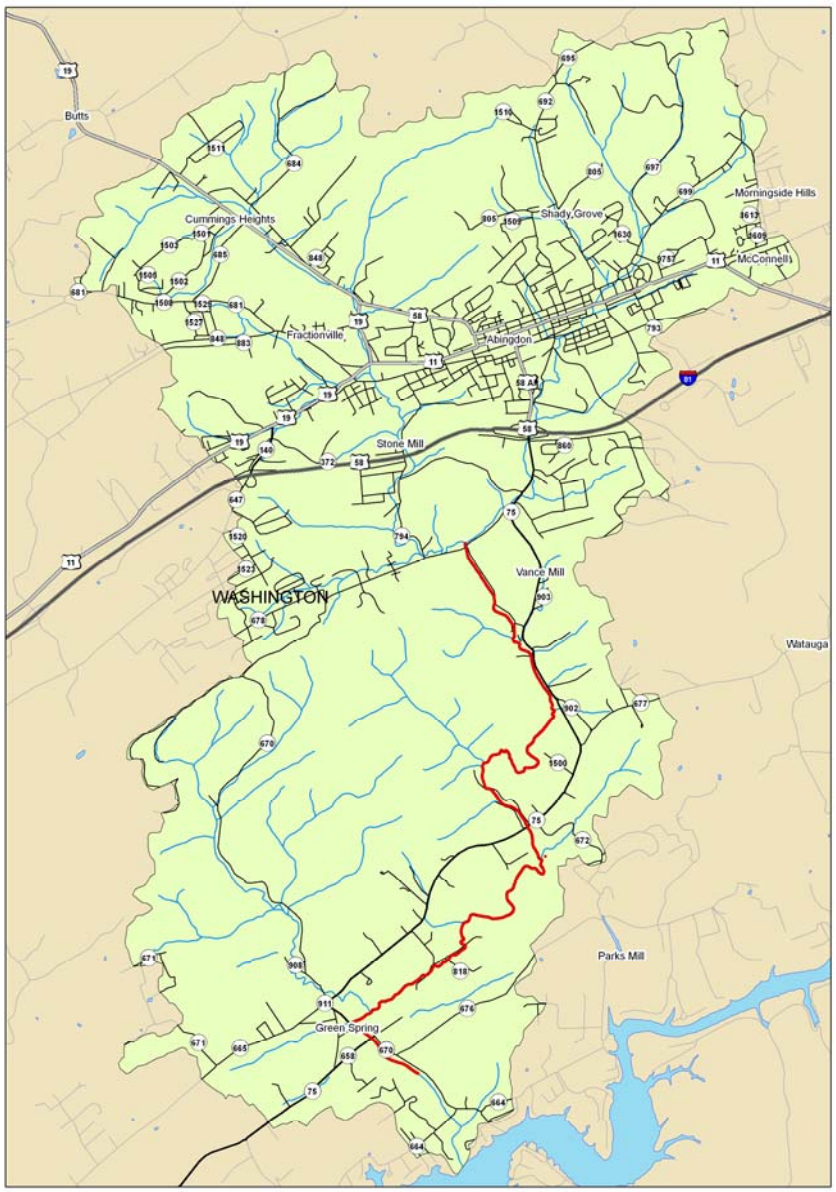
# Bacteria and Benthic Total Maximum Daily Load Development for Wolf Creek

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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

Wolf Creek (VAS-O06R-01) was first listed as impaired streams in 1998 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) indicating that the recreational use goal and aquatic life goal were not being met. The stream segment was further listed in 2002, 2004, and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002, 2004, and 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data. The impaired portion of Wolf Creek (VAS-O06R-01) delineated by VADEQ, which runs 7.83 miles beginning from the confluence with Town Creek, just south of Abingdon, to the backwaters of South Holston Lake, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 6-CWLF001.18.

The Wolf Creek impairment watershed is located in Washington County, Virginia. The Wolf Creek impairment begins south of the Town of Abingdon, Virginia near the community of Vance Mill, Virginia and flows approximately 13 miles, along Route 75, south toward the community of Green Spring, Virginia. It continues downstream to the back waters of the South Holston Lake. The Wolf Creek watershed is approximately 17,324 acres predominately pasture, constituting approximately 44.4% of the total watershed area. The remaining land uses are divided between forest (33.2%), residential (21%), and cropland (0.9%).

VADEQ personnel monitored pollutant concentrations throughout Wolf Creek. Of the 8 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 6-CWLF001.18, 12.5% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Consequently, this segment of Wolf Creek (VAS-O06R) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

Data were considered from two benthic sampling stations. The Virginia Stream Condition Index (VaSCI) based on eight bio-monitoring metrics was utilized to assess samples collected at each station. Stream health scores, in the form of SCI values, range from 0-100. A maximum score of 100 represents the best benthic community sites. The threshold criterion defines "non-impaired" sites as those with a VaSCI of 60 or above, and "impaired" sites as those with a score below 60. Impaired conditions exist at both stations on Wolf Creek. The biological assessments conducted on the Wolf Creek indicate that some pollutant(s) is interfering with attainment of the General Standard, as impaired invertebrate communities have been observed in the listed segment of this river. Although biological assessments are indicative of the impacts of pollution, the specific pollutant(s) and source(s) are not necessarily known based on biological assessments alone.

## Stressor Analysis

TMDLs must be developed for a specific pollutant. Since the benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Wolf Creek. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from VADEQ monitoring provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible. Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause. Each candidate stressor was evaluated based on available monitoring data, field observations, and consideration of potential sources in the watershed. Depending on the weight of evidence available, each potential stressor was placed into one of the following three categories:

Non-stressor: Stressor with data indicating normal conditions, without water quality standard exceedances, or without observable impacts usually associated with the stressor.

Possible stressor: Stressor with data indicating possible links to the benthic impairment, but without conclusive data to demonstrate direct impact on benthic community.

Most probable stressor(s): Stressor with conclusive data linking it to the poor health of the benthic community, or the most plausible of the possible stressors. TMDL is developed for the most probable stressor(s).

The evaluation resulted in pH, temperature, dissolved oxygen, and ammonia being classified as non- stressors; nutrients, heavy metals, and organics were classified as possible stressors; and sediment was classified as the most probable stressors adversely affecting the benthic community in Wolf Creek watershed.

## Pollutant Sources

Currently, there are two active point source discharges with a VPDES permit to discharge bacteria within the Wolf Creek watershed. However, the majority of the fecal coliform load originates from nonpoint sources. Nonpoint sources of fecal coliform are primarily agricultural (i.e., land-applied animal waste, manure deposited directly on pastures by livestock, and a significant fecal coliform load due to cattle directly depositing manure in streams) with a significant load applied to residential and forest land use categories. Non-agricultural anthropogenic nonpoint sources of fecal coliform loadings include straight pipes, leaking sanitary sewer, failing septic systems, and pet waste. Wildlife contributes to fecal coliform loadings on all land uses, according to the acceptable habitat range for each species. The amounts of fecal coliform produced in different locations (e.g., confinement, pasture, forest)

were estimated on a monthly basis to account for seasonal variability in wildlife habitat and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement or in streams, the amount of manure storage, and spreading schedules, were considered on a monthly basis.

Sediment can be delivered to the stream from point sources, nonpoint sources, and the processes of scour and deposition (primarily a function of stream flow) in the stream. Additional natural occurring sediment is deposited in the summer and early fall in the form of travertine. The out-gassing of $CO_2$ when cool ground water containing a high concentration of dissolved carbonates mixes with warmer water in the stream results in deposition of travertine. The travertine covers rocks, cobbles, and exposed bedrock with a carbonate encrustation and has formed numerous dams, ledges, and pools in Wolf Creek. Depending on the scouring action of stream flow, this naturally occurring sedimentation can change the stream morphology. Sediment loadings from permitted sources are attributable to the total suspended solids (TSS) present in discharge effluent or stormwater runoff. There are three VPDES permitted facilities currently active or under application within the Wolf Creek watershed discharging TSS. Stormwater permits are divided between two industrial, one concrete plant, and one mining facilities. Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses. During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. Vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration, and land management practices influence this process. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to wash-off during rainfall events.

## Modeling

The Hydrologic Simulation Program – Fortran (HSPF) was used to simulate the fate and transport of fecal coliform bacteria in the Wolf 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. Observed stream flow values were not available for Wolf Creek, therefore a “paired watershed” approach was used for hydrologic calibration and validation. The approach assumes that the paired watershed and Wolf Creek watershed have similar hydrologic responses based on physical, geologic, and hydrologic characteristics. The Middle Fork Holston River watershed was chosen as the paired watershed due to similar physiographic and hydrologic characteristics. Hydrology calibration and validation were performed based on the physical, hydrologic, and land use data for the Middle Fork Holston River watershed. After calibration and validation completion, the parameterization for the Middle Fork Holston River model was transferred to the Wolf Creek model. Parameters describing watershed characteristics such as land use, slope, infiltration rate, and F-Tables were updated to reflect the physical properties in Wolf Creek watershed.

The Middle Fork Holston River model was calibrated using observed flow values from USGS station #03474000 on Middle Fork Holston River near Seven Mile Ford, VA and USGS station #003475000 on Middle Fork Holston River near Mock Mill, VA for the period January 1, 2003 to December 31, 2007. The calibration period covered a wide range of hydrologic conditions, including low- and high-flow conditions, as well as seasonal variations. The calibrated HSPF model was validated on a separate period from January 1, 1998 to December 31, 2002. Calibration parameters were adjusted within the recommended ranges until the model performance was deemed acceptable. The period January 1, 1997 through December 31, 2001 was chosen for water quality calibration and January 1, 2002 through December 31, 2006 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 6-CWLF006.55, 6-CWLF001.18, 6-CWLF001.46 within the Wolf Creek impairment were used to calibrate the water quality component of HSPF. 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.

A reference watershed approach was used to establish the numeric sediment TMDL endpoint for Wolf Creek. The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. The reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment. The headwater section of Cripple Creek was selected as the reference watershed. The Generalized Watershed Loading Function (GWLF) model was used to simulate sediment load from potential sources in the impaired and reference watersheds.

## 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 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. An explicit margin of safety of 10% of the reference load was used for the sediment TMDL to account for uncertainties in the methodologies used to determine sediment loadings.

## TMDL Allocation Scenarios

The wasteload allocated to permitted point sources in the watershed was based on the design flow or calculated runoff and the permitted concentration of *E. coli* or total suspended solids for each facility. No reduction in permitted source loads is required.

After calibrating to the existing water quality conditions, different scenarios were evaluated to identify implementable scenarios that meet both the calendar-month geometric

mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero exceedances. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Required reductions in fecal coliform loading from existing conditions for the selected TMDL allocation 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.

Sediment load allocations for nonpoint sources not covered under the general wastewater permits were based on an equal percent reduction from controllable sources. Sediment loads from forest land use are considered to be representative of the natural condition and were not subject to reductions. Overall, the sediment load in the Wolf Creek watershed must be reduced by 58% in order to meet the established TMDL endpoint. This translates to a 78% reduction in sediment from cropland, pasture, transitional, and residential land uses; along with sediment from channel erosion.

Using equation [E.1], summaries of the Wolf Creek bacteria and sediment TMDLs for the selected allocation scenario are shown in Tables E.1 through E.4.

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

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 Wolf Creek impairment.**

| Pollutant | WLA[1] (cfu/yr) | LA[2] (cfu/yr) | MOS | TMDL[3] (cfu/yr) |
|---|---|---|---|---|
| *E. coli* | 7.31E+13 | 8.10E+12 | Implicit | 8.12E+13 |

**Table E.2. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Wolf Creek impairment.**

| Pollutant | WLA[1] (cfu/d) | LA[2] (cfu/d) | MOS | TMDL[3] (cfu/d) |
|---|---|---|---|---|
| *E. coli* | 2.00E+11 | 1.55E+12 | Implicit | 1.75E+12 |

**Table E.3. Yearly sediment loads (T/yr) modeled after TMDL allocation in Wolf Creek impairment.**

| WLA (T/yr) | LA (T/yr) | MOS (T/yr) | TMDL (T/yr) |
|---|---|---|---|
| 301.6 | 177.7 | 61.1 | 540.4 |

**Table E.4. Daily sediment loads (T/d) modeled after TMDL allocation in Wolf Creek impairment.**

| WLA (T/d) | LA (T/d) | MOS (T/d) | TMDL (T/d) |
|---|---|---|---|
| 1.23 | 1.61 | 0.32 | 3.16 |

## 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 and benthic impairments on Wolf 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 and biological 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 Wolf 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).The Stage 1 allocation for the Wolf Creek bacteria impairment

requires a 100% reduction in straight pipes, 79% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 79% reduction in nonpoint source loadings to residential land use, a 79% reduction in nonpoint source loadings to pasture land use, a 79% 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. 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.

## Public Participation

During development of the Wolf Creek Bacteria and Benthic TMDL, public participation was encouraged through two public meetings and two Technical Advisory Committee meetings. The first public meeting was held at the Glade Spring Community Center in Glade Spring, VA on August 7, 2008 to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. The final public meeting was held at the Glade Spring Community Center in Glade Spring, VA on July 28, 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 Wolf Creek TMDL, a TMDL Technical Advisory Committee was also established to help advise the TMDL developers. Technical Advisory Committee meetings were held prior to public meetings. Technical Advisory Committee meetings were held for this project on June 17, 2008 and July 20, 2009 at the Mount Rogers Planning District Commission in Marion, VA. The general public was solicited to participate on the Technical Advisory Committee during the first public meeting in addition to agencies and groups already represented on the Technical Advisory Committee. The Technical Advisory Committee membership for the Wolf Creek Bacteria and Benthic TMDL included representatives from the following agencies and organizations: Virginia Department of Environmental Quality, Virginia Department of Conservation and Recreation, Virginia Cooperative Extension, Virginia Department of Health, Mount Rogers Planning District Commission, Holston River Soil and Water Conservation District, Town of Abingdon, and Washington 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*

Wolf Creek (VAS-O06R-01) was first listed as impaired streams in 1998 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 1998) indicating that the recreational use goal and aquatic life goal were not being met. The stream segment was further listed in 2002, 2004, and 2006 on Virginia's Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2002, 2004, and 2006) based on Virginia Department of Environmental Quality (VADEQ) monitoring data.

The impaired portion of Wolf Creek (VAS-O06R-01) delineated by VADEQ, which runs 7.83 miles beginning from the confluence with Town Creek, just south of Abingdon, to the backwaters of South Holston Lake, is listed as impaired by fecal coliform and *E. coli* bacteria on Virginia's 2006 list (VADEQ, 2006) due to water quality exceedances of the bacteria standard at station 6-CWLF001.18.

### *1.1.3 Watershed Location and Description*

The Wolf Creek impairment watershed is located in Washington County, Virginia near the Town of Abington (Figure 1.1). The Wolf Creek impairment begins south of Abingdon near the community of Vance Mill, Virginia and flows approximately 13 miles, along Route 75, south toward the community of Green Spring, Virginia. It continues downstream to the back waters of the South Holston Lake. The Wolf Creek watershed is approximately 17,324 acres predominately pasture, constituting approximately 44.4% of the total watershed area. The remaining land uses are divided between forest (33.2%), residential (21%), and cropland (0.9%).

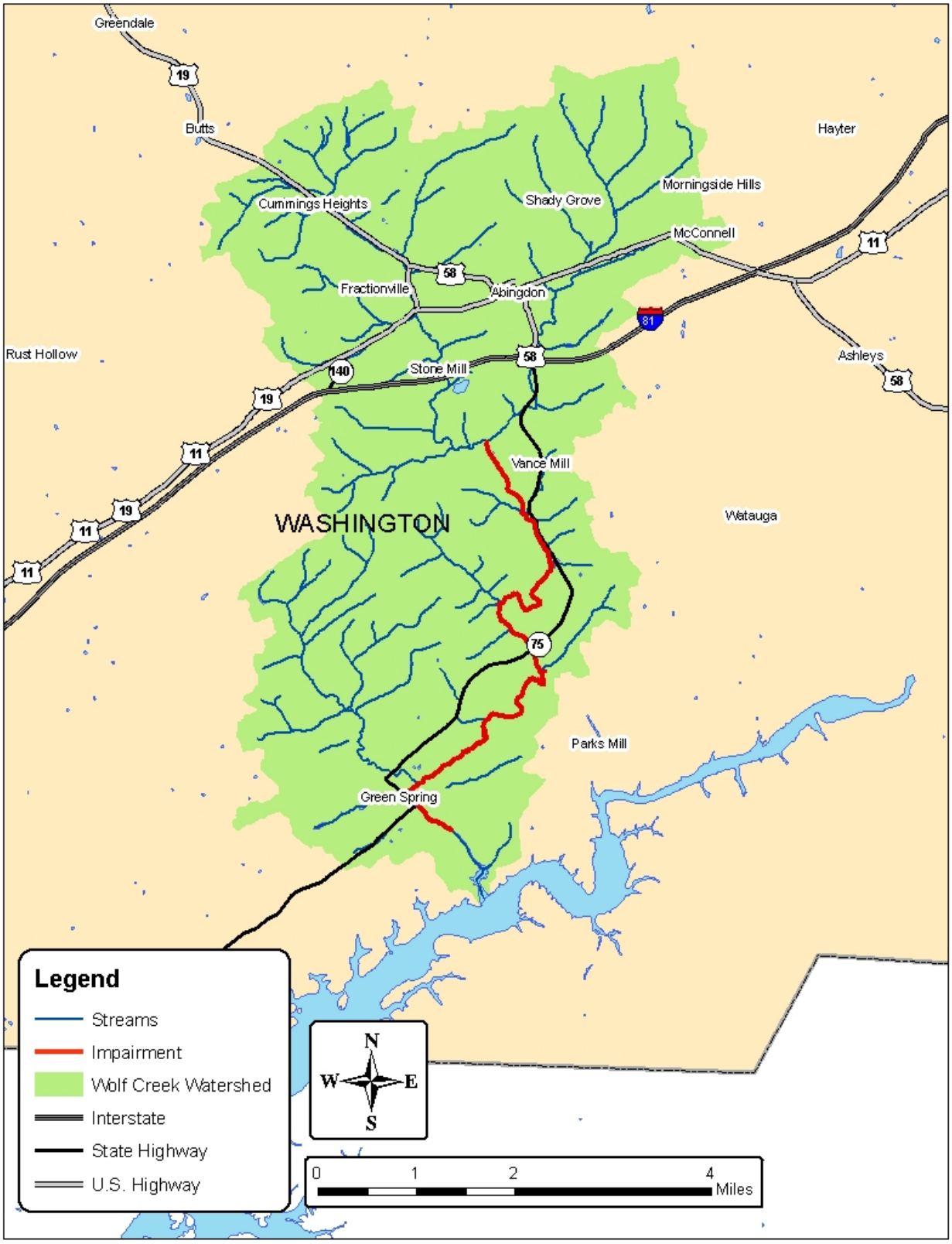


**Figure 1.1. Location of Wolf Creek watershed.**

### *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 Wolf Creek 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 for Wolf 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

Wolf Creek (VAS-O06R) watershed was subdivided into sub-watersheds for fecal coliform modeling purposes, as discussed in Section 5.2. The impaired portion of Wolf Creek runs for approximately 7.83 miles, from the Town Creek confluence, downstream beyond the Route 75 Bridge, past Green Spring, to the backwaters of the South Holston Lake. Wolf Creek is a perennial stream with a trapezoidal channel cross-section.

## 2.2 Ecoregion

The Wolf Creek watershed is located in the Northern Ridge and Valley Ecoregion. 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. Large calcium carbonate deposits chararacteristic of the region have influenced travertine deposition in Wolf Creek. Travertine deposits occur when cool ground water containing a high concentration of dissolved carbonates mixes with warmer water in the stream in summer and fall. 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.

## 2.3 Climate

The climate of the Wolf Creek (VAS-O06R) watershed is characterized based on the meteorological observations from 12/1/1969 to 12/31/2008 assembled by the Southeast Regional Climate Center for the Abingdon 3 S, Virginia (440021) station. Average annual precipitation is 46.36 inches with 50.0% of the precipitation occurring during the crop-growing season (May-October) (SERCC, 2009). Average annual snowfall is 15.2 inches with the highest snowfall occurring during January (SERCC, 2009). Average annual daily temperature is 66.6°F. The highest average daily temperature of 84.8°F occurs in July while the lowest average daily temperature of 23.7°F occurs in January (SERCC, 2009).

## 2.4 Land Use

General depiction of land use draining to the impairment is outlined in Section 1.1.3. Details of landuse used in this study are described in Section 5.3 with landuse per subwatershed listed in Table 5.2.For purposes of this study, it was assumed that residential development in the Wolf Creek watershed will continue at the overall average rate of 3.3% annually.

## 2.5 Bacteria Water Quality Data

### *2.5.1 Historic Data for Fecal Coliform*

Of the 8 water quality samples collected from January 2000 through December 2004 (the 2006 Section 303(d) 5-year listing period) at VADEQ station 6-CWLF001.18, 12.5% of the samples exceeded the then-applicable instantaneous fecal coliform water quality standard. Consequently, this segment of Wolf Creek (VAS-O06R) was determined as not supporting of the Clean Water Act's Recreation Use Goal for the 2006 Section 305(b) water quality assessment report and was included in the 2006 Section 303(d) List of Impaired Waters (VADEQ, 2006).

VADEQ personnel monitored pollutant concentrations throughout Wolf Creek. 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 at monitoring stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 in Wolf Creek watershed from 1990 through the most recent data collected at the time this report was written are plotted in Figures 2.1 through 2.3, respectively.

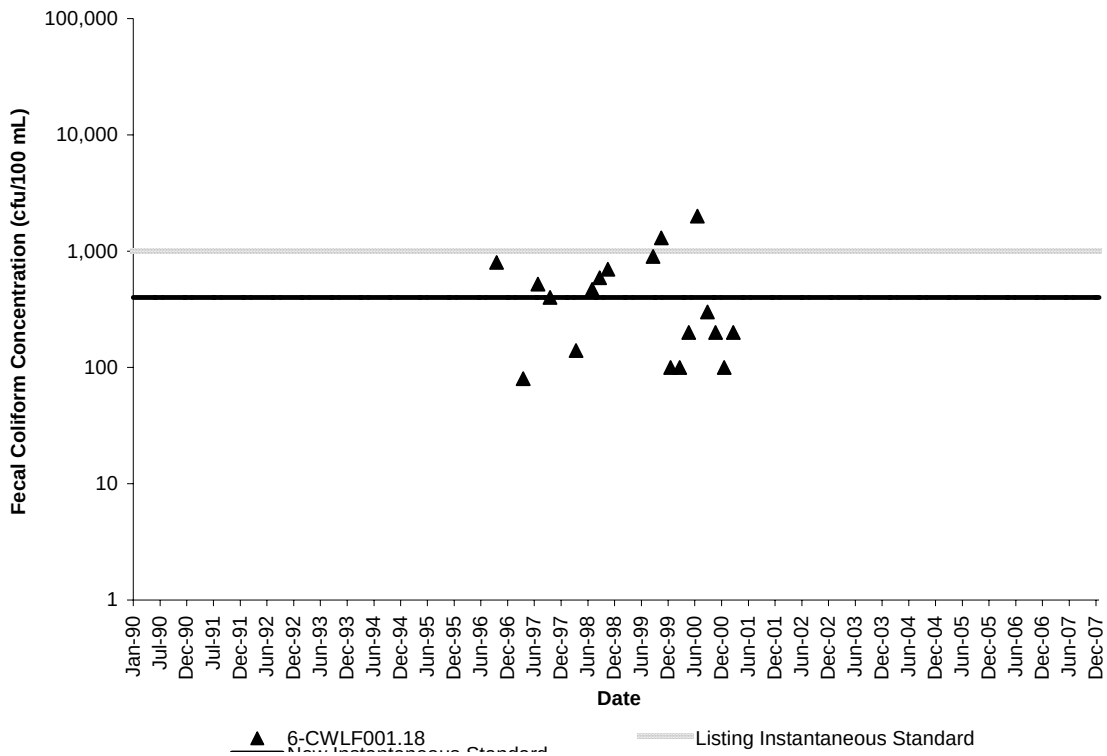


**Figure 2.1. Fecal coliform concentrations (VADEQ station 6-CWLF001.18) in Wolf Creek impairment.**

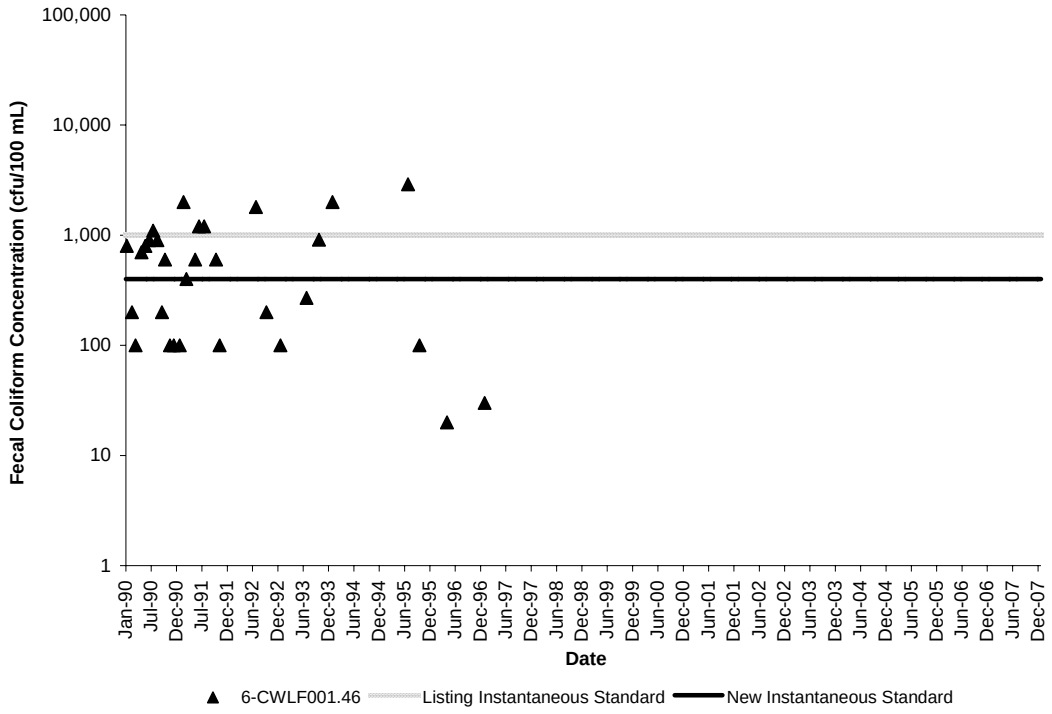


**Figure 2.2. Fecal coliform concentrations (VADEQ station 6-CWLF001.46) in Wolf Creek impairment.**

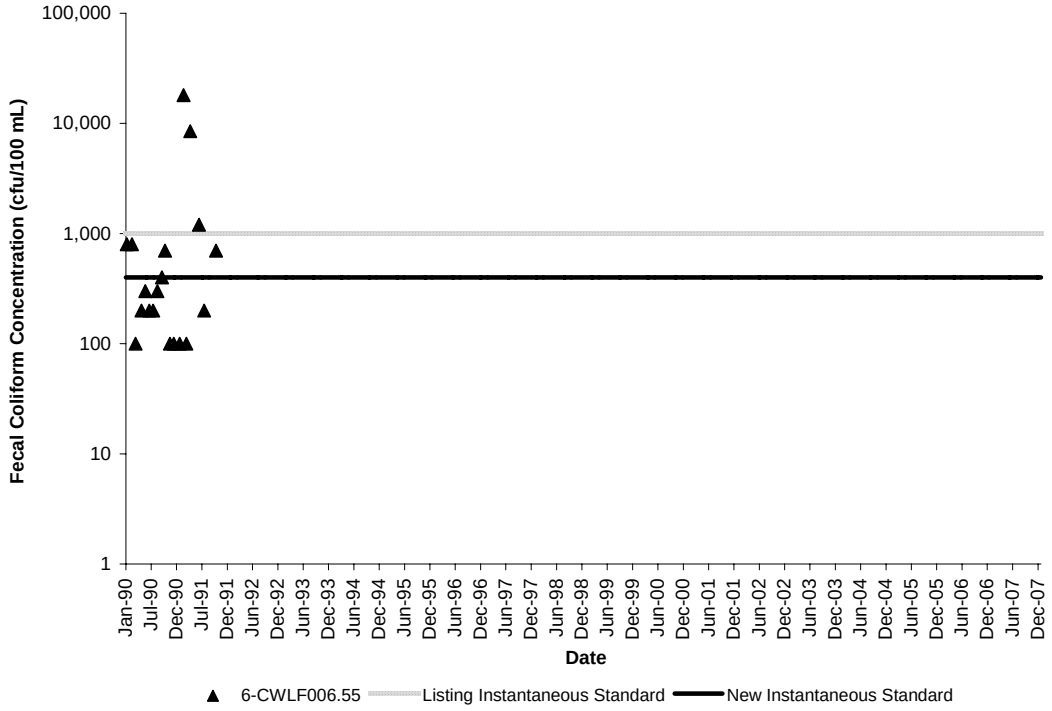


**Figure 2.3. Fecal coliform concentrations (VADEQ station 6-CWLF006.55) in Wolf Creek impairment.**

Seasonal variability of fecal coliform concentrations in the stream network was evaluated by plotting the mean monthly fecal coliform concentration values. Mean monthly fecal coliform concentration values were determined as the average of zero to four 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 (Table 2.1). Mean monthly fecal coliform bacteria concentrations were plotted for stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 (Figures 2.4 – 2.6).

Figure 2.4 shows the highest mean fecal coliform concentrations occurred in the fall months and July at station 6-CWLF001.18. At station 6-CWLF001.46, the highest averages were generally recorded in the summer months (highest in July) followed by the winter months (highest in February) (Figure 2.5). The highest mean fecal coliform concentrations occurred in February and March at station 6-CWLF006.55 (Figure 2.6). 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 Figures 2.4 through 2.6.

**Table 2.1. Number of samples collected per month from 1/1/90 to 12/31/07 in the Wolf Creek impairment.**

| Month | Samples Collected at | | |
|---|---|---|---|
| | **6-CWLF001.18 (#)** | **6-CWLF001.46 (#)** | **6-CWLF006.55 (#)** |
| January | 3 | 5 | 2 |
| February | 0 | 2 | 2 |
| March | 3 | 2 | 2 |
| April | 2 | 2 | 2 |
| May | 2 | 2 | 1 |
| June | 0 | 2 | 2 |
| July | 4 | 5 | 2 |
| August | 0 | 1 | 1 |
| September | 3 | 1 | 1 |
| October | 2 | 5 | 2 |
| November | 3 | 2 | 1 |
| December | 0 | 1 | 1 |
| **Total** | **22** | **30** | **19** |

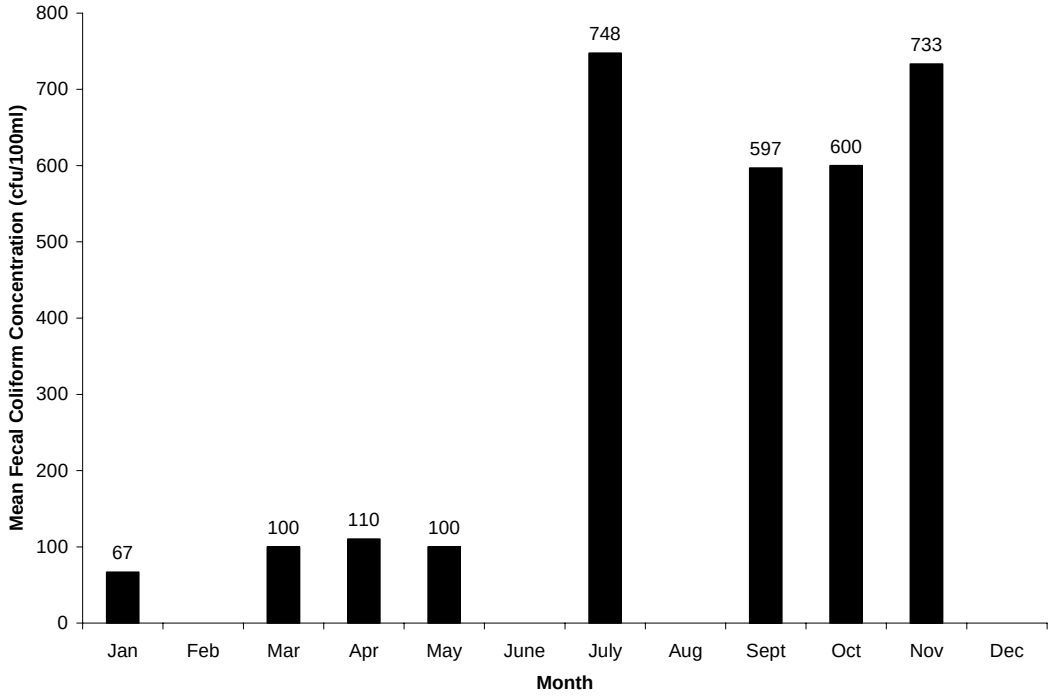


**Figure 2.4. Impact of seasonality on fecal coliform concentrations (VADEQ station 6-CWLF001.18) in Wolf Creek impairment from January 1990 through December 2007.**

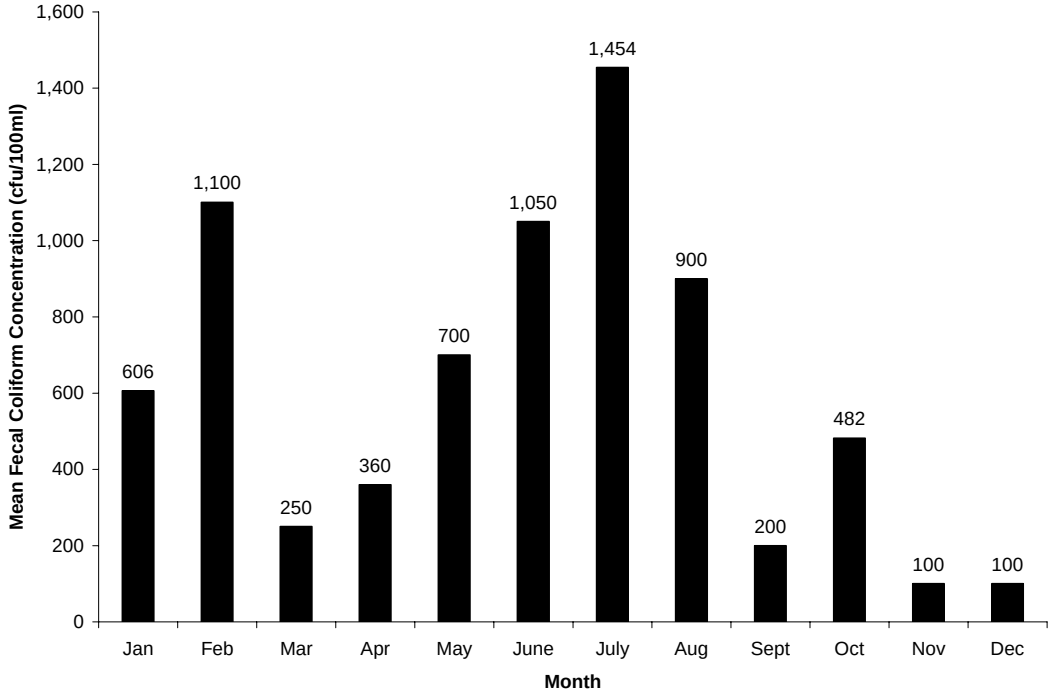


**Figure 2.5. Impact of seasonality on fecal coliform concentrations (VADEQ station 6-CWLF001.46) in Wolf Creek impairment from January 1990 through December 2007.**

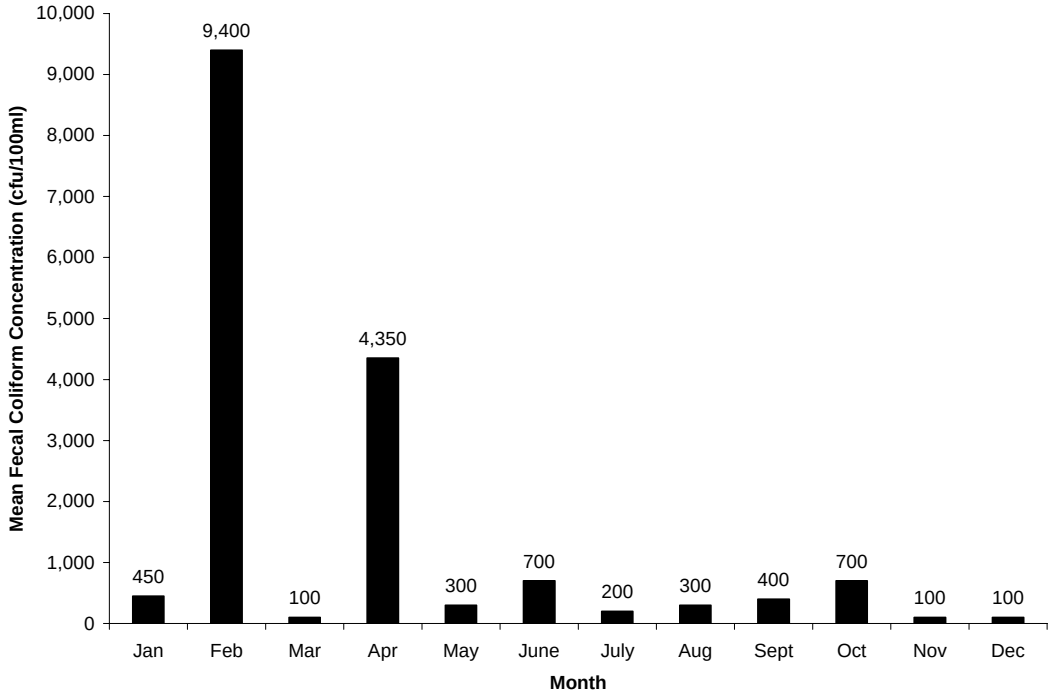


**Figure 2.6. Impact of seasonality on fecal coliform concentrations (VADEQ station 6-CWLF006.55) in Wolf Creek impairment from January 1990 through December 2007.**

### *2.5.2 Historic Data for E. coli*

VADEQ staff examined water samples collected at station 6-CWLF001.18, 6-CWLF006.75, 6-CWLF007.55, and 6-CWLF008.00 for concentration of *E. coli* (Figures 2.7 through 2.10). This analysis was conducted concurrently with other monthly testing at the stations. Ten of the 50 (20%) samples analyzed from station 6-CWLF001.18 exceeded the instantaneous *E. coli* bacteria standard of 235 cfu/100 mL. Of the 38 water quality samples collected at station 6-CWLF006.75, nineteen (50%) of the samples exceeded the instantaneous *E. coli* bacteria standard. At station 6-CWLF007.55, four of six (66%) samples exceeded the instantaneous *E. coli* bacteria standard. Of the 18 water quality samples collected at station 6-CWLF008.00, three (17%) of the samples exceeded the instantaneous *E. coli* bacteria standard.

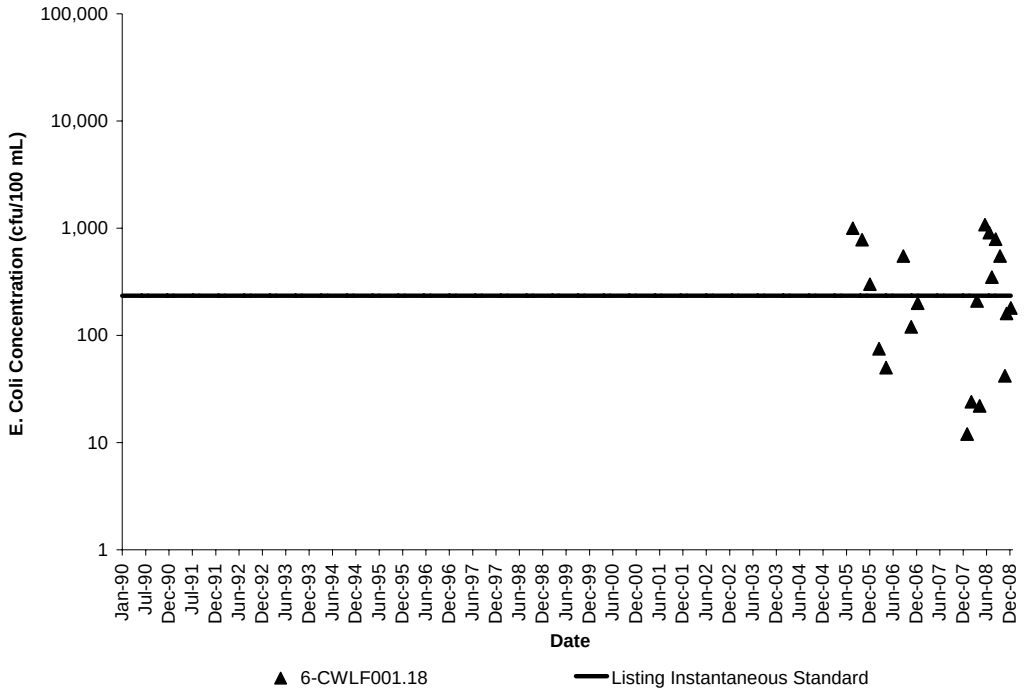


**Figure 2.7. E. coli concentrations (VADEQ station 6-CWLF001.18) in Wolf Creek impairment.**

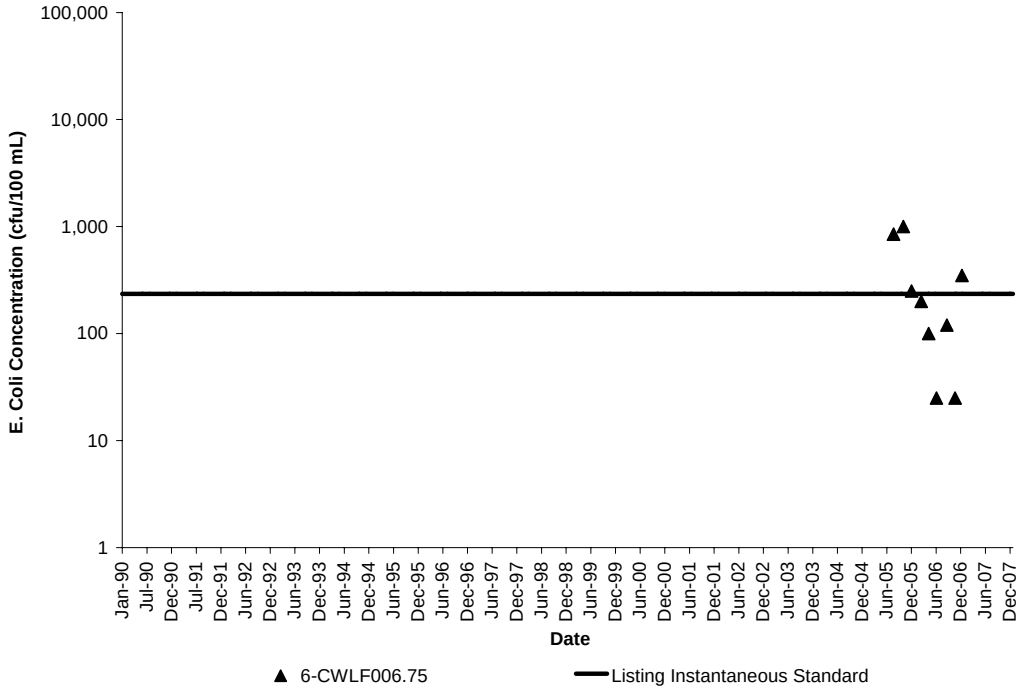


**Figure 2.8. E. coli concentrations (VADEQ station 6-CWLF006.75) in Wolf Creek impairment.**

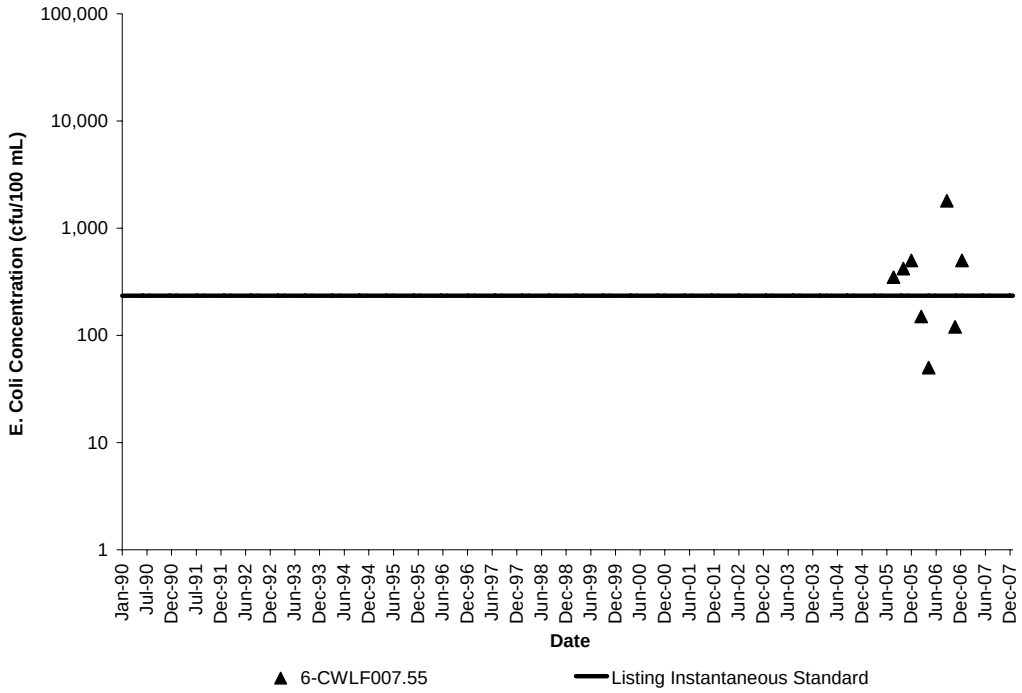


**Figure 2.9. E. coli concentrations (VADEQ station 6-CWLF007.55) in Wolf Creek impairment.**

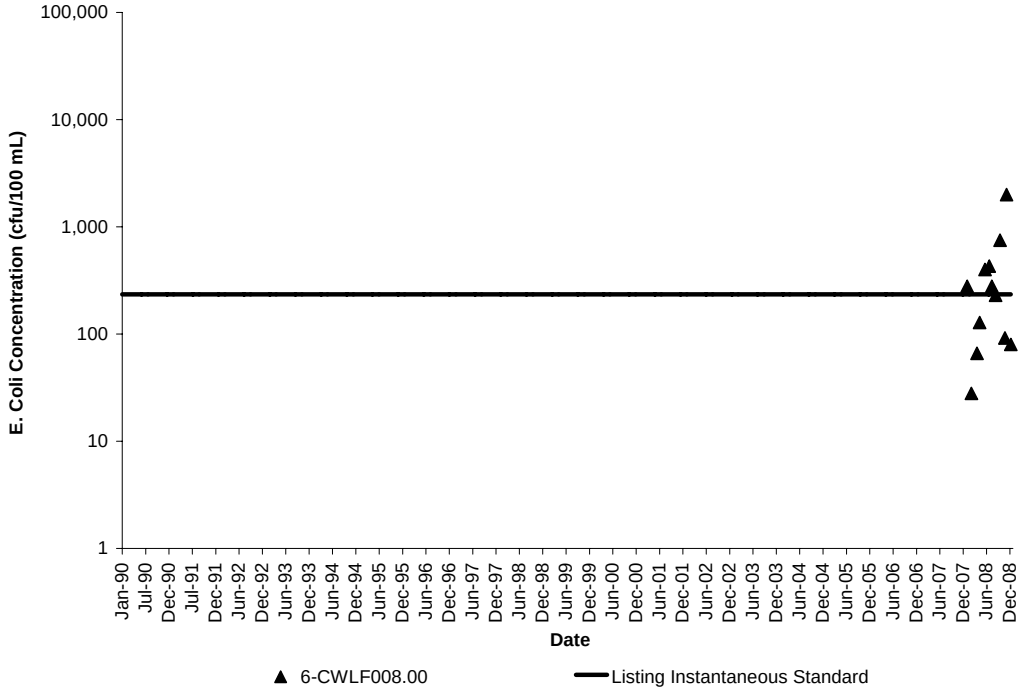


**Figure 2.10. E. coli concentrations (VADEQ station 6-CWLF008.00) in Wolf Creek impairment.**

### *2.5.3 Historic Data for Bacterial Source Tracking*

The results from 12 monthly bacteria source tracking (BST) samples collected in 2008 at stations 6-CTOW000.58, 6-CWLF008.00, and 6-CWLF001.18, 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 in Wolf 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%. Tables 2.2 through 2.4 summarize 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 6-CTOW000.58, 41.7% (five of 12) of the samples exceeded the *E. coli* bacteria instantaneous standard. The exceedances occurred in March, June, September, November, and December of 2008. Six of 12 (50.0%) samples exceeded the *E. coli* bacteria instantaneous standard at station 6-CWLF008.00. The exceedances occurred in January, May, June, July, September, and November of 2008. The five exceedances (41.7%) of the *E. coli* bacteria instantaneous standard occurred in May, June, July, August, and September of 2008 at station 6-CWLF001.18.

**Table 2.2. Presence/absence analysis of bacteria sources at station 6-CTOW000.58 in Wolf Creek watershed.**

| Bacteria Source | Frequency of Presence in All Samples[1] (%) | Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%) |
|---|---|---|
| Wildlife | 50 | 60 |
| Human | 75 | 100 |
| Livestock | 17 | 20 |
| Pet | 67 | 80 |

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

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

**Table 2.3. Presence/absence analysis of bacteria sources at station 6-CWLF008.00 in Wolf Creek watershed.**

| Bacteria Source | Frequency of Presence in All Samples[1] (%) | Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%) |
|---|---|---|
| Wildlife | 50 | 67 |
| Human | 58 | 83 |
| Livestock | 58 | 50 |
| Pet | 75 | 83 |

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

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

**Table 2.4. Presence/absence analysis of bacteria sources at station 6-CWLF001.18 in Wolf Creek watershed.**

| Bacteria Source | Frequency of Presence in All Samples[1] (%) | Frequency of Presence in Samples Exceeding Water Quality Standards[2] (%) |
|---|---|---|
| Wildlife | 58 | 80 |
| Human | 67 | 40 |
| Livestock | 50 | 80 |
| Pet | 58 | 80 |

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

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

## 2.6 Biological Monitoring Data

Potential data used in the stressor identification analysis are included in Table 2.5 and presented in the following sections.

**Table 2.5. Inventory of DEQ environmental monitoring data for Wolf Creek.**

| Data Type | Collection Period | Monitoring Stations | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 6CWLF001.18 | 6CWLF001.46 | 6CWLF004.10 | 6CWLF006.55 | 6CWLF006.75 | 6CWLF007.31 | 6CWLF007.55 | 6CWLF008.00 | 6CTOW000.58 |
| Biological (Benthic) Monitoring | 1995 – 2008 | | | X | | | X | | | |
| Ambient Water Quality Monitoring | | | | | | | | | | |
| *Physical* | 1990 – 2008 | X | X | X | X | X | | X | X | X |
| *Nutrients* | 1990 – 2008 | X | X | X | X | X | | X | X | X |
| *Metals* | 1990 – 2008 | X | X | | X | | | | | |
| *Organics* | 1990 – 2008 | X | X | | X | | | | | |
| Sediment and Fish Tissue Sampling | 1997, 2002, 2007 | | | | X | | | | | |
| Diurnal DO Testing | N/A | | | | | | | | | |
| Toxicity Study | N/A | | | | | | | | | |

N/A – no data available

### *2.6.1 Benthic Data*

Biological monitoring data was collected at two stations (6-CWLF004.10 and 6-CWLF007.31) from 1995 to present, and evaluated using the modified Rapid Bioassessment Protocol II (RBP II) and Virginia Stream Condition Index (VSCI) metrics. Metrics and impairment classification are shown in Tables 2.6 and 2.7.Taxa data describing the quantities of the individual benthic macroinvertebrate organisms in each of the assessments are included in Tables 2.8 and 2.9. The RBP II assessment ratings are included for reference. Habitat data associated with each biological assessment were obtained and are summarized in Tables 2.10 and 2.11. Figure 2.11 illustrates the average, minimum, and maximum habitat scores at station 6-CWLF004.10 in Wolf Creek. Individual metric scores of 10 or below are considered poor or marginal. All values for embeddedness and sediment deposition were below 10. At least 50% of the values for epifaunal substrate and riparian zone were below 10. Averages and at least 50% of the values for the remaining habitat scores were above 10. At station 6-CWLF007.31, habitat scores for embeddedness, sediment deposition, bank stability, and riparian zone were 10 or below.

**Table 2.6. RBP II and VSCI metric and assessment data for station 6CWLF004.10 in Wolf Creek.**

| | 12-Jun-97 | 02-Oct-97 | 02-Dec-98 | 09-May-00 | 31-May-07 | 24-Sep-07 |
|---|---|---|---|---|---|---|
| **RBP II Metric** | | | | | | |
| Taxa Richness | 10 | 9 | 9 | 9 | N/D | N/D |
| MFBI | 5.04 | 5.41 | 5.48 | 4.77 | N/D | N/D |
| SC/CF | 1.46 | 0.09 | 0.31 | 5.00 | N/D | N/D |
| EPT/Chi Abund | 1.17 | 7.36 | 2.19 | 0.77 | N/D | N/D |
| % Dominant | 31.1 | 61.1 | 47.2 | 44.6 | N/D | N/D |
| EPT Index | 3 | 5 | 5 | 4 | N/D | N/D |
| Community Loss Index | 0.70 | 1.44 | 1.56 | 1.22 | N/D | N/D |
| SH/Tot | 0.01 | 0.03 | 0.02 | 0.01 | N/D | N/D |
| Biological Condition Score | 24 | 18.00 | 15.00 | 18.00 | N/D | N/D |
| % of Reference | 50.0 | 38.0 | 31.0 | 38.0 | N/D | N/D |
| RBP II Assessment | MODERATELY IMPAIRED | MODERATELY IMPAIRED | MODERATELY IMPAIRED | MODERATELY IMPAIRED | N/D | N/D |
| **VA Stream Condition Index** | | | | | | |
| Total Taxa | N/D | N/D | N/D | N/D | 7 | 10 |
| EPT Taxa | N/D | N/D | N/D | N/D | 2 | 3 |
| % Ephemeropta | N/D | N/D | N/D | N/D | 43.4 | 13.7 |
| % EPT less Hydropsychidae | N/D | N/D | N/D | N/D | 0 | 0 |
| % Chironomidae | N/D | N/D | N/D | N/D | 95.3 | 97.1 |
| % Top 2 Dominant Taxa | N/D | N/D | N/D | N/D | 75.5 | 72.5 |
| HBI (Family Level) | N/D | N/D | N/D | N/D | 4.8 | 5.0 |
| % Scrapers | N/D | N/D | N/D | N/D | 12.3 | 50.0 |
| SCI Score | N/D | N/D | N/D | N/D | 44.0 | 50.4 |
| SCI Assessment | N/D | N/D | N/D | N/D | Impaired | Impaired |

N/D – no data available.

**Table 2.7. RBP II and VSCI metric and assessment data for station 6CWLF007.31 in Wolf Creek.**

| | 11/5/1995 |
|---|---|
| **RBP II Metric** | |
| Taxa Richness | 9 |
| MFBI | 5.23 |
| SC/CF | 0.80 |
| EPT/Chi Abund | 6.08 |
| % Dominant | 43.9 |
| EPT Index | 6 |
| Community Loss Index | 1.22 |
| SH/Tot | 0.00 |
| Biological Condition Score | 24 |
| % of Reference | 50.0 |
| RBP II Assessment | MODERATELY IMPAIRED |
| **VA Stream Condition Index** | |
| Total Taxa | N/D |
| EPT Taxa | N/D |
| % Ephemeropta | N/D |
| % EPT less Hydropsychidae | N/D |
| % Chironomidae | N/D |
| % Top 2 Dominant Taxa | N/D |
| HBI (Family Level) | N/D |
| % Scrapers | N/D |
| SCI Score | N/D |
| SCI Assessment | N/D |

N/D – no data available.

## Table 2.8. Taxa data for station 6CWLF004.10 in Wolf Creek.

| Order | Final ID | Functional Feeding Group | Tolerance Value | 12-Jun-97 | 02-Oct-97 | 02-Dec-98 | 09-May-00 | 31-May-07 | 24-Sep-07 |
|---|---|---|---|---|---|---|---|---|---|
| Amphipoda | Talitridae | Collector | 8 | | | | | | 3 |
| Coleoptera | Elmidae | Scraper | 4 | 32 | 4 | 6 | 54 | 13 | 40 |
| Coleoptera | Psephenidae | Scraper | 4 | 1 | | | | | 1 |
| Decapoda - Crayfish | Cambaridae | Shredder | 5 | | | | | 1 | |
| Diptera | Tipulidae | Shredder | 3 | 1 | 4 | 2 | 1 | 3 | |
| Diptera | Chironomidae (A) | Collector | 6 | 29 | 14 | 31 | 35 | 5 | 3 |
| Diptera | Empididae | Predator | 6 | 1 | 1 | | | | |
| Diptera | Simuliidae | Filterer | 6 | 4 | | 1 | 1 | 4 | 4 |
| Ephemeroptera | Oligoneuridae | Collector | 2 | | 1 | 2 | 1 | | |
| Ephemeroptera | Baetiscidae | Collector | 3 | | | | 6 | | 7 |
| Ephemeroptera | Baetidae | Collector | 4 | 13 | 22 | 5 | | 46 | |
| Ephemeroptera | Ephemerellidae | Collector | 4 | | 1 | 7 | | | |
| Ephemeroptera | Heptageniidae | Scraper | 4 | 1 | 2 | 3 | 8 | | 7 |
| Gastropoda | Pleuroceridae | Scraper | 4 | 1 | | | 3 | | 1 |
| Limpets | Ancylidae | Scraper | 6 | | | | | | 2 |
| Trichoptera | Hydropsychidae | Filterer | 6 | 20 | 77 | 51 | 12 | 34 | 34 |
| **Total Organisms =** | | | | 103 | 126 | 108 | 121 | 106 | 102 |
| **RBP II Assessment** | | | | Moderately Impaired | Moderately Impaired | Moderately Impaired | Moderately Impaired | Moderately Impaired | Moderately Impaired |

**Table 2.9. Taxa data for station 6CWLF007.31 in Wolf Creek.**

| Order | Final ID | Functional Feeding Group | Tolerance Value | 05-Nov-95 |
|---|---|---|---|---|
| Coleoptera | Elmidae | Scraper | 4 | 12 |
| Diptera | Chironomidae (A) | Collector | 6 | 13 |
| Ephemeroptera | Oligoneuridae | Collector | 2 | 1 |
| Ephemeroptera | Baetidae | Collector | 4 | 2 |
| Ephemeroptera | Ephemerellidae | Collector | 4 | 2 |
| Ephemeroptera | Heptageniidae | Scraper | 4 | 26 |
| Pelecypoda | Corbiculidae | Filterer | 8 | 3 |
| Trichoptera | Hydroptilidae | Scraper | 6 | 1 |
| Trichoptera | Hydropsychidae | Filterer | 6 | 47 |
| **Total Organisms =** | | | | 107 |
| **RBP II Assessment** | | | | Moderately Impaired |

**Table 2.10. Habitat scores for station 6CWLF004.10 in Wolf Creek.**

| Habitat Metrics | Habitat Scores[1] | | | | | |
|---|---|---|---|---|---|---|
| | 06/12/1997 | 10/02/1997 | 12/02/1998 | 05/09/2000 | 05/31/2007 | 09/24/2007 |
| Epifaunal Substrate | 11 | 8 | 14 | 10 | 10 | 11 |
| Embeddedness | 4 | 9 | 6 | 6 | 9 | 8 |
| Velocity / Depth Regimes | 13 | 15 | 13 | 14 | 10 | 10 |
| Sediment Deposition | 7 | 8 | 6 | 6 | 7 | 5 |
| Channel Flow Status | 18 | 19 | 9 | 17 | 15 | 13 |
| Channel Alteration | 18 | 18 | 18 | 17 | 16 | 15 |
| Riffle Frequency | 16 | 17 | 13 | 13 | 16 | 10 |
| Bank Stability | 13 | 8 | 4 | 13 | 14 | 13 |
| Vegetation Protection | 19 | 18 | 17 | 18 | 10 | 14 |
| Riparian Zone | 12 | 12 | 7 | 8 | 10 | 14 |
| ***Total Habitat Score*** | ***131*** | ***132*** | ***107*** | ***122*** | ***117*** | ***113*** |

[1]Habitat condition categories: 0-5 = "Poor"; 6-10 = "Marginal"; 11-15 = "Sub-optimal"; 16-20 = "Optimal".

**Table 2.11. Habitat scores for station 6CWLF007.31 in Wolf Creek.**

| Habitat Metrics | Habitat Scores[1] 11/05/1995 |
|---|---|
| Epifaunal Substrate | 11 |
| Embeddedness | 8 |
| Velocity / Depth Regimes | 17 |
| Sediment Deposition | 10 |
| Channel Flow Status | 18 |
| Channel Alteration | 16 |
| Riffle Frequency | 12 |
| Bank Stability | 10 |
| Vegetation Protection | 18 |
| Riparian Zone | 9 |
| ***Total Habitat Score*** | ***129*** |

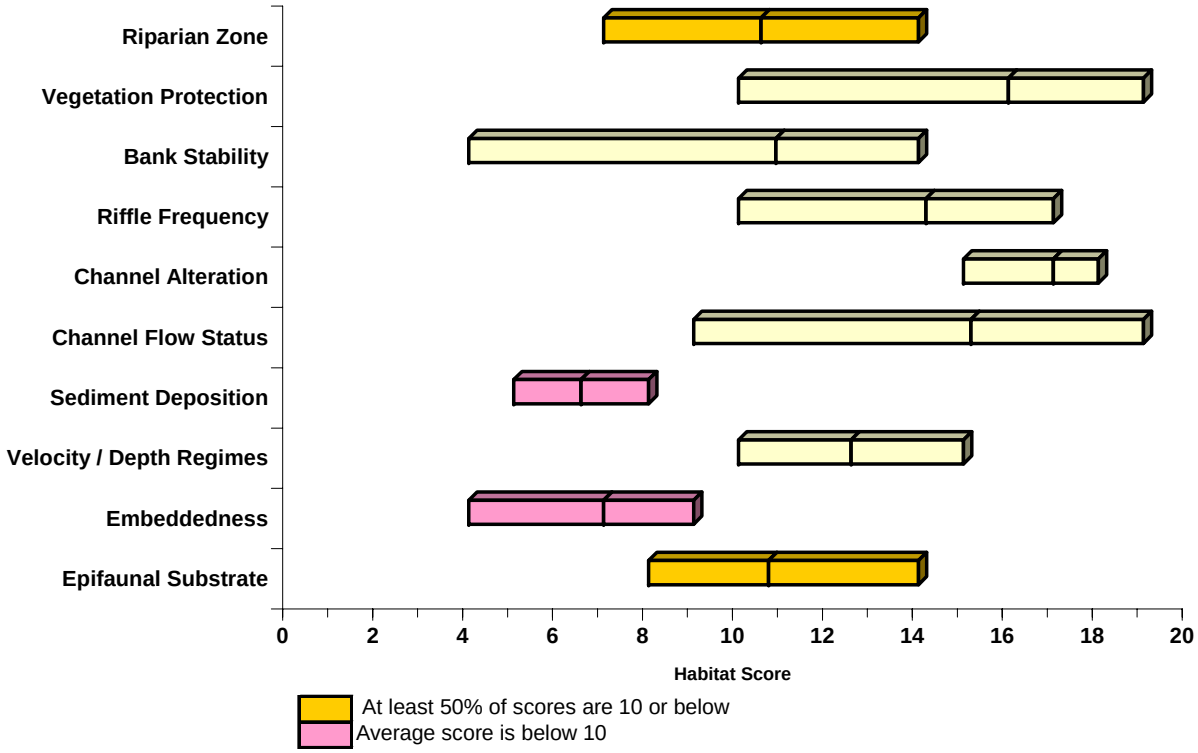


**Figure 2.11. Average, minimum, and maximum habitat scores at monitoring station 6CWLF004.10 in Wolf Creek.**

## 2.7 VADEQ Ambient Monitoring Data

Ambient water quality data were collected at various points along Wolf Creek and Town Creek. In this analysis, data collected at eight stations within and just upstream of the impaired reach was examined. Stations on Wolf Creek were located at river miles 1.18, 1.46, 4.10, 6.55, 6.75, 7.55, and 8.00 (Table 2.5). The Town Creek station was located at river mile 0.58 (Table 2.5).

### *2.7.1 Physical*

Tables 2.12 through 2.19 contain summary of data collected at the various water quality stations. Summary of data includes number of observations between January 1, 1990 and March 31, 2008; mean, minimum; and maximum values. The data temporal range varies from parameter to parameter, and there is not always a good overlap between biological and ambient monitoring data. Data for physical parameters collected in the watershed are depicted in Figures 2.12 through 2.23. Summary of observations includes:

- Measured pH values at all water quality monitoring (WQM) stations are within the expected range for Class IV waters and does not appear to be a stressor to the benthic community;
- All except two specific conductance values were above the reference filter limit;
- Dissolve oxygen values at all WQM stations were above the daily average concentration for Class IV waters (i.e., 5 mg/l) and does not appear to be a stressor to the benthic community;
- Temperature values at all WQM stations were below the maximum temperature criteria for Class IV waters (i.e., 31°C) and does not appear to be a stressor to the benthic community;
- Exceedances of the turbidity stressor screening value of 10 NTU were observed at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55;
- The total solids stressor screening value of 300 mg/l was exceeded at all WQM stations; and
- TSS values at WQM stations 6-CWLF001.18, 6-CWLF001.46, 6-CWLF006.55, and 6-CWLF007.55 exceeded the stressor screening value of 10 mg/l.

