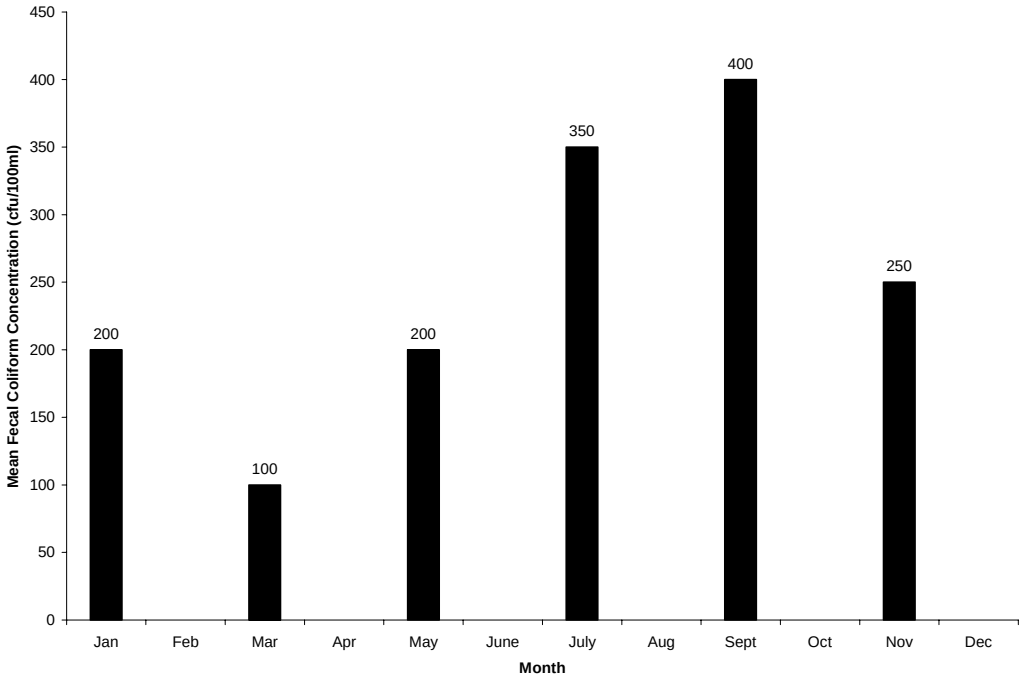

Figure 2.14. Impact of seasonality on fecal coliform concentrations at VADEQ station 9-CPL028.10 from January 2000 through December 2007 in Cripple Creek watershed.

2.4.2 Historic Data for E. coli

VADEQ staff examined water samples collected at stations 9-CPL001.03, 9-CPL002.82, 9-CPL008.68, 9-CPL018.47, 9-CPL022.99, and 9-CPL028.10 for their concentration of *E. coli* (Figures 2.15 through 2.20). This analysis was conducted concurrently with other monthly testing at the stations.

Two of the 8 (25%) samples analyzed from station 9-CPL001.03 exceeded the instantaneous *E. coli* bacteria standard of 235 cfu/100 mL. Of the 10 water quality samples collected at station 9-CPL018.47, five (50%) of the samples exceeded the instantaneous *E. coli* bacteria standard. At station 9-CPL028.10, none of the 10 samples taken violated the instantaneous *E. coli* bacteria standard.

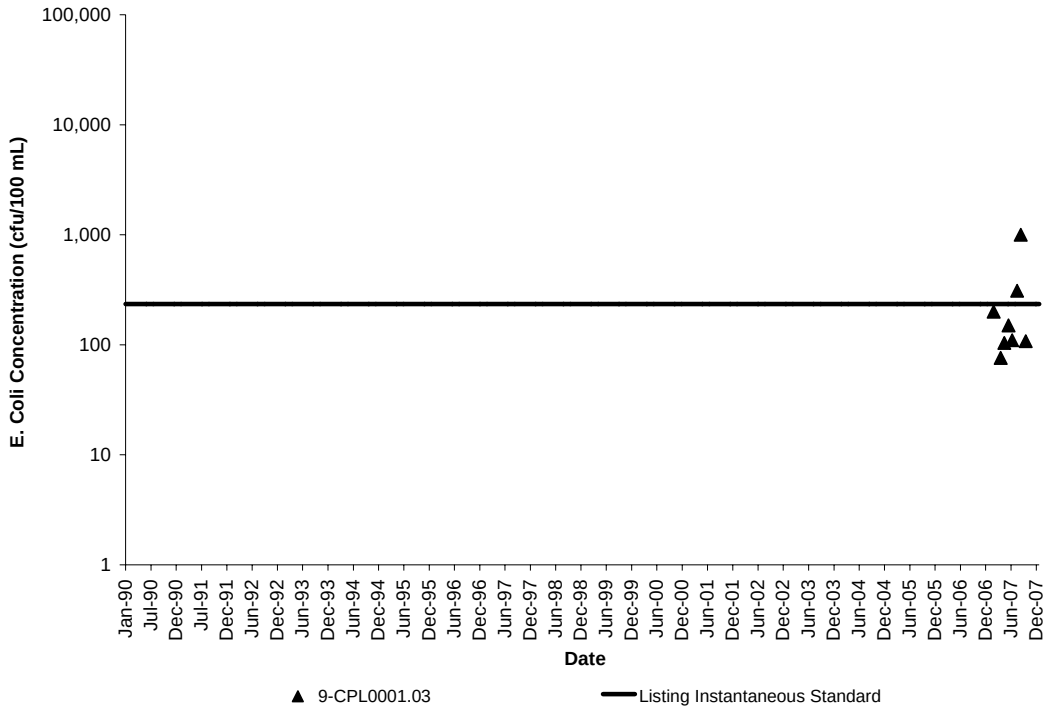

Figure 2.15. *E. coli* concentrations at VADEQ station 9-CPL001.03 in Cripple Creek watershed.

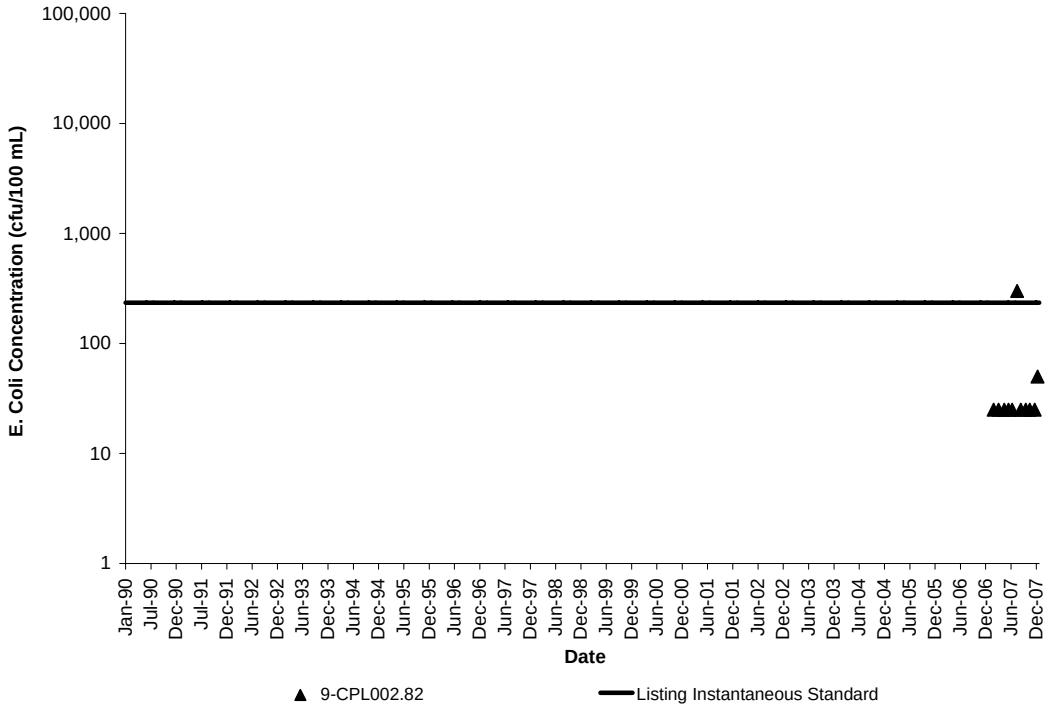

Figure 2.16. *E. coli* concentrations at VADEQ station 9-CPL002.82 in Cripple Creek watershed.

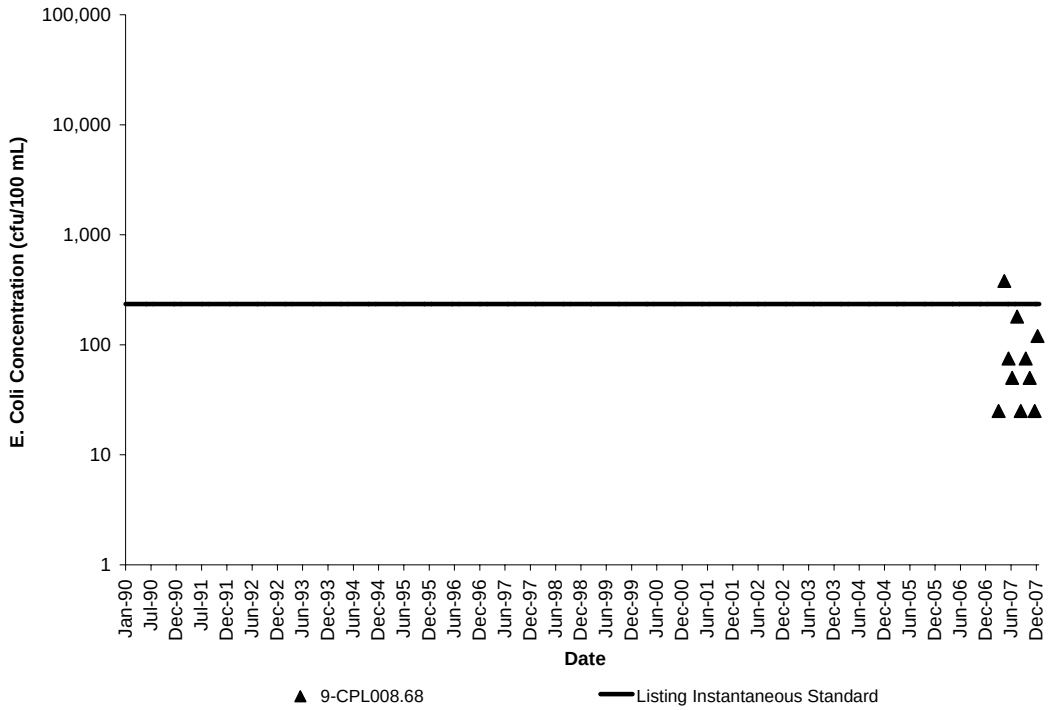

Figure 2.17. *E. coli* concentrations at VADEQ station 9-CPL008.68 in Cripple Creek watershed.

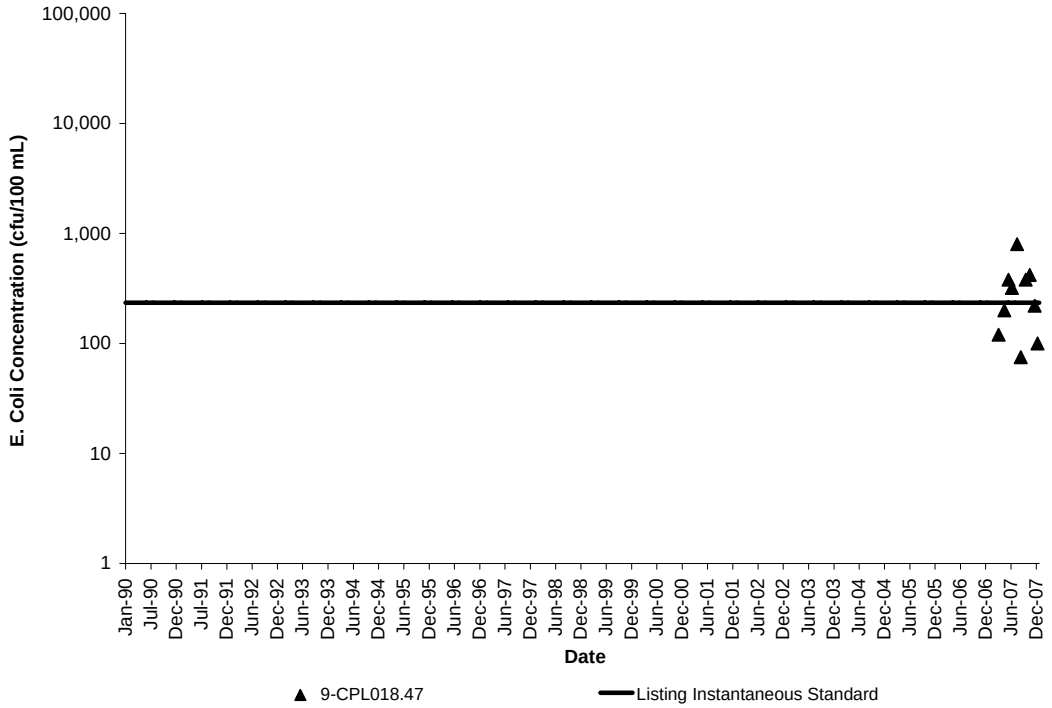

Figure 2.18. *E. coli* concentrations at VADEQ station 9-CPL018.47 in Cripple Creek watershed.

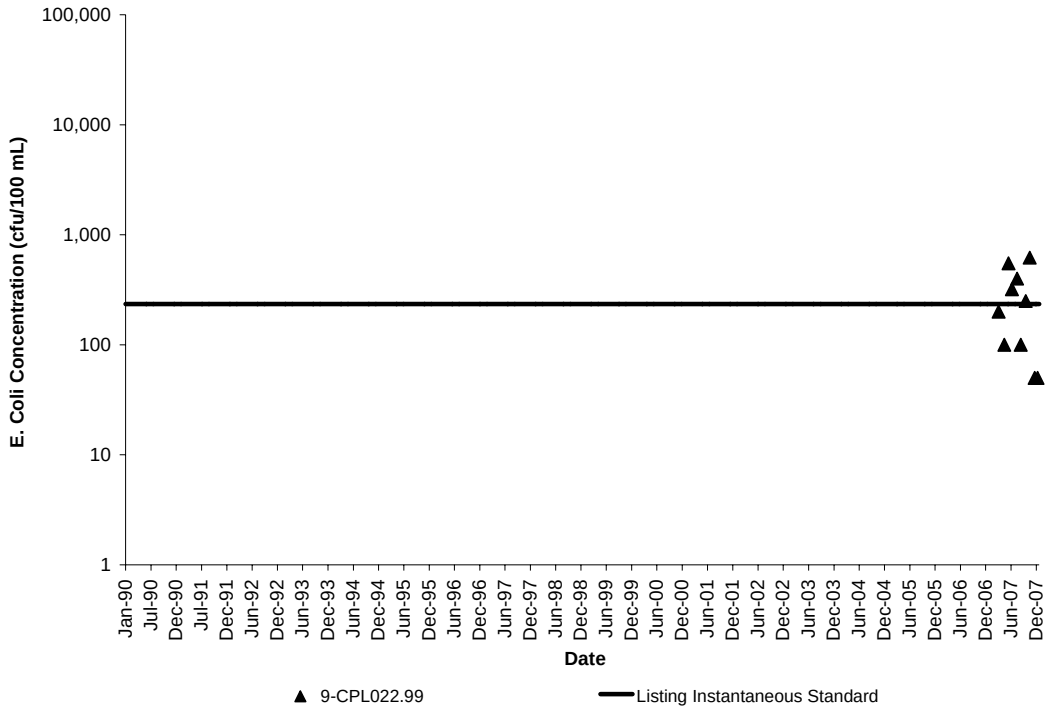

Figure 2.19. *E. coli* concentrations at VADEQ station 9-CPL022.99 in Cripple Creek watershed.

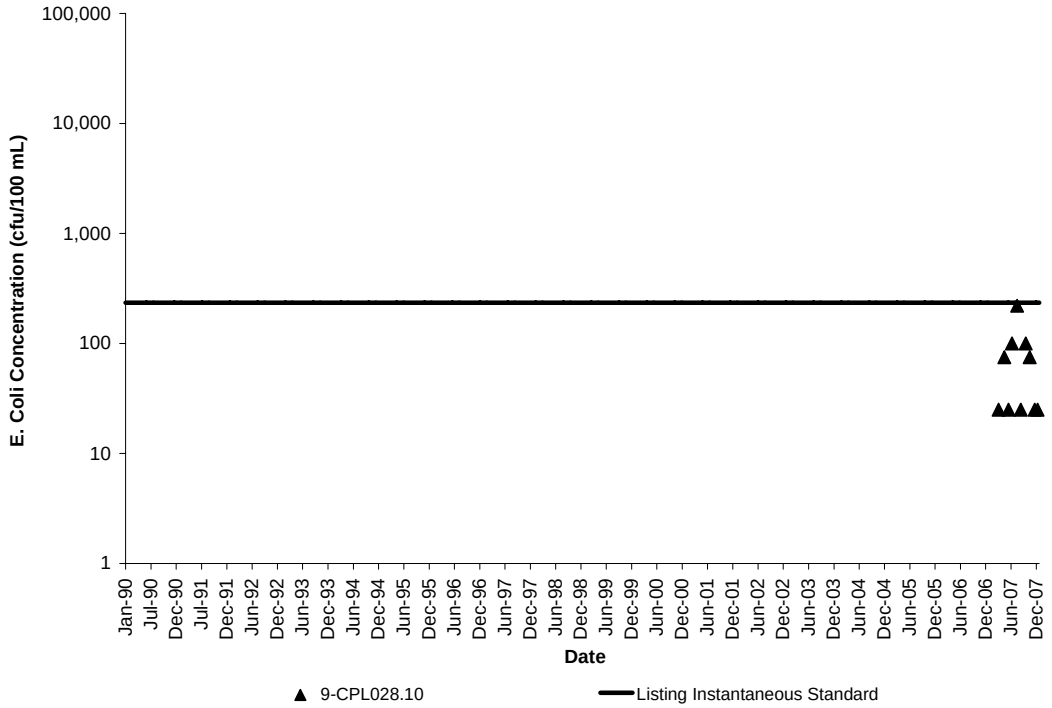

Figure 2.20. *E. coli* concentrations at VADEQ station 9-CPL028.10 in Cripple Creek watershed.

2.4.3 Historic Data for Bacterial Source Tracking

The results from 11 monthly bacteria source tracking (BST) samples collected from March 2007 to January 2008 at station 9-CPL001.03 were received at the time this report was prepared. The BST analysis was performed by MapTech, Inc. The results of the BST analysis provide a measure of the relative contribution of bacteria sources to the bacteria concentration found in the water samples. The bacteria sources were lumped into four categories: wildlife, human, livestock, and pet. Data resulting from the BST study are referenced in Appendix B. A discussion of the BST results provided by VADEQ indicates there is 90% confidence that the indicated proportions for each sample are within 15% of the sampled population (Appendix B). These data represent a brief glimpse of bacteria concentration Cripple Creek 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%. Table 2.3 summarizes the results of the presence/absence analysis of the BST data. The BST data were used to verify modeling methods and assumptions.

E. coli enumerations were also performed on the BST samples. These data are referenced in Appendix B. At station 9-CPL001.03, 18.2% (two of 11) of the samples exceeded the *E. coli* bacteria instantaneous standard. The exceedances occurred in July and August of 2007.

Table 2.3. Presence/absence analysis of bacteria sources at station 9-CPL001.03 in Cripple Creek watershed.

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

1 – This is a measure of the number of times the source is present in all 11 samples.

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

Chapter 3. Bacteria Source Assessment

Potential bacteria sources in the Cripple Creek watershed 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); Smyth County Planning Department; Wythe County Planning Department; Natural Resources Conservation Service (NRCS); Virginia Department of Agricultural and Consumer Services (VDACS); Big Walker SWCD; Evergreen SWCD; 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 Cripple Creek watershed, 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. Potential bacteria sources in the Cripple Creek watershed.

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

3.1 Permitted Discharges

Currently, one individual Virginia Pollutant Discharge Elimination System municipal and industrial permitted facilities, as well as general permits issued for domestic sewage discharges of less than or equal to 1,000 gallons per day exist in the Cripple Creek watershed (Table 3.2). This facility is not permitted to discharge bacteria.

Table 3.2. Active VPDES permitted bacteria point source in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Permit Number	Facility Name	Sub-shed	Design Flow (MGD)	FC Load (cfu/yr)	*E. coli* Load (cfu/yr)
VA0086452	Wythe Co Water and Wastewater-Speedwell WTP	CRC-08	0.002	0	0

Phase II Municipal Separate Storm Sewer System (MS4) permits were also reviewed and found no facilities with MS4 permits discharge within the Cripple Creek watershed.

3.2 Humans

There are no homes served by municipal sanitary sewer in the Cripple Creek watershed. Wastewater from 2,128 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed has an estimated population of 395 people (178 households at an average of 2.22 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 7.70×10^{11} cfu/day (2.81×10^{14} cfu/year).

The Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed has an estimated population of 2,408 people (1,161 households at an average of 2.07 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce 1.95×10^{9} cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of 4.70×10^{12} cfu/day (1.71×10^{15} cfu/year).

The Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed has an estimated population of 1,658 people (789 households at an average of 2.10 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce 1.95×10^{9} cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of 3.23×10^{12} cfu/day (1.18×10^{15} cfu/year).

Bacteria from humans can be transported to streams from failing septic systems, straight pipes discharging directly into streams, or biosolids applications to pasture and cropland.

3.2.1 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-1967, 1967-1987, and post-1987) based on 1990, 2000, and 2004 U.S. Census Bureau demographics data (UCSB, 1990, 2000, and 2004). In accordance with estimates from Dr. Raymond B. Reneau, Jr. from Virginia Tech, a 15% failure rate for systems designed and installed prior to 1967, a 8% failure rate for systems designed and installed between 1967 and 1987, and a 3% failure rate on all systems designed and installed after 1987 was used in the development of the Cripple Creek 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 2008 were established using 1990, 2000, and 2004 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 2.22 persons/household was 4.33×10^9 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 Tables 3.3 through 3.5.

3.2.2 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-1969 and 1970-1988 age categories. Any houses within 150 ft of streams are considered potential straight pipe dischargers. Using the age categories (pre-1969, 1970 – 1988, post 1988), 10% of old houses (pre-1969) within 150 ft of streams and 2% of mid-age houses (1970 – 1988) within 150 ft of streams are assumed to be straight pipe dischargers (CTWS, 2004). This method yielded 16, 55, and 45 houses that potentially could be classified as straight pipes in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment watersheds (Table 3.3 through 3.5).

3.2.3 Biosolids

According to the VADEQ records, none of the facilities permitted for biosolids land application are currently disposing biosolids via land application in the Cripple Creek watershed.

3.3 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 these densities and number of households in each watershed, 94 dogs and 107 cats were projected to reside in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed. All pets were combined for modeling purposes into a standard 'unit pet' category. This 'unit pet' was assumed equivalent to one dog or several cats, and a rate of one 'unit pet' per household was used to calculate a total pet population of 178. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed is 8.01×10^{10} cfu/day (2.92×10^{13} cfu/yr).

In Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, 615 dogs and 697 cats were projected to reside in the watershed. All pets were combined for modeling purposes into a standard 'unit pet' category. This 'unit pet' was assumed equivalent to one dog or several cats, and a rate of one 'unit pet' per household was used to calculate a total pet population of 1,163. 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 Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed is 5.22×10^{11} cfu/day (1.91×10^{14} cfu/yr).

An estimated 419 dogs and 475 cats were projected to reside in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed. All pets were combined for modeling purposes into a standard 'unit pet' category. This 'unit pet' was assumed equivalent to one dog or several cats, and a rate of one 'unit pet' per household was used to calculate a total pet population of 791. 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 Impairment 2 watershed is 3.56×10^{11} cfu/day (1.30×10^{14} cfu/yr).

Pet population distribution among subwatersheds is listed in Tables 3.3 through 3.5. 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 3.3. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Sub-shed	Human Population	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
		Pre-1967	1967-1987	Post-1987			
CRC-01	395	140	26	13	21	16	178
Total	**395**	**140**	**26**	**13**	**21**	**16**	**178**

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

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 Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Sub-shed	Human Population	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
		Pre-1967	1967-1987	Post-1987			
CRC-02	465	165	47	34	27	17	246
CRC-03	2	1	0	0	0	0	1
CRC-04	456	145	49	44	26	6	238
CRC-05	456	133	33	33	21	14	199
CRC-06	78	23	6	6	4	0	35
CRC-07	104	39	6	5	6	1	50
CRC-08	208	69	14	12	11	4	95
CRC-09	319	111	20	17	18	7	148
CRC-10	320	119	16	16	19	6	151
Total	**2,408**	**805**	**191**	**167**	**132**	**55**	**1,163**

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

Table 3.5. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Sub-shed	Human Population	Unsewered Houses in Each Age Category			Failing Septic System	Straight Pipes	Pet Population[a]
		Pre-1967	1967-1987	Post-1987			
CRC-11	145	55	9	7	9	0	71
CRC-12	41	16	2	2	2	1	20
CRC-13	258	104	12	11	15	10	127
CRC-14	351	118	14	25	18	13	157
CRC-15	223	86	10	11	12	12	107
CRC-16	18	8	1	1	1	0	10
CRC-17	331	104	14	33	17	8	151
CRC-18	234	107	5	7	17	1	119
CRC-19	57	26	1	2	4	0	29
Total	**1,658**	**624**	**68**	**99**	**95**	**45**	**791**

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

3.4 Domesticated Animal Sources

In the Cripple Creek watershed, bacteria from domesticated animal 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. Domesticated animal populations in the Cripple Creek watershed were estimated based on Virginia Agriculture Statistics Service (VASS) data and communication with staff from SWCD, NRCS, VADCR, VCE, watershed residents, and local producers.

3.4.1 Cattle

Based on information obtained from VADCR and SWCD, there are one, three, and two dairy farms presently operating in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watersheds, respectively. Based on information provided, it was determined that there were 720 milk cows, 360 dry cows, and 360 heifers distributed between the farms. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Tables 3.6 through 3.8). Beef cattle in the Cripple Creek watershed (6,418 pairs) included cow/calf and feeder operations (Tables 3.6 through 3.8).

Table 3.6. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
CRC-01	400	1	528
Total	**400**	**1**	**528**

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

Table 3.7. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
CRC-02	420	2	1,081
CRC-03	0	0	6
CRC-04	0	0	428
CRC-05	100	1	870
CRC-06	0	0	0
CRC-07	0	0	0
CRC-08	0	0	105
CRC-09	0	0	793
CRC-10	0	0	600
Total	**520**	**3**	**3,883**

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

Table 3.8. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watersheds.

Subwatershed	Dairy Cattle[a]	No. of Dairy Operations	Beef Cattle (pairs)
CRC-11	0	0	0
CRC-12	0	0	100
CRC-13	0	0	441
CRC-14	0	0	252
CRC-15	200	1	559
CRC-16	0	0	53
CRC-17	0	0	417
CRC-18	320	1	141
CRC-19	0	0	44
Total	**520**	**2**	**2,007**

[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 3.9.
- 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 3.9). 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 3.9. Time spent by cattle in confinement and in the stream in Cripple Creek 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 Tables 3.10 through 3.12 for dairy cattle and in Tables 3.13 through 3.15 for beef cattle. Tables 3.13 through 3.15 reflect animal unit (i.e., 1,000 lb) per beef cow-calf pair variation throughout year.

Table 3.10. Distribution of the dairy cattle[a] population in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	230.00	129.43	32.41	8.10	0.05	0.00
February	230.00	129.43	32.41	8.10	0.05	0.00
March	80.00	243.59	61.01	15.25	0.15	0.00
April	60.00	258.78	64.81	16.20	0.21	0.00
May	60.00	258.70	64.79	16.20	0.32	0.00
June	60.00	258.37	64.71	16.18	0.74	0.00
July	60.00	258.37	64.71	16.18	0.74	0.00
August	60.00	258.37	64.71	16.18	0.74	0.00
September	60.00	258.70	64.79	16.20	0.32	0.00
October	60.00	258.78	64.81	16.20	0.21	0.00
November	80.00	243.59	61.01	15.25	0.15	0.00
December	230.00	129.43	32.41	8.10	0.05	0.00

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

Table 3.11. Distribution of the dairy cattle[a] population in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	299.00	168.26	42.14	10.53	0.07	0.00
February	299.00	168.26	42.14	10.53	0.07	0.00
March	104.00	316.67	79.31	19.83	0.20	0.00
April	78.00	336.41	84.25	21.06	0.28	0.00
May	78.00	336.31	84.22	21.06	0.41	0.00
June	78.00	335.89	84.12	21.03	0.97	0.00
July	78.00	335.89	84.12	21.03	0.97	0.00
August	78.00	335.89	84.12	21.03	0.97	0.00
September	78.00	336.31	84.22	21.06	0.41	0.00
October	78.00	336.41	84.25	21.06	0.28	0.00
November	104.00	316.67	79.31	19.83	0.20	0.00
December	299.00	168.26	42.14	10.53	0.07	0.00

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

Table 3.12. Distribution of the dairy cattle[a] population in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream[b]	Loafing[c]
January	299.00	168.26	42.14	10.53	0.07	0.00
February	299.00	168.26	42.14	10.53	0.07	0.00
March	104.00	316.67	79.31	19.83	0.20	0.00
April	78.00	336.41	84.25	21.06	0.28	0.00
May	78.00	336.31	84.22	21.06	0.41	0.00
June	78.00	335.89	84.12	21.03	0.97	0.00
July	78.00	335.89	84.12	21.03	0.97	0.00
August	78.00	335.89	84.12	21.03	0.97	0.00
September	78.00	336.31	84.22	21.06	0.41	0.00
October	78.00	336.41	84.25	21.06	0.28	0.00
November	104.00	316.67	79.31	19.83	0.20	0.00
December	299.00	168.26	42.14	10.53	0.07	0.00

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

Table 3.13. Distribution of the beef cattle population (pairs) in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	242.88	277.37	69.47	17.37	0.11	0.00
February	285.12	325.61	81.55	20.39	0.13	0.00
March	0.00	558.68	139.92	34.98	0.34	0.00
April	0.00	574.67	143.92	35.98	0.47	0.00
May	0.00	590.56	147.90	36.97	0.73	0.00
June	0.00	605.87	151.73	37.93	1.74	0.00
July	0.00	621.92	155.75	38.94	1.79	0.00
August	0.00	637.97	159.77	39.94	1.84	0.00
September	0.00	654.84	164.00	41.00	0.81	0.00
October	0.00	401.87	100.64	25.16	0.33	0.00
November	0.00	422.03	105.69	26.42	0.26	0.00
December	232.32	265.31	66.44	16.61	0.11	0.00

*Number of beef cattle defecating in stream.

Table 3.14. Distribution of the beef cattle population (pairs) in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	1786.18	2039.86	510.86	127.71	0.84	0.00
February	2096.82	2394.62	599.70	149.93	0.98	0.00
March	0.00	4108.64	1028.96	257.24	2.53	0.00
April	0.00	4226.21	1058.40	264.60	3.47	0.00
May	0.00	4343.07	1087.67	271.92	5.35	0.00
June	0.00	4455.67	1115.87	278.97	12.83	0.00
July	0.00	4573.70	1145.43	286.36	13.17	0.00
August	0.00	4691.73	1174.99	293.75	13.51	0.00
September	0.00	4815.79	1206.06	301.51	5.93	0.00
October	0.00	2955.39	740.14	185.04	2.43	0.00
November	0.00	3103.65	777.27	194.32	1.91	0.00
December	1708.52	1951.17	488.65	122.16	0.80	0.00

*Number of beef cattle defecating in stream.

Table 3.15. Distribution of the beef cattle population (pairs) in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Month	Confined	Pasture 1	Pasture 2	Pasture 3	Stream*	Loafing
January	923.22	1054.34	264.05	66.01	0.43	0.00
February	1083.78	1237.70	309.97	77.49	0.51	0.00
March	0.00	2123.63	531.84	132.96	1.31	0.00
April	0.00	2184.40	547.06	136.76	1.79	0.00
May	0.00	2244.80	562.18	140.55	2.77	0.00
June	0.00	2302.99	576.76	144.19	6.63	0.00
July	0.00	2364.00	592.04	148.01	6.80	0.00
August	0.00	2425.01	607.31	151.83	6.98	0.00
September	0.00	2489.13	623.37	155.84	3.07	0.00
October	0.00	1527.55	382.56	95.64	1.25	0.00
November	0.00	1604.18	401.75	100.44	0.99	0.00
December	883.08	1008.50	252.57	63.14	0.41	0.00

*Number of beef cattle defecating in stream.

3.4.1.1 Direct Manure Deposition in Streams

Direct manure loading to streams is due to both dairy and beef cattle 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed is 26,560 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 3.07×10^{10} cfu/day (1.12×10^{13} cfu/year). For Cripple Creek (VAS-N09R-01-BAC_CPL02A98), the average annual manure

loading directly deposited by cattle in the stream is 130,804 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 1.85×10^{11} cfu/day (6.74×10^{13} cfu/year). For Cripple Creek (VAS-N09R-01-BAC_CPL01B04), the average annual manure loading directly deposited by cattle in the stream is 74,302 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is 9.97×10^{10} cfu/day (3.64×10^{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.

