Fecal Bacteria and General Standard Total Maximum Daily Load Development for Peak Creek

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EXECUTIVE SUMMARY

Background and Applicable Standards

Peak Creek was placed on the Commonwealth of Virginia's 1996 Section 303(d) TMDL Priority List because of violations of the fecal coliform bacteria water quality standard and the General Standard (benthic). The focus of this TMDL is on the fecal coliform and benthic impairments in Peak Creek. Based on exceedances of the standard recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the stream does not support primary contact recreation (*e.g.,* swimming, wading, and fishing). The new applicable state standard (Virginia Water Quality Standard 9 VAC 25-260-170) specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 400 colony-forming units (cfu) per 100 milliliters (ml). Alternatively, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 200-cfu/100 ml. A review of available monitoring data for the watershed indicated that fecal coliform bacteria were consistently elevated above the 400-cfu/100 ml standard. EPA directed that the state develop a water quality standard for *E. coli* bacteria to eventually replace the fecal coliform standard. This new standard specifies that the number of *E. coli* bacteria shall not exceed a maximum allowable level of 235-cfu /100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). In addition, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 126-cfu/100 ml.

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP). Using the RBP, the health of the benthic macroinvertebrate community is typically assessed through measurement of 8 biometrics that measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level. Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, moderately impaired, or severely impaired). Using this methodology, Peak Creek was rated as moderately impaired.

TMDL Endpoint and Water Quality Assessment

Fecal Coliform

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife, grazing livestock, land application of manure, land application of biosolids, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (straight pipes, dairy parlor waste, etc.). There is one Virginia Pollutant Discharge Elimination System (VPDES) permitted discharge in the Peak Creek watershed: Magnox (VA0000281). It is not expected to contain measurable amounts of fecal coliform, however it does discharge copper and zinc. There is one general permit (VAG402040) for a private residence in Peak Creek which discharges fecal coliform.

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* target was a geometric mean not exceeding 126-cfu/100 ml and a single sample maximum of 235-cfu/100 ml. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

General Standard (benthic)

TMDLs must be developed for a specific pollutant(s). While benthic assessments are very good at determining if a particular stream segment is impaired, they usually do not provide enough information to determine the cause(s) of the impairment. The process outlined in EPA's Stressor Identification Guidance Document (EPA, 2000) was used to systematically identify the most probable stressor(s) for Peak Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical data from ambient monitoring stations 9-PKC007.82, 9-PKC009.29 and 9-PKC011.11 was used in the analysis to provide evidence to support or eliminate potential stressors.

Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Landuse data, as well as a visual assessment of conditions along the stream, provided additional information to eliminate or support candidate stressors. The potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature, and organic matter.

The results of the stressor analysis for Peak Creek were divided into three categories:

> **Non-Stressor**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.
>
> **Possible Stressor**: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.
>
> **Most Probable Stressor**: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

Some evidence exists that organic matter should be considered as a possible stressor. It is anticipated that reductions will occur in the primary sources of organic matter via implementation of the fecal bacteria TMDL developed for Peak Creek. Comprehensive analyses strongly suggest, however, that the most significant stressors are metals (*i.e.*, Cu and Zn). Sampling by VADEQ and others provide conclusive evidence that elevated metals are present throughout Peak Creek, even at the non-impaired reference station. Therefore, multiple sources of metals exist in the watershed. In summary, the selected stressors were the ones that had the most chemical and biological evidence. MapTech personnel met with VADEQ regional and headquarters staff on March 1, 2004 and it was collectively decided that metals were the single most important stressor in Peak Creek. It is recognized that there are other contributing factors to the impairments (such as the channelization of Peak Creek through the Town of Pulaski). VADEQ should continue regular chemical and biological sampling in this watershed. Special studies should also be periodically employed. It will be necessary to identify all significant sources of heavy metals in the watershed and collect the information necessary to determine if other stressors need to be addressed in the future. The General Standard (benthic) TMDL for Peak Creek was developed for metals Cu and Zn.

Sources of Cu and Zn include: naturally occurring concentrations in soils, elevated concentrations in soils disturbed by historical mining operations, urban stormwater, permitted loads from industrial discharge and stormwater, and stormwater from a contaminated industrial site. Delivery mechanisms to the stream include direct loads, transport with sediment in storm runoff, and transport of dissolved metals in storm runoff.

Water Quality Modeling

Fecal Coliform

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and perform TMDL allocations. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. Due to the lack of continuous stream flow data for Peak Creek, the paired watershed approach (with additional refinement using instantaneous flow measurements) was used to calibrate the HSPF model. Through this approach, the HSPF model was calibrated using data from a hydrologically similar watershed, where continuous stream flow was available. The calibrated parameters from the model (*e.g.*, lower zone storage), in conjunction with physically derived parameters (*e.g.*, land slope and slope length) specific to Peak Creek, were used as an initial representation of the watershed. This representation was then refined through calibration to instantaneous flow measurements collected primarily during base-flow conditions. The Upper Tinker Creek watershed was compared to the Peak Creek watershed and chosen as an appropriate watershed for a paired-watershed calibration. The hydrologic comparison of the watersheds was established by examining the landuse distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group. The HSPF input parameters for Upper Tinker Creek watershed were used as base input parameters for Peak Creek when calibrating Peak Creek with the flow values from USGS