**Table 2.12. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF001.18 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 32 | 8.08 | 8.41 | 7.70 |
| Specific Conductance, µmhos/cm | 31 | 442.24 | 578.00 | 264.00 |
| Turbidity - Hach Turbidimeter, FTU | 13 | 5.41 | 9.80 | 1.90 |
| Turbidity - Lab, NTU | 11 | 9.33 | 24.00 | 3.20 |
| Dissolved Oxygen (DO), mg/L | 31 | 10.62 | 14.30 | 6.59 |
| Temperature, Celsius (°C) | 32 | 14.07 | 26.40 | 0.36 |
| Total Solids, mg/L | 13 | 297.54 | 334.00 | 246.00 |
| Total Suspended Solids, mg/L | 13 | 10.38 | 18.00 | 3.00 |
| Total Inorganic Solids, mg/L | 13 | 76.85 | 138.00 | 51.00 |
| Total Inorganic Suspended Solids, mg/L | 13 | 3.00 | 3.00 | 3.00 |
| Total Dissolved Solids, mg/L | 19 | 288.05 | 330.00 | 239.00 |
| BOD 5, mg/L | 12 | 1.92 | 4.00 | 1.00 |
| COD – High Level, mg/L | 9 | 9.00 | 15.00 | 5.00 |

**Table 2.13. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF001.46 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 41 | 8.08 | 8.63 | 7.57 |
| Specific Conductance, µmhos/cm | 23 | 338.61 | 470.00 | 100.00 |
| Turbidity - Hach Turbidimeter, FTU | 10 | 11.89 | 30.00 | 2.53 |
| Turbidity - Lab, NTU | 22 | 12.20 | 45.00 | 0.86 |
| Dissolved Oxygen (DO), mg/L | 19 | 9.80 | 11.85 | 7.28 |
| Temperature, Celsius (°C) | 41 | 13.76 | 24.80 | 2.15 |
| Total Solids, mg/L | 40 | 273.58 | 320.00 | 200.00 |
| Total Suspended Solids, mg/L | 40 | 23.03 | 89.00 | 2.00 |
| Total Inorganic Solids, mg/L | 40 | 56.28 | 101.00 | 30.00 |
| Total Inorganic Suspended Solids, mg/L | 40 | 3.63 | 14.00 | 1.00 |
| Total Dissolved Solids, mg/L | 18 | 231.85 | 280.00 | 22.30 |
| BOD 5, mg/L | 40 | 1.66 | 5.00 | 1.00 |
| COD - High Level, mg/L | 40 | 8.78 | 24.00 | 2.40 |

**Table 2.14. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF004.10 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 3 | 8.50 | 8.80 | 8.30 |
| Specific Conductance, µmhos/cm | 3 | 513.33 | 528.00 | 493.00 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 3 | 2.77 | 3.60 | 2.00 |
| Dissolved Oxygen (DO), mg/L | 3 | 11.37 | 11.50 | 11.20 |
| Temperature, Celsius (°C) | 3 | 9.37 | 12.70 | 6.30 |
| Total Solids, mg/L | 3 | 318.67 | 352.00 | 292.00 |
| Total Suspended Solids, mg/L | 3 | 5.67 | 6.00 | 5.00 |
| Total Inorganic Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Inorganic Suspended Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Dissolved Solids, mg/L | N/A | N/A | N/A | N/A |
| BOD 5, mg/L | N/A | N/A | N/A | N/A |
| COD - High Level, mg/L | N/A | N/A | N/A | N/A |

**Table 2.15. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF006.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 28 | 8.27 | 8.57 | 7.72 |
| Specific Conductance, µmhos/cm | 3 | 424.33 | 473.00 | 389.00 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 22 | 23.15 | 184.00 | 1.00 |
| Dissolved Oxygen (DO), mg/L | N/A | N/A | N/A | N/A |
| Temperature, Celsius (°C) | 28 | 9.88 | 17.50 | 1.93 |
| Total Solids, mg/L | 22 | 291.23 | 433.00 | 166.00 |
| Total Suspended Solids, mg/L | 22 | 29.64 | 191.00 | 3.00 |
| Total Inorganic Solids, mg/L | 22 | 56.09 | 92.00 | 26.00 |
| Total Inorganic Suspended Solids, mg/L | 22 | 4.27 | 22.00 | 1.00 |
| Total Dissolved Solids, mg/L | N/A | N/A | N/A | N/A |
| BOD 5, mg/L | 22 | 2.14 | 6.00 | 1.00 |
| COD - High Level, mg/L | 22 | 10.80 | 50.00 | 1.00 |

**Table 2.16. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF006.75 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 8 | 8.15 | 8.28 | 8.00 |
| Specific Conductance, µmhos/cm | 7 | 548.06 | 612.00 | 516.30 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 8 | 3.82 | 6.82 | 1.14 |
| Dissolved Oxygen (DO), mg/L | 7 | 9.45 | 11.26 | 7.90 |
| Temperature, Celsius (°C) | 8 | 14.88 | 19.50 | 8.34 |
| Total Solids, mg/L | 7 | 330.43 | 354.00 | 313.00 |
| Total Suspended Solids, mg/L | 8 | 6.75 | 9.00 | 3.00 |
| Total Inorganic Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Inorganic Suspended Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Dissolved Solids, mg/L | 7 | 330.43 | 354.00 | 313.00 |
| BOD 5, mg/L | N/A | N/A | N/A | N/A |
| COD - High Level, mg/L | N/A | N/A | N/A | N/A |

**Table 2.17. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF007.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 8 | 7.98 | 8.23 | 7.90 |
| Specific Conductance, µmhos/cm | 7 | 523.16 | 561.70 | 502.00 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 8 | 3.84 | 8.50 | 1.65 |
| Dissolved Oxygen (DO), mg/L | 7 | 9.66 | 11.37 | 7.70 |
| Temperature, Celsius (°C) | 8 | 13.50 | 18.60 | 6.62 |
| Total Solids, mg/L | 7 | 310.86 | 330.00 | 295.00 |
| Total Suspended Solids, mg/L | 8 | 6.63 | 17.00 | 3.00 |
| Total Inorganic Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Inorganic Suspended Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Dissolved Solids, mg/L | 7 | 310.86 | 330.00 | 295.00 |
| BOD 5, mg/L | N/A | N/A | N/A | N/A |
| COD - High Level, mg/L | N/A | N/A | N/A | N/A |

**Table 2.18. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CWLF008.00 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 3 | 8.03 | 8.10 | 7.90 |
| Specific Conductance, µmhos/cm | 3 | 536.33 | 552.00 | 516.00 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 3 | 3.60 | 5.30 | 2.10 |
| Dissolved Oxygen (DO), mg/L | 3 | 11.17 | 11.90 | 10.70 |
| Temperature, Celsius (°C) | 3 | 10.47 | 13.10 | 8.50 |
| Total Solids, mg/L | 3 | 319.33 | 336.00 | 304.00 |
| Total Suspended Solids, mg/L | 3 | 6.67 | 8.00 | 5.00 |
| Total Inorganic Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Inorganic Suspended Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Dissolved Solids, mg/L | 3 | 319.33 | 336.00 | 304.00 |
| BOD 5, mg/L | N/A | N/A | N/A | N/A |
| COD - High Level, mg/L | N/A | N/A | N/A | N/A |

**Table 2.19. Physical, DO, temperature, solids, and biochemical water quality data summary for station 6CTOW000.58 in Town Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 3 | 7.90 | 8.00 | 7.80 |
| Specific Conductance, µmhos/cm | 3 | 556.33 | 607.00 | 528.00 |
| Turbidity - Hach Turbidimeter, FTU | N/A | N/A | N/A | N/A |
| Turbidity - Lab, NTU | 3 | 4.07 | 6.80 | 2.00 |
| Dissolved Oxygen (DO), mg/L | 3 | 11.20 | 11.60 | 10.50 |
| Temperature, Celsius (°C) | 3 | 9.77 | 11.90 | 8.20 |
| Total Solids, mg/L | 3 | 310.00 | 322.00 | 300.00 |
| Total Suspended Solids, mg/L | 3 | 4.67 | 6.00 | 4.00 |
| Total Inorganic Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Inorganic Suspended Solids, mg/L | N/A | N/A | N/A | N/A |
| Total Dissolved Solids, mg/L | 3 | 310.00 | 322.00 | 300.00 |
| BOD 5, mg/L | N/A | N/A | N/A | N/A |
| COD - High Level, mg/L | N/A | N/A | N/A | N/A |

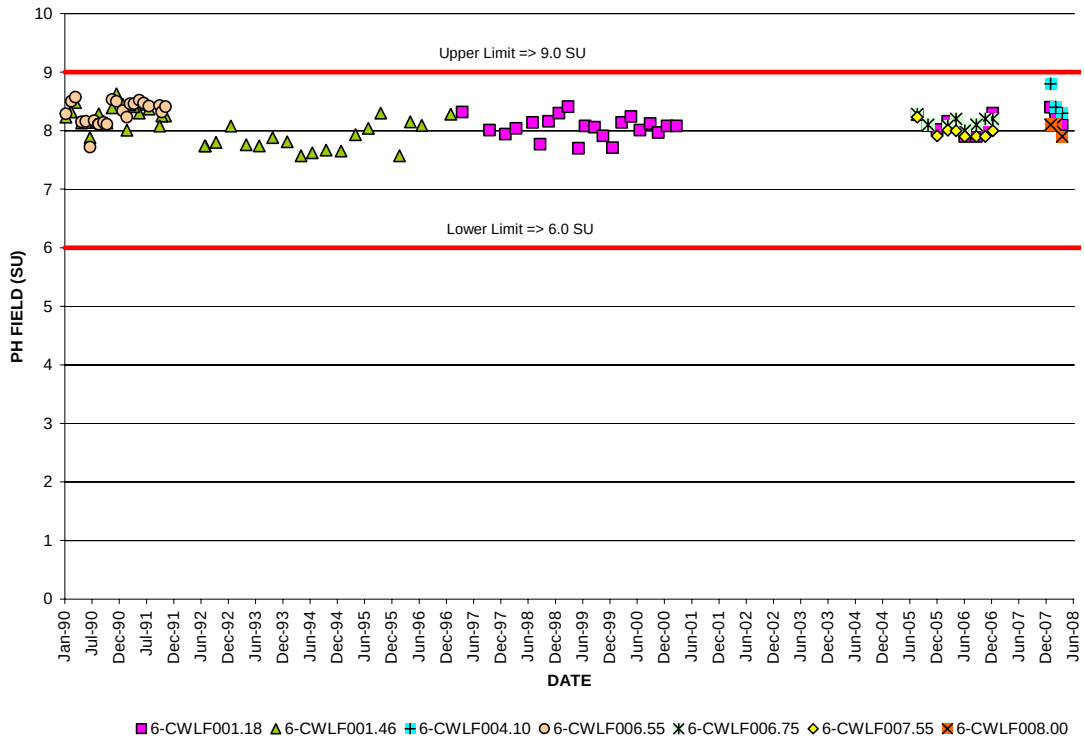


**Figure 2.12. Field pH values at water quality monitoring stations in Wolf Creek.**

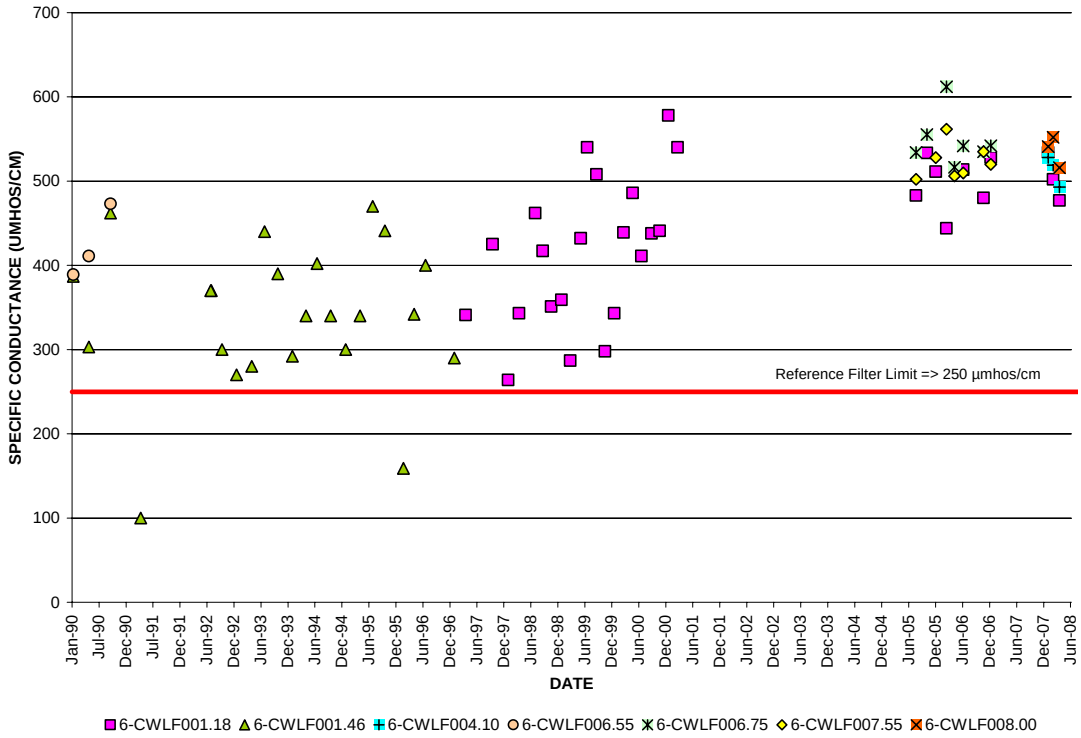


**Figure 2.13. Specific conductance values at water quality monitoring stations in Wolf Creek.**

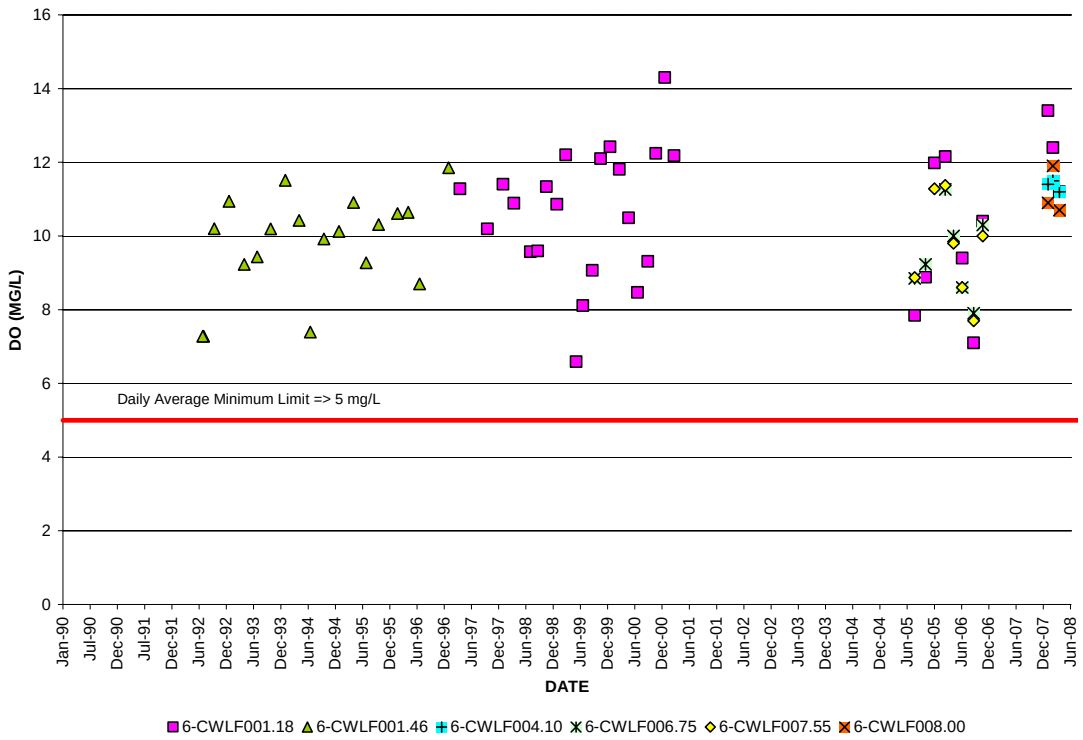


**Figure 2.14. Dissolved oxygen values at water quality monitoring stations in Wolf Creek.**

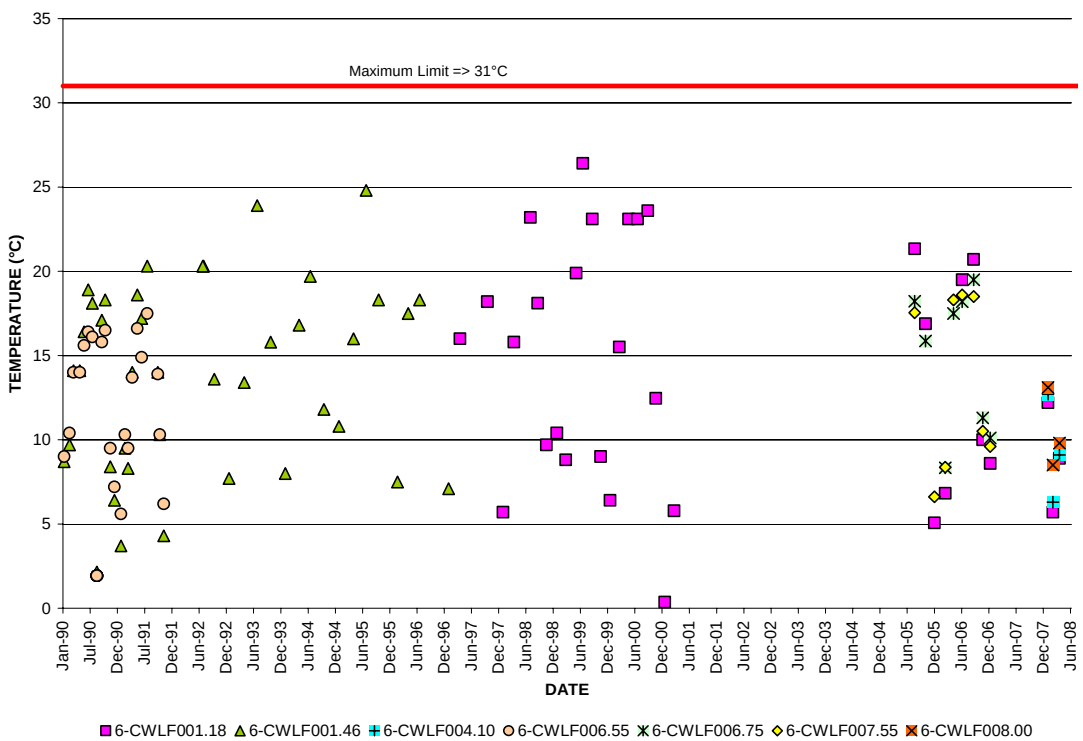


**Figure 2.15. Temperature values at water quality monitoring stations in Wolf Creek.**

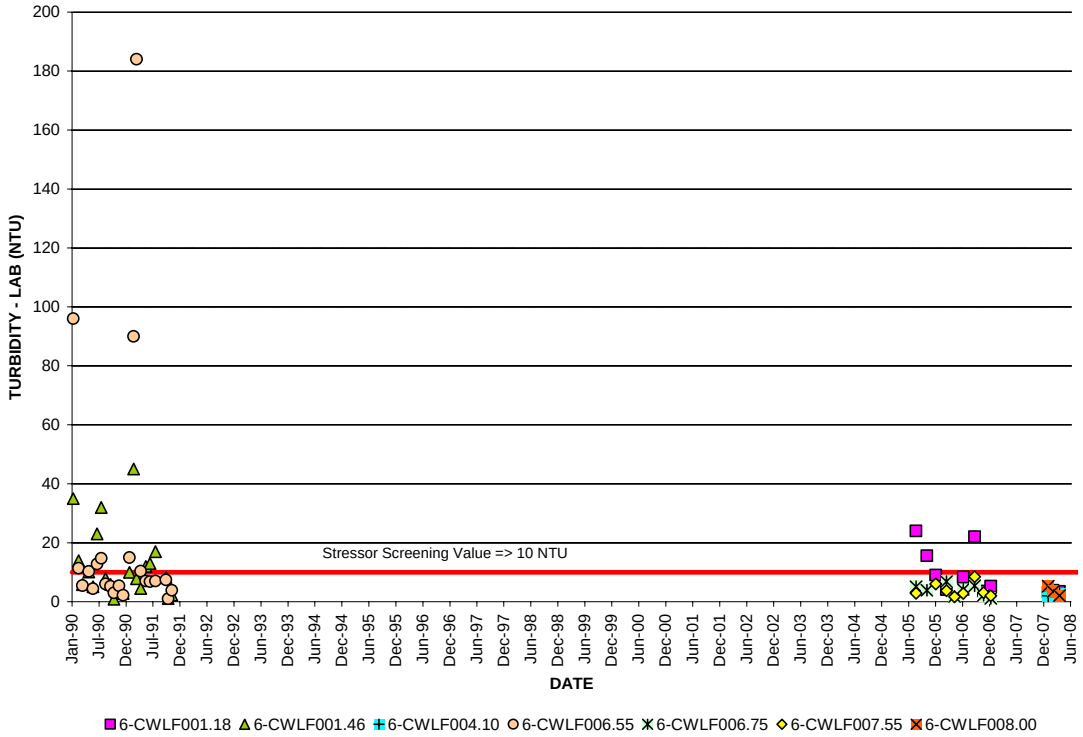


**Figure 2.16. Turbidity values at water quality monitoring stations in Wolf Creek.**

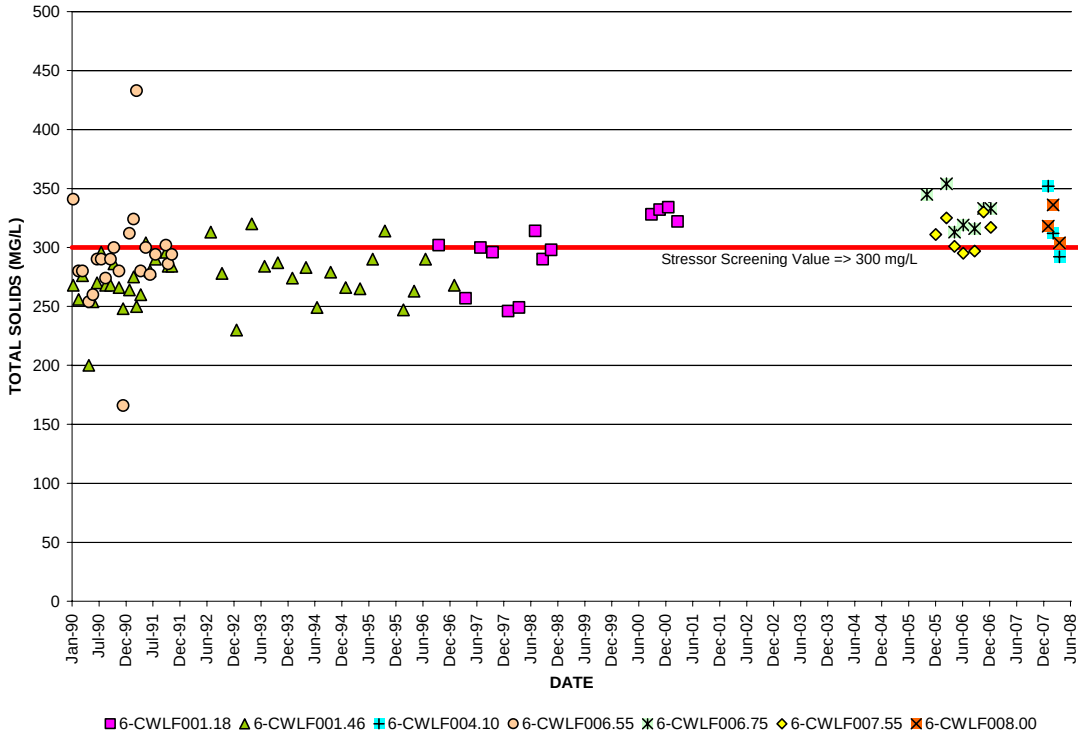


**Figure 2.17. Total solids values at water quality monitoring stations in Wolf Creek.**

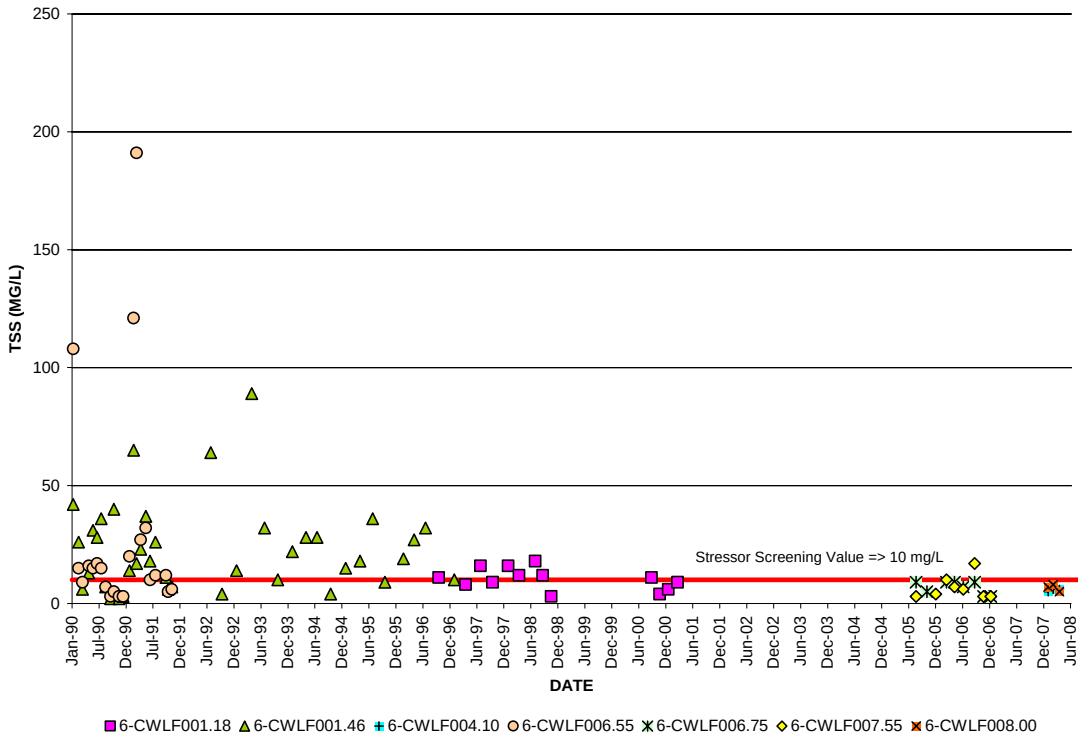


**Figure 2.18. Total suspended solids (TSS) values at water quality monitoring stations in Wolf Creek.**

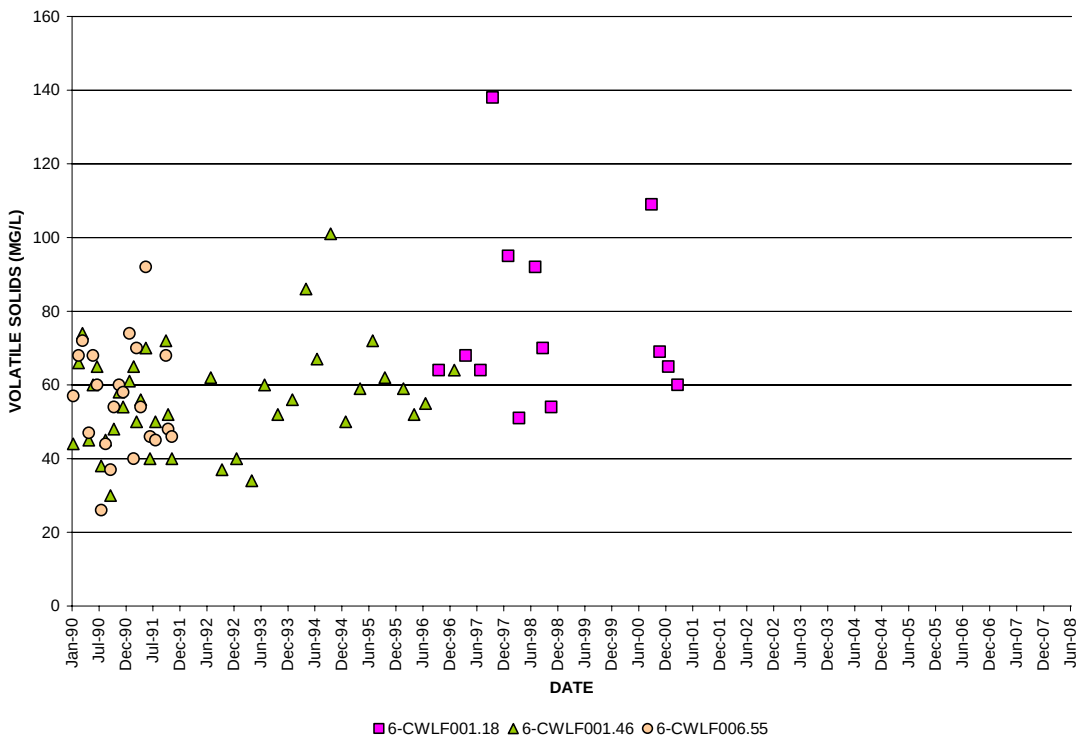


**Figure 2.19. Volatile solids values at water quality monitoring stations in Wolf Creek.**

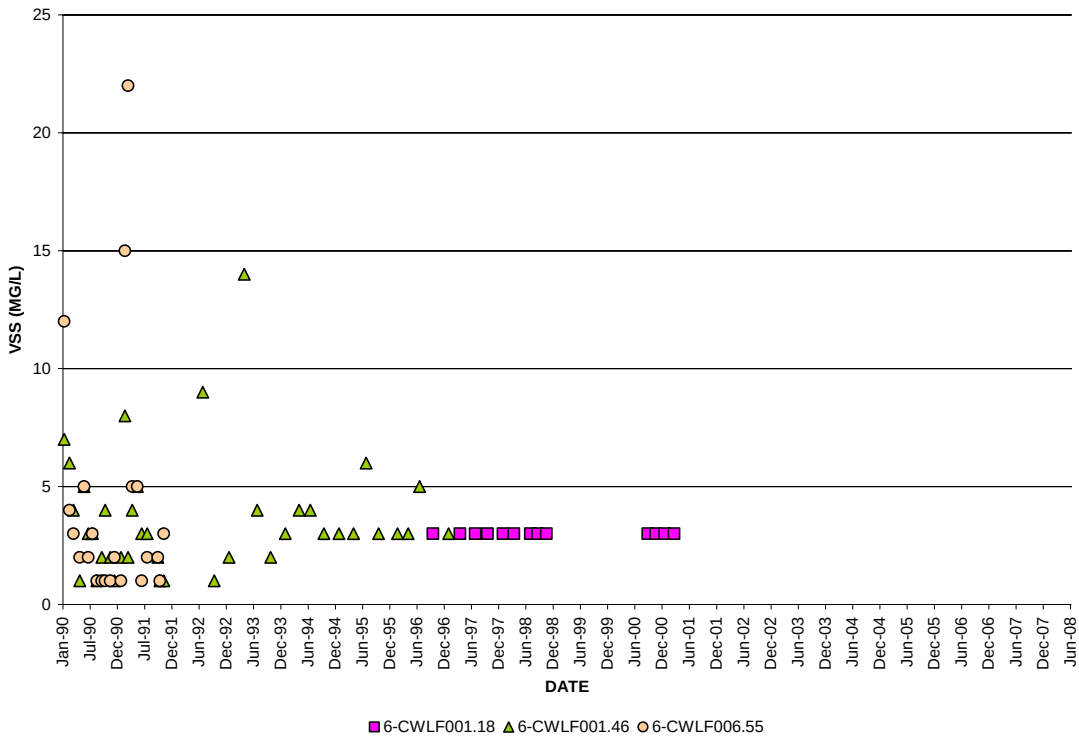


**Figure 2.20. Volatile suspended solids values at water quality monitoring stations in Wolf Creek.**

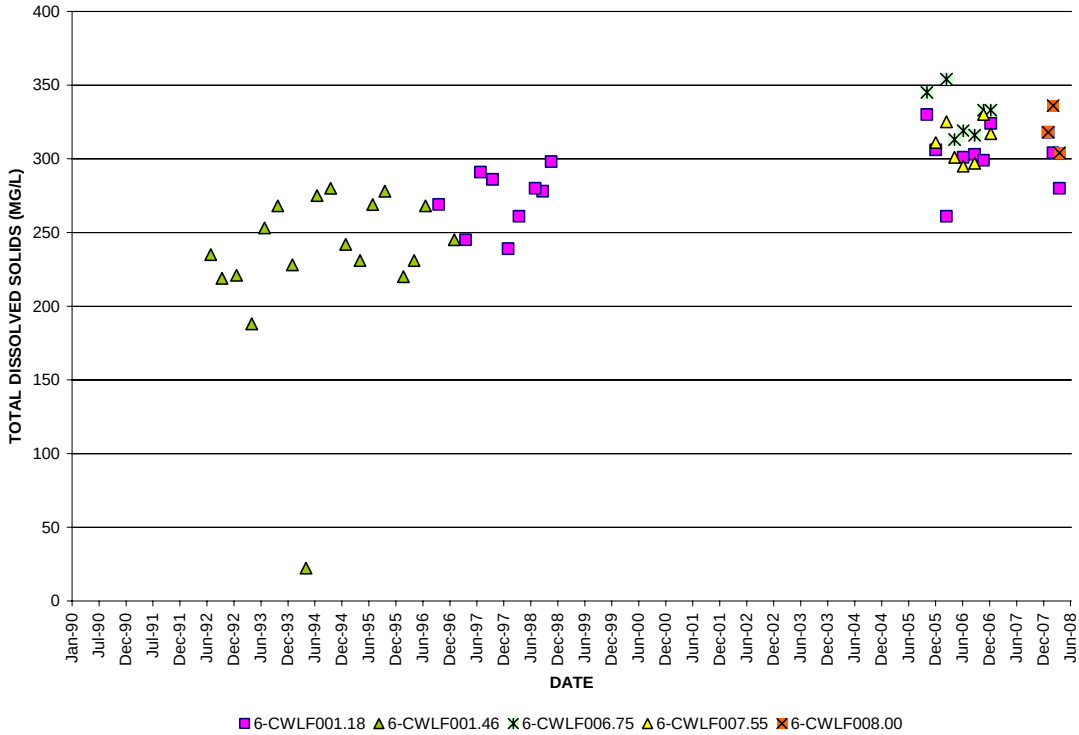


**Figure 2.21. Total dissolved solids values at water quality monitoring stations in Wolf Creek.**

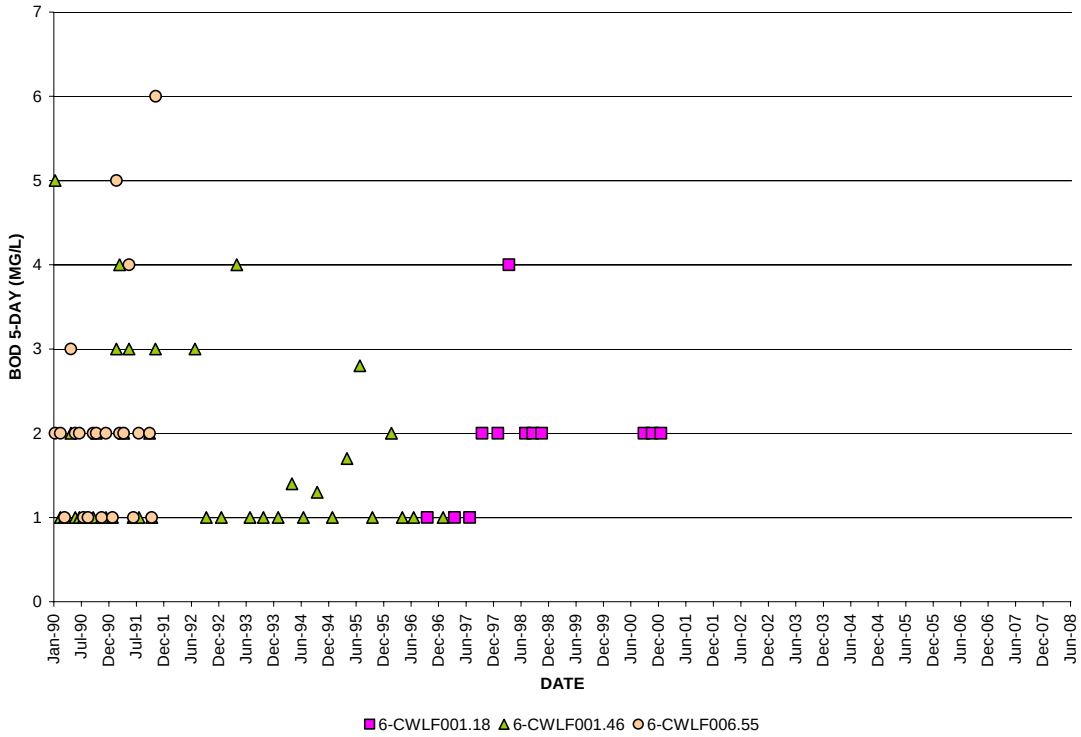


**Figure 2.22. Biochemical oxygen demand (BOD5) values at water quality monitoring stations in Wolf Creek.**

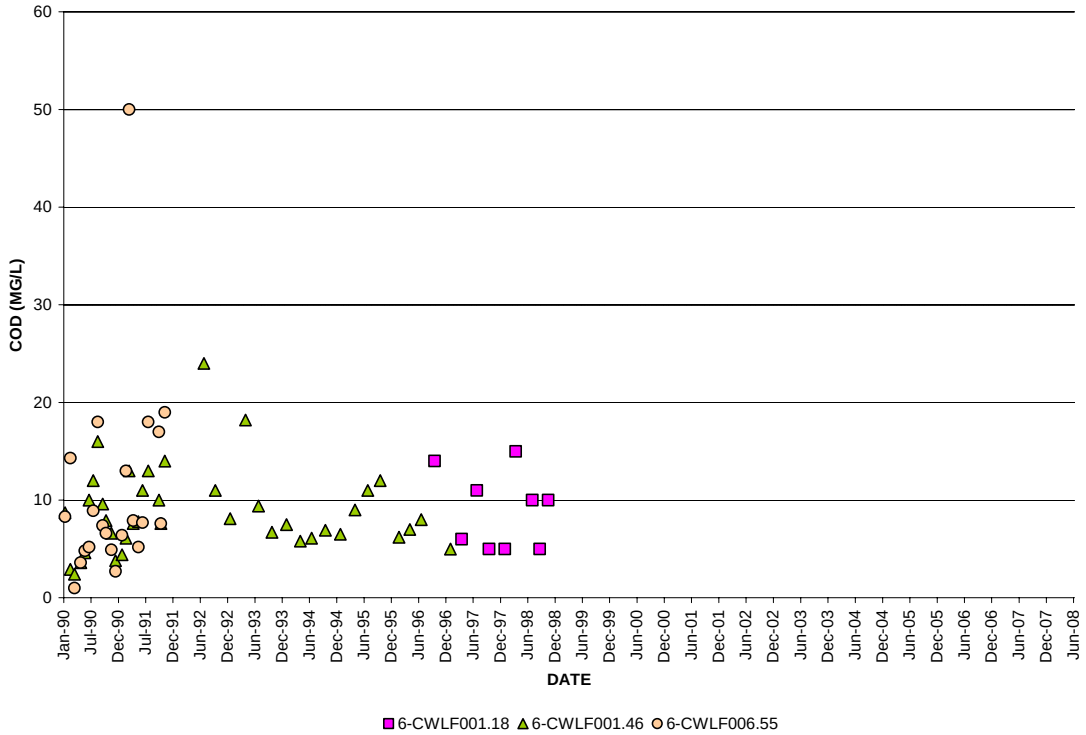


**Figure 2.23. Chemical oxygen demand values at water quality monitoring stations in Wolf Creek.**

### *2.7.2 Metals*

Tables 2.20 through 2.22 contain summary of data collected at the various water quality stations. Summary of data includes number of observations between January 1, 1990 and March 31, 2008; mean, minimum; and maximum values. The data temporal range varies from parameter to parameter, and there is not always a good overlap between biological and ambient monitoring data. Total metal concentrations were measured at WQM stations 6-CWLF001.46 and 6-CWLF006.55 and sedimentary metal concentrations were measured at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55. Data for metal parameters collected in the watershed are depicted in Figures 2.24 through 2.53. Summary of observations includes:

- Sedimentary cadmium values at WQM stations 6-CWLF001.18 and 6-CWLF001.46 exceeded the consensus probable effect concentration of 4.98 ppm; and
- All other total metal concentrations and sedimentary metal concentrations at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 were below the applicable consensus probable effect concentration and do not appear to be a stressor to the benthic community.

**Table 2.20. Metals water quality data summary for station 6CWLF001.18 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| **METALS - TOTAL** | | | | |
| Aluminum, µg/L | N/A | N/A | N/A | N/A |
| Antimony, µg/L | N/A | N/A | N/A | N/A |
| Arsenic µg/L | N/A | N/A | N/A | N/A |
| Beryllium, µg/l | N/A | N/A | N/A | N/A |
| Cadmium, µg/l | N/A | N/A | N/A | N/A |
| Chromium, µg/l | N/A | N/A | N/A | N/A |
| Copper, µg/l | N/A | N/A | N/A | N/A |
| Iron, µg/l | N/A | N/A | N/A | N/A |
| Lead, µg/l | N/A | N/A | N/A | N/A |
| Magnesium, µg/l | N/A | N/A | N/A | N/A |
| Manganese, µg/l | N/A | N/A | N/A | N/A |
| Mercury, µg/l | N/A | N/A | N/A | N/A |
| Nickel, µg/l | N/A | N/A | N/A | N/A |
| Selenium, µg/l | N/A | N/A | N/A | N/A |
| Silver,µg/l | N/A | N/A | N/A | N/A |
| Thallium, µg/l | N/A | N/A | N/A | N/A |
| Zinc,µg/l | N/A | N/A | N/A | N/A |
| **METALS - SEDIMENT** | | | | |
| Aluminum, mg/kg | 2 | 7,657 | 9,814 | 5,500 |
| Antimony, mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Arsenic mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Beryllium, mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Cadmium, mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Chromium, mg/kg | 2 | 12.10 | 13.00 | 11.20 |
| Copper, mg/kg | 2 | 10.89 | 14.00 | 7.78 |
| Iron, mg/kg | 2 | 17,867 | 22,134 | 13,600 |
| Lead, mg/kg | 2 | 15.21 | 16.41 | 14.00 |
| Manganese, mg/kg | 2 | 636.50 | 973.00 | 300.00 |
| Mercury, mg/kg | 2 | 0.30 | 0.30 | 0.30 |
| Nickel, mg/kg | 2 | 11.09 | 13.00 | 9.17 |
| Selenium, mg/kg | 2 | 1.00 | 1.00 | 1.00 |
| Silver,mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Thallium, mg/kg | 2 | 5.00 | 5.00 | 5.00 |
| Zinc,mg/kg | 2 | 57.05 | 61.00 | 53.10 |

**Table 2.21. Metals water quality data summary for station 6CWLF001.46 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| **METALS - TOTAL** | | | | |
| Aluminum, µg/L | N/A | N/A | N/A | N/A |
| Antimony, µg/L | N/A | N/A | N/A | N/A |
| Arsenic µg/L | 6 | 10.00 | 10.00 | 10.00 |
| Berylium, µg/l | 5 | 10.00 | 10.00 | 10.00 |
| Cadmium, µg/l | 6 | 10.00 | 10.00 | 10.00 |
| Chromium, µg/l | 5 | 10.00 | 10.00 | 10.00 |
| Copper, µg/l | 5 | 10.00 | 10.00 | 10.00 |
| Iron, µg/l | 5 | 512.69 | 1,087.25 | 98.63 |
| Lead, µg/l | 5 | 10.00 | 10.00 | 10.00 |
| Magnesium, µg/l | 5 | 16,382 | 18,910 | 14,290 |
| Manganese, µg/l | 6 | 45.62 | 71.02 | 18.98 |
| Mercury, µg/l | 6 | 0.30 | 0.30 | 0.30 |
| Nickel, µg/l | 6 | 10.00 | 10.00 | 10.00 |
| Selenium, µg/l | 6 | 18.33 | 20.00 | 10.00 |
| Silver,µg/l | N/A | N/A | N/A | N/A |
| Thallium, µg/l | 6 | 18.33 | 20.00 | 10.00 |
| Zinc,µg/l | 6 | 15.02 | 29.96 | 10.00 |
| **METALS - SEDIMENT** | | | | |
| Aluminum, mg/kg | 3 | 16,890 | 22,500 | 6,670 |
| Antimony, mg/kg | 3 | 14.00 | 28.00 | 5.00 |
| Arsenic mg/kg | 7 | 5.71 | 8.00 | 3.00 |
| Berylium, mg/kg | 7 | 4.00 | 5.00 | 1.00 |
| Cadmium, mg/kg | 7 | 3.86 | 5.00 | 1.00 |
| Chromium, mg/kg | 7 | 17.71 | 29.00 | 8.00 |
| Copper, mg/kg | 7 | 27.43 | 53.00 | 11.00 |
| Iron, mg/kg | 3 | 19,800 | 23,900 | 12,100 |
| Lead, mg/kg | 7 | 23.57 | 41.00 | 8.00 |
| Manganese, mg/kg | 3 | 512.67 | 775.00 | 221.00 |
| Mercury, mg/kg | 7 | 0.36 | 0.70 | 0.10 |
| Nickel, mg/kg | 7 | 11.57 | 24.00 | 5.00 |
| Selenium, mg/kg | 7 | 2.92 | 14.00 | 1.00 |
| Silver,mg/kg | 5 | 5.00 | 5.00 | 5.00 |
| Thallium, mg/kg | 7 | 4.00 | 5.00 | 1.00 |
| Zinc,mg/kg | 7 | 82.14 | 143.00 | 33.00 |

**Table 2.22. Metals water quality data summary for station 6CWLF006.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| **METALS - TOTAL** | | | | |
| Aluminum, µg/L | N/A | N/A | N/A | N/A |
| Antimony, µg/L | N/A | N/A | N/A | N/A |
| Arsenic µg/L | 1 | 10.00 | 10.00 | 10.00 |
| Beryllium, µg/l | N/A | N/A | N/A | N/A |
| Cadmium, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Chromium, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Copper, µg/l | 1 | 20.00 | 20.00 | 20.00 |
| Iron, µg/l | 1 | 220.00 | 220.00 | 220.00 |
| Lead, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Magnesium, µg/l | N/A | N/A | N/A | N/A |
| Manganese, µg/l | 1 | 20.00 | 20.00 | 20.00 |
| Mercury, µg/l | 1 | 0.30 | 0.30 | 0.30 |
| Nickel, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Selenium, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Silver,µg/l | N/A | N/A | N/A | N/A |
| Thallium, µg/l | 1 | 10.00 | 10.00 | 10.00 |
| Zinc,µg/l | 1 | 20.00 | 20.00 | 20.00 |
| **METALS - SEDIMENT** | | | | |
| Aluminum, mg/kg | N/A | N/A | N/A | N/A |
| Antimony, mg/kg | N/A | N/A | N/A | N/A |
| Arsenic mg/kg | 1 | 3.00 | 3.00 | 3.00 |
| Beryllium, mg/kg | 1 | 1.00 | 1.00 | 1.00 |
| Cadmium, mg/kg | 1 | 1.00 | 1.00 | 1.00 |
| Chromium, mg/kg | 1 | 19.00 | 19.00 | 19.00 |
| Copper, mg/kg | 1 | 20.00 | 20.00 | 20.00 |
| Iron, mg/kg | N/A | N/A | N/A | N/A |
| Lead, mg/kg | 1 | 17.00 | 17.00 | 17.00 |
| Manganese, mg/kg | 1 | 20.00 | 20.00 | 20.00 |
| Mercury, mg/kg | 1 | 0.13 | 0.13 | 0.13 |
| Nickel, mg/kg | 1 | 17.00 | 17.00 | 17.00 |
| Selenium, mg/kg | 1 | 4.00 | 4.00 | 4.00 |
| Silver,mg/kg | N/A | N/A | N/A | N/A |
| Thallium, mg/kg | 1 | 1.00 | 1.00 | 1.00 |
| Zinc,mg/kg | 1 | 70.00 | 70.00 | 70.00 |