3.4.1.2 Direct Manure Deposition on Pastures

Dairy and beef 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 14,341; 7,183 and 3,567, 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), averaged over the year, are 8.16×10^{15}, 2.08×10^{15}, and 4.82×10^{14} cfu/ac-year for pastures 1, 2, and 3, respectively. In the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, manure loadings for pastures 1, 2, and 3 were 8,718; 4,371; and 2,162 lb/ac-year and fecal coliform loadings were 4.99×10^{15}, 1.28×10^{16}, and 2.90×10^{15}. In Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, manure loadings for pastures 1, 2, and 3 were 8,527; 4,275; and 2,115 lb/ac-year and fecal coliform loadings were 2.70×10^{16}, 6.93×10^{15}, and 1.56×10^{15}.

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.

3.4.1.3 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 is 2,460,605 gallons in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed; 11,475,743 in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed; and 6,618,216 in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is 3.88 x 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 80.5 acres of cropland and 0.0 acres of pasture in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed. For the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, it was estimated that liquid dairy manure was applied to 60.8 acres of cropland and 74.2 acres of pasture 1. For the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, it was estimated that liquid dairy manure was applied to 51.8 acres of cropland and 89.4 acres of pasture 1.

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 3.16. Dry cows and heifers were assumed to produce only solid manure.

Table 3.16. Schedule of cattle waste application in Cripple Creek 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.

3.4.1.4 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 Tables 3.17 through 3.18.

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) (Tables 3.17 through 3.19). 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 (Tables 3.17 through 3.19). Solid manure is applied at the rate of12 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 3.16. Based on availability of land and solid manure, as well as the assumptions regarding application rate, it was estimated that solid manure was applied to 68.6 acres of cropland and 11.8 acres of pasture 1 in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed. For the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, it was estimated that solid manure was applied to 106.6 acres of cropland and 342.8 acres of pasture 1. For the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, it was estimated that solid manure was applied to 198.1 acres of cropland and 48.9 acres of pasture 1.

Table 3.17. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) 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	100	1,400	115	2.17	**4.40**
Heifer	100	640	40.7	2.17	
Beef (pairs)	528	1,000	60	5.5	

[a]Source: BSE (2003)

Table 3.18. 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 Cripple Creek (VAS-N09R-01-BAC_CPL02A98) 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	130	1,400	115	2.17	**5.23**
Heifer	130	640	40.7	2.17	
Beef (pairs)	3,883	1,000	60	5.5	

[a]Source: BSE (2003)

Table 3.19. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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	130	1,400	115	2.17	**5.02**
Heifer	130	640	40.7	2.17	
Beef (pairs)	2,007	1,000	60	5.5	

[a]Source: BSE (2003)

3.4.2 Poultry

Based on confined animal feeding operations information obtained from VADCR and feedback from the TAC, no poultry facilities are presently operating in the Cripple Creek watershed. In addition, no imported poultry litter to the watershed was identified.

3.4.3 Horses

The estimated number of horses in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed is included in Tables 3.20, 3.21, and 3.22, respectively. 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 is $1.72x10^{10}$ cfu/day ($6.29x10^{12}$ cfu/year) in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, $1.40x10^{11}$ cfu/day ($5.12x10^{13}$

cfu/year) in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, and 8.41×10^{10} cfu/day (3.70×10^{13} cfu/year) in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Table 3.20. Horse and sheep population by subwatershed in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Subwatershed	Horses	Ewes
CRC-01	41	41
Total	**41**	**41**

Table 3.21. Horse and sheep population by subwatershed in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Subwatershed	Horses	Ewes
CRC-02	66	45
CRC-03	1	1
CRC-04	31	29
CRC-05	87	114
CRC-06	0	0
CRC-07	0	0
CRC-08	10	14
CRC-09	79	103
CRC-10	60	78
Total	**334**	**384**

Table 3.22. Horse and sheep population by subwatershed in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Subwatershed	Horses	Ewes
CRC-11	0	0
CRC-12	10	13
CRC-13	44	57
CRC-14	25	33
CRC-15	56	73
CRC-16	5	7
CRC-17	42	54
CRC-18	14	18
CRC-19	4	6
Total	**200**	**261**

3.4.4 Other Livestock Sources

Based on county sheep population data obtained from VASS and input from SWCDs, the sheep population was distributed to individual subwatersheds (Tables 3.20 through 3.22). Based on information provided, it was determined that there were 686 ewes throughout the Cripple Creek watershed. Other minor livestock-related sources of bacteria (e.g., goat) were present during watershed visits; however, a significant population was not identified within the Cripple Creek watershed. The potential bacteria load from these sources was accounted for during water quality calibration

3.5 Wildlife

Fecal coliform production rates for wildlife species considered in this study are listed in Tables 3.25 through 3.27. The total wildlife fecal coliform production each year in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watersheds is 6.74×10^{13} cfu/yr, 6.40×10^{16} cfu/yr, and 2.56×10^{14} cfu/yr, respectively

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 3.23).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.23). 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 3.23, 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 Tables 3.24 through 3.26.

Table 3.23. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Cripple Creek watershed.

Wildlife Type	Habitat	Population Density (animal/ac-habitat)	Direct Fecal Deposition in Streams (%)
Deer	Primary: Forest and agricultural areas Secondary: rest of watershed	0.031	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	0.003[b]	0.25
Wood Duck	300 feet buffer around main streams	0.004[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 3.24. Distribution of wildlife among sub-watersheds in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
CRC-01	213	307	538	33	28	33	55
Total	**213**	**307**	**538**	**33**	**28**	**33**	**55**

Table 3.25. Distribution of wildlife among sub-watersheds in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
CRC-02	244	379	1,124	41	34	40	49
CRC-03	1	2	13	0	0	0	0
CRC-04	262	392	531	42	31	37	53
CRC-05	271	341	1,099	36	28	34	27
CRC-06	48	58	0	7	5	6	10
CRC-07	71	85	0	9	7	9	17
CRC-08	129	149	147	16	14	16	24
CRC-09	193	236	912	24	21	24	12
CRC-10	213	247	569	26	22	26	24
Total	**1,431**	**1,890**	**4,395**	**201**	**162**	**192**	**216**

Table 3.26. Distribution of wildlife among sub-watersheds in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Subwatershed	Deer (#)	Raccoon (#)	Muskrat (#)	Beaver (#)	Geese (#)	Wood Duck (#)	Wild Turkey (#)
CRC-11	102	129	0	15	10	12	21
CRC-12	29	13	34	1	3	4	3
CRC-13	226	274	581	29	23	28	32
CRC-14	183	186	337	20	19	22	30
CRC-15	167	192	577	20	18	21	15
CRC-16	12	18	68	2	1	2	1
CRC-17	144	174	561	19	15	18	15
CRC-18	43	44	99	5	5	5	4
CRC-19	10	15	45	2	1	1	1
Total	**915**	**1,046**	**2,301**	**111**	**95**	**113**	**122**

3.6 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Cripple Creek watershed along with average fecal coliform production rates are shown in Table 3.27 through 3.29. The total fecal coliform production by all sources in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watersheds is 1.26×10^{16} cfu/yr, 1.36×10^{17} cfu/yr, and 4.04×10^{16} cfu/yr, respectively.

Table 3.27. Potential fecal coliform sources and daily fecal coliform production by source in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) 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			
Milk and Dry Cows	300	25,000	750,514
Heifers	100	8,800	114,364
Beef Cattle (pairs)	528	33,000	2,355,761
Horses	41	420	1,723
Poultry	0	93	0
Humans	395	1,950	31,478
Pets (Dog & Cats)	178	450	8,061
Deer	213	350	7,460
Raccoon	307	50	1,536
Muskrat	538	25	1,346
Beaver	33	0.2	1
Wild Turkey	55	93	512
Geese	28	800	5,929
Wood Duck	33	2,400	1,677

[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.

Table 3.28. Potential fecal coliform sources and daily fecal coliform production by source in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) 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			
Milk and Dry Cows	390	25,000	975,668
Heifers	130	8,800	148,673
Beef Cattle (pairs)	3,883	33,000	17,324,656
Horses	334	420	650,445
Poultry	0	93	0
Humans	2,408	1,950	165,104
Pets (Dog & Cats)	1,163	450	52,371
Deer	1,431	350	148,673
Raccoon	1,890	50	17,324,656
Muskrat	4,395	25	10,995
Beaver	201	0.2	4
Wild Turkey	216	93	2,010
Geese	162	800	34,497
Wood Duck	192	2,400	9,702

[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.

Table 3.29. Potential fecal coliform sources and daily fecal coliform production by source in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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			
Milk and Dry Cows	390	25,000	975,668
Heifers	130	8,800	148,673
Beef Cattle (pairs)	2,007	33,000	8,954,567
Horses	200	420	8,406
Poultry	0	93	0
Humans	1,658	1,950	122,242
Pets (Dog & Cats)	791	450	35,619
Deer	915	350	32,082
Raccoon	1,046	50	5,229
Muskrat	2,301	25	5,759
Beaver	111	0.2	2
Wild Turkey	122	93	1,135
Geese	95	800	20,242
Wood Duck	113	2,400	5,649

[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 Tables 3.30 through 3.32. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Tables 3.30 through 3.32.

From Table 3.30, it is clear in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed that nonpoint source loadings to the land surface are more than 238 times as large as direct loadings to the streams, with pastures receiving about 97.5% of the total fecal coliform load. From Table 3.31, it is clear in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed that nonpoint source loadings to the land surface are more than 324 times as large as direct loadings to the streams, with pastures receiving about 98.1% of the total fecal coliform load. From Table 3.32, it is clear in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed that nonpoint source loadings to the land surface are more than 263 times as large as direct loadings to the streams, with pastures receiving about 97.4% 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 3.30. Annual fecal coliform loadings to the stream and the various land use categories in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	2,589	0.24
Cattle in Stream	1,115	0.10
Wildlife in Stream	902	0.08
Loading to Land Surfaces		
Cropland	6,009	0.55
Pasture 1	817,422	74.23
Pasture 2	208,472	18.93
Pasture 3	48,221	4.38
Forest	4,643	0.42
Residential*	11,842	1.08
Total	**1,101,216**	**100.00**

*Includes loads received from failed septic systems and pets.

Table 3.31. Annual fecal coliform loadings to the stream and the various land use categories in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	8,361	0.12
Cattle in Stream	6,745	0.10
Wildlife in Stream	5,573	0.08
Loading to Land Surfaces		
Cropland	8,880	0.13
Pasture 1	5,021,638	74.73
Pasture 2	1,280,831	19.06
Pasture 3	290,177	4.32
Forest	26,922	0.40
Residential*	71,017	1.06
Total	**6,720,144**	**100.00**

*Includes loads received from failed septic systems and pets.

Table 3.32. Annual fecal coliform loadings to the stream and the various land use categories in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Source	Fecal Coliform Loading ($x10^{10}$ cfu/year)	Percent of Total Loading (%)
Direct Loading to Streams		
Straight Pipes	7,003	0.19
Cattle in Stream	3,637	0.10
Wildlife in Stream	3,201	0.09
Loading to Land Surfaces		
Cropland	14,472	0.40
Pasture 1	2,706,268	74.11
Pasture 2	693,538	18.99
Pasture 3	156,803	4.29
Forest	16,277	0.45
Residential*	50,617	1.39
Total	**3,651,815**	**100.00**

*Includes loads received from failed septic systems and pets.

Chapter 4. Modeling Process for Bacteria 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 for the bacteria TMDL 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 Fork Shenandoah River watershed. The ARCGIS 9.2 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 model for the Cripple Creek watershed is discussed below in Sections 4.2 through 4.6. This information is translated into model parameters. Hydrology parameters required for the PWATER, IWATER, HYDR, and ADCALC sub-modules are listed in BASINS Version 3.0 User's Manual 3.0 (USEPA, 2001). Water quality parameters required as inputs for PQUAL, IQUAL, and GQUAL are given in the BASINS Version 3.0 User's Manual (USEPA, 2001). Values for the hydrology and water quality parameters were estimated based on local conditions when possible; otherwise the default parameters provided within HSPF were used.

4.2 Selection of Sub-watersheds

The stream network was delineated based on the blue line stream network from USGS topographic maps with each subwatershed having at least one stream segment. Subwatershed delineation of the Cripple Creek TMDL impairment watershed 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 Cripple Creek watershed is approximately 88,886 acres and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into 19 subwatersheds as shown in Figure 4.1. Cripple Creek Impairment #1 begins at subwatershed CRC-01, at the headwaters of Cripple Creek, and continues until the confluences with Blue Spring Creek (CRC-02) and Crigger Creek (CRC-04), where Cripple Creek continues through the unimpaired watersheds CRC-03 and CRC-05. Cripple Creek Impairment #2 begins in subwatershed CRC-09 where Dry Run (CRC-06, CRC-07, and CRC-08) joins Cripple Creek and flows downstream through subwatershed CRC-10 to the confluence with Francis Mill Creek (CRC-11 and CRC-12). Cripple Creek continues through unimpaired watersheds CRC-13, CRC-15 and CRC-16 in which it is met by unimpaired segment Slate Spring Branch (CRC-14). Cripple Creek Impairment #3 begins at the confluence with Dean Branch (CRC-17) at subwatershed CRC-18 and flows downstream through subwatershed CRC-19 to confluence with New River.

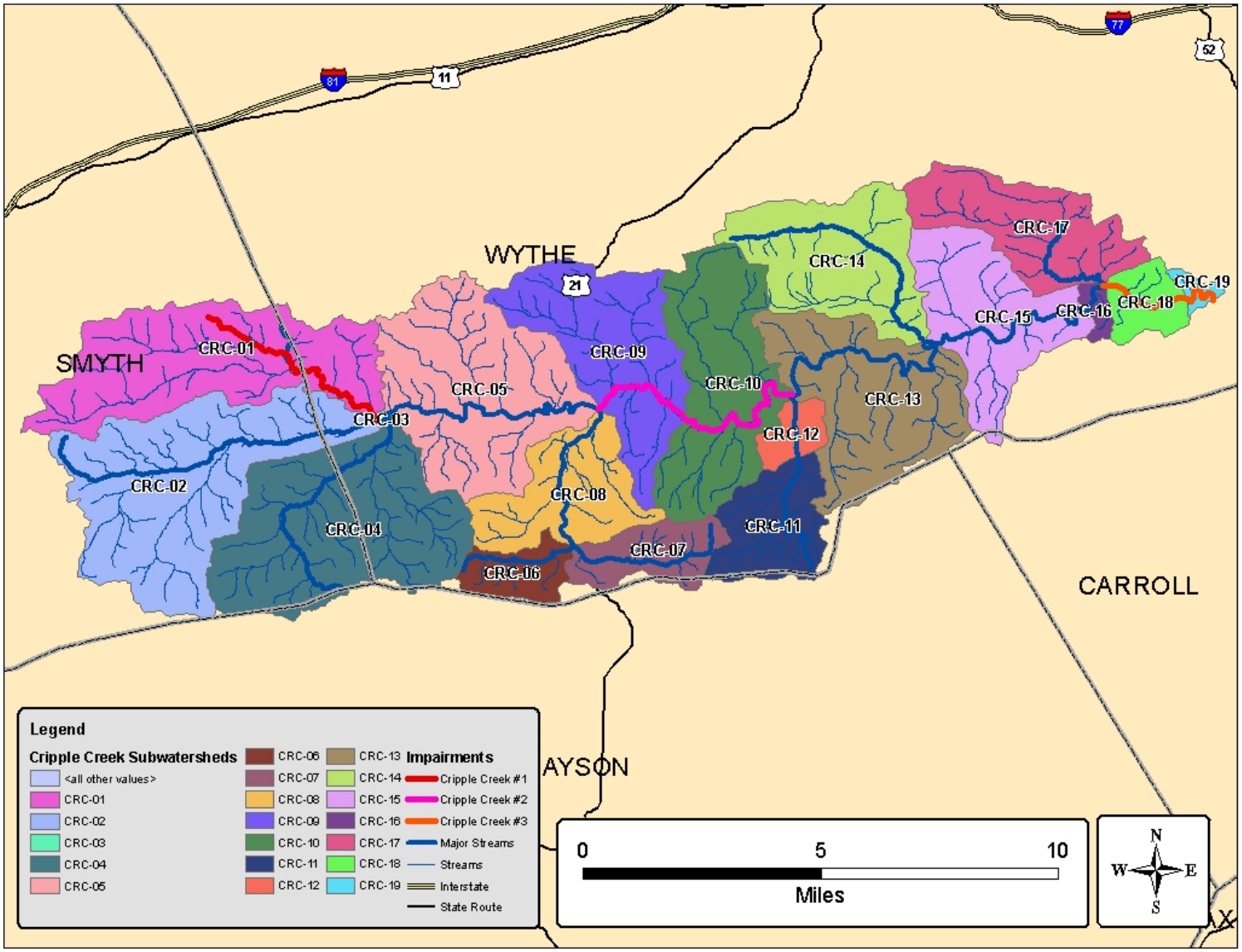

Figure 4.1. Cripple Creek impairment subwatersheds.

4.3 Land Use

The National Land Cover Data (NLCD) produced by U.S. Geological Survey (USGS) in cooperation with the USEPA was used for this study. NLCD was developed from 30-meter Landsat 7 thematic mapper (TM) data between 1990 and 1994 and updated with data between 1999 and 2003 acquired by the Multi-resolution Land Characterization (MRLC) Consortium, a partnership between USGS, USEPA, U.S. Forest Service, National Oceanic and Atmospheric Administration (NOAA), Bureau of Land Management (BLM), NRCS, National Park Service (NPS), National Aeronautics and Space Administration (NASA), and United States Fish and Wildlife Service (USFWS). NLCD is classified into 21 land use types. The NLCD land use types within the watershed were consolidated into eight categories based on similarities in hydrologic and waste application/production features (Table 4.1). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

As discussed in Section 4.2, subwatersheds were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figure 4.1). Land use distribution in the subwatersheds as well as in the entire Cripple Creek watershed is presented in Table 4.2.

Table 4.1. Consolidation of NLCD land use categories for Cripple Creek watershed.

TMDL Land Use Categories	Pervious / Impervious* (%)	NLCD Land Use Classification (Class No.)
Cropland	Pervious (100)	Cultivated Crops (82)
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)	Developed, Open Space (21) Developed, Low Intensity (22) Developed, Medium Intensity (23) Developed, High Intensity (24)
Water	Impervious (100)	Open Water (11)
Wetland	Pervious (100)	Woody Wetlands (91) Emergent Herbaceous Wetlands (92)
Forest	Pervious (100)	Barren Land, Rock, Sand, Clay (31) Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43)

*Percent pervious / impervious information was used in modeling (described in later sections).

Table 4.2. Land use distribution in Cripple Creek watershed.

Subwatershed	Cropland (ac)	Forest (ac)	Residential (ac)	Pasture (ac)	Transitional (ac)	Water (ac)	Wetland (ac)	Total (ac)
CRC-1	149.1	6,010.1	228.6	2,259.7	27.6	0.0	8.4	8,683.5
CRC-2	43.8	6,289.2	231.4	3,885.8	23.2	0.0	2.7	10,476.1
CRC-3	2.3	0.0	4.5	33.2	1.6	0.0	0.0	41.6
CRC-4	30.4	7,666.9	232.1	1,753.9	15.0	0.0	6.0	9,704.3
CRC-5	17.1	3,884.9	324.2	4,587.0	47.3	0.0	0.9	8,861.4
CRC-6	0.0	1,522.1	5.2	0.0	0.0	0.0	0.0	1,527.3
CRC-7	0.0	2,166.3	68.6	1.2	3.3	0.0	0.0	2,239.3
CRC-8	1.2	3,471.6	202.5	552.5	17.5	0.0	2.7	4,248.0
CRC-9	39.4	1,815.6	387.2	4,178.2	25.7	0.0	0.0	6,446.1
CRC-10	34.9	3,491.3	244.8	3,162.9	11.4	0.0	1.0	6,946.3
CRC-11	0.0	3,100.8	35.3	1.2	1.8	0.0	0.0	3,139.1
CRC-12	0.0	381.2	48.4	524.5	4.1	0.0	0.0	958.2
CRC-13	60.8	4,671.2	166.9	2,322.2	37.8	0.0	1.0	7,259.9
CRC-14	38.5	4,347.1	170.5	1,325.4	35.2	1.4	2.5	5,920.6
CRC-15	118.0	2,176.8	233.5	2,946.2	30.5	0.0	1.0	5,506.1
CRC-16	0.5	103.5	16.7	278.9	0.0	0.0	2.0	401.6
CRC-17	61.9	2,240.9	242.0	2,198.3	21.6	0.0	0.0	4,764.6
CRC-18	11.6	587.6	83.5	745.6	4.8	0.0	0.5	1,433.6
CRC-19	5.3	73.3	16.6	231.9	0.0	0.0	1.1	328.3
Total (ac)	**614.8**	**54,000.6**	**2,942.4**	**30,988.4**	**308.4**	**1.4**	**29.8**	**88,885.9**
Total (%)	**0.69**	**60.75**	**3.31**	**34.86**	**0.35**	**0.00**	**0.03**	**100.00**

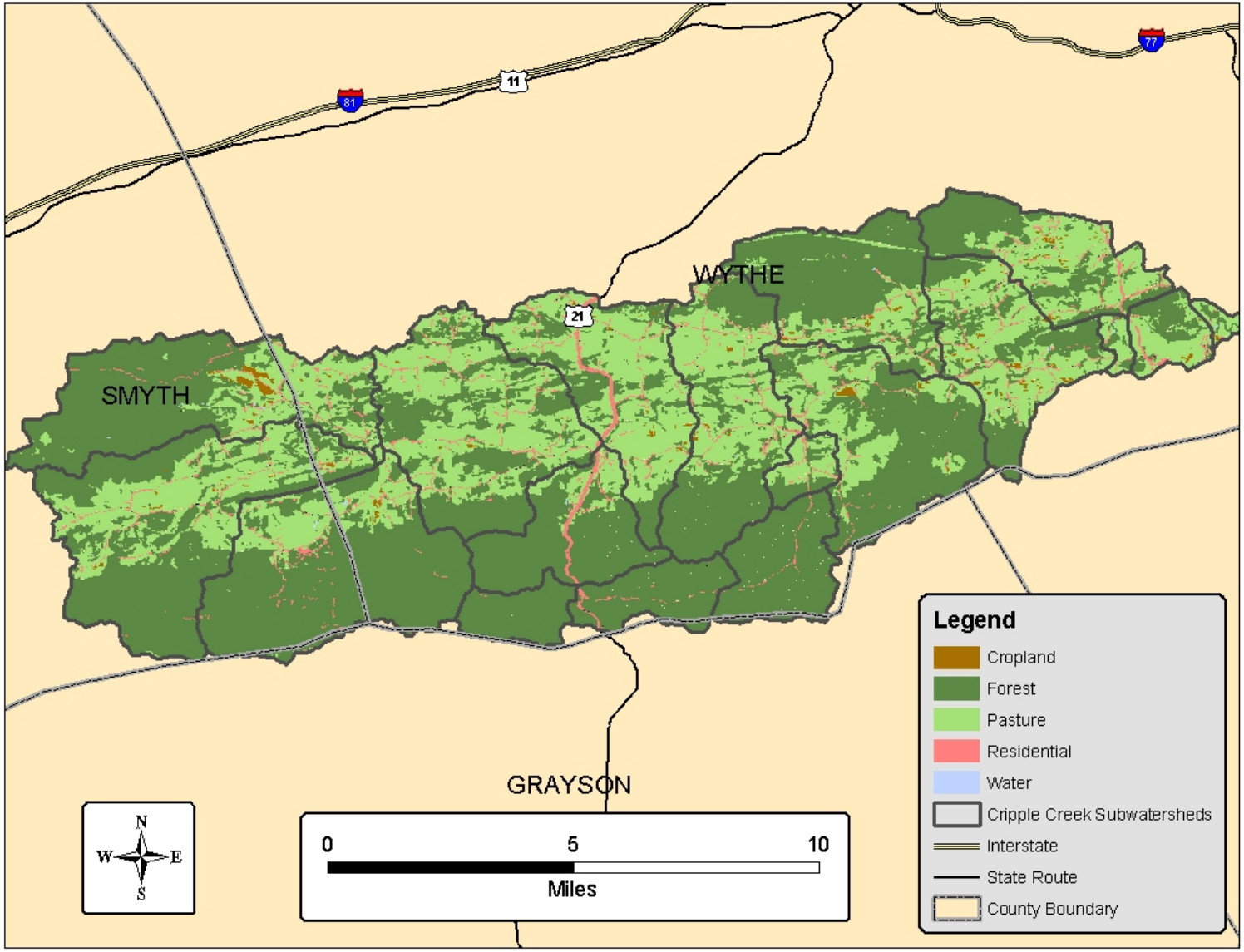

Figure 4.2. Cripple Creek watershed land use distribution.

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.

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, 2008), part of the National Weather Service (NWS). Simulations performed for Cripple Creek watershed used hourly weather data from the Troutdale 3 SSE (448547) and Abingdon 3 S (440021) weather stations. Daily precipitation data from stations Troutdale s SSE (448547), Abingdon 3 S (440021), and Saltville 1 N (447506) were 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 is one permitted point discharge of bacteria located in the Cripple Creek watershed. This source was modeled using the permitted concentration and design discharge. Currently, MS4 permitted facilities do not exist in the Cripple Creek watershed.

Fecal coliform loads that are directly deposited into the stream by straight pipes, or by cattle and wildlife in the stream, were treated as direct nonpoint sources in the model. Fecal coliform that is land-applied or deposited on land was treated as nonpoint source loading; all or part of that load may get transported to the stream as a result of surface runoff during rainfall events. Direct 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 land-based 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 Cripple Creek watershed (Table 4.3).

Table 4.3. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources in the Cripple Creek watershed.

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 4.0 cfu/100mL. Based on Local Steering Committee (LSC) 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 to VADEQ. 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. Some BMPs were accounted for during calibration, such as grassed buffer strips between pasture or cropland and stream edges.

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

The Cripple Creek model was calibrated using observed flow values from USGS station #03166000 on Cripple Creek near Ivanhoe, VA for the period January 1, 2000 to December 31, 2004. The model was validated for the period January 1, 1995 to December 31, 1999. The daily average flow data were used in the hydrologic calibration and validation. Output from the HSPF model for both calibration and validation was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable.

The HSPEXP decision support system developed by USGS and tools developed by Engineering Concepts, Inc. were used to calibrate and validate the hydrologic portion of HSPF. Calibration and validation criteria as well as model performance are presented in Tables 4.4 and 4.5. All criteria were within the recommended ranges. As shown in Figures 4.3 and 4.4, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 4.5 and 4.6 for a representative storm. The agreement of the simulated and observed time series can be further seen through the comparison of their cumulative frequency curves (Figures 4.7 and 4.8).

Table 4.4. Summary statistics for the calibration period (1/1/00 to 12/31/04) at USGS station #03166000 in Cripple Creek watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	76.67	76.87	0.26
Total of Highest 10% Flow Volume (in)	15	25.28	27.37	8.29
Total of Lowest 50% Flow Volume (in)	10	17.01	15.88	-6.66
Total Winter Flow Volume (in)	30	21.94	21.69	-1.14
Total Summer Flow Volume (in)	30	16.11	15.87	-1.45
Total Storm Volume (in)	30	56.64	60.78	7.30
Groundwater Recession Coefficient	1	0.97	0.98	1.00
Coefficient of Determination, r^2	0.81			

Table 4.5. Summary statistics for the validation period (1/1/95 to 12/31/99) at USGS station #03166000 in Cripple Creek watershed.

	Criterion (%)	Observed	Modeled	Error (%)
Total Flow Volume(in)	10	69.54	68.98	-0.79
Total of Highest 10% Flow Volume (in)	15	23.10	23.09	-0.05
Total of Lowest 50% Flow Volume (in)	10	14.80	13.35	-9.81
Total Winter Flow Volume (in)	30	29.49	30.63	3.87
Total Summer Flow Volume (in)	30	8.34	7.15	-14.24
Total Storm Volume (in)	30	50.01	54.37	8.72
Groundwater Recession Coefficient	1	0.97	0.98	1.00
Coefficient of Determination, r^2	0.84			

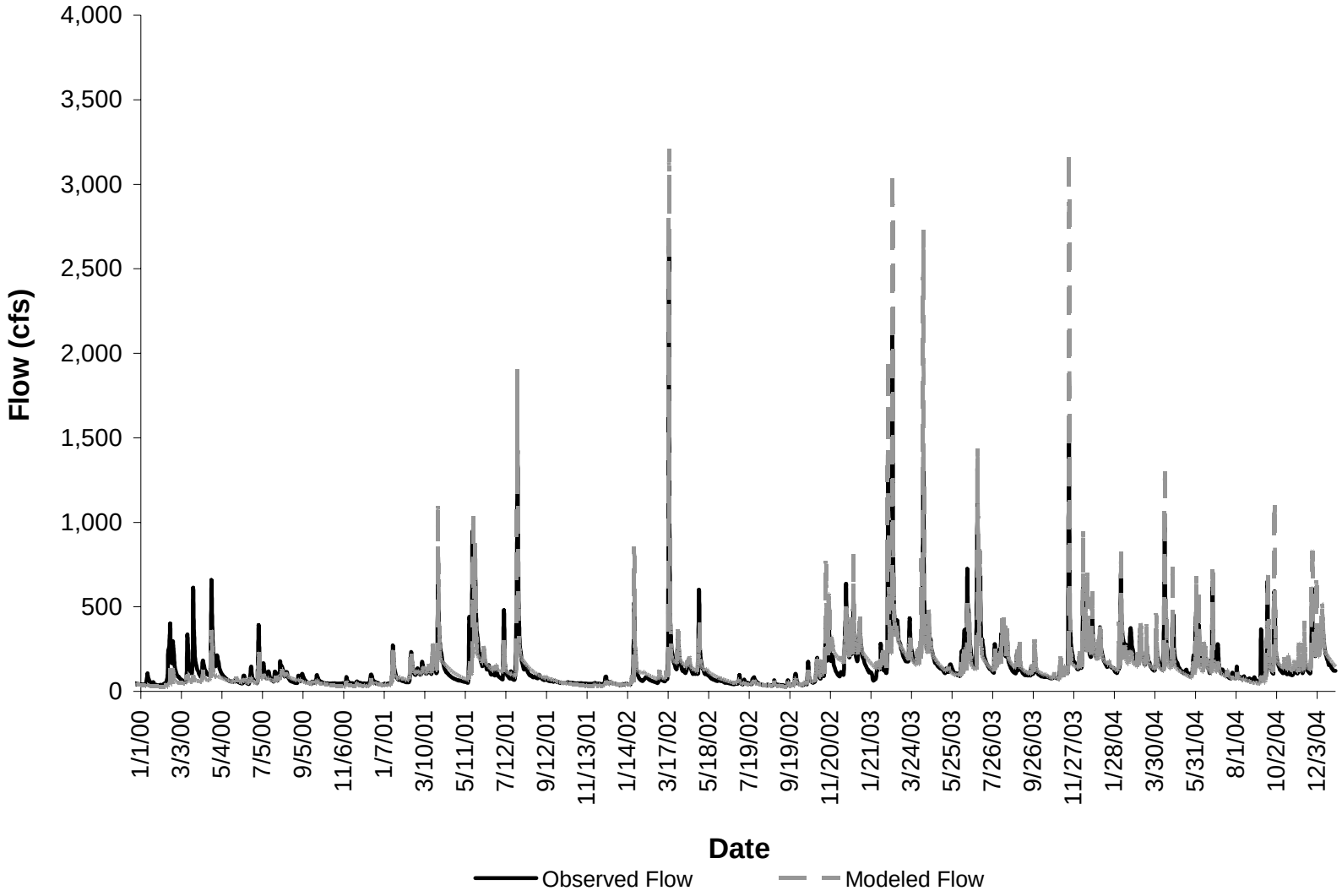

Figure 4.3. Observed and modeled flows for the calibration period 1/1/00 to 12/31/04 at USGS station #03166000 in Cripple Creek watershed.