Stations #03168450 (Peak Creek at Magnox-Pulaski, Pulaski, VA) and #03168750 (Thorne Springs Branch near Dublin, VA). The flow period used for hydrologic calibration included 10/1/86 through 9/30/01. For purposes of modeling watershed inputs to in-stream water quality, the Peak Creek drainage area was divided into nine subwatersheds. The water quality calibration and validation were conducted using monitored data collected at VADEQ monitoring stations between October 1993 and September 2002. Modeled coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

General Standard (benthic) – Copper and Zinc

Copper and Zinc loads to the stream were considered in two manners. First, the likelihood of dissolved metals reaching acute levels of toxicity in the water column during low-flow and storm events was assessed. The impact of point source discharges of Cu and Zn during low flow was analyzed and it was determined that the concentrations of Cu and Zn would not likely approach the acute criteria for aquatic life (*i.e.*, 13 μg/l and 120 μg/l for Cu and Zn, respectively). It was anticipated that acidic runoff from historic industrial sites may leach significant levels of dissolved Cu and Zn to the stream during storm events. The weight of evidence at this time, including site observations and collected data, points to soils at or from the Allied Signal site as the main source of contamination. An equilibrium speciation model (MINTEQA2 for Windows, Allison Geoscience Consultants, Inc. and HydroGeoLogic, Inc., version 1.50) was used to examine this possibility. It was determined that dissolved Cu and Zn may reach acutely toxic levels in stormwater, however, it was considered unlikely that concentration of the dissolved constituents would ever reach toxic levels in the stream, due to dilution and precipitation of the metals when stormwater mixed with the more-basic stream water.

The dissolved constituent analysis supported the conclusions of the stressor identification, which indicated that high concentrations of Cu and Zn in stream sediment were the primary stressors. Metal concentrations in stream sediment were modeled using a steady-state mass-balance approach. Virginia has no criteria for metal concentrations in stream sediment; therefore a reference watershed approach was used to define allowable

TMDL loading rates in the Peak Creek watershed. This approach pairs two watersheds – one that is supportive of their designated use(s) and one whose streams are impaired. The Upper Peak Creek watershed was selected as the TMDL reference for Peak Creek. The TMDL target was defined as the median monitored sediment concentrations of Cu and Zn at the non-impaired Upper Peak Creek site (9-PKC011.11). Sediment delivery to the stream was modeled using the Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992). Sufficient flow data was not available within or from a nearby watershed for hydrologic calibration. Since the model was originally developed for use in ungaged watersheds, the model was used with recommended model parameters for the landuses and conditions found in the watershed.

Existing Conditions

Fecal Coliform

Wildlife populations and ranges, biosolids application rates and practices, rate of failure, location, and number of septic systems, domestic pet populations, numbers of cattle and other livestock; and information on livestock and manure management practices for the Peak Creek watershed were used to calculate fecal coliform load from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates due to these sources were calculated for the watershed and incorporated into the model. To accommodate the structure of the model, calculation of the fecal coliform accumulation and source contributions on a monthly basis accounted for seasonal variation in watershed activities such as wildlife feeding patterns and land application of manure. Also represented in the model were direct nonpoint sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock.

Contributions from all of these sources were updated to 2003 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record covering the period October 1986 to September 1991. Under existing conditions (2003), the HSPF model provided a comparable match to the VADEQ monitoring data, with output from the model indicating violations of both the instantaneous and geometric mean standards throughout the watershed.

General Standard (benthic) – Copper and Zinc

Concentrations of Cu and Zn in the stream sediments were modeled and calibrated to the median concentrations observed at ambient monitoring stations that coincide with the outlets of Model Segments. The modeled loads delivered from the contaminated site (Allied Signal) were an order of magnitude greater than the loads from any other source (Table ES.1).

Table ES.1 Existing conditions of Cu and Zn in sediment, as modeled, at four points in the Peak Creek drainage.

Pollutant Source	Sediment (Mg/yr)	Cu (g/yr)	Zn (g/y)
Segment 1 (Reference)			
Background	578	28,916	339,476
Resulting Concentration (mg/kg)		50	587
Segment 2			
Background	1,760	52,514	253,956
Urban Stormwater	30	36,560	193,851
Allied Signal Stormwater	16	56,405	1,405,621
Magnox Process Water	4.89	8,037	28,970
Magnox Stormwater	0.09	49	6,003
Resulting Concentration (mg/kg)		76	933
Segment 3			
Background	289	8,166	31,566
Urban Stormwater	16	20,357	107,939
Allied Signal Stormwater	23	2,459,282	2,035,641
Resulting Concentration (mg/kg)		983	1,620
Segment 4			
Background	2,143	55,093	127,138
Urban Stormwater	21	25,832	136,968
Resulting Concentration (mg/kg)		564	956

Load Allocation Scenarios

Fecal Coliform

The next step in the TMDL process was to determine how to proceed from existing watershed conditions to reduce the various source loads to levels that would result in attainment of the water quality standards. Because Virginia's *E. coli* standard does not permit any exceedances of the standard, modeling was conducted for a target value of 0% exceedance of the 126 cfu/100 ml geometric mean standard and 0% exceedance of the sample maximum *E. coli* standard of 235 cfu/100 ml. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the target of 0% exceedance. The reductions in percentages in loading from existing conditions are given in Table ES.2. Scenario 3 in Table ES.2 would generally be adopted as the targets for a stage I implementation goals.