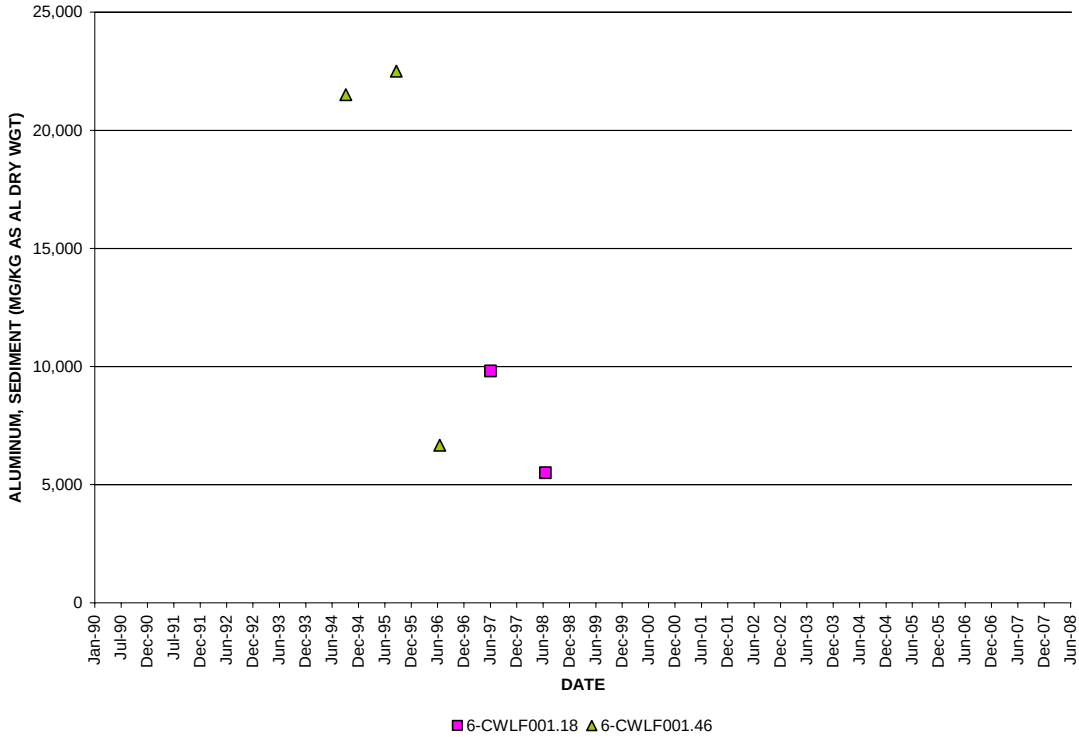


**Figure 2.24. Sedimentary aluminum values at water quality monitoring stations in Wolf Creek.**

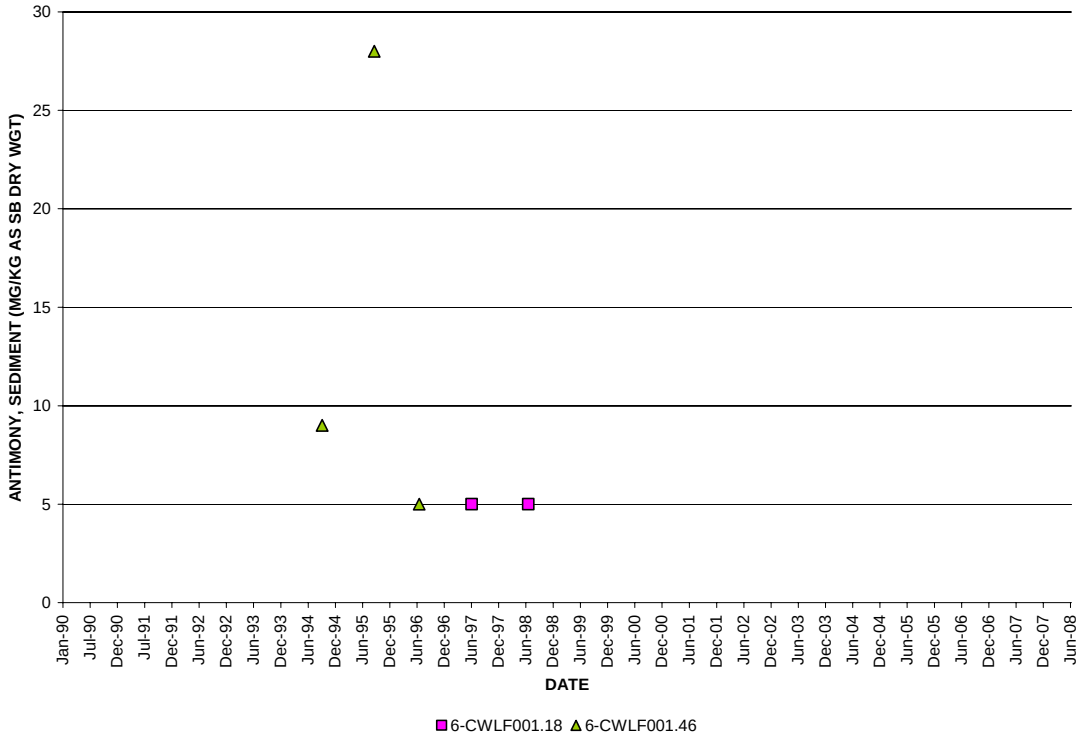


**Figure 2.25. Sedimentary antimony values at water quality monitoring stations in Wolf Creek.**

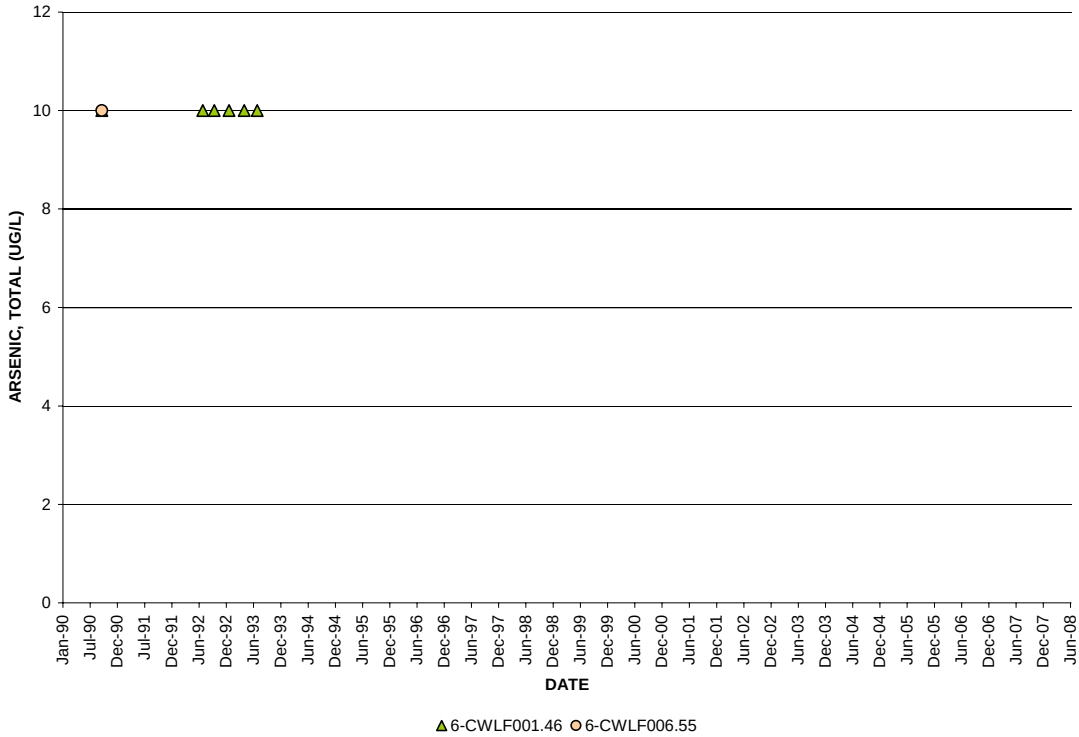


**Figure 2.26. Total arsenic values at water quality monitoring stations in Wolf Creek.**

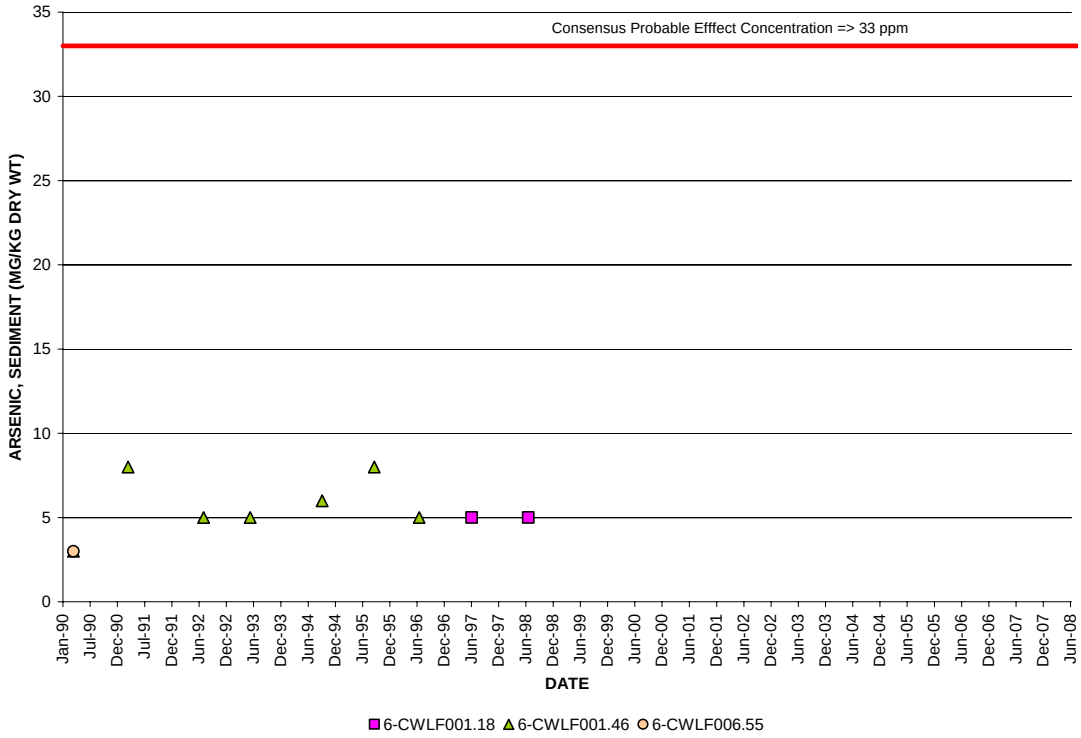


**Figure 2.27. Sedimentary arsenic values at water quality monitoring stations in Wolf Creek.**

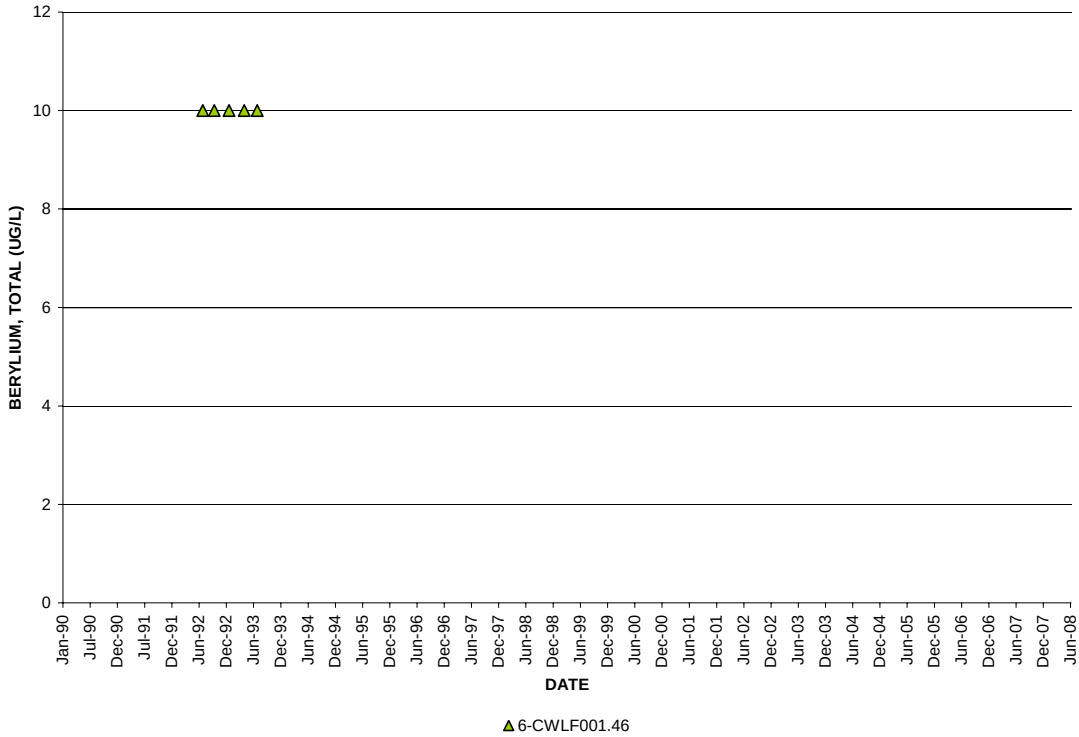


**Figure 2.28. Total beryllium values at water quality monitoring stations in Wolf Creek.**

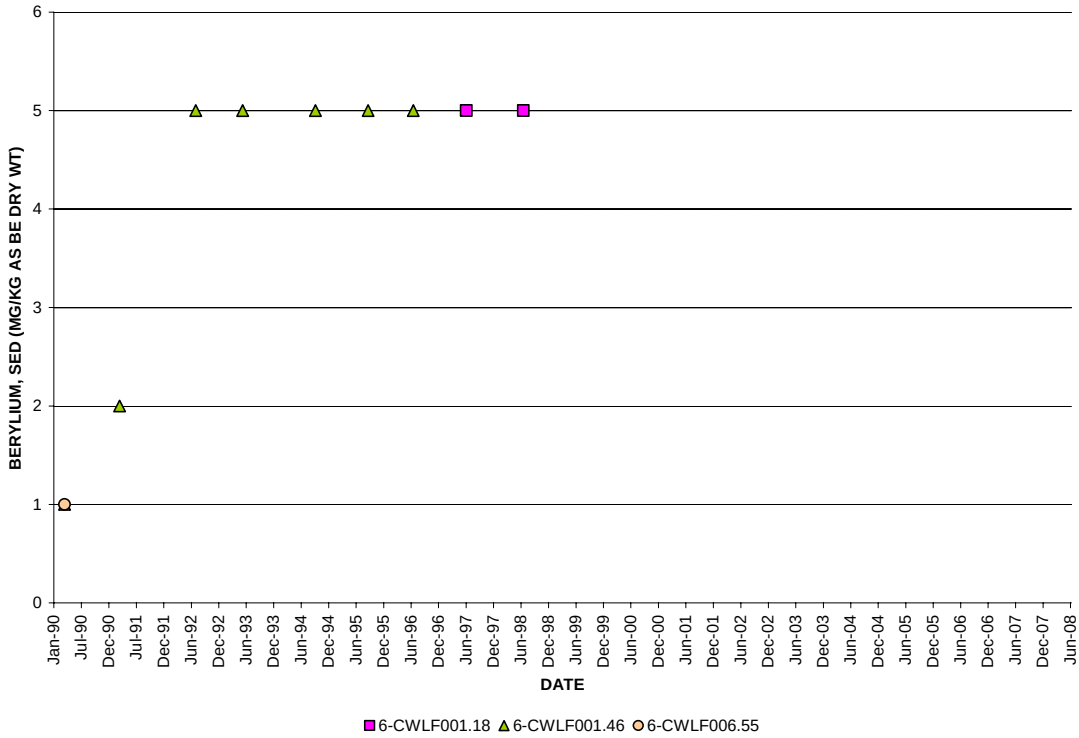


**Figure 2.29. Sedimentary beryllium values at water quality monitoring stations in Wolf Creek**.

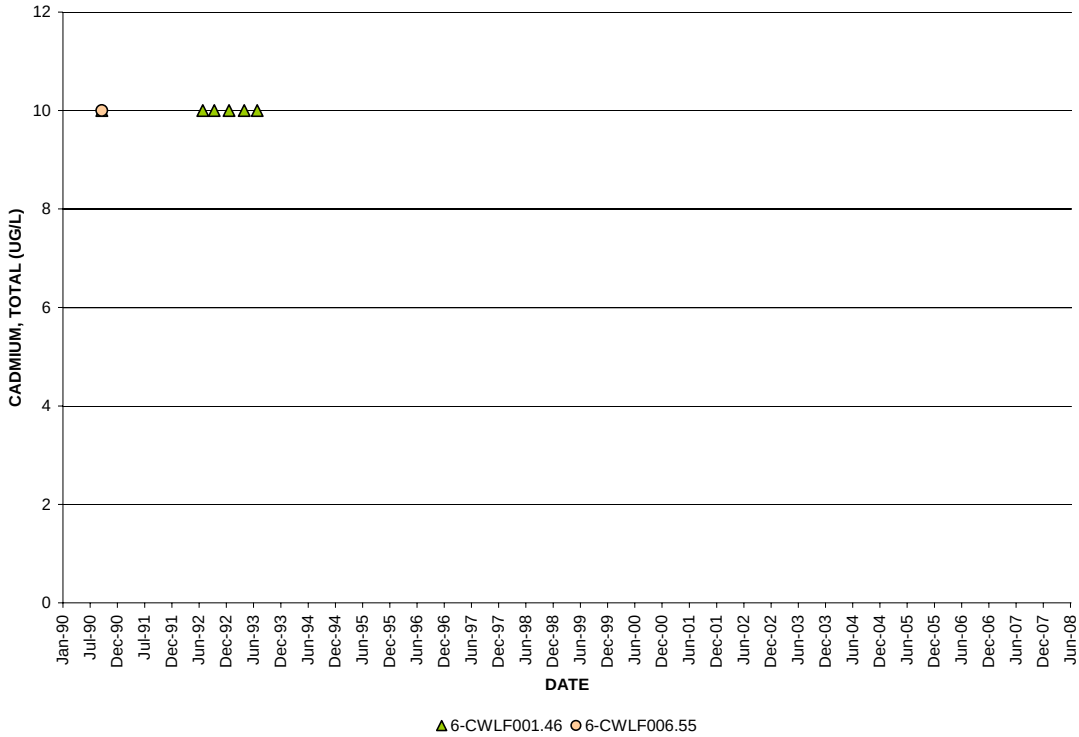


**Figure 2.30. Total cadmium values at water quality monitoring stations in Wolf Creek.**

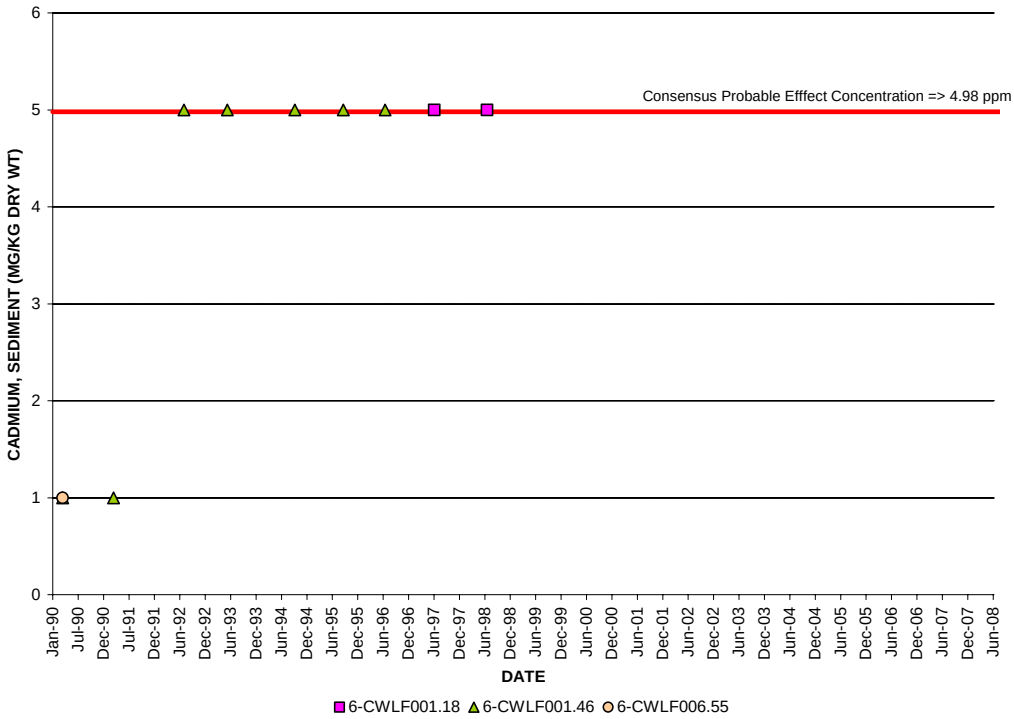


**Figure 2.31. Sedimentary cadmium values at water quality monitoring stations in Wolf Creek.**

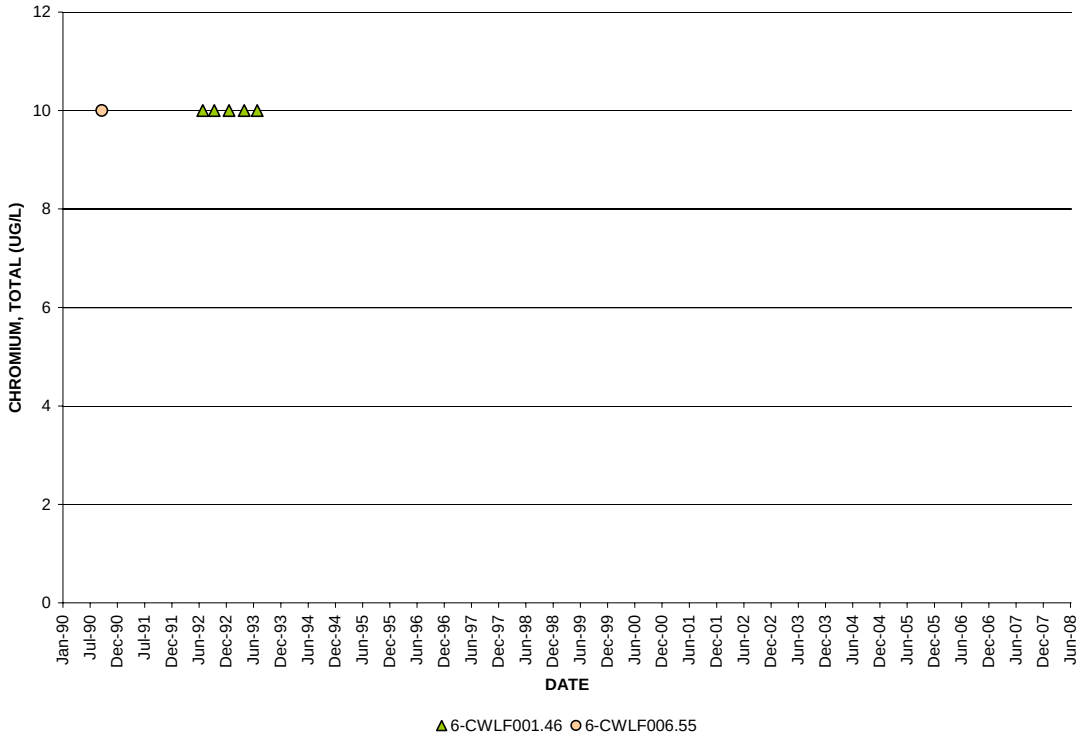


**Figure 2.32. Total chromium values at water quality monitoring stations in Wolf Creek.**

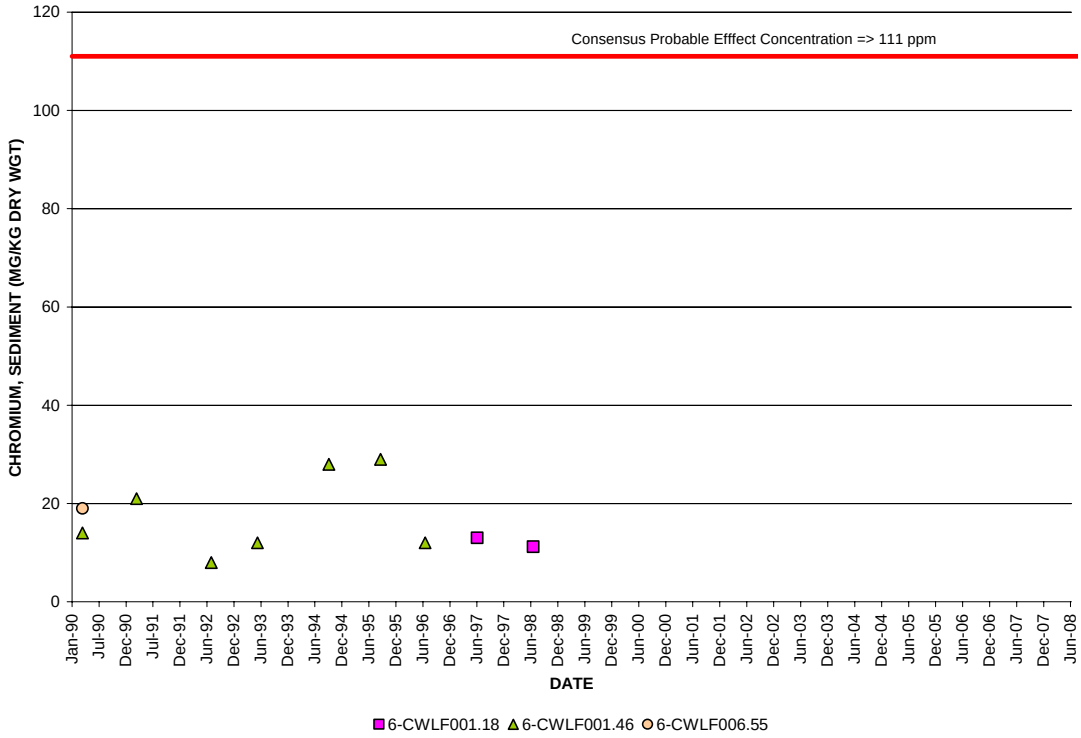


**Figure 2.33. Sedimentary chromium values at water quality monitoring stations in Wolf Creek.**

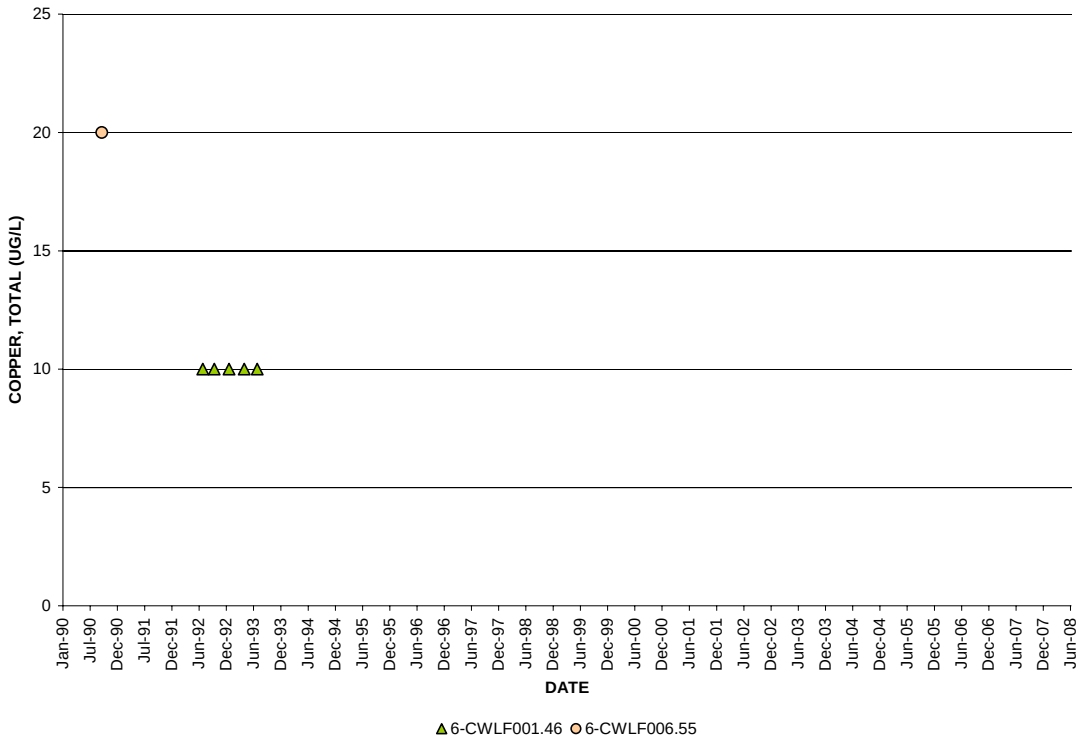


**Figure 2.34. Total copper values at water quality monitoring stations in Wolf Creek.**

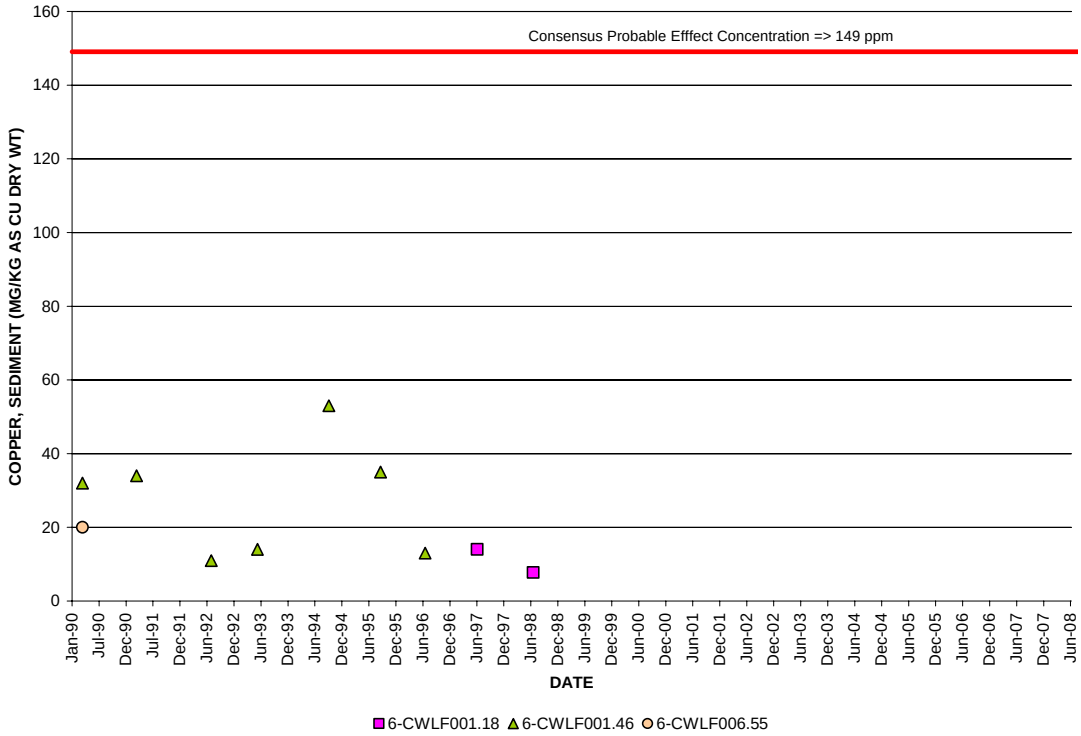


**Figure 2.35. Sedimentary copper values at water quality monitoring stations in Wolf Creek.**

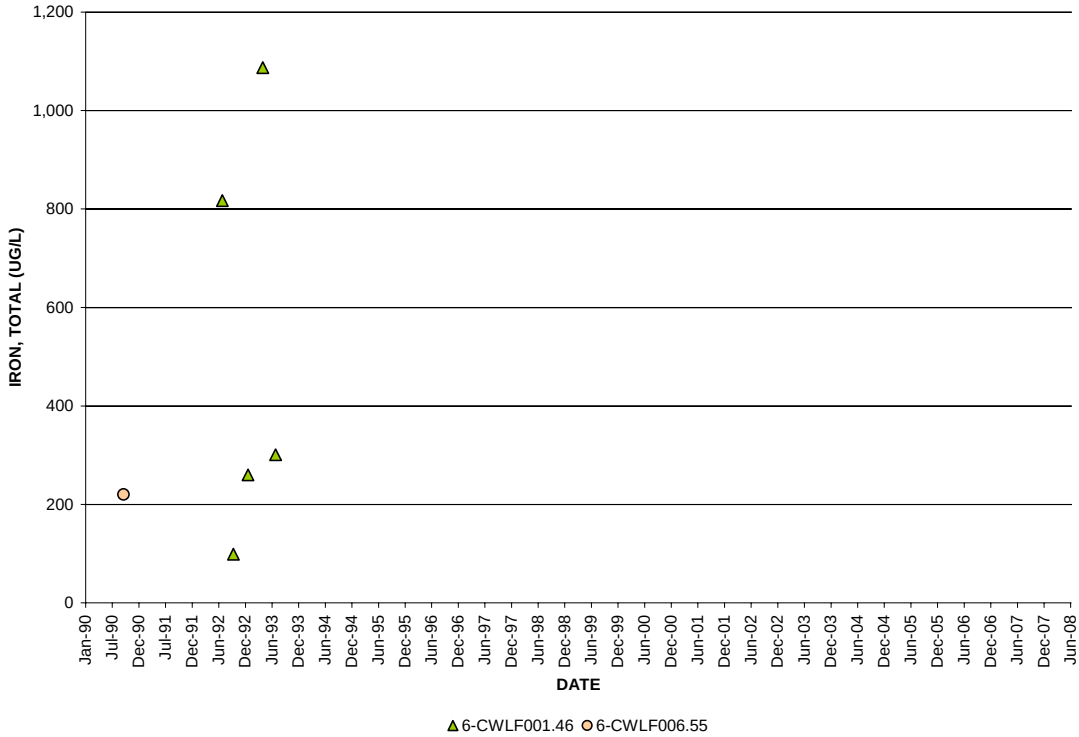


**Figure 2.36. Total iron values at water quality monitoring stations in Wolf Creek.**

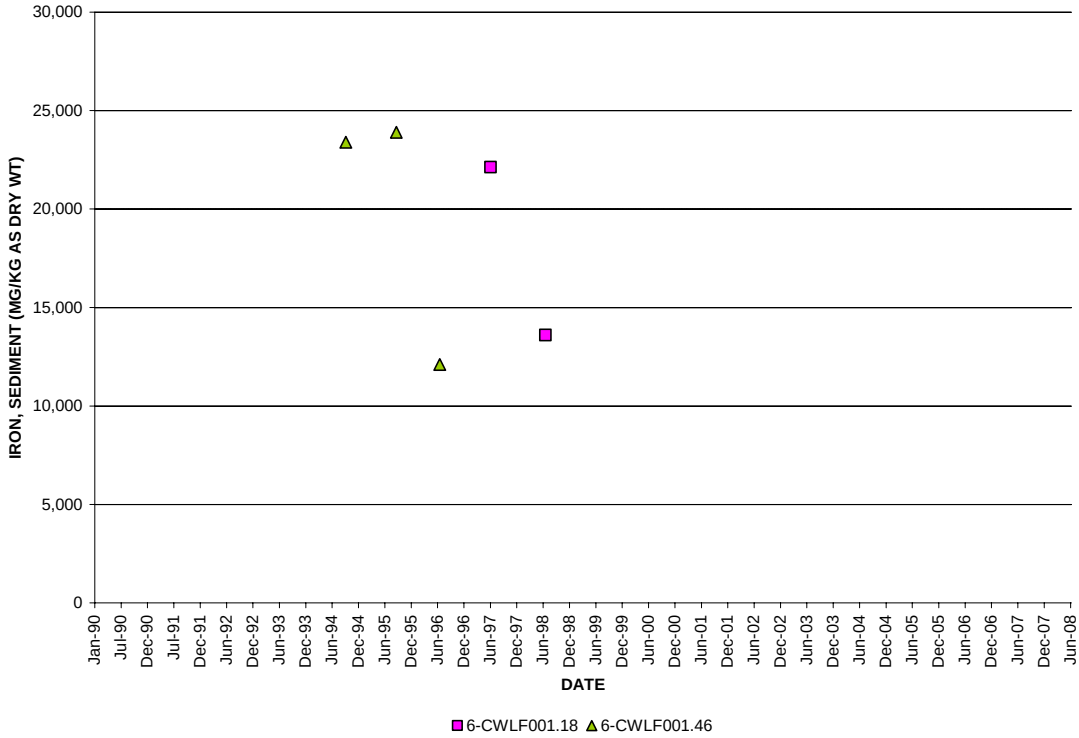


**Figure 2.37. Sedimentary iron values at water quality monitoring stations in Wolf Creek.**

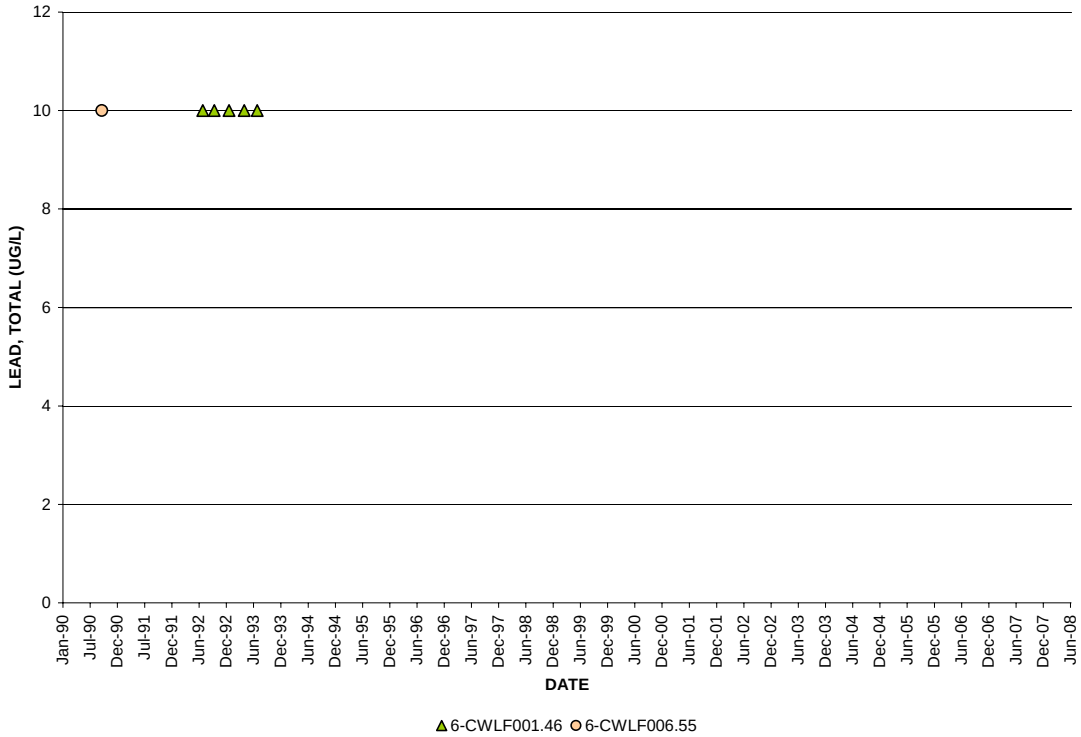


**Figure 2.38. Total lead values at water quality monitoring stations in Wolf Creek.**

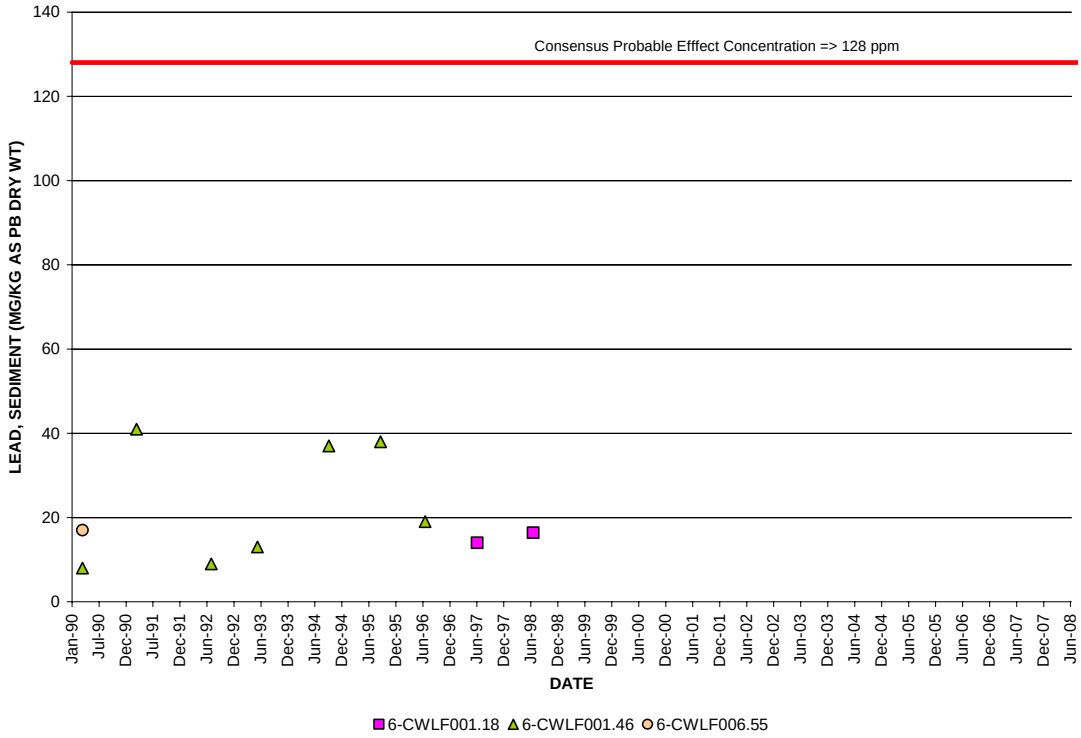


**Figure 2.39. Sedimentary lead values at water quality monitoring stations in Wolf Creek.**

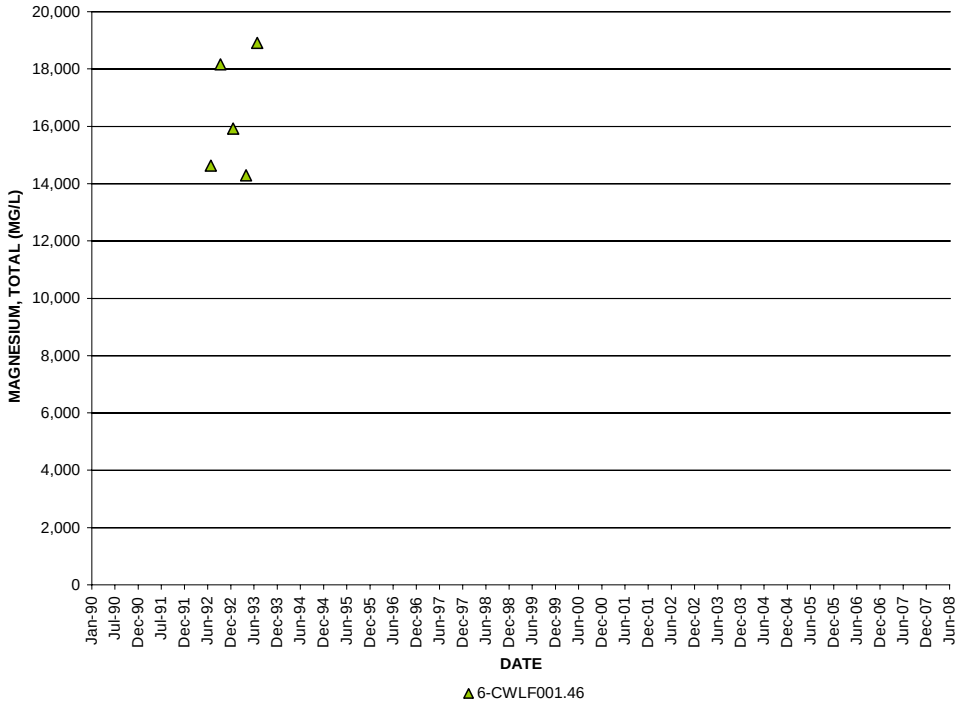


**Figure 2.40. Total magnesium values at water quality monitoring stations in Wolf Creek.**

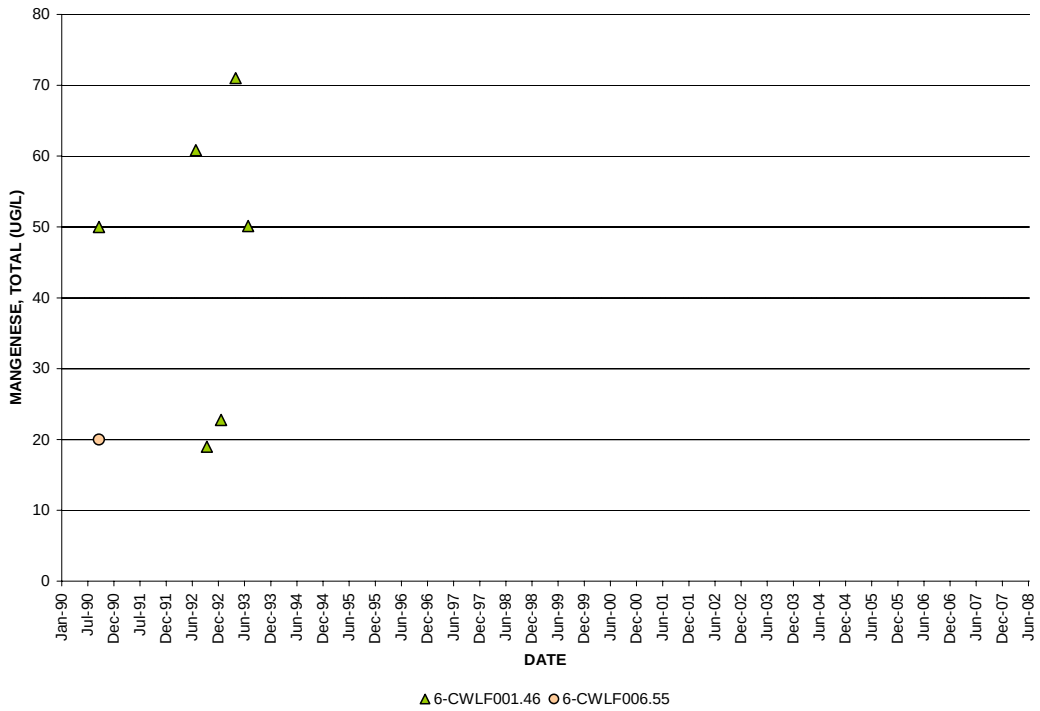


**Figure 2.41. Total manganese values at water quality monitoring stations in Wolf Creek.**

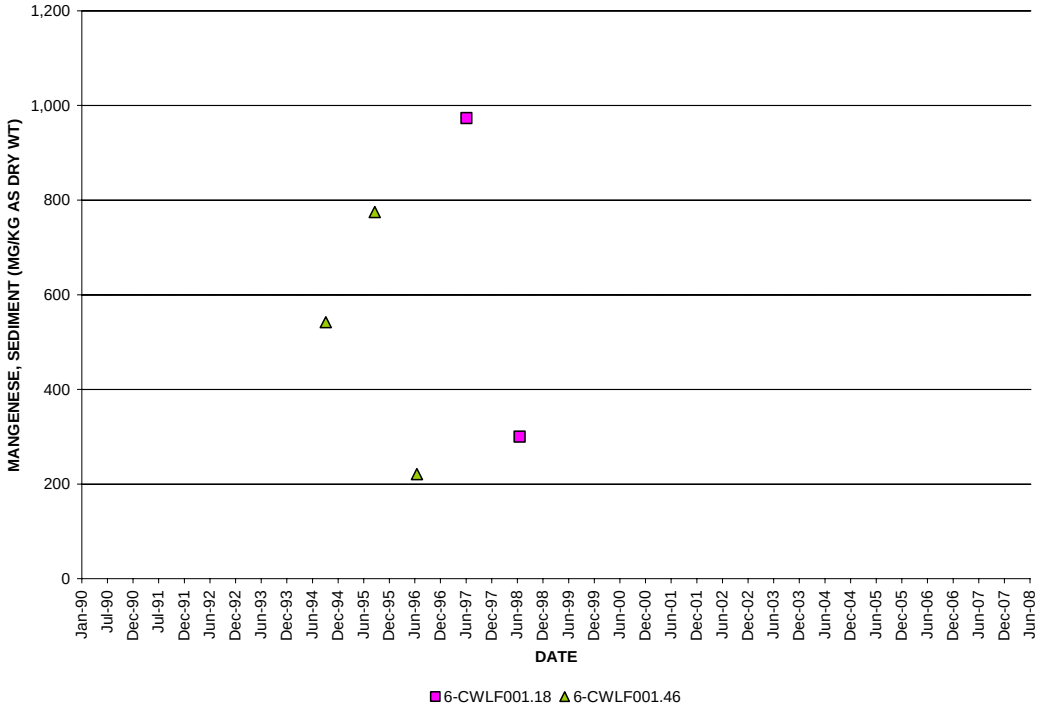


**Figure 2.42. Sedimentary manganese values at water quality monitoring stations in Wolf Creek.**

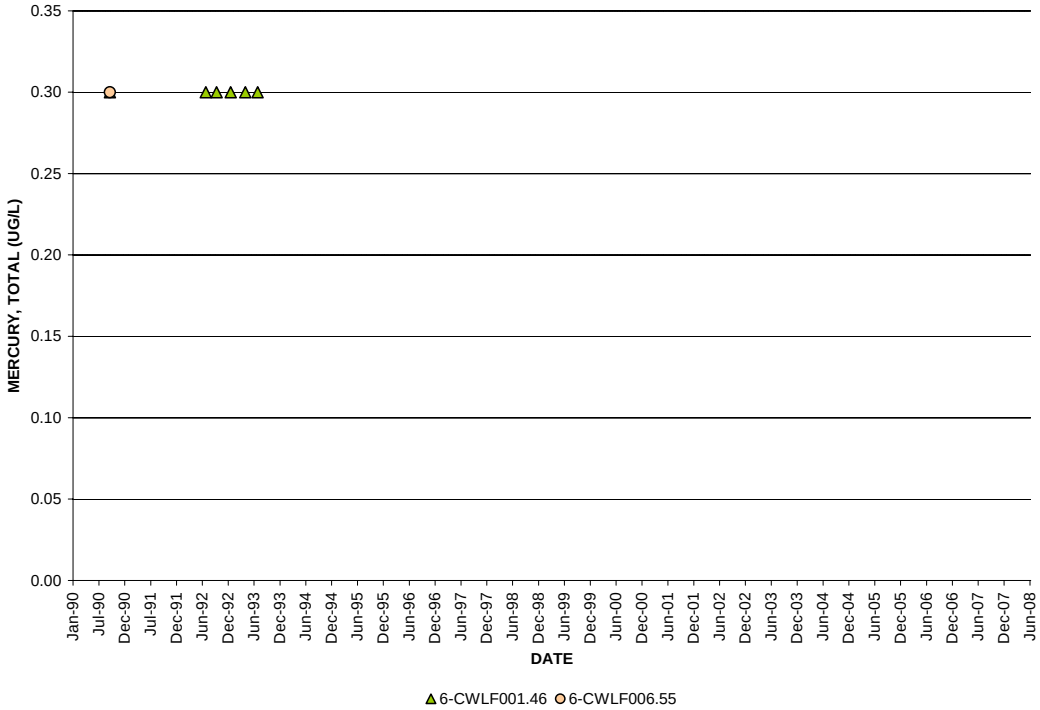


**Figure 2.43. Total mercury values at water quality monitoring stations in Wolf Creek.**

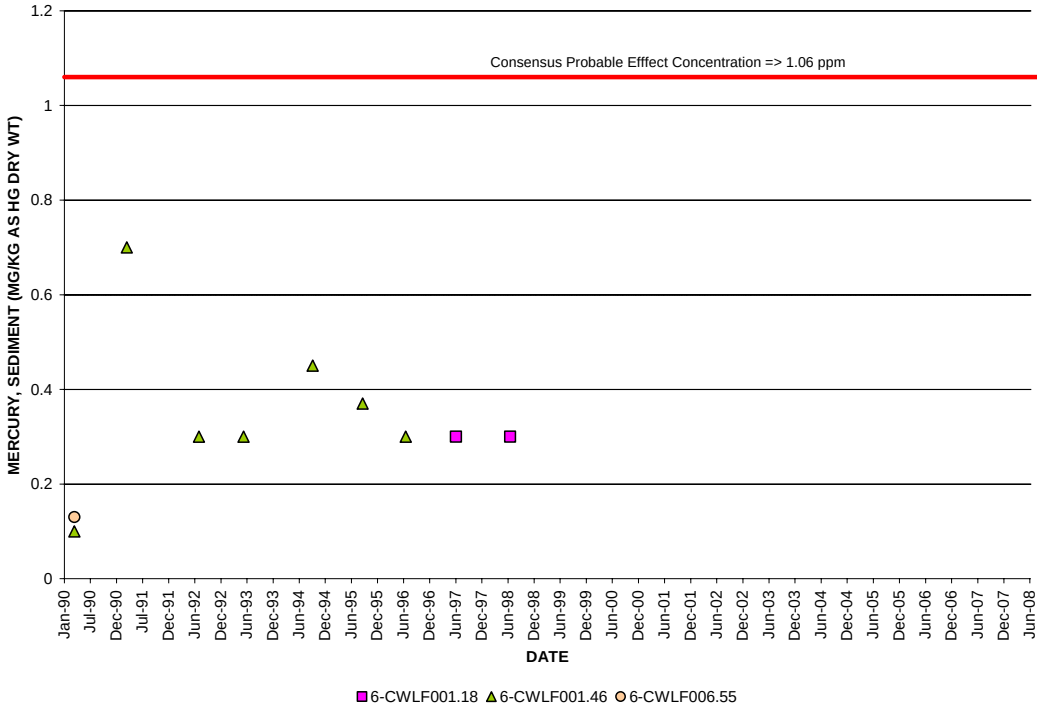


**Figure 2.44. Sedimentary mercury values at water quality monitoring stations in Wolf Creek.**

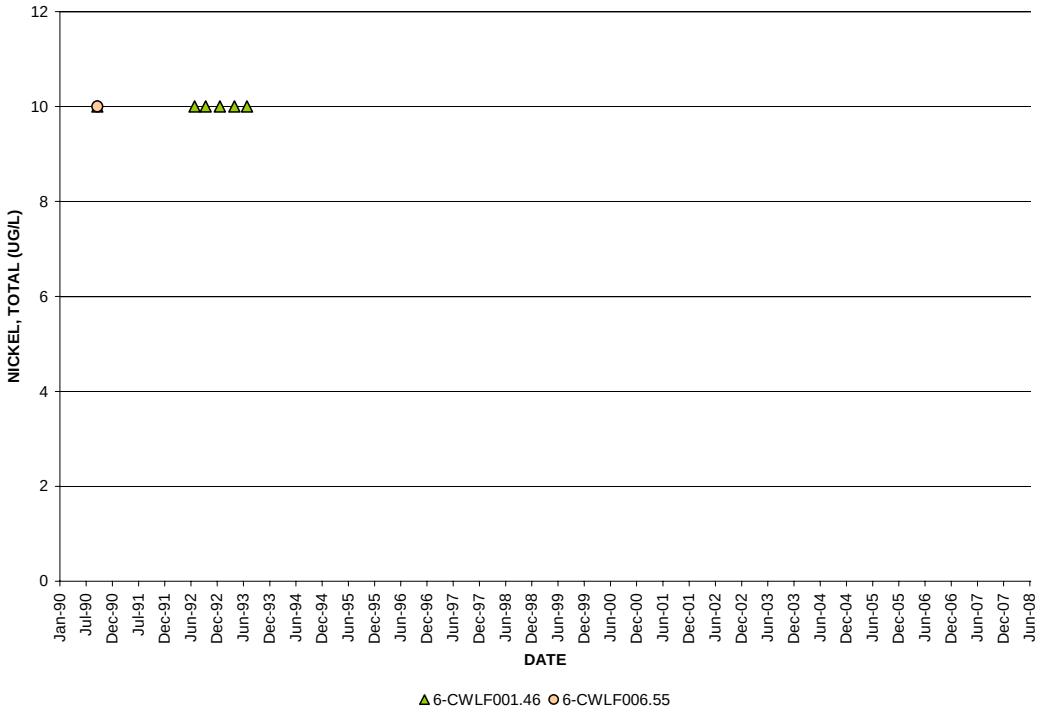


**Figure 2.45. Total nickel values at water quality monitoring stations in Wolf Creek.**

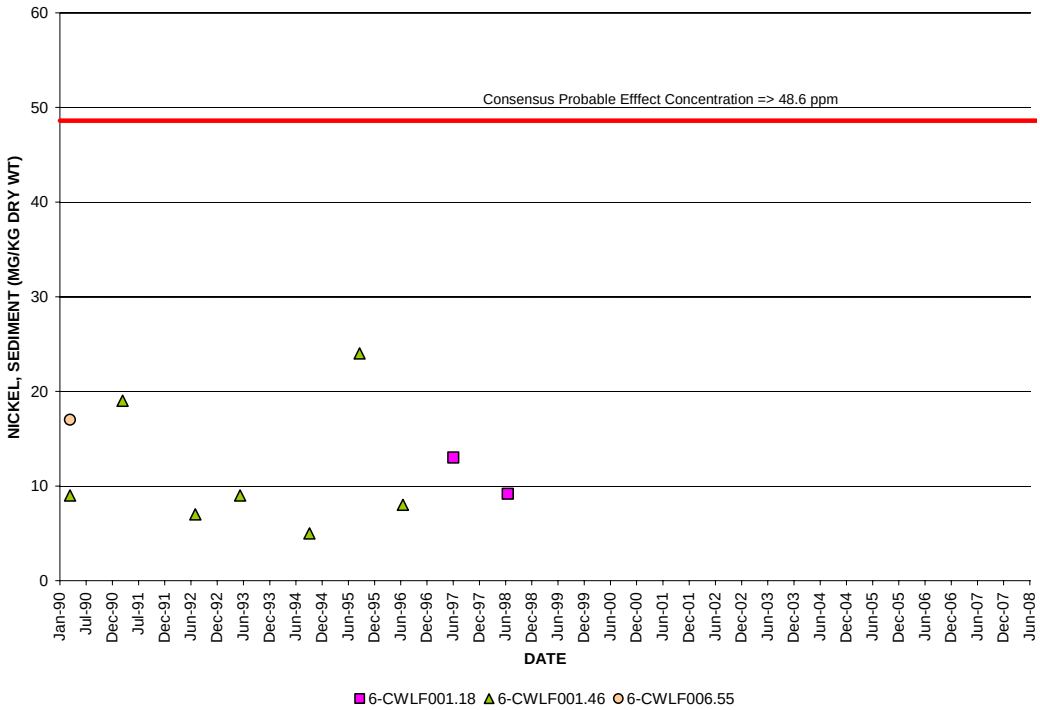


**Figure 2.46. Sedimentary nickel values at water quality monitoring stations in Wolf Creek.**

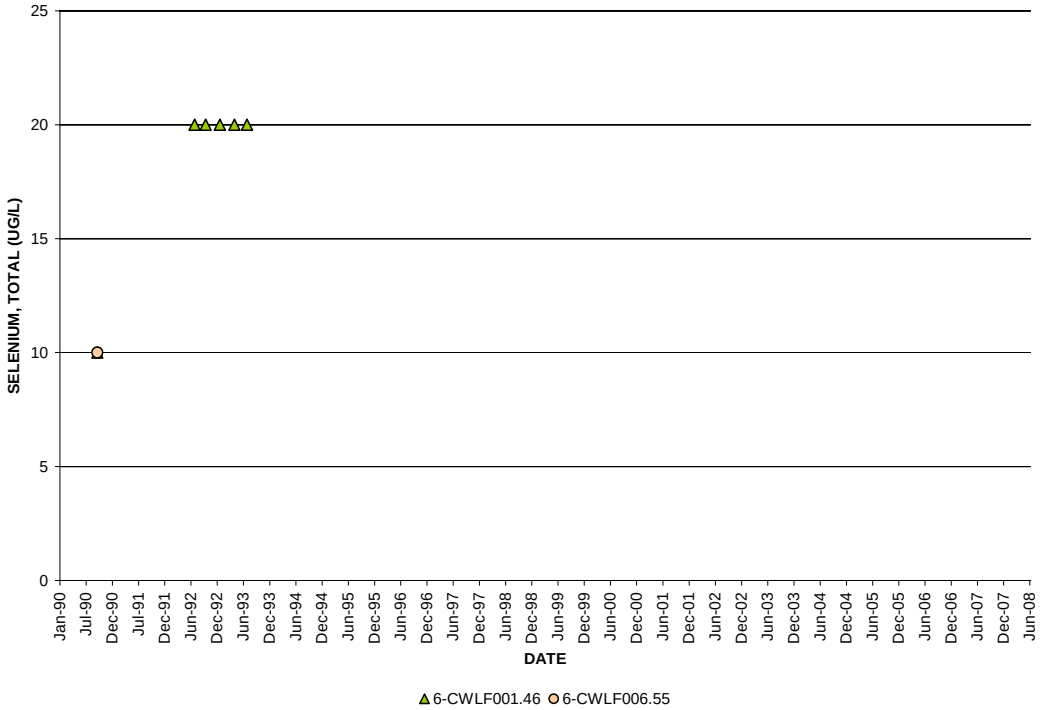


**Figure 2.47. Total selenium values at water quality monitoring stations in Wolf Creek.**

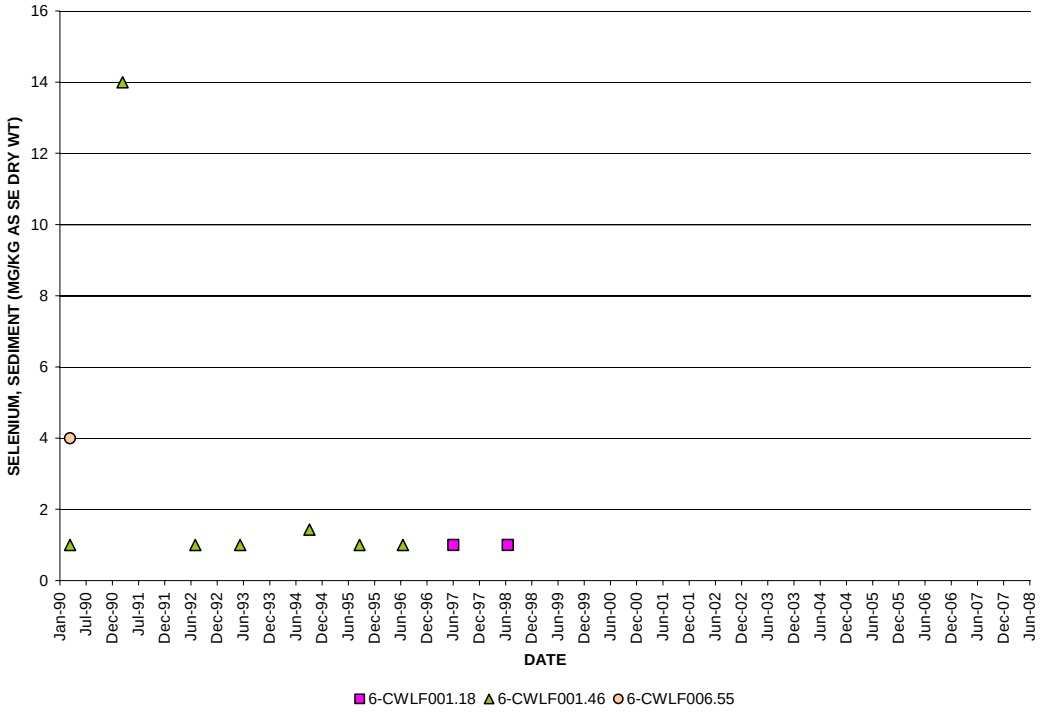


**Figure 2.48. Sedimentary selenium values at water quality monitoring stations in Wolf Creek.**

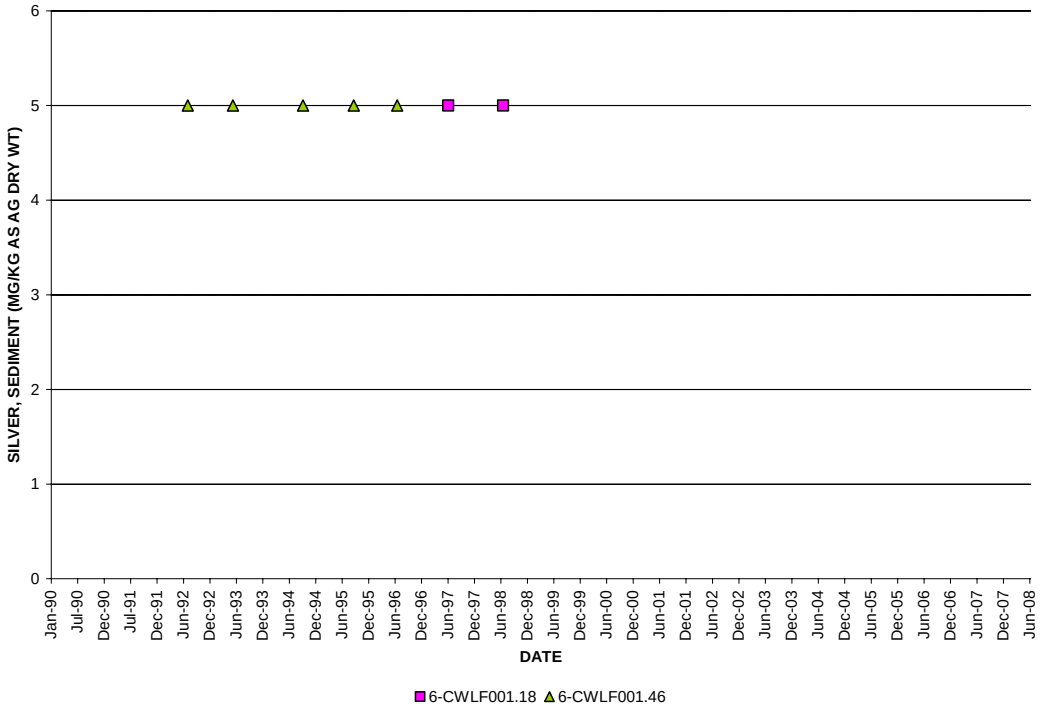


**Figure 2.49. Sedimentary silver values at water quality monitoring stations in Wolf Creek.**

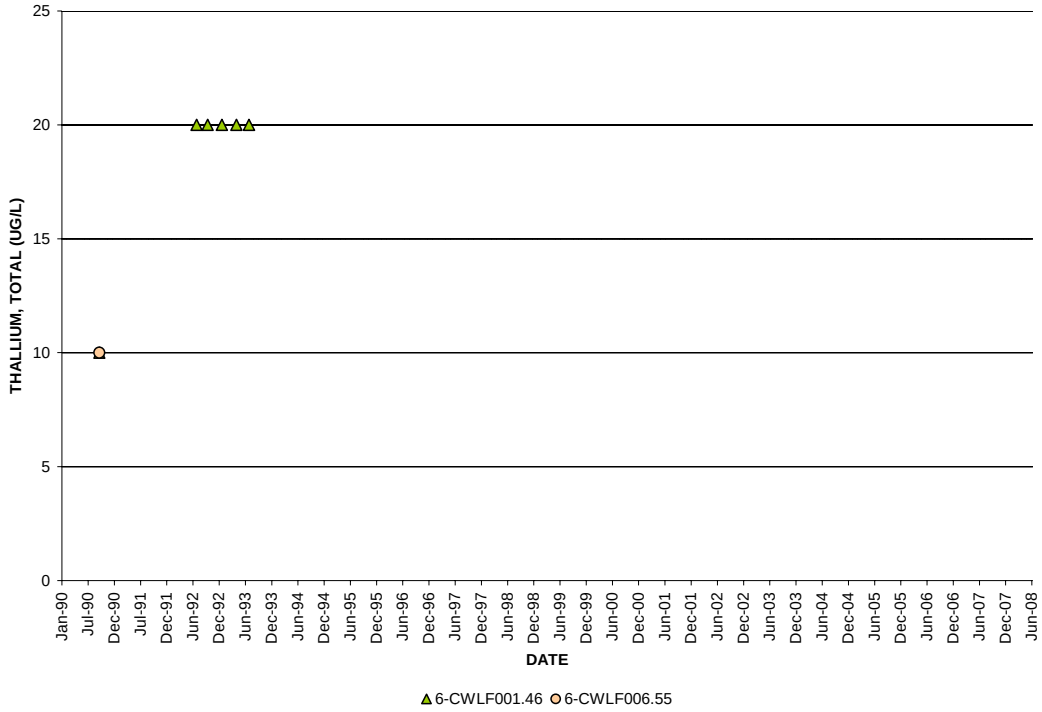


**Figure 2.50. Total thallium values at water quality monitoring stations in Wolf Creek.**

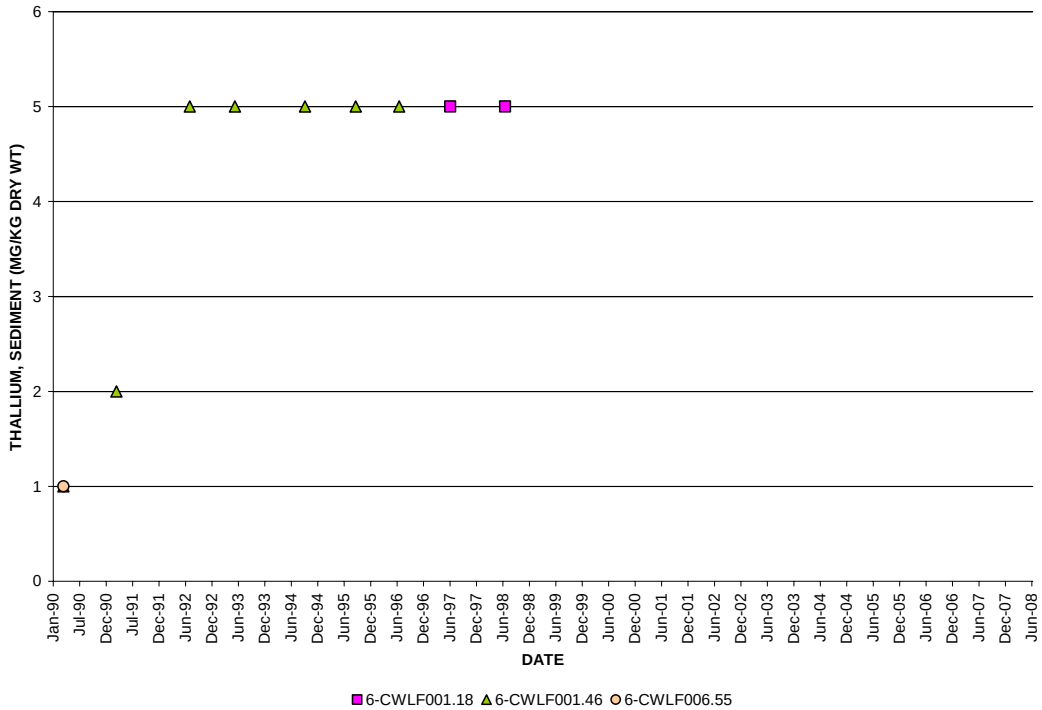


**Figure 2.51. Sedimentary thallium values at water quality monitoring stations in Wolf Creek.**

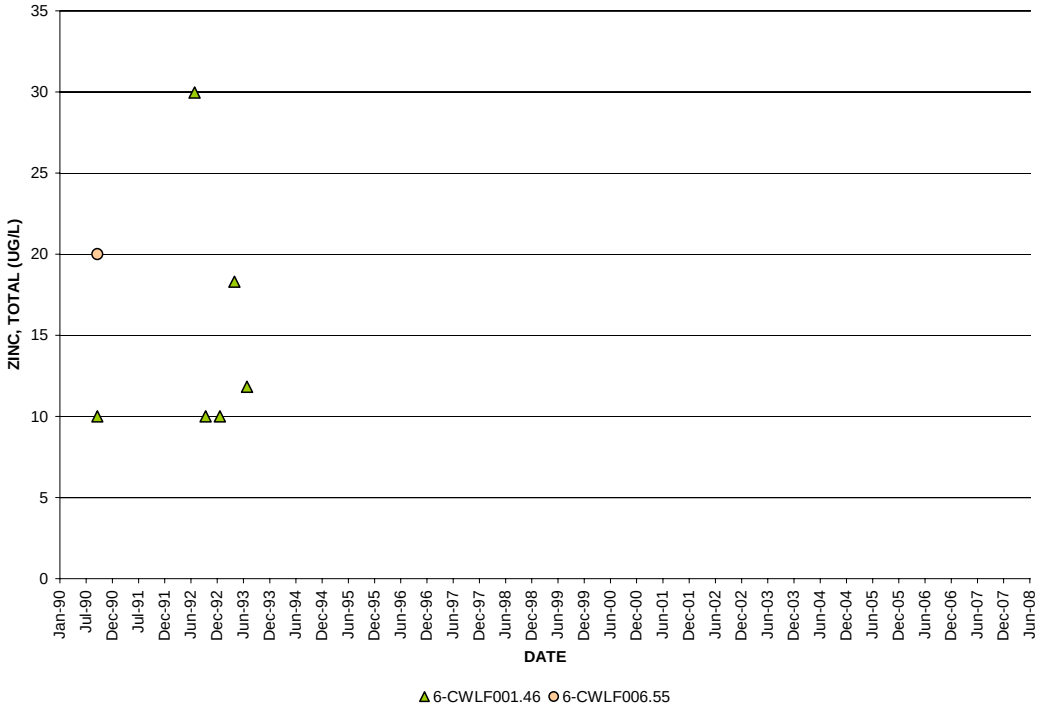


**Figure 2.52. Total zinc values at water quality monitoring stations in Wolf Creek.**

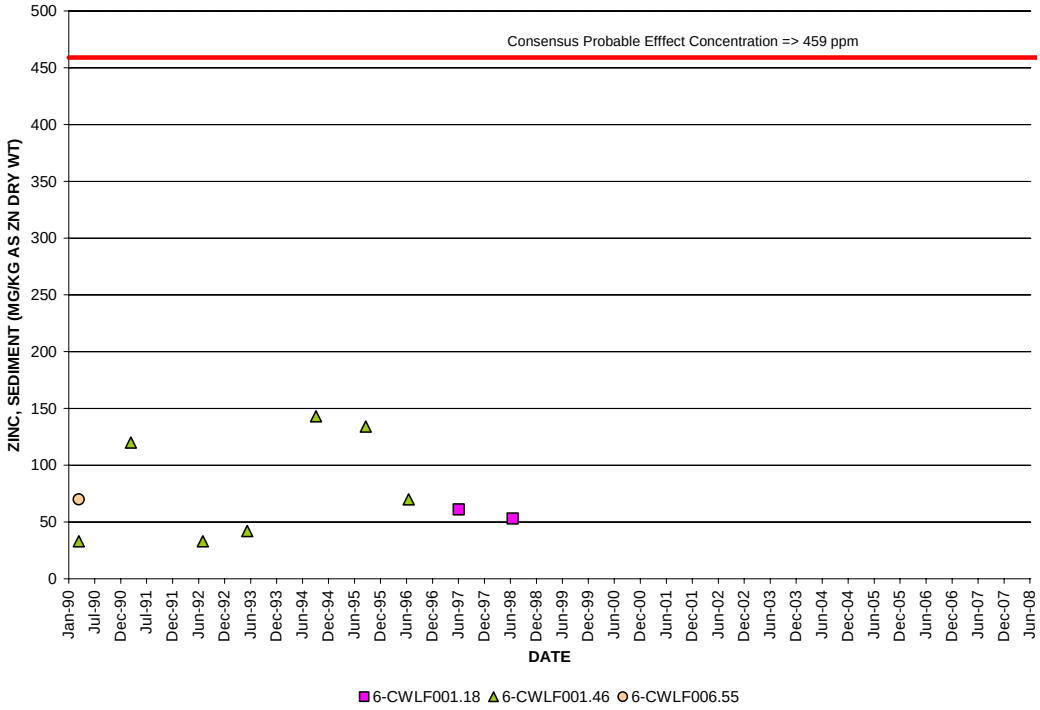


**Figure 2.53. Sedimentary zinc values at water quality monitoring stations in Wolf Creek.**

### *2.7.3 Nutrients*

Tables 2.23 through 2.30 contain summary of data collected at the various water quality stations. Summary of data includes number of observations between January 1, 1990 and March 31, 2008; mean, minimum; and maximum values. The data temporal range varies from parameter to parameter, and there is not always a good overlap between biological and ambient monitoring data. Data for nutrient parameters collected in the watershed are depicted in Figures 2.54 through 2.65. Summary of observations includes:

- All total nitrogen values at WQM stations 6-CWLF001.18, 6-CWLF004.10, and 6-CWLF006.75 exceeded the stressor screening value of 2 mg/l and exceedances occurred at WQM stations 6-CWLF007.55 and 6-CWLF008.00;
- Ammonia values were well below the chronic freshwater criteria and does not appear to be a stressor on the benthic community;
- All nitrate values at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 exceeded the stressor screening value of 1.5 mg/l except one value at WQM station 6-CWLF001.46;
- Numerous exceedances of the total kjeldahl nitrogen stressor screening value of 0.3mg/l were observed at WQM stations 6-CWLF001.18, 6-CWLF001.46, and CWLF006.55;
- All total phosphorous values exceeded the stressor screening value of 0.05mg/l at WQM stations 6-CWLF001.18, 6-CWLF001.46 (except one value), 6-CWLF004.10, 6-CWLF006.55, and CWLF006.75, in addition, no exceedances were observed at WQM stations 6-CWLF007.55 and 6-CWLF008.00;
- Two chloride values at WQM station 6-CWLF001.18 exceeded the stressor screening value of 30 mg/l; and
- Sulfate values at all WQM stations were below the stressor screening value of 50 mg/l and does not appear to be a stressor to the benthic community.

**Table 2.23. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF001.18 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 11 | 3.86 | 5.76 | 2.54 |
| NH3+NH4-N - Total, mg/L | 11 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | 12 | 0.02 | 0.10 | 0.01 |
| NO3-N - Total, mg/L | 12 | 3.19 | 4.92 | 1.96 |
| NO2 and NO3 N - Total, mg/L | N/A | N/A | N/A | N/A |
| Total Kjeldahl Nitrogen, mg/L | 12 | 0.32 | 0.50 | 0.10 |
| Total Phosphorus, mg/L | 22 | 0.34 | 0.62 | 0.10 |
| Orthophosphate - Total, mg/L | 12 | 0.23 | 0.53 | 0.06 |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | 9 | 204.61 | 220.00 | 176.00 |
| Hardness - Total CACO3, mg/L | 13 | 218.00 | 255.00 | 168.00 |
| Chloride - Total, mg/L | 13 | 18.92 | 45.70 | 5.00 |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | 13 | 18.25 | 29.50 | 10.50 |

**Table 2.24. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF001.46 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| NH3+NH4-N - Total, mg/L | 39 | 0.06 | 0.29 | 0.04 |
| NO2-N - Total, mg/L | 40 | 0.03 | 0.10 | 0.01 |
| NO3-N - Total, mg/L | 40 | 2.24 | 3.72 | 1.38 |
| NO2 and NO3 N - Total, mg/L | N/A | N/A | N/A | N/A |
| Total Kjeldahl Nitrogen, mg/L | 40 | 0.37 | 0.80 | 0.10 |
| Total Phosphorus, mg/L | 40 | 0.17 | 0.39 | 0.05 |
| Orthophosphate - Total, mg/L | 40 | 0.12 | 0.37 | 0.03 |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | 40 | 192.10 | 216.00 | 111.60 |
| Hardness - Total CACO3, mg/L | 40 | 218.00 | 328.00 | 130.00 |
| Chloride - Total, mg/L | 40 | 11.99 | 19.50 | 6.95 |
| Fluoride - Total, mg/L | 26 | 0.22 | 0.58 | 0.10 |
| Sulfate - Total, mg/L | 39 | 15.03 | 23.20 | 10.50 |

**Table 2.25. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF004.10 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 3 | 3.22 | 3.41 | 2.89 |
| NH3+NH4-N - Total, mg/L | 3 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO3-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO2 and NO3 N - Total, mg/L | 3 | 3.09 | 3.31 | 2.84 |
| Total Kjeldahl Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| Total Phosphorus, mg/L | 2 | 0.41 | 0.54 | 0.28 |
| Orthophosphate - Total, mg/L | N/A | N/A | N/A | N/A |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | N/A | N/A | N/A | N/A |
| Hardness - Total CACO3, mg/L | N/A | N/A | N/A | N/A |
| Chloride - Total, mg/L | N/A | N/A | N/A | N/A |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | N/A | N/A | N/A | N/A |

**Table 2.26. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF006.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| NH3+NH4-N - Total, mg/L | 20 | 0.07 | 0.28 | 0.04 |
| NO2-N - Total, mg/L | 21 | 0.03 | 0.14 | 0.01 |
| NO3-N - Total, mg/L | 21 | 2.16 | 4.16 | 1.64 |
| NO2 and NO3 N - Total, mg/L | N/A | N/A | N/A | N/A |
| Total Kjeldahl Nitrogen, mg/L | 22 | 0.45 | 1.10 | 0.10 |
| Total Phosphorus, mg/L | 22 | 0.15 | 0.30 | 0.09 |
| Orthophosphate - Total, mg/L | 22 | 0.08 | 0.22 | 0.02 |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | 21 | 202.21 | 224.00 | 154.10 |
| Hardness - Total CACO3, mg/L | 22 | 222.50 | 250.00 | 180.00 |
| Chloride - Total, mg/L | 22 | 12.44 | 18.80 | 0.15 |
| Fluoride - Total, mg/L | 22 | 0.24 | 0.60 | 0.10 |
| Sulfate - Total, mg/L | 21 | 15.28 | 21.10 | 11.20 |

**Table 2.27. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF006.75 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 8 | 4.78 | 7.98 | 2.68 |
| NH3+NH4-N - Total, mg/L | 8 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO3-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO2 and NO3 N - Total, mg/L | 8 | 4.42 | 7.14 | 2.25 |
| Total Kjeldahl Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| Total Phosphorus, mg/L | 8 | 0.53 | 0.76 | 0.30 |
| Orthophosphate - Total, mg/L | N/A | N/A | N/A | N/A |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | N/A | N/A | N/A | N/A |
| Hardness - Total CACO3, mg/L | N/A | N/A | N/A | N/A |
| Chloride - Total, mg/L | N/A | N/A | N/A | N/A |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | N/A | N/A | N/A | N/A |

**Table 2.28. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF007.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 8 | 2.15 | 2.74 | 1.84 |
| NH3+NH4-N - Total, mg/L | 8 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO3-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO2 and NO3 N - Total, mg/L | 8 | 1.89 | 2.31 | 1.52 |
| Total Kjeldahl Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| Total Phosphorus, mg/L | 8 | 0.02 | 0.05 | 0.01 |
| Orthophosphate - Total, mg/L | N/A | N/A | N/A | N/A |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | N/A | N/A | N/A | N/A |
| Hardness - Total CACO3, mg/L | N/A | N/A | N/A | N/A |
| Chloride - Total, mg/L | N/A | N/A | N/A | N/A |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | N/A | N/A | N/A | N/A |

**Table 2.29. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CWLF008.00 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 3 | 2.44 | 2.76 | 1.95 |
| NH3+NH4-N - Total, mg/L | 3 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO3-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO2 and NO3 N - Total, mg/L | 3 | 2.36 | 2.79 | 1.79 |
| Total Kjeldahl Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| Total Phosphorus, mg/L | 2 | 0.02 | 0.02 | 0.02 |
| Orthophosphate - Total, mg/L | N/A | N/A | N/A | N/A |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | N/A | N/A | N/A | N/A |
| Hardness - Total CACO3, mg/L | N/A | N/A | N/A | N/A |
| Chloride - Total, mg/L | N/A | N/A | N/A | N/A |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | N/A | N/A | N/A | N/A |

**Table 2.30. Nutrients, chlorophyll A, and inorganic water quality data summary for station 6CTOW000.58 in Town Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Total Nitrogen, mg/L | 3 | 2.21 | 2.47 | 1.71 |
| NH3+NH4-N - Total, mg/L | 3 | 0.04 | 0.04 | 0.04 |
| NO2-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO3-N - Total, mg/L | N/A | N/A | N/A | N/A |
| NO2 and NO3 N - Total, mg/L | 3 | 2.13 | 2.48 | 1.54 |
| Total Kjeldahl Nitrogen, mg/L | N/A | N/A | N/A | N/A |
| Total Phosphorus, mg/L | 2 | 0.03 | 0.03 | 0.02 |
| Orthophosphate - Total, mg/L | N/A | N/A | N/A | N/A |
| Chlorophyll A, µg/L | N/A | N/A | N/A | N/A |
| Alkalinity - Total, mg/L | N/A | N/A | N/A | N/A |
| Hardness - Total CACO3, mg/L | N/A | N/A | N/A | N/A |
| Chloride - Total, mg/L | N/A | N/A | N/A | N/A |
| Fluoride - Total, mg/L | N/A | N/A | N/A | N/A |
| Sulfate - Total, mg/L | N/A | N/A | N/A | N/A |