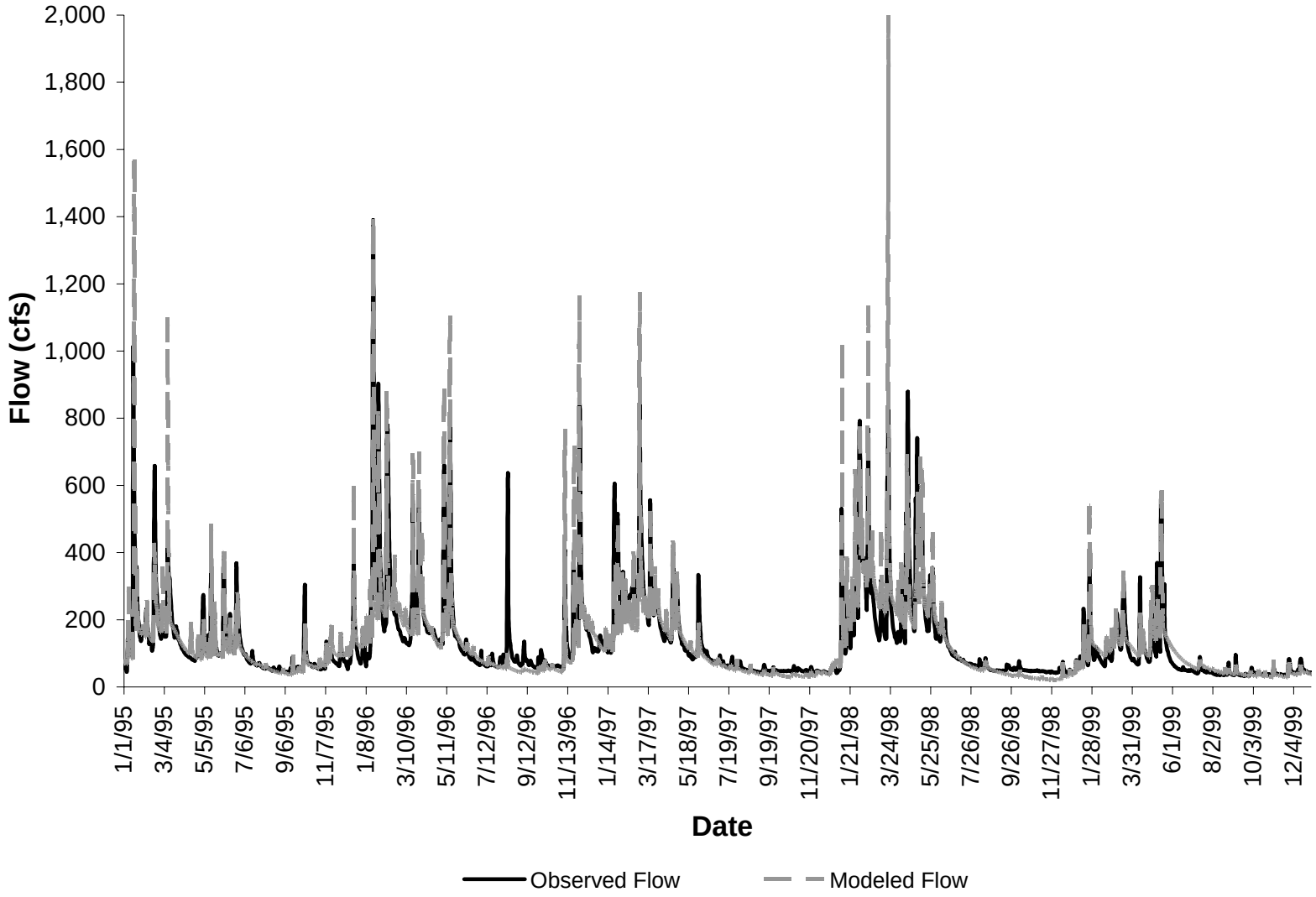

Figure 4.4. Observed and modeled flows for the validation period 1/1/95 to 12/31/99 at USGS station #03166000 in Cripple Creek watershed.

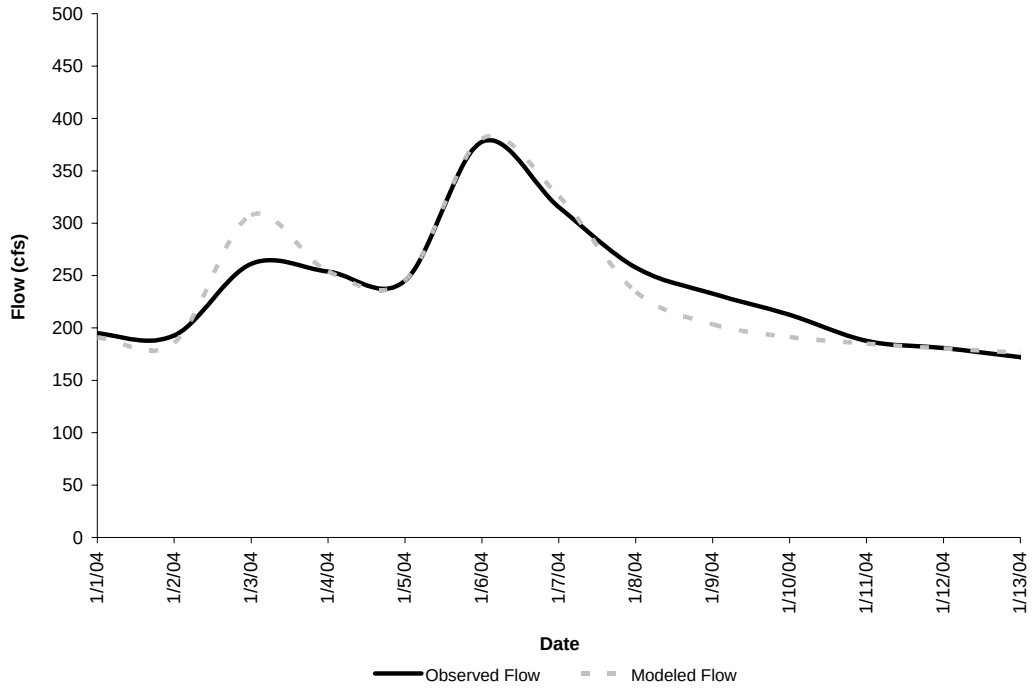

Figure 4.5. Observed and modeled flows for representative storm (1/1/04-1/131/04) during the calibration period at USGS station #03166000 in Cripple Creek watershed.

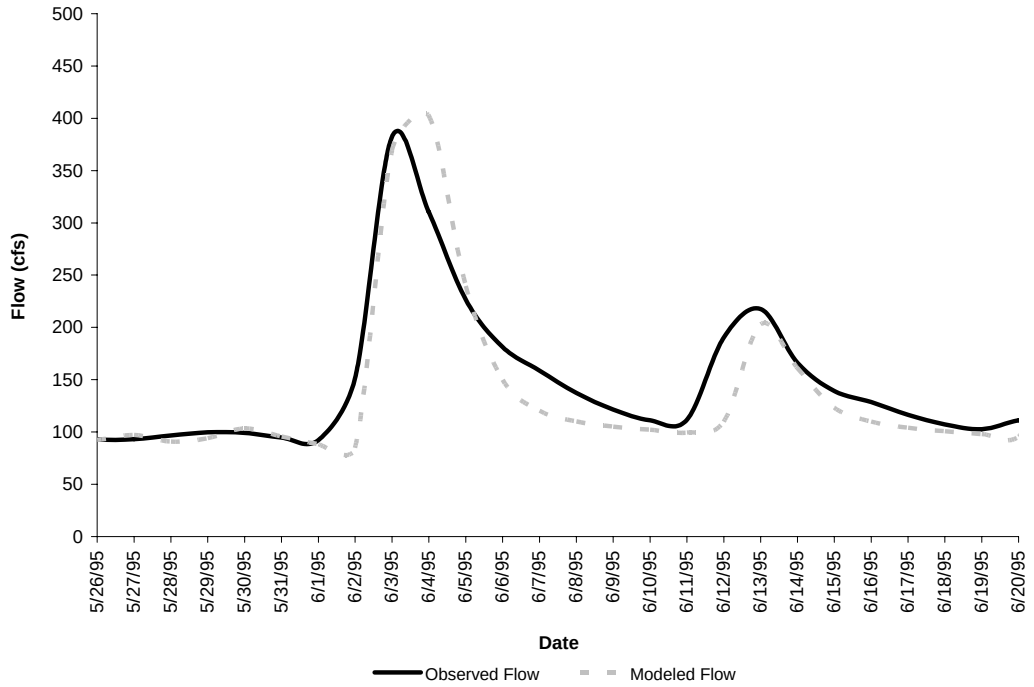

Figure 4.6. Observed and modeled flows for a representative storm (5/26/95-6/20/95) during the validation period at USGS station #03166000 in Cripple Creek watershed.

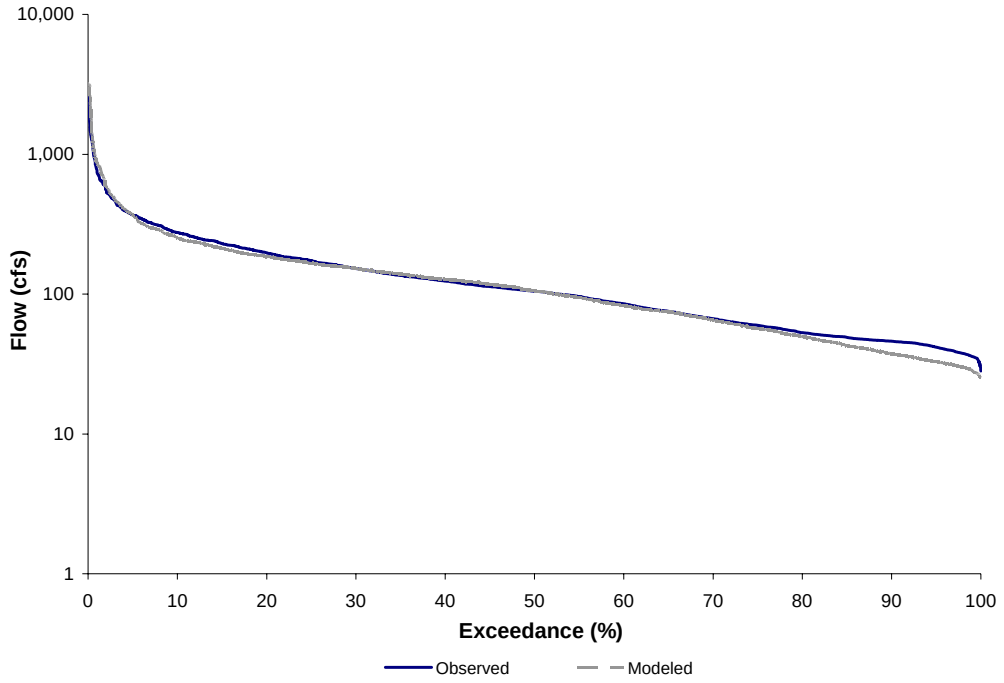

Figure 4.7. Cumulative frequency curves for the calibration period 1/1/00 to 12/31/04 at USGS station #03166000 in Cripple Creek watershed.

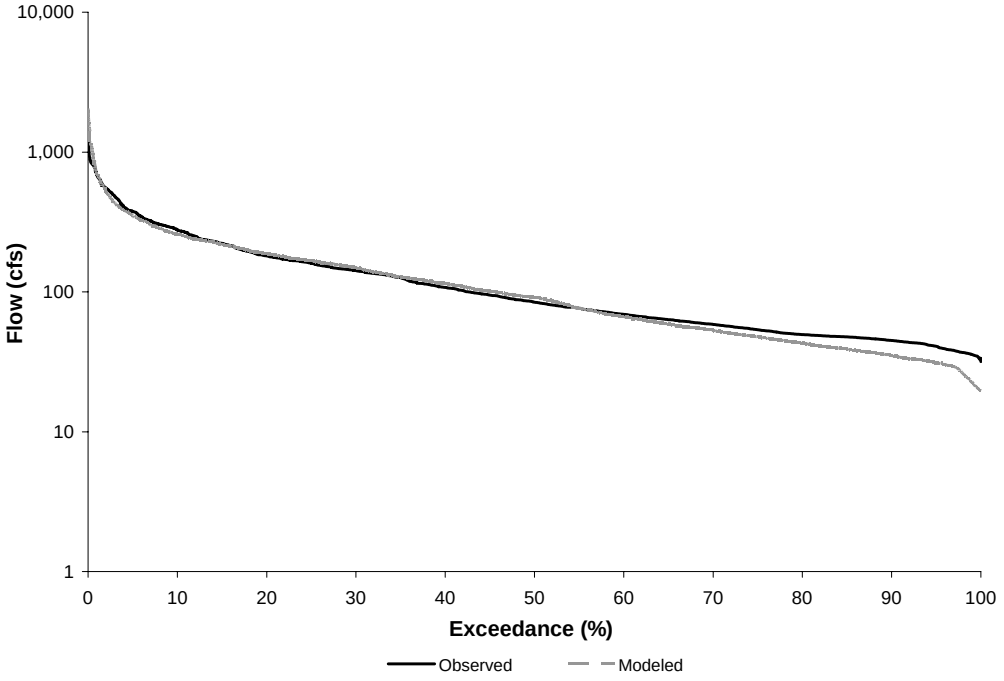

Figure 4.8. Cumulative frequency curves for the validation period 1/1/95 to 12/31/99 at USGS station #03166000 in Cripple Creek watershed.

Flow partitioning for Cripple Creek hydrologic model calibration and validation is shown in Table 4.6.

Table 4.6. Flow partitioning for the calibration and validation periods in Cripple Creek watershed.

Average Annual Flow	Calibration	Validation
Total Runoff (in)	27.0	24.2
Surface Runoff (in)	3.9 (14.3%)	2.5 (10.4%)
Interflow (in)	4.0 (14.7%)	3.1 (12.8%)
Baseflow (in)	19.2(71.0%)	18.6 (76.8%)

A list of final calibration parameters for the hydrology calibration can be found in Tables 4.7 and 4.8.

Table 4.7. Calibrated hydrology HSPF parameters (PERLND) for Cripple 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	6.5	Soil properties
INFILT	Index to infiltration capacity	in/hr	0.01	0.25	0.001	0.5	0.10	0.046-0.097	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	0.005-0.167	0.011-0.109	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	0.975	0.991	Calibrate
PWAT-PARM3									
PETMAX	Temp below which evapotranspiration (ET) is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
INFEXP	Exponent in infiltration equation	none	2	2	1	3	2	2	Soil properties
INFILD	Ratio of max/mean infiltration capacities	none	2	2	1	3	2	2	Soil properties
DEEPFR	Fraction of groundwater inflow to deep recharge	none	0.0	0.2	0.0	0.5	0.0	0.0	Geology
BASETP	Fraction of remain ET from active baseflow	none	0.0	0.05	0.0	0.2	0.1	0.0	Riparian vegetation
AGWETP	Fraction of remain ET from active groundwater	none	0.0	0.05	0.0	0.2	0.0	0.0 – 0.7	Marsh/wetlands ET
PWAT-PARM4									
CEPSC	Interception storage capacity	in	0.03	0.2	0.01	0.4	0.1-0.3	0.01 – 0.224	Vegetation
UZSN	Upper zone nominal soil moisture storage	in	0.10	1	0.05	2	1.50	1.5 – 2.0	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	2.0	0.85	Soils, topography, land use
IRC	Interflow recession parameter	none	0.5	0.7	0.3	0.85	0.8	0.3 – 0.519	Soils, topography, land use
LZETP	Lower zone ET parameter	none	0.2	0.7	0.1	0.9	0.3-0.9	0.3 - 0.896	Vegetation

* USEPA, 2000.

Table 4.8. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for Cripple 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	0.20	0.011-0.109	Topography
NSUR	Manning's n (roughness)	none	0.15	0.35	0.1	0.5	0.1	0.1	Land use, surface condition
RETSC	Retention/interception storage capacity	in	0.03	0.2	0.01	0.4	0.065	0.065	Land use, surface condition
IWAT-PARM3									
PETMAX	Temp below which ET is reduced	deg. F	35	45	32	48	40	40	Climate, vegetation
PETMIN	Temp below which ET is set to zero	deg. F	30	35	30	40	35	35	Climate, vegetation
RCHRES									
HYDR-PARM2									
KS	Weighting factor for hydraulic routing	none	0.3	0.7	0.0	0.9	0.5	0.5	Stream channel, topography

* USEPA, 2000.

4.7.2 Water Quality

The simulation of water quality concentrations (e.g., bacteria concentrations) is built on the hydrology simulation. The simulation runs at an hourly time step with average daily fecal coliform bacteria concentrations output at the stream reaches. Based on critical period analysis and availability of data, modeling periods were chosen for water quality calibration and validation for the impairment.

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). The listed model parameters were adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established.

A number of factors, not inclusive to description below, complicate the water quality calibration. The difficulty in measuring bacteria concentrations is attributed to variability in bacteria density in feces, variability in location and timing of fecal deposition, variability in bacteria amount delivered to the stream, and environmental impacts on re-growth and die-off.

The bacteria concentrations are highly dependent on flow conditions and variability associated with modeling stream flows compounds the variability in modeling the bacteria concentrations. The usually limited number of grab samples collected at each VADEQ station and the practice of censoring both high (over 8,000 cfu/100 ml or 16,000 cfu/100 ml) and low (under 100 cfu/100 ml or 18 cfu/100 ml) concentrations hinder the water quality calibration process.

The period January 1, 2000 through December 31, 2004 was chosen for water quality calibration and January 1, 1995 through December 31, 1999 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 9-CPL028.10, 9-CPL026.75, 9-CPL018.47, 9-CPL008.68, 9-CPL003.10, and 9-CPL001.03 within the Cripple Creek impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 4.9. Observations from VADEQ stations 9-CPL028.10, 9-CPL026.75, 9-CPL018.47, 9-CPL008.68, 9-CPL003.10, and 9-CPL001.03; were graphically compared to corresponding modeled concentrations at subwatersheds CPC-01, CRC-03, CRC-09, CRC-13, CRC-16, and CRC-18; respectively (Figures 4.9 through 4.15). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day. Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period.

To provide a quantitative measure of the agreement between observed and modeled data, the fecal coliform geometric mean concentrations and 400 cfu/100mL fecal coliform instantaneous water quality standard exceedance rates were calculated. Tables 4.10 and 4.11 illustrate the comparison of observed and modeled geometric mean concentration and exceedance rates for the calibration and validation periods, respectively. The highest difference (i.e., -5.7%) between observed and modeled geometric mean concentrations was recorded during the calibration period at subwatersheds CRC-03 and CRC-18. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 4.10 and 4.11. A difference of one exceedance during the calibration period in subwatersheds CRC-01, CRC-03, CRC-09. CRC-13, CRC-16, and CRC-18 results in an exceedance rate difference of 8%, 8%, 8%, 8%, 14%, and 8%, respectively. A variation of one exceedance during the validation period in subwatersheds CRC-16 results in an exceedance rate difference of 5%. The highest difference in the water quality standard exceedance rates (i.e., 16%) was recorded during the calibration period in subwatershed 18. Twelve observations were available for comparison during this period resulting in an 8% weighting when comparing the water quality standard exceedance rate. This translates into two model observations that were above 400 cfu/100ml; however, two measured observations were at 400 cfu/100ml and would not be classified as over the standard. The modeled versus

observed geometric mean concentrations and exceedance rates comparison yielded acceptable results for the calibration and validation periods.

Based on the qualitative and quantitative analyses performed during hydrology and water quality calibration and validation, it was established that the developed model adequately represented the processes and interactions associated with the production and transport of bacteria within the Cripple Creek watershed.

Table 4.9. Calibrated water quality HSPF parameters for Cripple Creek 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	24E04-07E08	24E04-07E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	02E06-62E08	02E06-62E09	Land use
WSQOP	Wash-off rate	in/hr	0.05	3.00	0.01	5.0	1.0	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	03E06-03E08	03E06-03E08	Land use
SQOLIM	Maximum accumulations of constituent	#/ac	0.01	1E30	0.01	1E40	25E06-29E08	25E06-29E08	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	2.5	3.0-6.0	Stream channel, environment
THFST	Temperature correction coefficient for FSTDEC	none	1	2	1	2	1.07	1.07	Water temperature

* USEPA, 2000.

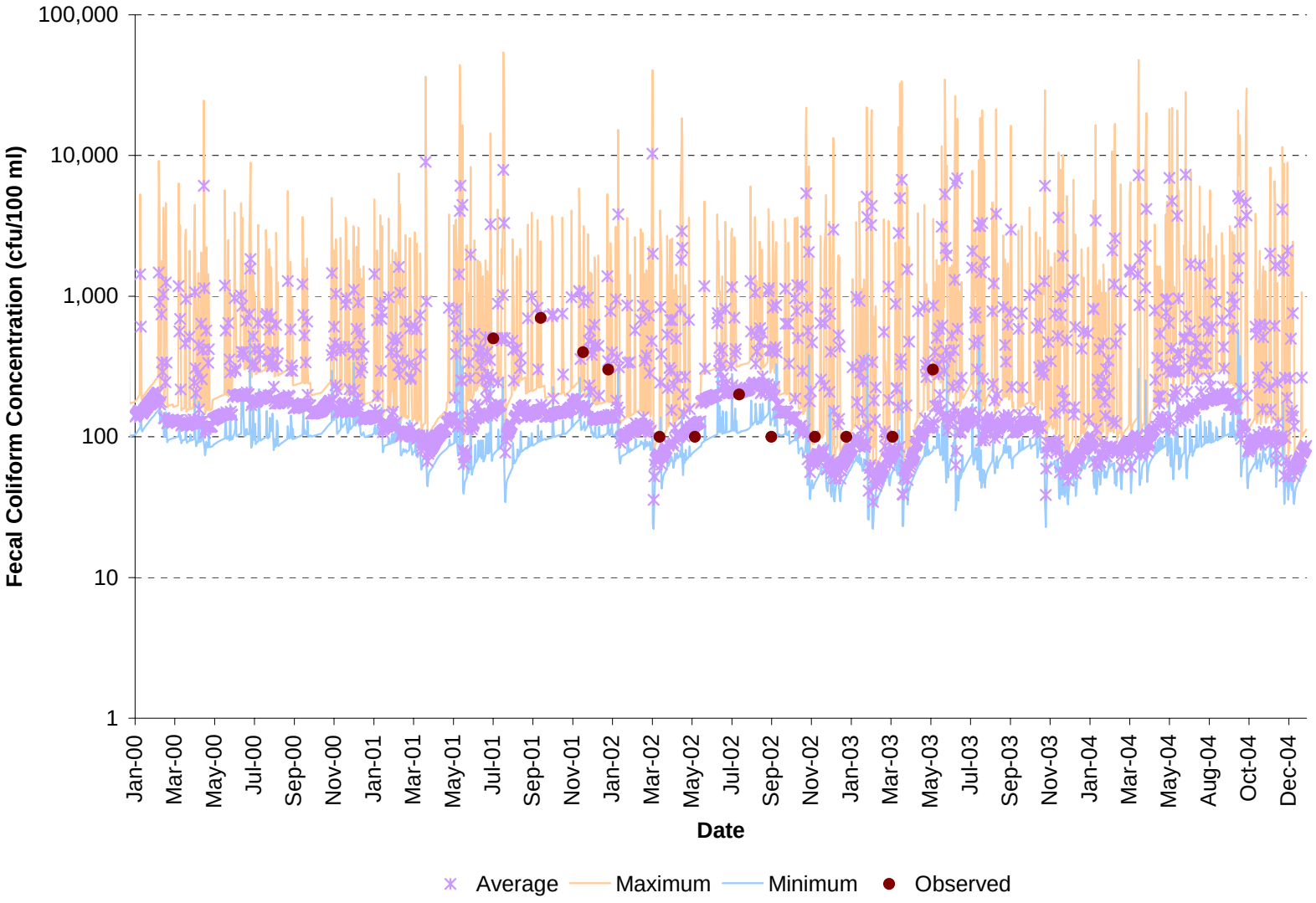

Figure 4.9. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-01 in Cripple Creek watershed.

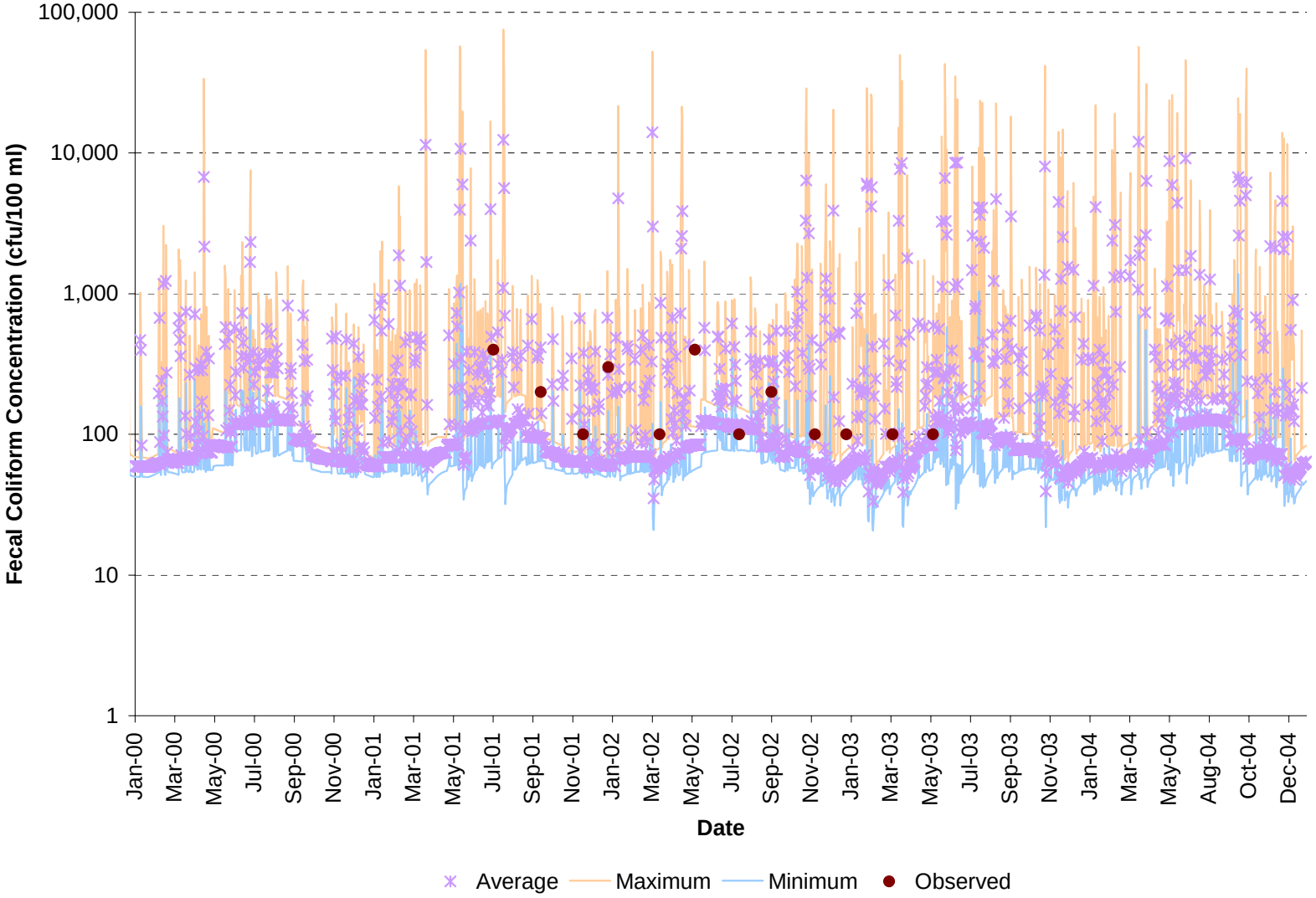

Figure 4.10. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-03 in Cripple Creek watershed.

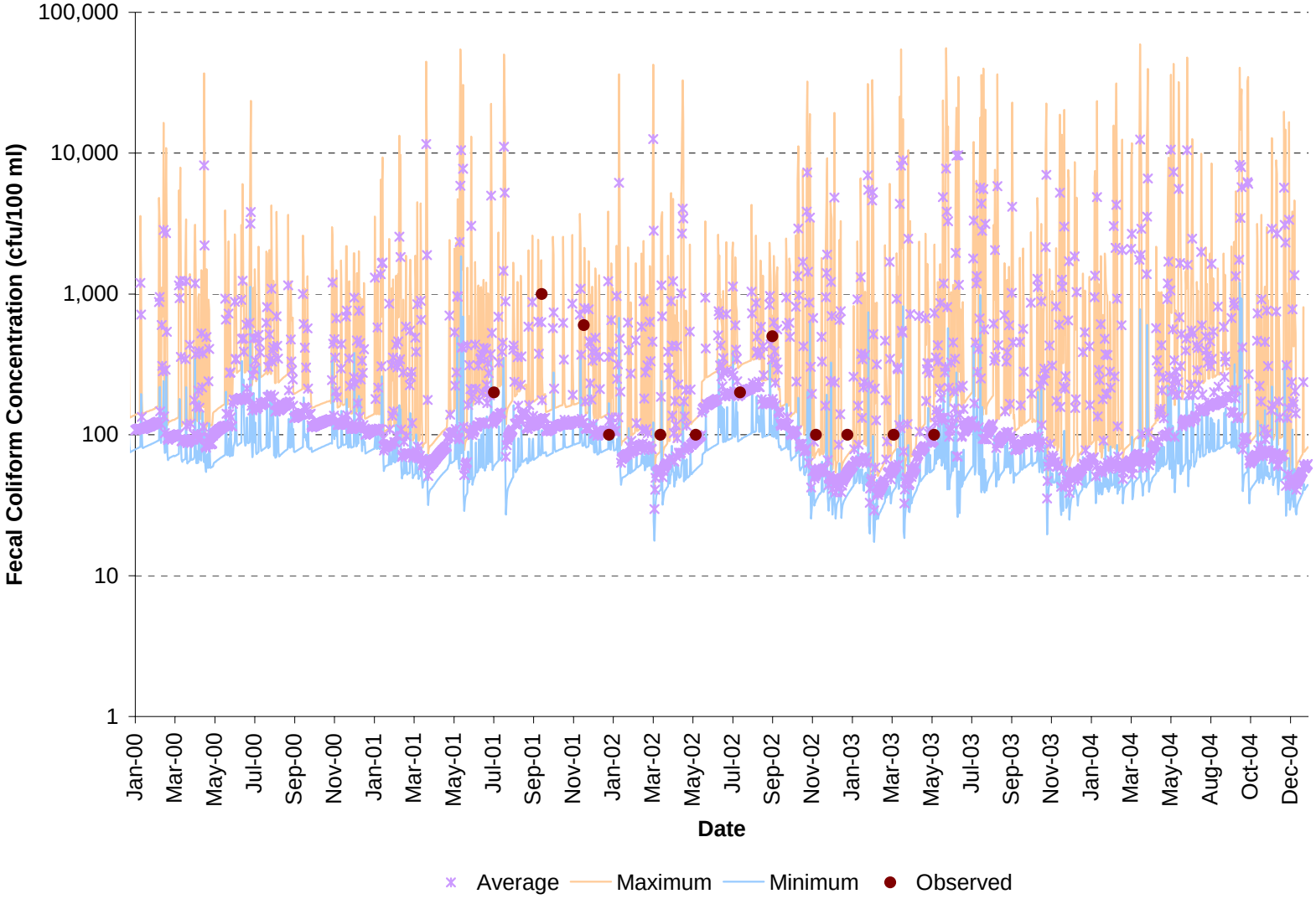

Figure 4.11. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-09 in Cripple Creek watershed.

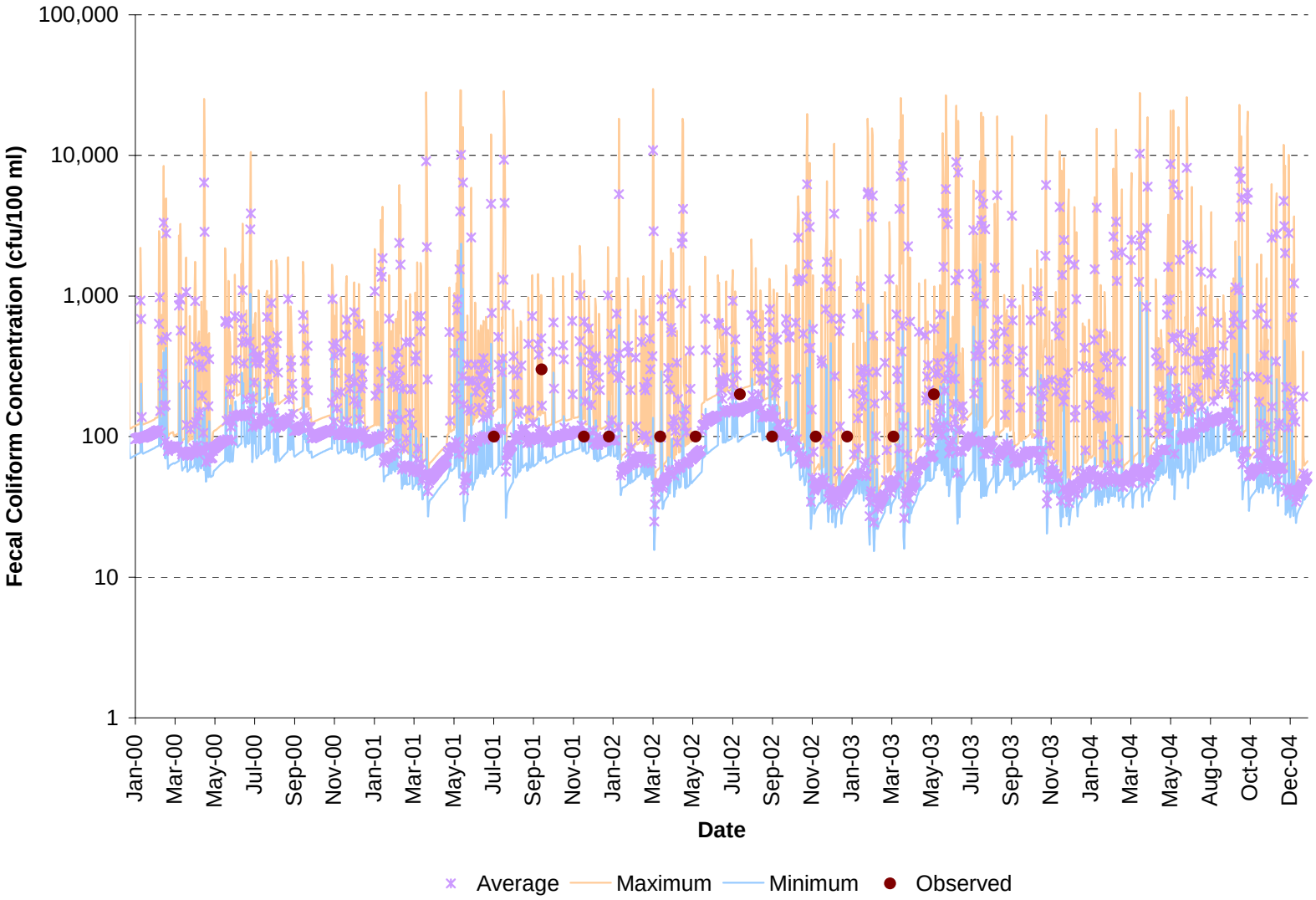

Figure 4.12. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-13 in Cripple Creek watershed.