Table ES.2 Allocation scenarios for bacterial concentration with current loading estimates in the Peak Creek impairment.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	21.7	17.5
2	0	0	0	0	0	100	20.0	17.4
3 [1]	0	0	90	50	50	100	1.67	9.53
4	0	0	100	99	99	100	0.0	1.04
5	0	99	100	99	99	100	0.0	0.11
6 [2]	0	68	100	99.5	99.5	100	0.0	0.0

[1] Stage I implementation scenario.
[2] Final TMDL allocation.

General Standard (benthic) – Copper and Zinc

For modeling allocations, loads from permitted sources were adjusted to permitted levels. Reductions were then made to the loads from specific sources, starting with the Allied Signal site and including additional sites as warranted. The targeted value for Zn can be achieved through an 83% reduction in the load from the Allied Signal site. The load reductions for Cu are distributed between the Allied Signal site, urban stormwater, and background sources (Table ES.3).

Table ES.3 Allocation scenario 2, focusing on load reductions from the Allied Signal site and a combination of urban stormwater and background loads.

Pollutant Source	Cu Reduction	Cu (g/yr)	Zn Reduction	Zn (g/y)
Segment 1 (Reference)				
Background	0%	28,916	0%	339,476
Resulting Concentration (mg/kg)		**50**		**587**
Segment 2				
Background	40%	31,508	0%	253,956
Urban Stormwater	40%	21,936	0%	193,851
Allied Signal Stormwater	99%	564	83%	238,956
Magnox Process Water	0%	12,322	0%	56,008
Magnox Stormwater	0%	141	0%	957
Resulting Concentration (mg/kg)		**40**		**453**
Segment 3				
Background	40%	4,900	0%	31,566
Urban Stormwater	40%	12,214	0%	107,939
Allied Signal Stormwater	99%	24,593	83%	346,059
Resulting Concentration (mg/kg)		**50**		**577**
Segment 4				
Background	0%	55,093	0%	127,138
Urban Stormwater	0%	25,832	0%	136,968
Resulting Concentration (mg/kg)		**45**		**375**

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to 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 General Standard (benthic) impairments on Peak Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once EPA has approved a TMDL, measures must be taken to reduce pollution levels in the stream. These measures, 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 recent *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and is available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

In general, Virginia intends for the required 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 to control bacteria and minimize streambank erosion 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.

Watershed stakeholders will have 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 Stage I scenarios are targeted at controllable, anthropogenic bacteria and metal sources.

Public Participation

During development of the TMDL for the Peak Creek watershed, public involvement was encouraged through several meetings. A basic description of the TMDL process and the agencies involved was presented at the kickoff meeting on May 29, 2003 and the New River Roundtable Agricultural subcommittee met on August 9, 2003. The 1st public meeting was held on September 30, 2003 to discuss the source assessment input, bacterial source tracking, and model calibration data. A "Field Day" was offered on November 18, 2003 to all stakeholders in the Back Creek, Crab Creek, and Peak Creek watershed areas. Participants were shown examples of aquatic life from a nearby reference stream, then looked at 2 sites on Back Creek to contrast the differences and discuss potential implementation strategies. The final model simulations and the TMDL load allocations were presented during the 2nd public meeting on March 17, 2004.

The meetings served to facilitate understanding of, and involvement in, the TMDL process. Posters that graphically illustrated the "state of the watershed" were on display at each meeting to provide an additional information component for the stakeholders. MapTech personnel were on hand to provide further clarification of the data as needed. Input from these meetings was utilized in the development of the TMDL and improved confidence in the allocation scenarios that were developed.

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PART I: BACKGROUND AND APPLICABLE STANDARDS

1. INTRODUCTION

1.1 Background

The need for TMDLs for the Peak Creek watershed area is based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (United States Environmental Protection Agency, 1999), states:

> *According to Section 303(d) of the Clean Water Act and EPA water quality planning and management regulations, States are required to identify waters that do not meet or are not expected to meet water quality standards even after technology-based or other required controls are in place. The waterbodies are considered water quality-limited and require TMDLs.*
>
> *…A TMDL is a tool for implementing State water quality standards, and is based on the relationship between pollution sources and in-stream water quality conditions. The TMDL establishes the allowable loadings or other quantifiable parameters for a waterbody and thereby provides the basis for States to establish water quality-based controls. These controls should provide the pollution reduction necessary for a waterbody to meet water quality standards.*

The Peak Creek watershed in Virginia's Pulaski County is part of the New River basin (Figure 1.1). Peak Creek flows into Claytor Lake, a reservoir on the New River. The New River flows into the Ohio River, which flows into the Mississippi River and eventually flows into the Gulf of Mexico.

According to the 1996 303(d) TMDL Priority List (VADEQ 1996), Peak Creek was listed as impaired. Virginia Department of Environmental Quality (VADEQ) has identified this segment as impaired with regard to both fecal coliform and the General Standard (benthic). Peak Creek remained on the 1998 303(d) Total Maximum Daily Load Priority List and Report and 2002 303(d) Report on Impaired Waters lists.