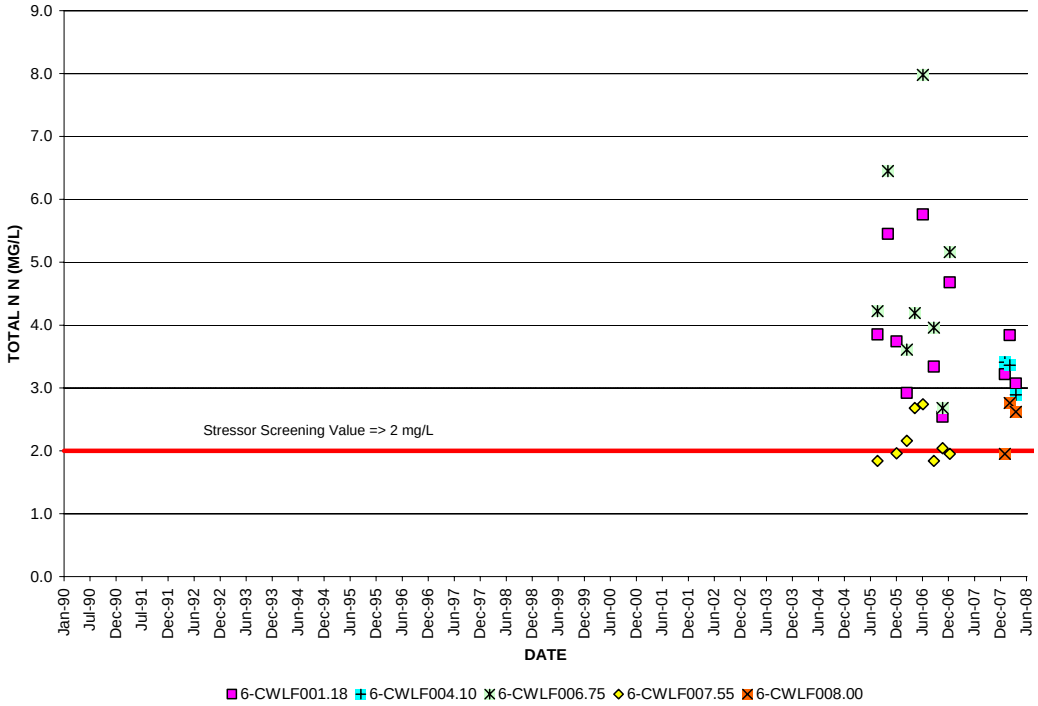


**Figure 2.54. Total nitrogen values at water quality monitoring stations in Wolf Creek.**

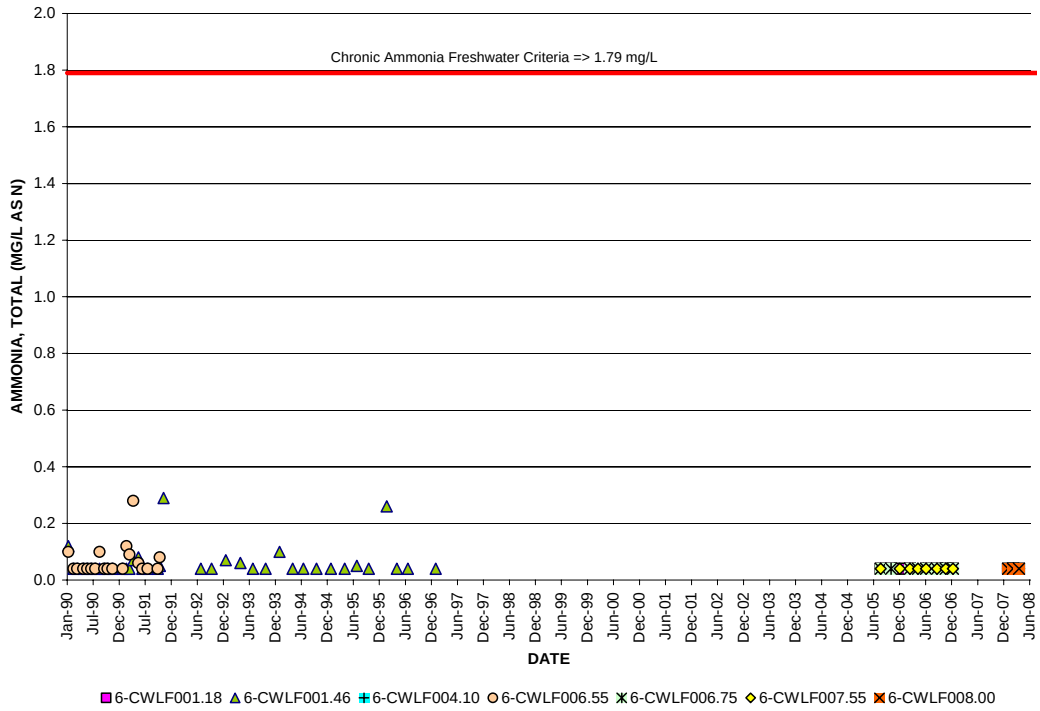


**Figure 2.55. Ammonia values at water quality monitoring stations in Wolf Creek.**

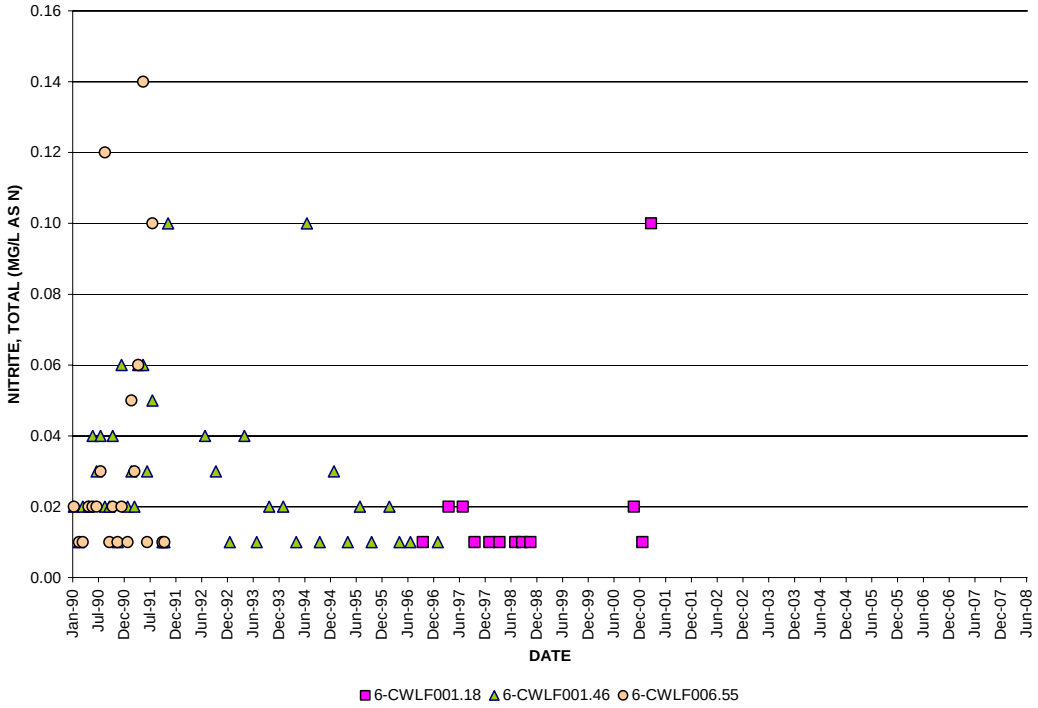


**Figure 2.56. Nitrite values at water quality monitoring stations in Wolf Creek.**

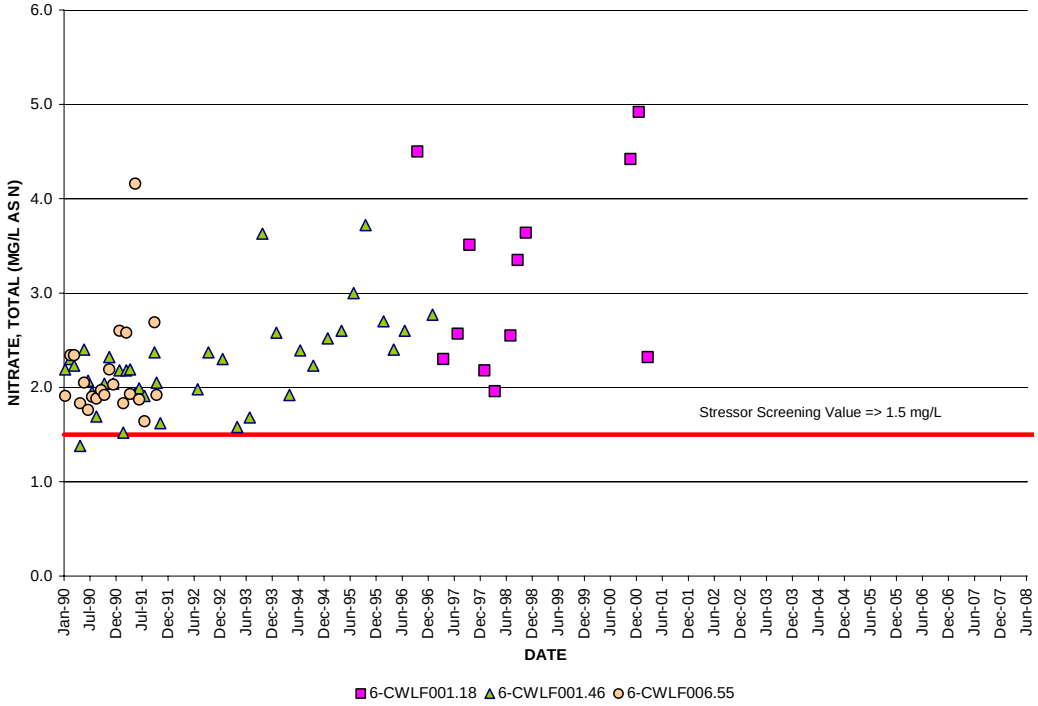


**Figure 2.57. Nitrate values at water quality monitoring stations in Wolf Creek.**

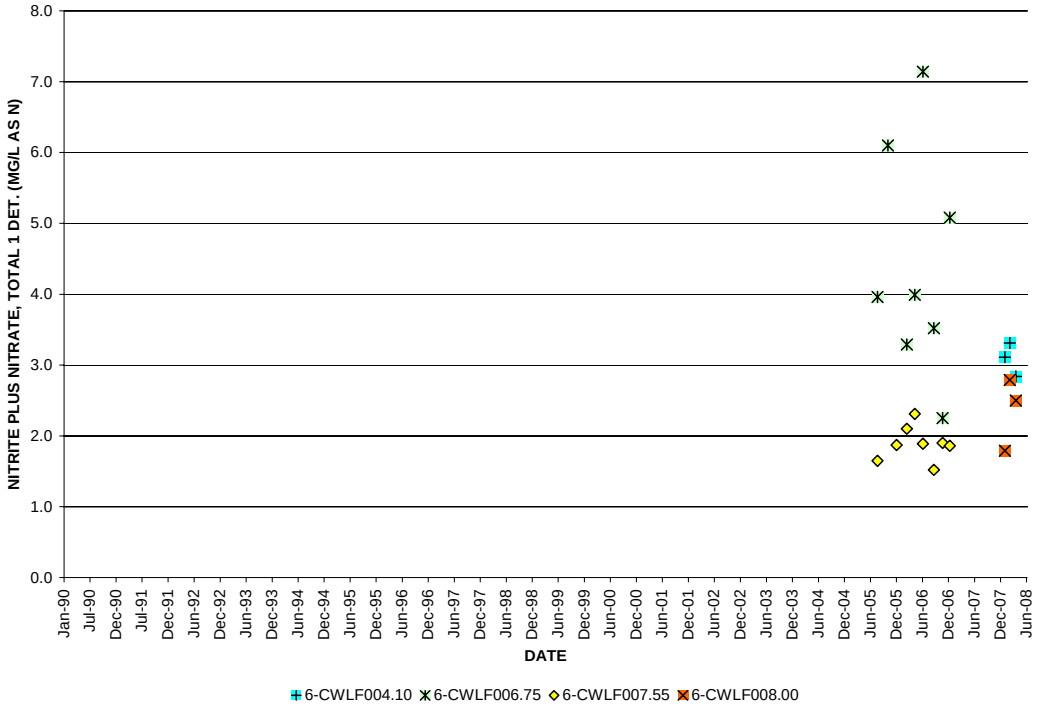


**Figure 2.58. Nitrite plus nitrate values at water quality monitoring stations in Wolf Creek.**

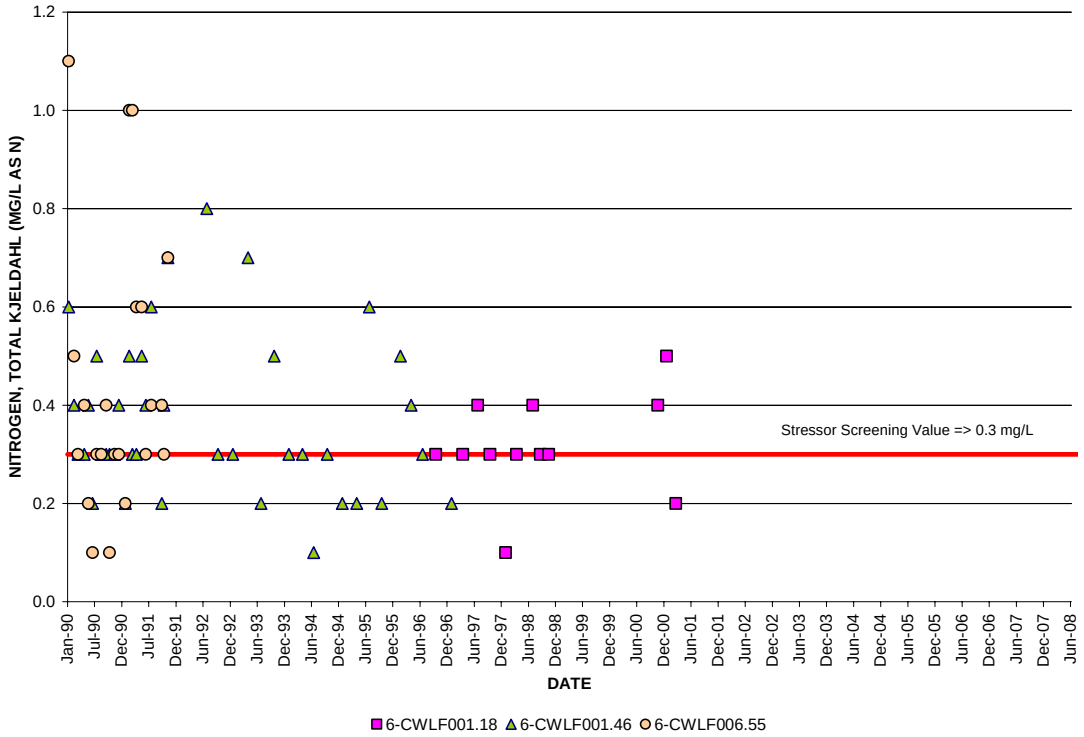


**Figure 2.59. Total kjeldahl nitrogen values at water quality monitoring stations in Wolf Creek.**

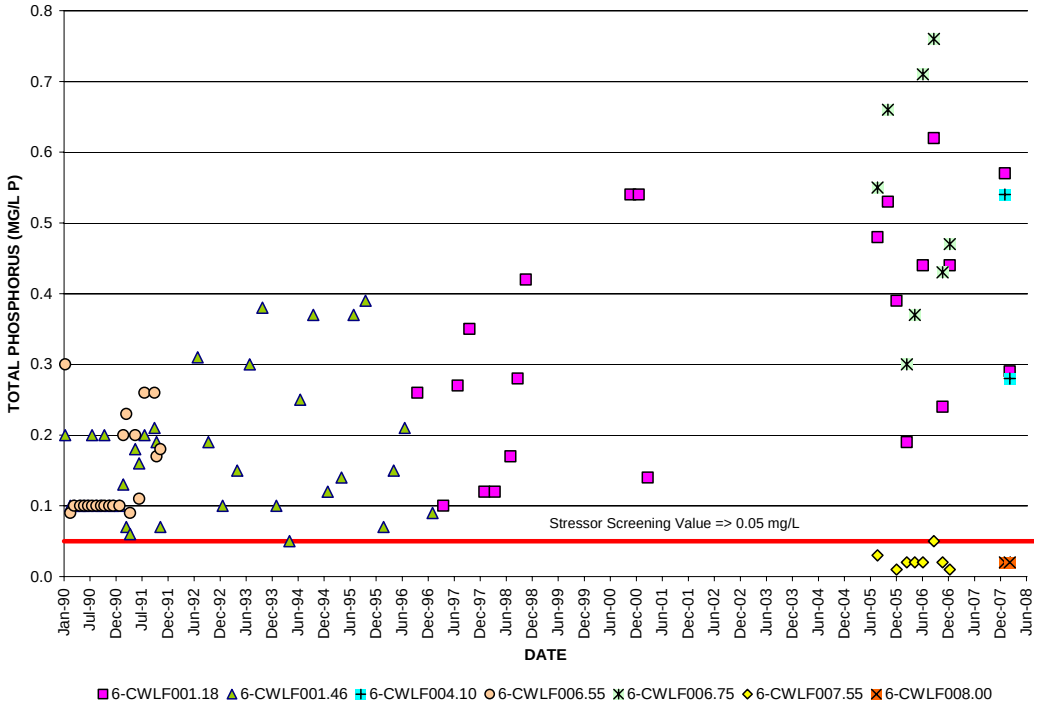


**Figure 2.60. Total phosphorous values at water quality monitoring stations in Wolf Creek.**

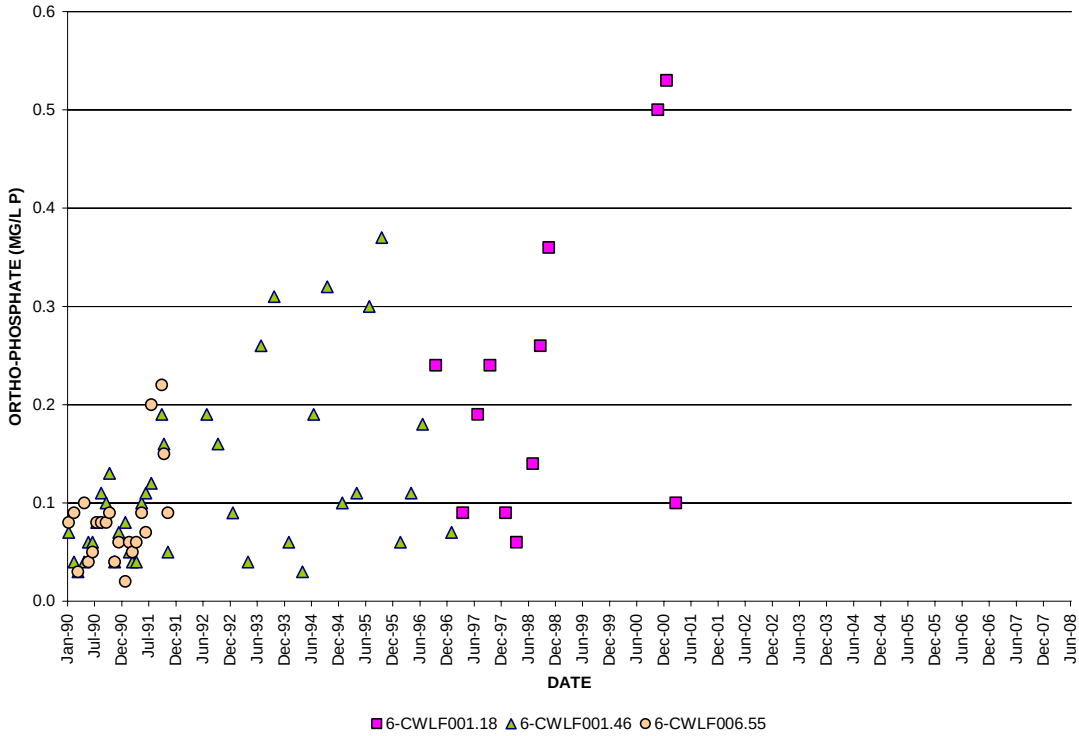


**Figure 2.61. Ortho-phosphate values at water quality monitoring stations in Wolf Creek.**

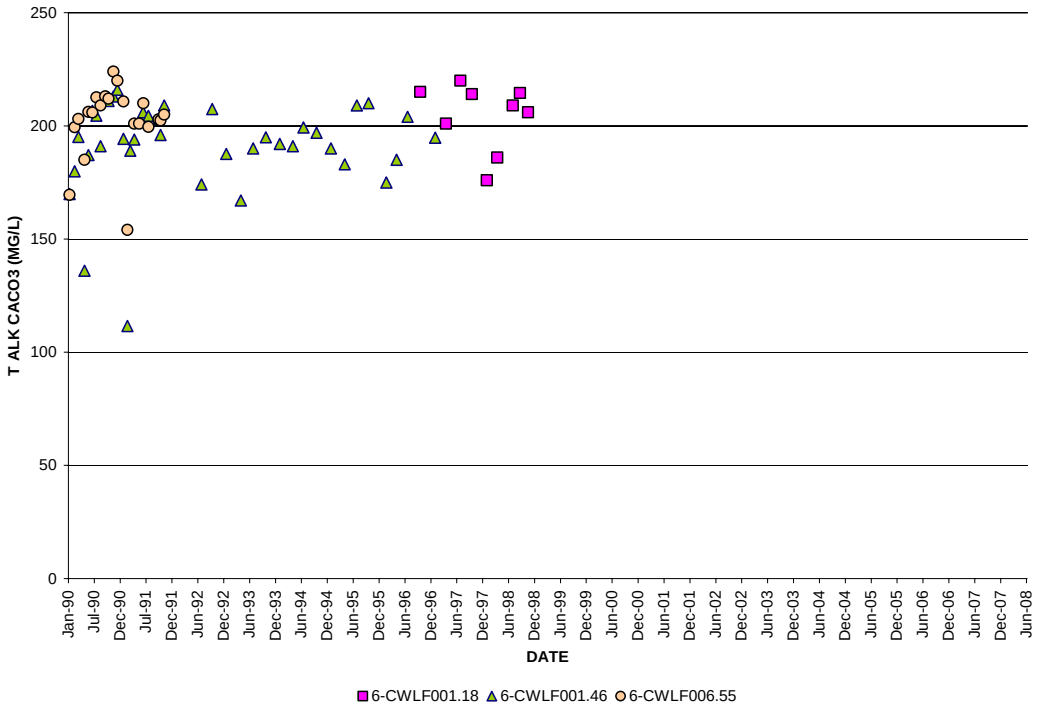


**Figure 2.62. Alkalinity values at water quality monitoring stations in Wolf Creek.**

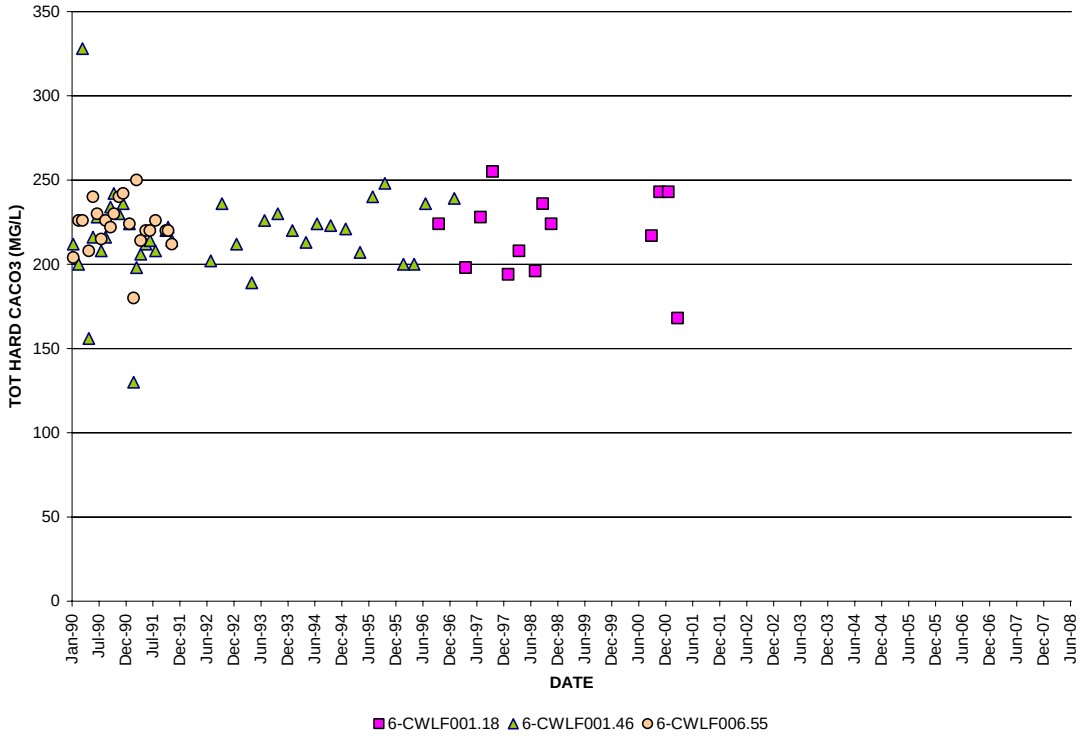


**Figure 2.63. Hardness values at water quality monitoring stations in Wolf Creek.**

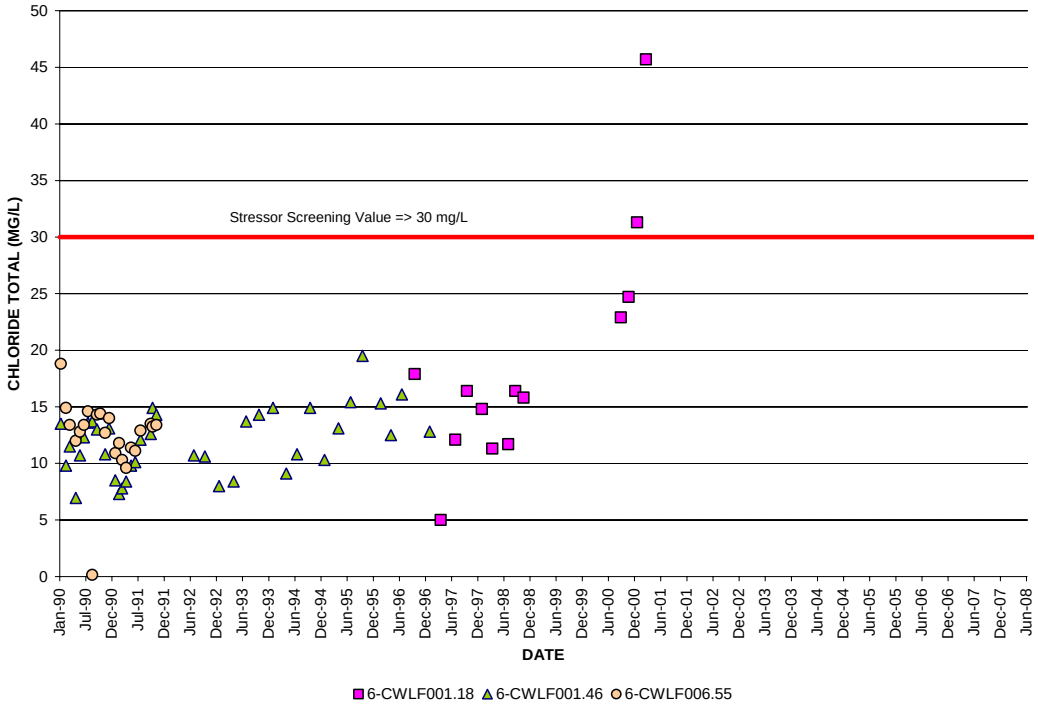


**Figure 2.64. Chloride values at water quality monitoring stations in Wolf Creek.**

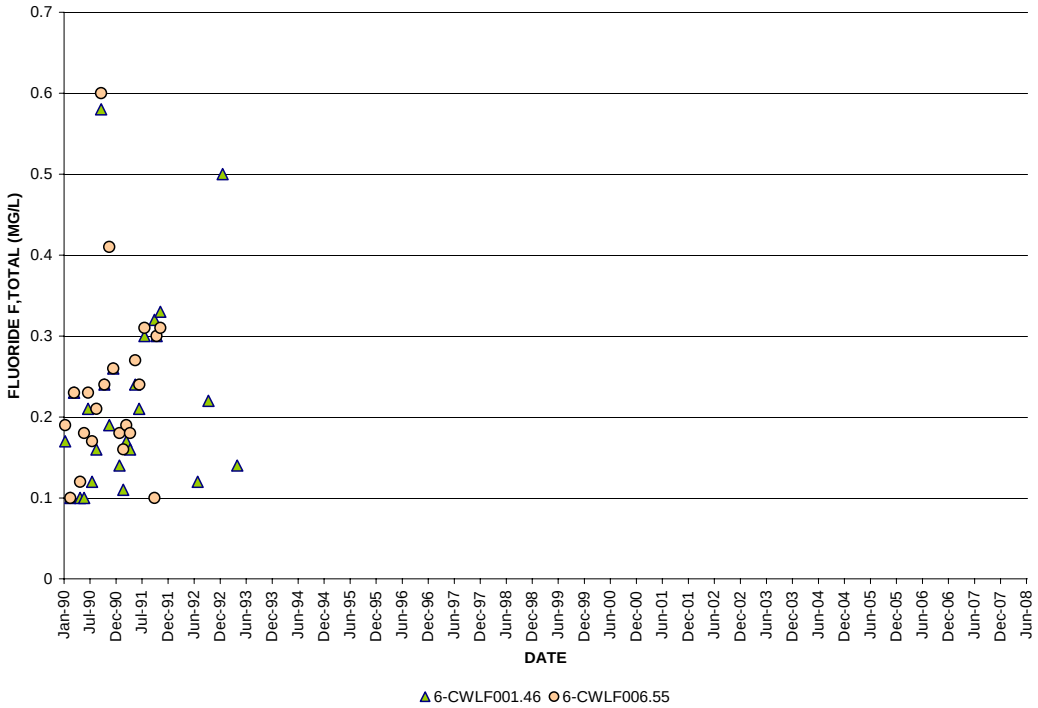


**Figure 2.65. Fluoride values at water quality monitoring stations in Wolf Creek.**

### *2.7.4 Organics*

Tables 2.31 through 2.33 contain summary of data collected at the various water quality stations. Summary of data includes number of observations between January 1, 1990 and March 31, 2008; mean, minimum; and maximum values. The data temporal range varies from parameter to parameter, and there is not always a good overlap between biological and ambient monitoring data. Data for organic parameters collected in the watershed are depicted in Figures 2.66 through 2.78. Summary of observations includes:

- Sedimentary DDD values at WQM stations 6-CWLF001.18 and 6-CWLF001.46 exceeded the consensus probable effect concentration of 28 ppb;
- Sedimentary DDE values at WQM station 6-CWLF001.46 exceeded the consensus probable effect concentration of 31.3 ppb;
- Sedimentary dieldrin values at WQM station 6-CWLF001.46 exceeded the consensus probable effect concentration of 61.3 ppb;
- All sedimentary heptachloepoxide values at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 exceeded the consensus probable effect concentration of 16 ppb; and
- All other sedimentary organic concentrations at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 were below an applicable consensus probable effect concentration and do not appear to be a stressor to the benthic community.

**Table 2.31. Organics water quality data summary for station 6CWLF001.18 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Aldrin, µg/kg | 3 | 23.33 | 30.00 | 20.00 |
| Chlordane Tech Mix & Metabs, µg/kg | 3 | 86.67 | 120.00 | 70.00 |
| DDD, µg/kg | 3 | 30.00 | 30.00 | 30.00 |
| DDE, µg/kg | 3 | 30.00 | 30.00 | 30.00 |
| DDT, µg/kg | 3 | 30.00 | 30.00 | 30.00 |
| Dicofol, µg/kg | 3 | 210.00 | 290.00 | 170.00 |
| Dieldrin, µg/kg | 3 | 23.33 | 30.00 | 20.00 |
| Endrin, µg/kg | 3 | 63.33 | 90.00 | 50.00 |
| Heptachlor epoxide, µg/kg | 3 | 23.33 | 30.00 | 20.00 |
| Heptachlor, µg/kg | 3 | 23.33 | 30.00 | 20.00 |
| PCBs - Total, µg/kg | 3 | 33.33 | 60.00 | 20.00 |
| Pentachlorophenol, µg/kg | 3 | 106.67 | 140.00 | 90.00 |
| Toxaphene, µg/kg | 3 | 170.00 | 230.00 | 140.00 |

**Table 2.32. Organics water quality data summary for station 6CWLF001.46 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Aldrin, µg/kg | 5 | 88.00 | 110.00 | 30.00 |
| Chlordane Tech Mix & Metabs, µg/kg | 5 | 255.00 | 500.00 | 40.00 |
| DDD, µg/kg | 5 | 81.00 | 100.00 | 20.00 |
| DDE, µg/kg | 5 | 82.00 | 100.00 | 20.00 |
| DDT, µg/kg | 5 | 80.00 | 100.00 | 30.00 |
| Dicofol, µg/kg | 5 | 117.00 | 160.00 | 80.00 |
| Dieldrin, µg/kg | 5 | 85.00 | 110.00 | 20.00 |
| Endrin, µg/kg | 5 | 111.00 | 170.00 | 30.00 |
| Heptachlor epoxide, µg/kg | 5 | 85.00 | 110.00 | 20.00 |
| Heptachlor, µg/kg | 5 | 58.02 | 100.00 | 0.10 |
| PCBs - Total, µg/kg | 5 | 252.00 | 500.00 | 30.00 |
| Pentachlorophenol, µg/kg | 5 | 97.00 | 160.00 | 50.00 |
| Toxaphene, µg/kg | 5 | 524.20 | 1000.00 | 1.00 |

**Table 2.33. Organics water quality data summary for station 6CWLF006.55 in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| Aldrin, µg/kg | 1 | 100.00 | 100.00 | 100.00 |
| Chlordane Tech Mix & Metabs, µg/kg | 1 | 1.00 | 1.00 | 1.00 |
| DDD, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| DDE, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| DDT, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| Dicofol, µg/kg | 1 | 100.00 | 100.00 | 100.00 |
| Dieldrin, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| Endrin, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| Heptachlor epoxide, µg/kg | 1 | 100.00 | 100.00 | 100.00 |
| Heptachlor, µg/kg | 1 | 0.10 | 0.10 | 0.10 |
| PCBs - Total, µg/kg | 1 | 500.00 | 500.00 | 500.00 |
| Pentachlorophenol, µg/kg | 1 | 0.01 | 0.01 | 0.01 |
| Toxaphene, µg/kg | 1 | 1.00 | 1.00 | 1.00 |

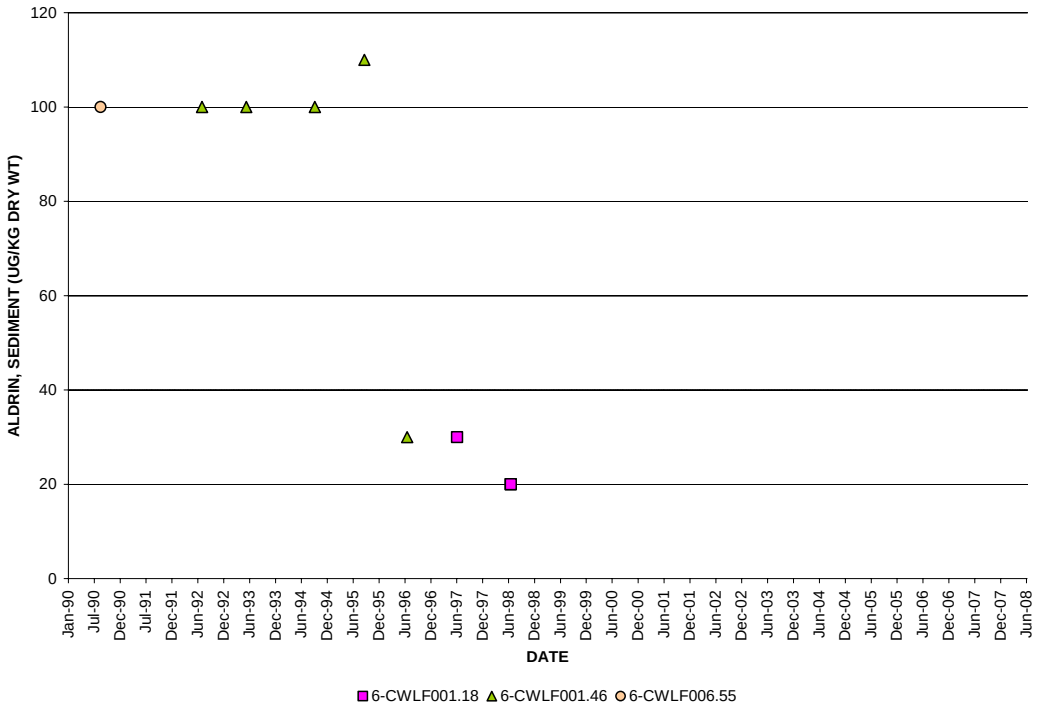


**Figure 2.66. Sedimentary aldrin values at water quality monitoring stations in Wolf Creek.**

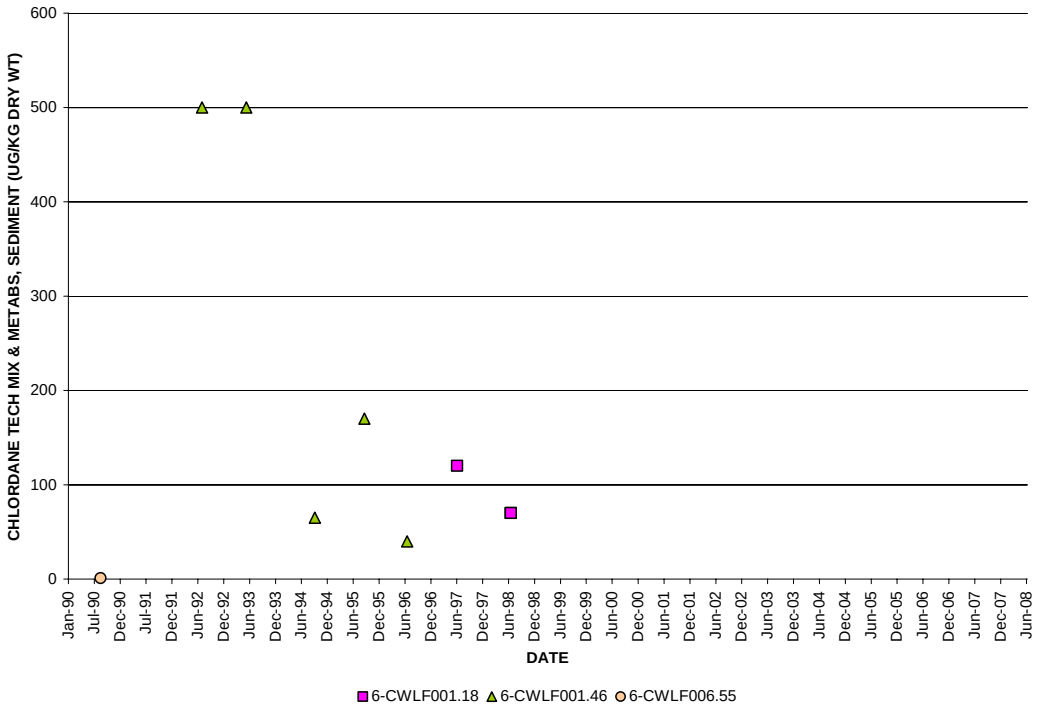


**Figure 2.67. Sedimentary cdanedrytech values at water quality monitoring stations in Wolf Creek.**

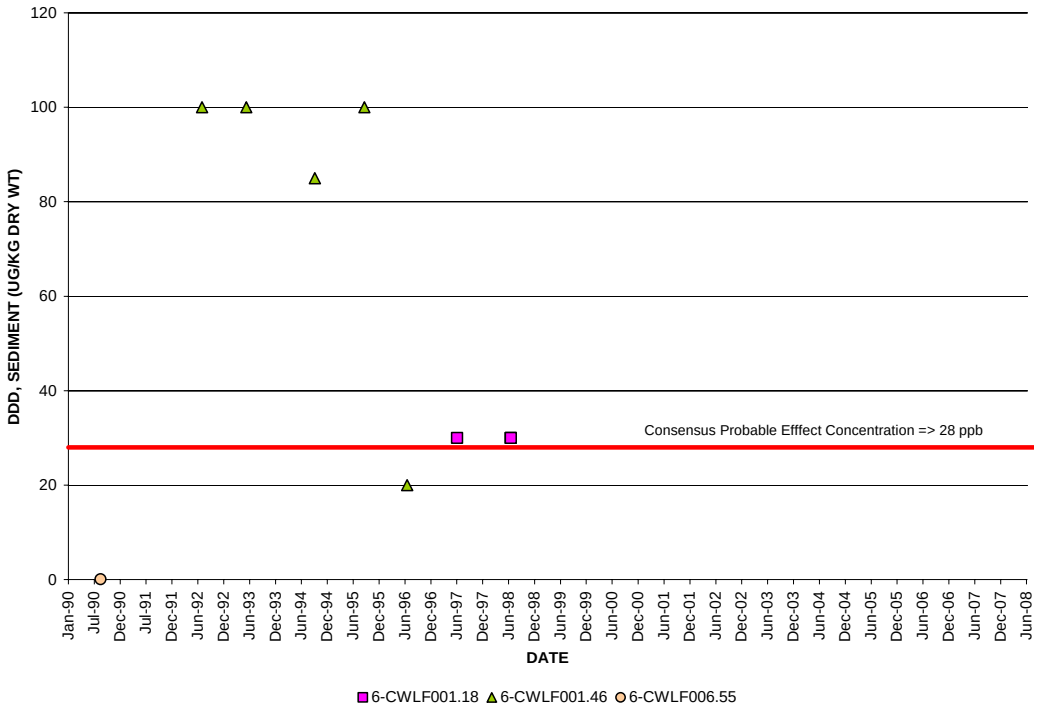


**Figure 2.68. Sedimentary DDD values at water quality monitoring stations in Wolf Creek.**

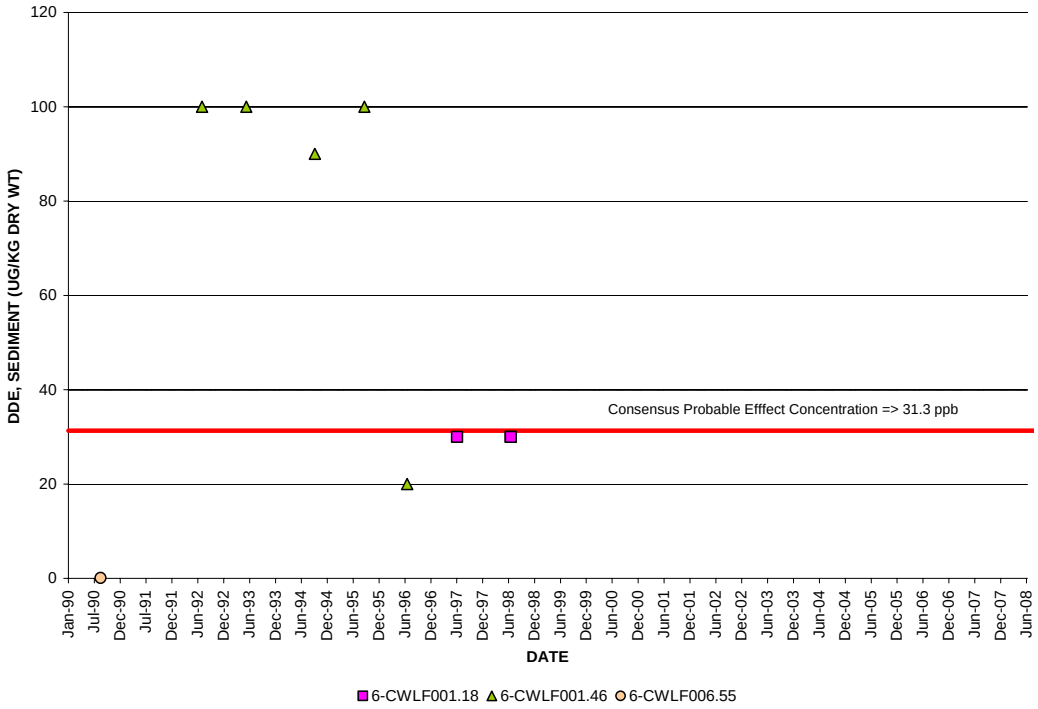


**Figure 2.69. Sedimentary DDE values at water quality monitoring stations in Wolf Creek.**

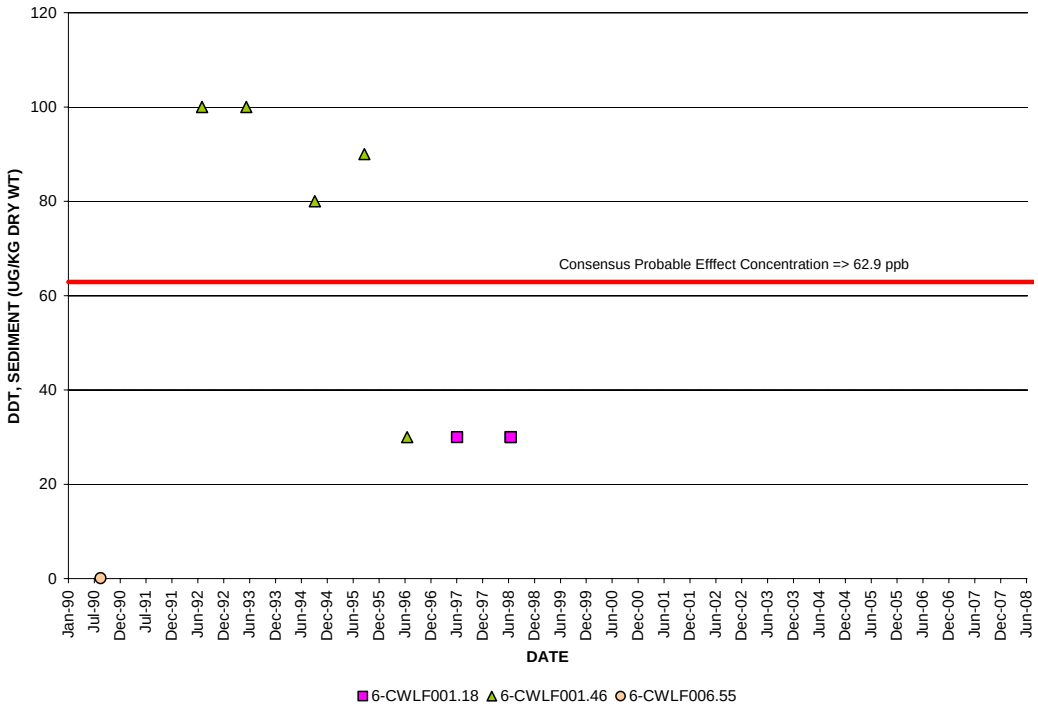


**Figure 2.70. Sedimentary DDT values at water quality monitoring stations in Wolf Creek.**

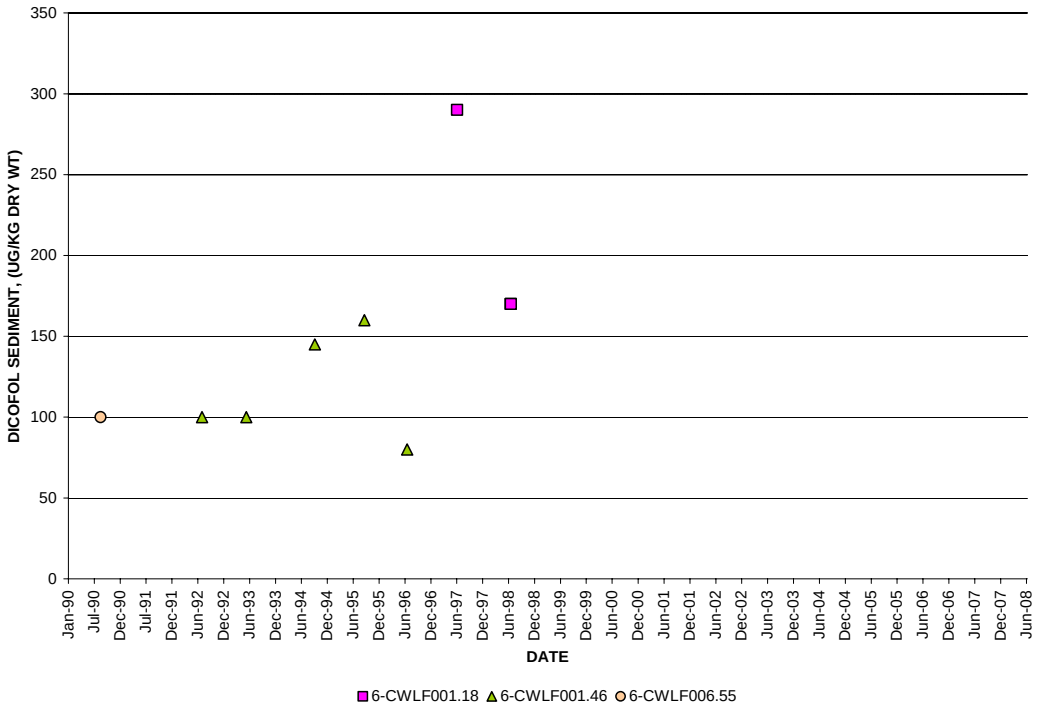


**Figure 2.71. Sedimentary dicofol values at water quality monitoring stations in Wolf Creek.**

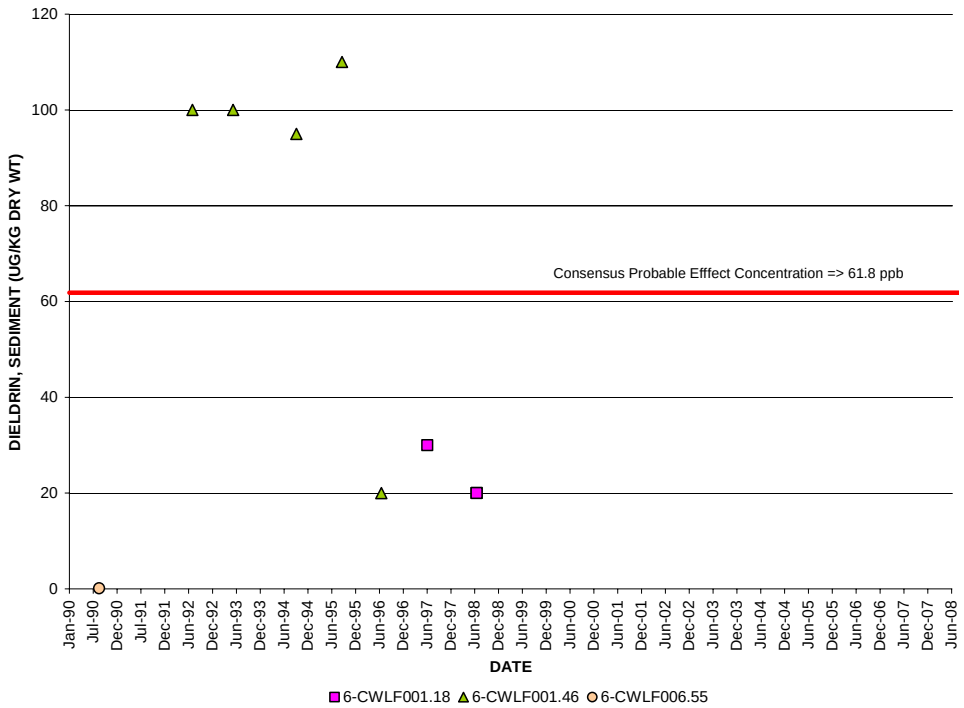


**Figure 2.72. Sedimentary dieldrin values at water quality monitoring stations in Wolf Creek.**

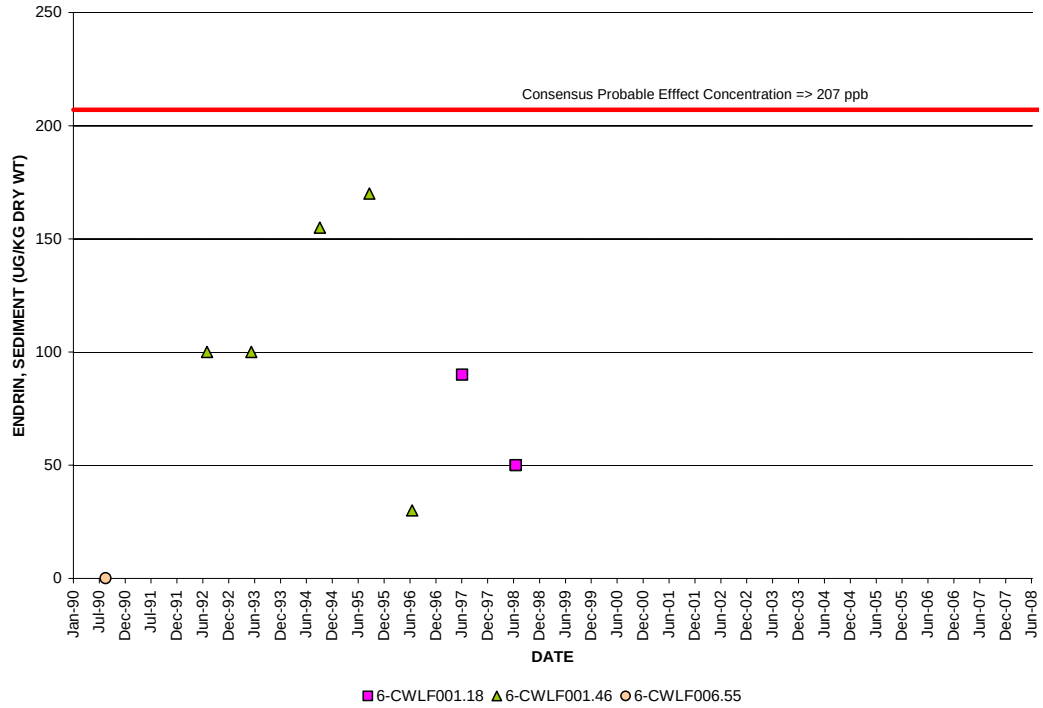


**Figure 2.73. Sedimentary endrin values at water quality monitoring stations in Wolf Creek.**

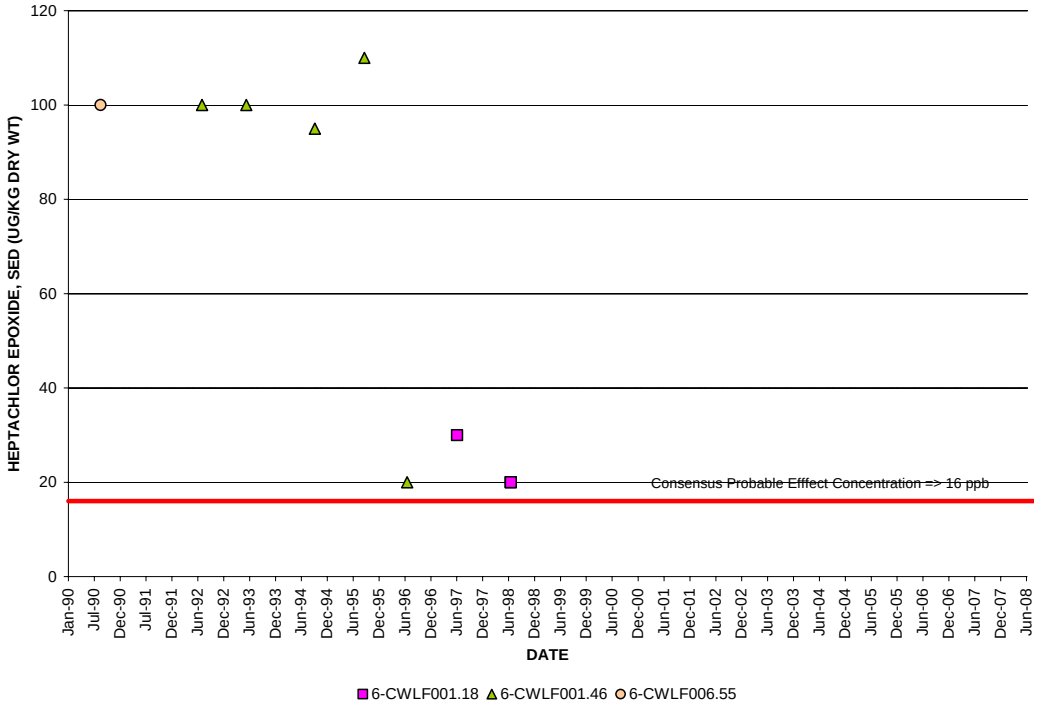


**Figure 2.74. Sedimentary heptachlorepoxide values at water quality monitoring stations in Wolf Creek.**

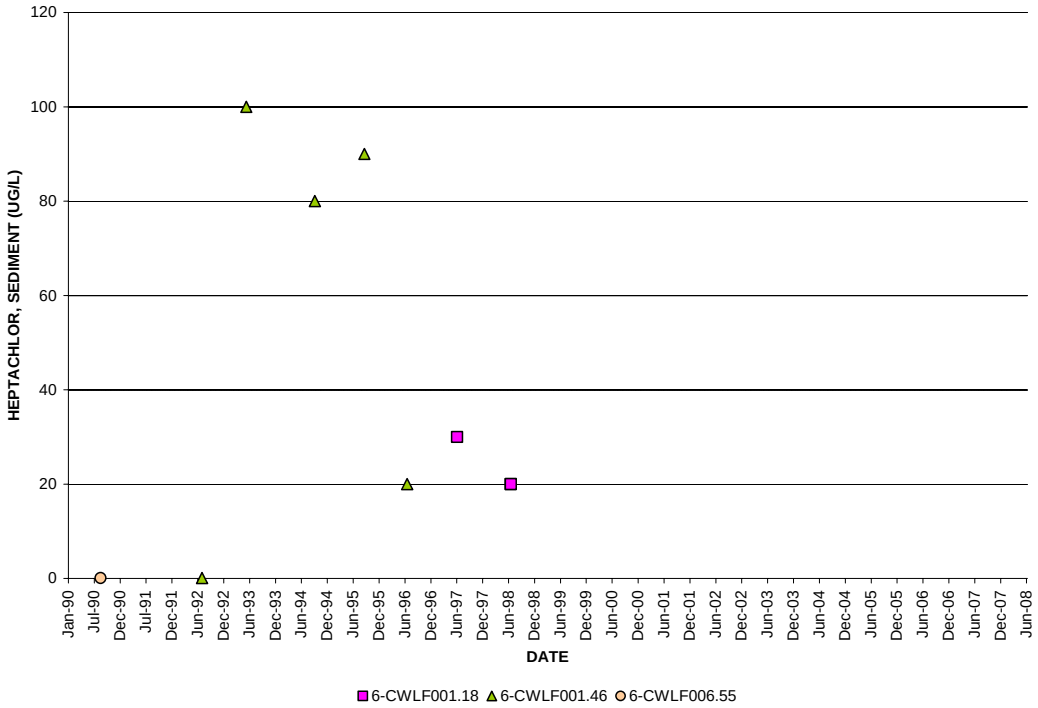


**Figure 2.75. Sedimentary heptachlor values at water quality monitoring stations in Wolf Creek.**

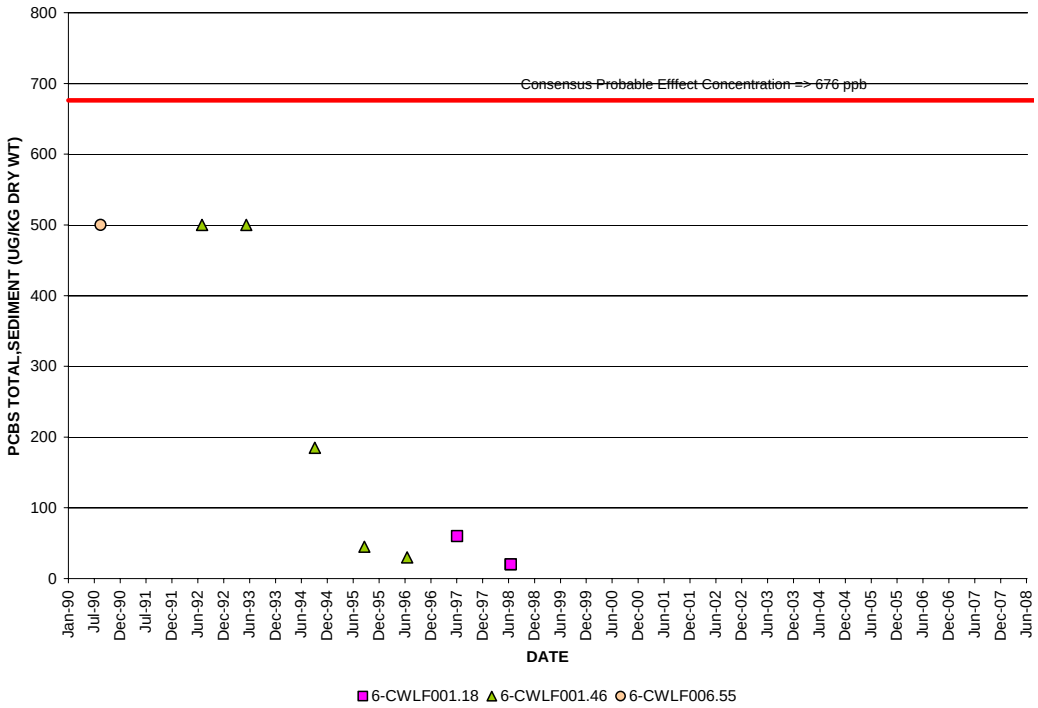


**Figure 2.76. Sedimentary PCB values at water quality monitoring stations in Wolf Creek.**

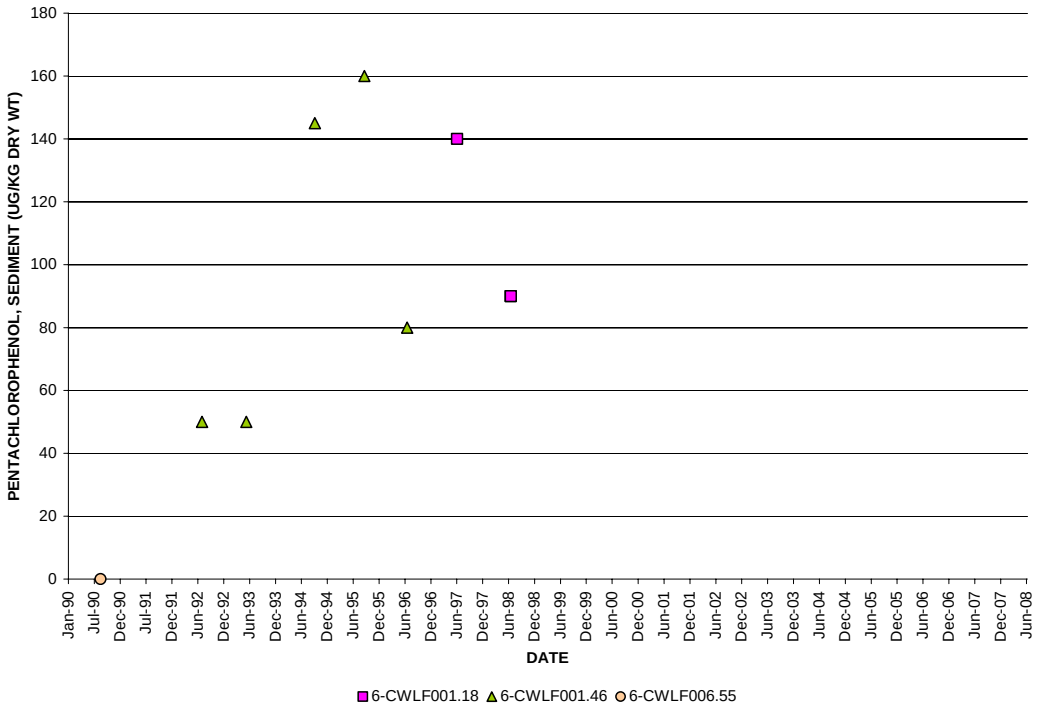


**Figure 2.77. Sedimentary PCP values at water quality monitoring stations in Wolf Creek.**

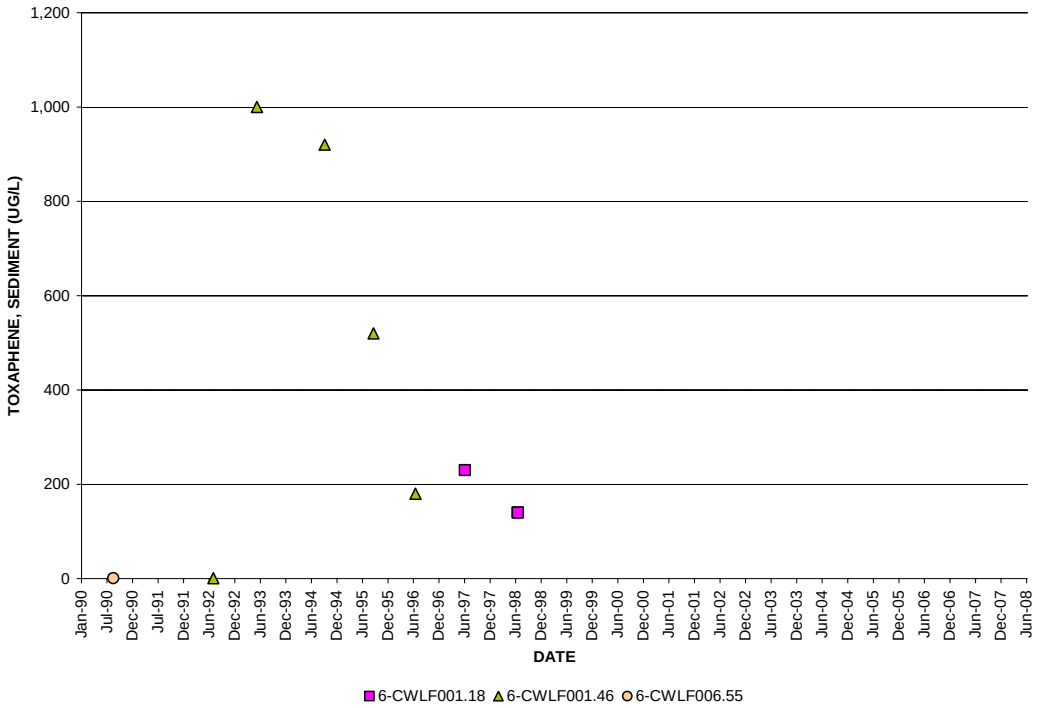


**Figure 2.78. Sedimentary toxaphene values at water quality monitoring stations in Wolf Creek.**

## 2.8 Fish Tissue and Sediment Study

The Department of Environmental Quality - Office of Water Quality Programs' Fish Tissue and Sediment Contaminants Monitoring Program conducts routine studies of fish tissue and sediment samples in state waters. Typically, data is collected in two to three river basins per year. The data are assessed to determine the human health risks for individuals who may consume fish from state waters and to identify impaired aquatic ecosystems. At least one sediment sample is collected at each station where fish tissue are sampled and analyzed for a suit of bioaccumulative chemical contaminants. These include selected heavy metals, selected non-halogenated organic compounds (PAHs) and halogenated organic compounds (DDT, Chlordane, PCBs, etc.). Values highlighted in red indicate exceedance of the NOAA's Effects Low Range.