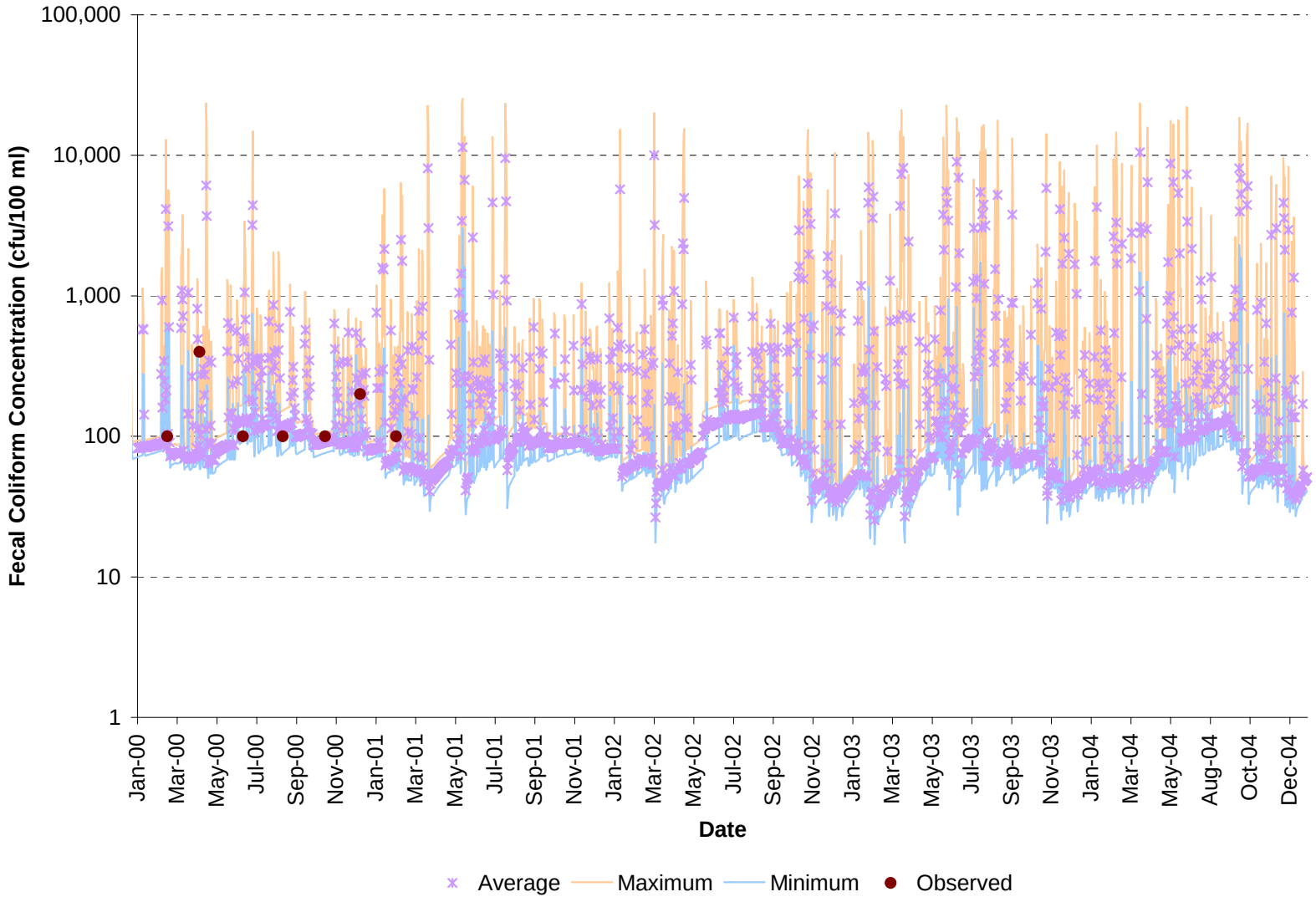

Figure 4.13. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-16 in Cripple Creek watershed.

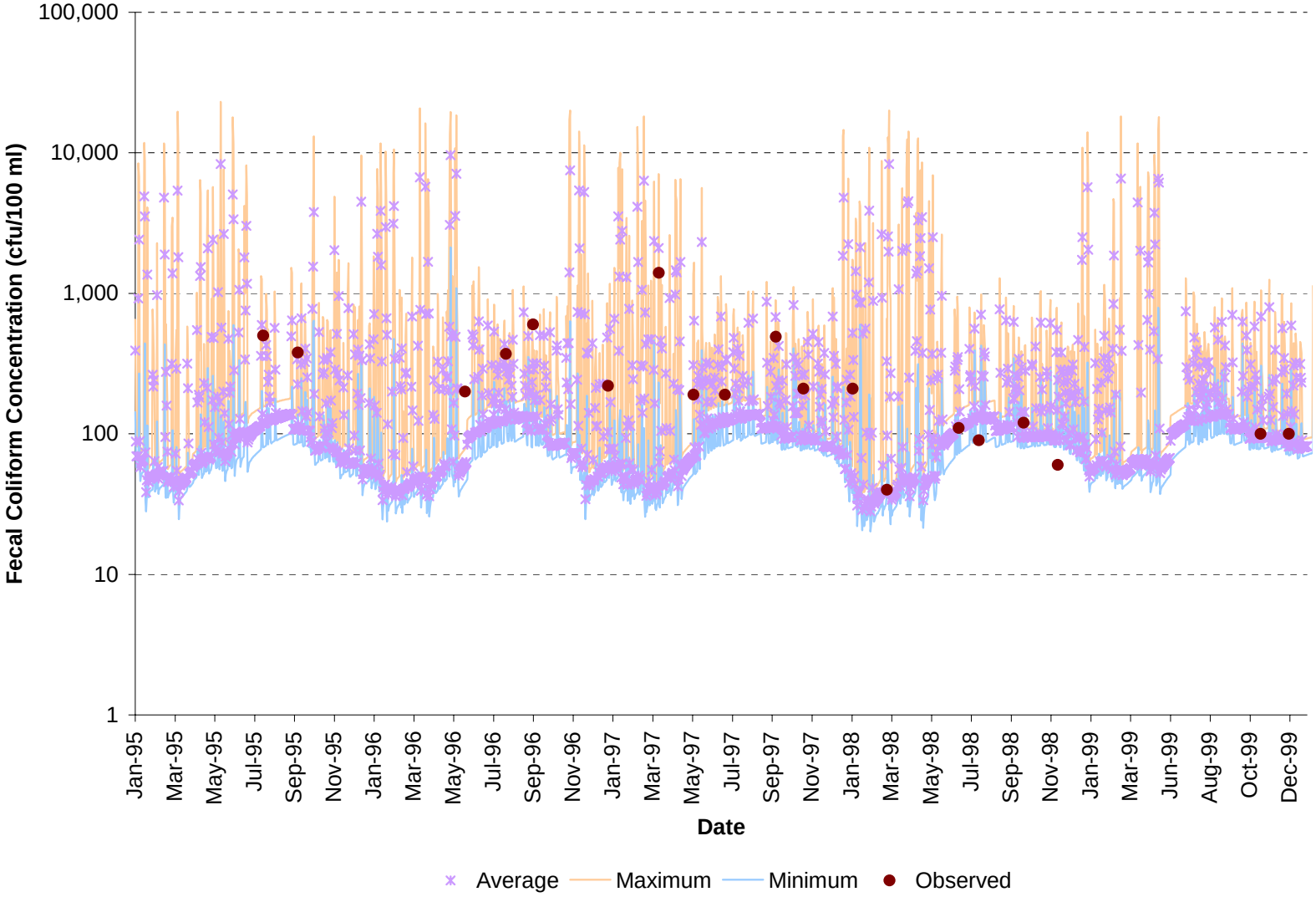

Figure 4.14. Water quality validation results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-16 in Cripple Creek watershed.

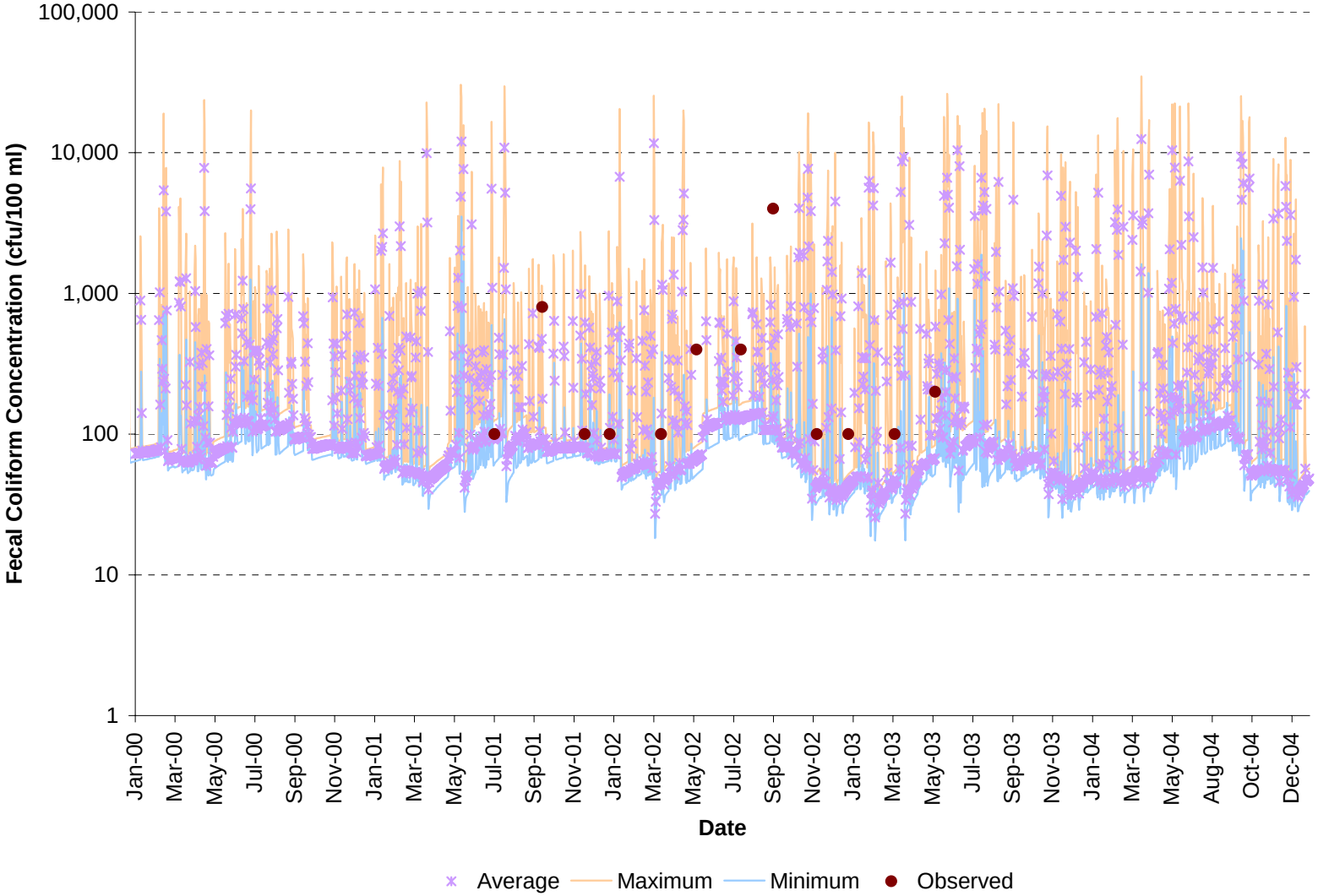

Figure 4.15. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed CRC-18 in Cripple Creek watershed.

Table 4.10. Observed and modeled geometric mean concentrations and instantaneous water quality standard exceedance rates for the calibration period in Cripple Creek watershed.

Parameter	Sub CRC-01	Sub CRC-03	Sub CRC-09	Sub CRC-13	Sub CRC-16	Sub CRC-18
Geometric Mean of Observed Values, (cfu/100mL)	192	155	181	123	135	216
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	194	147	183	119	134	214
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	16.7	0.0	25.0	0.0	0.0	16.7
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	25.0	0.0	25.0	0.0	0.0	33.3

Table 4.11. Observed and modeled geometric mean concentrations and instantaneous water quality standard exceedance rates for the validation period in Cripple Creek watershed.

Parameter	Sub CRC-01	Sub CRC-03	Sub CRC-09	Sub CRC-13	Sub CRC-16	Sub CRC-18
Geometric Mean of Observed Values, (cfu/100mL)	N/D	N/D	N/D	N/D	191	N/D
Geometric Mean of Corresponding Modeled Values (cfu/100mL)	N/D	N/D	N/D	N/D	206	N/D
Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	N/D	N/D	N/D	N/D	21.1	N/D
Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%)	N/D	N/D	N/D	N/D	21.1	N/D

N/D – no data available

Chapter 5. TMDL 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04). 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 exceedances will occur if the TMDL plan is followed.

Bacteria loadings were updated to reflect 2008 conditions for the existing conditions and allocation runs. The simulation period selected for the load allocation study was January 2000 to December 2004. 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 2008 conditions were inserted into the model and simulated for the period January 2000 to December 2004. Model output was translated to average daily *E. coli* concentrations and the monthly geometric mean was calculated. Average daily *E. coli* concentrations at the impairment outlets were compared to the single sample maximum standard of 235 cfu/100 mL. Subwatershed outlets were used for comparison of modeled concentrations to water quality standards for the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairments. Appendix C contains tables with monthly land-based and direct bacteria loadings for existing conditions.

5.2.1 Cripple Creek (VAS-N09R-01-BAC_CPL01A04)

Figure 5.1 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.2). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment was subwatershed CRC-01.

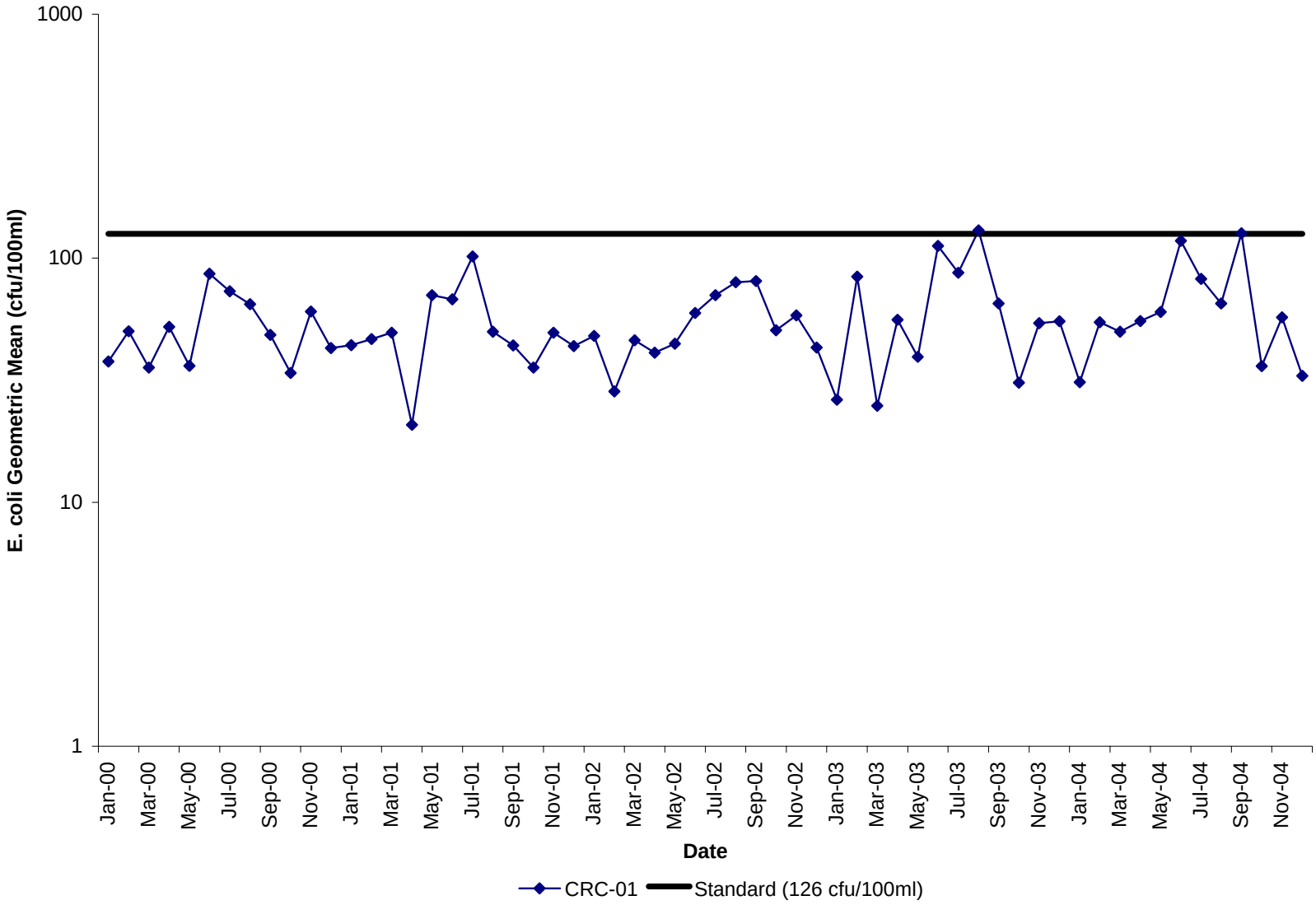

Figure 5.1. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatershed CRC-01 in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

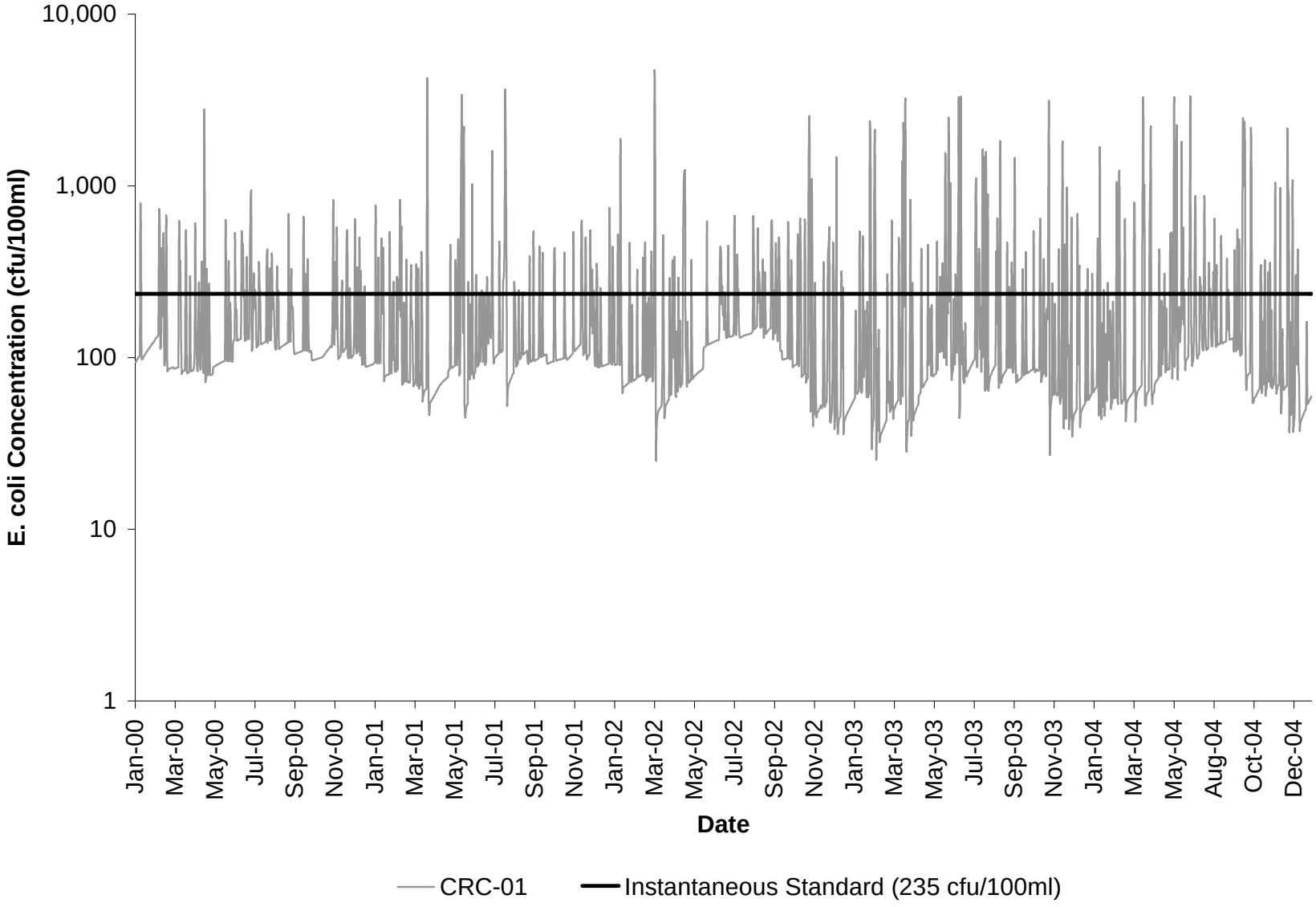
10,000
1,000
100
10
1
E. coli Concentration (cfu/100ml)
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Aug-04
Oct-04
Dec-04
Date
CRC-01
Instantaneous Standard (235 cfu/100ml)

Figure 5.2. Daily average *E. coli* concentrations for subwatershed CRC-01 in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

5.2.2 Cripple Creek (VAS-N09R-01-BAC_CPL02A98)

Figure 5.3 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.4). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment was subwatershed CRC-10.

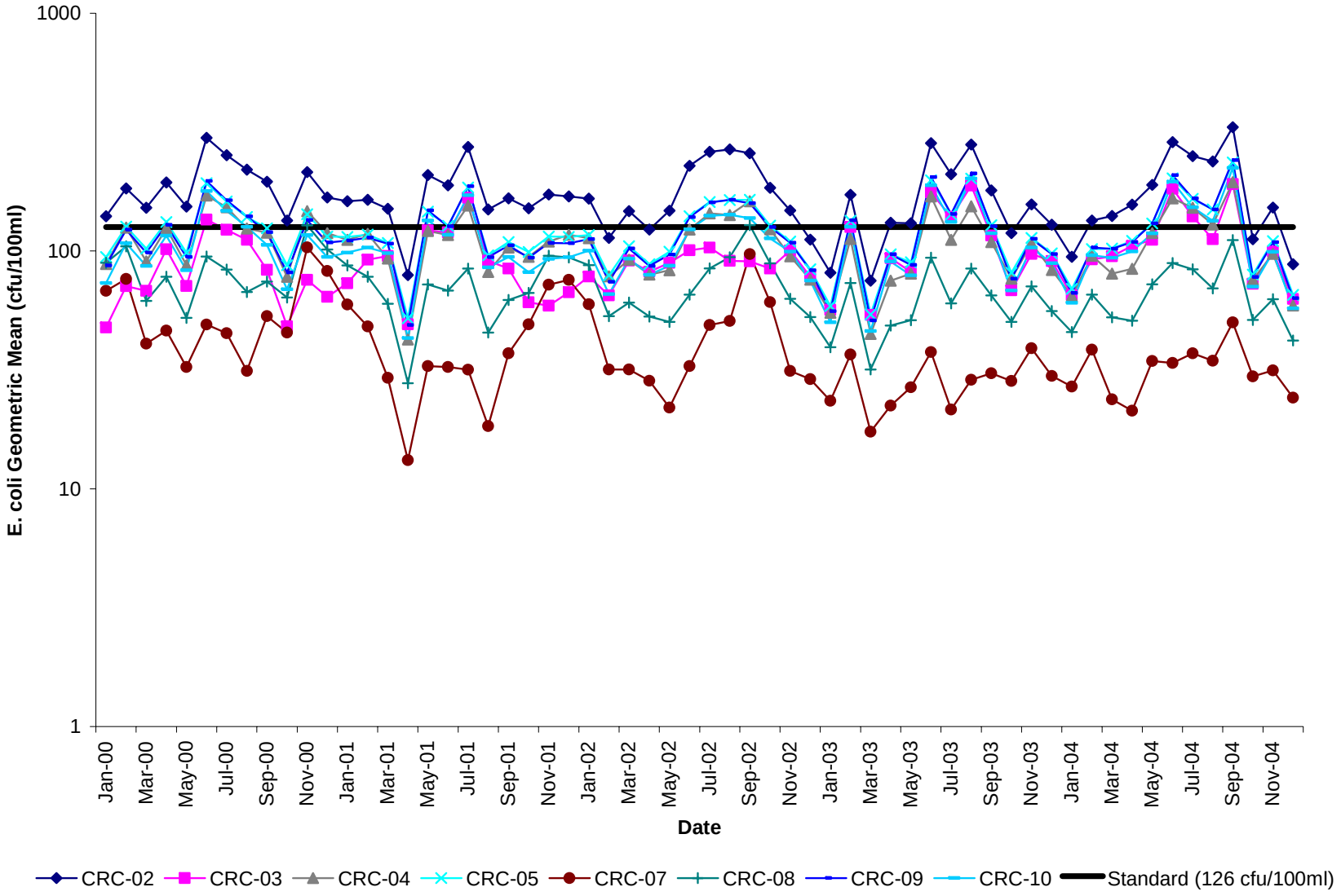

Figure 5.3. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds CRC-02 through CRC-10 in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

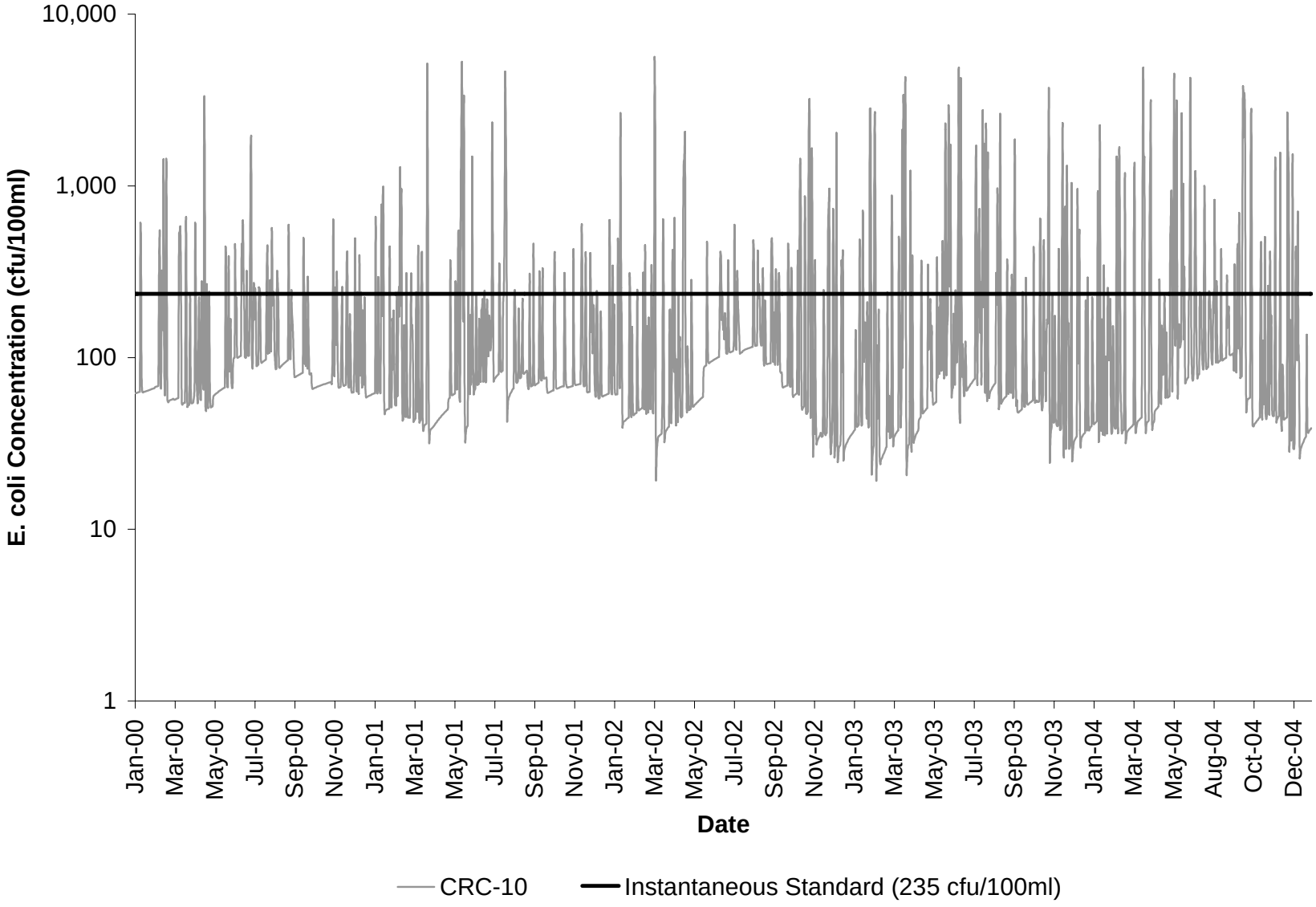
10,000
1,000
100
10
1
E. coli Concentration (cfu/100ml)
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Aug-04
Oct-04
Dec-04
Date
CRC-10
Instantaneous Standard (235 cfu/100ml)

Figure 5.4. Daily average *E. coli* concentrations for subwatershed CRC-10 in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

5.2.3 Cripple Creek (VAS-N09R-01-BAC_CPL01B04)

Figure 5.5 shows the monthly geometric mean for each subwatershed in relation to the monthly geometric mean (126 cfu/100mL) standard. Average daily *E. coli* concentrations at the impairment outlet were compared to the single sample maximum standard of 235 cfu/100 mL (Figure 5.6). The subwatershed outlet used for comparison of modeled concentrations to water quality standards for the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment was subwatershed CRC-19.