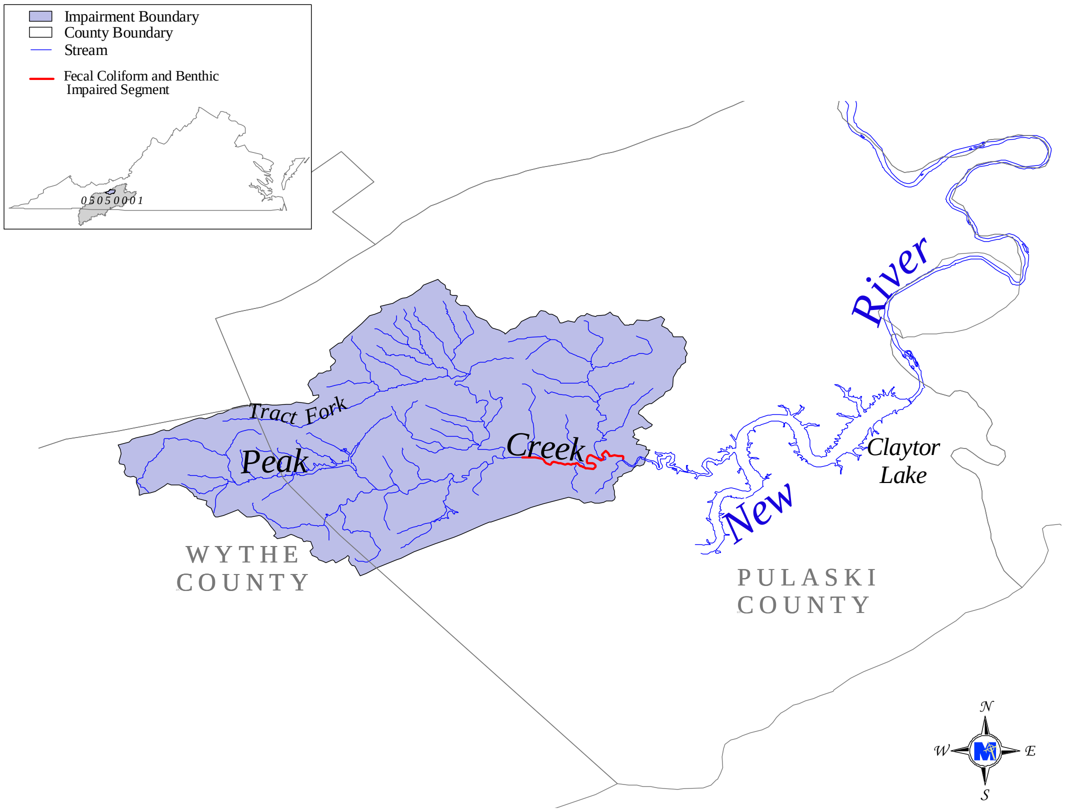

Figure 1.1 Location of impaired stream in the Peak Creek Watershed.

Peak Creek (waterbody ID # VAW-N17R) was listed as impaired for both fecal coliform and benthic impairments. Peak Creek was initially listed as a General Standard impairment during the 1998 assessment period. Peak Creek had a rating of moderately impaired at benthic monitoring station 9PKC009.29 and was. During the 2002 assessment period, Peak Creek had a rating of moderately impaired at station 9PKC009.29. Subsequently, during the 2002 assessment period, Peak Creek was overlisted for fecal coliform impairment. During the 2002 assessment period, 4 of 23 samples taken at river mile 09.29 violated the standard. The impairment of Peak Creek extends approximately 0.2 miles downstream of Washington St. Bridge to the Backwaters of Claytor Lake.

The Peak Creek watershed (USGS Hydrologic Unit Code #0505001) is part of the New River basin. The land area of the affected watersheds is approximately 54,000 acres, with pasture/hay and woodland as the primary landuses (Figure 1.2).

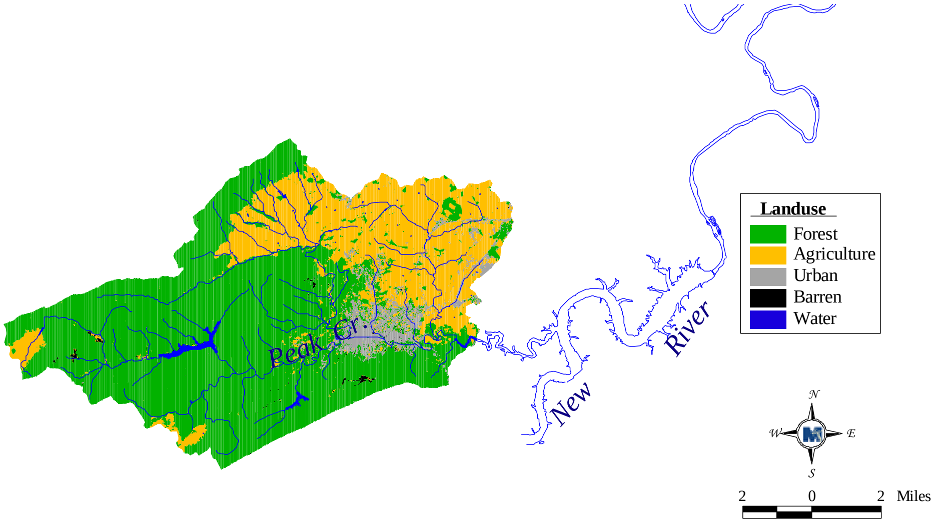

Figure 1.2 Landuses in the Peak Creek Watershed.