**Table 2.34, Results of sediment analysis for heavy metals at station 6CWLF006.55 in Wolf Creek.**

| | Sampling Date | 06/18/97 | 06/18/02 | | | |
|---|---|---|---|---|---|---|
| | DEQ Station | 6CWLF006.55 | 6CWLF006.55 | | | |
| | Parameter | Observed Value | Observed Value | NOAA's Effects Range-Median | NOAA's Effects Range-Low | Freshwater Consensus-Based Probable Effect Concentration |
| % | TOC | 0.04 | 1.16 | *** | *** | *** |
| | Al | 0.17 | 1.13 | *** | *** | *** |
| ppm (dry wgt. Basis) | Ag | 0.2 | 0.5 | *3.7* | *1* | *N/A*[1] |
| | As | 3.0 | 9.6 | *70* | *8.2* | *33* |
| | Cd | 0.25 | 0.22 | *9.6* | *1.2* | *4.98* |
| | Cr | 6 | 22 | *370* | *81* | *111* |
| | Cu | 6 | 28 | *270* | *34* | *149* |
| | Hg | 0.24 | 0.13 | *0.71* | *0.15* | *1.06* |
| | Ni | 0.6 | 16.2 | *51.6* | *20.9* | *48.6* |
| | Pb | 30.0 | 27.9 | *223* | *46.7* | *128* |
| | Sb | <0.5 | <0.5 | *** | *** | *** |
| | Se | <0.5 | <0.5 | *** | *** | *** |
| | Tl | <0.3 | <0.3 | *** | *** | *** |
| | Zn | 52 | 85 | *410* | *150* | *459* |

[1] N/A = not available

**Table 2.35. Results of sediment analysis for non-halogenated organic compounds (PAHs) at station 6CWLF006.55 in Wolf Creek.**

| | Sampling Date | 06/18/97 | 06/18/02 | | | |
|---|---|---|---|---|---|---|
| | DEQ Station | 6CWLF006.55 | 6CWLF006.55 | | | |
| | Parameter | Observed Value | Observed Value | NOAA'S Effects Range-Median | NOAA'S Effects Range-Low | Freshwater Consensus-Based Probable Effect Concentration |
| % | TOC | 0.04 | 1.16 | *** | *** | *** |
| ppb | Total PAH | 2,313 | 1,823 | *44,792* | *4,022* | *22,800* |
| | High MW PAH | 987 | 1,651 | *9,600* | *1,700* | *N/A*[1] |
| | Low MW PAH | 117 | 172 | *3,160* | *552* | *N/A* |
| ppb (dry wgt. Basis) | NAP[5] | N/A | 2 | *2,100* | *160* | *561* |
| | NAP 2-Me | N/A | 3 | *670* | *70* | *N/A* |
| | NAP 1-Me | N/A | 2 | *** | *** | *** |
| | biphenyl | N/A | 1 | *** | *** | *** |
| | NAP d-Me | N/A | 2 | *** | *** | *** |
| | naphthylene ace~ | N/A | 1 | *640* | *44* | *N/A* |
| | naphthene ace~ | N/A | 2 | *500* | *16* | *N/A* |
| | NAP t-Me | N/A | 2 | *** | *** | *** |
| | fluorene | 5 | 2 | *540* | *19* | *536* |
| | PHH | 94 | 131 | *1,500* | *240* | *1,170* |
| | ATH | 17.2 | 10.1 | *1,100* | *85.3* | *845* |
| | PHH 1-Me | 25 | 14 | *** | *** | *** |
| | FTH | 281 | 220 | *5,100* | *600* | *2,230* |
| | pyrene | 205 | 219 | *2,600* | *665* | *1,520* |
| | ATH benz(a) | 155 | 94 | *1,600* | *261* | *1,050* |
| | chrysene | 184 | 149 | *2,800* | *384* | *1,290* |
| | FTH benzo (b) | 138 | 180 | *** | *** | *** |
| | FTH benzo (k) | 81 | 129 | *** | *** | *** |
| | pyrene benzo (e) | 111 | 141 | *** | *** | *** |
| | pyrene benzo (a) | 137 | 178 | *1,600* | *430* | *1,450* |
| | perylene | 40 | 48 | *** | *** | *** |
| | pyrene IND | 97 | 126 | *** | *** | *** |
| | ATH db (a,h) | 25.9 | 40.9 | *260* | *63.4* | *N/A* |
| | perylene benzo (ghi) | 86 | 125 | *** | *** | *** |

[1] N/A = not available

**Table 2.36. Results of sediment analysis for halogenated organic compounds at station 6CWLF006.55 in Wolf Creek.**

| | Sampling Date | 06/18/97 | 06/18/02 | | | |
|---|---|---|---|---|---|---|
| | DEQ Station | 6CWLF006.55 | 6CWLF006.55 | | | |
| | Parameter | Observed Value | Observed Value | NOAA's Effects Range-Median | NOAA's Effects Range-Low | Freshwater Consensus-Based Probable Effect Concentration |
| % | TOC | 0.04 | 1.16 | *** | *** | *** |
| ppb (dry wgt. Basis) | Total PCB | ND[2] | 4.3 | *180* | *22.7* | *676* |
| | Total Chlordane | ND | 2.0 | *6* | *0.5* | *17.6* |
| | Sum DDE | N/A[1] | 1.2 | *27* | *2.2* | *31.3* |
| | Sum DDD | N/A | 0.5 | *20* | *2* | *28* |
| | Sum DDT | N/A | 6.2 | *7* | *1* | *62.9* |
| | Total DDT | ND | 7.93 | *46.1* | *1.58* | *572* |
| | Total BDE | N/A | 20.3 | *** | *** | *** |
| | HCB | N/A | N/A | *** | *** | *** |
| | OCDD | N/A | 0.19 | *** | *** | *** |
| | TetCAN | N/A | 0.16 | *** | *** | *** |
| | CPD 1 | N/A | 0.70 | *** | *** | *** |

[1] N/A = not available, [2] ND = non-detect

**Table 2.37. Results of fish tissue analysis for heavy metals at station 6CWLF006.55 in Wolf Creek.**

| | | 06/18/97 | | | 06/18/02 | | | |
|---|---|---|---|---|---|---|---|---|
| | | Northern Hogsucker | White Sucker | Rock Bass | Rock Bass | White Sucker | Carp | DEQ Screening Value |
| No. Fish Analyzed | | 10 | 10 | 10 | 5 | 6 | 3 | |
| Length (cm) | | 20.2 - 26.2 | 19.3 - 22.7 | 16.8 - 21.5 | 13.6 - 16.0 | 21.4 - 28.1 | 51.0 - 53.4 | |
| Weight (g) | | 83.3 - 193.8 | 60.3 - 121.8 | 95.3 - 196.9 | 44 - 98 | 104 - 262 | 1792 - 2178 | |
| As | ppm (wet weight basis) | <0.5 | <0.5 | <0.5 | <0.05 | <0.05 | <0.05 | *0.1* |
| Cd | | <0.02 | <0.02 | <0.02 | <0.01 | <0.01 | <0.01 | *11.00* |
| Cr | | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | *32* |
| Hg | | 0.09 | 0.13 | 0.24 | 0.096 | 0.086 | 0.19 | *0.3 / 0.5* |
| Pb | | <0.1 | <0.1 | <0.1 | 0.17 | 0.3 | <0.1 | *N/A* |
| Se | | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | <0.5 | *54.0* |
| Tl | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Zn | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Ag | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Al | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Cu | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Ni | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |
| Sb | | N/A | N/A | N/A | N/A | N/A | N/A | *N/A* |

**Table 2.38. Results of fish tissue analysis for non-halogenated organic compounds (PAHs) at station 6CWLF006.55 in Wolf Creek.**

| | | 06/18/97 | | | 06/18/02 | | | |
|---|---|---|---|---|---|---|---|---|
| | | White Sucker | Northern Hogsucker | Rock Bass | Rock Bass | White Sucker | Carp | DEQ Screening Value |
| No. Fish Analyzed | | 10 | 10 | 10 | 5 | 6 | 3 | |
| Length (cm) | | 19.3 - 22.7 | 20.2 - 26.2 | 16.8 - 21.5 | 13.6 - 16.0 | 21.4 - 28.1 | 51.0 - 53.4 | |
| Weight (g) | | 60.3 - 121.8 | 83.3 - 193.8 | 95.3 - 196.9 | 44 - 98 | 104 - 262 | 1792 - 2178 | |
| Total PAH | ppb (wet weight basis) | 4.81 | 4.08 | 1.77 | 5.35 | 4.53 | 11.15 | *N/A* |
| Sum PAH | | 0.06 | 0.03 | 0.04 | 0.01 | 0.01 | 0.00 | *15* |
| NAP | | 0.21 | 0.20 | 0.15 | 0.95 | 0.66 | 1.33 | *220,000* |
| NAP 2-Me | | 0.37 | 0.36 | 0.26 | 0.45 | 0.40 | 0.99 | *N/A* |
| NAP 1-Me | | 0.23 | 0.16 | 0.11 | 0.28 | 0.28 | 0.85 | *N/A* |
| biphenyl | | 0.34 | 0.12 | 0.06 | 0.14 | 0.08 | 0.14 | *540,000* |
| NAP d-Me | | 0.17 | 0.13 | 0.05 | 0.11 | 0.12 | 0.24 | *N/A* |
| naphthylene ace | | 0.05 | 0.04 | 0.01 | 0.05 | 0.03 | 0.27 | *N/A* |
| naphthene ace | | 0.17 | 0.09 | 0.03 | 0.18 | 0.19 | 0.64 | *650,000* |
| NAP t-Me | | 0.29 | 0.30 | 0.11 | 0.13 | 0.14 | 0.28 | *N/A* |
| fluorene | | 0.34 | 0.27 | 0.09 | 0.27 | 0.24 | 0.65 | *430,000* |
| PHH | | 0.91 | 1.10 | 0.39 | 0.71 | 0.72 | 2.20 | *N/A* |
| ATH | | 0.10 | 0.09 | 0.03 | 0.42 | 0.31 | 0.64 | *3,200,000* |
| PHH 1-Me | | 0.23 | 0.34 | 0.09 | 0.18 | 0.15 | 0.23 | *N/A* |
| FTH | | 0.59 | 0.38 | 0.18 | 0.93 | 0.71 | 1.86 | *430,000* |
| pyrene | | 0.37 | 0.31 | 0.06 | 0.42 | 0.35 | 0.82 | *320,000* |
| ATH benz(a) | | 0.04 | 0.02 | 0.00 | 0.05 | 0.00 | 0.00 | *15* |
| chrysene | | 0.13 | 0.06 | 0.03 | 0.07 | 0.00 | 0.00 | *15* |
| FTH benzo (b) | | 0.06 | 0.02 | 0.07 | 0.00 | 0.07 | 0.00 | *15* |
| FTH benzo (k) | | 0.08 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 15 |
| pyrene benzo (e) | | 0.05 | 0.03 | 0.01 | 0.00 | 0.08 | 0.00 | 15 |
| pyrene benzo (a) | | 0.03 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 15 |
| perylene | | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |
| pyrene IND | | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15 |
| ATH db (a,h) | | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 15 |
| perylene benzo (ghi) | | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | N/A |

**Table 2.39. Results of fish tissue analysis for halogenated organic compounds at station 6CWLF006.55 in Wolf Creek.**

| | | 06/18/97 | | | 06/18/02 | | | 06/18/02 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Northern Hogsucker | Rock Bass | White Sucker | Rock Bass | White Sucker | Carp | Bluegill Sunfish | Northern Hogsucker | Carp #1 | Carp #2 | Carp #3 | DEQ Screening Value |
| **No. Fish Analyzed** | | 10 | 10 | 10 | 5 | 6 | 3 | 3 | 5 | 1 | 1 | 1 | |
| **Length (cm)** | | 20.2 - 26.2 | 16.8 - 21.5 | 19.4 - 22.7 | 13.6 - 16.0 | 21.4 - 28.1 | 51.0 - 53.4 | 13.1 - 15.7 | 22.2 - 27.0 | 50.2 | 50.1 | 46.5 | |
| **Weight (g)** | | 84.3 - 193.8 | 95.3 - 196.9 | 60.4 - 121.8 | 44 - 98 | 104 - 262 | 1792 - 2178 | 44 - 92 | 122 - 204 | 1458 | 1696 | 1396 | |
| **Total PCB** | **ppb (wet weight basis)** | 112.5 | 12.8 | 23.7 | 25.2 | 15.8 | 140.1 | 0.6 | 2.2 | 20.3 | 28.6 | 23.0 | *50/54/500* |
| **Total Chlordane** | | 27.3 | 20.5 | 27.6 | 10.5 | 9.3 | 75.3 | N/A | N/A | N/A | N/A | N/A | *310* |
| **Sum DDE** | | 7.3 | 2.2 | 4.8 | 1.8 | 1.4 | 18.5 | N/A | N/A | N/A | N/A | N/A | *320* |
| **Sum DDD** | | 2.9 | 1.0 | 4.3 | 0.5 | 0.7 | 12.7 | N/A | N/A | N/A | N/A | N/A | *450* |
| **Sum DDT** | | 0.9 | N/A | 0.8 | 0.2 | 0.1 | 0.9 | N/A | N/A | N/A | N/A | N/A | *320* |
| **Total DDT** | | 11.1 | 3.1 | 9.8 | 2.6 | 2.3 | 32.0 | N/A | N/A | N/A | N/A | N/A | *320* |
| **Total BDE** | | 133.7 | 16.4 | 92.4 | 80.0 | 61.4 | 344.2 | N/A | N/A | N/A | N/A | N/A | *5,000* |
| **HCB** | | N/A | N/A | N/A | N/A | 0.1 | 0.5 | N/A | N/A | N/A | N/A | N/A | *70* |
| **Heptachlorepoxide** | | 1.7 | 0.8 | 2.3 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | *10* |
| **PCA** | | N/A | N/A | N/A | 0.1 | 0.3 | 1.3 | N/A | N/A | N/A | N/A | N/A | *N/A* |
| **Aldrin** | | 2.86 | 0.48 | 0.97 | N/A | N/A | N/A | N/A | N/A | N/A | N/A | N/A | *6.3* |
| **Heptachlor** | | 0.0 | N/A | N/A | N/A | N/A | 0.4 | N/A | N/A | N/A | N/A | N/A | *24* |
| **Dieldrin** | | N/A | N/A | N/A | N/A | 0.25 | N/A | N/A | N/A | N/A | N/A | N/A | *6.7* |
| **alpha BHC** | | N/A | N/A | N/A | N/A | 0.1 | 0.3 | N/A | N/A | N/A | N/A | N/A | *20* |
| **gamma BHC** | | N/A | N/A | N/A | N/A | N/A | 0.4 | N/A | N/A | N/A | N/A | N/A | *3,200* |
| **Total BHC** | | N/A | N/A | N/A | N/A | 0.1 | 0.7 | N/A | N/A | N/A | N/A | N/A | *20* |
| **CPD 2** | | N/A | N/A | N/A | N/A | N/A | 1.5 | N/A | N/A | N/A | N/A | N/A | *N/A* |
| **CPD 4** | | N/A | N/A | N/A | N/A | 0.1 | 0.5 | N/A | N/A | N/A | N/A | N/A | *N/A* |
| **CPD 5** | | N/A | N/A | N/A | 0.4 | 1.2 | 3.8 | N/A | N/A | N/A | N/A | N/A | *N/A* |

## 2.9 Wolf Creek Water Reclamation Facility Monitoring

Water samples were collected form January 2005 through November 2006 above and below the Wolf Creek Water Reclamation Facility. Tables 2.40 and 2.41 list summary of data collected above and below the facility, respectively. Temporal variation is depicted in Figures 2.79 through 2.84.

**Table 2.40. Water quality data summary for samples collected above the Wolf Creek Water Reclamation Facility in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 25 | 7.90 | 8.44 | 7.60 |
| Dissolved Oxygen (DO), mg/L | 25 | 10.41 | 12.47 | 7.87 |
| Temperature, Celsius (°C) | 25 | 12.24 | 18.30 | 6.20 |
| BOD 5, mg/L | 25 | 1.18 | 6.00 | 0.50 |
| NO3-N – Total, mg/L | 25 | 4.41 | 12.76 | 0.80 |
| Orthophosphate - Total, mg/L | 25 | 0.59 | 4.24 | 0.04 |

**Table 2.41. Water quality data summary for samples collected below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

| WATER QUALITY CONSTITUENT | # of SAMPLES | MEAN | MAXIMUM | MINIMUM |
|---|---|---|---|---|
| pH - Field, std units | 25 | 7.64 | 8.47 | 1.00 |
| Dissolved Oxygen (DO), mg/L | 25 | 10.46 | 12.65 | 8.19 |
| Temperature, Celsius (°C) | 25 | 12.67 | 19.20 | 6.10 |
| BOD 5, mg/L | 25 | 1.72 | 4.60 | 0.70 |
| NO3-N - Total, mg/L | 25 | 7.50 | 26.40 | 1.20 |
| Orthophosphate - Total, mg/L | 25 | 1.76 | 3.96 | 0.60 |

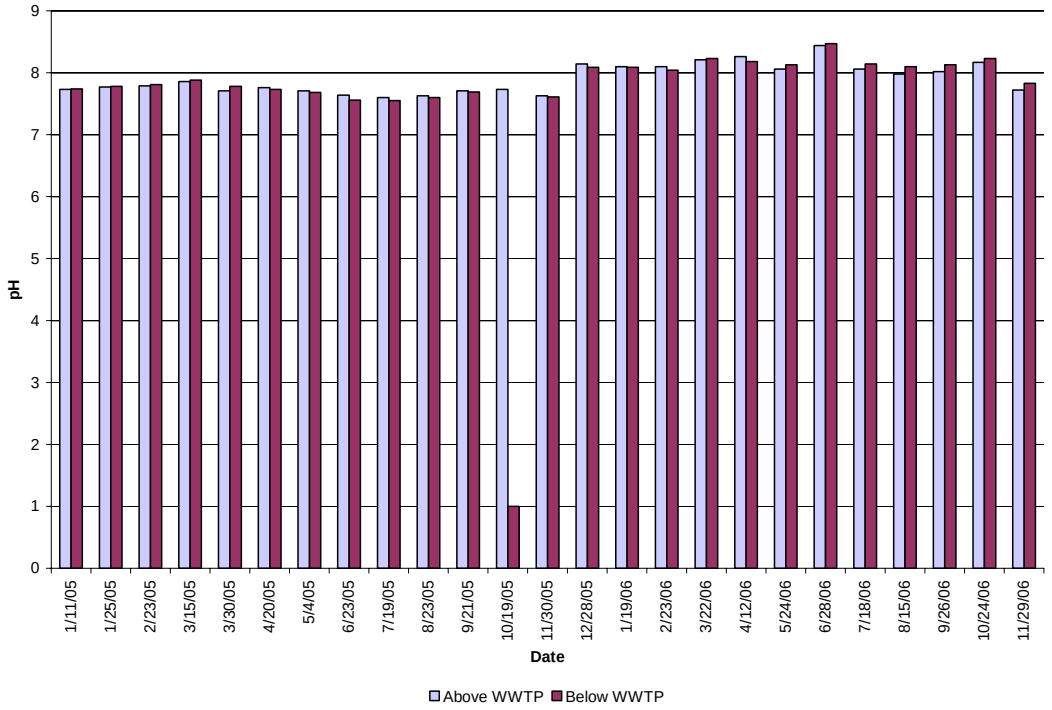


**Figure 2.79. Values of pH collected above and below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

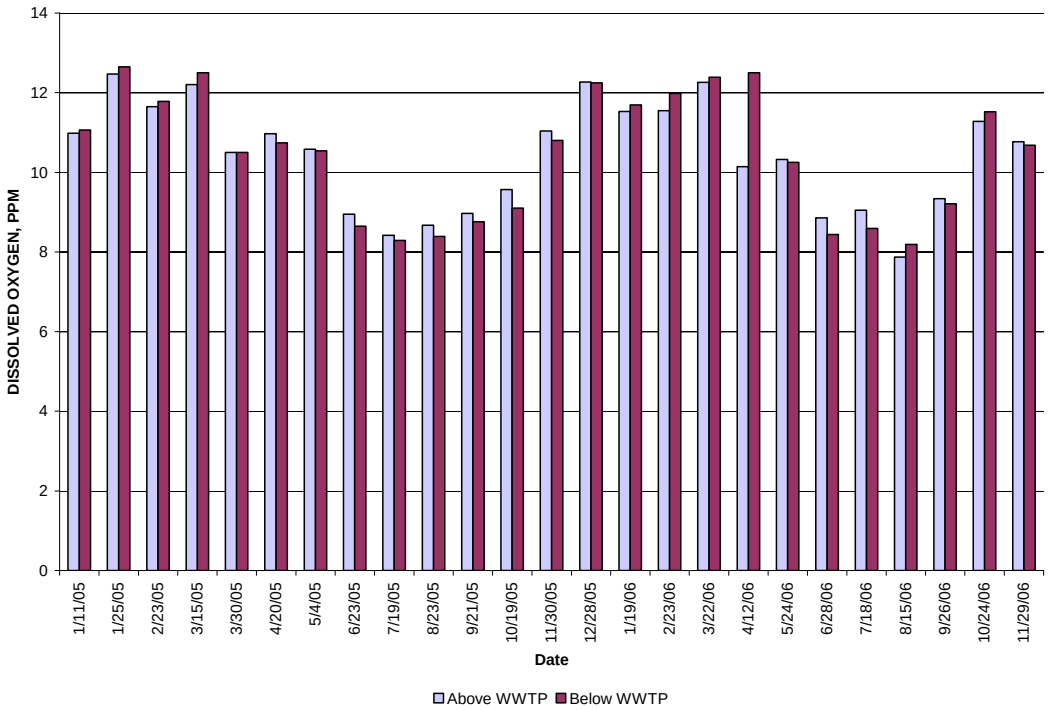


**Figure 2.80. Dissolved oxygen values collected above and below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

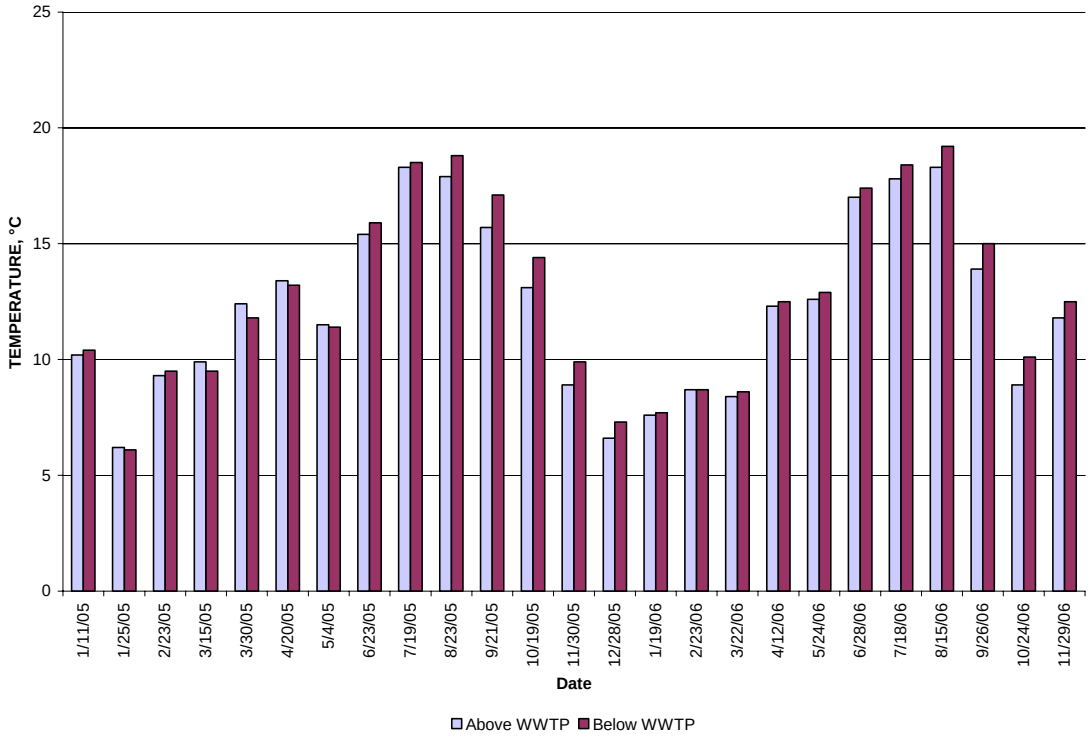


**Figure 2.81. Temperature values collected above and below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

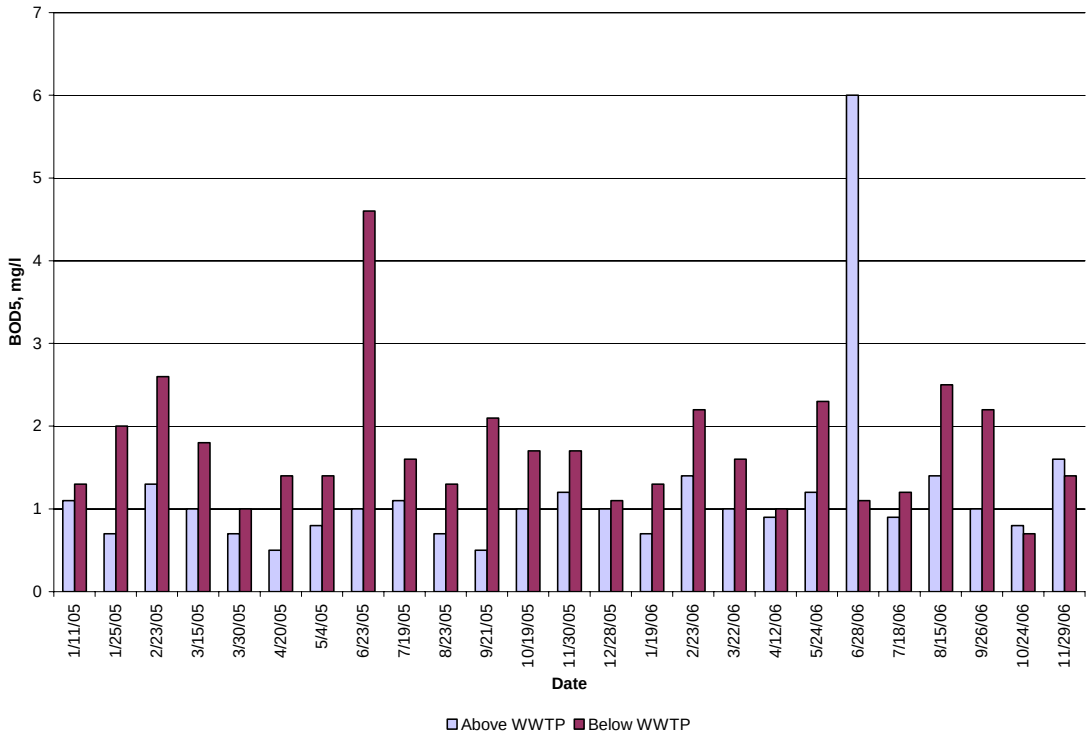


**Figure 2.82. BOD5 values collected above and below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

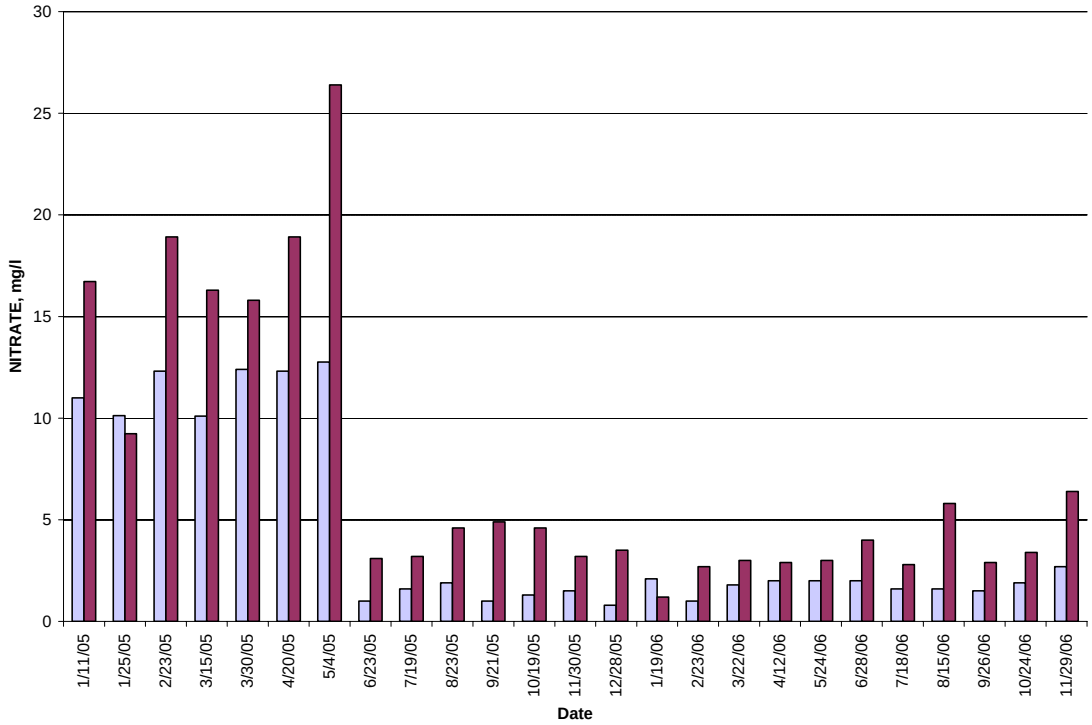


**Figure 2.83. Nitrate values collected above and below the Wolf Creek Water Reclamation Facility in Wolf Creek.**

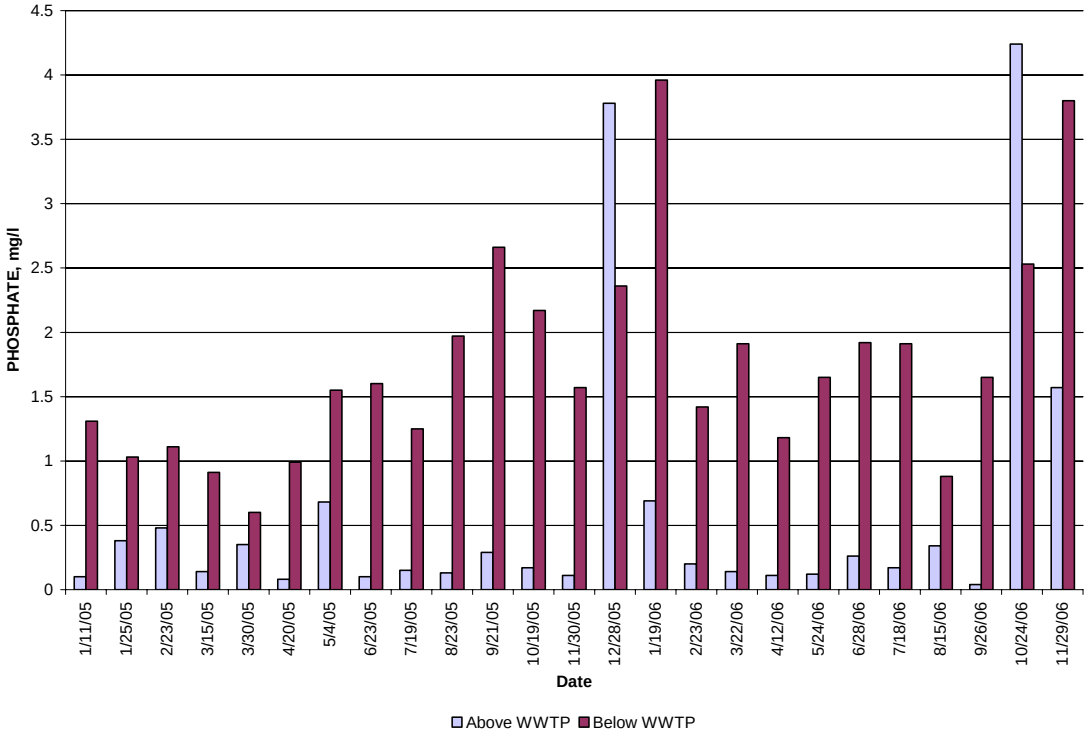


**Figure 2.84. Phosphate values collected above and below the Wolf Creek Water Water Reclamation Facility in Wolf Creek.**

# Chapter 3. Bacteria Source Assessment

Potential bacteria sources in the Wolf 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); Washington County; Town of Abingdon; Natural Resources Conservation Service (NRCS); Virginia Department of Agricultural and Consumer Services (VDACS); Holston River 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 Wolf 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 Wolf 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

Permitted point sources in the Wolf Creek watershed include all individual Virginia Pollutant Discharge Elimination System municipal and industrial permitted facilities, as well as general permits issued for domestic sewage discharges of less than or equal to 1,000 gallons per day. The 2007 VPDES Permit Manual defines an individual municipal facility as:

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

The permit manual defines an industrial facility is defined as:

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

For this reason, permitted point sources of fecal coliform include only the individual municipal or general domestic sewage permits (permits classified as industrial do not discharge bacteria). The individual municipal and general domestic sewage permits are required to maintain a fecal coliform concentration of 200 cfu/100 mL or less, and are required to meet the *E. coli* standard of 126 cfu/100 mL or less in their effluent on permit renewal. Table 3.2 shows the point sources in the Wolf Creek watershed. In allocation scenarios, the entire allowable point source discharge concentration of 200 cfu/100 mL of fecal coliform was used. The ultimate waste load allocation (WLA) was calculated using the *E. coli* limit of 126 cfu/100mL, and *E. coli* loads based on the facility design flow are presented in Table 3.2.

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

**Table 3.2. Active VPDES permitted point sources in the Wolf Creek watershed.**

| Subwatershed | Permit No | Facility Name | Design Flow (MGD) | Fecal Coliform Load (cfu/yr) | *E. coli* Load (cfu/yr) |
|---|---|---|---|---|---|
| WOC-05 | VA0026531 | Wolf Creek Water Reclamation Facility | 7.00 | 1.93E+13 | 1.22E+13 |
| WOC-06 | VAG400245 | Virginia Highlands Christian Fellowship Church STP | 0.001 | 2.68E+09 | 1.69E+09 |
| WOC-07 | VA0028321 | Bristol Virginia Utilities Board - WTP | 0.114 | 0.00E+00 | 0.00E+00 |

## 3.2 Humans

There are 2,389 homes served by municipal sanitary sewer in the Wolf Creek watershed. Wastewater from 1,493 households within the watershed is treated on site by traditional sewage handling and disposal systems.

The Wolf Creek watershed has an estimated population of 7,954 people (3,882 households at an average of 2.05 people per household (UCSB, 2000); actual people per household varies among sub-watersheds). Humans produce $1.95 \times 10^9$ cfu/day-person (Geldreich et al., 1978), resulting in a total fecal coliform production of $1.55 \times 10^{13}$ cfu/day ($5.66 \times 10^{15}$ cfu/year) in Wolf Creek watershed.

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 Wolf 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 $1.95 \times 10^9$ 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 2.05 persons/household was $4.00 \times 10^9$ cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur during storm events. The number of failing septic systems in the watershed is given in Table 3.3.

### *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 25 houses that potentially could be classified as straight pipes in the Wolf Creek watershed (Table 3.3).

### *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 Wolf 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, 2,057 dogs and 2,329 cats were projected to reside in the Wolf Creek impairment. All pets were combined for modeling purposes into a standard ‘unit pet’ category. This ‘unit pet’ was assumed equivalent to one dog or several cats, and a rate of one ‘unit pet’ per household was used to calculate a total pet population of 3,882 for Wolf Creek watershed. The maximum typical fecal coliform production for both dogs and cats is $5.0 \times 10^{9}$ cfu/day-animal (Keeling, 2003), and the typical ranges overlap significantly. The pet population was estimated to produce $4.50 \times 10^{8}$ cfu/day-animal based on these published values. The total bacteria production attributed to pets in the Wolf Creek watershed is $1.75 \times 10^{12}$ cfu/day ($6.38 \times 10^{14}$ cfu/yr). The pet population distribution among the subwatersheds is listed in Table 3.3. 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 Wolf Creek 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 | | | |
| WOC-01 | 997 | 187 | 27 | 9 | 30 | 0 | 501 |
| WOC-02 | 2,613 | 372 | 95 | 34 | 64 | 1 | 1,231 |
| WOC-03 | 1,718 | 103 | 18 | 7 | 17 | 1 | 867 |
| WOC-04 | 1,601 | 160 | 38 | 18 | 27 | 1 | 800 |
| WOC-05 | 45 | 12 | 3 | 4 | 2 | 2 | 21 |
| WOC-06 | 119 | 19 | 6 | 8 | 3 | 2 | 55 |
| WOC-07 | 70 | 14 | 4 | 6 | 3 | 0 | 33 |
| WOC-08 | 80 | 22 | 5 | 8 | 4 | 2 | 38 |
| WOC-09 | 33 | 9 | 2 | 3 | 1 | 1 | 15 |
| WOC-10 | 80 | 22 | 6 | 8 | 4 | 2 | 38 |
| WOC-11 | 66 | 18 | 4 | 6 | 3 | 2 | 31 |
| WOC-12 | 201 | 55 | 14 | 20 | 9 | 5 | 95 |
| WOC-13 | 147 | 40 | 10 | 15 | 7 | 4 | 70 |
| WOC-14 | 129 | 35 | 9 | 13 | 6 | 2 | 61 |
| WOC-15 | 55 | 15 | 4 | 6 | 3 | 0 | 26 |
| **Total** | **7,954** | **1,083** | **245** | **165** | **183** | **25** | **3,882** |

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

## 3.4 Domesticated Animal Sources

In the Wolf 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 Wolf 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 is one dairy farm presently operating in the Wolf Creek watershed. Based on information provided, it was determined that there were 135 milk cows, 68 dry cows, and 68 heifers distributed at the farm. The dairy cattle population was distributed among the sub-watersheds based on the location of the dairy farm (Table 3.4). Beef cattle in the Wolf Creek watershed (1,327 pairs) included cow/calf and feeder operations (Table 3.4).

**Table 3.4. Distribution of dairy cattle, dairy operations, and beef cattle among subwatersheds in the Wolf Creek watershed.**

| Subwatershed | Dairy Cattle[a] | No. of Dairy Operations | Beef Cattle (pairs) |
|---|---|---|---|
| WOC-01 | 0 | 0 | 250 |
| WOC-02 | 0 | 0 | 292 |
| WOC-03 | 0 | 0 | 186 |
| WOC-04 | 0 | 0 | 102 |
| WOC-05 | 0 | 0 | 3 |
| WOC-06 | 0 | 0 | 1 |
| WOC-07 | 0 | 0 | 36 |
| WOC-08 | 0 | 0 | 0 |
| WOC-09 | 0 | 0 | 23 |
| WOC-10 | 0 | 0 | 52 |
| WOC-11 | 0 | 0 | 53 |
| WOC-12 | 0 | 0 | 30 |
| WOC-13 | 0 | 0 | 134 |
| WOC-14 | 271 | 1 | 116 |
| WOC-15 | 0 | 0 | 49 |
| **Total** | **271** | **1** | **1,327** |

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 3.5.
- 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 3.5). 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 3.5. Time spent by cattle in confinement and in the stream in Wolf 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 Table 3.6 for dairy cattle and in Table 3.7 for beef cattle. Table 3.7 reflects animal unit (i.e., 1,000 lb) per beef cow-calf pair variation throughout year.

**Table 3.6. Distribution of the dairy cattle[a] population in the Wolf Creek watershed.**

| Month | Confined | Pasture 1 | Pasture 2 | Pasture 3 | Stream[b] |
|---|---|---|---|---|---|
| January | 155.65 | 87.82 | 21.99 | 5.50 | 0.04 |
| February | 155.65 | 87.82 | 21.99 | 5.50 | 0.04 |
| March | 54.00 | 165.19 | 41.37 | 10.34 | 0.10 |
| April | 40.50 | 175.44 | 43.94 | 10.98 | 0.14 |
| May | 40.50 | 175.38 | 43.92 | 10.98 | 0.22 |
| June | 40.50 | 175.16 | 43.87 | 10.97 | 0.50 |
| July | 40.50 | 175.16 | 43.87 | 10.97 | 0.50 |
| August | 40.50 | 175.16 | 43.87 | 10.97 | 0.50 |
| September | 40.50 | 175.38 | 43.92 | 10.98 | 0.22 |
| October | 40.50 | 175.44 | 43.94 | 10.98 | 0.14 |
| November | 54.00 | 165.19 | 41.37 | 10.34 | 0.10 |
| December | 155.65 | 87.82 | 21.99 | 5.50 | 0.04 |

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

**Table 3.7. Distribution of the beef cattle population (pairs) in the Wolf Creek watershed.**

| Month | Confined | Pasture 1 | Pasture 2 | Pasture 3 | Stream* |
|---|---|---|---|---|---|
| January | 489.44 | 558.95 | 139.98 | 35.00 | 0.23 |
| February | 574.56 | 656.16 | 164.33 | 41.08 | 0.27 |
| March | 0.00 | 1125.83 | 281.95 | 70.49 | 0.69 |
| April | 0.00 | 1158.05 | 290.02 | 72.50 | 0.95 |
| May | 0.00 | 1190.07 | 298.04 | 74.51 | 1.47 |
| June | 0.00 | 1220.92 | 305.76 | 76.44 | 3.51 |
| July | 0.00 | 1253.26 | 313.86 | 78.47 | 3.61 |
| August | 0.00 | 1285.60 | 321.96 | 80.49 | 3.70 |
| September | 0.00 | 1319.60 | 330.48 | 82.62 | 1.63 |
| October | 0.00 | 809.82 | 202.81 | 50.70 | 0.67 |
| November | 0.00 | 850.45 | 212.98 | 53.25 | 0.52 |
| December | 468.16 | 534.65 | 133.90 | 33.47 | 0.22 |

*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 (Table 3.6) and beef cattle (Table 3.7) 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 Wolf Creek watershed is 39,266 lbs. Fecal coliform loading due to cows defecating in the stream, averaged over the year, is $5.29 \times 10^{10}$ cfu/day ($1.93 \times 10^{13}$ 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 (Table 3.6) and beef (Table 3.7) 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 Wolf Creek watershed, pasture 1, pasture 2, and pasture 3 have average annual cattle manure loadings of 6,214; 3,119; and 1,534 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 Wolf Creek, averaged over the year, are $3.39 \times 10^{12}$, $1.76 \times 10^{12}$, and $7.55 \times 10^{11}$ cfu/ac-year for pastures 1, 2, and 3; respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

#### 3.4.1.3 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 in the Wolf Creek watershed is 358,680 gallons. Based on per capita fecal coliform production of milk cows, the fecal coliform concentration in fresh liquid dairy manure is $3.88 \times 10^7$ 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 32.5 acres of cropland and 36.9 acres of pasture 1 in the Wolf Creek watershed.

The typical crop rotation in the watershed is a seven-year rotation with three years of corn-rye and four years of rotational hay (BSE, 2003). It was assumed that 50% of the corn acreage was under no-till cultivation. Liquid manure is applied to cropland during February through May (prior to planting) and in October-November (after the crops are harvested). For spring application to cropland, liquid manure is applied on the soil surface to rotational hay and no-till corn and is incorporated into the soil for corn in conventional tillage. In fall, liquid manure is incorporated into the soil for cropland under rye and surface-applied to cropland under rotational hay. It was assumed that only 10% of the subsurface-applied fecal coliform was available for removal in surface runoff based on local knowledge. The application schedule of liquid manure (BSE, 2003) is given in Table 3.8. Dry cows and heifers were assumed to produce only solid manure.

**Table 3.8. Schedule of cattle waste application in Wolf 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 Table 3.9.

Solid manure is last on the priority list for application to land (it falls behind liquid manure and poultry litter). The amount of solid manure produced in each sub-watershed was estimated based on the populations of dry cows, heifers, and beef cattle in the sub-watershed and their confinement schedules. Solid manure from dry cows, heifers, and beef cattle exhibits different fecal coliform concentrations (cfu/lb) (Table 3.9). Hence, a weighted average fecal coliform concentration in solid manure was calculated based on the relative manure contribution from dry cows, heifers, and beef cattle (Table 3.9). 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 3.8. 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 72.9 acres of cropland and 57.8 acres of pasture 1 in the Wolf Creek watershed.

**Table 3.9. 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 Wolf Creek watershed.**

| Type of Cattle | Population | Typical Weight (lb) [a] | Solid Manure Produced (lb/animal-day) [a] | Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) [a] | Weighted Average Fecal Coliform Concentration in Fresh Manure ($x10^8$ cfu/lb) |
|---|---|---|---|---|---|
| Dry Cow | 68 | 1,400 | 115 | 2.17 | 5.11 |
| Heifer | 68 | 640 | 40.7 | 2.17 | |
| Beef (pairs) | 1,327 | 1,000 | 60 | 5.5 | |

[a]Source: BSE (2003)

### *3.4.2 Poultry*

Based on confined animal feeding operations information obtained from VADCR, no poultry facilities are presently operating in the Wolf Creek watershed.

### *3.4.3 Horses*

The estimated number of horses in the Wolf Creek watershed is included in Table 3.10. The horse population in the watershed has risen in the last several years. Horse populations were estimated using data from the 2001 Virginia Equine Report produced by VASS (VASS, 2002). The number of horses within the watershed was estimated by distributing the equine population evenly throughout all pasture in each county and determining the number of horses in the watershed based on pasture area in the watershed. The same method was used to determine the equine population in each subwatershed. The estimates were adjusted based on feedback from the TAC.

The typical horse produces $4.2x10^8$ cfu/day (VADCR, 2003). Therefore, the daily fecal coliform production by horses in the Wolf Creek watershed is $1.06x10^{11}$ cfu/day ($3.88x10^{13}$ cfu/year).

**Table 3.10. Horse and Sheep population by subwatershed in the Wolf Creek watershed.**

| Subwatershed | Horses | Goat | Sheep |
|---|---|---|---|
| WOC-01 | 48 | 34 | 21 |
| WOC-02 | 56 | 40 | 25 |
| WOC-03 | 35 | 25 | 0 |
| WOC-04 | 20 | 14 | 0 |
| WOC-05 | 1 | 0 | 0 |
| WOC-06 | 0 | 0 | 0 |
| WOC-07 | 7 | 5 | 0 |
| WOC-08 | 0 | 0 | 0 |
| WOC-09 | 4 | 3 | 0 |
| WOC-10 | 10 | 7 | 0 |
| WOC-11 | 10 | 7 | 0 |
| WOC-12 | 6 | 4 | 0 |
| WOC-13 | 25 | 18 | 0 |
| WOC-14 | 22 | 16 | 0 |
| WOC-15 | 9 | 7 | 0 |
| **Total** | **253** | **180** | **46** |

### *3.4.4 Other Livestock Sources*

Based on county sheep population data obtained from VASS and input from SWCD, the sheep population was distributed to individual subwatersheds (Table 3.10). Based on information provided, it was determined that there were 46 ewes throughout the Wolf Creek watershed. An estimated population of 180 goats in the Wolf Creek watershed was based on feedback from the TAC (Table 3.10). Other minor livestock-related sources of bacteria were present during watershed visits; however, a significant population was not identified within the Wolf 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 Table 3.13. The total wildlife fecal coliform production each year in the Wolf Creek watershed is $1.34 \times 10^{14}$cfu/yr.

Wildlife fecal coliform contributions can be from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF, USF&WS, and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Preferred habitat, habitat area, and population density were determined for each species (Table 3.11).

Professional judgment was used in estimating the percent of each wildlife species defecating directly into streams based upon their habitat (Table 3.11). 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 3.11, and further details of the wildlife habitat were used to distribute the populations among the sub-watersheds. For example, the deer population was evenly distributed across the watershed, whereas the 66 feet buffer around streams and impoundments determined the muskrat population. Therefore, a sub-watershed with more stream length and impoundments would have more muskrats than a sub-watershed with shorter stream length and fewer impoundments. Distribution of wildlife among sub-watersheds is given in Table 3.12.

**Table 3.11. Wildlife habitat description, population density, and percent direct fecal deposition in streams in the Wolf Creek watershed.**

| Wildlife Type | Habitat | Population Density (animal/ac-habitat) | Direct Fecal Deposition in Streams (%) |
|---|---|---|---|
| Deer | Primary: Forest and agricultural areas<br>Secondary: rest of watershed | 0.019 | 0.10 |
| Raccoon | Primary: 600 feet buffer around streams and impoundments<br>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<br>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 3.12. Distribution of wildlife among sub-watersheds in Wolf Creek watershed.**

| Subwatershed | Deer (#) | Raccoon (#) | Muskrat (#) | Beaver (#) | Geese (#) | Wood Duck (#) | Bear (#) | Wild Turkey (#) |
|---|---|---|---|---|---|---|---|---|
| WOC-01 | 37 | 104 | 415 | 9 | 8 | 9 | 1 | 3 |
| WOC-02 | 39 | 128 | 388 | 8 | 11 | 13 | 1 | 3 |
| WOC-03 | 28 | 72 | 251 | 6 | 6 | 7 | 1 | 3 |
| WOC-04 | 15 | 60 | 108 | 3 | 6 | 7 | 0 | 1 |
| WOC-05 | 6 | 18 | 6 | 2 | 1 | 1 | 1 | 2 |
| WOC-06 | 8 | 20 | 3 | 2 | 1 | 2 | 1 | 3 |
| WOC-07 | 6 | 15 | 51 | 2 | 1 | 1 | 0 | 1 |
| WOC-08 | 12 | 28 | 2 | 3 | 2 | 2 | 1 | 5 |
| WOC-09 | 5 | 15 | 112 | 3 | 1 | 1 | 0 | 1 |
| WOC-10 | 11 | 21 | 251 | 9 | 2 | 2 | 0 | 2 |
| WOC-11 | 9 | 23 | 254 | 8 | 2 | 2 | 0 | 1 |
| WOC-12 | 29 | 81 | 142 | 24 | 5 | 6 | 2 | 10 |
| WOC-13 | 21 | 84 | 642 | 17 | 4 | 5 | 1 | 3 |
| WOC-14 | 18 | 74 | 556 | 15 | 3 | 4 | 0 | 2 |
| WOC-15 | 7 | 32 | 233 | 6 | 1 | 2 | 0 | 1 |
| **Total** | **251** | **775** | **3,414** | **117** | **54** | **64** | **9** | **41** |

## 3.6 Summary: Contribution from All Sources

A synopsis of the fecal coliform loads characterized and accounted for in the Wolf Creek watershed along with average fecal coliform production rates are shown in Table 3.13. The total fecal coliform production by all sources in the Wolf Creek watershed is $2.33 \times 10^{16}$ cfu/yr.

**Table 3.13. Potential fecal coliform sources and daily fecal coliform production by source in Wolf Creek 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* | 203 | 25,000 | 507,848 |
| *Heifers* | 68 | 8,800 | 77,768 |
| Beef Cattle (pairs) | 1,327 | 33,000 | 4,747,215 |
| Horses | 253 | 420 | 10,633 |
| Humans | 7,954 | 1,950 | 207,356 |
| Pets (Dog & Cats) | 3,882 | 450 | 174,810 |
| Deer | 251 | 350 | 8,791 |
| Raccoon | 775 | 50 | 3,878 |
| Muskrat | 3,414 | 25 | 8,533 |
| Beaver | 117 | 0.2 | 2 |
| Wild Turkey | 41 | 93 | 382 |
| Geese | 54 | 800 | 11,680 |
| Wood Duck | 64 | 2,400 | 3,335 |

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

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

Based on the inventory of fecal coliform sources, a summary of the contributions made by the nonpoint sources to annual fecal coliform loading directly to the stream and to various land use categories is given in Table 3.14. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.14.

From Table 3.14, it is clear in the Wolf Creek watershed that nonpoint source loadings to the land surface are more than 262 times as large as direct loadings to the streams, with pastures receiving about 92.6% 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 5.

**Table 3.14. Annual fecal coliform loadings to the stream and the various land use categories in the Wolf Creek watershed.**

| Source | Fecal Coliform Loading ($x10^{10}$ cfu/year) | Percent of Total Loading (%) |
|---|---|---|
| *Direct Loading to Streams* | | |
| Straight Pipes | 3,842 | 0.18 |
| Cattle in Stream | 1,925 | 0.09 |
| Wildlife in Stream | 2,324 | 0.11 |
| *Loading to Land Surfaces* | | |
| Cropland | 5,877 | 0.28 |
| Pasture 1 | 1,497,478 | 70.49 |
| Pasture 2 | 387,357 | 18.23 |
| Pasture 3 | 83,145 | 3.91 |
| Forest | 6,810 | 0.32 |
| Residential* | 135,649 | 6.39 |
| **Total** | **2,124,407** | **100.00** |

*Includes loads received from failed septic systems and pets.

# Chapter 4. Benthic Stressor Analysis

## 4.1 Introduction

TMDLs must be developed for a specific pollutant. Since the benthic impairment is based on a biological inventory, rather than on a physical or chemical water quality parameter, the pollutant is not explicitly identified in the assessment, as it is with physical and chemical parameters. The process outlined in USEPA's Stressor Identification Guidance Document (USEPA, 2000) was used to identify the critical stressor for Middle Fork Holston River. A list of candidate causes was developed from the listing information, biological data, published literature, and stakeholder input. Chemical and physical monitoring data from VADEQ monitoring provided additional evidence to support or eliminate the potential candidate causes. Biological metrics and habitat evaluations in aggregate provided the basis for the initial impairment listing, but individual metrics were also used to look for links with specific stressors, where possible.

Logical pathways were explored between observed effects in the benthic community, potential stressors, and intermediate steps or interactions that would be consistent in establishing a cause and effect relationship with each candidate cause.

The evaluation includes possible stressors such as dissolved oxygen, temperature, pH, metals, organic chemicals, nutrients, toxic compounds, and sediments. Each candidate stressor was evaluated based on available monitoring data, field observations, and consideration of potential sources in the watershed. Depending on the weight of evidence available, each potential stressor was placed into one of the following three categories:

Non-stressor: Stressor with data indicating normal conditions, without water quality standard exceedances, or without observable impacts usually associated with the stressor.

Possible stressor: Stressor with data indicating possible links to the benthic impairment, but without conclusive data to demonstrate direct impact on benthic community.

Most probable stressor(s): Stressor with conclusive data linking it to the poor health of the benthic community, or the most plausible of the possible stressors. TMDL developed for the most probable stressor(s).

## 4.2 Non-Stressors

### *4.2.1 pH*

Benthic macro-invertebrates require a specific pH range of 6.0 to 9.0 to thrive. Changes in pH may adversely affect the survival of benthic macro-invertebrates. Treated wastewater, mining discharge, and urban runoff can potentially alter in-stream levels of pH.

Measured pH values at all water quality monitoring (WQM) stations are within the expected range for Class IV waters. Therefore, pH does not appear to be adversely impacting benthic communities in Wolf Creek and is classified as a non-stressor.

### *4.2.2 Temperature*

Elevated temperatures can stress benthic organisms and provide sub-optimal conditions for their survival. Wolf Creek is classified as a Class IV mountain stream with a maximum temperature standard of 31°C. No exceedances of the temperature standard were recorded by VADEQ ambient monitoring, or by monitoring during collection of the biological samples. Therefore, no evidence supported temperature as a stressor, and it was classified as a non-stressor.

### *4.2.3 Dissolved Oxygen*

Adequate dissolved oxygen (DO) levels are necessary for invertebrates and other aquatic organisms to survive in the benthic sediments of rivers or streams. Decreases in in-stream oxygen levels can result in oxygen depletion or anoxic sediments, which adversely impact the river's benthic community. Dissolve oxygen values at all WQM stations were above the daily average concentration for Class IV waters (i.e., 5 mg/l); therefore, dissolved oxygen is not considered to be impacting the benthic community and was classified as a non-stressor.

### *4.2.4 Ammonia*

High values of ammonia are toxic to many fish species and may impact the benthic community as well. All values recorded at VADEQ ambient monitoring stations were at or below 0.3 mg/L, well below the chronic ammonia freshwater criteria of 1.79 mg/L. No fish kills have been reported in this watershed and nothing in the ambient monitored data indicates ammonia as a stressor, therefore ammonia was classified as a non-stressor.

## 4.3 Possible Stressors

### *4.3.1 Nutrients*

Excessive nutrient inputs can lead to excessive algal growth, eutrophication, and low DO concentrations that may adversely affect the survival of benthic macro-invertebrates. In particular, DO levels may become low during overnight hours due to respiration. Exceedances of the stressor screening values for total nitrogen nitrate, and TKN were observed at various water quality monitoring stations throughout the Wolf Creek watershed. Ammonia values were not elevated with all values well below the chronic freshwater criteria. The stressor screening value for total phosphorous was exceeded at WQM stations 6-CWLF001.18, 6-CWLF001.46, 6-CWLF004.10, 6-CWLF006.55, and CWLF006.75. No exceedances were observed at WQM stations 6-CWLF007.55 and 6-CWLF008.00. No diurnal dissolved oxygen sampling was performed in the Wolf Creek watershed. While the benthic community in Wolf Creek has occasional high populations of Chironomidae or Hydropsychidae – organisms associated with excessive nutrients, it has also contained high numbers of low pollution tolerant organisms. Several low riparian vegetation

habitat metric scores have been recorded, which could promote increased nutrient transport through surface runoff. Improvements (e.g., correcting overflows) to several permitted point sources have occurred over the last five years that will help reduce nutrient loadings. Given these improvements and since nutrients would be reduced through implementation of control measures to address bacteria and sediment loads in the Wolf Creek watershed, the Technical Advisory Committee decided to classify nutrients as a possible stressor

### *4.3.2 Heavy Metals*

Sedimentary cadmium values at WQM stations 6-CWLF001.18 and 6-CWLF001.46 exceeded the consensus probable effect concentration of 4.98 ppm. All other total metal concentrations and sedimentary metal concentrations at WQM stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 were below the applicable consensus probable effect concentration and do not appear to be a stressor to the benthic community; therefore, heavy metals was classified as a possible stressor.

### *4.3.3 Organics*

Exceedances of sedimentary DDD, DDE, dieldrin, and heptachloepoxide consensus probable effect concentrations were observed at water quality monitoring stations in the watershed. All other sedimentary organic concentrations at water quality monitoring stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55 were below an applicable consensus probable effect concentration and do not appear to be a stressor to the benthic community; therefore, organics was classified as a possible stressor.

## 4.4 Most Probable Stressors

### *4.4.1 Sediment*

Sedimentation has been identified as a most probable stressor in the Wolf Creek benthic impaired segment, based on the composition of the benthic community, benthic habitat data, and excessive TSS values from the stations along the impaired segment. At station 6-CWLF004.10, all values for embeddedness and sediment deposition were below 10 and at least 50% of values for epifaunal substrate and riparian zone were below 10. At station 6-CWLF007.31, habitat scores for embeddedness, sediment deposition, bank stability, and riparian zone were 10 or below. Samples of the benthic community in Wolf Creek have shown high populations of Chironomids and Hydropsychids, which thrive in sediment rich water. TSS values at water quality monitoring stations 6-CWLF001.18, 6-CWLF001.46, 6-CWLF006.55, and 6-CWLF007.55 exceeded the stressor screening value of 10 mg/lc. Exceedances of the turbidity stressor screening value of 10 NTU were observed at water quality monitoring stations 6-CWLF001.18, 6-CWLF001.46, and 6-CWLF006.55. The total solids stressor screening value of 300 mg/l was exceeded at all water quality monitoring stations.

# Chapter 5. Modeling Process for Fecal Coliform TMDL Development

A key component in developing a TMDL is establishing the relationship between pollutant loadings (both point and nonpoint) and in-stream water quality conditions. Once this relationship has been developed, management options for reducing pollutant loadings to streams can be assessed. In developing a TMDL, it is critical to understand the processes that affect the fate and transport of the pollutants and cause the impairment of the water body of concern. Pollutant transport to water bodies is evaluated using a variety of tools, including monitoring, geographic information systems (GIS), and computer simulation models. In this chapter, modeling process, input data requirements, model calibration procedure and results, and model validation results for the bacteria TMDL are discussed.

## 5.1 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 Wolf Creek 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 Wolf Creek watershed is discussed below in Sections 5.2 through 5.6. 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.

## 5.2 Selection of Sub-watersheds

The stream network was delineated based on the blue line stream network from USGS topographic maps with each subwatershed having at least one stream segment. Subwatershed delineation was based on potential fecal loadings, flow and water quality data availability, and HSPF model constraints. Because loadings of fecal coliform are believed to be associated with land use activities, subwatersheds were chosen based on uniformity of land use. HSPF outputs flow and fecal coliform concentration at subwatershed outlets, therefore subwatershed outlets were chosen to correspond to flow and water quality station locations. An hourly model time-step was used requiring the time of concentration in each subwatershed to be greater than one hour.

The Wolf Creek watershed is 17,342 acres and the model framework selected is suitable for this size. To account for the spatial distribution of fecal coliform sources, the watershed was divided into 15 subwatersheds as shown in Figure 5.1. The unimpaired segments WOC-01 & WOC-02; and WOC-03 & WOC-04 drain into the beginning of the Wolf Creek impairment, which begins in WOC-05 at the confluence of Town Creek and Wolf Creek (VAS-O06R-01). The impairment flows though WOC-06, WOC-07, WOC-09, WOC-10, WOC-11, and WOC-14 where it ends at the backwaters of the South Holston Lake. Other unimpaired subwatersheds that flow into the impairment include WOC-08, WOC-12, and WOC-13.

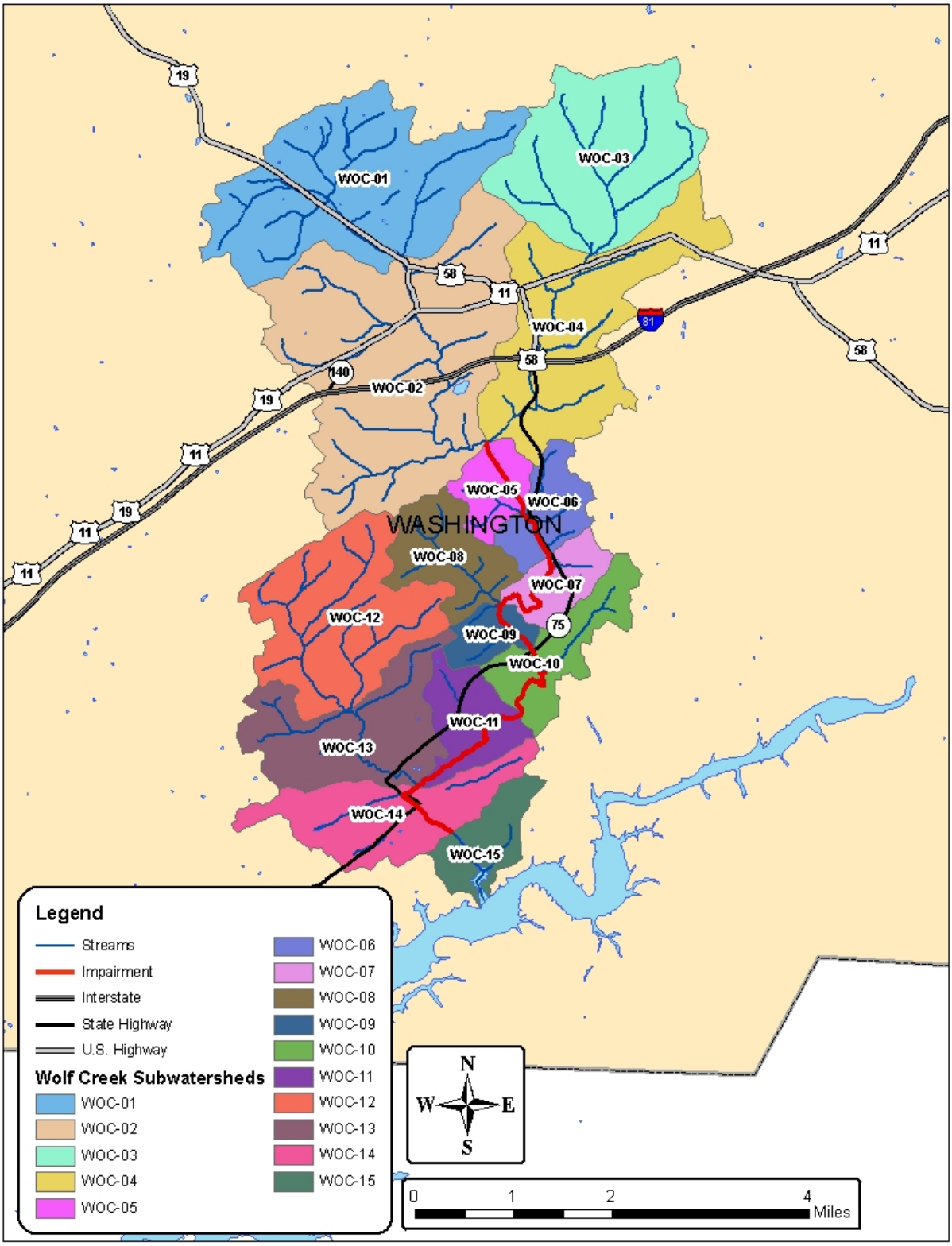


**Figure 5.1. Wolf Creek subwatersheds.**

## 5.3 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 5.1). The land use categories were assigned pervious/impervious percentages, which allowed a land use with both pervious and impervious fractions to be modeled using both the PERLND and IMPLND modules. Some hydrology and water quality model parameters used in the PERLND and IMPLND modules are a function of land use.

**Table 5.1. Consolidation of NLCD land use categories for Wolf Creek (VAS-O06R) watersheds.**

| TMDL Land Use Categories | Pervious / Impervious* (%) | NLCD Land Use Classification (Class No.) |
|---|---|---|
| Cropland | Pervious (100) | Row Crops (82)<br>Small grains (83) |
| Pasture 1 | Pervious (100) | Pasture/Hay (81) |
| Pasture 2 | Pervious (100) | Pasture/Hay (81) |
| Pasture 3 | Pervious (100) | Pasture/Hay (81) |
| Residential | Pervious (72), Impervious (28) | Low Density Residential (21)<br>High Intensity Residential (22)<br>Commercial/Industrial/Transportation (23) |
| Water | Impervious (100) | Open Water (11) |
| Wetland | Pervious (100) | Woody Wetlands (91)<br>Emergent Herbaceous Wetlands (92) |
| Forest | Pervious (100) | Transitional (33)<br>Deciduous Forest (41)<br>Evergreen Forest (42)<br>Mixed Forest (43) |

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

As discussed in Section 5.2, subwatersheds in each impairment were defined to spatially analyze waste or fecal coliform distribution within the watershed (Figure 5.1). Land use distribution in the subwatersheds as well as in the entire Wolf Creek watershed is presented in Table 5.2.

**Table 5.2. Land use distribution in Wolf Creek watershed.**

| Total Landuse | | | | | | | |
|---|---|---|---|---|---|---|---|
| | **Cropland** | **Forest** | **Residential** | **Pasture** | **Transitional** | **Water** | **Wetland** |
| **WOC-1** | 46.5 | 486.5 | 410.3 | 1452.7 | 0.9 | 0.0 | 0.0 |
| **WOC-2** | 18.5 | 383.9 | 1378.6 | 1693.2 | 16.2 | 0.0 | 5.7 |
| **WOC-3** | 2.0 | 441.5 | 327.4 | 1078.6 | 0.0 | 0.0 | 0.5 |
| **WOC-4** | 7.5 | 207.6 | 1149.4 | 594.3 | 12.1 | 0.0 | 0.0 |
| **WOC-5** | 4.3 | 324.1 | 12.0 | 19.7 | 1.2 | 0.0 | 0.0 |
| **WOC-6** | 0.0 | 414.2 | 31.1 | 4.3 | 0.3 | 0.0 | 0.0 |
| **WOC-7** | 3.3 | 125.7 | 37.9 | 209.8 | 0.0 | 0.0 | 0.0 |
| **WOC-8** | 0.0 | 647.8 | 0.0 | 2.7 | 2.3 | 0.0 | 0.0 |
| **WOC-9** | 1.1 | 127.5 | 1.6 | 135.2 | 0.0 | 0.0 | 0.0 |
| **WOC-10** | 3.8 | 285.6 | 43.5 | 302.8 | 1.8 | 0.0 | 3.6 |
| **WOC-11** | 9.5 | 182.9 | 36.3 | 306.4 | 2.8 | 0.0 | 2.8 |
| **WOC-12** | 8.3 | 1392.9 | 59.8 | 171.9 | 6.1 | 0.0 | 0.6 |
| **WOC-13** | 22.9 | 361.9 | 37.3 | 776.4 | 1.2 | 0.0 | 0.0 |
| **WOC-14** | 32.5 | 268.6 | 74.4 | 671.7 | 0.0 | 1.4 | 0.0 |
| **WOC-15** | 1.5 | 107.8 | 47.5 | 282.1 | 6.7 | 5.2 | 1.6 |
| **Total** | **161.8** | **5758.5** | **3647.3** | **7701.6** | **51.5** | **6.5** | **14.8** |
| **Total %** | **0.9%** | **33.2%** | **21.0%** | **44.4%** | **0.3%** | **0.0%** | **0.1%** |

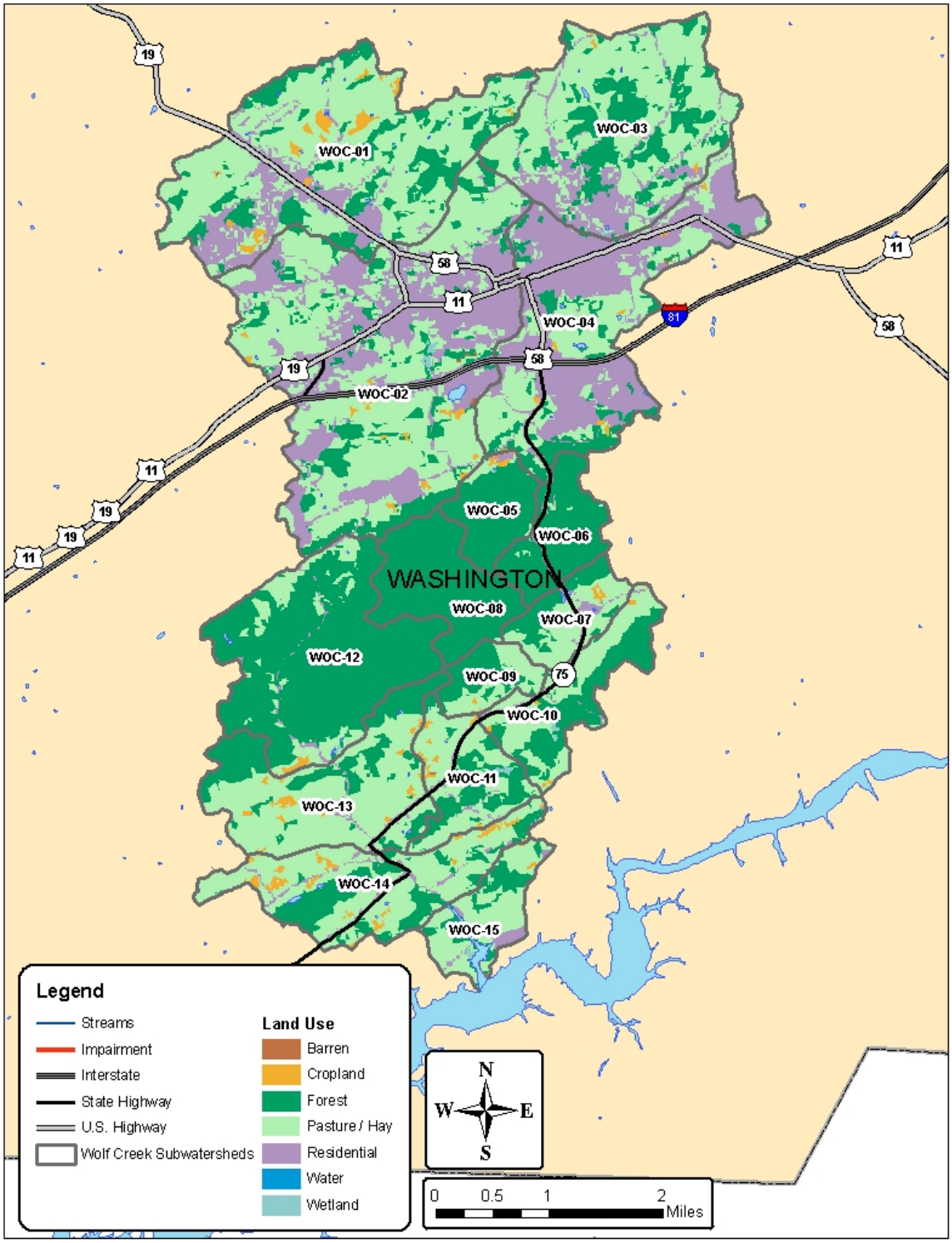


**Figure 5.2. Wolf Creek watershed land use distribution.**

## 5.4 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.

## 5.5 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 Wolf 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 3 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.