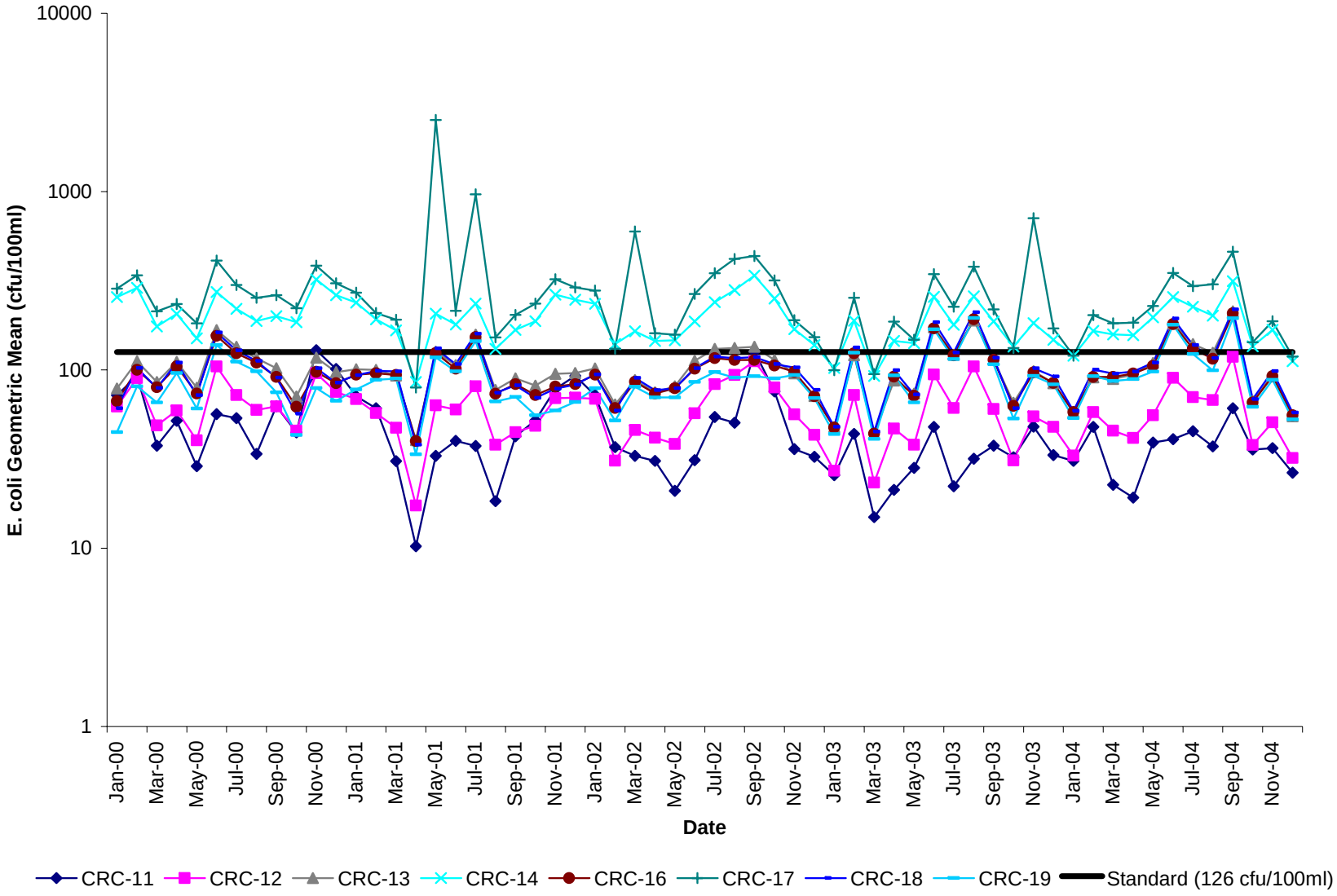

Figure 5.5. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds CRC-11 through CRC-19, in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

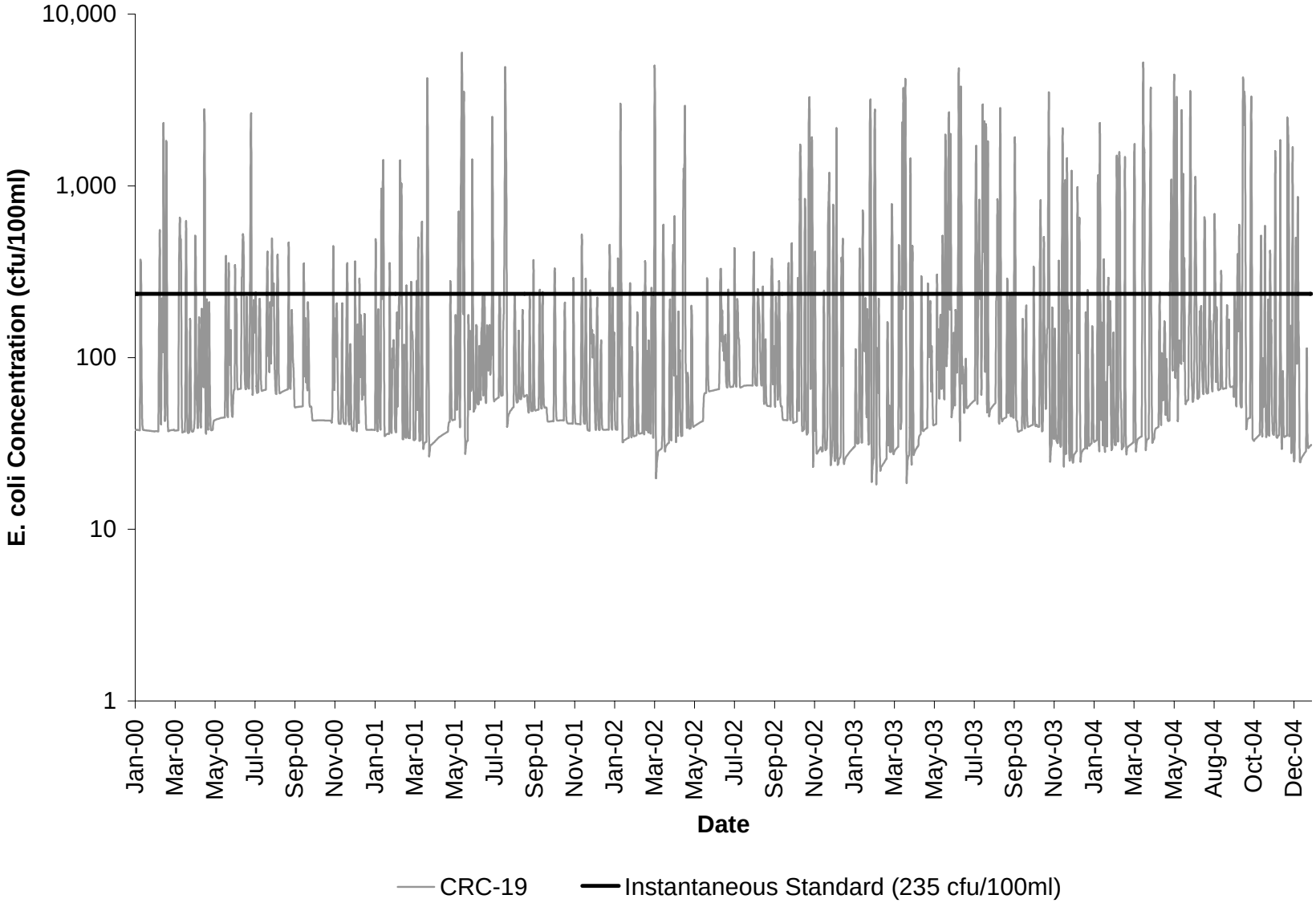
10,000
1,000
100
10
1
E. coli Concentration (cfu/100ml)
Jan-00
Mar-00
May-00
Jul-00
Sep-00
Nov-00
Jan-01
Mar-01
May-01
Jul-01
Sep-01
Nov-01
Jan-02
Mar-02
May-02
Jul-02
Sep-02
Nov-02
Jan-03
Mar-03
May-03
Jul-03
Sep-03
Nov-03
Jan-04
Mar-04
May-04
Aug-04
Oct-04
Dec-04
Date
CRC-19
Instantaneous Standard (235 cfu/100ml)

Figure 5.6. Daily average *E. coli* concentrations for subwatershed CRC-19 in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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 2000 to December 2004, 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04)

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 5.7 and 5.8, respectively. Figures 5.9 and 5.10, 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 5.7 with Figure 5.8 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.9 to Figure 5.10 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.

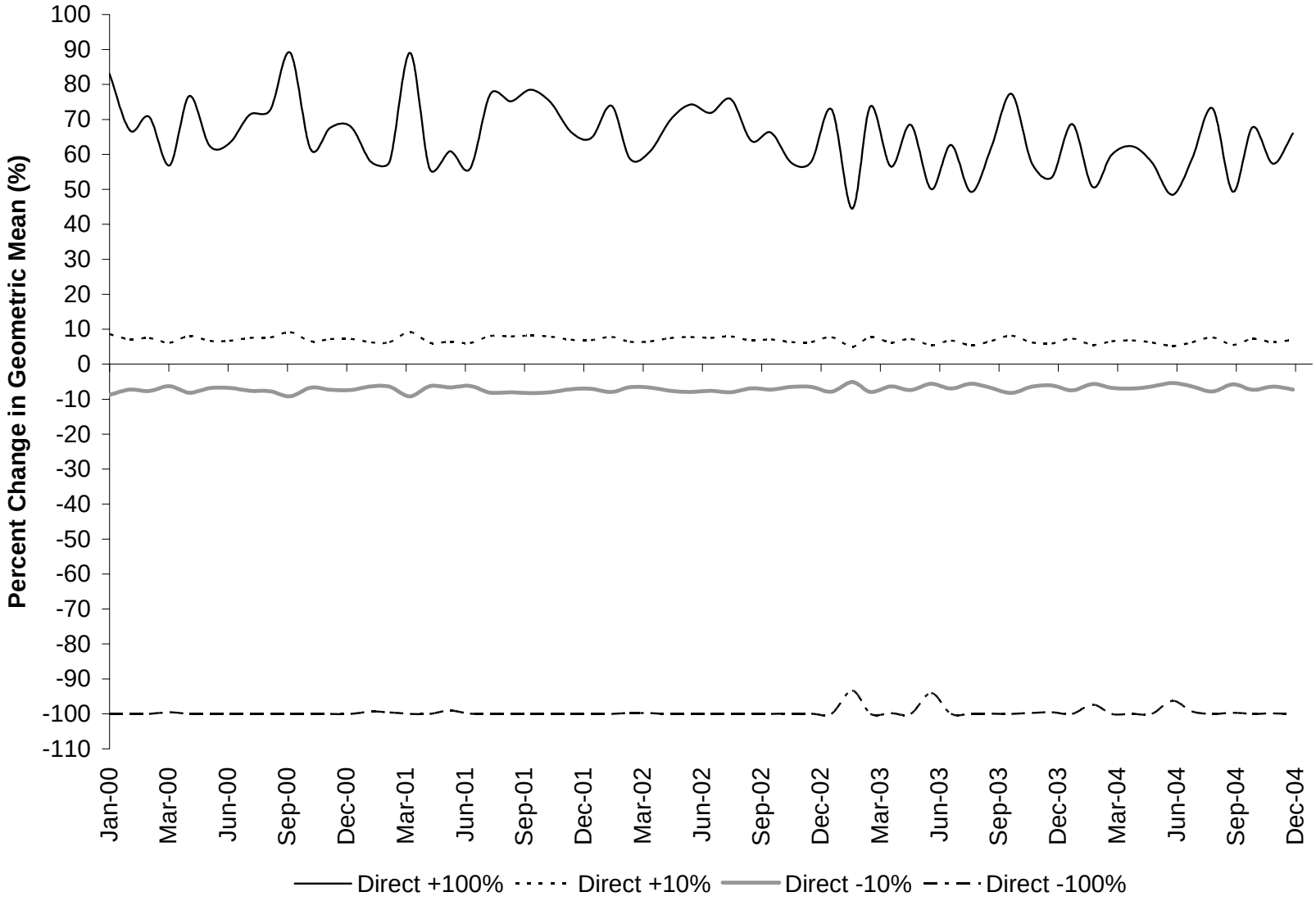

Figure 5.7. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed CRC-01) of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, as affected by direct load changes.

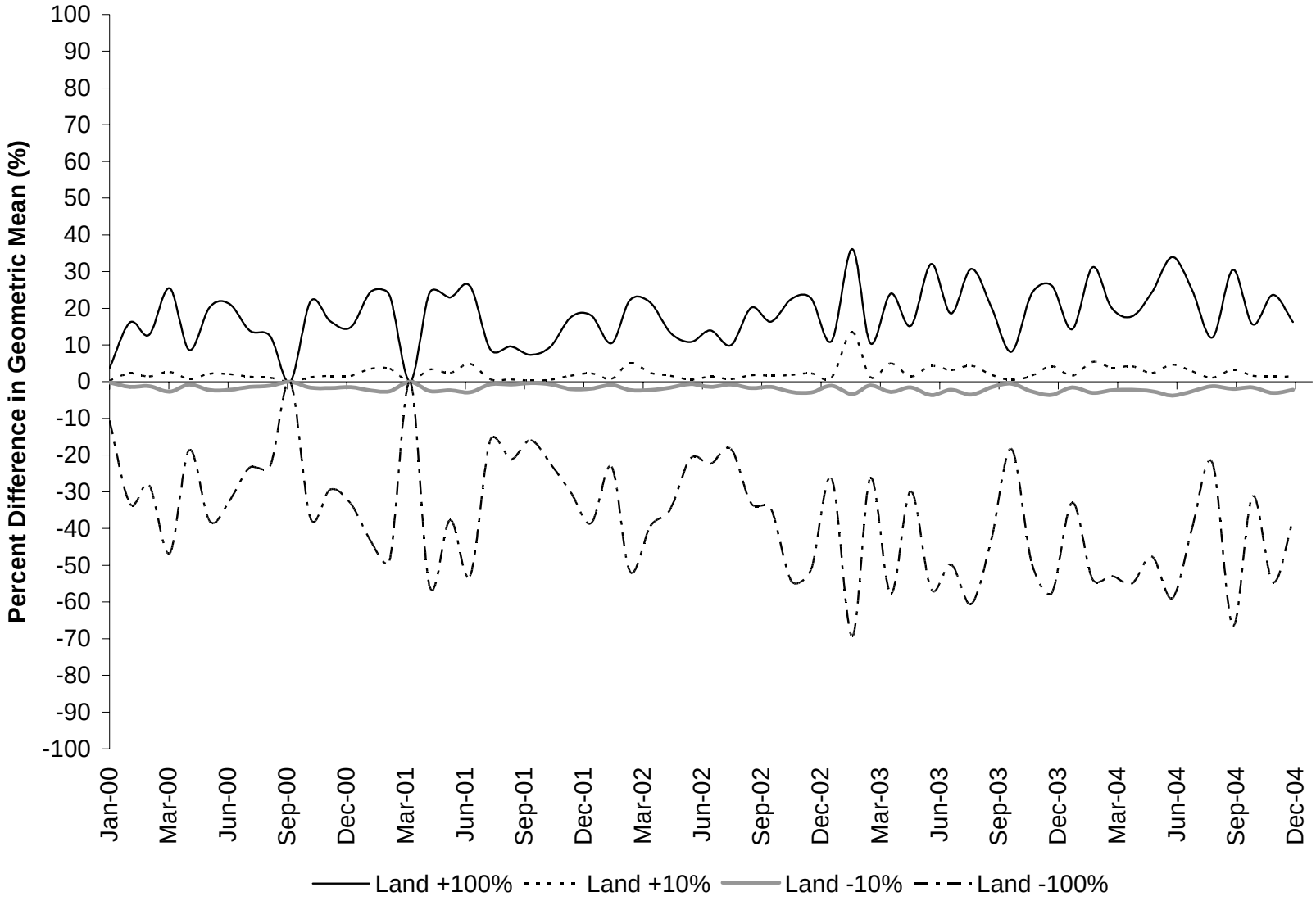

Figure 5.8. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed CRC-01) of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, as affected by land-based load changes.

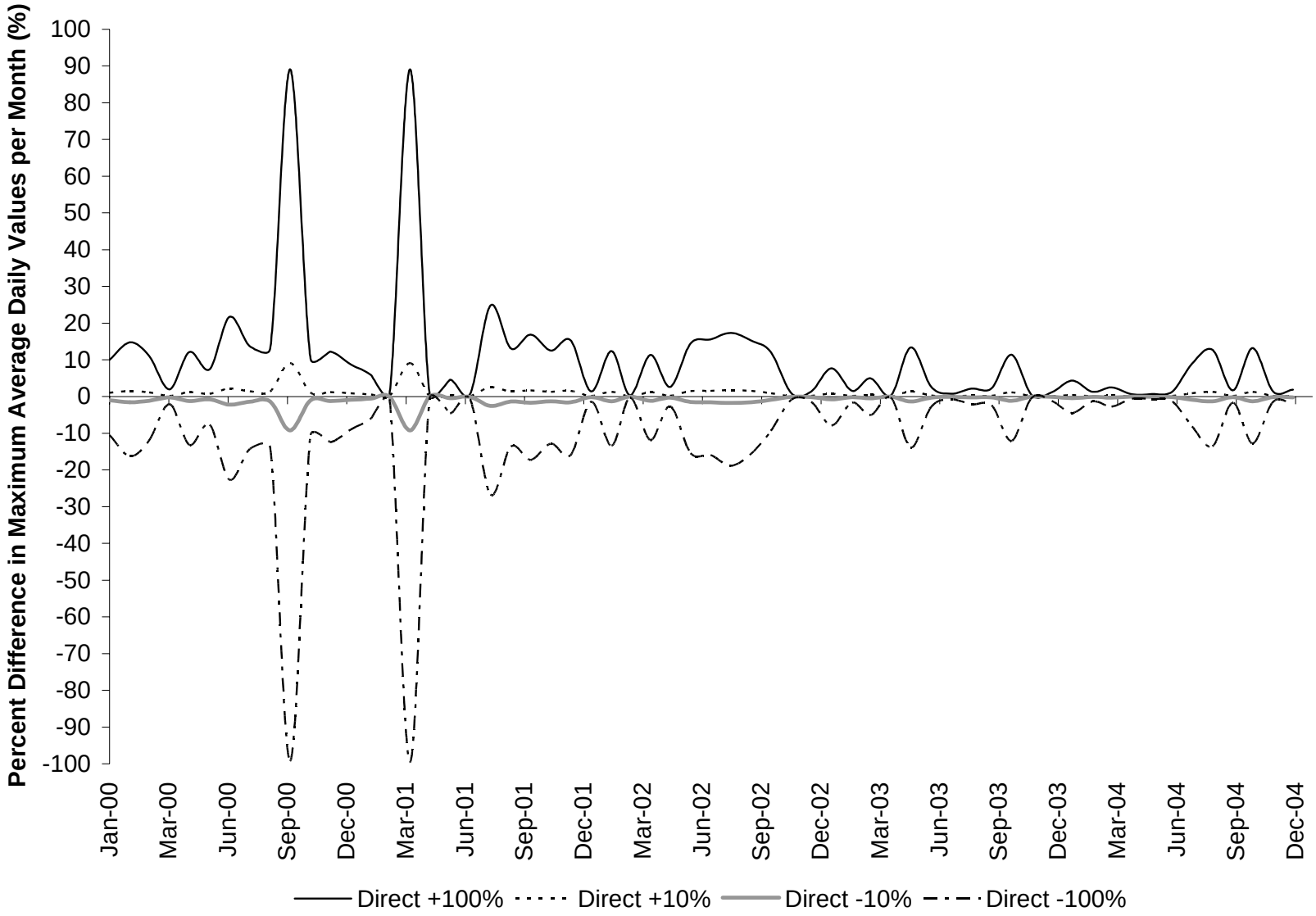

Figure 5.9. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed CRC-02) of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, as affected by direct load changes.

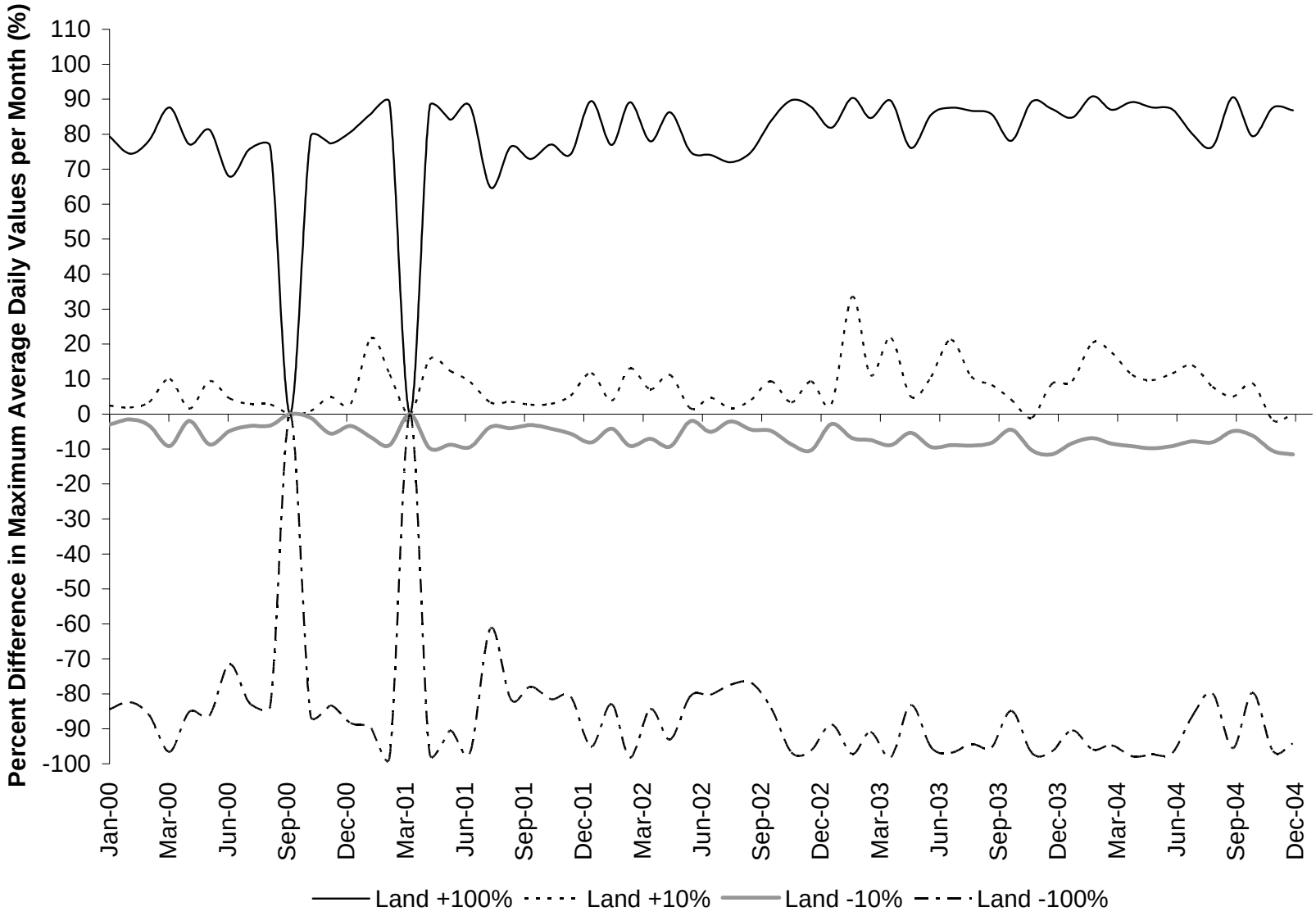

Figure 5.10. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed CRC-02) of Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed, as affected by land-based load changes.

5.3.2 Cripple Creek (VAS-N09R-01-BAC_CPL02A98)

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 5.11 and 5.12, respectively. Figures 5.13 and 5.14, 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 5.11 with Figure 5.12 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.13 to Figure 5.14 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.

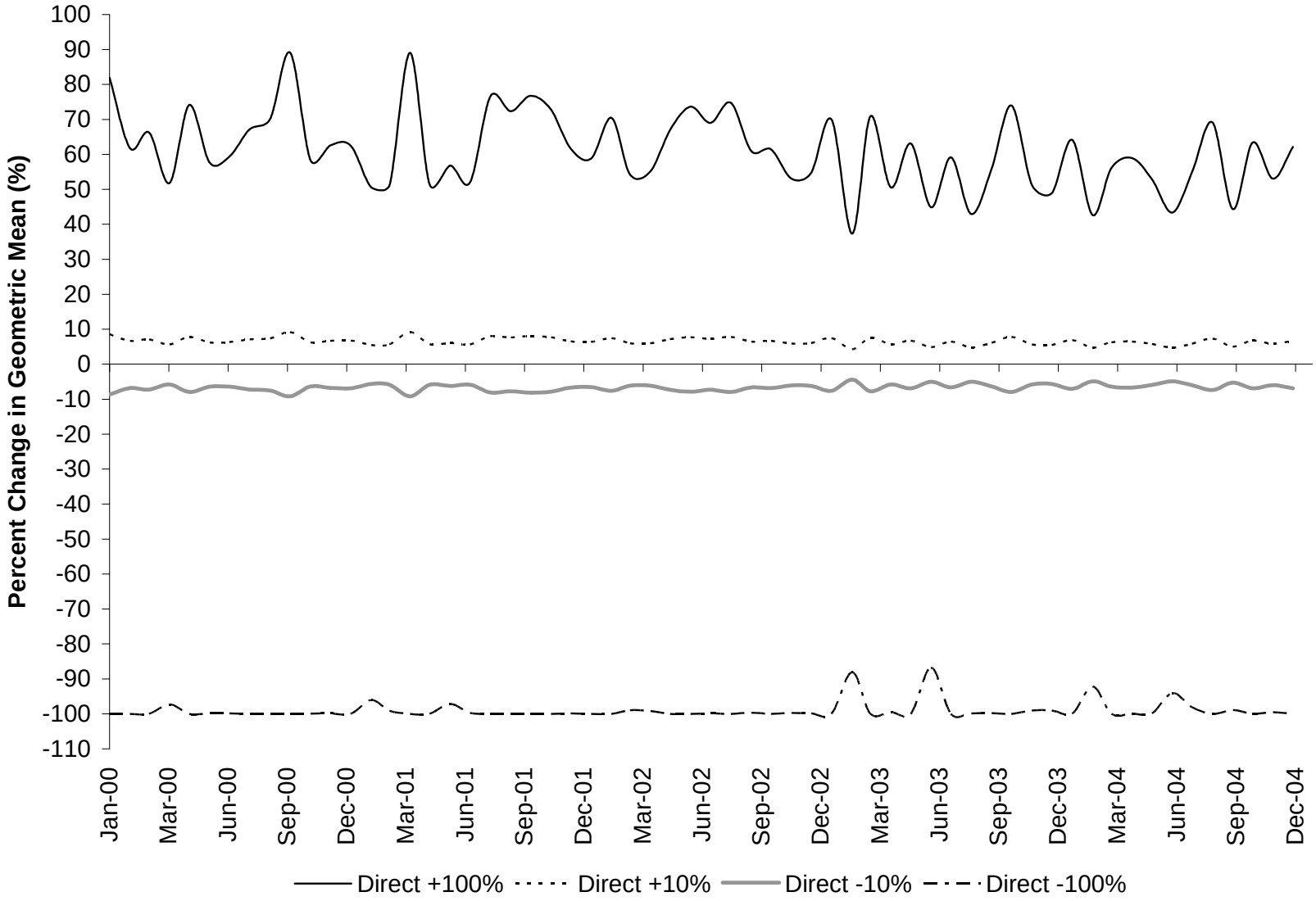

Figure 5.11. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatersheds CRC-02 to CRC-10) of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, as affected by direct load changes.

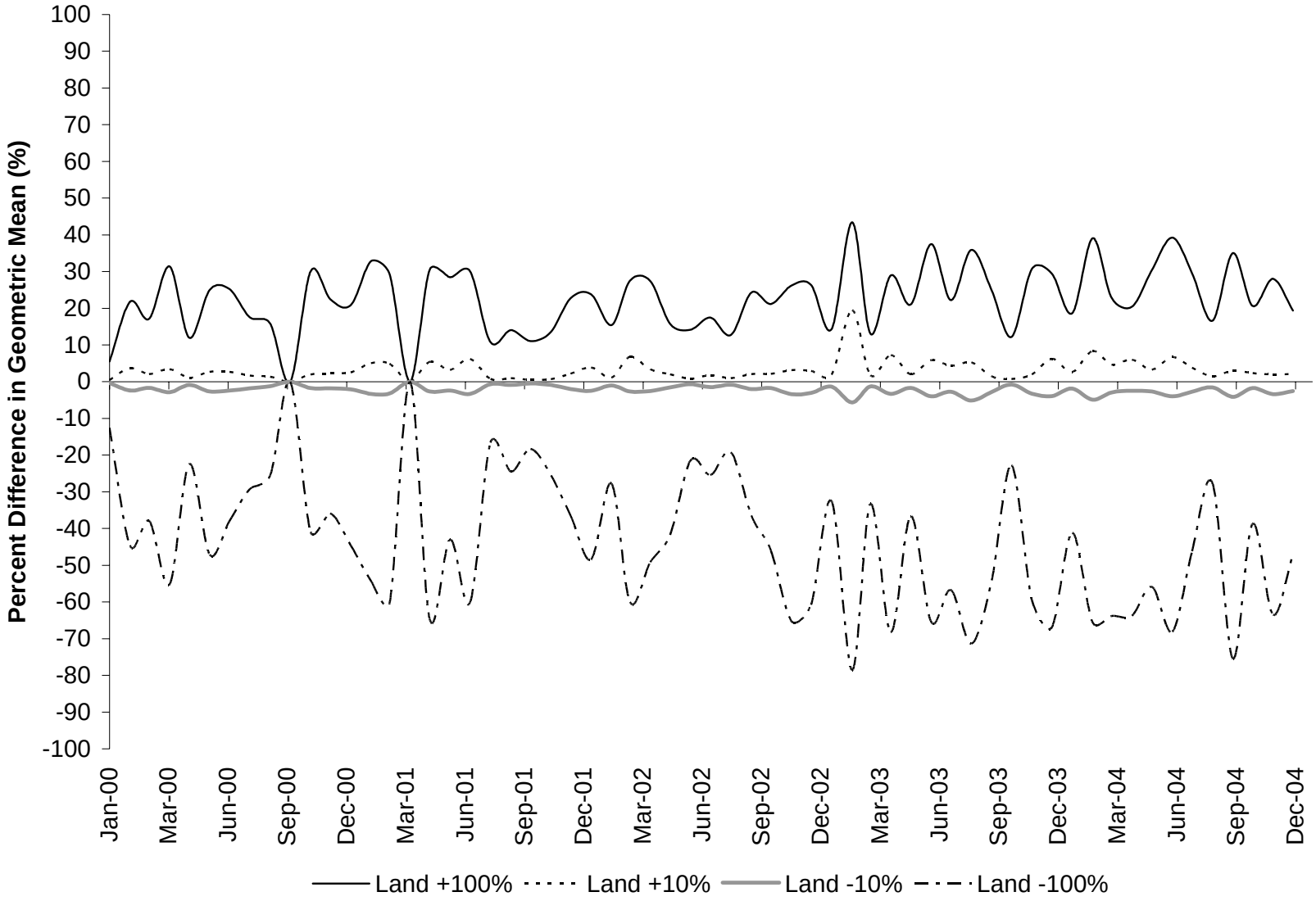

Figure 5.12. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatersheds CRC-02 to CRC-10) of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, as affected by land-based load changes.

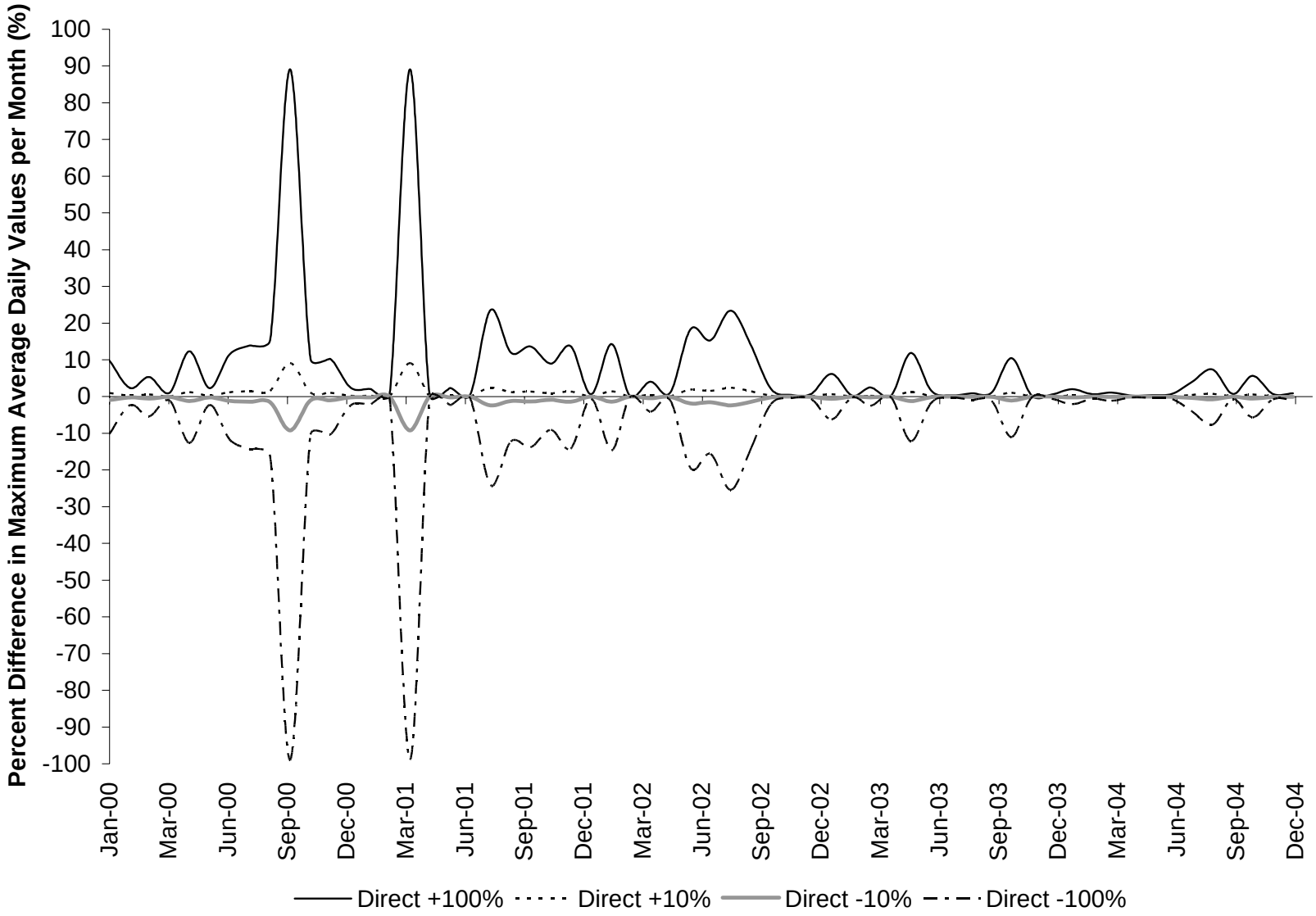

Figure 5.13. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatersheds CRC-02 to CRC-10) of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, as affected by direct load changes.