The National Land Cover Data (NLCD) produced cooperatively between USGS and EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 5 Thematic Mapper (TM) satellite images taken between 1990 and 1994, digital landuse coverage was developed identifying up to 21 possible landuse types. Classification, interpretation, and verification of the land cover dataset involved several data sources (when available) including: aerial photography; soils data; population and housing density data; state or regional land cover data sets;

USGS landuse and land cover (LUDA) data; 3-arc-second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and landuse proportions for each impaired segment are given in Table 1.1.

Table 1.1 Area affecting the impairment and contributing landuses.

	Peak Creek
Landuse	**Acreage**
Water	247
Residential/Recreational	1,687
Commercial & Services	653
Barren	200
Woodland/Wetland	35,471
Pasture/Hay	13,446
Livestock Access	695
Cropland	1,577

The estimated human population within the drainage area is 14,451 (USCB, 1990, 2000). Among Virginia counties, Pulaski County ranks 19th for the number of dairy cows, 18th for the number of all cattle and calves, 18th for beef cattle, 6th for the number of sheep and lambs and 11th for production of corn silage. Pulaski County is also home to 471 species of wildlife, including 53 types of mammals (*e.g.,* beaver, raccoon, and white - tailed deer) and 418 types of birds (*e.g.,* wood duck, wild turkey, Canada goose)(VDGIF, 1999).

For the period from 1948 to 2000, the Peak Creek watershed received average annual precipitation of approximately 37.11 inches, with 54% of the precipitation occurring during the May through October growing season (SERCC, 2002). Average annual snowfall is 11.8 inches with the highest snowfall occurring during February (SERCC, 2002). Average annual daily temperature is 52.8 ºF. The highest average daily temperature of 83.6 ºF occurs in July, while the lowest average daily temperature of 22.8 ºF occurs in January (SERCC, 2002).

1.2 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's State Water Control Board *Water Quality Standards*, the term ‘water quality standards’ means "…provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law and the federal Clean Water Act."

As stated in Virginia state law 9 VAC 25-260-10 (Designation of uses),

> *A. All state waters, including wetlands, 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.*
>
> ◆
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*
>
> *G. The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*
>
> 1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
>
> 2. *Natural, ephemeral, intermittent or low flow conditions or water levels 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 requirements to enable uses to be met;*
>
> ◆
>
> 6. *Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

Because this study addresses both fecal coliform and benthic impairments, two water quality criteria are applicable. 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC 25-260-20) applies to the benthic impairment.

1.3 Applicable Criteria for Fecal Coliform Impairment

Prior to 2002, Virginia Water Quality Standards specified the following criteria for a non-shellfish supporting waterbody to be in compliance with Virginia's fecal standard for contact recreational use:

> *A. General requirements. In all surface waters, except shellfish waters and certain waters addressed in subsection B of this section, the 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 30-day period, or a fecal coliform bacteria level of 1,000 per 100 ml at any time.*

If the waterbody exceeded either criterion more than 10% of the time, the waterbody was classified as impaired and the development and implementation of a TMDL was indicated in order to bring the waterbody into compliance with the water quality criterion. Based on the sampling frequency, only one criterion was applied to a particular datum or data set. If the sampling frequency was one sample or less per 30 days, the instantaneous criterion was applied; for a higher sampling frequency, the geometric criterion was applied. This was the criterion used for listing the impairments included in this study. Sufficient fecal coliform bacteria standard violations were recorded at VADEQ water quality monitoring stations to indicate that the recreational use designations are not being supported.

EPA subsequently recommended that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. EPA is pursuing the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. The adoption of the *E. coli* and *enterococci* standard is now in effect in Virginia as of January 15, 2003.

The new criteria, outlined in 9 VAC 25-260-170, read as follows:

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. 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. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*
>
> *2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

	Geometric Mean[1]	*Single Sample Maximum*[2]
Freshwater[3]		
E. coli	*126*	*235*
Saltwater and Transition Zone[3]		
enterococci	*35*	*104*

[1] For two or more samples taken during any calendar month.

[2] No single sample maximum for enterococci and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.

[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

These criteria were used in developing the bacteria TMDLs included in this study.

1.4 Applicable Criterion for Benthic Impairment

The **General Standard,** as defined in Virginia state law 9 VAC 25-260-20, states:

> *A. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life.*

The General Standard is implemented by VADEQ through application of the Rapid Bioassessment Protocol II (RBP). Using the RBP, the health of the benthic macroinvertebrate community is typically assessed through measurement of 8 biometrics (Table 1.2) which measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level.

Each biometric measured at a target station is compared to the same biometric measured at a reference (non-impaired) station to determine each biometric score. These scores are then summed and used to determine the overall bioassessment (*e.g.*, non-impaired, moderately impaired, or severely impaired).

Table 1.2 Components of the RBP Assessment.

Biometric	Benthic Health [1]
Taxa Richness	↑
Modified Family Biotic Index	↓
Scraper to Filtering Collector Ratio	↑
EPT / Chironomid Ratio	↑
% Contribution of Dominant Family	↓
EPT Index	↑
Community Loss Index	↓
Shredder to Total Ratio	↑

[1] An upward arrow indicates a positive response in benthic health when the associated biometric increases.

PART II: FECAL BACTERIA TMDLS

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Selection of a TMDL Endpoint and Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of Peak Creek is protected during times when it is most vulnerable.