## 5.6 Accounting for Pollutant Sources

### *5.6.1 Overview*

There are two permitted point discharges of bacteria located in the Wolf Creek watershed. This source was modeled using the permitted concentration and design discharge. Currently, MS4 permitted facilities do not exist in the Wolf 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 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 5.6.4. 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.

### *5.6.2 Modeling Fecal Coliform Die-off*

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

$$C_t = C_0 10^{-kt} \qquad [5.1]$$

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 Middle Fork Holston River watershed (Table 5.3).

**Table 5.3. First order decay rates for different animal waste storage as affected by storage/application conditions and their sources in the Wolf 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 [5.1]. 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.

### *5.6.3 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 Technical Advisory Committee (TAC) feedback, no instances of groundwater contamination were acknowledged and as a result it was assumed that the groundwater contained no bacteria. Loads from direct nonpoint sources in each watershed are described in detail in Chapter 3.

### *5.6.4 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.

### *5.6.5 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.

## 5.7 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.

### *5.7.1 Hydrology*

Observed stream flow values were not available for Wolf Creek, therefore a “paired watershed” approach was used for hydrologic calibration and validation. The approach assumes that the paired watershed and Wolf Creek watershed have similar hydrologic responses based on physical, geologic, and hydrologic characteristics. The Middle Fork Holston River watershed was chosen as the paired watershed due to similar physiographic and hydrologic characteristics. Hydrology calibration and validation were performed based on the physical, hydrologic, and land use data for the Middle Fork Holston River watershed. After calibration and validation completion, the parameterization for the Middle Fork Holston River model was transferred to the Wolf Creek model. Parameters describing watershed characteristics such as land use, slope, infiltration rate, and F-Tables were updated to reflect the physical properties in Wolf Creek watershed.

The Middle Fork Holston River model was calibrated using observed flow values from USGS station #03474000 on Middle Fork Holston River near Seven Mile Ford, VA and USGS station #003475000 on Middle Fork Holston River near Mock Mill, VA for the period January 1, 2003 to December 31, 2007. The model was validated for the period January 1, 1998 to December 31, 2002. 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 5.4 through 5.7. All criteria were within the recommended ranges. As shown in Figures 5.3 through 5.6, the simulated flow for both the calibration and validation matched the observed flow well. The agreement with observed flows is further illustrated in Figures 5.7 through 5.10 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 5.11 through 5.14).

**Table 5.4. Summary statistics for the calibration period (1/1/03 to 12/31/07) at USGS station #03474000 in Middle Fork Holston River watershed.**

| | Criterion (%) | Observed | Modeled | Error (%) |
|---|---|---|---|---|
| Total Flow Volume(in) | 10 | 86.21 | 84.20 | -2.32 |
| Total of Highest 10% Flow Volume (in) | 15 | 31.01 | 34.31 | 10.63 |
| Total of Lowest 50% Flow Volume (in) | 10 | 16.41 | 16.90 | 2.93 |
| Total Winter Flow Volume (in) | 20 | 30.31 | 30.44 | 0.41 |
| Total Summer Flow Volume (in) | 20 | 12.38 | 13.52 | 9.20 |
| Total Storm Volume (in) | 20 | 70.76 | 74.27 | 4.96 |
| Groundwater Recession Coefficient | 1 | 0.97 | 0.98 | 1.0 |
| Coefficient of Determination, $r^2$ | 0.77 | | | |

**Table 5.5. Summary statistics for the calibration period (1/1/03 to 12/31/07) at USGS station #03475000 in Middle Fork Holston River watershed.**

| | Criterion (%) | Observed | Modeled | Error (%) |
|---|---|---|---|---|
| Total Flow Volume(in) | 10 | 85.60 | 85.45 | -0.18 |
| Total of Highest 10% Flow Volume (in) | 15 | 28.50 | 30.81 | 8.09 |
| Total of Lowest 50% Flow Volume (in) | 10 | 18.11 | 18.43 | 1.81 |
| Total Winter Flow Volume (in) | 20 | 29.76 | 30.27 | 1.70 |
| Total Summer Flow Volume (in) | 20 | 13.71 | 14.32 | 4.44 |
| Total Storm Volume (in) | 20 | 68.65 | 74.06 | 7.88 |
| Groundwater Recession Coefficient | 1 | 0.97 | 0.98 | 1.0 |
| Coefficient of Determination, $r^2$ | 0.82 | | | |

**Table 5.6. Summary statistics for the validation period (1/1/98 to 12/31/02) at USGS station #03474000 in Middle Fork Holston River watershed.**

| | Criterion (%) | Observed | Modeled | Error (%) |
|---|---|---|---|---|
| Total Flow Volume(in) | 20 | 70.81 | 69.65 | -1.64 |
| Total of Highest 10% Flow Volume (in) | 25 | 28.63 | 29.04 | 1.46 |
| Total of Lowest 50% Flow Volume (in) | 20 | 12.13 | 12.81 | 5.61 |
| Total Winter Flow Volume (in) | 30 | 25.07 | 24.30 | -3.09 |
| Total Summer Flow Volume (in) | 30 | 12.64 | 11.62 | -8.08 |
| Total Storm Volume (in) | 30 | 54.84 | 58.69 | 7.01 |
| Groundwater Recession Coefficient | 1 | 0.97 | 0.98 | 1.0 |
| Coefficient of Determination, $r^2$ | 0.72 | | | |

**Table 5.7. Summary statistics for the validation period (1/1/98 to 12/31/02) at USGS station #03475000 in Middle Fork Holston River watershed.**

| | Criterion (%) | Observed | Modeled | Error (%) |
|---|---|---|---|---|
| Total Flow Volume(in) | 20 | 68.89 | 70.60 | 2.49 |
| Total of Highest 10% Flow Volume (in) | 25 | 26.08 | 26.62 | 2.05 |
| Total of Lowest 50% Flow Volume (in) | 20 | 13.54 | 14.04 | 3.69 |
| Total Winter Flow Volume (in) | 30 | 23.53 | 23.64 | 0.47 |
| Total Summer Flow Volume (in) | 30 | 12.78 | 12.35 | -3.40 |
| Total Storm Volume (in) | 30 | 49.49 | 58.41 | 18.04 |
| Groundwater Recession Coefficient | 1 | 0.97 | 0.98 | 1.0 |
| Coefficient of Determination, $r^2$ | 0.78 | | | |

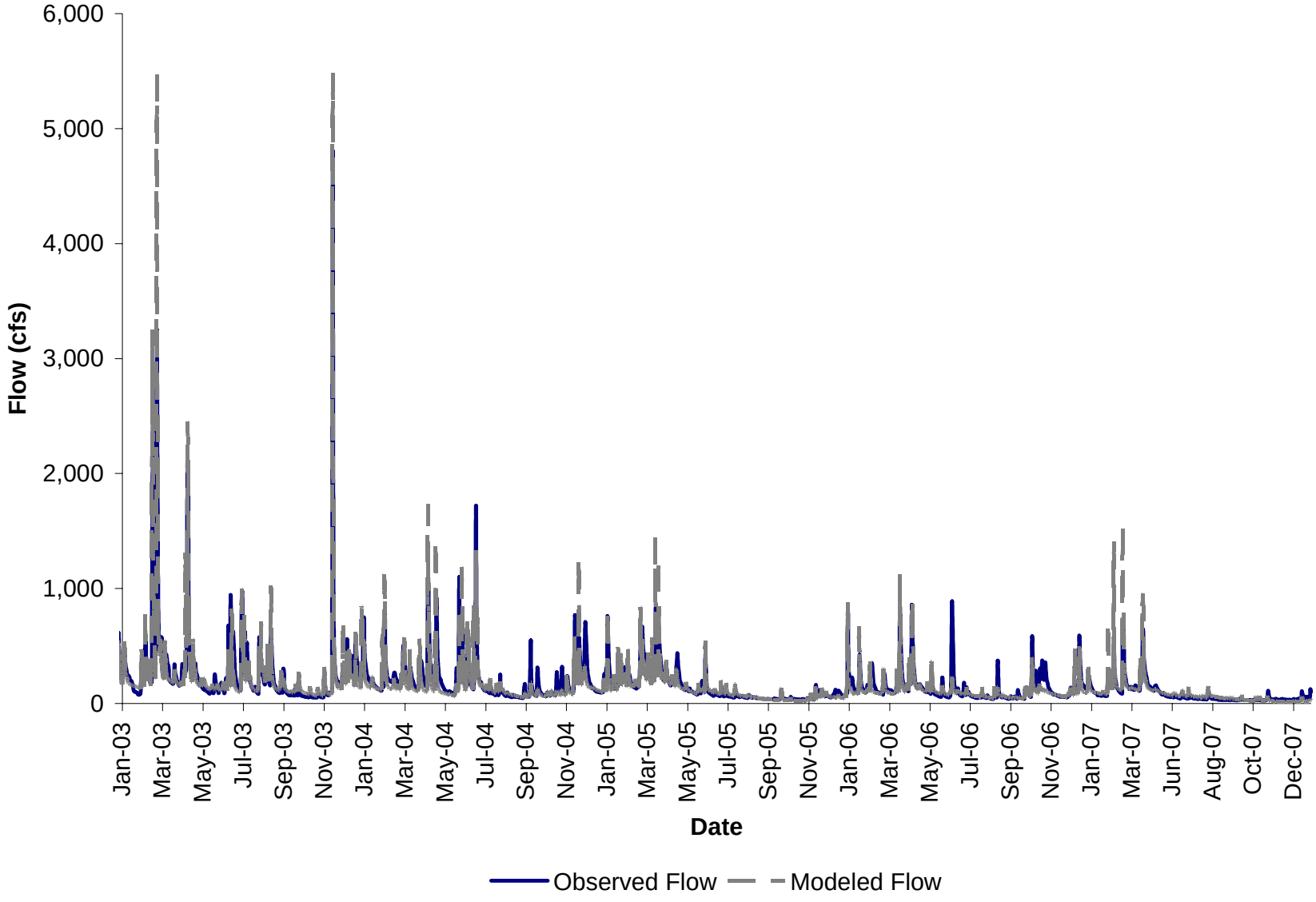


**Figure 5.3. Observed and modeled flows for the calibration period 1/1/03 to 12/31/07 at USGS station #03474000 in Middle Fork Holston River watershed.**

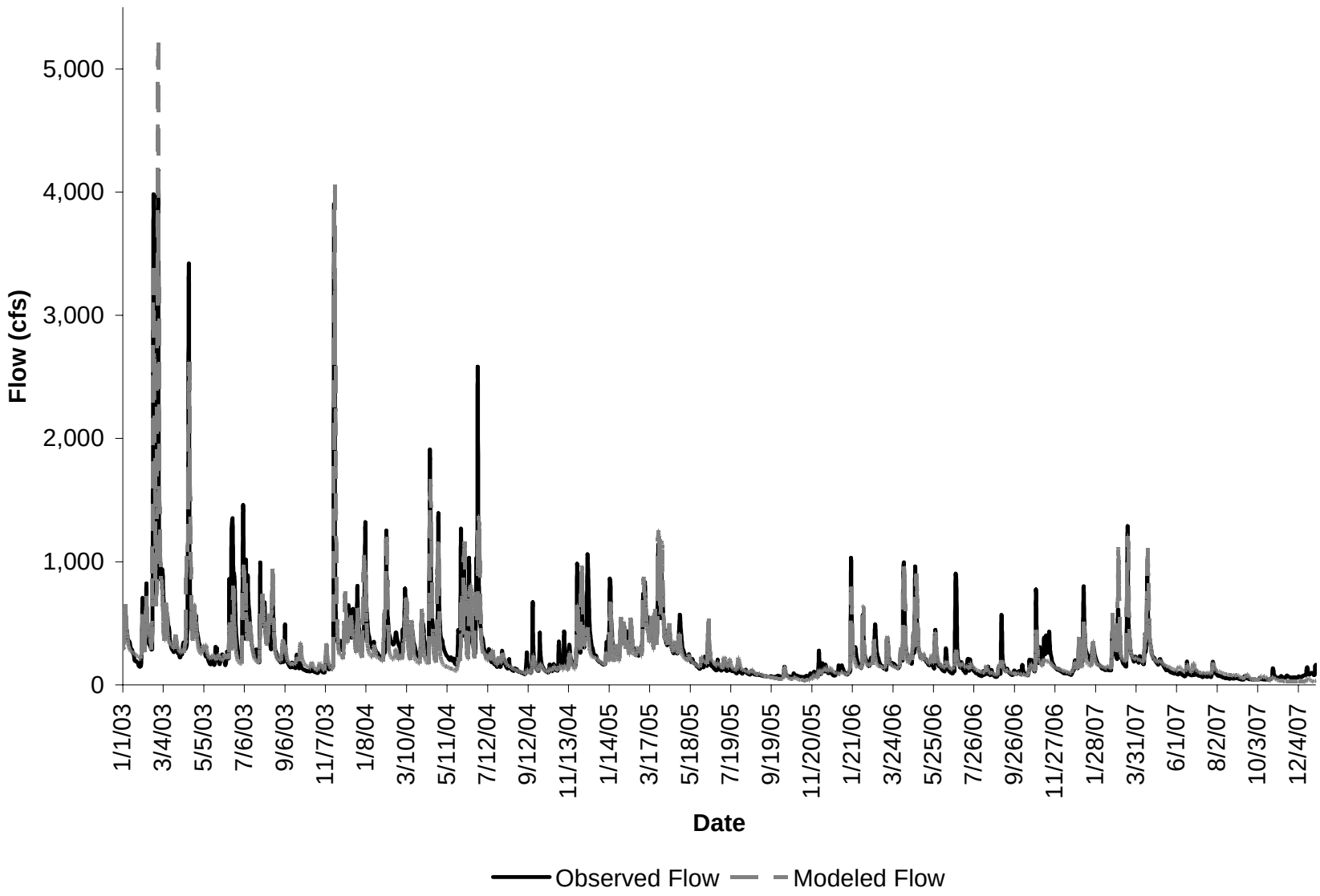


**Figure 5.4. Observed and modeled flows for the calibration period 1/1/03 to 12/31/07 at USGS station #03475000 in Middle Fork Holston River watershed.**

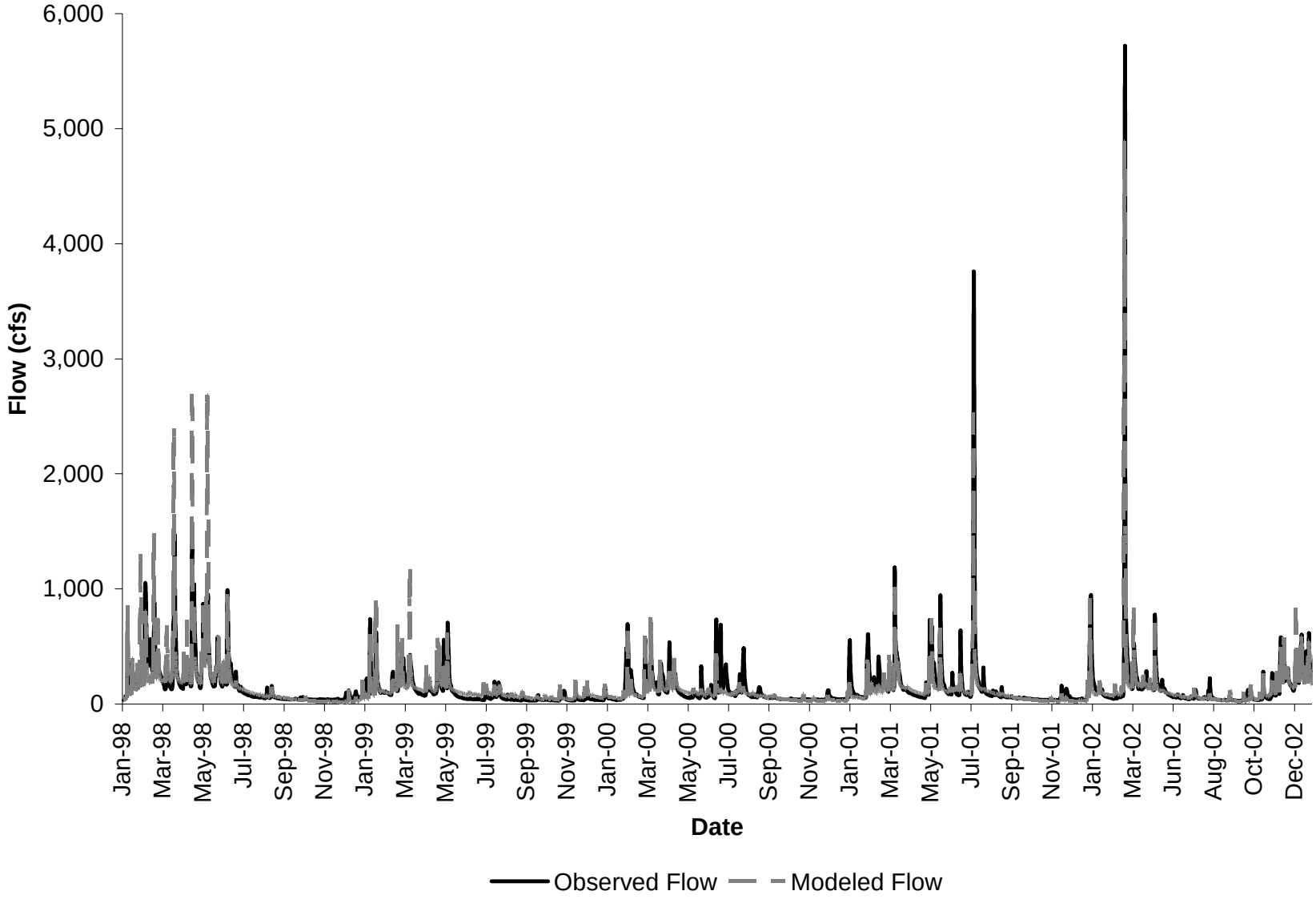


**Figure 5.5. Observed and modeled flows for the validation period 1/1/98 to 12/31/02 at USGS station #03474000 in Middle Fork Holston River watershed.**

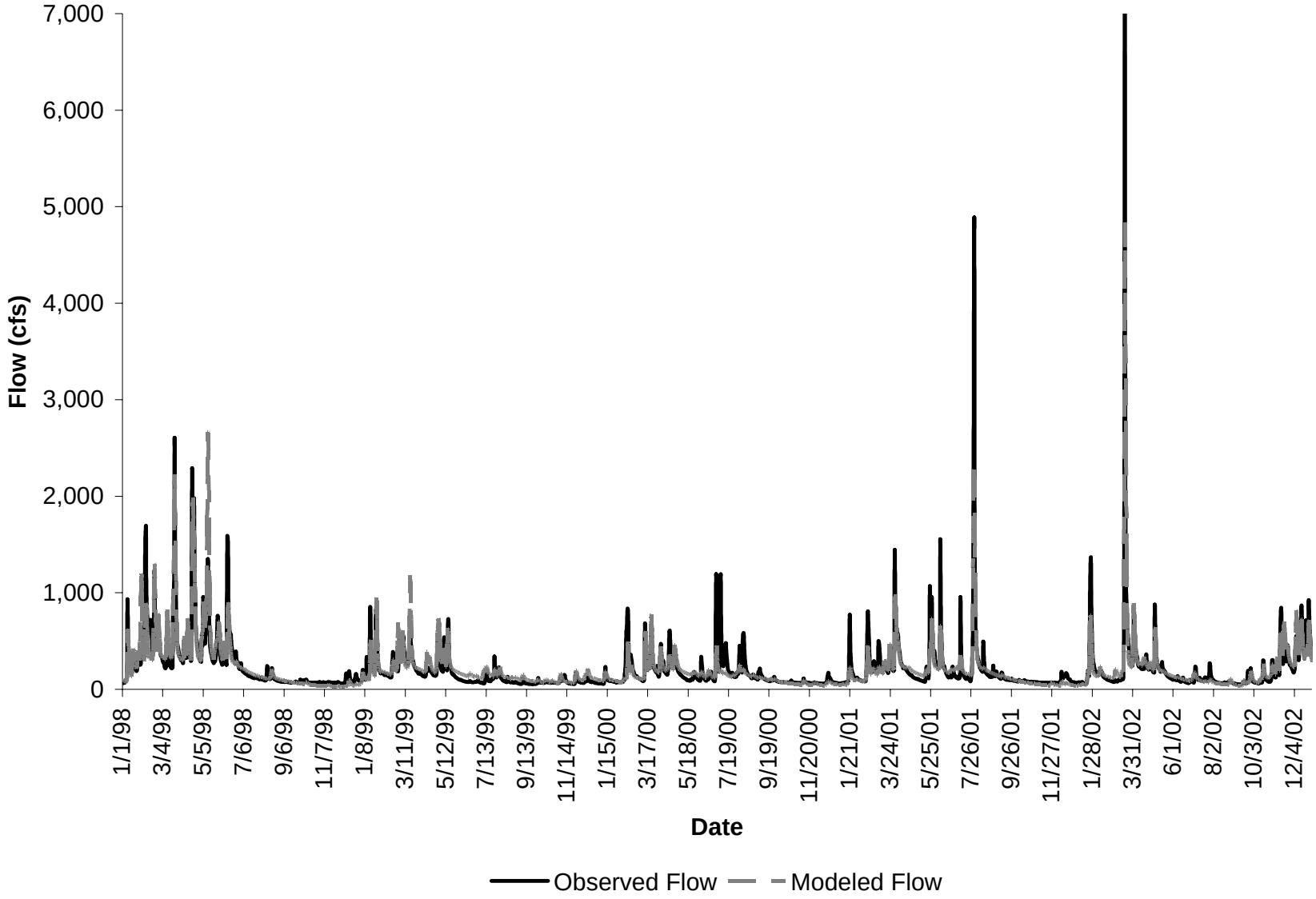


**Figure 5.6. Observed and modeled flows for the validation period 1/1/98 to 12/31/02 at USGS station #03475000 in Middle Fork Holston River watershed.**

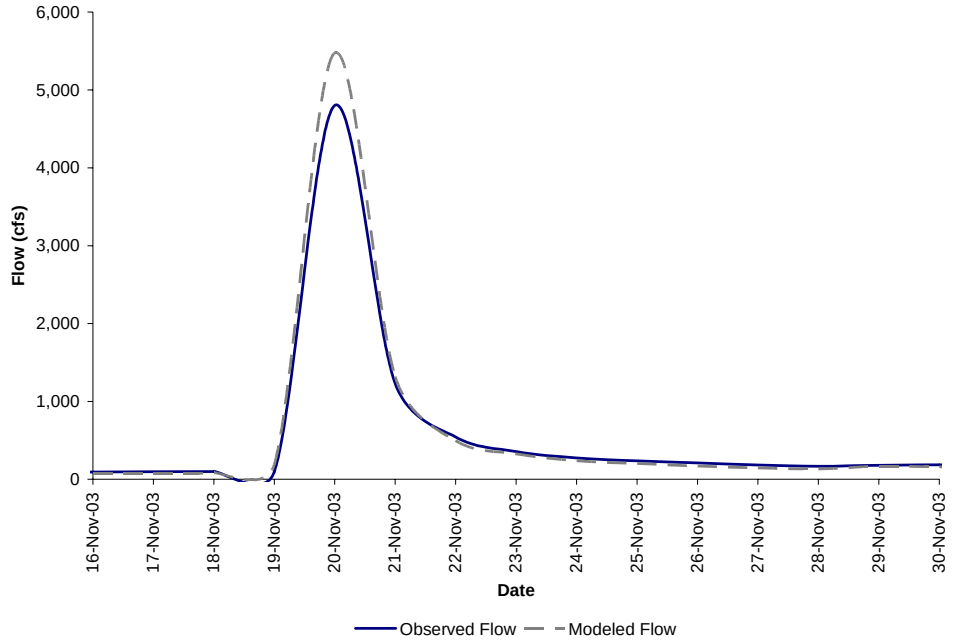


**Figure 5.7. Observed and modeled flows for representative storm (11/16/03-11/30/03) during calibration period at USGS station #03474000 in Middle Fork Holston River watershed.**

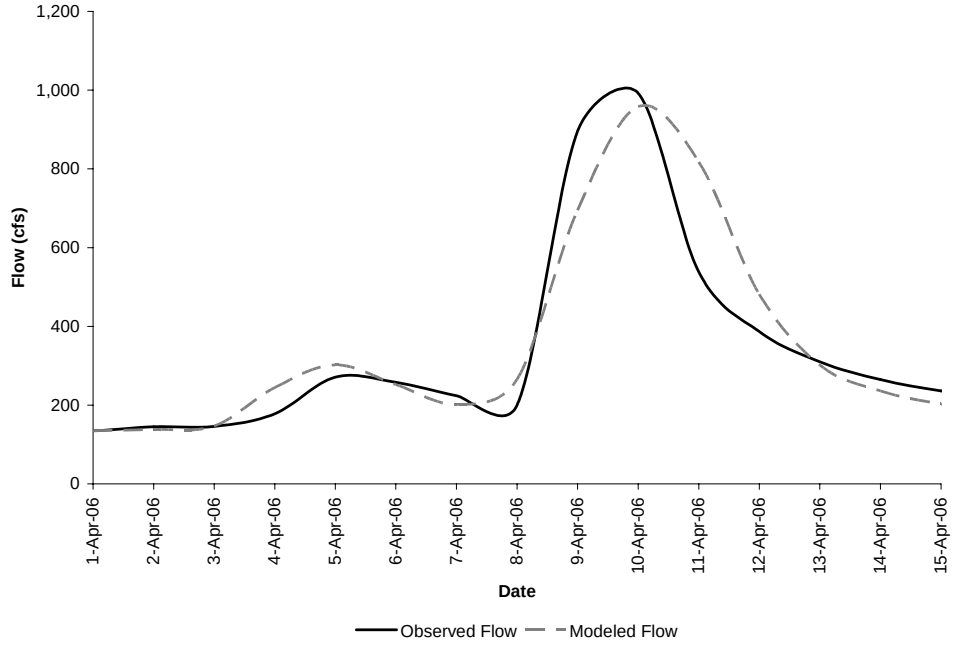


**Figure 5.8. Observed and modeled flows for representative storms (4/1/06-4/15/06) during calibration period at USGS station #03475000 in Middle Fork Holston River watershed.**

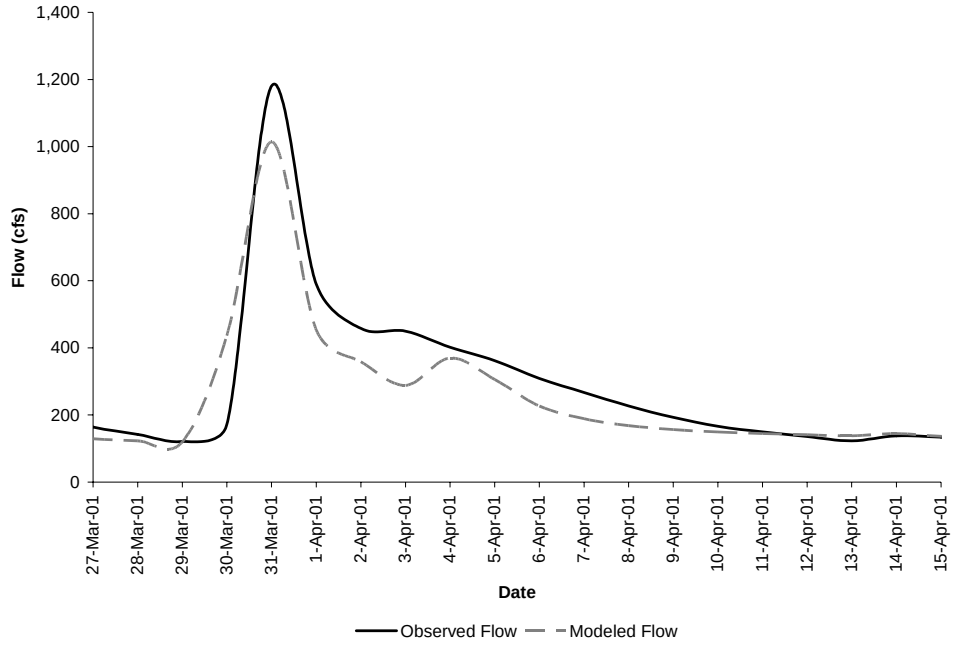


**Figure 5.9. Observed and modeled flows for a representative storm (3/27/01-4/15/01) during the validation period at USGS station #03474000 in Middle Fork Holston River watershed.**

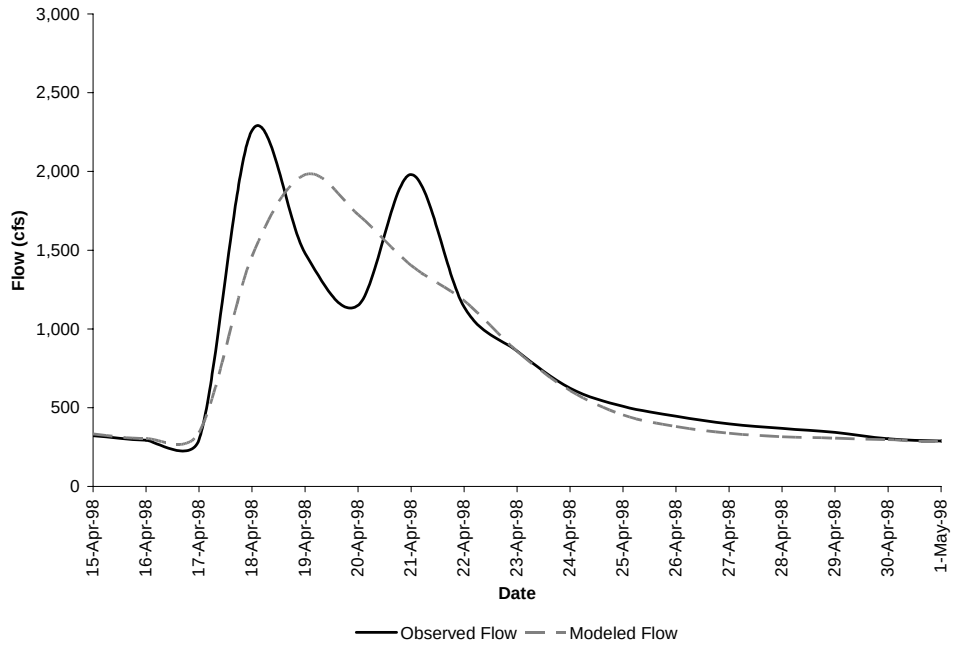


**Figure 5.10. Observed and modeled flows for a representative storm (4/15/98-5/1/98) during the validation period at USGS station #03475000 in Middle Fork Holston River watershed.**

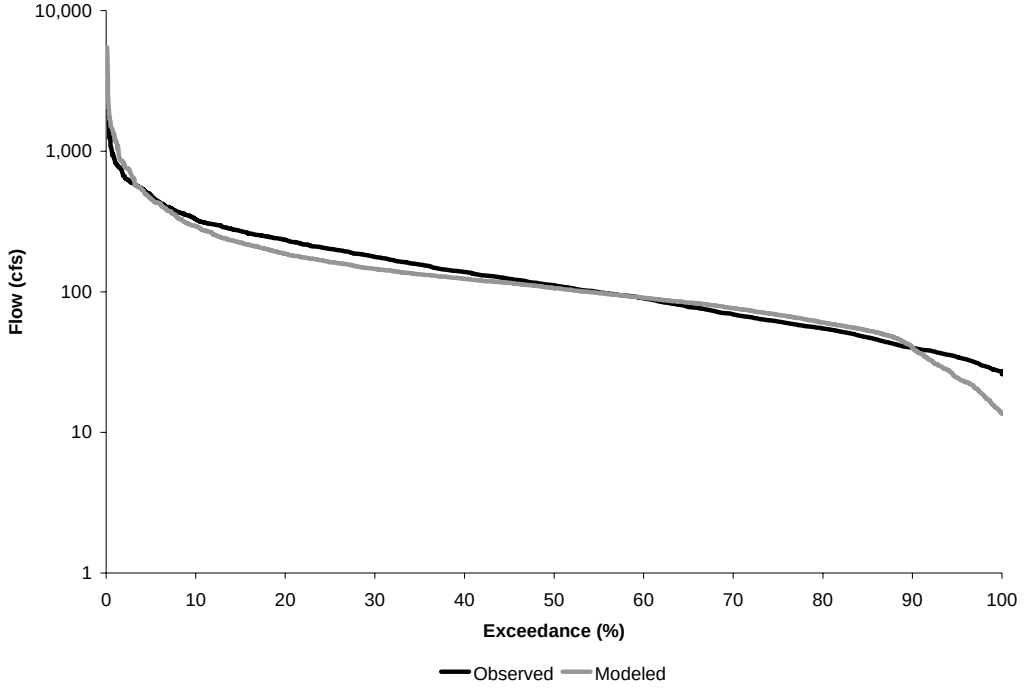


**Figure 5.11. Cumulative frequency curves for the calibration period 1/1/03 to 12/31/07 at USGS station #03474000 in Middle Fork Holston River watershed.**

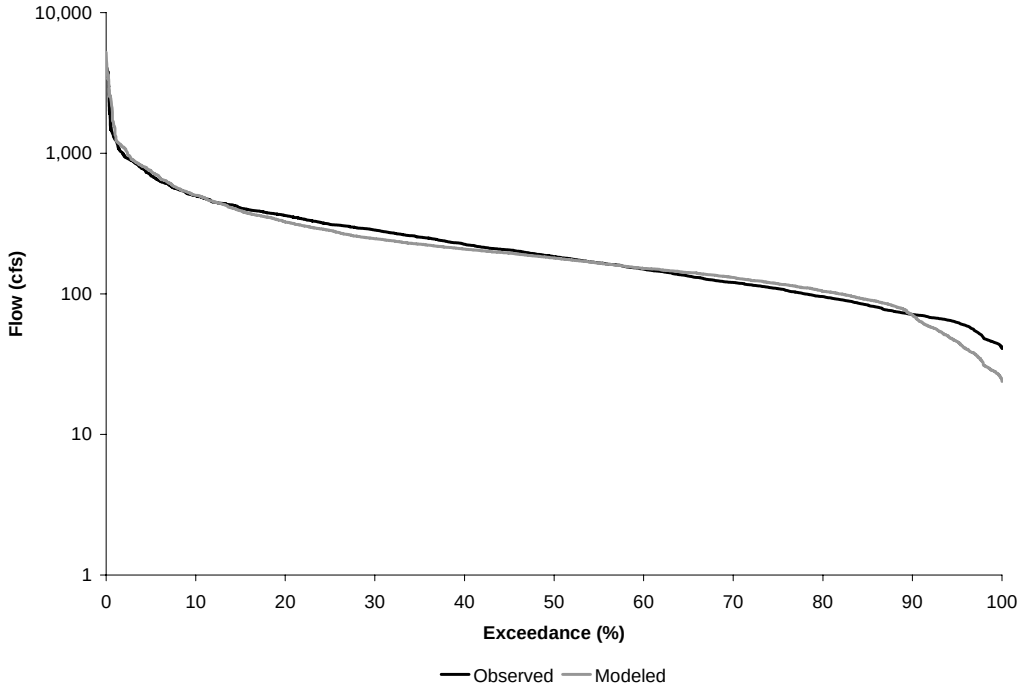


**Figure 5.12. Cumulative frequency curves for the calibration period 1/1/03 to 12/31/07 at USGS station #03475000 in Middle Fork Holston River watershed.**

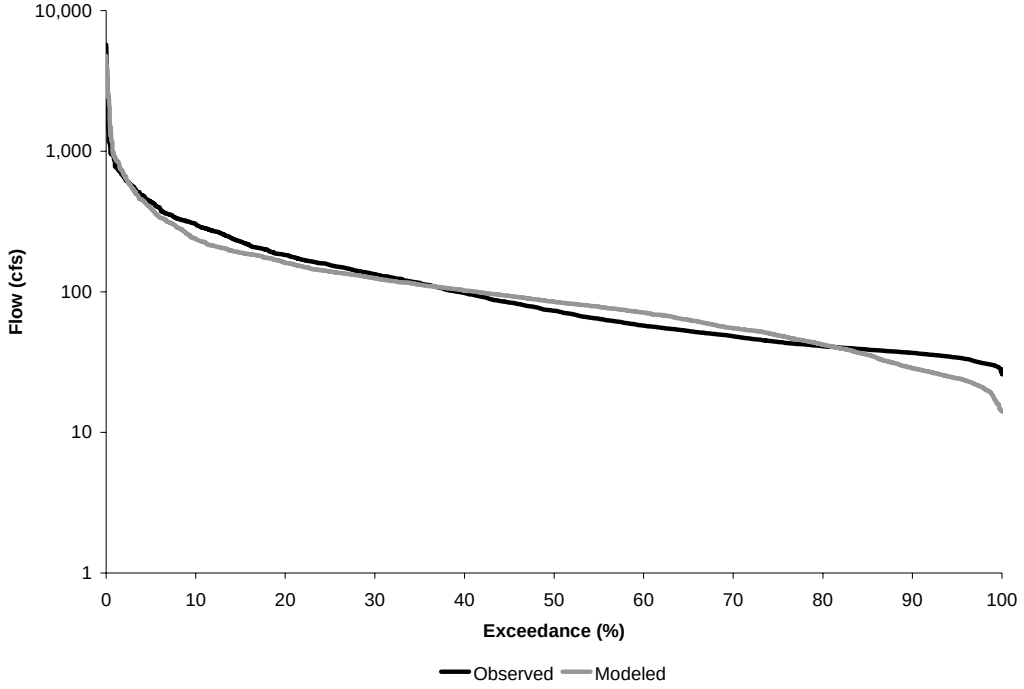


**Figure 5.13. Cumulative frequency curves for the validation period 1/1/98 to 12/31/02 at USGS station #03474000 in Middle Fork Holston River watershed.**

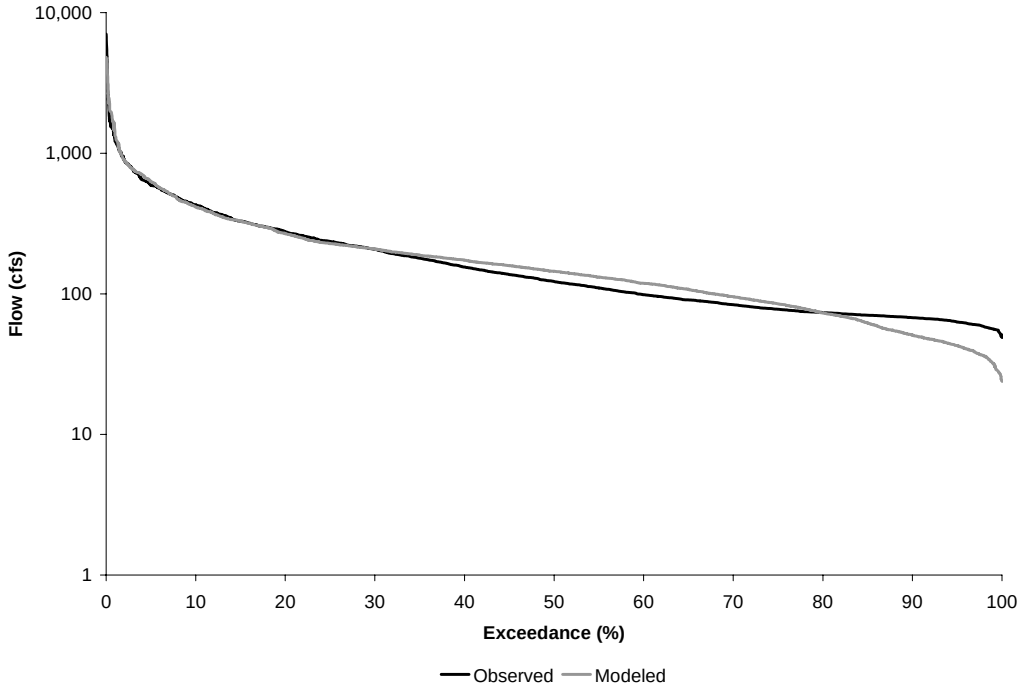


**Figure 5.14. Cumulative frequency curves for the validation period 1/1/98 to 12/31/02 at USGS station #03475000 in Middle Fork Holston River watershed.**

Flow partitioning for Middle Fork Holston River hydrologic model calibration and validation is shown in Table 5.8.

**Table 5.8. Flow partitioning for the calibration and validation periods in Middle Fork Holston River watershed.**

| Average Annual Flow | Calibration | Validation |
|---|---|---|
| Total Runoff (in) | 50.0 | 42.2 |
| Surface Runoff (in) | 11.6 (23.8%) | 9.0 (22.4%) |
| Interflow (in) | 9.6 (19.6%) | 6.7 (16.6%) |
| Baseflow (in) | 28.8 (59.0%) | 26.5 (66.0%) |

A list of final calibration parameters for the hydrology calibration can be found in Tables 5.9 and 5.10.

**Table 5.9. Calibrated hydrology HSPF parameters (PERLND) for Wolf 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 | 3.0 | 3.5 | Soil properties |
| INFILT | Index to infiltration capacity | in/hr | 0.01 | 0.25 | 0.001 | 0.5 | 0.10 | 0.003-0.320 | 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 | 0.020-0.097 | 0.020-0.097 | 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 | 0.981 | 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 | 1.0 | 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 - 0.890 | Vegetation |

* USEPA, 2000.

**Table 5.10. Calibrated hydrology HSPF parameters (IMPLND and RCHRES) for Wolf 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 | 0.023-0.283 | 0.023-0.283 | 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.

### *5.7.2 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, 1997 through December 31, 2001 was chosen for water quality calibration and January 1, 2002 through December 31, 2006 was chosen for water quality validation. Fecal coliform bacteria observations from the VADEQ ambient water quality monitoring stations 6-CWLF006.55, 6-CWLF001.18, 6-CWLF001.46 within the Wolf Creek impairment were used to calibrate the water quality component of HSPF. The final water quality calibration parameters are shown in Table 5.11. Observations from VADEQ stations 6-CWLF006.55, 6-CWLF001.18, 6-CWLF001.46; were graphically compared to corresponding modeled concentrations at subwatersheds MFH-02, MFH-09, MFH-14, MFH-20, MFH-21, MFH-22, MFH-29; respectively (Figures 5.15 through 5.18). It should be noted that each observed bacteria concentration datum represents a “snapshot” resulting from the examination of one grab sample, while the modeled data represent a continuous time series of bacteria concentration. Uncertainty exists in the stream condition the grab sample represents. For example, was the sample taken as the bacteria concentration was increasing or decreasing in the stream? The short-period fluctuations in the modeled bacteria concentration represent the variability within daily concentrations associated with the wildlife, livestock, and straight pipe direct deposition distribution across each day. Careful inspection of graphical comparisons between continuous simulation results and limited observed points yielded acceptable results given the modeling constraints listed above. Seasonal variations are exhibited by the modeled concentrations, and most observed concentrations are simulated accurately for the calibration period.

To provide a quantitative measure of the agreement between observed and modeled data, the geometric mean and exceedance rate of the 400 cfu/100mL fecal coliform instantaneous standard were calculated. Tables 5.12 and 5.13 show the observed and modeled comparisons of the geometric mean and exceedance rates for the calibration and validation periods, respectively. The difference between observed and modeled geometric mean concentrations ranged from 3.4% to -4.7% during the calibration period (Table 5.12). The highest difference (-4.7%) was recorded during at subwatershed WOC-14B. During the validation period, differences between observed and modeled geometric mean concentrations ranged from 1.7% to 8.4% (Table 5.13) at subwatersheds WOC-14A and WOC-14B, respectively. It should be noted that a limited number of observed values were available for comparison when determining exceedance rates in Tables 5.12 and 5.13. Modeled exceedance rates matched all observed exceedance rates during the calibration and validation periods. 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 Wolf Creek watershed.

**Table 5.11. Calibrated water quality HSPF parameters for Wolf 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 | 00E00-07E08 | 00E00-07E08 | Land use |
| SQOLIM | Maximum accumulations of constituent | #/ac | 0.01 | 1E30 | 0.01 | 1E40 | 00E00-46E08 | 00E00-46E08 | Land use |
| WSQOP | Wash-off rate | in/hr | 0.05 | 3.00 | 0.01 | 5.0 | 2.0 | 2.0 | Land use |
| IOQC | Constituent concentration in interflow | #/ft$^3$ | 0 | 1E6 | 0 | 1E10 | 1E03 | 1E03 | Land use |
| AOQC | Constituent concentration in active groundwater | #/ft$^3$ | 0 | 1E6 | 0 | 1E10 | 0E00 | 0E00 | Land use |
| **IMPLND** | | | | | | | | | |
| **QUAL-INPUT** | | | | | | | | | |
| SQO | Initial storage of constituent | #/ac | 0 | 1E20 | 0 | 1E30 | 1E09 | 1E09 | Land use |
| ACQOP | Rate of accumulation of constituent | #/day | 0 | 1E20 | 0 | 1E30 | 00E00-05E08 | 00E00-05E08 | Land use |
| SQOLIM | Maximum accumulations of constituent | #/ac | 0.01 | 1E30 | 0.01 | 1E40 | 00E00-43E08 | 00E00-43E08 | 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 | 1.5 | 2.5-5.0 | Stream channel, environment |
| THFST | Temperature correction coefficient for FSTDEC | none | 1 | 2 | 1 | 2 | 1.07 | 1.07 | Water temperature |

* USEPA, 2000.

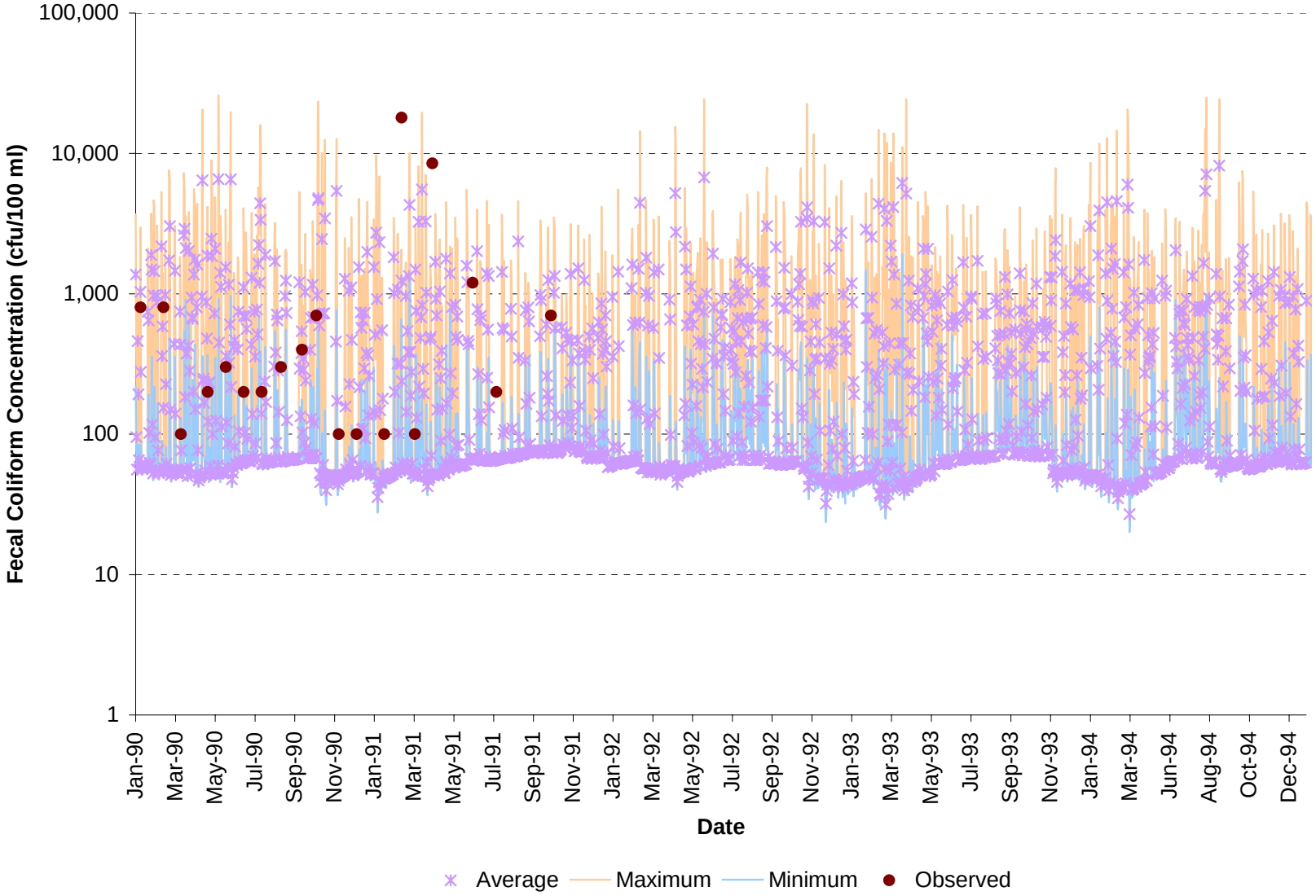


**Figure 5.15. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed WOC-05 in Wolf Creek watershed.**

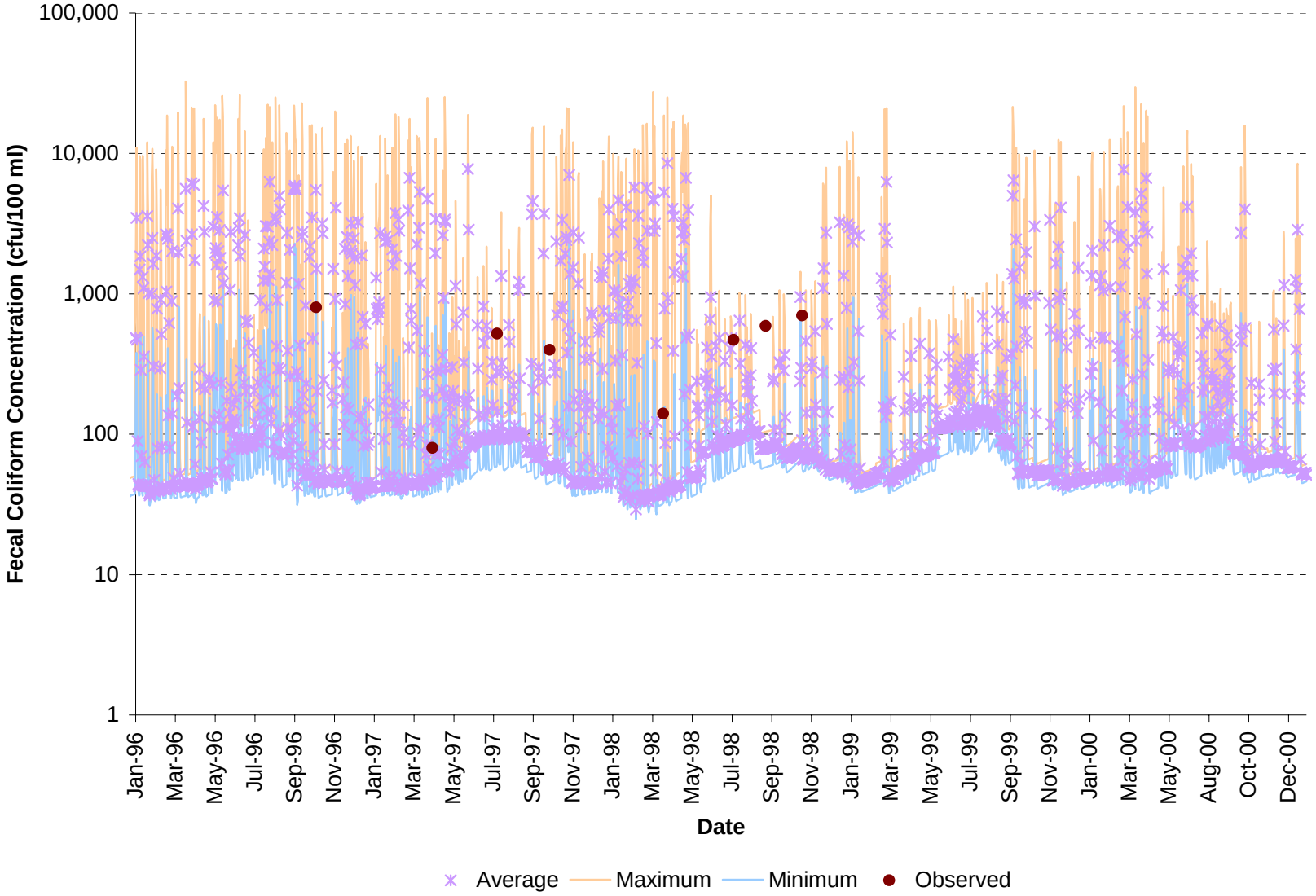


**Figure 5.16. Water quality validation results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed WOC-14a in Wolf Creek watershed.**

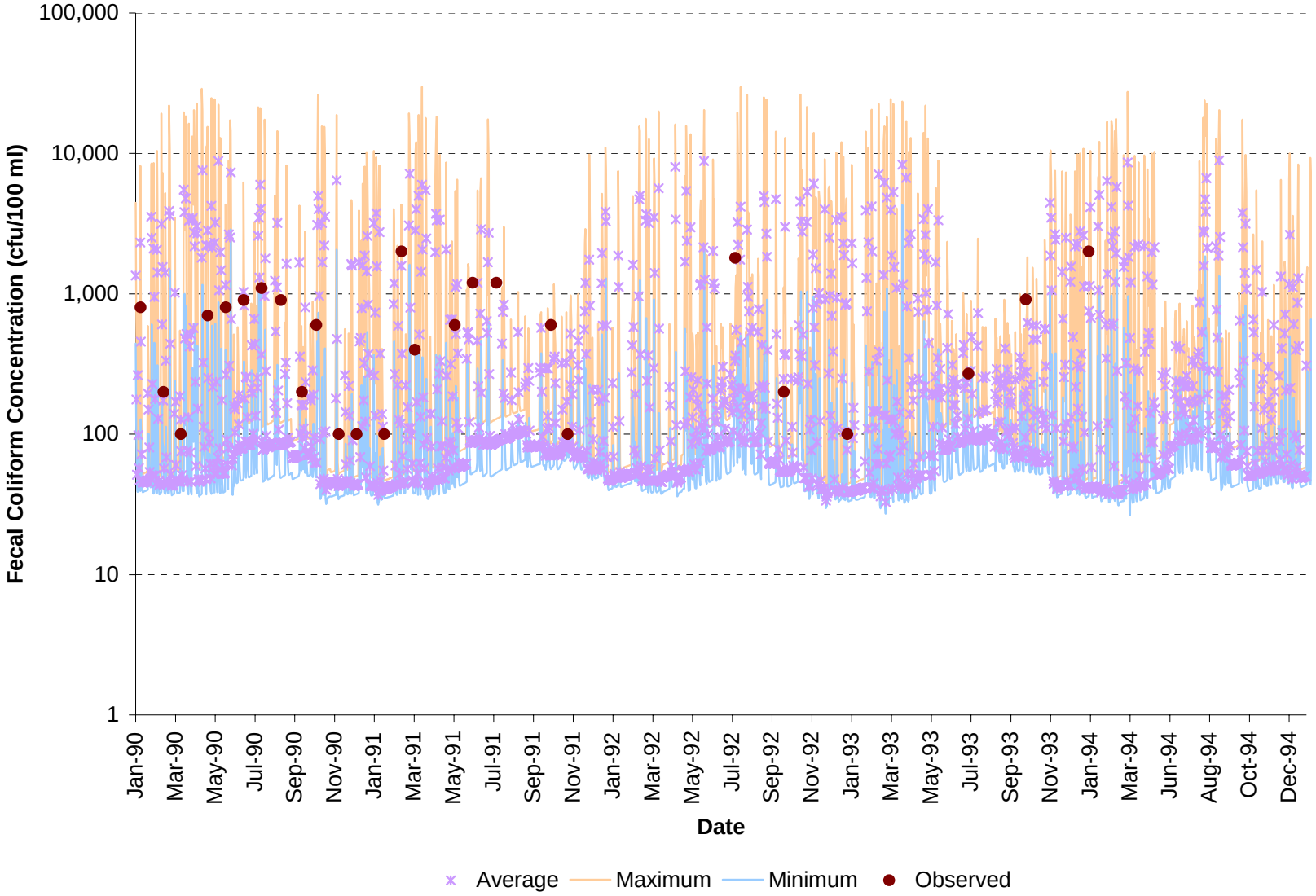


**Figure 5.17. Water quality calibration results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed WOC-14b in Wolf Creek watershed.**

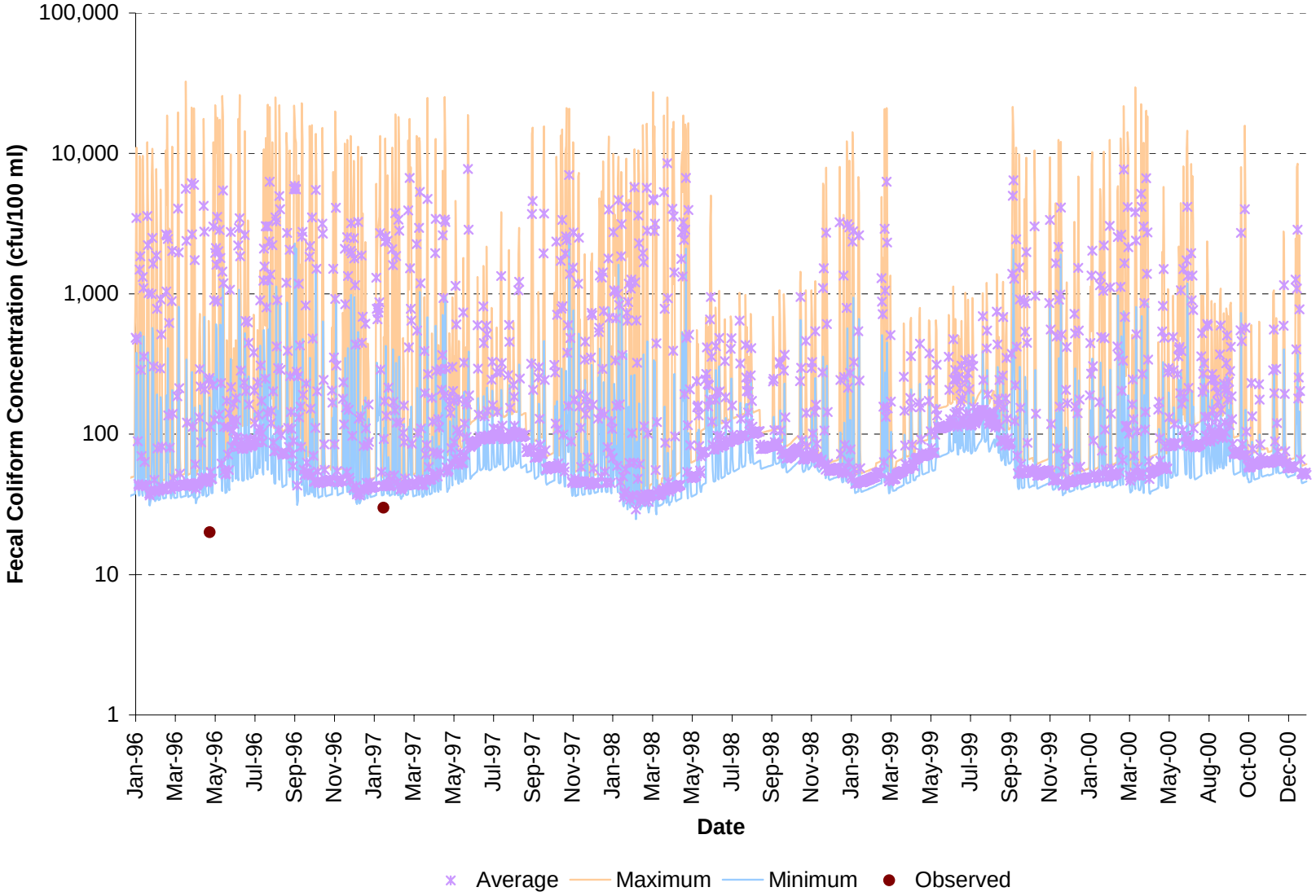


**Figure 5.18. Water quality validation results with observed and modeled average, maximum, and minimum daily fecal coliform concentrations for subwatershed WOC-14b in Wolf Creek watershed.**

**Table 5.12. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the calibration period in Wolf Creek watershed.**

| Parameter | Sub WOC-05 | Sub WOC-14A | Sub WOC-14B |
|---|---|---|---|
| Geometric Mean of Observed Values (cfu/100mL) | 404 | N/A | 445 |
| Geometric Mean of Corresponding Modeled Values (cfu/100mL) | 386 | N/A | 460 |
| Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%) | 36.8 | N/A | 57.7 |
| Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%) | 36.8 | N/A | 57.7 |

**Table 5.13. Observed and modeled geometric mean concentrations and exceedance rates of instantaneous standards for the validation period in Wolf Creek watershed.**

| Parameter | Sub WOC-05 | Sub WOC-14A | Sub WOC-14B |
|---|---|---|---|
| Geometric Mean of Observed Values (cfu/100mL) | N/A | 366 | 115 |
| Geometric Mean of Corresponding Modeled Values (cfu/100mL) | N/A | 372 | 125 |
| Observed Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%) | N/A | 50.0 | 25.0 |
| Modeled Fecal Coliform Instantaneous Standard, 400 cfu/100mL, Exceedance Rate (%) | N/A | 50.0 | 25.0 |

# Chapter 6. Modeling Process for Development of Sediment TMDL

For Wolf Creek, the stressor analysis identified sediment as a most probable stressor impacting the benthic macroinvertebrate community (see Section 4.4). Virginia currently does not have numeric criteria for sediment. A reference watershed approach was used to establish the numeric sediment TMDL endpoint for Wolf Creek. The Penn State Visual Basic™ version of Generalized Watershed Loading Function (GWLF) with modifications for use with ArcView watershed model (Evans et al., 2001) was used to simulate sediment loads from potential sources in both the impaired and reference watersheds. The model also included modifications made by Yagow et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The TMDLs were then developed for the impaired watersheds based on these endpoints and the results from load allocation scenarios.

## 6.1 Reference Watershed

Virginia has no numeric in-stream criteria for sediment. As a result, a “reference watershed” approach was used to set allowable loads for sediment in the impaired watershed. The reference watershed approach pairs two watersheds – one whose streams are supportive of their designated uses and one whose streams are impaired. This reference watershed may be, but does not have to be, the watershed corresponding to the reference monitoring site used for determining comparative biological metric scores. The reference watershed is selected on the basis of similarity of land use, topographical, ecological, and soils characteristics with those of the impaired watershed. This approach is based on the assumption that reduction of the stressor loads in the impaired watershed to the level of the loads in the reference watershed will result in elimination of the benthic impairment. The reference watershed approach involves assessment of the impaired reach and its watershed, identification of potential causes of impairment through a benthic stressor analysis, selection of an appropriate reference watershed, model parameterization and pollutant simulation within the TMDL watershed, definition of the TMDL endpoint, and development of alternative TMDL reduction (allocation) scenarios. Where a simulated load is used as the TMDL endpoint, pollutant loads are also simulated from the reference watershed. TMDL endpoints may be developed using either modeled loads or a statistical measure of monitored pollutant concentrations from the reference watershed.

Results from biological monitoring at VADEQ stations have shown a healthy benthic community resulting in an un-impaired designation in the Cripple Creek watershed. Due to similarity of land use, topographical, ecological, and soils characteristics, the Cripple Creek watershed was chosen as the reference watershed for sediment load comparison (Figure 6.1 through 6.9). The Cripple Creek headwater section was used as comparison to Wolf Creek. For overall watershed context, the entire Cripple Creek watershed is depicted in the following figures.