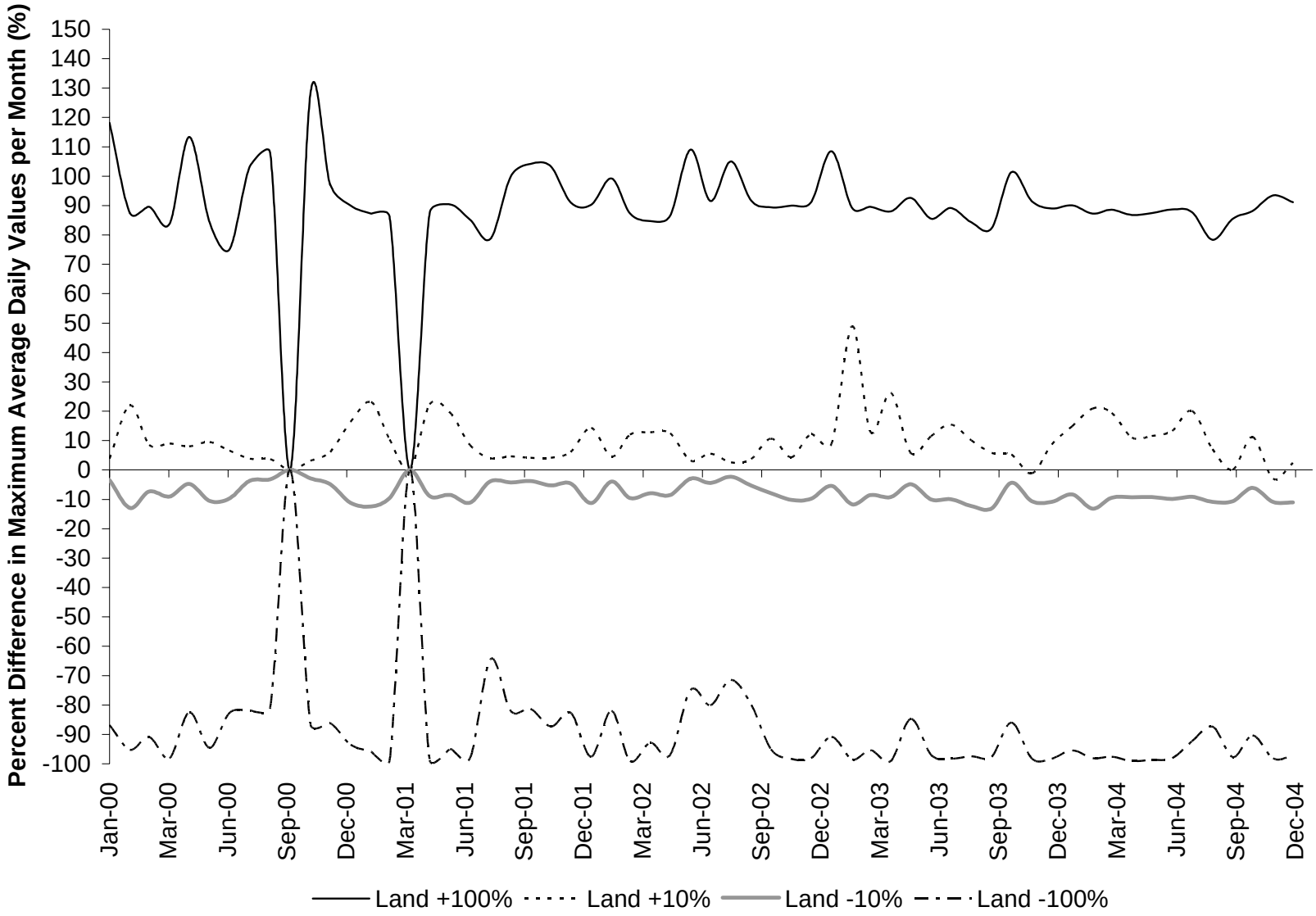

Figure 5.14. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatersheds CRC-02 to CRC-10) of Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed, as affected by land-based load changes.

5.3.3 Cripple Creek (VAS-N09R-01-BAC_CPL01B04)

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 5.15 and 5.16, respectively. Figures 5.17 and 5.18, 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 5.15 with Figure 5.16 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 5.17 to Figure 5.18 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.

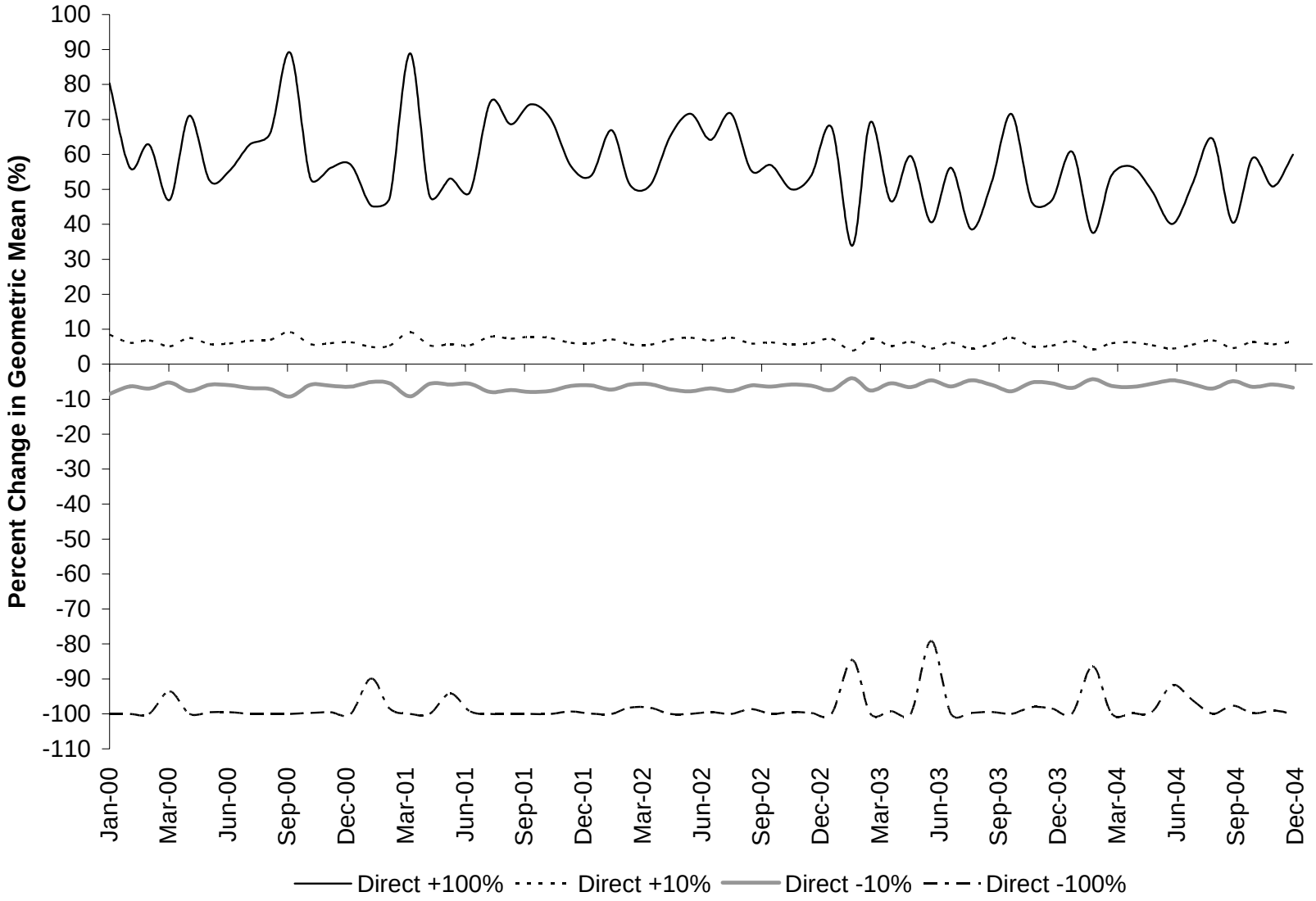

Figure 5.15. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed CRC-11 to CRC-19) of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, as affected by direct load changes.

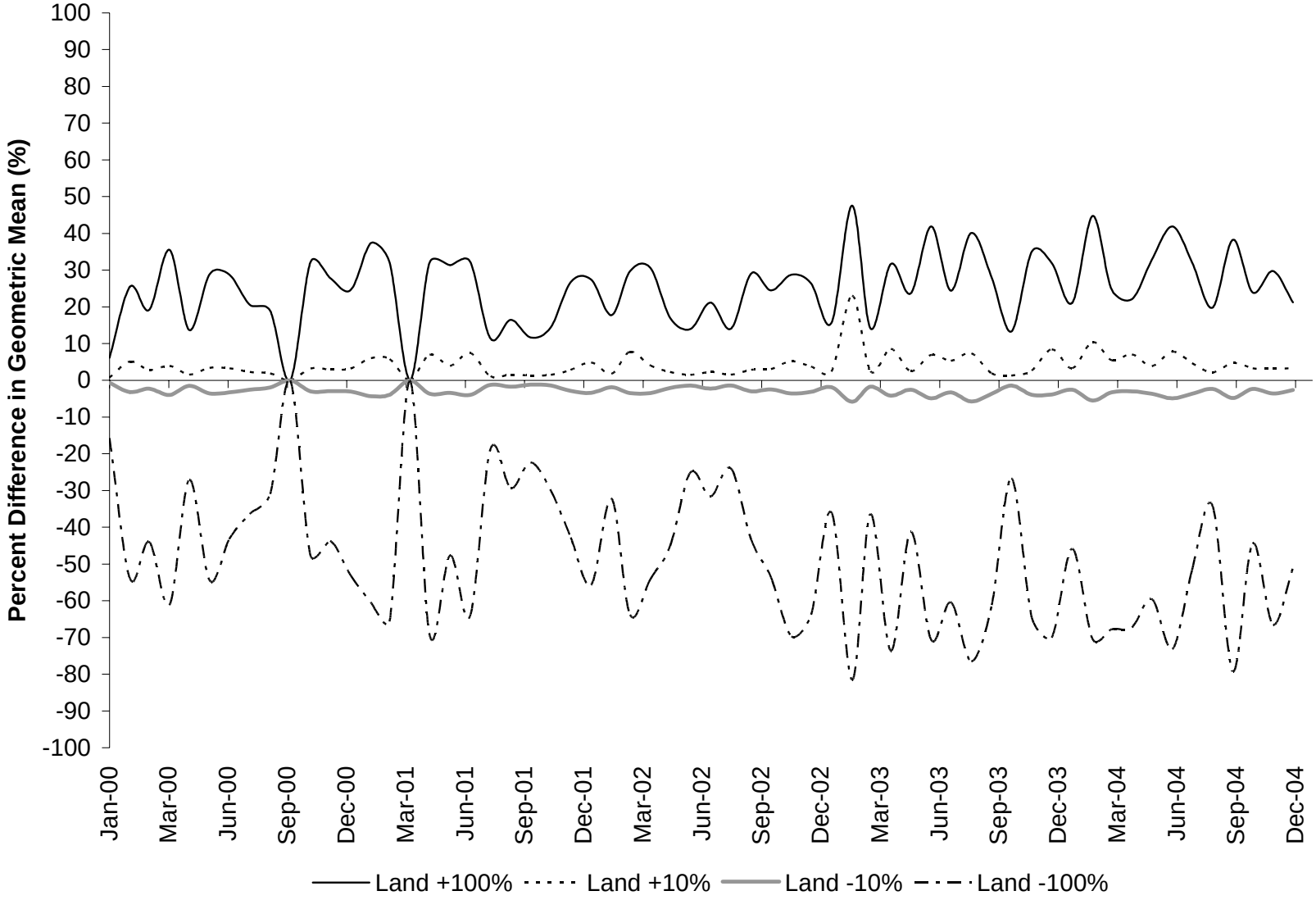

Figure 5.16. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatersheds CRC-11 to CRC-19) of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, as affected by land-based load changes.

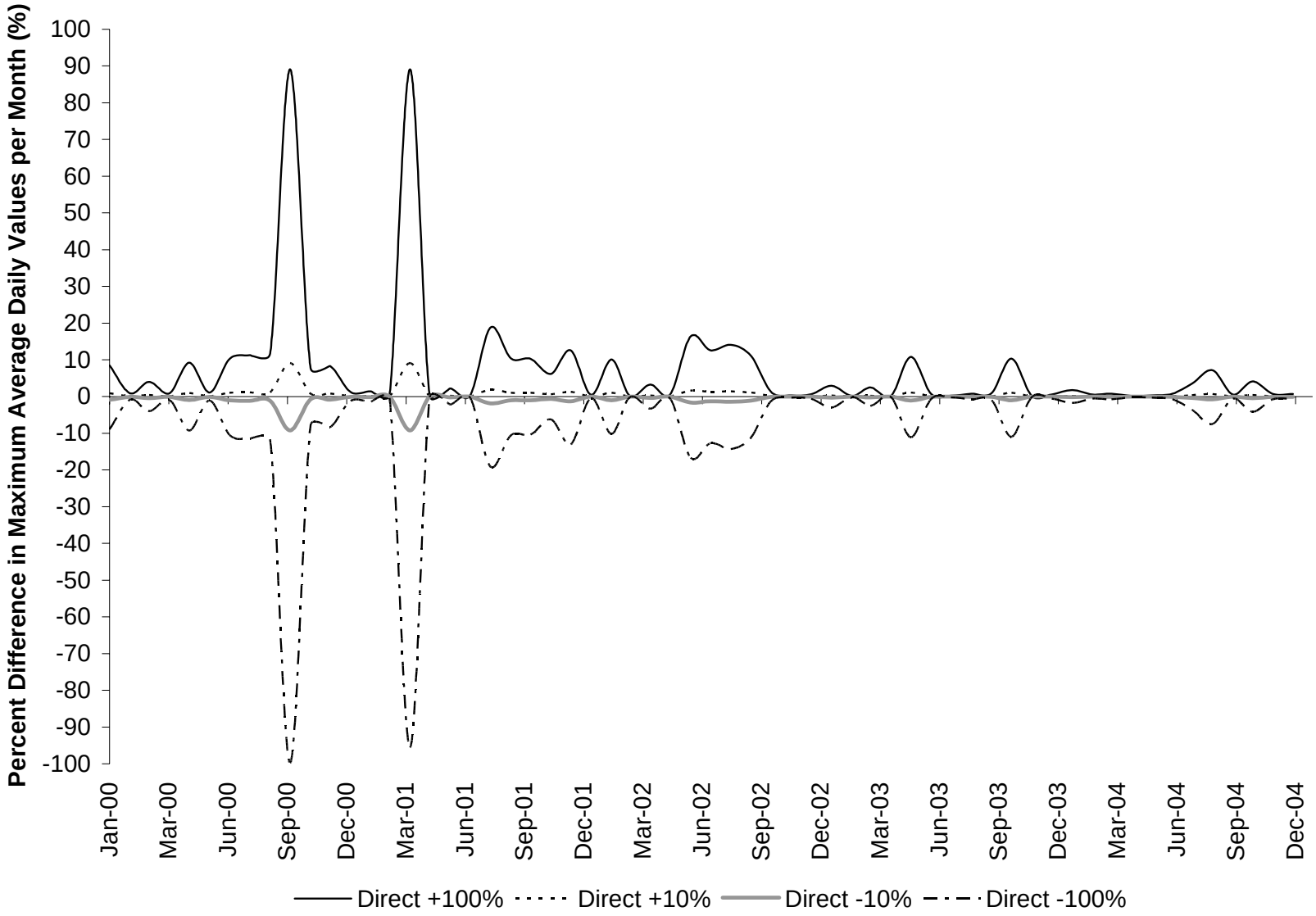

Figure 5.17. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatersheds CRC-11 to CRC-19) of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, as affected by direct load changes.

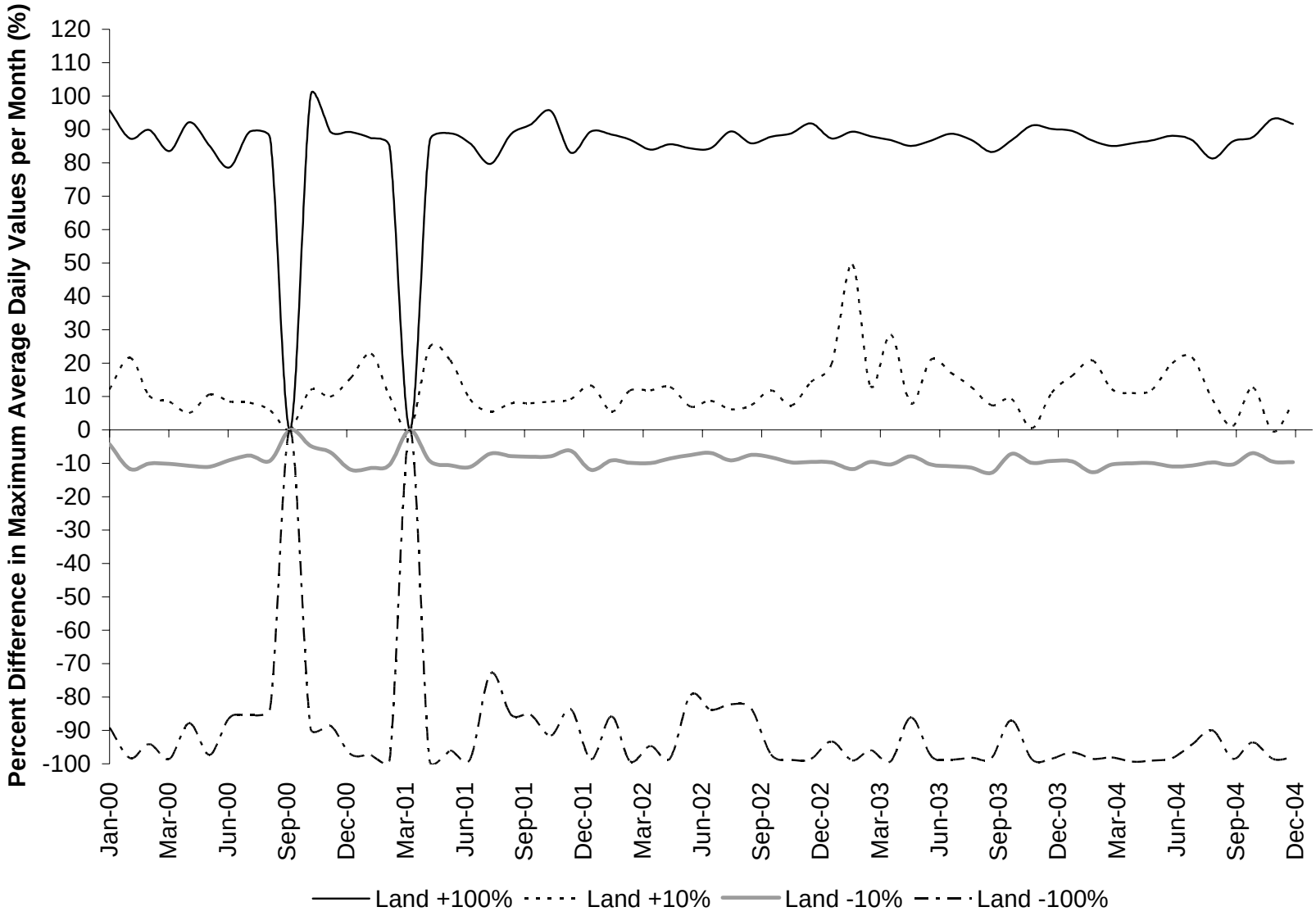

Figure 5.18. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatersheds CRC-11 to CRC-19) of Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed, as affected by land-based load changes.

5.4 TMDL Allocation Scenarios

Direct and land-based loads representing existing conditions were reduced in a variety of allocation scenarios (addressing anthropogenic sources first) until the *E. coli* TMDL goals of a calendar-month geometric mean of 126 cfu/100mL and the single sample maximum limit of 235 cfu/100mL were met. The representative modeling period selected for allocation scenarios was January 2000 through December 2004. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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 three impairments, the final allocation scenarios for the three segments were similar.

One active point discharge in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment currently has a VPDES permit; however, the facility is not permitted to discharge bacteria. The ultimate waste load allocation (WLA) for Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) was calculated at <1% of the TMDL. No municipalities with MS4 permits were identified within the Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watersheds.

Scenarios to address the load allocations to nonpoint 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 2007 and 2008 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairments and their results are summarized in Sections 5.4.1 through 5.4.3.

The general approach used to determine the TMDL allocation was very similar among the three impairments. The first scenario represents existing conditions. Scenario number 1 reduces straight pipes and livestock directly deposited loads by 100%, keeping the remaining source reductions at 0%. Scenarios numbered 2 through 4 represent a stepwise reduction of the following anthropogenic sources: residential land-based, cropland land-based, and pasture land-based. In these scenarios, wildlife loads (directly deposited and forest land-based) were not reduced and straight pipes and livestock directly deposited loads were reduced 100%. Load from straight pipes was reduced by 100% in all reduction scenarios since they are illegal. The results of Scenarios 1 through 4 were then used to formulate additional scenarios that led to the

TMDL allocation. These additional scenarios were designed to first determine non-anthropogenic source reductions required to meet bacteria water quality standards, if any. Subsequent scenarios were used to determine required reductions in anthropogenic sources (Sections 5.4.1 through 5.4.3). (Further discussion of wildlife reduction allocations can be found in Section 6.5.4.)

Future growth in discharges from permitted point sources in the Cripple Creek watershed was accounted for by developing the WLA at <1% of the TMDL. These WLAs did not result in exceedance of the water quality standard. This growth-expanded allocation was calculated and presented based on the current limits of existing permits in the watershed, but it will be allocated to both new and existing permits as determined by the VADEQ Virginia Pollutant Discharge Elimination System program. All current permit limits remain in effect and can only be altered through the VADEQ permitting process. 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 in Smyth County peaked in 2006 and decreased by about 50% from that in 2008. Beef cattle populations in Wythe County have increased on average 5% each year from 1999 to 2007. 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04), Cripple Creek (VAS-N09R-01-BAC_CPL02A98), and Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairments that meets both the calendar-month geometric mean and single sample maximum water quality goals addresses the following issues:

- The TMDL was developed to meet the calendar-month geometric mean and single sample water quality standards.
- Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations on which the bacteria TMDLs were 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 Cripple Creek are seasonal. The TMDL accounts for these seasonal effects.
- The exceedance rates listed in the allocation scenario table indicate the highest exceedance rate observed at a subwatershed outlet within the impaired segments (i.e., subwatershed CRC-01, CRC-09, and CRC-18). Some scenarios resulted in bacteria water quality standard exceedances in subwatersheds upstream of the outlet but not within the impaired reach subwatersheds.
- The TMDL was developed to account for future growth in the Cripple Creek watershed.

5.4.1 Cripple Creek (VAS-N09R-01-BAC_CPL01A04)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.1. Scenarios 5 through 7 are further reductions to the anthropogenic sources. Scenario 5 tested the land use load reductions at 96%. Table 5.1 shows that exceedances are present when the anthropogenic sources are tested at a 96% reduction rate. Scenario 6 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition was performed to match the land-based anthropogenic source reductions. Scenario 7 tested the land use and livestock directly deposited loads at a 97% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) watershed.

Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.19 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.2 presents the existing and allocated direct and land-applied fecal coliform and *E. coli* 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 Cripple Creek impairment. Table 5.4 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.1. TMDL allocation scenarios for Cripple Creek (VAS-N09R-01-BAC_CPL01A04) 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	19.1
1	100	0	100	0	0	0	0	0.0	14.8
2	100	50	100	50	50	0	0	0.0	8.2
3	100	75	100	75	75	0	0	0.0	3.6
4	100	90	100	90	90	0	0	0.0	1.2
5	100	96	100	96	96	0	0	0.0	0.1
6	100	97	100	97	97	0	0	0.0	0.0
7	100	97	97	97	97	0	0	0.0	0.0

Table 5.2. Annual nonpoint source fecal coliform and *E. coli* loads for existing conditions and final allocation along with corresponding reductions in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Source	Fecal Coliform		*E. coli*[1]		Scenario Reduction
	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	(%)
Direct					
Straight Pipes	2.59E+13	0.00E+00	2.10E+12	0.00E+00	100
Livestock	1.12E+13	3.36E+11	9.72E+11	3.87E+10	97
Wildlife	9.02E+12	9.02E+12	7.97E+11	7.97E+11	0
Total	*4.61E+13*	*9.36E+12*	*3.87E+12*	*8.35E+11*	80
Land-based					
Residential	1.18E+14	3.54E+12	8.46E+12	3.37E+11	97
Cropland	6.01E+13	1.80E+12	4.55E+12	1.81E+11	97
Pasture	1.07E+16	3.21E+14	5.33E+14	2.12E+13	97
Forest	4.64E+14	4.64E+14	2.98E+13	2.98E+13	0
Total	*1.13E+16*	*7.90E+14*	*5.76E+14*	*5.15E+13*	93

[1] Loads derived from fecal coliform loads using equation 5.1

Table 5.3. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.94E+10	2.91E+12	N/A	2.94E+12

N/A – not applicable because MOS was implicit.

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

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

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

Table 5.4. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	8.05E+07	4.17E+11	N/A	4.17E+11

N/A – not applicable because MOS was implicit.

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

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

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

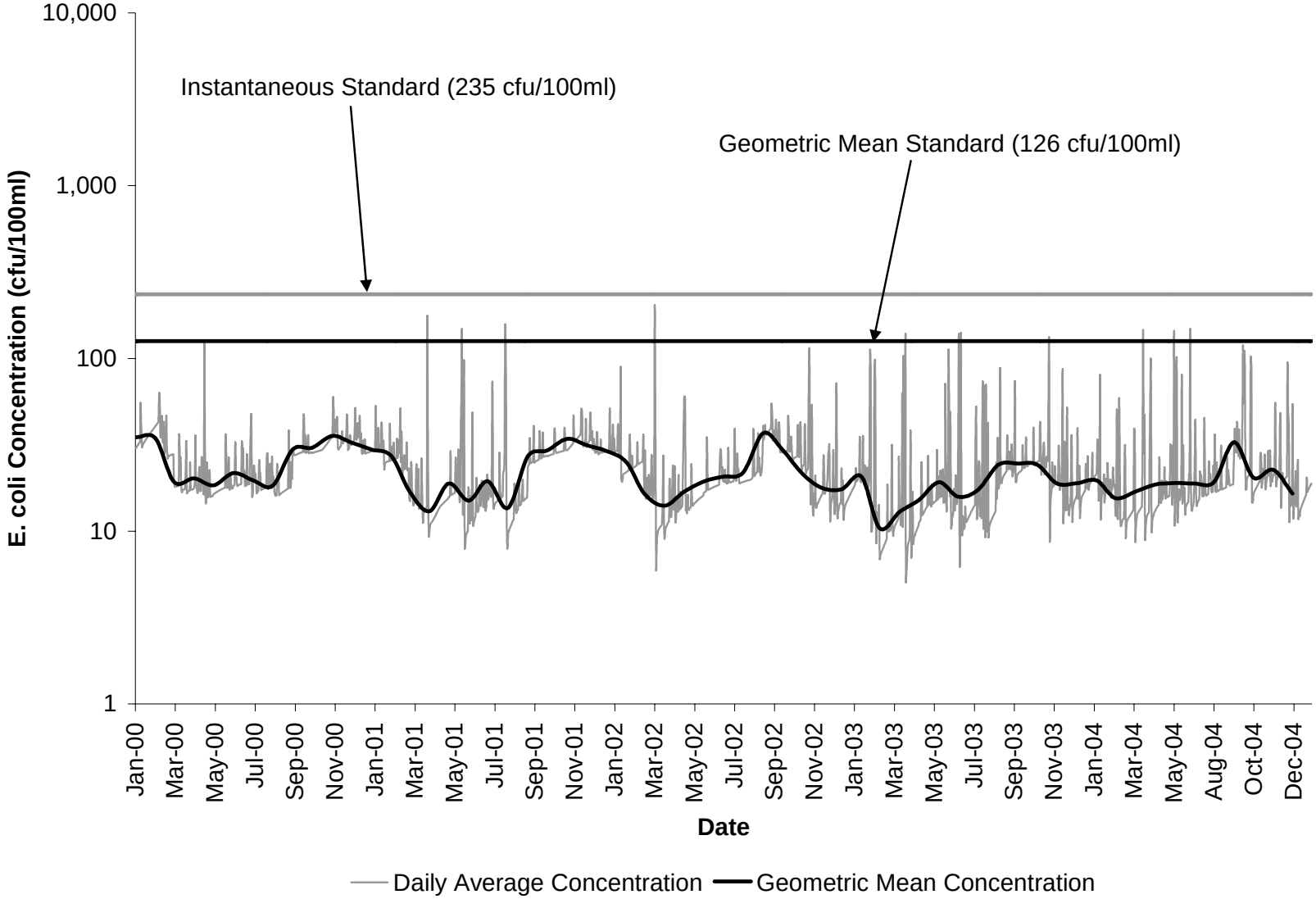

Figure 5.19. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.1) in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

5.4.2 Cripple Creek (VAS-N09R-01-BAC_CPL02A98)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.5. Scenarios 5 through 7 are further reductions to the anthropogenic sources. Scenario 5 tested the anthropogenic land use load reductions at 97%. Table 5.5 shows that exceedances are present when the anthropogenic sources are tested at a 97% reduction rate. Scenario 6 tested the anthropogenic land use load reductions at 98%. Table 5.5 shows that exceedances are present when the anthropogenic sources are tested at a 98% reduction rate. Scenario 6 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the anthropogenic land use load reductions. Scenario 7 tested the land use and livestock directly deposited loads at a 98% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) watershed.

Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.20 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.6 presents the existing and allocated direct and land-applied fecal coliform and *E. coli* 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 Cripple Creek impairment. Table 5.8 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.5. TMDL allocation scenarios for Cripple Creek (VAS-N09R-01-BAC_CPL02A98) 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	38.3	19.1
1	100	0	100	0	0	0	0	3.3	14.1
2	100	50	100	50	50	0	0	0.0	9.5
3	100	75	100	75	75	0	0	0.0	5.4
4	100	90	100	90	90	0	0	0.0	2.3
5	100	97	100	97	97	0	0	0.0	0.1
6	100	98	100	98	98	0	0	0.0	0.0
7	100	98	98	98	98	0	0	0.0	0.0

Table 5.6. Annual nonpoint source fecal coliform and *E. coli* loads for existing conditions and final allocation along with corresponding reductions in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Source	Fecal Coliform		*E. coli*[1]		Scenario Reduction
	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	(%)
Direct					
Straight Pipes	8.36E+13	0.00E+00	6.17E+12	0.00E+00	100
Livestock	6.74E+13	1.35E+12	5.06E+12	1.39E+11	98
Wildlife	5.57E+13	5.57E+13	4.25E+12	4.25E+12	0
Total	*2.07E+14*	*5.70E+13*	*1.55E+13*	*4.38E+12*	72
Land-based					
Residential	7.10E+14	1.42E+13	4.40E+13	1.21E+12	98
Cropland	8.88E+13	1.78E+12	6.52E+12	1.79E+11	98
Pasture	6.59E+16	1.32E+15	2.83E+15	7.79E+13	98
Forest	2.69E+14	2.69E+14	1.81E+13	1.81E+13	0
Total	*6.70E+16*	*1.60E+15*	*2.90E+15*	*9.73E+13*	98

[1] Loads derived from fecal coliform loads using equation 5.1

Table 5.7. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	1.87E+11	1.85E+13	N/A	1.87E+13

N/A – not applicable because MOS was implicit.

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

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

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

Table 5.8. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	5.12E+08	2.87E+12	N/A	2.87E+12

N/A – not applicable because MOS was implicit.