Peak Creek was initially placed on the Virginia 2002 Section 303(d) Report on Impaired Waters for violations of the fecal bacteria standard. Elevated levels of fecal coliform bacteria recorded at VADEQ ambient water quality monitoring stations showed that this stream segment does not support the primary contact recreation use.

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Peak Creek TMDL, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations (Section 1.2 of this document). In order to remove a water body from a state’s list of impaired waters; the Clean Water Act requires compliance with that state's water quality standard. Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals (section 4.2 of this document), assessment of TMDLs was made using both the geometric mean standard of 126 cfu/100 ml and the instantaneous standard of 235 cfu/100 ml. Therefore, the in-stream *E. coli* targets for these TMDLs were a monthly geometric mean not exceeding 126 cfu/100 ml and a single sample not exceeding 235 cfu/100 ml.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and will help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Peak Creek watershed are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include nonpoint sources that are not precipitation driven (*e.g.*, direct fecal deposition to stream).

A graphical analysis of measured fecal coliform concentrations versus the level of flow at the time of measurement showed that there was no obvious critical flow level (Figure 2.1 through Figure 2.6). That is, the analysis showed no obvious dominance of either nonpoint sources or point sources. Violations of the standard were recorded in all flow regimes. Based on this analysis, a time period for modeling allocation scenarios was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting period was October 1980 through September 1985.

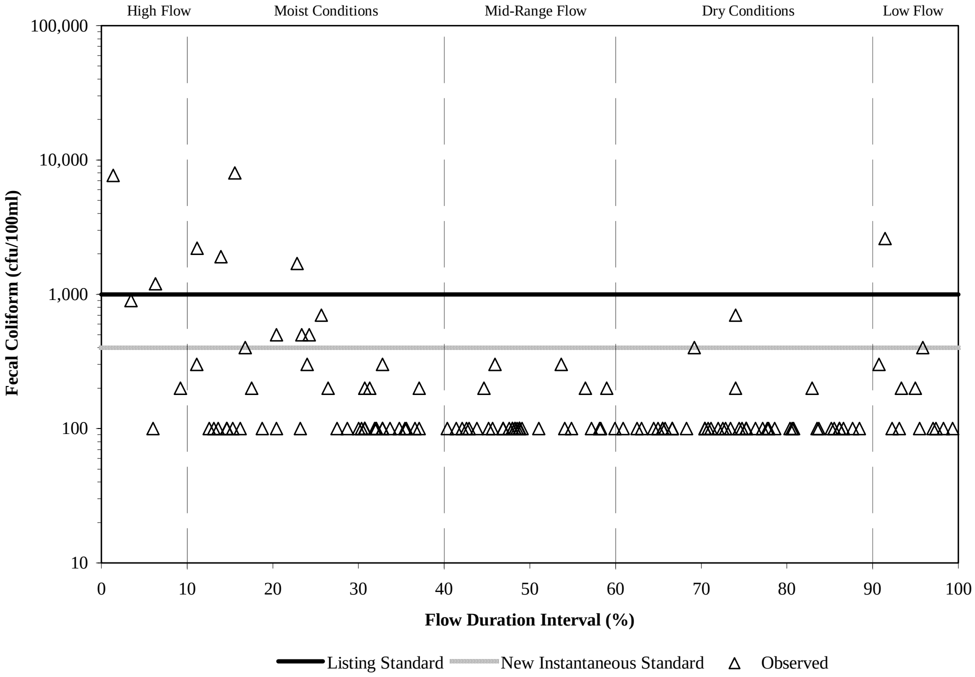

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 9PKC004.65) and discharge in the Peak Creek.

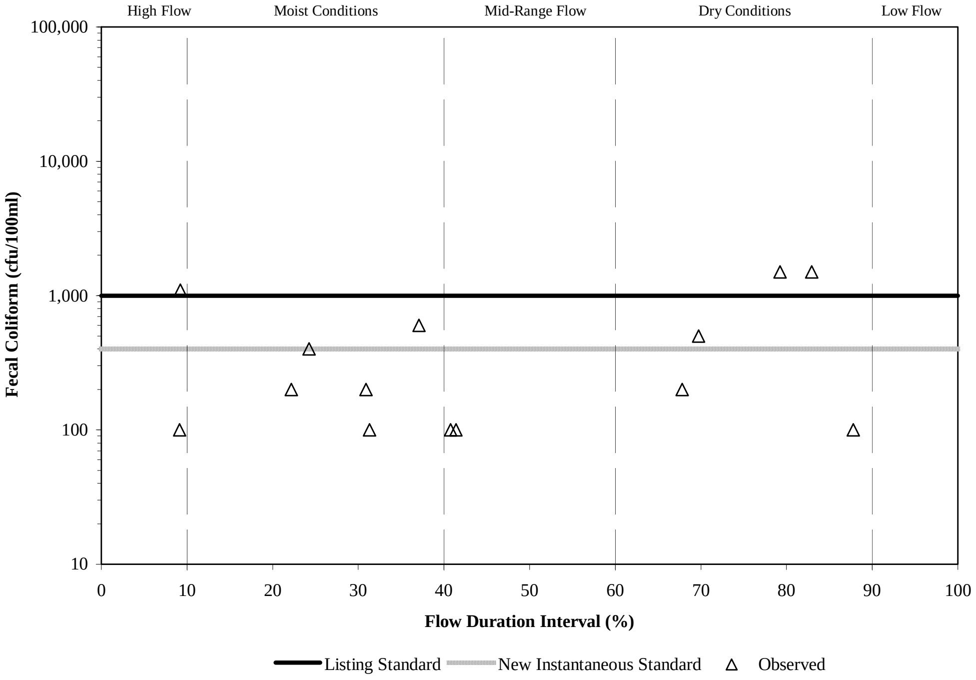

Figure 2.2 **Relationship between fecal coliform concentrations (VADEQ Station 9PKC007.82) and discharge in the Peak Creek.**