**Figure 6.1. Location of Wolf Creek watershed in relation to Cripple Creek watershed.**

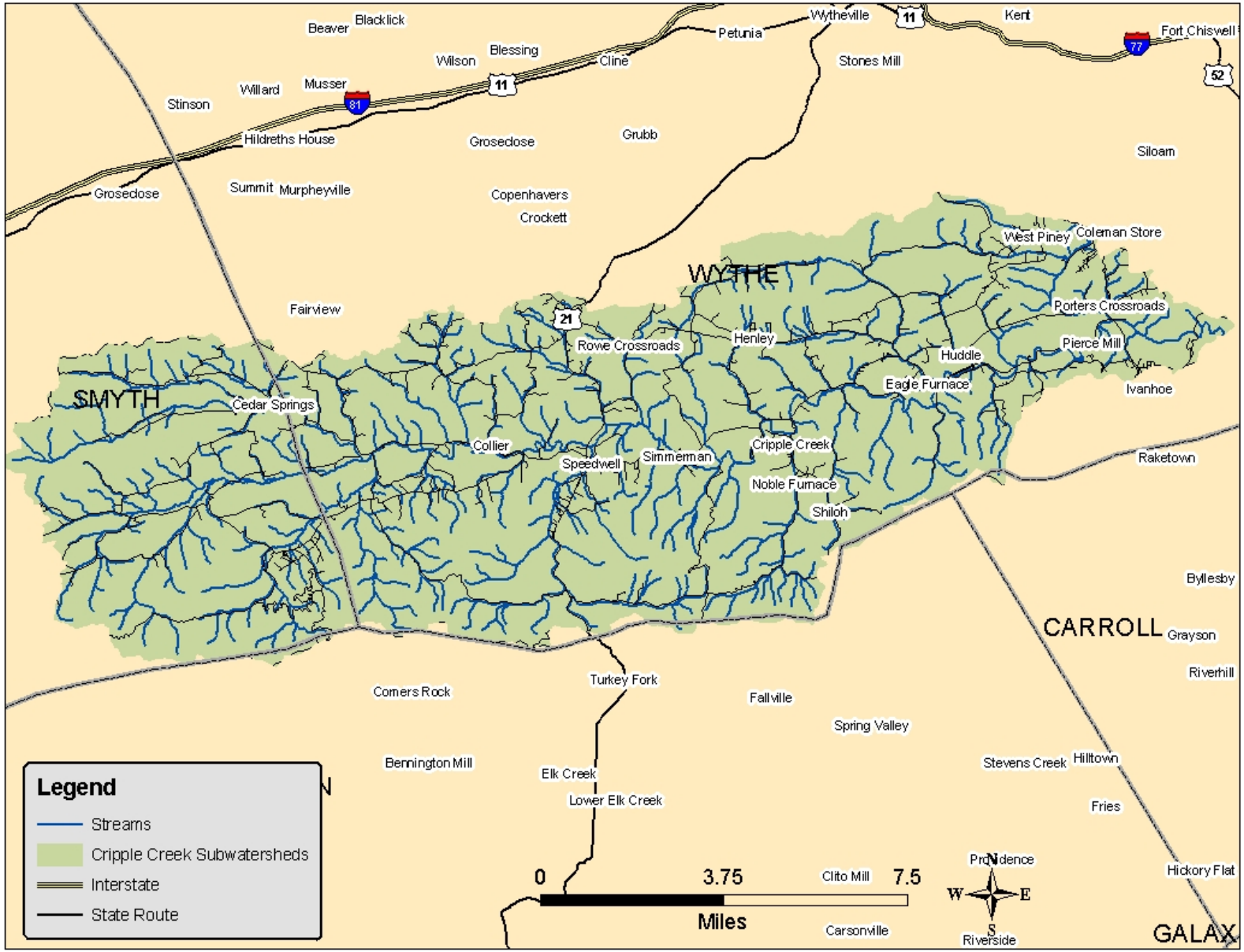


**Figure 6.2. Location of Cripple Creek watershed.**

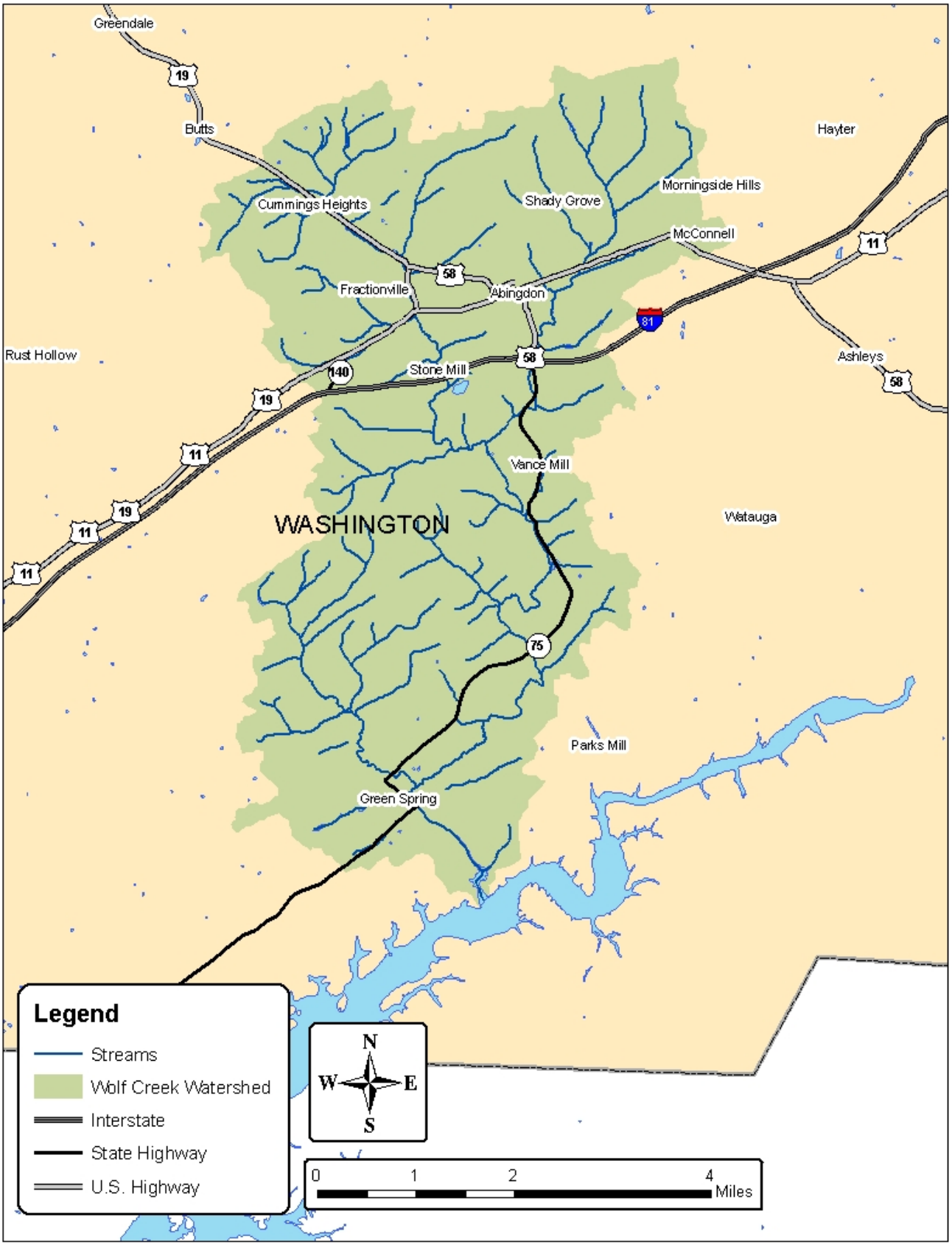


**Figure 6.3. Location of Wolf Creek watershed.**

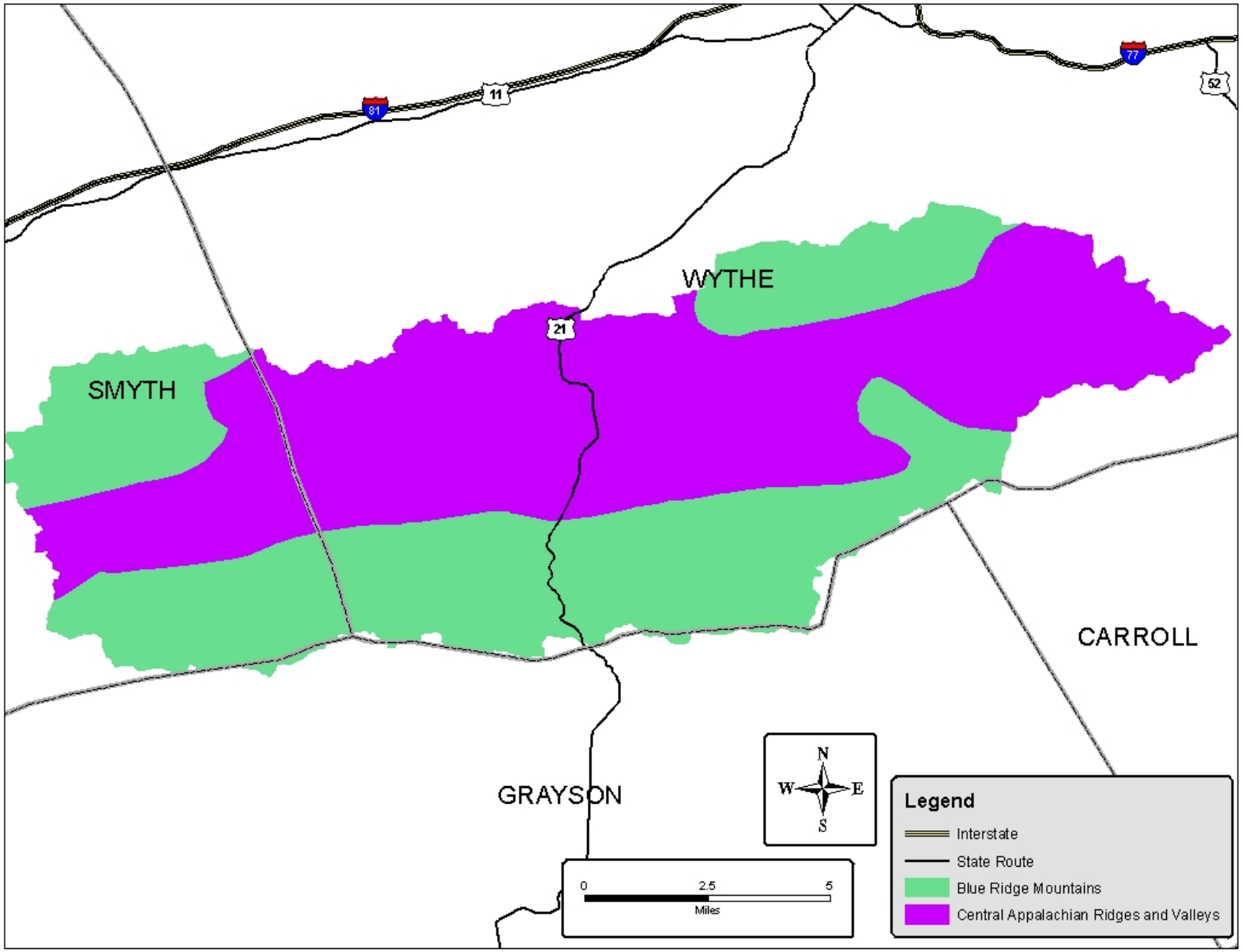


**Figure 6.4. Ecoregions in Cripple Creek watershed.**

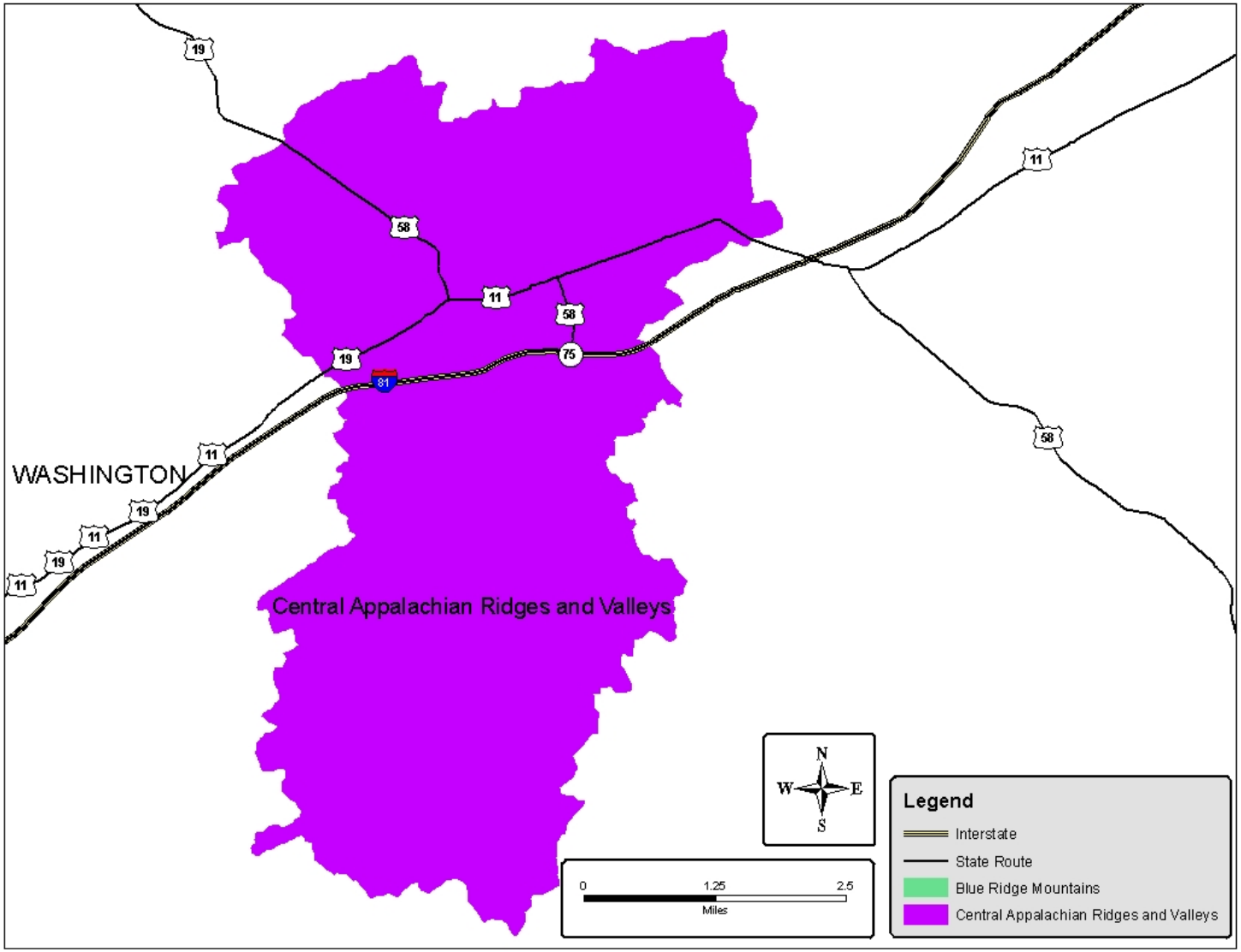


**Figure 6.5. Ecoregion in Wolf Creek watershed.**

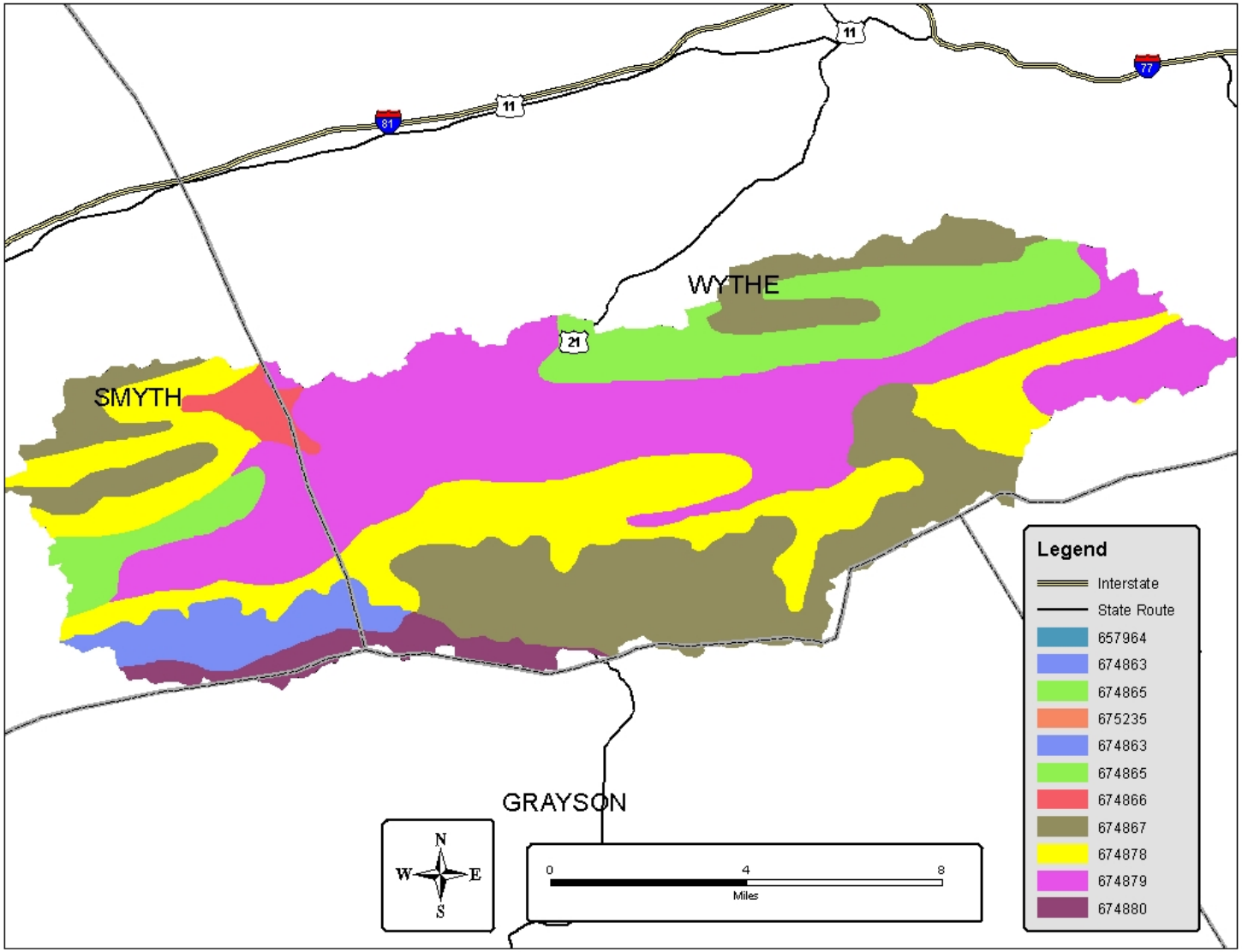


**Figure 6.6. Soils in the Cripple Creek watershed.**

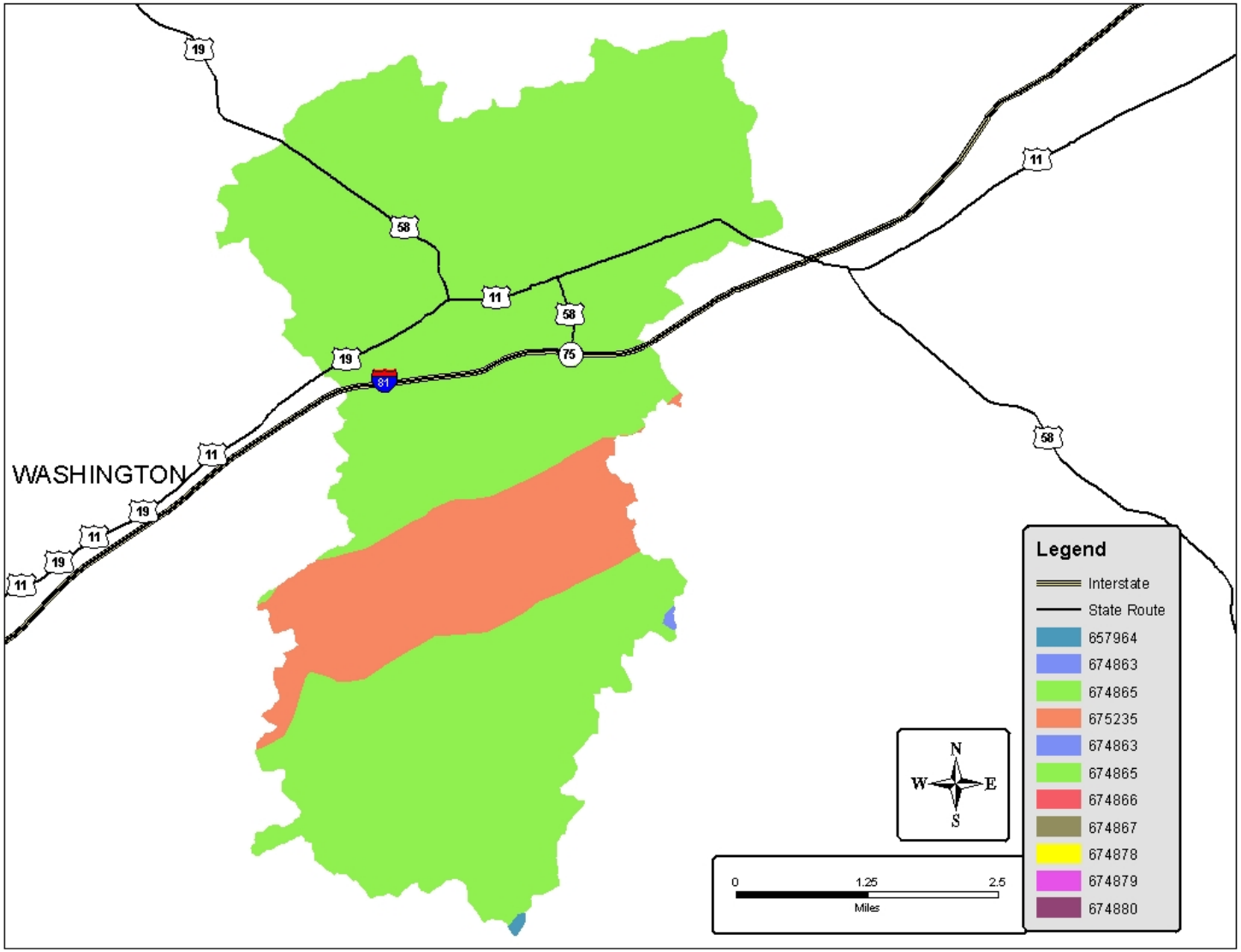


**Figure 6.7. Soils in the Wolf Creek watershed.**

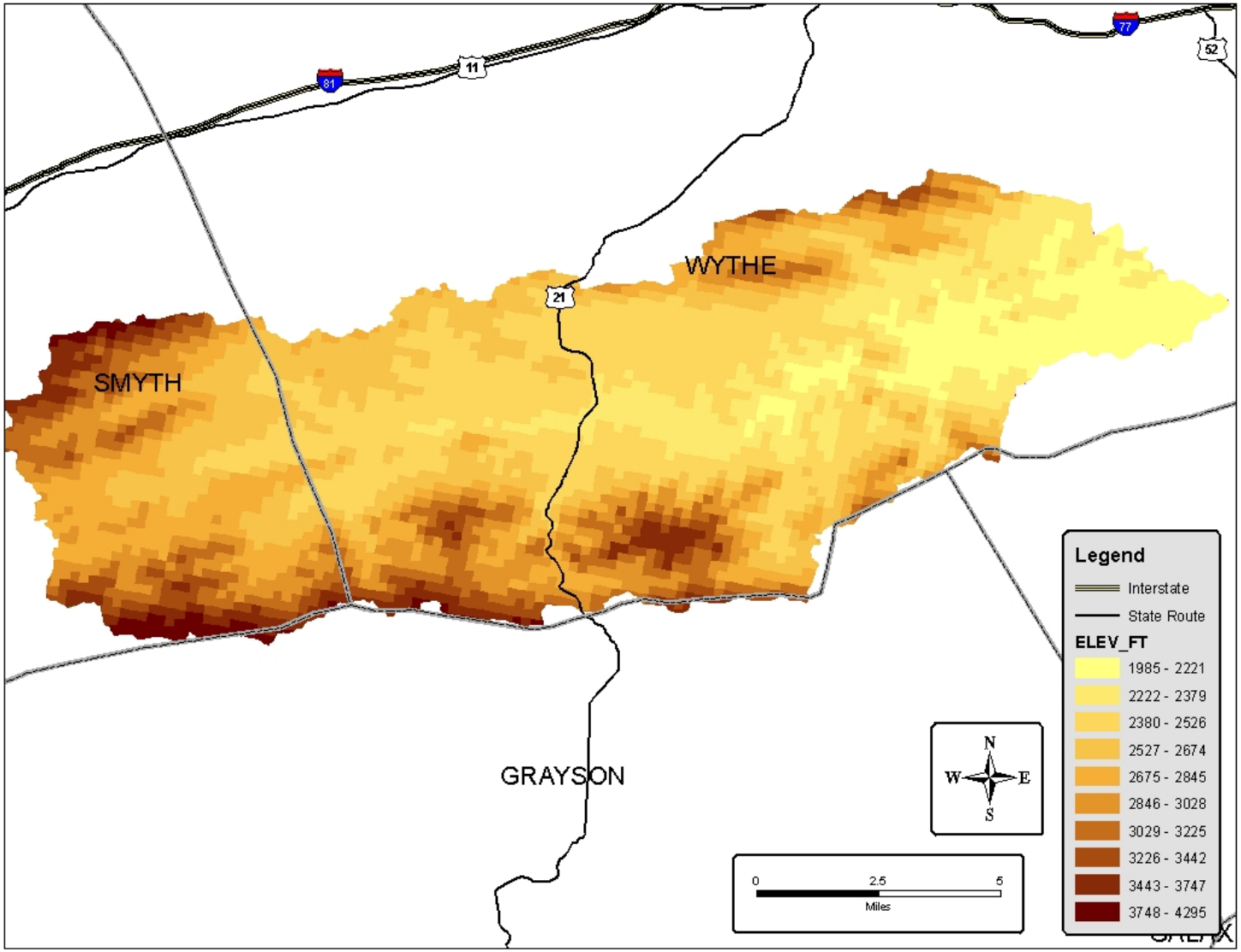


**Figure 6.8. Land elevations in the Cripple Creek watershed.**

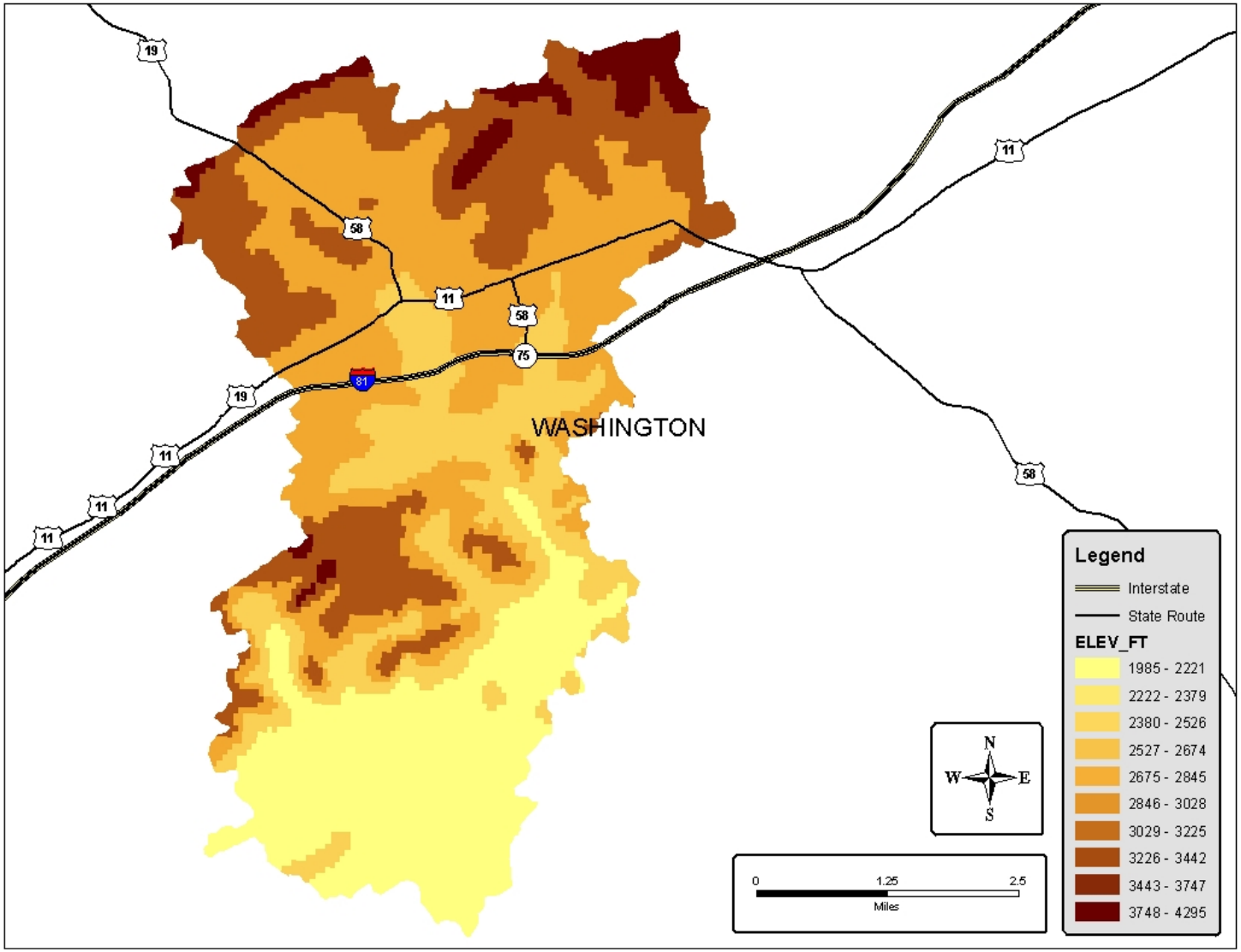


**Figure 6.9. Land elevations in the Wolf Creek watershed.**

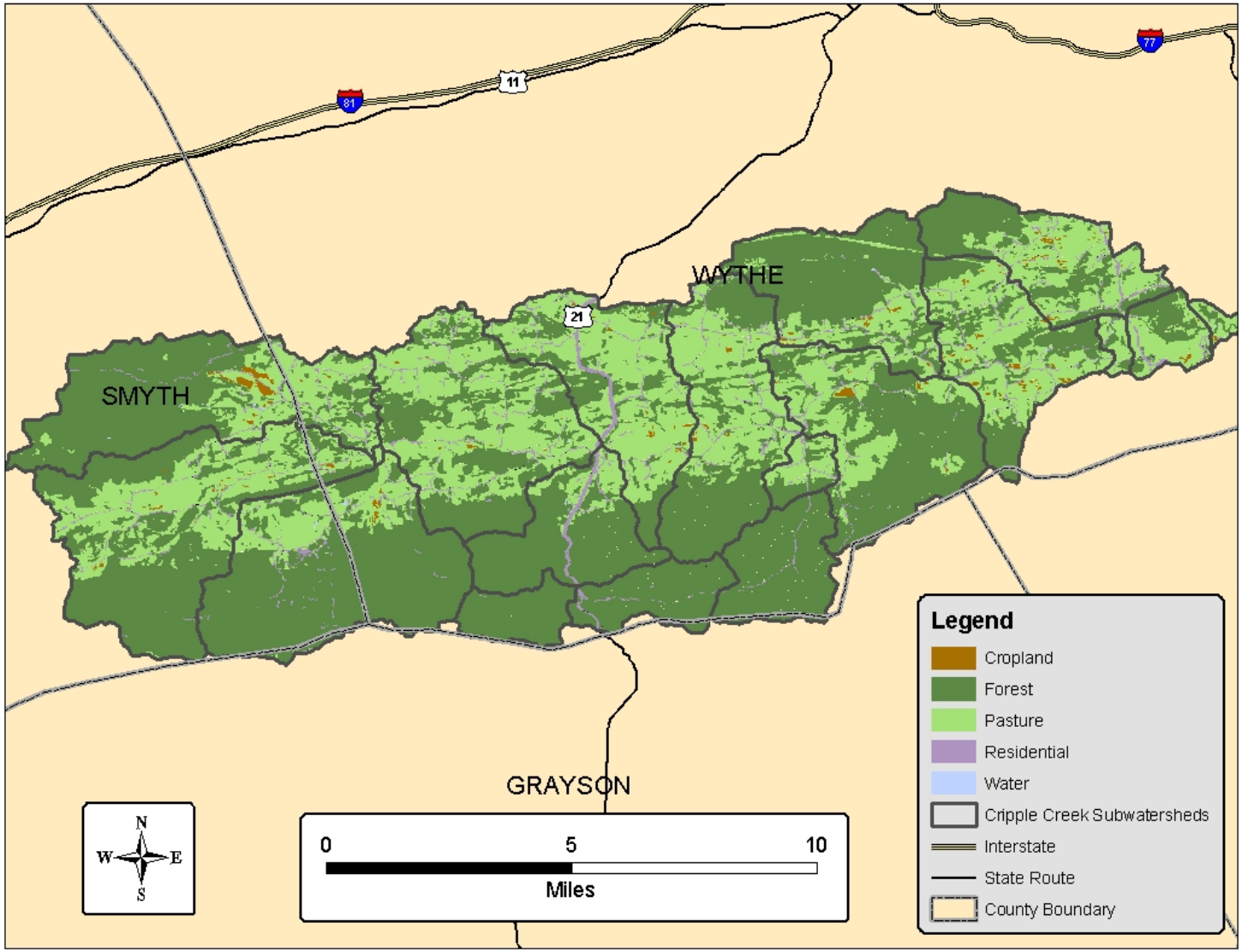


**Figure 6.10. Landuse in the Cripple Creek watershed.**

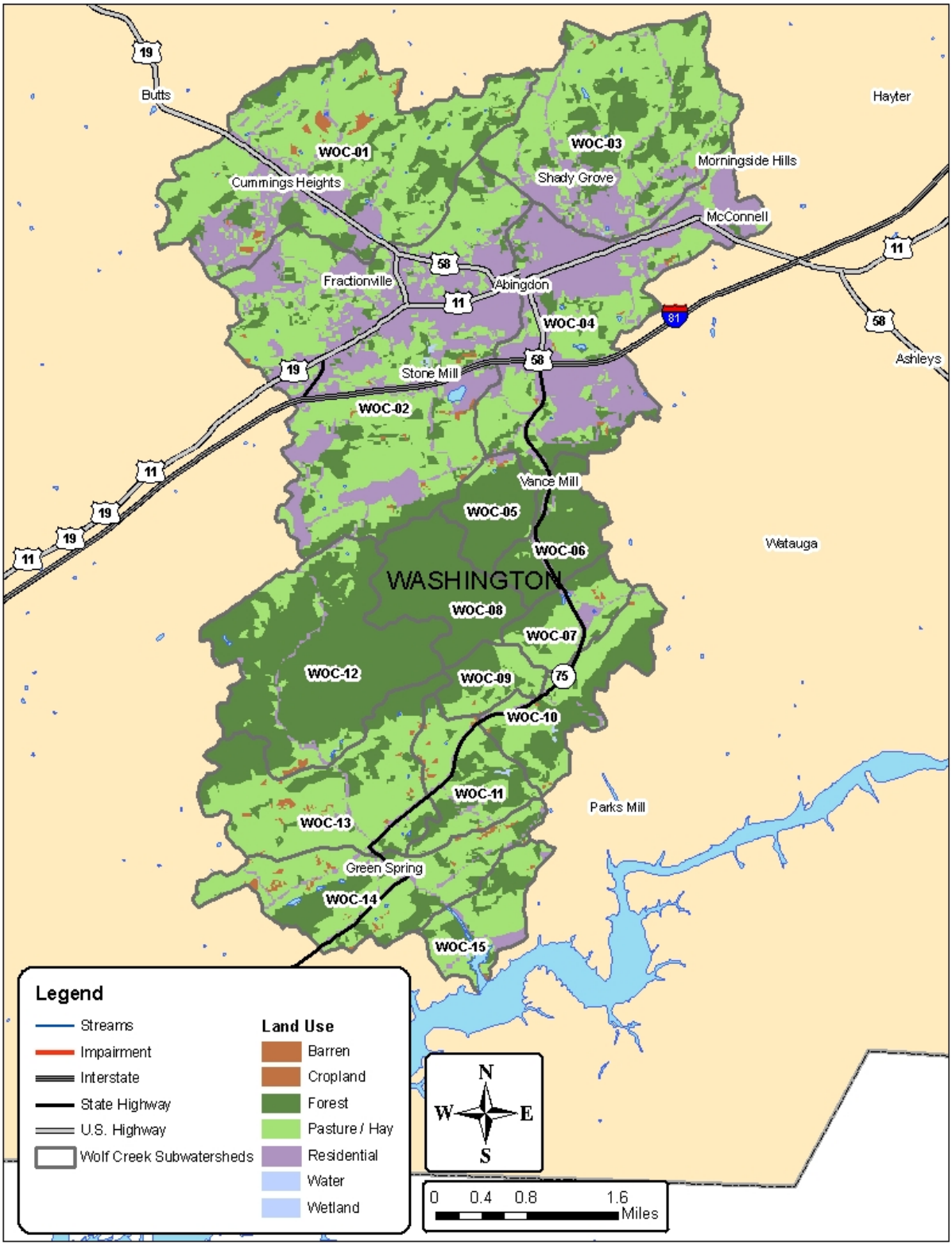


**Figure 6.11. Landuse in the Wolf Creek watershed.**

## 6.2 Sediment Source Representation

Excessive sedimentation can adversely affect benthic invertebrate communities through a loss of habitat and degradation of water quality. Sediment can be delivered to the stream from point sources or by nonpoint source runoff from sparsely vegetated land areas. In addition, the processes of scour and deposition (primarily a function of stream flow) can generate sediment in the stream. During periods of high flow, increased erosion of the stream channel occurs. The eroded materials are deposited downstream as stream flow decreases.

### *6.2.1 Permitted Point Sources*

Sediment loadings from permitted sources are attributable to the total suspended solids (TSS) present in discharge effluent or stormwater runoff. There are three VPDES permitted facilities currently active or under application within the Wolf Creek watershed discharging TSS (Table 6.1). Stormwater permits are divided between two industrial, one concrete plant, and one mining facilities (Table 6.2).

**Table 6.1. VPDES permitted facilities discharging sediment in the Wolf Creek watershed.**

| Facility Name | Permit Number | VPDES Permit Category | Permit Type | TSS Design Flow (MGD) | TSS Avg. (mg/L) |
|---|---|---|---|---|---|
| Wolf Creek Water Reclamation Facility | VA0026531 | Individual | Municipal | 7.000 | 30 |
| Bristol Virginia Utilities Board - WTP | VA0028321 | Individual | Industrial | 0.114 | 30 |
| Virginia Highlands Christian Fellowship Church STP | VAG400245 | General | SFDS | 0.001 | 30 |

**Table 6.2. Industrial, concrete plant, and mining stormwater permitted facilities contributing sediment in the Wolf Creek watershed.**

| Facility | Permit Number | Type | Yearly Runoff (cm/acre) | Total Suspended Solids (mg/L) |
|---|---|---|---|---|
| Highlands Petroleum Oil Corporation | VAR050110 | Industrial | 82.42 | 100 |
| American Commercial Incorporated - Abingdon | VAR050029 | Industrial | 82.42 | 100 |
| Lakeside Ready Mix Inc | VAG110116 | Concrete Plant | 82.42 | 100 |
| Aggregates USA LLC-Abingdon Quarry | VAG840009 | Mining | 82.42 | 100 |

### *6.2.2 Nonpoint Sources*

Sediment generation is accelerated through human-induced land-disturbing activities related to a variety of agricultural, forestry, mining, transportation, and residential land uses. During runoff events, sediment loading occurs from both pervious and impervious surfaces around the watershed. For pervious areas, soil is detached by rainfall impact or shear stresses created by overland flow and transported by overland flow to nearby streams. This process is influenced by vegetative cover, soil erodibility, slope, slope length, rainfall intensity and duration,

and land management practices. During periods without rainfall, dirt, dust and fine sediment build up on impervious areas through dry deposition, which is then subject to wash-off during rainfall events. Sediment generated from impervious areas can be reduced through the use of management practices that reduce the surface load subject to wash-off. The land use types in the Wolf Creek watershed were characterized from NLCD 2001. The Wolf Creek watershed is predominately pasture, constituting approximately 44% of the total watershed area. The remaining land uses are divided between forest (34%), residential (21%), and cropland (1%). Land use distribution for Wolf Creek watersheds was previously shown in Chapter 5.

Sediment loads from forest land uses are generally lower. In addition to forest canopies intercepting and dampening the impact of rainfall, extensive root systems and vegetative cover assist in stabilizing the soil. Sediment loads from agricultural lands (i.e., pasture and cropland) tend to be elevated due to the exposure of soil. Sediment loads from developed land uses tend to be high. Soil erosion occurs on the pervious land segments and solids build-up and wash-off occurs on the impervious land segments. Transitional land use (e.g., forest clear-cuts or construction sites) typically have sparse vegetative cover, exposing the soil, and resulting in high sediment loads.

### *6.2.3 Channel and Streambank Erosion*

Sediment loading derived from in-stream bank erosion is dependent upon numerous watershed characteristics. These include soils, physiographic information, and land use. Land use types found in the watershed may affect hydrology. In particular, livestock with stream access can significantly alter the physical dimensions of streams through trampling and shearing, whereby; the bank full width increases, decreasing stream depth, increasing sediment, and adversely affecting aquatic habitat. An increase in impervious land without appropriate stormwater control, increases runoff volume and peaks and leads to greater channel erosion potential. Also, watersheds defined by steep topography may experience high levels of runoff that cause in-stream erosion. Conditions noted above have been observed in the Wolf Creek watershed, therefore; overall amount of sediment generated by in-stream erosion would be expected to be high.

### *6.2.4 Travertine Deposition*

Additional natural occurring sediment is deposited in the summer and early fall in the form of travertine. The out-gassing of $CO_2$ when cool ground water containing a high concentration of dissolved carbonates mixes with warmer water in the stream results in deposition of travertine. The travertine covers rocks, cobbles, and exposed bedrock with a carbonate encrustation and has formed numerous dams, ledges, and pools in Wolf Creek. Depending on the scouring action of stream flow, this naturally occurring sedimentation can change the stream morphology.

## 6.3 Model Development

The model selected for development of the sediment TMDLs was the Virginia Tech modified version (Yagow and Hession, 2007) of Generalized Watershed Loading Functions

(GWLF) model, originally developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in un-gaged watersheds. GWLF is a continuous simulation spatially-lumped parameter model that operates on a daily time step. The model estimates runoff, sediment, and dissolved and attached nitrogen and phosphorus loads delivered to streams from complex watersheds with a combination of point and nonpoint sources of pollution. The model considers flow inputs from both surface runoff and groundwater.

The hydrology in the model is simulated with a daily water balance procedure that takes into consideration types of storages within the system. Runoff is generated based on the Soil Conservation Service's Curve Number method as presented in Technical Release 55 (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1983; Wischmeier and Smith, 1978). Sediment estimates uses a delivery ratio as a function of watershed area coupled with erosion estimates. The sediment transported depends on the transport capacity of runoff.

GWLF uses three input files for weather, transport, and nutrient data. The weather file contains daily temperature and precipitation for the period of simulation. The transport file contains input data primarily related to hydrology and sediment transport, while the nutrient file contains primarily nutrient values for the various land uses, point sources, and septic system types.

### *6.3.1 Climate Data*

The climate in Wolf Creek watershed was characterized by meteorological observations from the National Weather Service Cooperative Troutdale S SSE (448547), Abingdon 3 S (440021), and Saltville 1 N (447506) weather stations located in Washington and Smyth Counties, Virginia. The period of record used for modeling was from January 1987 through December 2003.

### *6.3.2 Land use*

Landuse for the Wolf Creek watershed was derived from the NLCD 2001 landuse – land cover digital data, as discussed in Chapter 5. The NLCD land use types within the watershed were consolidated into 12 categories based on similarities in hydrologic and pollutant production features. The pasture/hay category was subdivided into three categories based on percentages assessed during the 2002 Statewide NPS Pollution Assessment study (Yagow et al., 2002). Cropland was divided into high-tillage cropland and low-tillage cropland based on input from the Technical Advisory Committee and field observations. Land use distribution in the Wolf Creek watershed is presented in Chapter 5.

### *6.3.3 Model Input Parameters*

In addition to weather data, GWLF requires specification of input parameters relating to hydrology, erosion, and sediment yield. All parameters were evaluated in a consistent manner between the reference and impaired watersheds, in order to ensure their comparability for the reference watershed approach. All GWLF parameter values were evaluated from a combination of GWLF user manual guidance (Haith et al., 1992), AVGWLF procedures (Evans et al., 2001),

procedures developed during the 2002 State-wide NPS pollution assessment (Yagow et al., 2002), and best professional judgment. Generally, Appendix B of the GWLF manual (Haith et al., 1992) served as the primary source of guidance in developing input parameters. Hydrologic and sediment parameters are all included in GWLF's transport input file, with the exception of urban sediment buildup rates, which are in the nutrient input file with other nutrient parameters. Descriptions of each of the hydrologic, sediment, and nutrient parameters are listed below according to whether the parameters were related to the overall watershed, to the month of the year, or to individual land uses (adapted from Bull Creek TMDL report).

**Hydrology Parameters**

Watershed-Related Parameter Descriptions

- *Unsaturated Soil Moisture Capacity (SMC)*: The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute - available water capacity.
- *Recession coefficient (day-1)*: The recession coefficient is a measure of the rate at which stream flow recedes following the cessation of a storm, and is approximated by averaging the ratios of stream flow on any given day to that on the following day during a wide range of weather conditions, all during the recession limb of each storm's hydrograph. This parameter was evaluated using the following relationship from Lee et al. (2000): RecCoeff = 0.045+1.13/(0.306+Area in square kilometers).
- *Seepage coefficient (day-1)*: The seepage coefficient represents the amount of flow lost as seepage to deep storage (initially set to zero).

The following parameters were initialized by running the model for a 1-year period prior to the period used for load calculation:

- *Initial unsaturated storage (cm)*: Initial depth of water stored in the unsaturated (surface) zone.
- *Initial saturated storage (cm)*: Initial depth of water stored in the saturated zone.
- *Initial snow (cm)*: Initial amount of snow on the ground at the beginning of the simulation.
- *Antecedent Rainfall for each of 5 previous days (cm)*: The amount of rainfall on each of the five days preceding the first day in the weather file.

Month-Related Parameter Descriptions

- *Month*: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that all annual detached sediment is flushed from the system at the end of each Apr-Mar cycle.
- *ET_CV*: Composite evapotranspiration cover coefficient, calculated as an area-weighted average from land uses within each watershed.
- *Hours per Day*: Mean number of daylight hours.
- *Erosion Coefficient*: This is a regional coefficient used in Richardson's equation for calculating daily rainfall erosivity. Each region is assigned separate coefficients for the months October-March, and for April- September.

Land Use-Related Parameter Descriptions

- *Curve Number*: The SCS curve number (CN) is used in calculating runoff associated with a daily rainfall event, evaluated using SCS TR-55 guidance.

**Sediment Parameters**

Watershed-Related Parameter Descriptions

- *Sediment delivery ratio*: The fraction of erosion – detached sediment – that is transported or delivered to the edge of the stream, calculated as an inverse function of watershed size (Evans et al., 2001).

Land Use-Related Parameter Descriptions

- *USLE K-factor*: The soil erodibility factor was calculated as an area-weighted average of all component soil types.
- *USLE LS-factor*: This factor is calculated from slope and slope length measurements by land use. Slope is evaluated by GIS analysis, and slope length is calculated as an inverse function of slope.
- *USLE C-factor*: The vegetative cover factor for each land use was evaluated following GWLF manual guidance, Wischmeier and Smith (1978), and Hession et al. (1997); and then adjusted after consultation with local NRCS personnel.
- *Daily sediment buildup rate on impervious surfaces*: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.

Streambank Erosion Parameter Descriptions (Evans et al., 2003)

- *% Developed land*: percentage of the watershed with urban-related land uses – defined as all land in MDR, HDR, and COM land uses, as well as the impervious portions of LDR.
- *Animal density*: calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by the watershed area in acres.
- *Curve Number*: area-weighted average value for the watershed.
- *K Factor*: area-weighted USLE soil erodibility factor for the watershed.
- *Slope*: mean percent slope for the watershed.
- *Stream length*: calculated as the total stream length of natural perennial stream channels, in meters. Excludes any non-erosive hardened and piped sections of the stream.
- *Mean channel depth (m)*: calculated from relationships developed either by the Chesapeake Bay Program or by USDA-NRCS by physiographic region, of the general form – y = a * Ab, where y = mean channel depth in ft, and A = drainage area in square miles (USDA-NRCS, 2005).

**Nutrient Parameters**

Watershed-Related Parameter Descriptions

- Background N/P concentrations in GW
- Population on septic systems
- Per capita septic system loads (N/P)
- N and P point source loads

Land Use-Related Parameter Descriptions

- Dissolved N in runoff by land cover type
- Dissolved P in runoff by land cover type
- N/P buildup in urban areas
- Background P concentrations in soil
- Background N concentrations in soil

- Months of manure spreading
- N/P concentrations in manure runoff

## 6.4 Sediment Load Estimates

### *6.4.1 Cripple Creek*

Both the reference and TMDL watersheds were modeled to develop the sediment TMDL. The size of the selected reference watershed, Cripple Creek, was adjusted to match the area of the Wolf Creek watershed. Land use distributions and other watershed characteristics were preserved throughout the adjustment. The sediment load TMDL target endpoint (t/yr) was established as the sediment load from the area-adjusted reference watersheds, "Cripple Creek as Wolf Creek" (Table 6.3). The GWLF model was used to estimate sediment loading contributions from each land use and estimate channel erosion. Point source sediment loads were based on design flow or calculated runoff and the permitted concentration of total suspended solids for each facility.

**Table 6.3. Sediment sources and loads calculated for Cripple Creek watershed.**

| Sediment Sources | Cripple Creek as Wolf Creek (t/yr) |
|---|---|
| Hi till cropland | 9.2 |
| Low-till cropland | 47.3 |
| Pasture 1 | 106.1 |
| Pasture 2 | 149.1 |
| Pasture 3 | 142.8 |
| Transitional | 11.1 |
| Forest | 52.6 |
| Open urban grass | 44.9 |
| Low density residential | 0.5 |
| Medium density residential | 0.1 |
| High density residential | 0.0 |
| Channel erosion | 47.2 |
| Point sources | 0.0 |
| TOTAL | *611.0* |

### *6.4.2 Wolf Creek*

Point source sediment loads were based on design flow or calculated runoff and the permitted concentration of total suspended solids for each facility. The GWLF model was used to estimate sediment loading contributions from each land use and estimate channel erosion. Point source and nonpoint source loads for Wolf Creek are presented below in Table 6.4**.**

**Table 6.4. Sediment sources and loads calculated for Wolf Creek watershed.**

| Sediment Sources | Existing Load (t/yr) | Portion of Total Load (%) |
|---|---|---|
| Hi till cropland | 15.2 | 1.2 |
| Low-till cropland | 76.3 | 5.9 |
| Pasture 1 | 130.2 | 10.1 |
| Pasture 2 | 187.1 | 14.5 |
| Pasture 3 | 183.7 | 14.2 |
| Transitional | 14.6 | 1.1 |
| Forest | 26.6 | 2.1 |
| Open urban grass | 183.2 | 14.2 |
| Low density residential | 11.2 | 0.9 |
| Medium density residential | 12.6 | 1.0 |
| High density residential | 5.9 | 0.5 |
| Channel erosion | 144.3 | 11.2 |
| Point sources | 301.6 | 23.3 |
| TOTAL | 1,292.6 | 100.0 |

## 6.5 Accounting for Critical Conditions and Seasonal Variations

### *6.5.1 Selection of Representative Modeling Period*

Selection of the modeling period was based on the availability of daily weather data and the need to represent variability in weather patterns over time in the watershed. Since observed flow data were not available and calibration to a specific time frame was not an option in this watershed, a long period of weather inputs was selected to represent long-term variability in the watershed. The model was run using a weather time series from April 1987 through December 2003. The remaining period was used to calculate average annual sediment loads in the Wolf Creek watershed.

### *6.5.2 Critical Conditions*

The GWLF model is a continuous simulation model that uses daily time steps for weather data and water balance calculations. The period of rainfall selected for modeling was

chosen as a multi-year period that was representative of typical weather conditions for the area, and included “dry”, “normal” and “wet” years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – and critical conditions during high flow – generally associated with nonpoint source loads.

### *6.5.3 Seasonal Variability*

The GWLF model used for this analysis considers seasonal variation through a number of mechanisms. Daily time steps are used for weather data and water balance calculations. The model also allows for monthly-variable parameter inputs for evapotranspiration cover coefficients, daylight hours/day, and rainfall erosivity coefficients for user-specified growing season months.

# Chapter 7. TMDL Allocations

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 Wolf Creek Bacteria and Benthic TMDL was to determine what reductions in pollutant loadings from point and nonpoint sources are required to meet state water quality standards. The TMDL considers all sources contributing bacteria and sediment to Wolf Creek. 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:

$$TMDL = WLA + LA + MOS \qquad [7.1]$$

where:

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

## 7.1 Bacteria TMDL

### *7.1.1 Background*

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:

$$\log_2(EC) = -0.0172 + 0.91905*\log_2(FC) \quad [7.2]$$

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.

### *7.1.2 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 Wolf Creek impairment. Appendix C contains tables with monthly land-based and direct bacteria loadings for existing conditions.

Figures 7.1 and 7.2 show 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 7.3). Subwatershed 14 was used for comparison of modeled concentrations to water quality standards for the Wolf Creek impairment.

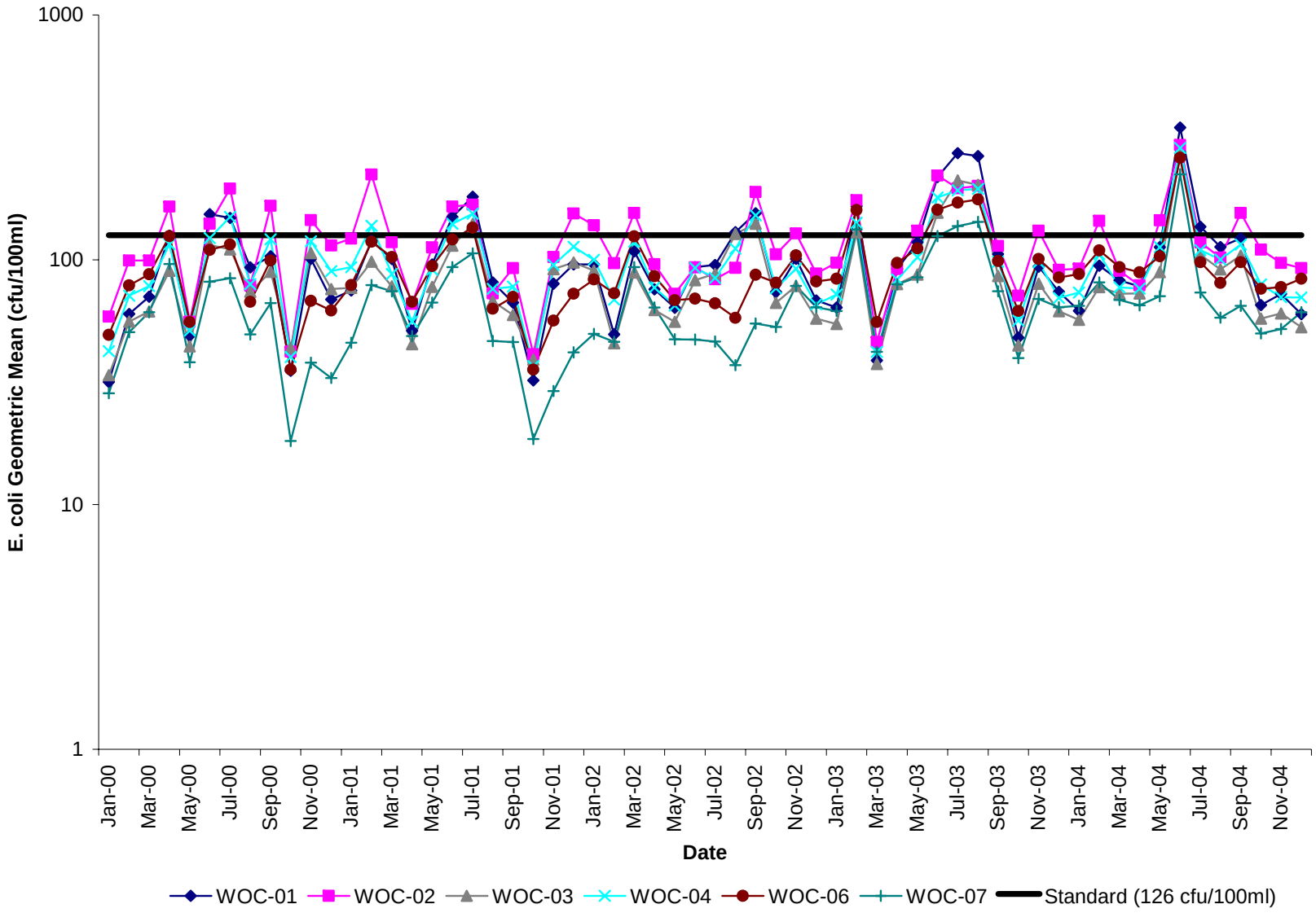


**Figure 7.1. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds WOC-01 to WOC-07 in the Wolf Creek watershed.**

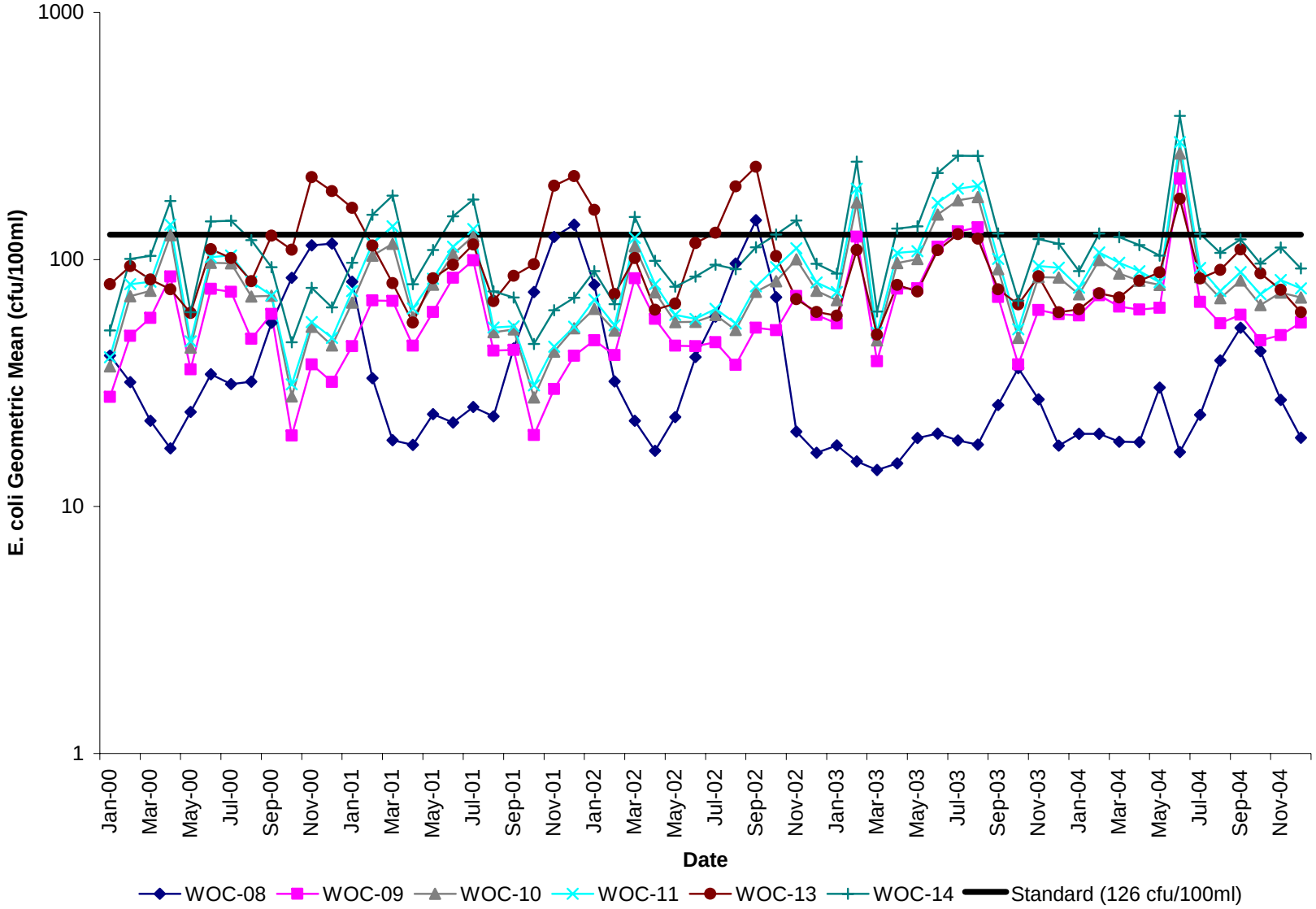


**Figure 7.2. Monthly *E. coli* geometric mean concentrations for existing conditions in subwatersheds WOC-08 to WOC-14 in the Wolf Creek watershed**

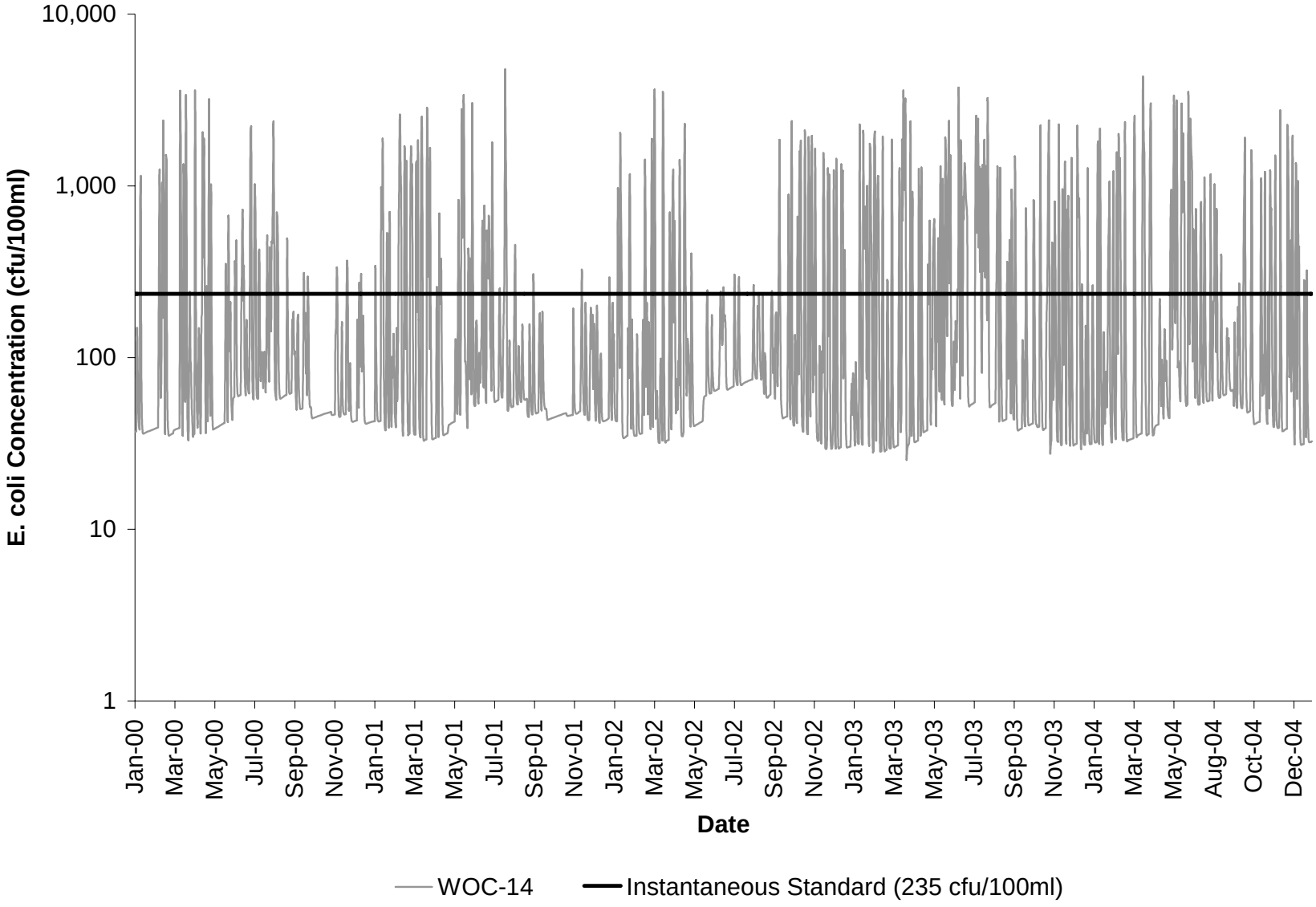


**Figure 7.3. Daily average *E. coli* concentrations for subwatershed WOC-14 in Wolf Creek watershed.**

### *7.1.3 Impact Analysis*

Analyses were conducted to assess the impact of unknown variability in source allocations on changes in direct and land-based loads. Model output from existing conditions was set as the comparative base to adjustments in direct and land-based loads of +100%, +10%, -10%, and -100% of the base value. Model simulations were made for the period January 1993 to December 1997, corresponding with the period used in the allocation scenarios. Percent difference in monthly geometric mean *E. coli* concentration and maximum daily average *E. coli* concentration per month for each direct and land-based load change to base value was calculated and plotted. Analysis results were used to assess the affects of future growth on the rate of water quality standards exceedance.

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 7.4 and 7.5, respectively. Figures 7.6 and 7.7, 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 7.4 with Figure 7.5 that increasing directly deposited loads impact the in-stream geometric mean *E. coli* concentrations more significantly than increasing land-based loads. Comparing Figure 7.6 to Figure 7.7 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.