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

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

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

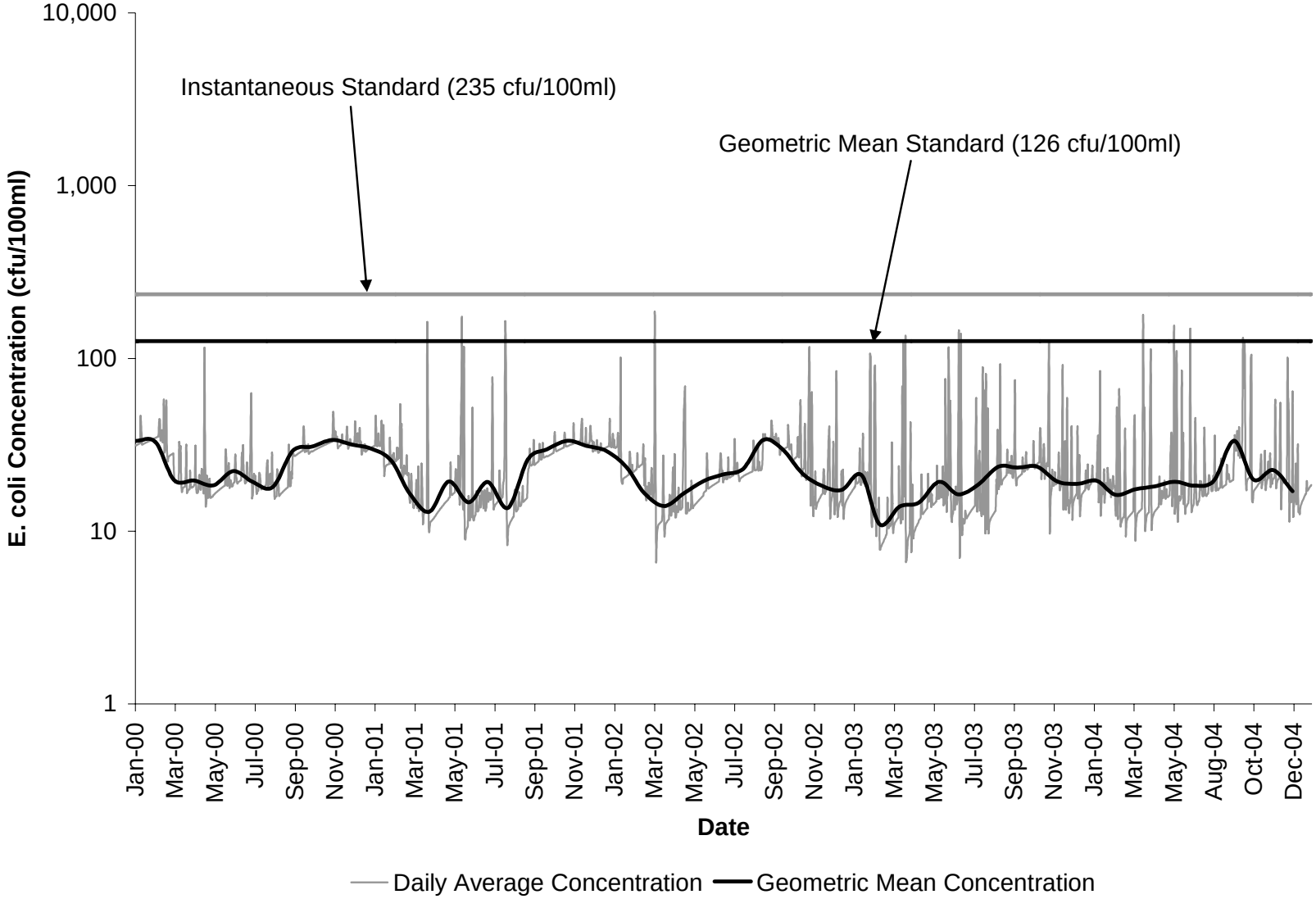

Figure 5.20. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.6) in Cripple Creek (VAS_N09R-00) impairment.

5.4.3 Cripple Creek (VAS-N09R-01-BAC_CPL01B04)

Formulations of Scenarios 1 through 4 are discussed in Section 5.4. The results of those scenarios, and additional scenarios, are displayed in Table 5.9. Scenarios 5 through 7 are further reductions to the anthropogenic sources. Scenario 5 tested the anthropogenic land use load reductions at 97%. Table 5.9 shows that exceedances are present when the anthropogenic sources are tested at a 97% reduction rate. Scenario 6 tested the residential land-based loads at a 98% reduction rate with cropland land-based and pasture land-based loads at a 98% reduction rate. Scenario 6 met the 0% exceedance criteria of both standards, but an attempt to reduce the livestock direct deposition load was performed to match the cropland land-based and pasture land-based loads. Scenario 7 tested the cropland land-based, pasture land-based loads, and livestock directly deposited loads at a 98% reduction rate. Scenario 7 met the 0% exceedance criteria of both standards and was selected as the final TMDL allocation. It was determined that no reductions were required in wildlife loads (directly deposited and forest land-based) to meet the bacteria water quality standards in the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) watershed.

Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 5.21 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 5.10 presents the existing and allocated direct and land-applied fecal coliform and *E. coli* 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 Cripple Creek impairment. Table 5.12 presents the TMDL for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Table 5.9. TMDL allocation scenarios for Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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	38.3	19.1
1	100	0	100	0	0	0	0	3.3	14.1
2	100	50	100	50	50	0	0	1.7	9.5
3	100	75	100	75	75	0	0	0.0	5.9
4	100	90	100	90	90	0	0	0.0	2.9
5	100	97	100	97	97	0	0	0.0	0.1
6	100	98	100	98	98	0	0	0.0	0.0
7	100	98	98	98	98	0	0	0.0	0.0

Table 5.10. Annual nonpoint source fecal coliform and *E. coli* loads for existing conditions and final allocation along with corresponding reductions in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Source	Fecal Coliform		*E. coli*[1]		Scenario Reduction
	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	Existing Condition Load (cfu/yr)	TMDL Allocation Load (cfu/yr)	(%)
Direct					
Straight Pipes	7.00E+13	0.00E+00	5.24E+12	0.00E+00	100
Livestock	3.64E+13	7.28E+11	2.87E+12	7.88E+10	98
Wildlife	3.20E+13	3.20E+13	2.55E+12	2.55E+12	0
Total	*1.38E+14*	*3.27E+13*	*1.07E+13*	*2.63E+12*	76
Land-based					
Residential	5.06E+14	1.01E+13	3.23E+13	8.84E+11	98
Cropland	1.45E+14	2.90E+12	1.02E+13	2.81E+11	98
Pasture	3.56E+16	7.12E+14	1.61E+15	4.42E+13	98
Forest	1.63E+14	1.63E+14	1.14E+13	1.14E+13	0
Total	*3.64E+16*	*8.88E+14*	*1.66E+15*	*5.67E+13*	98

[1] Loads derived from fecal coliform loads using equation 5.1

Table 5.11. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Pollutant	WLA[1] (cfu/yr)	LA[2] (cfu/yr)	MOS	TMDL[3] (cfu/yr)
E. coli	2.82E+11	2.79E+13	N/A	2.82E+13

N/A – not applicable because MOS was implicit.

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

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

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

Table 5.12. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Pollutant	WLA[1] (cfu/d)	LA[2] (cfu/d)	MOS	TMDL[3] (cfu/d)
E. coli	7.73E+08	5.32E+12	N/A	5.32E+12

N/A – not applicable because MOS was implicit.

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

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

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

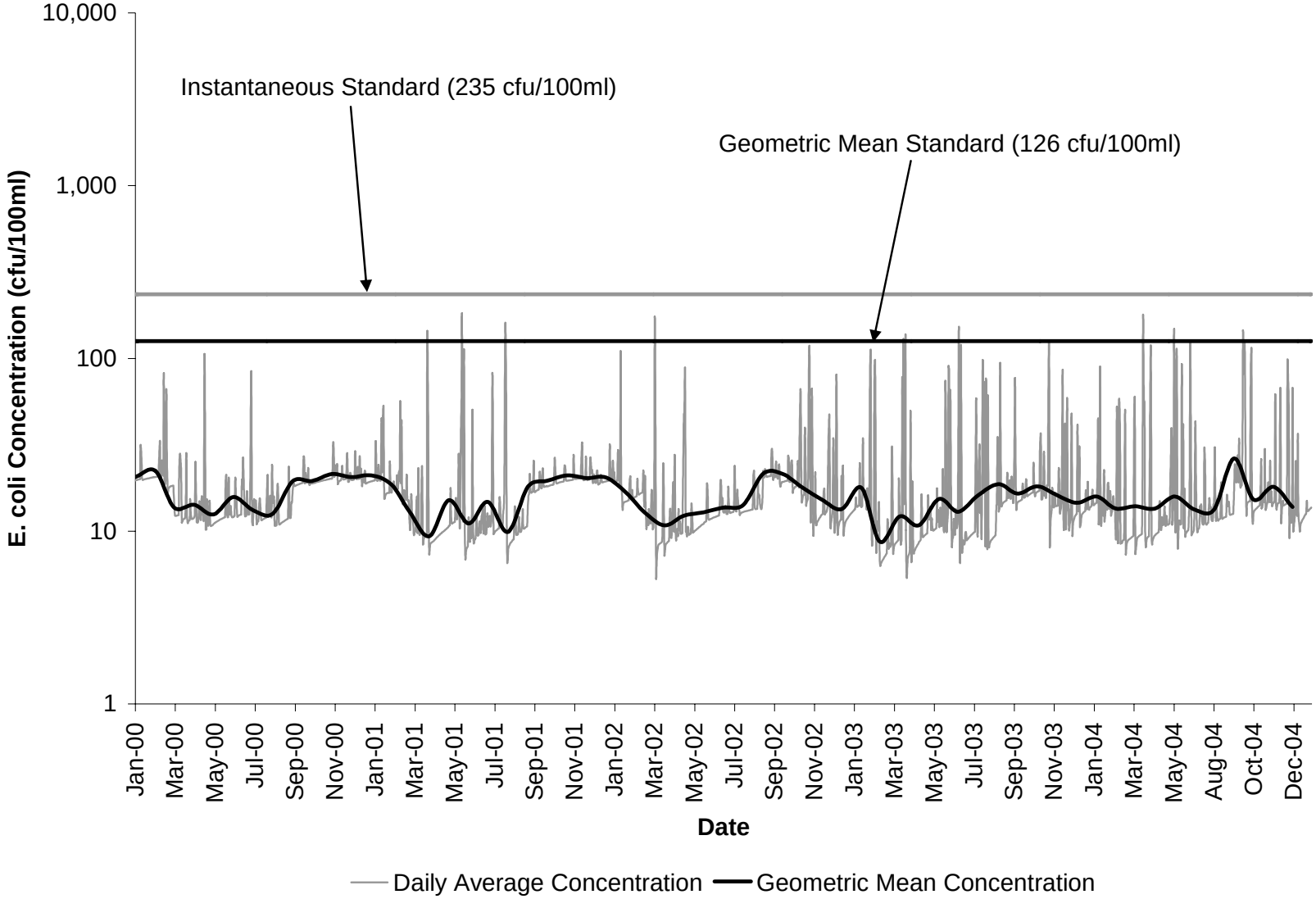

Figure 5.21. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean *E. coli* concentrations from successful TMDL allocation (Allocation Scenario 7 from Table 5.11) in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Chapter 6. TMDL Implementation and Reasonable Assurance

Once a TMDL has been approved by USEPA, measures must be taken to reduce pollution levels from both point and non point sources in the stream (see section 6.4.2). For point sources, all new or revised VPDES/NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR '122.44 (d)(1)(vii)(B) and must be submitted to USEPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.virginia.gov/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

6.1 Staged Implementation

In general, Virginia intends for the required bacteria reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, the most promising management practice is livestock exclusion from streams. This has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the cattle deposits themselves and by providing additional riparian buffers.

Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

In urban areas, reducing the human bacteria loading from leaking sewer lines could be accomplished through a sanitary sewer inspection and management program. Other BMPs that might be appropriate for controlling urban wash-off from parking lots and roads and that could be readily implemented may include more restrictive ordinances to reduce fecal loads from pets, improved garbage collection and control, and improved street cleaning.

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

1. It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;

2. It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;

3. It provides a mechanism for developing public support; through periodic updates on BMP implementation and water quality improvements;
4. It helps ensure that the most cost effective practices are implemented first; and
5. It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

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

6.2 Stage 1 Scenarios

The goal of the Stage 1 implementation scenarios is to reduce the bacteria loading reductions from controllable sources (excluding wildlife) such that exceedances of the single sample maximum criterion (235 cfu/100ml) are less than 10 percent, with no reduction from wildlife sources. The less than 10 percent exceedance rate is a conservative estimate of the extent of implementation needed to have each impaired segment de-listed, currently; a less than 10.5% exceedance rate is required. In addition, the 10 percent exceedance rate criteria mirrors the new proposed bacteria standard meeting a 10% exceedance rate of the single sample maximum criterion (235 cfu/100ml) and a 0% exceedance rate of the geometric mean criterion (126 cfu/100 ml). After the proposed bacteria standard is adopted by the VWCB, the Stage I implementation scenario will become the TMDL allocation scenario, since it will meet the new revised standard.

HSPF was run with a one-hour time step for the period January 2000 to December 2004, 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 6.2.3.

6.2.1 Cripple Creek (VAS-N09R-01-BAC_CPL01A04)

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 37% reduction in nonpoint source loadings to residential land use, a 57% reduction in nonpoint source loadings to pasture land use, a 37% reduction in nonpoint source loadings to cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.91% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.1 for the Cripple Creek (VAS-N09R-01-BAC_CPL01A04) 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 Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	2.59E+13	0.00E+00	100
Livestock	1.12E+13	2.80E+12	75
Wildlife	9.02E+12	9.02E+12	0
Total	*4.61E+13*	*1.18E+13*	74
Land-based			
Residential	1.18E+14	7.43E+13	37
Cropland	6.01E+13	3.79E+13	37
Pasture	1.07E+16	6.74E+15	37
Forest	4.64E+14	4.64E+14	0
Total	*1.13E+16*	*7.32E+15*	35

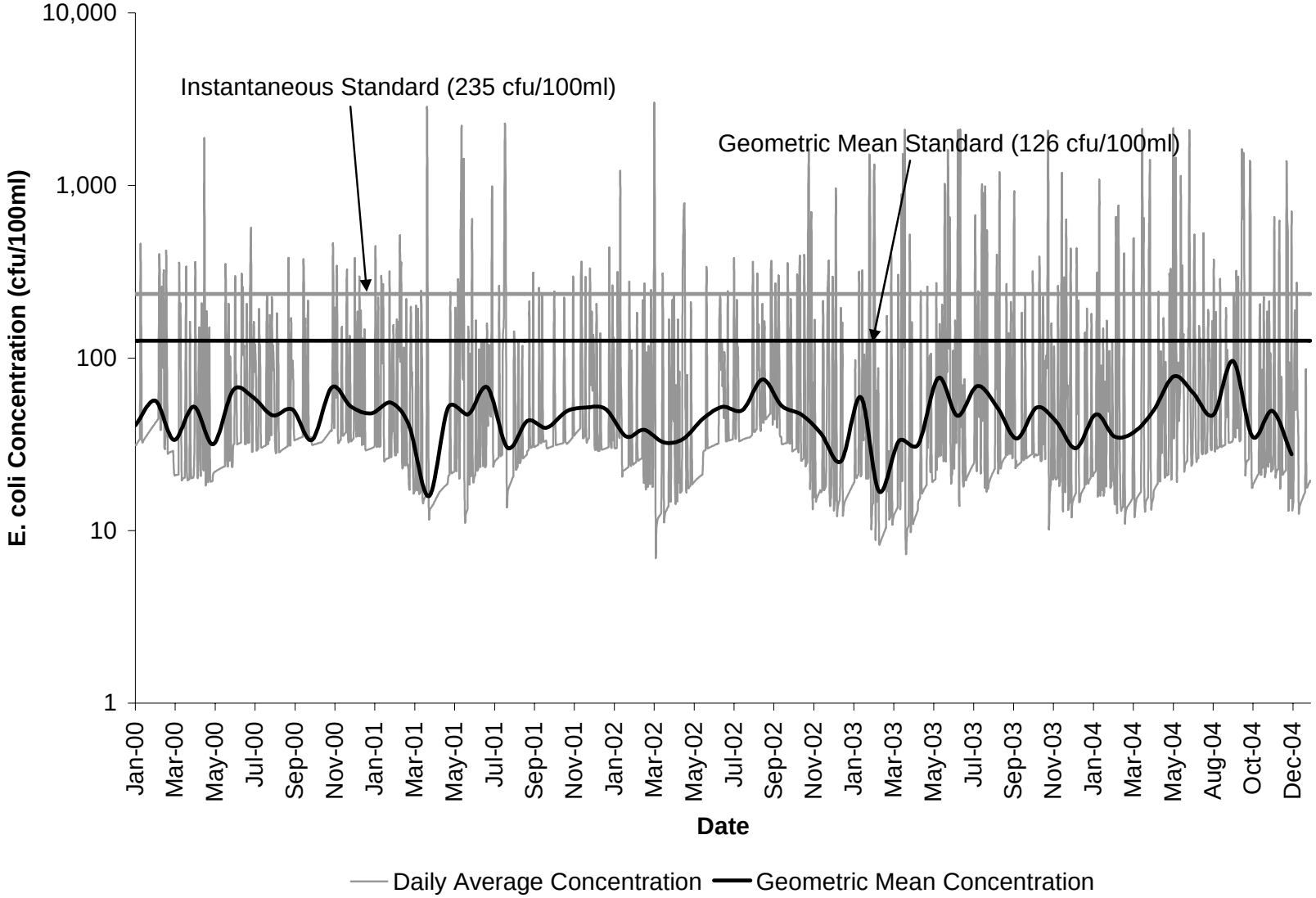

Figure 6.1. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Cripple Creek (VAS-N09R-01-BAC_CPL01A04) impairment.

6.2.2 Cripple Creek (VAS-N09R-01-BAC_CPL02A98)

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment requires a 100% reduction in straight pipes, 75% reduction in livestock direct deposition, a 0% reduction in wildlife direct deposition, a 47% 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 9.96% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.2 for the Cripple Creek (VAS-N09R-01-BAC_CPL02A98) 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 Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	8.36E+13	0.00E+00	100
Livestock	6.74E+13	1.69E+13	75
Wildlife	5.57E+13	5.57E+13	0
Total	*2.07E+14*	*7.26E+13*	65
Land-based			
Residential	7.10E+14	3.76E+14	47
Cropland	8.88E+13	4.71E+13	47
Pasture	6.59E+16	3.49E+16	47
Forest	2.69E+14	2.69E+14	0
Total	*6.70E+16*	*3.56E+16*	47

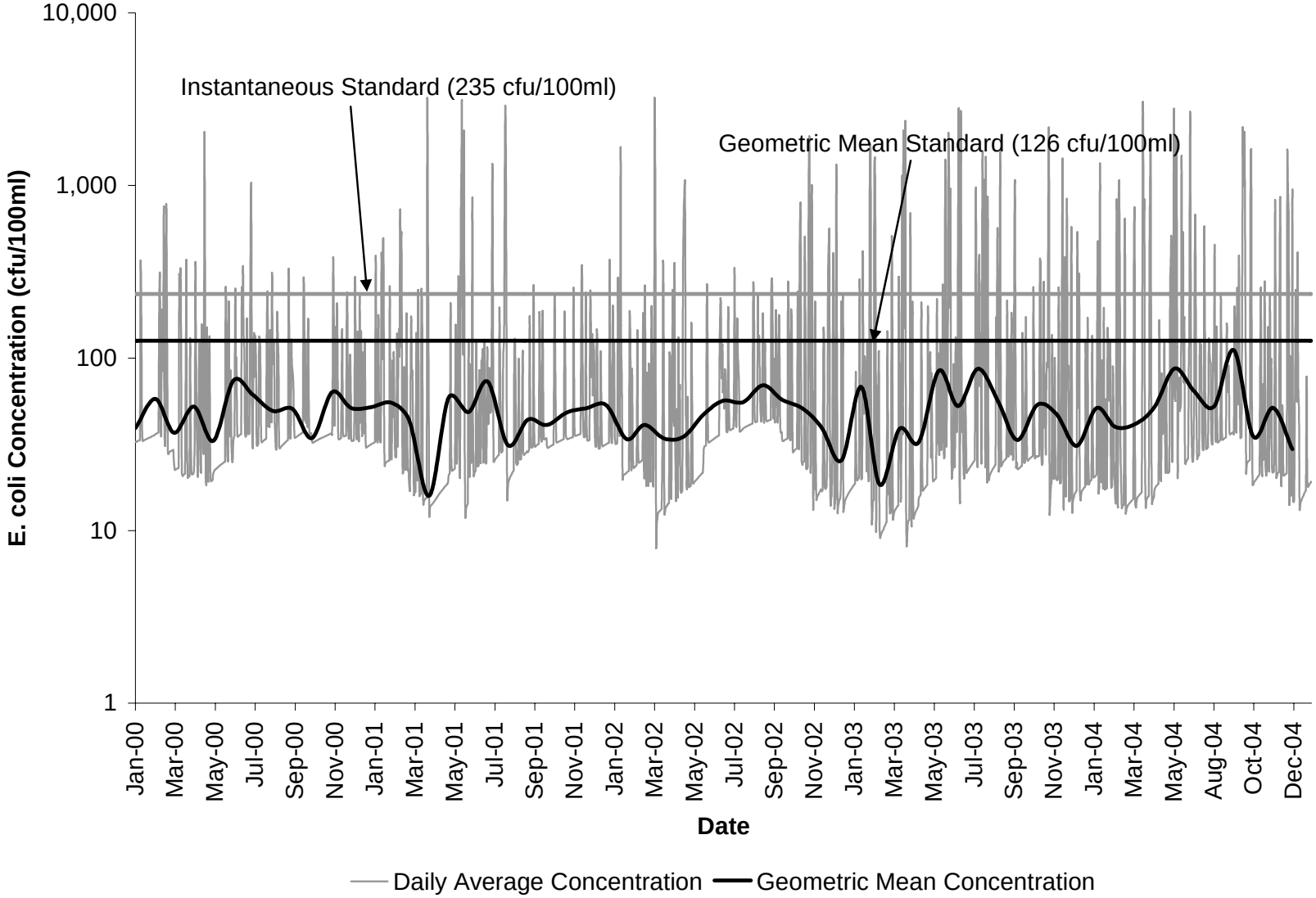

Figure 6.2. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Cripple Creek (VAS-N09R-01-BAC_CPL02A98) impairment.

6.2.3 Cripple Creek (VAS-N09R-01-BAC_CPL01B04)

The Stage 1 allocation for the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment requires a 100% reduction in straight pipes, 75.% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 45% reduction in nonpoint source loadings to residential land use, pasture land use, and cropland, and no reduction in nonpoint source loadings to forest land. This scenario resulted in a 9.96% instantaneous standard exceedance rate. Fecal coliform loadings for the existing allocation and Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 6.3 for the Cripple Creek (VAS-N09R-01-BAC_CPL01B04) 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 Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

Source	Existing Condition Load (cfu/yr)	Stage 1 Allocation Load (cfu/yr)	Scenario Reduction (%)
Direct			
Straight Pipes	7.00E+13	0.00E+00	100
Livestock	3.64E+13	9.10E+12	75
Wildlife	3.20E+13	3.20E+13	0
Total	*1.38E+14*	*4.11E+13*	70
Land-based			
Residential	5.06E+14	2.78E+14	45
Cropland	1.45E+14	7.98E+13	45
Pasture	3.56E+16	1.96E+16	45
Forest	1.63E+14	1.63E+14	0
Total	*3.64E+16*	*2.01E+16*	45

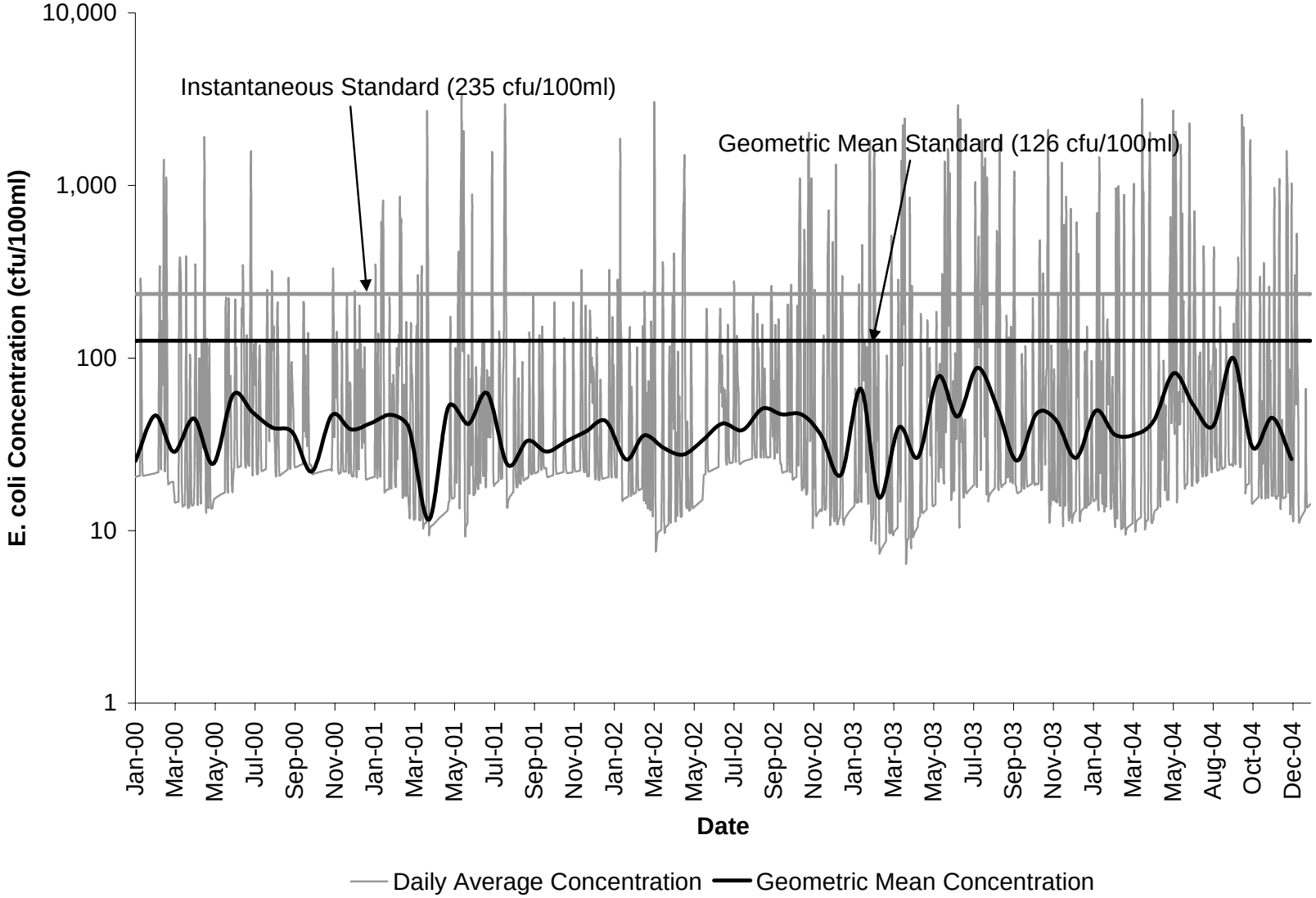

Figure 6.3. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Cripple Creek (VAS-N09R-01-BAC_CPL01B04) impairment.

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 watershed. Several BMPs known to be effective in controlling bacteria have also been identified for implementation to control sediment and nutrients in the southern rivers region.

6.4 Reasonable Assurance for Implementation

6.4.1 Follow-up Monitoring

Following the development of the TMDL, the VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004 (http://www.deq.virginia.gov/waterguidance/pdf/032004.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

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

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

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be

made to ensure that ancillary monitoring follows established quality assurance/quality control (QA/QC) guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

In order 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 assumptions and requirements of any applicable TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to USEPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. USEPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes 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 IP development, especially those implemented through the water quality based effluent limitations. However, those requirements that are considered BMPs may be enhanced by inclusion in the TMDL IP, and their connection to the targeted

impairment. New permitted point source discharges will be allowed under the waste load allocation provided they implement applicable VPDES requirements (including any BMP, offset, trading, or payment-in-lieu conditions established to meet any future reduction requirements). Permits issued for facilities with wasteload allocations developed as part of a TMDL must be consistent with the assumptions and requirements of these wasteload allocations (WLA), as per USEPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, USEPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at http://www.deq.virginia.gov/waterguidance/.

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) that are both covered by NPDES permits and expected to be included in TMDL implementation plans. It is the intent of the Commonwealth that the TMDL will be implemented using existing regulations and programs. 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 MS4s. USEPA approved VADCR's VPDES stormwater 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 MS4 and construction stormwater permitting programs. More information is available on VADCR's web site through the following link: http://www.dcr.virginia.gov/sw/vsmp. Additional information on Virginia's Stormwater Management program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/soil_&_water/stormwat.shtml. As there are no MS4s permitted in the watershed at the time of this TMDL, they are not included in this study.

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 Implementation Funding Sources

The implementation on pollutant reductions from non-regulated nonpoint sources relies heavily on incentive-based programs. Therefore, the identification of funding sources for non-regulated implementation activities is a key to success. Cooperating agencies, organizations and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans". The TMDL Implementation Plan Guidance Manual contains information on a variety of funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, USEPA Section 319 funds Virginia's Nonpoint Source Management Program, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, and the Virginia Water Quality Improvement Fund (available for nonpoint source pollution). With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become an important funding stream for agricultural BMPs. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at http://www.dcr.virginia.gov/soil_&_water/wqia.shtml.

6.4.4 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that even after removal of all bacteria sources (other than wildlife), the stream will not attain standards under all flow regimes at all times. Virginia and USEPA are not proposing the elimination of natural wildlife to allow for the attainment of water quality standards. However, managing overpopulations of wildlife remains an option available to local stakeholders. Should during the implementation plan development phase of a TMDL process, and in consultation with a local government or land owner, the Department of Game and Inland Fisheries (VDGIF) determine that a population of resident geese, deer or other wildlife is a at "nuisance" levels, measures to reduce such populations may be deemed acceptable if undertaken under the supervision, or issued permit, of the VDGIF or the U.S. Fish and Wildlife Service as appropriate.

Additional information on VDGIF's wildlife programs can be found at http://www.dgif.virginia.gov/hunting/va_game_wildlife/.

Based on the above, USEPA and Virginia have developed a process to address the wildlife issue. First step in this process is the development of a Stage 1 scenario such as those presented previously in this chapter. The pollutant reductions in the Stage 1 scenario are targeted only at the controllable, anthropogenic bacteria sources identified in the TMDL, setting aside control strategies for wildlife except for cases of overpopulations. During the implementation of the Stage 1 scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described above. VADEQ will re-assess water quality in the stream during and subsequent to the implementation of the Stage 1 scenario to determine if the water quality standard is attained. This effort will also evaluate if the modeling assumptions were correct.

If water quality standards are not being met, a use attainability analysis (UAA) may be initiated to reflect the presence of naturally high bacteria levels due to uncontrollable sources. In some cases, the effort may never have to go to the UAA phase because the water quality standard exceedances attributed to wildlife in the model may have been very small and infrequent and within the margin of error.

6.4.5 Attainability of Designated Use

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use. In order for a stream to be assigned a new designated use, or a subcategory of a use, the current designated use must be removed. To remove a designated use, the state must demonstrate that the use is not an existing use, and that downstream uses are protected. Such uses will be attained by implementing effluent limits required under §301b and §306 of Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10 paragraph I).

The state must also demonstrate that attaining the designated use is not feasible because:

1. Naturally occurring pollutant concentration prevents the attainment of the use;
2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;
3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;
4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;

5. Physical conditions related to natural features of the water body, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or

6. Controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the USEPA, will be able to provide comment during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/pdf/WQS05A_1.pdf.

A 2006 amendment to the Code of Virginia under 62.1-44.19:7E provides an opportunity for aggrieved parties in the TMDL process to present to the State Water Control Board reasonable grounds indicating that the attainment of the designated use for a water is not feasible. The Board may then allow the aggrieved party to conduct a UAA according to the criteria listed above and a schedule established by the Board. The amendment further states “If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed.”

Chapter 7. Public Participation

The development of the Cripple Creek TMDL would not have been possible without public participation. The stakeholder insight provided is gratefully acknowledged.

The first public meeting was held at the Speedwell Volunteer Fire Department on July 29, 2008 to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. Thirty-four people attended the meeting. Copies of the presentation materials, watershed history results, source assessment per subwatershed, and various TMDL information handouts were available for public distribution. Public notice of the meetings was printed in the Virginia Register and advertised on the VADEQ and Mount Rogers Planning District Commission websites. Notification regarding the meetings was sent to area appointed and elected officials and Technical Advisory Committee (TAC) members. Members of the TAC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meetings through advertisements in the community calendar section of local newspapers, through post card mailings randomly distributed throughout the watershed, and through advertisements on the local cable television channels. There was a 30-day public comment period for the public meeting (July 29, 2008 to August 29, 2008), and no written comment was received.

The second and final public meeting was held at the Speedwell Volunteer Fire Department on July 23, 2009 to discuss the source allocations and reductions required to meet the TMDL. Copies of the draft TMDL report were available for public review and comment. Public notice of the meetings was printed in the Virginia Register and advertised on the VADEQ and Mount Rogers Planning District Commission websites. Notification regarding the meeting was sent to area appointed and elected officials, TAC members, and prior public meeting attendees. Members of the TAC were encouraged to distribute fliers advertising the meetings as appropriate. The general public was notified of the meeting through advertisements in the community calendar section of local newspapers and through advertisements on the local cable television channels. In addition, postcard mailings were randomly distributed throughout the watershed. There was a 30-day public comment period for the meeting extending from July 23, 2009 to August 23, 2009. Twenty-five people attended and no written comment was received.