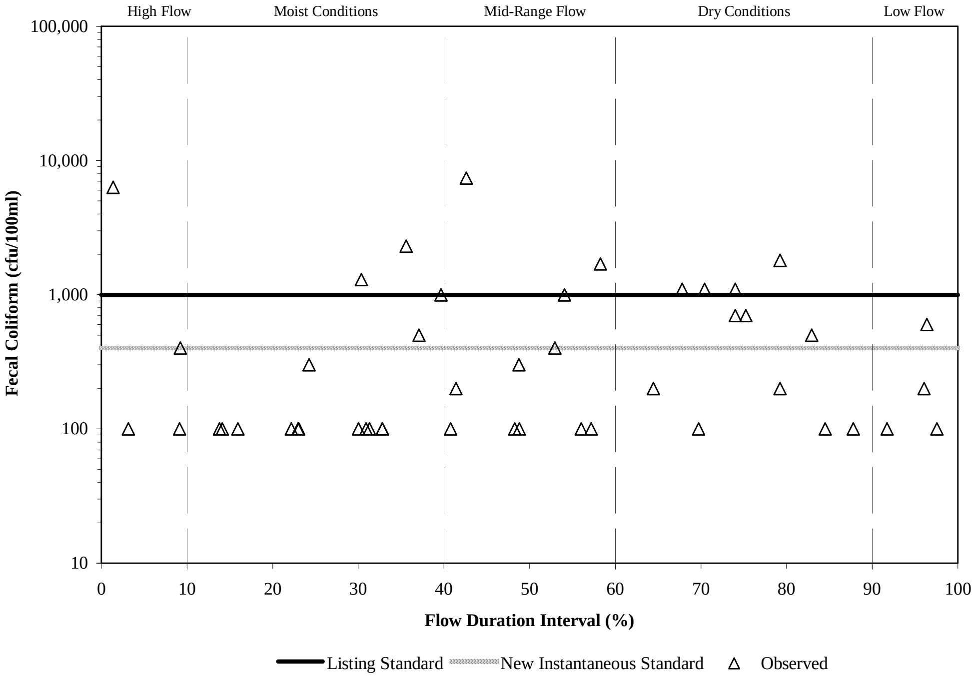

Figure 2.3 **Relationship between fecal coliform concentrations (VADEQ Station 9PKC009.29) and discharge in the Peak Creek.**

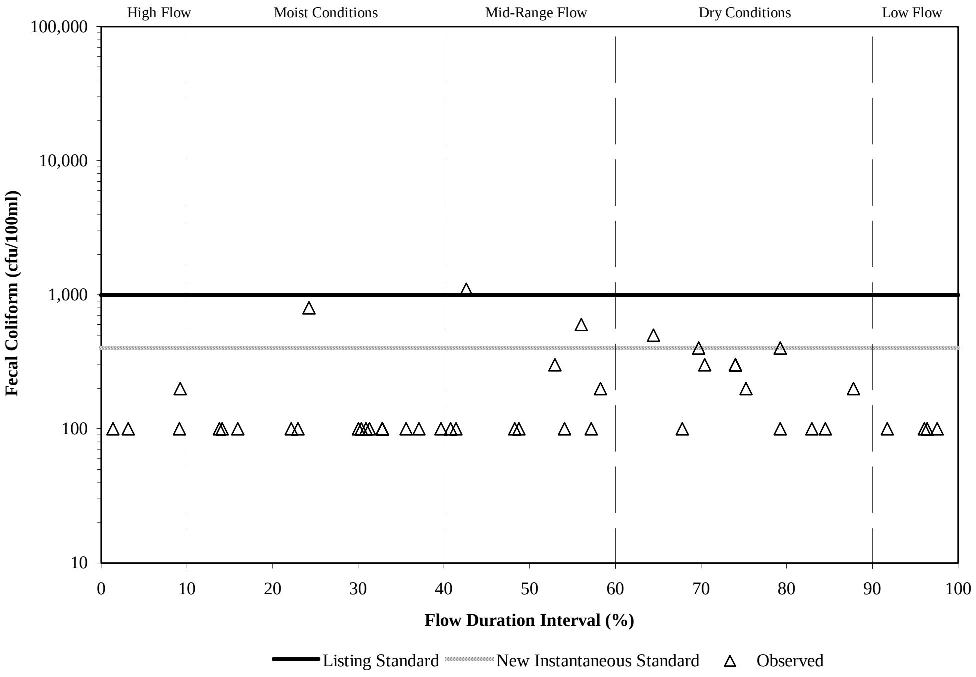

Figure 2.4 **Relationship between fecal coliform concentrations (VADEQ Station 9PKC011.11) and discharge in the Peak Creek.**