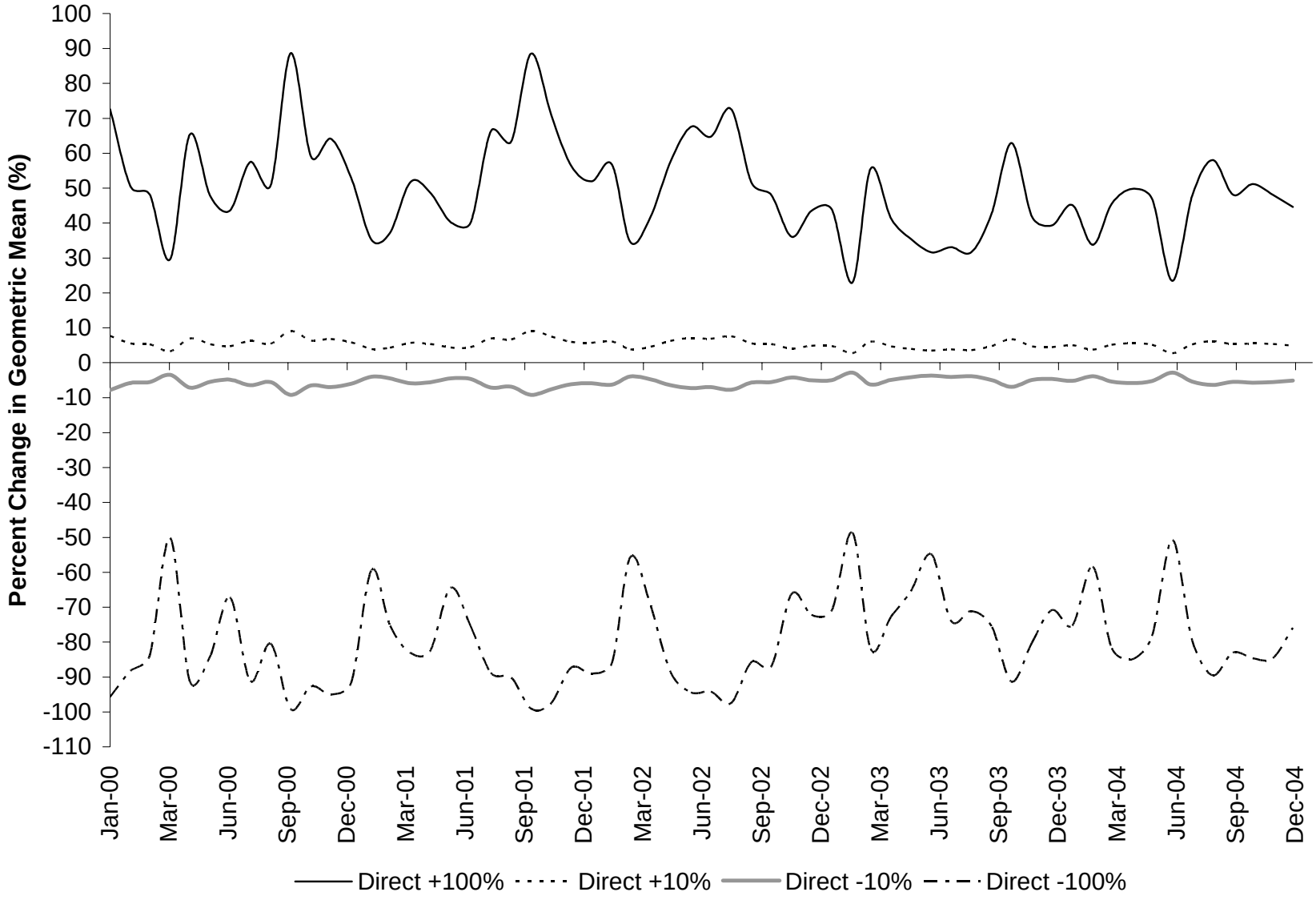


**Figure 7.4. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed WOC-14) of Wolf Creek watershed, as affected by direct load changes.**

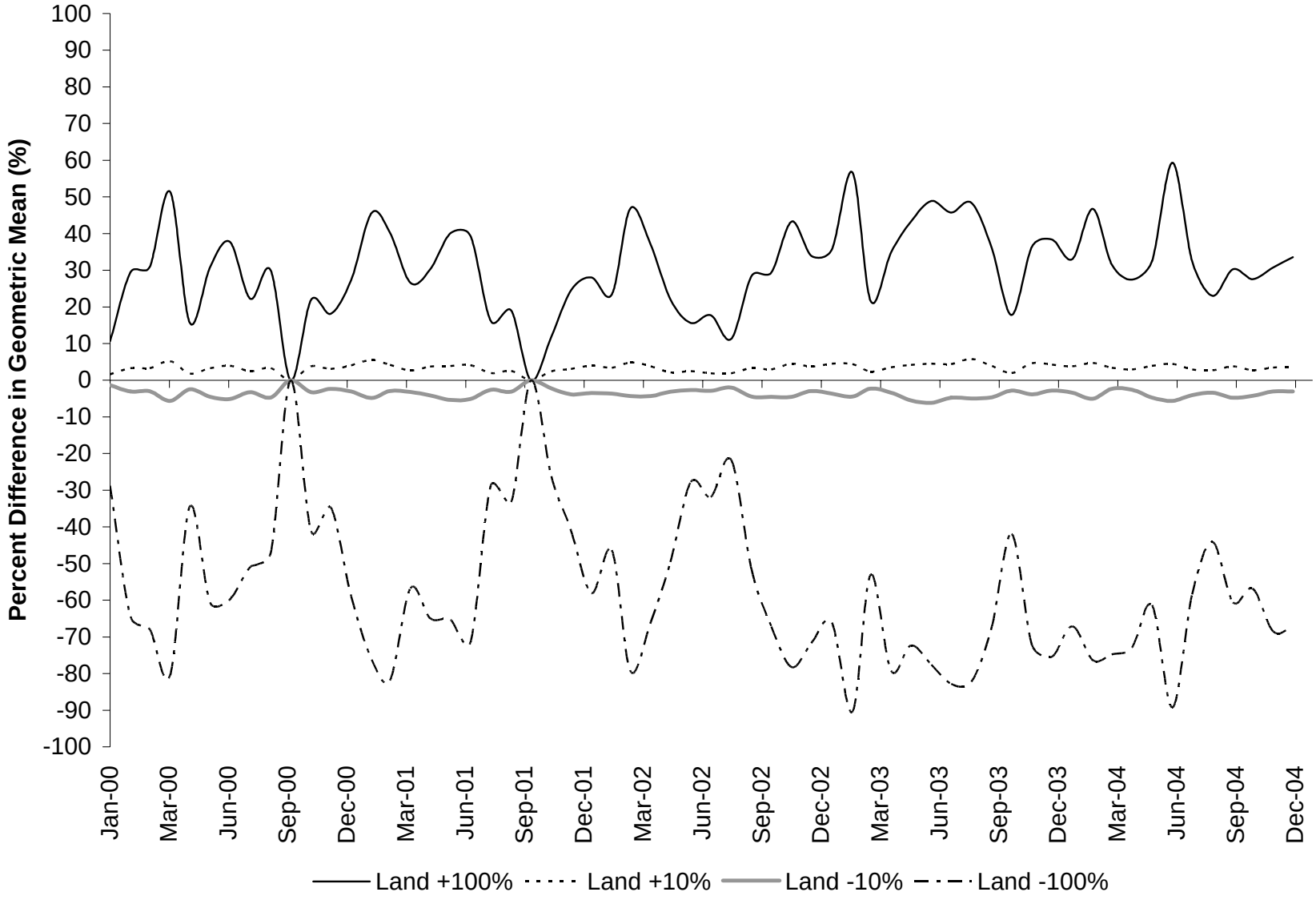


**Figure 7.5. Results of impact analysis on monthly geometric mean *E. coli* concentration at outlet (subwatershed WOC-14) of Wolf Creek watershed, as affected by land-based load changes.**

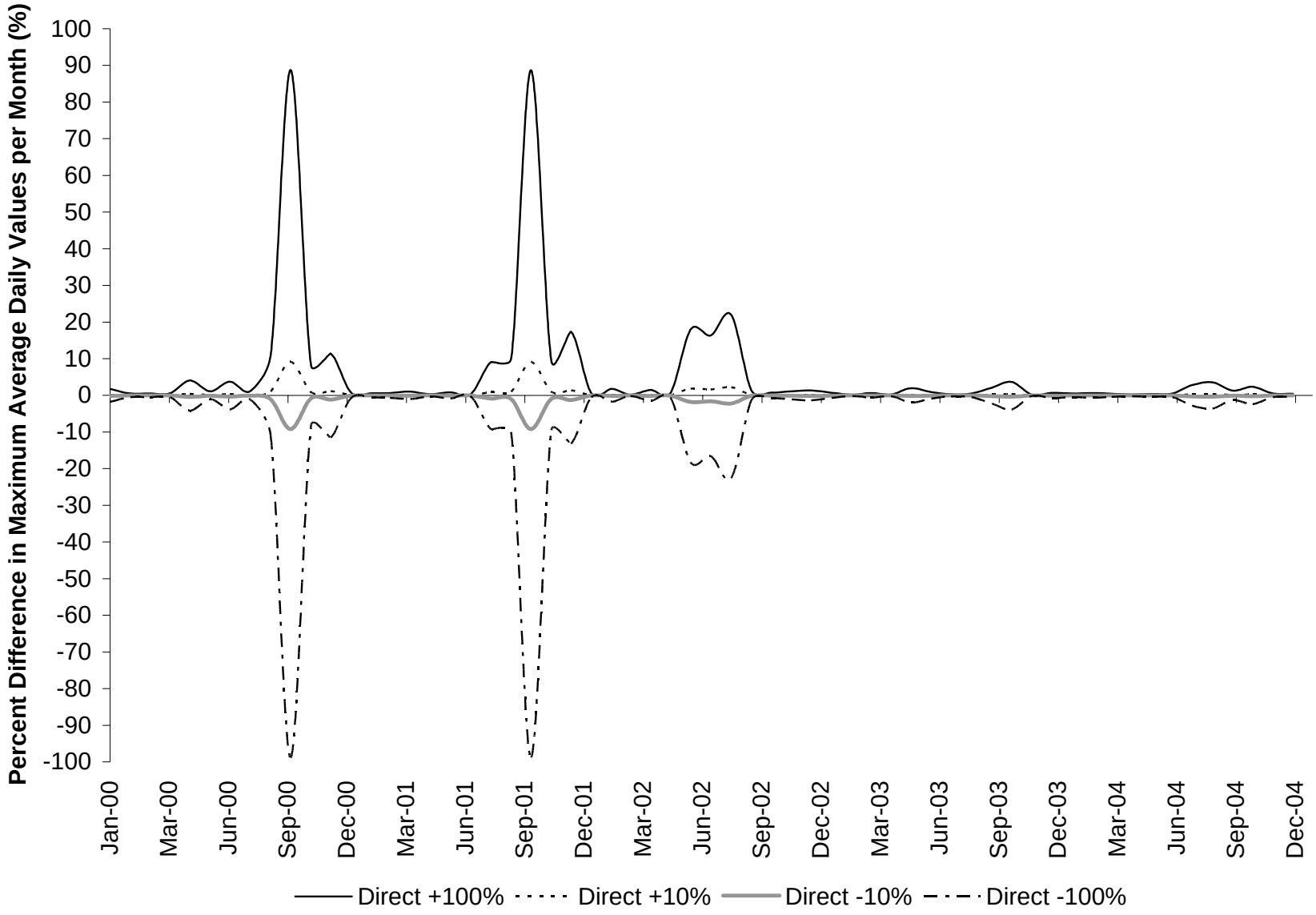


**Figure 7.6. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed WOC-14) of Wolf Creek watershed, as affected by direct load changes.**

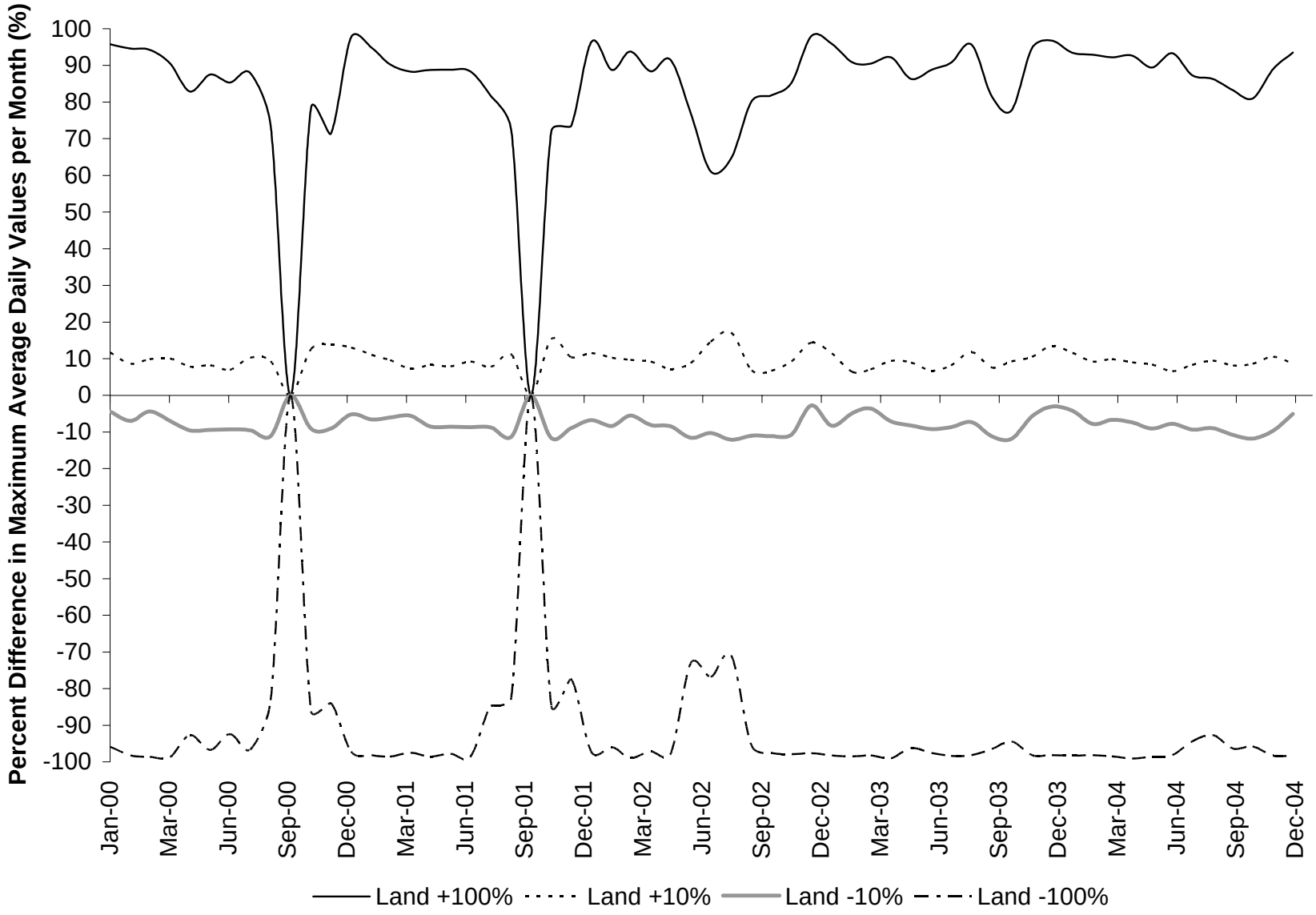


**Figure 7.7. Results of impact analysis on maximum daily average *E. coli* concentration per month at outlet (subwatershed WOC-14) of Wolf Creek watershed, as affected by land-based load changes.**

### *7.1.4 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 Wolf Creek impairment to meet bacteria water quality standards.

Two active point discharges in the Wolf Creek watershed currently have VPDES permits to discharge bacteria. No municipalities with MS4 permits were identified within the Wolf Creek watershed. The permitted point source discharges are described in Table 3.2. During allocation development, these permitted point sources were modeled with effluent fecal coliform concentrations of 200 cfu/100 mL and flows equal to their design flows as listed in Table 3.2. The ultimate waste load allocation (WLA) was calculated using the *E. coli* limit of 126 cfu/100mL and facility design discharge. An expansion matrix for the WLA is presented in Table 7.3.

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 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 8.5.4 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 Wolf Creek impairment and corresponding results are summarized in Table 7.1.

In Table 7.1, 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. Utilizing results of Scenarios 1 through 4, subsequent scenarios were used to determine required reductions in anthropogenic sources. Scenario 5 tested the land-based load reductions at 96%. Table 7.1 shows that exceedances are present when the anthropogenic sources are tested at an 96% reduction rate. Scenario 6 tested the land-based load reductions at 97% and met the 0% exceedance rate criterion for 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-based and livestock directly deposited loads at a 97% reduction rate.

Scenario 7 met the 0% exceedance rate criterion for 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 Wolf Creek watershed. Concentrations for the calendar-month and daily average *E. coli* values are shown in Figure 7.8 for the final TMDL allocation (Scenario 7), along with the geometric mean and instantaneous standards. Table 7.2 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 7.4 presents the final allocated in-stream *E. coli* loads for the Wolf Creek impairment. Table 7.5 presents the TMDL for the 99$^{th}$ percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml.

Increases in loads over the next five years must be considered to ensure the stated allocation will meet the water quality standards. Discharge from the permitted point sources in the Wolf Creek watershed was increased by five times the existing permit levels to determine the effect of possible facility expansion. The allocated load from permitted point sources was set assuming that they were operating at five times their design flow at their permitted maximum average concentration. These increases did not result in exceedances of the water quality standard. 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. Beef cattle populations in Washington 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 7.1.3. 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 Wolf Creek impairment that meets both the calendar-month geometric mean and single sample maximum water quality goals addresses the following issues:

- The TMDL was developed to meet the calendar-month geometric mean and single sample water quality standards.

- Because *E. coli* loading data were not available to quantify point or nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations on which the bacteria TMDL was based.
- The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
- An implicit MOS was incorporated by utilizing professional judgment and conservative estimates of model parameters.
- Both high- and low-flow stream conditions were considered while developing the TMDL.
- Both the flow regime and bacteria loading to Wolf 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 segment (i.e., subwatershed 14). 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 Wolf Creek watershed.

**Table 7.1. Bacteria TMDL allocation scenarios for Wolf Creek 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 | Single Sample |
| 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 33.33 | 23.32 |
| 1 | 100 | 0 | 100 | 0 | 0 | 0 | 0 | 8.33 | 22.06 |
| 2 | 100 | 50 | 100 | 50 | 50 | 0 | 0 | 1.67 | 16.31 |
| 3 | 100 | 75 | 100 | 75 | 75 | 0 | 0 | 0 | 10.89 |
| 4 | 100 | 90 | 100 | 90 | 90 | 0 | 0 | 0 | 3.34 |
| 5 | 100 | 96 | 100 | 96 | 96 | 0 | 0 | 0 | 0.11 |
| 6 | 100 | 97 | 100 | 97 | 97 | 0 | 0 | 0 | 0 |
| 7 | 100 | 97 | 97 | 97 | 97 | 0 | 0 | 0 | 0 |

**Table 7.2. Annual nonpoint source fecal coliform and *E. coli* loads for existing conditions and final allocation along with corresponding reductions in Wolf Creek 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 | 3.84E+13 | 0.00E+00 | 3.02E+12 | 0.00E+00 | 100 |
| Livestock | 1.93E+13 | 5.79E+11 | 1.60E+12 | 6.39E+10 | 97 |
| Wildlife | 2.32E+13 | 2.32E+13 | 1.90E+12 | 1.90E+12 | 0 |
| *Total* | *8.09E+13* | *2.38E+13* | *6.52E+12* | *1.96E+12* | 71 |
| **Land-based** | | | | | |
| Residential | 1.36E+15 | 4.08E+13 | 8.00E+13 | 3.19E+12 | 97 |
| Cropland | 5.88E+13 | 1.76E+12 | 4.46E+12 | 1.77E+11 | 97 |
| Pasture | 1.97E+16 | 5.91E+14 | 9.34E+14 | 3.72E+13 | 97 |
| Forest | 6.81E+13 | 6.81E+13 | 5.11E+12 | 5.11E+12 | 0 |
| *Total* | *2.12E+16* | *7.02E+14* | *1.02E+15* | *4.57E+13* | 97 |

[1] Loads derived from fecal coliform loads using equation 7.2

**Table 7.3. Expansion matrix for bacteria WLA in the Wolf Creek watershed.**

| Permit No | Facility Name | Design Flow (MGD) | Effluent Limit (cfu/100ml) | Wasteload Allocation (cfu/yr) |
|---|---|---|---|---|
| VA0026531 | Wolf Creek Water Reclamation Facility | 7 | 126 | 1.22E+13 |
| VAG400245 | Virginia Highlands Christian Fellowship Church STP | 0.001 | 126 | 1.69E+09 |
| Point Source Future Growth Allocation (5x) | | 35.005 | 126 | 6.09E+13 |
| | | | Total | 7.31E+13 |

**Table 7.4. Average annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Wolf Creek impairment.**

| Pollutant | WLA[1] (cfu/yr) | LA[2] (cfu/yr) | MOS | TMDL[3] (cfu/yr) |
|---|---|---|---|---|
| *E. coli* | 7.31E+13 | 8.10E+12 | Implicit | 8.12E+13 |

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 7.5. Daily *E. coli* bacteria loads (cfu/d) modeled after TMDL allocation in Wolf Creek impairment.**

| Pollutant | WLA[1] (cfu/d) | LA[2] (cfu/d) | MOS | TMDL[3] (cfu/d) |
|---|---|---|---|---|
| *E. coli* | 2.00E+11 | 1.55E+12 | Implicit | 1.75E+12 |

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 99$^{th}$ 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.

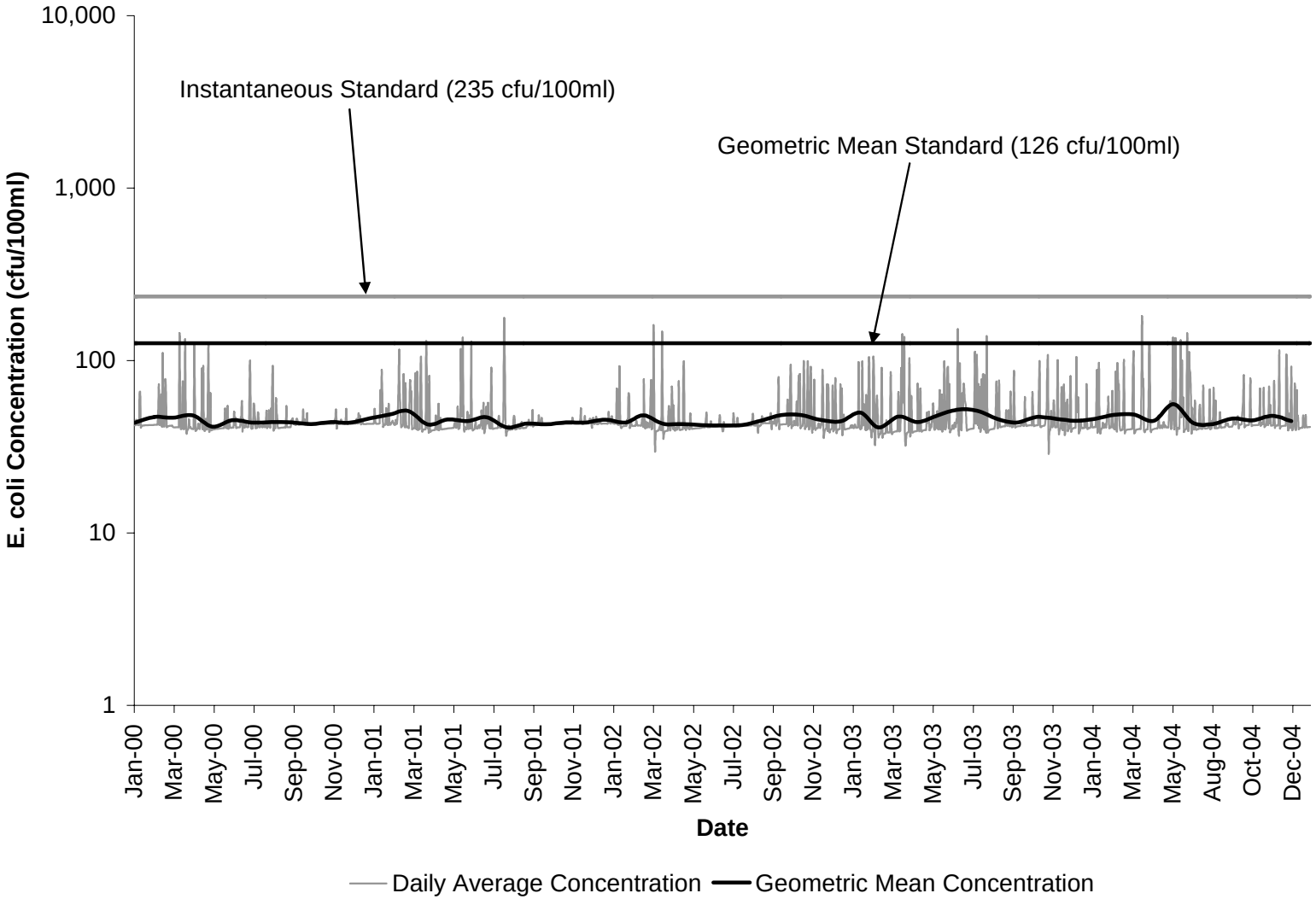


**Figure 7.8. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations from successful TMDL allocation (Allocation Scenario 7) in Wolf Creek impairment.**

## 7.2 Sediment TMDL

### *7.2.1 Point Source Wasteload Allocation*

The wasteload allocated to point sources in the watershed was based on the design flow or calculated runoff and the permitted concentration of total suspended solids for each facility (Table 7.6).

**Table 7.6. Sediment waste load allocations for permitted point sources in the Wolf Creek watershed.**

| Facility Name | Permit Number | Design Flow (MGD) | TSS (mg/L) | Yearly Load (T/yr) | Daily Load (T/day |
|---|---|---|---|---|---|
| Wolf Creek Water Reclamation Facility | VA0026531 | 7.000 | 30 | 290.2 | 1.18 |
| Bristol Virginia Utilities Board - WTP | VA0028321 | 0.114 | 30 | 4.7 | 0.019 |
| Virginia Highlands Christian Fellowship Church STP | VAG400245 | 0.001 | 30 | 0.04 | 0.00016 |
| 2 Industrial Stormwater Facilities | | N/A | 100 | 3.3 | .013 |
| 1 Concrete Plant Stormwater Facility | | N/A | 100 | 1.7 | .0069 |
| 1 Mining Stormwater Facilities | | N/A | 100 | 1.7 | .0069 |
| | | | Total Load = | 301.6 | 1.23 |

### *7.2.2 Nonpoint Source Load Allocation*

Load allocations for nonpoint sources not covered under the general wastewater permits were based on an equal percent reduction from controllable sources. Sediment loads from forest land use are considered to be representative of the natural condition and were not subject to reductions. The existing and allocated sediment loads for each nonpoint source in the Wolf Creek impaired watershed are presented in Table 7.7. In addition, the necessary percent reduction is shown for each source.

**Table 7.7. Load allocation summary with existing sediment load, sediment source reduction, and sediment allocation load for Wolf Creek impairment.**

| Sediment Sources | Existing Load (t/yr) | Sediment Source Reduction (%) | Allocation Load (t/yr) | (t/day) |
|---|---|---|---|---|
| Hi till cropland | 15.2 | 78 | 3.3 | .023 |
| Low-till cropland | 76.3 | 78 | 16.8 | .119 |
| Pasture 1 | 130.2 | 78 | 28.6 | .202 |
| Pasture 2 | 187.1 | 78 | 41.2 | .292 |
| Pasture 3 | 183.7 | 78 | 40.4 | .286 |
| Transitional | 14.6 | 78 | 3.2 | .023 |
| Forest | 26.6 | 0 | 26.6 | .109 |
| Open urban grass | 183.2 | 78 | 40.3 | .285 |
| Low density residential | 11.2 | 78 | 2.5 | .018 |
| Medium density residential | 12.6 | 78 | 2.8 | .020 |
| High density residential | 5.9 | 78 | 1.3 | .009 |
| Channel erosion | 144.3 | 78 | 31.7 | .224 |
| Point sources | 301.6 | 0 | 301.6 | 1.23 |
| TOTAL | 1,292.6 | | 540.4 | 2.84 |
| | | Reference Load (t/yr) = | 611.0 | |
| | | 10% Margin of Safety (t/yr) = | 61.1 | |
| | | Allocation Goal (t/yr) = | 549.9 | |
| | | Total Load after Allocation (t/yr) = | 540.4 | |

### *7.2.3 Margin of Safety*

An explicit margin of safety of 10% was used for the Wolf Creek impairment to account for uncertainties in the methodologies used to determine sediment loadings (Tables 7.8 and 7.9).

### *7.2.4 TMDL Allocations*

The sediment TMDL in Wolf Creek is designed to restore aquatic life uses by reducing sedimentation and improving benthic habitat. While sediment loadings are very dynamic, the accumulation of sediment in the stream is reflective of conditions over extended time periods,

ranging from seasonal to annual. Consequently, the most relevant expression of sediment loadings in the Wolf Creek TMDL is the annual average loading. Table 7.8 shows the total load, wasteload allocations, and margin of safety for Wolf Creek expressed as an average annual load. No sediment reductions to the point sources in Wolf Creek are required. The recommended allocations for each nonpoint source are provided in Table 7.7. Overall, the sediment load in the Wolf Creek watershed must be reduced by 58% in order to meet the established TMDL endpoint.

**Table 7.8. Yearly sediment loads (T/yr) modeled after TMDL allocation in Wolf Creek impairment.**

| WLA (T/yr) | LA (T/yr) | MOS (T/yr) | TMDL (T/yr) |
|---|---|---|---|
| 301.6 | 177.7 | 61.1 | 540.4 |

In order to comply with current USEPA guidance (USEPA, 2007), the Wolf Creek sediment TMDL was also expressed as a daily load by evaluating the variability and distribution of simulated loads (Table 7.9). The following formula from USEPA's *Technical Support Document for Water Quality-Based Toxics Control* (USEPA, 1991) and USEPA's draft *Options for Expressing Daily Loads in TMDLs* (USEPA, 2007) was used to calculate the daily expression of the TMDL:

$$MDL = LTA * \exp(Z_p \sigma_y - 0.5\sigma_y^{\ 2}) \qquad [7.2]$$

where,

*MDL* = maximum daily load,

*LTA* = long term average, which in this case is the average daily load calculated as the average annual load divided by 365,

$Z_p$ = $p^{th}$ percentage point of the standard normal distribution ($95^{th}$ percentile was used),

$\sigma_y = \sqrt{\ln(CV^2 + 1)}$ , and

*CV* = coefficient of variation (estimated at 0.6).

The total maximum daily load was determined from Equation 7.2 using a $95^{th}$ percentile, a CV of 0.6, and a long term average of 1.48 T/d. It should be noted that the maximum daily load expression represents extreme conditions (with a 5% frequency of occurrence), and routine loadings of this level would not meet average annual loadings that are necessary to restore aquatic life health.

**Table 7.9. Daily sediment loads (T/d) modeled after TMDL allocation in Wolf Creek impairment.**

| WLA (T/d) | LA (T/d) | MOS (T/d) | TMDL (T/d) |
|---|---|---|---|
| 1.23 | 1.61 | 0.32 | 3.16 |

# Chapter 8. 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 8.4.2). 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.

## 8.1 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.

## 8.2 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.

The Stage 1 allocation for the Wolf Creek impairment requires a 100% reduction in straight pipes, 79% reduction in livestock direct deposition, 0% reduction in wildlife direct deposition, a 79% reduction in nonpoint source loadings to residential land use, a 79% reduction in nonpoint source loadings to pasture land use, a 79% 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. Fecal coliform loadings for existing conditions and the Stage 1 allocation scenario for nonpoint sources by land use and direct nonpoint sources are presented in Table 8.1 for the Wolf Creek 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 8.1.

**Table 8.1. Annual nonpoint source fecal coliform loads for existing conditions and Stage 1 TMDL implementation scenario along with corresponding reductions in Wolf Creek impairment.**

| Source | Existing Condition Load (cfu/yr) | Stage 1 Allocation Load (cfu/yr) | Scenario Reduction (%) |
|---|---|---|---|
| **Direct** | | | |
| Straight Pipes | 3.84E+13 | 0.00E+00 | 100 |
| Livestock | 1.93E+13 | 4.05E+12 | 79 |
| Wildlife | 2.32E+13 | 2.32E+13 | 0 |
| *Total* | *8.09E+13* | *2.73E+13* | 66 |
| **Land-based** | | | |
| Residential | 1.36E+15 | 2.86E+14 | 79 |
| Cropland | 5.88E+13 | 1.23E+13 | 79 |
| Pasture | 1.97E+16 | 4.14E+15 | 79 |
| Forest | 6.81E+13 | 6.81E+13 | 0 |
| *Total* | *2.12E+16* | *4.50E+15* | 79 |

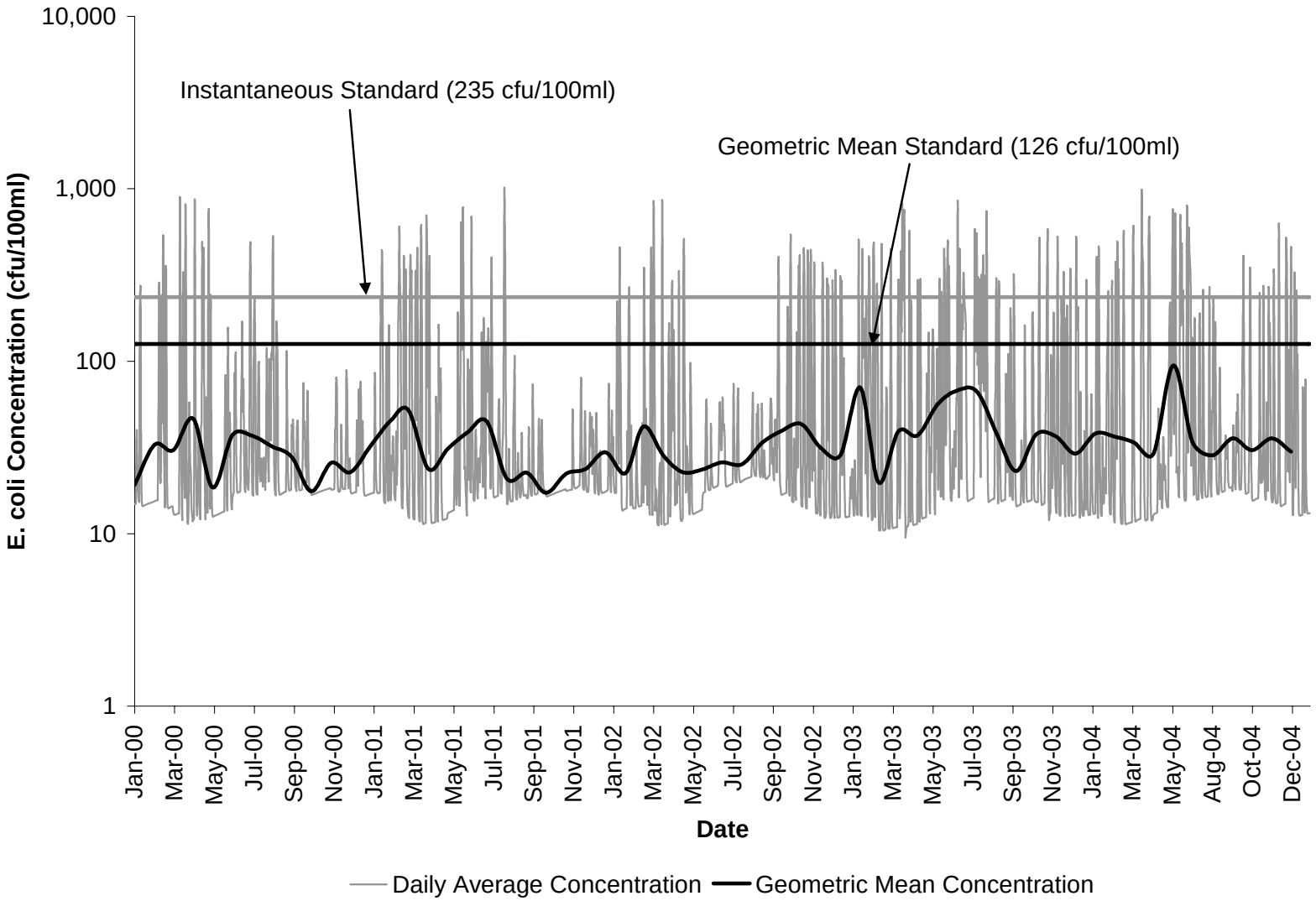


**Figure 8.1. Geometric mean standard, instantaneous single sample standard, and average daily and geometric mean E. coli concentrations for the Stage 1 TMDL implementation scenario in Wolf Creek impairment.**

## 8.3 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.

## 8.4 Reasonable Assurance for Implementation

### *8.4.1 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

### *8.4.2 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

### *8.4.3 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.

### *8.4.4 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.

### *8.4.5 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 9. Public Participation

The development of the Wolf 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 Glade Spring Community Center in Glade Spring, VA on August 7, 2008 to discuss the need for a TMDL, discuss the draft watershed source assessment, and review the approach for TMDL development. Twenty-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 (August 7, 2008 to September 7, 2008) and no written comment was received.

The second and final public meeting was held at the Glade Spring Community Center in Glade Spring, VA on July 28, 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 these meetings that extended from July 28, 2009 to August 28, 2009. Eleven people attended and no written comment was received.

In addition to keeping the public apprised of progress in the development of the Wolf 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 Wolf Creek TMDL included representatives from the following agencies and organizations:

- Virginia Department of Environmental Quality

- Virginia Department of Conservation and Recreation
- Virginia Department of Health
- Virginia Cooperative Extension
- Mount Rogers Planning District Commission
- Evergreen Soil and Water Conservation District
- Holston River Soil and Water Conservation District
- Town of Abingdon
- Smyth County
- Washington County

Twelve and fourteen 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 (WLA's) for point sources, load allocations (LA's) for nonpoint sources and natural background, plus a margin of safety (MOS). TMDLs can be expressed in terms of mass per time, toxicity, or other appropriate measures that relate to a state's water quality standard.

**Urban Runoff**
Surface runoff originating from an urban drainage area including streets, parking lots, and rooftops.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-CWLF001.18 in Wolf Creek watershed.**

| Station | Date | Observed Fecal Coliform Concentration (cfu/100mL) | Total Rainfall for Sampling Day and Preceding 5 Days (in) |
|---|---|---|---|
| 6-CWLF001.18 | 10/08/1996 | 800 | 0.96 |
| 6-CWLF001.18 | 04/07/1997 | 80 | 0.05 |
| 6-CWLF001.18 | 07/17/1997 | 520 | 0.00 |
| 6-CWLF001.18 | 10/07/1997 | 400 | 0.00 |
| 6-CWLF001.18 | 04/02/1998 | 140 | 0.46 |
| 6-CWLF001.18 | 07/21/1998 | 470 | 0.36 |
| 6-CWLF001.18 | 09/09/1998 | 590 | 0.32 |
| 6-CWLF001.18 | 11/05/1998 | 700 | 0.24 |
| 6-CWLF001.18 | 09/08/1999 | 900 | 0.92 |
| 6-CWLF001.18 | 11/03/1999 | 1300 | 0.89 |
| 6-CWLF001.18 | 01/05/2000 | 100 | 0.08 |
| 6-CWLF001.18 | 03/07/2000 | 100 | 0.00 |
| 6-CWLF001.18 | 05/08/2000 | 200 | 0.00 |
| 6-CWLF001.18 | 07/06/2000 | 2000 | 3.64 |
| 6-CWLF001.18 | 09/13/2000 | 300 | 0.03 |
| 6-CWLF001.18 | 11/06/2000 | 200 | 0.00 |
| 6-CWLF001.18 | 01/04/2001 | 100 | 0.14 |
| 6-CWLF001.18 | 03/07/2001 | 200 | 1.05 |

**Table A.2. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CWLF001.46 in Wolf Creek watershed.**

| Station | Date | Observed Fecal Coliform Concentration (cfu/100mL) | Total Rainfall for Sampling Day and Preceding 5 Days (in) |
|---|---|---|---|
| 6-CWLF001.46 | 01/08/1990 | 800 | 0.70 |
| 6-CWLF001.46 | 02/13/1990 | 200 | 1.23 |
| 6-CWLF001.46 | 03/12/1990 | 100 | 0.03 |
| 6-CWLF001.46 | 04/23/1990 | 700 | 0.88 |
| 6-CWLF001.46 | 05/21/1990 | 800 | 0.92 |
| 6-CWLF001.46 | 06/18/1990 | 900 | 0.85 |
| 6-CWLF001.46 | 07/16/1990 | 1,100 | 5.13 |
| 6-CWLF001.46 | 08/15/1990 | 900 | 0.82 |
| 6-CWLF001.46 | 09/17/1990 | 200 | 0.45 |
| 6-CWLF001.46 | 10/09/1990 | 600 | 0.38 |
| 6-CWLF001.46 | 11/13/1990 | 100 | 1.42 |
| 6-CWLF001.46 | 12/11/1990 | 100 | 0.00 |
| 6-CWLF001.46 | 01/23/1991 | 100 | 0.41 |
| 6-CWLF001.46 | 02/19/1991 | 2,000 | 2.71 |
| 6-CWLF001.46 | 03/12/1991 | 400 | 0.46 |
| 6-CWLF001.46 | 05/13/1991 | 600 | 1.75 |
| 6-CWLF001.46 | 06/10/1991 | 1,200 | 0.00 |
| 6-CWLF001.46 | 07/17/1991 | 1,200 | 0.71 |
| 6-CWLF001.46 | 10/10/1991 | 600 | 0.06 |
| 6-CWLF001.46 | 11/05/1991 | 100 | 0.00 |
| 6-CWLF001.46 | 07/23/1992 | 1,800 | 3.04 |
| 6-CWLF001.46 | 10/07/1992 | 200 | 1.33 |
| 6-CWLF001.46 | 01/14/1993 | 100 | 0.02 |
| 6-CWLF001.46 | 07/22/1993 | 270 | 0.35 |
| 6-CWLF001.46 | 10/19/1993 | 910 | 0.07 |
| 6-CWLF001.46 | 01/25/1994 | 2,000 | 0.16 |
| 6-CWLF001.46 | 07/20/1995 | 2,900 | 0.35 |
| 6-CWLF001.46 | 10/11/1995 | 100 | 0.33 |
| 6-CWLF001.46 | 04/25/1996 | 20 | 0.36 |
| 6-CWLF001.46 | 01/21/1997 | 30 | 0.62 |

**Table A.3. Observed fecal coliform concentration and antecedent rainfall for VADEQ station 9-CWLF006.55 in Wolf Creek watershed.**

| Station | Date | Observed Fecal Coliform Concentration (cfu/100mL) | Total Rainfall for Sampling Day and Preceding 5 Days (in) |
|---|---|---|---|
| 6-CWLF006.55 | 01/08/1990 | 800 | 0.70 |
| 6-CWLF006.55 | 02/13/1990 | 800 | 1.23 |
| 6-CWLF006.55 | 03/12/1990 | 100 | 0.03 |
| 6-CWLF006.55 | 04/23/1990 | 200 | 0.88 |
| 6-CWLF006.55 | 05/21/1990 | 300 | 0.92 |
| 6-CWLF006.55 | 06/18/1990 | 200 | 0.85 |
| 6-CWLF006.55 | 07/16/1990 | 200 | 5.13 |
| 6-CWLF006.55 | 08/15/1990 | 300 | 0.82 |
| 6-CWLF006.55 | 09/17/1990 | 400 | 0.45 |
| 6-CWLF006.55 | 10/09/1990 | 700 | 0.38 |
| 6-CWLF006.55 | 11/13/1990 | 100 | 1.42 |
| 6-CWLF006.55 | 12/11/1990 | 100 | 0.00 |
| 6-CWLF006.55 | 01/23/1991 | 100 | 0.41 |
| 6-CWLF006.55 | 02/19/1991 | 18,000 | 2.71 |
| 6-CWLF006.55 | 03/12/1991 | 100 | 0.46 |
| 6-CWLF006.55 | 04/08/1991 | 8,500 | 0.00 |
| 6-CWLF006.55 | 06/10/1991 | 1,200 | 0.00 |
| 6-CWLF006.55 | 07/17/1991 | 200 | 0.71 |
| 6-CWLF006.55 | 10/10/1991 | 700 | 0.06 |

# 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 6-CTOW000.58, 6-CWLF008.00, and 6-CWLF001.18.

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/032009bst.pdf

or contact VADEQ-SWRO

# Appendix C – Fecal Coliform Loading in Subwatersheds

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 2 | 16,902 | 4,507 | 849 | 90 | 1,686 |
| Feb. | 132 | 17,532 | 4,640 | 907 | 82 | 1,537 |
| Mar. | 653 | 30,528 | 7,919 | 1,702 | 60 | 1,686 |
| Apr. | 523 | 30,293 | 7,851 | 1,694 | 58 | 1,632 |
| May. | 132 | 32,072 | 8,306 | 1,799 | 60 | 1,686 |
| Jun. | 2 | 31,755 | 8,218 | 1,785 | 52 | 1,632 |
| Jul. | 2 | 33,591 | 8,686 | 1,894 | 54 | 1,686 |
| Aug. | 2 | 34,369 | 8,881 | 1,942 | 54 | 1,686 |
| Sep. | 2 | 34,051 | 8,792 | 1,929 | 87 | 1,632 |
| Oct. | 200 | 22,933 | 6,017 | 1,226 | 90 | 1,686 |
| Nov. | 200 | 23,138 | 6,059 | 1,246 | 87 | 1,632 |
| Dec. | 2 | 16,318 | 4,360 | 812 | 90 | 1,686 |
| Total | 1,849 | 323,483 | 84,236 | 17,785 | 862 | 19,866 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 1 | 5,652 | 1,738 | 106 | 119 | 3,928 |
| Feb. | 16 | 5,397 | 1,646 | 112 | 108 | 3,579 |
| Mar. | 76 | 7,232 | 2,134 | 205 | 76 | 3,928 |
| Apr. | 61 | 7,086 | 2,087 | 204 | 73 | 3,801 |
| May. | 16 | 7,412 | 2,179 | 216 | 76 | 3,928 |
| Jun. | 1 | 7,256 | 2,129 | 214 | 66 | 3,801 |
| Jul. | 1 | 7,588 | 2,223 | 227 | 68 | 3,928 |
| Aug. | 1 | 7,678 | 2,246 | 233 | 68 | 3,928 |
| Sep. | 1 | 7,522 | 2,196 | 231 | 115 | 3,801 |
| Oct. | 24 | 6,351 | 1,913 | 150 | 119 | 3,928 |
| Nov. | 24 | 6,256 | 1,879 | 152 | 115 | 3,801 |
| Dec. | 1 | 5,584 | 1,721 | 101 | 119 | 3,928 |
| Total | 219 | 81,014 | 24,092 | 2,148 | 1,122 | 46,279 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 11,680 | 3,054 | 631 | 69 | 1,762 |
| Feb. | 10 | 12,309 | 3,180 | 674 | 63 | 1,606 |
| Mar. | 48 | 22,223 | 5,593 | 1,266 | 47 | 1,762 |
| Apr. | 38 | 21,996 | 5,552 | 1,260 | 45 | 1,705 |
| May. | 10 | 23,047 | 5,880 | 1,338 | 47 | 1,762 |
| Jun. | 0 | 22,840 | 5,824 | 1,328 | 40 | 1,705 |
| Jul. | 0 | 24,177 | 6,163 | 1,408 | 41 | 1,762 |
| Aug. | 0 | 24,756 | 6,308 | 1,445 | 41 | 1,762 |
| Sep. | 0 | 24,629 | 6,252 | 1,435 | 67 | 1,705 |
| Oct. | 15 | 16,328 | 4,177 | 912 | 69 | 1,762 |
| Nov. | 15 | 16,510 | 4,219 | 927 | 67 | 1,705 |
| Dec. | 0 | 11,245 | 2,945 | 604 | 69 | 1,762 |
| Total | 135 | 231,742 | 59,148 | 13,227 | 667 | 20,762 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 6,438 | 1,685 | 346 | 63 | 2,021 |
| Feb. | 37 | 6,752 | 1,753 | 370 | 57 | 1,842 |
| Mar. | 182 | 12,076 | 3,078 | 694 | 40 | 2,021 |
| Apr. | 145 | 11,979 | 3,055 | 691 | 39 | 1,956 |
| May. | 37 | 12,643 | 3,235 | 733 | 40 | 2,021 |
| Jun. | 0 | 12,529 | 3,204 | 728 | 34 | 1,956 |
| Jul. | 0 | 13,263 | 3,391 | 772 | 35 | 2,021 |
| Aug. | 0 | 13,580 | 3,470 | 792 | 35 | 2,021 |
| Sep. | 0 | 13,481 | 3,439 | 787 | 61 | 1,956 |
| Oct. | 55 | 8,930 | 2,301 | 500 | 63 | 2,021 |
| Nov. | 55 | 9,028 | 2,324 | 508 | 61 | 1,956 |
| Dec. | 0 | 6,200 | 1,626 | 331 | 63 | 2,021 |
| Total | 512 | 126,900 | 32,561 | 7,250 | 591 | 23,817 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 163 | 41 | 10 | 16 | 95 |
| Feb. | 2 | 174 | 43 | 11 | 15 | 86 |
| Mar. | 8 | 326 | 82 | 20 | 16 | 95 |
| Apr. | 6 | 325 | 81 | 20 | 16 | 92 |
| May. | 2 | 345 | 86 | 22 | 16 | 95 |
| Jun. | 0 | 342 | 86 | 21 | 16 | 92 |
| Jul. | 0 | 363 | 91 | 23 | 16 | 95 |
| Aug. | 0 | 373 | 93 | 23 | 16 | 95 |
| Sep. | 0 | 370 | 92 | 23 | 16 | 92 |
| Oct. | 3 | 235 | 59 | 15 | 16 | 95 |
| Nov. | 3 | 239 | 60 | 15 | 16 | 92 |
| Dec. | 0 | 156 | 39 | 10 | 16 | 95 |
| Total | 24 | 3,412 | 852 | 213 | 194 | 1,117 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | |
|---|---|---|---|---|---|
| | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 54 | 14 | 3 | 25 | 184 |
| Feb. | 58 | 14 | 4 | 23 | 167 |
| Mar. | 111 | 27 | 7 | 20 | 184 |
| Apr. | 110 | 27 | 7 | 19 | 178 |
| May. | 115 | 29 | 7 | 20 | 184 |
| Jun. | 114 | 29 | 7 | 19 | 178 |
| Jul. | 121 | 30 | 8 | 20 | 184 |
| Aug. | 124 | 31 | 8 | 20 | 184 |
| Sep. | 124 | 31 | 8 | 24 | 178 |
| Oct. | 79 | 20 | 5 | 25 | 184 |
| Nov. | 80 | 20 | 5 | 24 | 178 |
| Dec. | 52 | 13 | 3 | 25 | 184 |
| Total | 1,142 | 284 | 71 | 263 | 2,163 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 2,283 | 598 | 122 | 12 | 139 |
| Feb. | 16 | 2,389 | 622 | 131 | 11 | 126 |
| Mar. | 79 | 4,258 | 1,090 | 245 | 12 | 139 |
| Apr. | 63 | 4,227 | 1,082 | 244 | 12 | 134 |
| May. | 16 | 4,470 | 1,145 | 259 | 12 | 139 |
| Jun. | 0 | 4,429 | 1,134 | 257 | 12 | 134 |
| Jul. | 0 | 4,688 | 1,200 | 273 | 12 | 139 |
| Aug. | 0 | 4,800 | 1,228 | 280 | 12 | 139 |
| Sep. | 0 | 4,762 | 1,217 | 278 | 12 | 134 |
| Oct. | 24 | 3,156 | 816 | 177 | 12 | 139 |
| Nov. | 24 | 3,191 | 824 | 179 | 12 | 134 |
| Dec. | 0 | 2,198 | 577 | 117 | 12 | 139 |
| Total | 223 | 44,853 | 11,533 | 2,560 | 142 | 1,635 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | |
|---|---|---|---|---|---|
| | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 0 | 0 | 33 | 171 |
| Feb. | 0 | 0 | 0 | 30 | 156 |
| Mar. | 0 | 0 | 0 | 26 | 171 |
| Apr. | 0 | 0 | 0 | 25 | 165 |
| May. | 0 | 0 | 0 | 26 | 171 |
| Jun. | 0 | 0 | 0 | 25 | 165 |
| Jul. | 0 | 0 | 0 | 26 | 171 |
| Aug. | 0 | 0 | 0 | 26 | 171 |
| Sep. | 0 | 0 | 0 | 32 | 165 |
| Oct. | 0 | 0 | 0 | 33 | 171 |
| Nov. | 0 | 0 | 0 | 32 | 165 |
| Dec. | 0 | 0 | 0 | 33 | 171 |
| Total | 1 | 1 | 0 | 345 | 2,011 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 1,442 | 377 | 79 | 12 | 60 |
| Feb. | 5 | 1,516 | 393 | 84 | 11 | 55 |
| Mar. | 26 | 2,727 | 691 | 157 | 12 | 60 |
| Apr. | 21 | 2,703 | 686 | 156 | 12 | 58 |
| May. | 5 | 2,844 | 727 | 166 | 12 | 60 |
| Jun. | 0 | 2,818 | 720 | 165 | 12 | 58 |
| Jul. | 0 | 2,984 | 762 | 175 | 12 | 60 |
| Aug. | 0 | 3,055 | 780 | 179 | 12 | 60 |
| Sep. | 0 | 3,036 | 773 | 178 | 12 | 58 |
| Oct. | 8 | 2,009 | 516 | 113 | 12 | 60 |
| Nov. | 8 | 2,032 | 521 | 115 | 12 | 58 |
| Dec. | 0 | 1,388 | 364 | 75 | 12 | 60 |
| Total | 73 | 28,554 | 7,312 | 1,644 | 145 | 709 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 3,266 | 855 | 178 | 24 | 171 |
| Feb. | 19 | 3,427 | 890 | 190 | 22 | 156 |
| Mar. | 92 | 6,140 | 1,565 | 355 | 16 | 171 |
| Apr. | 74 | 6,091 | 1,553 | 354 | 16 | 165 |
| May. | 19 | 6,429 | 1,645 | 375 | 16 | 171 |
| Jun. | 0 | 6,371 | 1,629 | 373 | 16 | 165 |
| Jul. | 0 | 6,745 | 1,724 | 395 | 16 | 171 |
| Aug. | 0 | 6,907 | 1,765 | 405 | 16 | 171 |
| Sep. | 0 | 6,857 | 1,749 | 403 | 23 | 165 |
| Oct. | 28 | 4,536 | 1,169 | 256 | 24 | 171 |
| Nov. | 28 | 4,587 | 1,180 | 260 | 23 | 165 |
| Dec. | 0 | 3,144 | 824 | 170 | 24 | 171 |
| Total | 261 | 64,500 | 16,548 | 3,716 | 236 | 2,012 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 1 | 3,319 | 868 | 181 | 22 | 135 |
| Feb. | 28 | 3,476 | 904 | 193 | 20 | 123 |
| Mar. | 139 | 6,208 | 1,592 | 362 | 14 | 135 |
| Apr. | 111 | 6,166 | 1,580 | 360 | 14 | 130 |
| May. | 28 | 6,535 | 1,674 | 383 | 14 | 135 |
| Jun. | 1 | 6,477 | 1,658 | 380 | 14 | 130 |
| Jul. | 1 | 6,857 | 1,754 | 403 | 14 | 135 |
| Aug. | 1 | 7,022 | 1,795 | 413 | 14 | 135 |
| Sep. | 1 | 6,963 | 1,780 | 410 | 21 | 130 |
| Oct. | 43 | 4,598 | 1,188 | 261 | 22 | 135 |
| Nov. | 43 | 4,650 | 1,200 | 265 | 21 | 130 |
| Dec. | 1 | 3,195 | 837 | 173 | 22 | 135 |
| Total | 395 | 65,466 | 16,830 | 3,786 | 212 | 1,588 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 1 | 1,878 | 491 | 103 | 84 | 446 |
| Feb. | 16 | 1,967 | 511 | 109 | 77 | 407 |
| Mar. | 79 | 3,513 | 900 | 205 | 64 | 446 |
| Apr. | 63 | 3,489 | 894 | 204 | 62 | 432 |
| May. | 16 | 3,698 | 947 | 217 | 64 | 446 |
| Jun. | 1 | 3,665 | 938 | 215 | 60 | 432 |
| Jul. | 1 | 3,880 | 992 | 228 | 62 | 446 |
| Aug. | 1 | 3,974 | 1,016 | 234 | 62 | 446 |
| Sep. | 1 | 3,940 | 1,007 | 232 | 81 | 432 |
| Oct. | 24 | 2,601 | 672 | 148 | 84 | 446 |
| Nov. | 24 | 2,631 | 679 | 150 | 81 | 432 |
| Dec. | 1 | 1,808 | 473 | 98 | 84 | 446 |
| Total | 226 | 37,043 | 9,520 | 2,143 | 865 | 5,258 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 2 | 8,435 | 2,209 | 458 | 54 | 307 |
| Feb. | 71 | 8,828 | 2,299 | 489 | 50 | 280 |
| Mar. | 351 | 15,738 | 4,039 | 916 | 39 | 307 |
| Apr. | 281 | 15,632 | 4,009 | 911 | 38 | 297 |
| May. | 71 | 16,566 | 4,246 | 967 | 39 | 307 |
| Jun. | 1 | 16,416 | 4,205 | 960 | 33 | 297 |
| Jul. | 2 | 17,380 | 4,450 | 1,018 | 34 | 307 |
| Aug. | 2 | 17,797 | 4,554 | 1,044 | 34 | 307 |
| Sep. | 1 | 17,646 | 4,513 | 1,037 | 53 | 297 |
| Oct. | 108 | 11,667 | 3,019 | 661 | 54 | 307 |
| Nov. | 108 | 11,797 | 3,048 | 671 | 53 | 297 |
| Dec. | 2 | 8,122 | 2,131 | 439 | 54 | 307 |
| Total | 998 | 166,024 | 42,722 | 9,572 | 536 | 3,615 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 2 | 12,819 | 3,296 | 741 | 44 | 281 |
| Feb. | 65 | 12,793 | 3,251 | 737 | 40 | 256 |
| Mar. | 316 | 24,882 | 6,163 | 1,458 | 31 | 281 |
| Apr. | 253 | 25,093 | 6,243 | 1,481 | 30 | 272 |
| May. | 65 | 25,897 | 6,540 | 1,552 | 31 | 281 |
| Jun. | 2 | 25,421 | 6,409 | 1,522 | 28 | 272 |
| Jul. | 2 | 26,551 | 6,713 | 1,595 | 29 | 281 |
| Aug. | 2 | 26,948 | 6,803 | 1,618 | 29 | 281 |
| Sep. | 2 | 26,623 | 6,679 | 1,590 | 42 | 272 |
| Oct. | 50 | 21,746 | 5,479 | 1,287 | 44 | 281 |
| Nov. | 98 | 20,758 | 5,219 | 1,225 | 42 | 272 |
| Dec. | 2 | 12,548 | 3,228 | 724 | 44 | 281 |
| Total | 860 | 262,081 | 66,024 | 15,529 | 432 | 3,313 |

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

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

| Month | Fecal Coliform loadings ($x10^{10}$ cfu/month) | | | | | |
|---|---|---|---|---|---|---|
| | Cropland | Pasture 1 | Pasture 2 | Pasture 3 | Forest | Residential[1] |
| Jan. | 0 | 3,102 | 814 | 168 | 20 | 128 |
| Feb. | 7 | 3,261 | 846 | 179 | 18 | 116 |
| Mar. | 36 | 5,859 | 1,483 | 335 | 14 | 128 |
| Apr. | 28 | 5,802 | 1,472 | 333 | 14 | 124 |
| May. | 7 | 6,093 | 1,559 | 354 | 14 | 128 |
| Jun. | 0 | 6,037 | 1,544 | 351 | 14 | 124 |
| Jul. | 0 | 6,390 | 1,633 | 372 | 14 | 128 |
| Aug. | 0 | 6,543 | 1,671 | 382 | 14 | 128 |
| Sep. | 0 | 6,504 | 1,656 | 379 | 19 | 124 |
| Oct. | 11 | 4,318 | 1,110 | 242 | 20 | 128 |
| Nov. | 11 | 4,365 | 1,121 | 245 | 19 | 124 |
| Dec. | 0 | 2,988 | 785 | 160 | 20 | 128 |
| Total | 101 | 61,263 | 15,693 | 3,500 | 198 | 1,505 |

[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 WOC-01.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 184,895 | 0.4% | 5,547 | 97% |
| Pasture | 42,550,417 | 95% | 1,276,511 | 97% |
| Forest | 86,200 | 0.2% | 86,200 | 0% |
| Residential | 1,986,647 | 4% | 59,599 | 97% |
| Total | 44,808,160 | 100% | 1,427,857 | 97% |

**Table D.2. Required annual reductions in direct nonpoint sources in sub-watershed WOC-01.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 41,413 | 57% | 1,242 | 97% |
| Wildlife in Streams | 30,918 | 43% | 30,918 | 0% |
| Total | 72,331 | 100% | 32,161 | 56% |

**Table D.3. Required annual reductions in nonpoint sources in sub-watershed WOC-02.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 21,947 | 0.1% | 658 | 97% |
| Pasture | 10,725,455 | 69% | 321,763 | 97% |
| Forest | 112,244 | 0.7% | 112,244 | 0% |
| Residential | 4,627,872 | 30% | 138,836 | 97% |
| Total | 15,487,518 | 100% | 573,501 | 96% |

**Table D.4. Required annual reductions in direct nonpoint sources in sub-watershed WOC-02.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 4,804 | 8% | 144 | 97% |
| Wildlife in Streams | 39,032 | 66% | 39,032 | 0% |
| Straight Pipes | 15,503 | 26% | 0 | 100% |
| Total | 59,339 | 100% | 39,176 | 34% |

**Table D.5. Required annual reductions in nonpoint sources in sub-watershed WOC-03.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 13,524 | 0% | 406 | 97% |
| Pasture | 30,411,739 | 93% | 912,351 | 97% |
| Forest | 66,674 | 0.2% | 66,674 | 0% |
| Residential | 2,076,162 | 6% | 62,285 | 97% |
| Total | 32,568,100 | 100% | 1,041,716 | 97% |

**Table D.6. Required annual reductions in direct nonpoint sources in sub-watershed WOC-03.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 30,811 | 46% | 924 | 97% |
| Wildlife in Streams | 22,171 | 33% | 22,171 | 0% |
| Straight Pipes | 14,470 | 21% | 0 | 100% |
| Total | 67,451 | 100% | 23,095 | 66% |

**Table D.7. Required annual reductions in nonpoint sources in sub-watershed WOC-04.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 51,242 | 0.3% | 1,537 | 97% |
| Pasture | 16,671,165 | 87% | 500,134 | 97% |
| Forest | 59,084 | 0.3% | 59,084 | 0% |
| Residential | 2,381,693 | 12% | 71,451 | 97% |
| Total | 19,163,184 | 100% | 632,206 | 97% |

**Table D.8. Required annual reductions in direct nonpoint sources in sub-watershed WOC-04.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 16,896 | 34% | 507 | 97% |
| Wildlife in Streams | 18,513 | 37% | 18,513 | 0% |
| Straight Pipes | 14,614 | 29% | 0 | 100% |
| Total | 50,023 | 100% | 19,020 | 62% |

**Table D.9. Required annual reductions in nonpoint sources in sub-watershed WOC-05.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 2,373 | 0.4% | 71 | 97% |
| Pasture | 447,670 | 77% | 13,430 | 97% |
| Forest | 19,421 | 3% | 19,421 | 0% |
| Residential | 111,717 | 19% | 3,351 | 97% |
| Total | 581,180 | 100% | 36,274 | 94% |

**Table D.10. Required annual reductions in direct nonpoint sources in sub-watershed WOC-05.**

| 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 | 497 | 1% | 15 | 97% |
| Wildlife in Streams | 3,472 | 10% | 3,472 | 0% |
| Straight Pipes | 30,880 | 89% | 0 | 100% |
| Total | 34,849 | 100% | 3,487 | 90% |

**Table D.11. Required annual reductions in nonpoint sources in sub-watershed WOC-06.**

| 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 |
|---|---|---|---|---|
| Pasture | 149,732 | 38% | 4,492 | 97% |
| Forest | 26,336 | 7% | 26,336 | 0% |
| Residential | 216,297 | 55% | 6,489 | 97% |
| Total | 392,365 | 100% | 37,317 | 90% |

**Table D.12. Required annual reductions in direct nonpoint sources in sub-watershed WOC-06.**

| 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 | 166 | 0.5% | 5 | 97% |
| Wildlife in Streams | 4,556 | 13% | 4,556 | 0% |
| Straight Pipes | 31,475 | 87% | 0 | 100% |
| Total | 36,197 | 100% | 4,561 | 87% |

**Table D.13. Required annual reductions in nonpoint sources in sub-watershed WOC-07.**

| 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 | 22,282 | 0.4% | 668 | 97% |
| Pasture | 5,894,576 | 97% | 176,837 | 97% |
| Forest | 14,174 | 0.2% | 14,174 | 0% |
| Residential | 163,525 | 3% | 4,906 | 97% |
| Total | 6,094,557 | 100% | 196,585 | 97% |

**Table D.14. Required annual reductions in direct nonpoint sources in sub-watershed WOC-07.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 5,963 | 57% | 179 | 97% |
| Wildlife in Streams | 4,441 | 43% | 4,441 | 0% |
| Total | 10,404 | 100% | 4,620 | 56% |

**Table D.15. Required annual reductions in nonpoint sources in sub-watershed WOC-08.**

| 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 |
|---|---|---|---|---|
| Pasture | 208 | 0.1% | 6 | 97% |
| Forest | 34,517 | 15% | 34,517 | 0% |
| Residential | 201,067 | 85% | 148 | 100% |
| Total | 235,792 | 100% | 34,671 | 85% |

**Table D.16. Required annual reductions in direct nonpoint sources in sub-watershed WOC-08.**

| 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 | 5,100 | 14% | 5,100 | 0% |
| Straight Pipes | 30,802 | 86% | 0 | 100% |
| Total | 35,903 | 100% | 5,100 | 86% |

**Table D.17. Required annual reductions in nonpoint sources in sub-watershed WOC-09.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 7,264 | 0.2% | 218 | 97% |
| Pasture | 3,750,959 | 98% | 112,529 | 97% |
| Forest | 14,454 | 0.4% | 14,454 | 0% |
| Residential | 70,858 | 2% | 2,126 | 97% |
| Total | 3,843,534 | 100% | 129,326 | 97% |

**Table D.18. Required annual reductions in direct nonpoint sources in sub-watershed WOC-09.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 3,810 | 15% | 114 | 97% |
| Wildlife in Streams | 5,821 | 23% | 5,821 | 0% |
| Straight Pipes | 15,401 | 62% | 0 | 100% |
| Total | 25,032 | 100% | 5,935 | 76% |

**Table D.19. Required annual reductions in nonpoint sources in sub-watershed WOC-10.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 26,109 | 0.3% | 783 | 97% |
| Pasture | 8,476,354 | 97% | 254,290 | 97% |
| Forest | 23,609 | 0.3% | 23,609 | 0% |
| Residential | 201,193 | 2% | 6,036 | 97% |
| Total | 8,727,265 | 100% | 284,719 | 97% |

**Table D.20. Required annual reductions in direct nonpoint sources in sub-watershed WOC-10.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 8,614 | 17% | 258 | 97% |
| Wildlife in Streams | 10,636 | 21% | 10,636 | 0% |
| Straight Pipes | 30,830 | 62% | 0 | 100% |
| Total | 50,080 | 100% | 10,894 | 78% |

**Table D.21. Required annual reductions in nonpoint sources in sub-watershed WOC-11.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 39,521 | 0.4% | 1,186 | 97% |
| Pasture | 8,608,232 | 98% | 258,247 | 97% |
| Forest | 21,199 | 0.2% | 21,199 | 0% |
| Residential | 158,760 | 2% | 4,763 | 97% |
| Total | 8,827,712 | 100% | 285,394 | 97% |

**Table D.22. Required annual reductions in direct nonpoint sources in sub-watershed WOC-11.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 8,779 | 17% | 263 | 97% |
| Wildlife in Streams | 10,712 | 21% | 10,712 | 0% |
| Straight Pipes | 30,802 | 61% | 0 | 100% |
| Total | 50,293 | 100% | 10,975 | 78% |

**Table D.23. Required annual reductions in nonpoint sources in sub-watershed WOC-12.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 22,608 | 0.4% | 678 | 97% |
| Pasture | 4,870,650 | 88% | 146,119 | 97% |
| Forest | 86,506 | 2% | 86,506 | 0% |
| Residential | 525,770 | 10% | 15,773 | 97% |
| Total | 5,505,535 | 100% | 249,077 | 95% |

**Table D.24. Required annual reductions in direct nonpoint sources in sub-watershed WOC-12.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 4,970 | 5% | 149 | 97% |
| Wildlife in Streams | 17,704 | 18% | 17,704 | 0% |
| Straight Pipes | 77,005 | 77% | 0 | 100% |
| Total | 99,679 | 100% | 17,853 | 82% |

**Table D.25. Required annual reductions in nonpoint sources in sub-watershed WOC-13.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 99,840 | 0.4% | 2,995 | 97% |
| Pasture | 21,831,866 | 98% | 654,955 | 97% |
| Forest | 53,561 | 0.2% | 53,561 | 0% |
| Residential | 361,471 | 2% | 10,844 | 97% |
| Total | 22,346,738 | 100% | 722,356 | 97% |

**Table D.26. Required annual reductions in direct nonpoint sources in sub-watershed WOC-13.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 22,197 | 20% | 666 | 97% |
| Wildlife in Streams | 26,858 | 24% | 26,858 | 0% |
| Straight Pipes | 61,604 | 56% | 0 | 100% |
| Total | 110,660 | 100% | 27,524 | 75% |

**Table D.27. Required annual reductions in nonpoint sources in sub-watershed WOC-14.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 85,984 | 0.2% | 2,580 | 97% |
| Pasture | 34,363,317 | 99% | 1,030,899 | 97% |
| Forest | 43,236 | 0.1% | 43,236 | 0% |
| Residential | 331,277 | 1.0% | 9,938 | 97% |
| Total | 34,823,815 | 100% | 1,086,653 | 97% |

**Table D.28. Required annual reductions in direct nonpoint sources in sub-watershed WOC-14.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 35,512 | 40% | 1,065 | 97% |
| Wildlife in Streams | 22,484 | 25% | 22,484 | 0% |
| Straight Pipes | 30,802 | 35% | 0 | 100% |
| Total | 88,798 | 100% | 23,549 | 73% |

**Table D.29. Required annual reductions in nonpoint sources in sub-watershed WOC-15.**

| Land Use | Current conditions load (x $10^8$ cfu/year) | Percent of total load from nonpoint sources | TMDL nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cropland | 10,072 | 0.1% | 302 | 97% |
| Pasture | 8,045,623 | 98% | 241,368 | 97% |
| Forest | 19,823 | 0.2% | 19,823 | 0% |
| Residential | 150,542 | 2% | 4,516 | 97% |
| Total | 8,226,060 | 100% | 266,010 | 97% |

**Table D.30. Required annual reductions in direct nonpoint sources in sub-watershed WOC-15.**

| Source | Current Conditions load (x $10^8$ cfu/year) | Percent of total load to stream from direct nonpoint sources | TMDL direct nonpoint source allocation load (x $10^8$ cfu/year) | Percent Reduction |
|---|---|---|---|---|
| Cattle in Streams | 8,117 | 45% | 244 | 97% |
| Wildlife in Streams | 10,008 | 55% | 10,008 | 0% |
| Total | 18,125 | 100% | 10,251 | 43% |