In addition to keeping the public apprised of progress in the development of the Cripple Creek TMDL, a TMDL TAC was also established to help advise the TMDL developers. TAC meetings were held prior to public meetings. TAC meetings were held for this project on June 17, 2008 and July 20, 2009 at the Mount Rogers Planning District Commission in Marion, VA. Public notice was provided for these meetings in the Virginia Register. The TAC meetings were also advertised on the VADEQ and Mount Rogers Planning District Commission websites. Notification regarding the meeting was sent to area appointed and elected officials and TAC members. The TAC membership for the Cripple Creek TMDL included representatives from the following agencies and organizations:

- Virginia Department of Environmental Quality
- Virginia Department of Conservation and Recreation

- Mount Rogers Planning District Commission
- Evergreen Soil and Water Conservation District
- Big Walker Soil and Water Conservation District
- Smyth County Government
- Wythe County Government

Four and 14 people attended the June and July 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 geomorphologic 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.

Bacterial Source Tracking (BST)
A collection of scientific methods used to track sources of fecal coliform.

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.

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 loads from straight pipes to streams.

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.

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.

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).

Instantaneous criterion
The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for fecal coliform is 1,000 cfu/100 mL. If this value is exceeded at any time, the water body is in exceedance of the state water quality standard.

Load Allocation (LA)
The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)
A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models). The MOS may also be assigned explicitly, as was done in this study, to ensure that the water quality standard is not violated.

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

Nonpoint Source
Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen
Disease-causing agent, especially microorganisms such as certain bacteria, protozoa, and viruses.

Point Source
Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution
Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach
Segment of a stream or river.

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

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

Simulation
The use of mathematical models to approximate the observed behavior of a natural water system in response to a specific known set of input and forcing conditions. Models that have been validated, or verified, are then used to predict the response of a natural water system to changes in the input or forcing conditions.

Straight Pipe
Delivers wastewater directly from a building, e.g., house or milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)
The sum of the individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

Urban Runoff
Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.1

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 and antecedent rainfall for VADEQ station 9-CPL001.03 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9CPL001.03	07/12/2001	100	1.53
9CPL001.03	09/24/2001	800	0.34
9CPL001.03	11/29/2001	100	0.3
9CPL001.03	01/07/2002	100	0.13
9CPL001.03	03/28/2002	100	0.22
9CPL001.03	05/22/2002	400	0.4
9CPL001.03	07/30/2002	400	0.98
9CPL001.03	09/18/2002	4,000	0.78
9CPL001.03	11/25/2002	100	0.78
9CPL001.03	01/13/2003	100	0
9CPL001.03	03/26/2003	100	0.07
9CPL001.03	05/28/2003	200	0.7

Table A.2. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CPL002.82 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL002.82	07/12/2001	300	1.53
9-CPL002.82	09/24/2001	400	0.34
9-CPL002.82	11/29/2001	200	0.3
9-CPL002.82	01/07/2002	100	0.13
9-CPL002.82	03/28/2002	100	0.22
9-CPL002.82	05/22/2002	100	0.4
9-CPL002.82	07/30/2002	100	0.98
9-CPL002.82	09/18/2002	200	0.78
9-CPL002.82	11/25/2002	100	0.78
9-CPL002.82	01/13/2003	100	0
9-CPL002.82	03/26/2003	100	0.07
9-CPL002.82	05/28/2003	100	0.7

Table A.3. Observed fecal coliform concentration and antecedent rainfall from 1992 to 1998 for VADEQ station 9-CPL003.10 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL003.10	05/28/1992	200	0.27
9-CPL003.10	07/08/1992	100	0.99
9-CPL003.10	09/09/1992	100	0.79
9-CPL003.10	11/04/1992	200	0.62
9-CPL003.10	01/11/1993	100	0.76
9-CPL003.10	03/10/1993	100	0.6
9-CPL003.10	05/17/1993	140	0.23
9-CPL003.10	07/20/1993	250	0.48
9-CPL003.10	09/15/1993	70	0
9-CPL003.10	11/18/1993	2,000	0.39
9-CPL003.10	01/10/1994	1,050	0.83
9-CPL003.10	04/12/1994	1,400	1.1
9-CPL003.10	07/19/1995	500	0.35
9-CPL003.10	09/11/1995	380	0.03
9-CPL003.10	05/28/1996	200	1.06
9-CPL003.10	07/31/1996	370	0.73
9-CPL003.10	09/11/1996	600	0.76
9-CPL003.10	01/06/1997	220	0.59
9-CPL003.10	03/26/1997	1,400	0
9-CPL003.10	05/19/1997	190	0.56
9-CPL003.10	07/07/1997	190	1.1
9-CPL003.10	09/24/1997	490	0.29
9-CPL003.10	11/06/1997	210	0.92
9-CPL003.10	01/22/1998	210	0.49
9-CPL003.10	03/16/1998	40	0.3
9-CPL003.10	07/06/1998	110	0.62
9-CPL003.10	08/06/1998	90	0.2
9-CPL003.10	10/15/1998	120	0
9-CPL003.10	12/07/1998	60	0.26

Table A.4. Observed fecal coliform concentration and antecedent rainfall from 1998 to 2001 for VADEQ station 9-CPL003.10 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL003.10	10/19/1999	100	0.16
9-CPL003.10	12/02/1999	100	0.22
9-CPL003.10	02/16/2000	100	1.37
9-CPL003.10	04/06/2000	400	1.31
9-CPL003.10	06/13/2000	100	0
9-CPL003.10	08/14/2000	100	2.18
9-CPL003.10	10/19/2000	100	0.13
9-CPL003.10	12/13/2000	200	1.02
9-CPL003.10	02/07/2001	100	0

Table A.5. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CPL008.68 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL008.68	07/12/2001	100	1.53
9-CPL008.68	09/24/2001	300	0.34
9-CPL008.68	11/29/2001	100	0.3
9-CPL008.68	01/07/2002	100	0.13
9-CPL008.68	03/28/2002	100	0.22
9-CPL008.68	05/22/2002	100	0.4
9-CPL008.68	07/30/2002	200	0.98
9-CPL008.68	09/18/2002	100	0.78
9-CPL008.68	11/25/2002	100	0.78
9-CPL008.68	01/13/2003	100	0
9-CPL008.68	03/26/2003	100	0.07
9-CPL008.68	05/28/2003	200	0.7

Table A.6. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CPL018.47 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL018.47	07/12/2001	200	1.53
9-CPL018.47	09/24/2001	1,000	0.34
9-CPL018.47	11/29/2001	600	0.3
9-CPL018.47	01/07/2002	100	0.13
9-CPL018.47	03/28/2002	100	0.22
9-CPL018.47	05/22/2002	100	0.4
9-CPL018.47	07/30/2002	200	0.98
9-CPL018.47	09/18/2002	500	0.78
9-CPL018.47	11/25/2002	100	0.78
9-CPL018.47	01/13/2003	100	0
9-CPL018.47	03/26/2003	100	0.07
9-CPL018.47	05/28/2003	100	0.7

Table A.7. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CPL026.75 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL026.75	07/12/2001	400	1.53
9-CPL026.75	09/24/2001	200	0.34
9-CPL026.75	11/29/2001	100	0.3
9-CPL026.75	01/07/2002	300	0.13
9-CPL026.75	03/28/2002	100	0.22
9-CPL026.75	05/22/2002	400	0.4
9-CPL026.75	07/30/2002	100	0.98
9-CPL026.75	09/18/2002	200	0.78
9-CPL026.75	11/25/2002	100	0.78
9-CPL026.75	01/13/2003	100	0
9-CPL026.75	03/26/2003	100	0.07
9-CPL026.75	05/28/2003	100	0.7

Table A.8. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CPL028.10 in Cripple Creek watershed.

Station	Date	Observed Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 Days (in)
9-CPL028.10	07/12/2001	500	1.53
9-CPL028.10	09/24/2001	700	0.34
9-CPL028.10	11/29/2001	400	0.3
9-CPL028.10	01/07/2002	300	0.13
9-CPL028.10	03/28/2002	100	0.22
9-CPL028.10	05/22/2002	100	0.4
9-CPL028.10	07/30/2002	200	0.98
9-CPL028.10	09/18/2002	100	0.78
9-CPL028.10	11/25/2002	100	0.78
9-CPL028.10	01/13/2003	100	0
9-CPL028.10	03/26/2003	100	0.07
9-CPL028.10	05/28/2003	300	0.7

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 station 9-CPL001.03.

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/pdf/bstreports/directoryListing/082008bst.pdf

or contact VADEQ-SWRO

Appendix C – Fecal Coliform Loading in Subwatersheds

Table C.1. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-01.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	6	40,636	10,514	2,298	454	1,005
Feb.	437	41,572	10,708	2,376	413	916
Mar.	2,161	77,201	19,617	4,573	338	1,005
Apr.	1,730	77,396	19,665	4,596	327	973
May.	437	81,458	20,727	4,851	338	1,005
Jun.	6	80,327	20,433	4,788	322	973
Jul.	6	84,645	21,525	5,050	333	1,005
Aug.	6	86,287	21,936	5,153	333	1,005
Sep.	6	85,239	21,652	5,093	439	973
Oct.	544	62,204	15,894	3,643	454	1,005
Nov.	662	61,057	15,596	3,579	439	973
Dec.	6	39,402	10,206	2,221	454	1,005
Total	6,009	817,422	208,472	48,221	4,643	11,842

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

Table C.2. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-02.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	2	74,321	19,244	4,195	509	1,153
Feb.	86	77,574	19,843	4,399	464	1,050
Mar.	424	144,378	35,989	8,381	366	1,153
Apr.	340	143,622	35,939	8,388	354	1,115
May.	86	149,730	37,970	8,876	366	1,153
Jun.	2	148,071	37,517	8,783	354	1,115
Jul.	2	156,208	39,609	9,286	366	1,153
Aug.	2	159,638	40,451	9,496	366	1,153
Sep.	2	158,656	40,008	9,405	493	1,115
Oct.	66	110,786	28,073	6,402	509	1,153
Nov.	130	110,209	27,892	6,376	493	1,115
Dec.	2	71,795	18,612	4,036	509	1,153
Total	1,144	1,504,989	381,146	88,023	5,150	13,581

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

Table C.3. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-03.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	380	100	20	0	1
Feb.	3	398	104	22	0	1
Mar.	16	708	182	41	0	1
Apr.	13	703	180	41	0	1
May.	3	745	191	43	0	1
Jun.	0	738	189	43	0	1
Jul.	0	781	200	46	0	1
Aug.	0	800	205	47	0	1
Sep.	0	793	203	46	0	1
Oct.	5	525	136	29	0	1
Nov.	5	531	137	30	0	1
Dec.	0	366	96	20	0	1
Total	45	7,467	1,924	428	4	16

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

Table C.4. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-04.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	1	26,270	6,846	1,452	559	1,129
Feb.	148	27,655	7,152	1,552	510	1,029
Mar.	736	49,950	12,688	2,913	431	1,129
Apr.	589	49,563	12,600	2,899	417	1,093
May.	148	52,311	13,350	3,078	431	1,129
Jun.	1	51,855	13,228	3,056	410	1,093
Jul.	1	54,912	14,002	3,241	424	1,129
Aug.	1	56,243	14,335	3,324	424	1,129
Sep.	1	55,855	14,212	3,302	541	1,093
Oct.	225	36,734	9,432	2,099	559	1,129
Nov.	225	37,172	9,533	2,132	541	1,093
Dec.	1	25,270	6,596	1,390	559	1,129
Total	2,081	523,789	133,974	30,439	5,807	13,304

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

Table C.5. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-05.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	1	56,554	14,796	3,086	426	1,072
Feb.	34	59,384	15,339	3,277	388	977
Mar.	166	108,051	27,145	6,174	305	1,072
Apr.	133	107,091	26,993	6,156	295	1,038
May.	34	111,967	28,564	6,528	305	1,072
Jun.	1	110,867	28,266	6,474	295	1,038
Jul.	1	117,243	29,886	6,859	305	1,072
Aug.	1	119,953	30,564	7,028	305	1,072
Sep.	1	119,298	30,268	6,974	412	1,038
Oct.	26	80,594	20,598	4,537	426	1,072
Nov.	51	81,031	20,686	4,579	412	1,038
Dec.	1	54,521	14,286	2,959	426	1,072
Total	448	1,126,555	287,392	64,632	4,303	12,636

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

Table C.6. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-06.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	0	0	0	105	191
Feb.	0	0	0	0	96	174
Mar.	0	0	0	0	85	191
Apr.	0	0	0	0	82	184
May.	0	0	0	0	85	191
Jun.	0	0	0	0	80	184
Jul.	0	0	0	0	83	191
Aug.	0	0	0	0	83	191
Sep.	0	0	0	0	102	184
Oct.	0	0	0	0	105	191
Nov.	0	0	0	0	102	184
Dec.	0	0	0	0	105	191
Total	0	0	0	0	1,113	2,246

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

Table C.7. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-07.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	0	0	0	156	276
Feb.	0	0	0	0	142	251
Mar.	0	0	0	0	128	276
Apr.	0	0	0	0	124	267
May.	0	0	0	0	128	276
Jun.	0	0	0	0	117	267
Jul.	0	0	0	0	121	276
Aug.	0	0	0	0	121	276
Sep.	0	0	0	0	151	267
Oct.	0	0	0	0	156	276
Nov.	0	0	0	0	151	267
Dec.	0	0	0	0	156	276
Total	0	0	0	0	1,652	3,250

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

Table C.8. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-08.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	6,592	1,729	357	262	528
Feb.	6	6,947	1,799	382	238	482
Mar.	29	12,543	3,162	716	204	528
Apr.	23	12,415	3,139	712	197	511
May.	6	13,009	3,324	756	204	528
Jun.	0	12,893	3,293	751	197	511
Jul.	0	13,647	3,484	796	204	528
Aug.	0	13,974	3,566	817	204	528
Sep.	0	13,902	3,534	811	253	511
Oct.	9	9,216	2,363	516	262	528
Nov.	9	9,319	2,386	524	253	511
Dec.	0	6,347	1,667	342	262	528
Total	81	130,804	33,445	7,480	2,739	6,227

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

Table C.9. Monthly nonpoint fecal coliform loadings in sub-watershed CRC-09.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	2	49,693	13,020	2,697	269	838
Feb.	192	52,246	13,557	2,880	245	764
Mar.	953	93,950	23,845	5,403	184	838
Apr.	763	93,123	23,671	5,377	178	811
May.	192	98,019	25,071	5,709	184	838
Jun.	2	97,141	24,833	5,668	176	811
Jul.	2	102,838	26,278	6,011	182	838
Aug.	2	105,304	26,895	6,165	182	838
Sep.	2	104,629	26,656	6,124	261	811
Oct.	291	69,235	17,811	3,894	269	838
Nov.	291	70,012	17,987	3,956	261	811
Dec.	2	47,841	12,556	2,581	269	838
Total	2,695	984,031	252,180	56,464	2,660	9,877

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	2	37,592	9,849	2,039	343	839
Feb.	170	39,502	10,255	2,178	313	764
Mar.	844	70,964	18,038	4,087	250	839
Apr.	676	70,361	17,907	4,068	242	812
May.	170	74,134	18,966	4,319	250	839
Jun.	2	73,469	18,786	4,287	242	812
Jul.	2	77,780	19,879	4,547	250	839
Aug.	2	79,645	20,347	4,664	250	839
Sep.	2	79,112	20,166	4,632	332	812
Oct.	258	52,332	13,473	2,946	343	839
Nov.	258	52,921	13,606	2,993	332	812
Dec.	2	36,190	9,498	1,952	343	839
Total	2,385	744,003	190,770	42,712	3,495	9,881

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	0	0	0	219	405
Feb.	0	0	0	0	200	369
Mar.	0	0	0	0	176	405
Apr.	0	0	0	0	171	392
May.	0	0	0	0	176	405
Jun.	0	0	0	0	171	392
Jul.	0	0	0	0	176	405
Aug.	0	0	0	0	176	405
Sep.	0	0	0	0	212	392
Oct.	0	0	0	0	219	405
Nov.	0	0	0	0	212	392
Dec.	0	0	0	0	219	405
Total	0	0	0	0	2,327	4,768

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	6,263	1,640	339	43	104
Feb.	5	6,603	1,708	363	39	95
Mar.	24	11,933	3,005	681	30	104
Apr.	19	11,811	2,984	677	29	101
May.	5	12,375	3,160	719	30	104
Jun.	0	12,265	3,130	714	27	101
Jul.	0	12,983	3,312	757	28	104
Aug.	0	13,294	3,390	777	28	104
Sep.	0	13,227	3,360	772	42	101
Oct.	7	8,763	2,244	490	43	104
Nov.	7	8,861	2,267	498	42	101
Dec.	0	6,030	1,582	325	43	104
Total	68	124,409	31,783	7,113	426	1,226

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	3	27,588	7,226	1,500	404	681
Feb.	233	28,897	7,525	1,602	368	621
Mar.	1,152	51,624	13,245	3,005	305	681
Apr.	922	51,281	13,149	2,991	296	659
May.	233	54,348	13,927	3,176	305	681
Jun.	3	53,861	13,795	3,153	294	659
Jul.	3	57,027	14,598	3,344	304	681
Aug.	3	58,399	14,942	3,429	304	681
Sep.	3	57,910	14,809	3,406	391	659
Oct.	353	38,225	9,890	2,166	404	681
Nov.	353	38,659	9,988	2,201	391	659
Dec.	3	26,558	6,968	1,436	404	681
Total	3,262	544,377	140,062	31,410	4,170	8,025

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	2	15,789	4,137	857	340	854
Feb.	133	16,534	4,308	916	310	778
Mar.	658	29,524	7,577	1,717	262	854
Apr.	527	29,327	7,522	1,709	254	827
May.	133	31,080	7,967	1,815	262	854
Jun.	2	30,801	7,891	1,802	252	827
Jul.	2	32,611	8,350	1,911	260	854
Aug.	2	33,395	8,546	1,960	260	854
Sep.	2	33,114	8,470	1,946	329	827
Oct.	202	21,867	5,659	1,238	340	854
Nov.	202	22,114	5,715	1,258	329	827
Dec.	2	15,200	3,990	821	340	854
Total	1,866	311,355	80,131	17,949	3,539	10,063

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	5	39,099	10,198	2,154	254	563
Feb.	398	40,391	10,486	2,261	231	513
Mar.	1,970	73,349	18,776	4,299	181	563
Apr.	1,577	73,229	18,732	4,300	175	545
May.	398	77,388	19,787	4,551	181	563
Jun.	5	76,486	19,548	4,504	170	545
Jul.	5	80,774	20,635	4,763	176	563
Aug.	5	82,512	21,070	4,872	176	563
Sep.	5	81,629	20,836	4,826	246	545
Oct.	544	56,954	14,670	3,272	254	563
Nov.	603	56,660	14,583	3,263	246	545
Dec.	5	37,792	9,871	2,072	254	563
Total	5,523	776,264	199,192	45,139	2,542	6,634

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	3,309	866	180	19	51
Feb.	3	3,490	902	193	17	47
Mar.	13	6,314	1,590	361	12	51
Apr.	10	6,249	1,578	359	11	50
May.	3	6,548	1,672	382	12	51
Jun.	0	6,490	1,656	379	11	50
Jul.	0	6,870	1,752	402	12	51
Aug.	0	7,035	1,794	412	12	51
Sep.	0	7,000	1,778	409	18	50
Oct.	4	4,634	1,186	260	19	51
Nov.	4	4,686	1,198	264	18	50
Dec.	0	3,185	835	173	19	51
Total	37	65,808	16,807	3,774	181	606

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	3	26,125	6,845	1,419	232	782
Feb.	220	27,359	7,127	1,515	211	712
Mar.	1,089	48,853	12,537	2,842	169	782
Apr.	872	48,527	12,445	2,828	163	756
May.	220	51,428	13,182	3,003	169	782
Jun.	3	50,966	13,056	2,981	161	756
Jul.	3	53,962	13,816	3,162	167	782
Aug.	3	55,259	14,141	3,243	167	782
Sep.	3	54,795	14,015	3,221	224	756
Oct.	334	36,183	9,364	2,048	232	782
Nov.	334	36,592	9,457	2,081	224	756
Dec.	3	25,150	6,601	1,358	232	782
Total	3,087	515,198	132,586	29,700	2,350	9,209

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	15,300	3,932	885	64	693
Feb.	23	15,336	3,884	882	58	631
Mar.	112	30,001	7,373	1,745	49	693
Apr.	90	30,206	7,469	1,773	48	670
May.	23	31,040	7,825	1,859	49	693
Jun.	0	30,522	7,670	1,823	40	670
Jul.	0	31,791	8,036	1,911	42	693
Aug.	0	32,318	8,146	1,939	42	693
Sep.	0	32,025	7,999	1,905	62	670
Oct.	17	25,993	6,536	1,536	64	693
Nov.	34	24,874	6,230	1,463	62	670
Dec.	0	14,971	3,849	865	64	693
Total	302	314,379	78,947	18,584	644	8,161

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

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

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)					
	Cropland	Pasture 1	Pasture 2	Pasture 3	Forest	Residential[1]
Jan.	0	2,766	726	150	12	163
Feb.	23	2,896	755	160	11	149
Mar.	115	5,165	1,326	300	5	163
Apr.	92	5,130	1,316	298	5	158
May.	23	5,436	1,394	317	5	163
Jun.	0	5,387	1,381	314	5	158
Jul.	0	5,704	1,461	333	5	163
Aug.	0	5,840	1,496	342	5	163
Sep.	0	5,791	1,482	340	12	158
Oct.	35	3,828	991	216	12	163
Nov.	35	3,871	1,001	219	12	158
Dec.	0	2,664	700	143	12	163
Total	325	54,477	14,030	3,133	99	1,924

[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 CRC-01 of Cripple Creek.

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	600,877	0.5%	18,026	97%
Pasture	107,411,484	98%	3,222,341	97%
Forest	464,334	0.4%	464,334	0%
Residential	1,184,243	1%	35,527	97%
Total	109,660,938	100%	3,740,229	97%

Table D.2. Required annual reductions in direct nonpoint sources in sub-watershed CRC-01 of Cripple Creek.

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	111,515	24%	3,345	97%
Wildlife in Streams	90,215	20%	90,215	0%
Straight Pipes	258,919	56%	0	100%
Total	460,649	100%	93,561	80%

Table D.3. Required annual reductions in nonpoint sources in sub-watershed CRC-02 of Cripple Creek.

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	114,439	0.1%	2,289	98%
Pasture	197,415,738	99%	3,948,311	98%
Forest	514,987	0.3%	514,987	0%
Residential	1,358,054	0.7%	27,161	98%
Total	199,403,219	100%	4,492,748	98%

Table D.4. Required annual reductions in direct nonpoint sources in sub-watershed CRC-02 of Cripple Creek.

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	204,322	37%	4,086	98%
Wildlife in Streams	120,042	21%	120,042	0%
Straight Pipes	234,975	42%	0	100%
Total	559,339	100%	124,128	78%

Table D.5. Required annual reductions in nonpoint sources in sub-watershed CRC-03 of Cripple Creek.

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	4,527	0.5%	91	98%
Pasture	981,842	99%	19,637	98%
Forest	363	0%	363	0%
Residential	1,644	0.2%	33	98%
Total	988,376	100%	20,124	98%

Table D.6. Required annual reductions in direct nonpoint sources in sub-watershed CRC-03 of Cripple Creek.

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	994	74%	20	98%
Wildlife in Streams	346	26%	346	0%
Total	1,340	100%	366	73%

Table D.7. Required annual reductions in nonpoint sources in sub-watershed CRC-04 of Cripple Creek.

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	208,087	0.3%	4,162	98%
Pasture	68,820,168	97%	1,376,402	98%
Forest	580,698	0.8%	580,698	0%
Residential	1,330,381	2%	26,608	98%
Total	70,939,333	100%	1,987,869	97%

Table D.8. Required annual reductions in direct nonpoint sources in sub-watershed CRC-04 of Cripple Creek.

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	70,898	28%	1,418	98%
Wildlife in Streams	100,428	39%	100,428	0%
Straight Pipes	84,107	33%	0	100%
Total	255,434	100%	101,846	60%

Table D.9. Required annual reductions in nonpoint sources in sub-watershed CRC-05 of Cripple Creek.

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	44,758	0%	895	98%
Pasture	147,857,847	99%	2,957,154	98%
Forest	430,311	0.3%	430,311	0%
Residential	1,263,603	0.8%	25,272	98%
Total	149,596,518	100%	3,413,632	98%

Table D.10. Required annual reductions in direct nonpoint sources in sub-watershed CRC-05 of Cripple Creek.

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	150,129	31%	3,003	98%
Wildlife in Streams	105,930	22%	105,930	0%
Straight Pipes	234,130	48%	0	100%
Total	490,189	100%	108,932	78%

Table D.11. Required annual reductions in nonpoint sources in sub-watershed CRC-06 of Cripple Creek.

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	42	0%	1	98%
Pasture	42	0%	1	98%
Forest	111,271	33%	111,271	0%
Residential	224,568	67%	4,491	98%
Total	335,923	100%	115,764	66%

Table D.12. Required annual reductions in direct nonpoint sources in sub-watershed CRC-06 of Cripple Creek.

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
Wildlife in Streams	14,279	100%	14,279	0%
Total	14,279	100%	14,279	0%

Table D.13. Required annual reductions in nonpoint sources in sub-watershed CRC-07 of Cripple Creek.

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	0%	1	98%
Pasture	53	0%	1	98%
Forest	165,194	34%	165,194	0%
Residential	324,965	66%	6,499	98%
Total	490,256	100%	171,695	65%

Table D.14. Required annual reductions in direct nonpoint sources in sub-watershed CRC-07 of Cripple Creek.

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
Wildlife in Streams	21,102	58%	21,102	0%
Straight Pipes	15,174	42%	0	100%
Total	36,276	100%	21,102	42%

Table D.15. Required annual reductions in nonpoint sources in sub-watershed CRC-08 of Cripple Creek.

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	8,119	0%	162	98%
Pasture	17,172,951	95%	343,459	98%
Forest	273,909	2%	273,909	0%
Residential	622,684	3%	12,454	98%
Total	18,077,663	100%	629,984	97%

Table D.16. Required annual reductions in direct nonpoint sources in sub-watershed CRC-08 of Cripple Creek.

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	17,393	14%	348	98%
Wildlife in Streams	41,696	34%	41,696	0%
Straight Pipes	64,350	52%	0	100%
Total	123,440	100%	42,044	66%

Table D.17. Required annual reductions in nonpoint sources in sub-watershed CRC-09 of Cripple Creek.

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	269,478	0.2%	5,390	98%
Pasture	129,267,504	99%	2,585,348	98%
Forest	265,993	0.2%	265,993	0%
Residential	987,724	0.8%	19,754	98%
Total	130,790,698	100%	2,876,484	98%

Table D.18. Required annual reductions in direct nonpoint sources in sub-watershed CRC-09 of Cripple Creek.

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	131,361	41%	2,627	98%
Wildlife in Streams	78,470	24%	78,470	0%
Straight Pipes	110,878	35%	0	100%
Total	320,709	100%	81,098	75%

Table D.19. Required annual reductions in nonpoint sources in sub-watershed CRC-10 of Cripple Creek.

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	238,537	0.2%	4,771	98%
Pasture	97,748,463	98%	1,954,967	98%
Forest	349,469	0.4%	349,469	0%
Residential	988,115	1.0%	19,762	98%
Total	99,324,585	100%	2,328,970	98%

Table D.20. Required annual reductions in direct nonpoint sources in sub-watershed CRC-10 of Cripple Creek.

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	99,390	37%	1,988	98%
Wildlife in Streams	74,964	28%	74,964	0%
Straight Pipes	92,491	35%	0	100%
Total	266,845	100%	76,952	71%

Table D.21. Required annual reductions in nonpoint sources in sub-watershed CRC-11 of Cripple Creek.

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	0%	1	98%
Pasture	53	0%	1	98%
Forest	232,681	33%	232,681	0%
Residential	476,757	67%	9,535	98%
Total	709,534	100%	242,218	66%

Table D.22. Required annual reductions in direct nonpoint sources in sub-watershed CRC-11 of Cripple Creek.

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
Wildlife in Streams	28,876	100%	28,876	0%
Total	28,876	100%	28,876	0%

Table D.23. Required annual reductions in nonpoint sources in sub-watershed CRC-12 of Cripple Creek.

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	6,827	0%	137	98%
Pasture	16,330,481	99%	326,609	98%
Forest	42,584	0.3%	42,584	0%
Residential	122,599	0.7%	2,452	98%
Total	16,502,491	100%	371,782	98%

Table D.24. Required annual reductions in direct nonpoint sources in sub-watershed CRC-12 of Cripple Creek.

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	16,565	40%	331	98%
Wildlife in Streams	9,592	23%	9,592	0%
Straight Pipes	14,954	36%	0	100%
Total	41,112	100%	9,924	76%

Table D.25. Required annual reductions in nonpoint sources in sub-watershed CRC-13 of Cripple Creek.

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	326,206	0.4%	6,524	98%
Pasture	71,584,858	98%	1,431,696	98%
Forest	417,001	0.6%	417,001	0%
Residential	802,544	1%	16,051	98%
Total	73,130,609	100%	1,871,272	97%

Table D.26. Required annual reductions in direct nonpoint sources in sub-watershed CRC-13 of Cripple Creek.

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	73,052	24%	1,461	98%
Wildlife in Streams	79,751	26%	79,751	0%
Straight Pipes	148,451	49%	0	100%
Total	301,254	100%	81,212	73%

Table D.27. Required annual reductions in nonpoint sources in sub-watershed CRC-14 of Cripple Creek.

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	186,644	0.4%	3,733	98%
Pasture	40,943,515	96%	818,870	98%
Forest	353,908	0.8%	353,908	0%
Residential	1,006,284	2%	20,126	98%
Total	42,490,351	100%	1,196,637	97%

Table D.28. Required annual reductions in direct nonpoint sources in sub-watershed CRC-14 of Cripple Creek.

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	41,744	13%	835	98%
Wildlife in Streams	59,991	19%	59,991	0%
Straight Pipes	211,458	68%	0	100%
Total	313,193	100%	60,826	81%

Table D.29. Required annual reductions in nonpoint sources in sub-watershed CRC-15 of Cripple Creek.

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	552,335	0.5%	11,047	98%
Pasture	102,059,473	99%	2,041,188	98%
Forest	254,243	0.2%	254,243	0%
Residential	663,434	0.6%	13,269	98%
Total	103,529,485	100%	2,319,746	98%

Table D.30. Required annual reductions in direct nonpoint sources in sub-watershed CRC-15 of Cripple Creek.

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	104,624	30%	2,092	98%
Wildlife in Streams	63,138	18%	63,138	0%
Straight Pipes	182,837	52%	0	100%
Total	350,599	100%	65,230	81%

Table D.31. Required annual reductions in nonpoint sources in sub-watershed CRC-16 of Cripple Creek.

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	3,698	0%	74	98%
Pasture	8,638,911	99%	172,778	98%
Forest	18,080	0.2%	18,080	0%
Residential	60,605	0.7%	1,212	98%
Total	8,721,293	100%	192,144	98%

Table D.32. Required annual reductions in direct nonpoint sources in sub-watershed CRC-16 of Cripple Creek.

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	8,779	61%	176	98%
Wildlife in Streams	5,680	39%	5,680	0%
Total	14,460	100%	5,856	60%

Table D.33. Required annual reductions in nonpoint sources in sub-watershed CRC-17 of Cripple Creek.

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	308,704	0.4%	6,174	98%
Pasture	67,748,517	98%	1,354,969	98%
Forest	234,975	0.3%	234,975	0%
Residential	920,944	1%	18,419	98%
Total	69,213,139	100%	1,614,537	98%

Table D.34. Required annual reductions in direct nonpoint sources in sub-watershed CRC-17 of Cripple Creek.

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	69,076	27%	1,382	98%
Wildlife in Streams	55,592	22%	55,592	0%
Straight Pipes	128,144	51%	0	100%
Total	252,812	100%	56,973	77%

Table D.35. Required annual reductions in nonpoint sources in sub-watershed CRC-18 of Cripple Creek.

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	30,212	0.1%	604	98%
Pasture	41,191,064	98%	823,821	98%
Forest	64,392	0.2%	64,392	0%
Residential	816,121	2%	16,322	98%
Total	42,101,791	100%	905,140	98%

Table D.36. Required annual reductions in direct nonpoint sources in sub-watershed CRC-18 of Cripple Creek.

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	42,598	60%	852	98%
Wildlife in Streams	14,559	20%	14,559	0%
Straight Pipes	14,431	20%	0	100%
Total	71,587	100%	15,411	78%

Table D.37. Required annual reductions in nonpoint sources in sub-watershed CRC-19 of Cripple Creek.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	32,483	0.4%	650	98%
Pasture	7,164,009	97%	143,280	98%
Forest	9,884	0.1%	9,884	0%
Residential	192,392	3%	3,848	98%
Total	7,398,768	100%	157,662	98%

Table D.38. Required annual reductions in direct nonpoint sources in sub-watershed CRC-19 of Cripple Creek.

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	7,289	72%	146	98%
Wildlife in Streams	2,883	28%	2,883	0%
Total	10,172	100%	3,029	70%