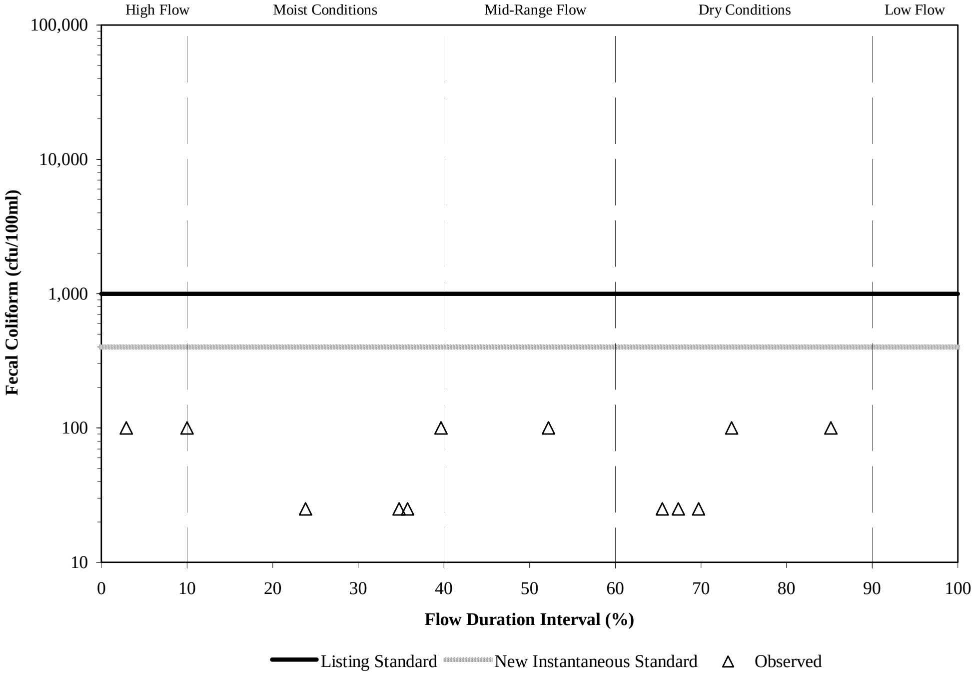

Figure 2.5 **Relationship between fecal coliform concentrations (VADEQ Station 9PKC016.91) and discharge in the Peak Creek.**

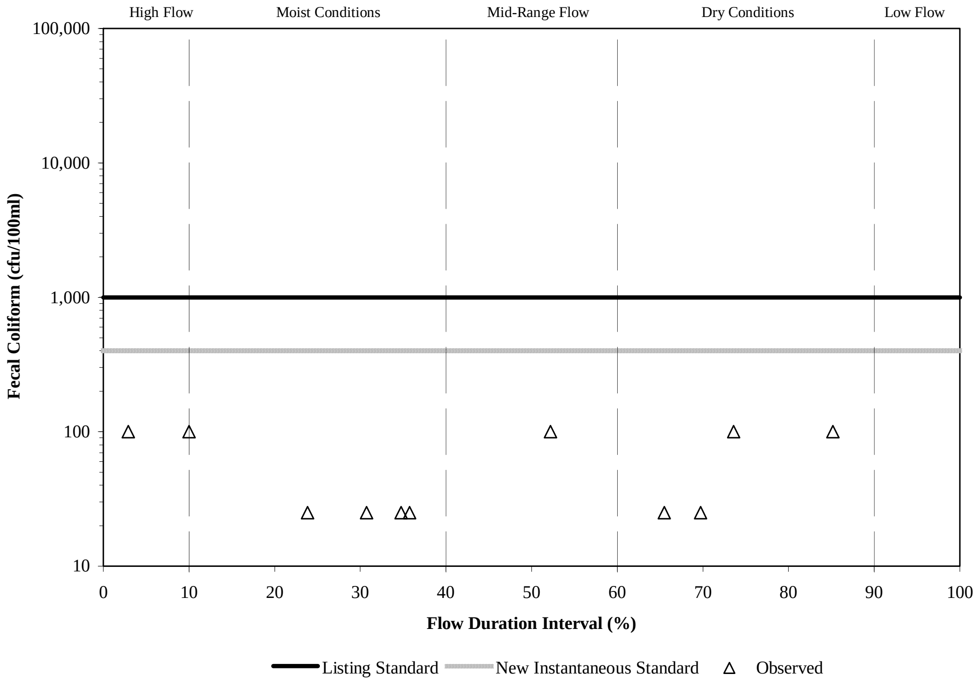

Figure 2.6 Relationship between fecal coliform concentrations (VADEQ Station 9PKC017.71) and discharge in the Peak Creek.

2.2 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Peak Creek watershed. An examination of data from water quality stations used in the 303(d) assessment and data collected during TMDL development were analyzed. Sources of data and pertinent results are discussed.

2.2.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from 6 VADEQ in-stream monitoring stations used for TMDL assessment; and
- Bacteria enumerations and bacterial source tracking from 1 VADEQ in-stream monitoring stations analyzed during TMDL development.

2.2.1.1 Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples, collected by VADEQ, were analyzed from January 1990 through October 2002 (Figure 2.7) and are included in the analysis. Samples were taken for the expressed purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 1,000 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.1 summarizes the fecal coliform samples collected at the in-stream monitoring stations used for TMDL assessment.

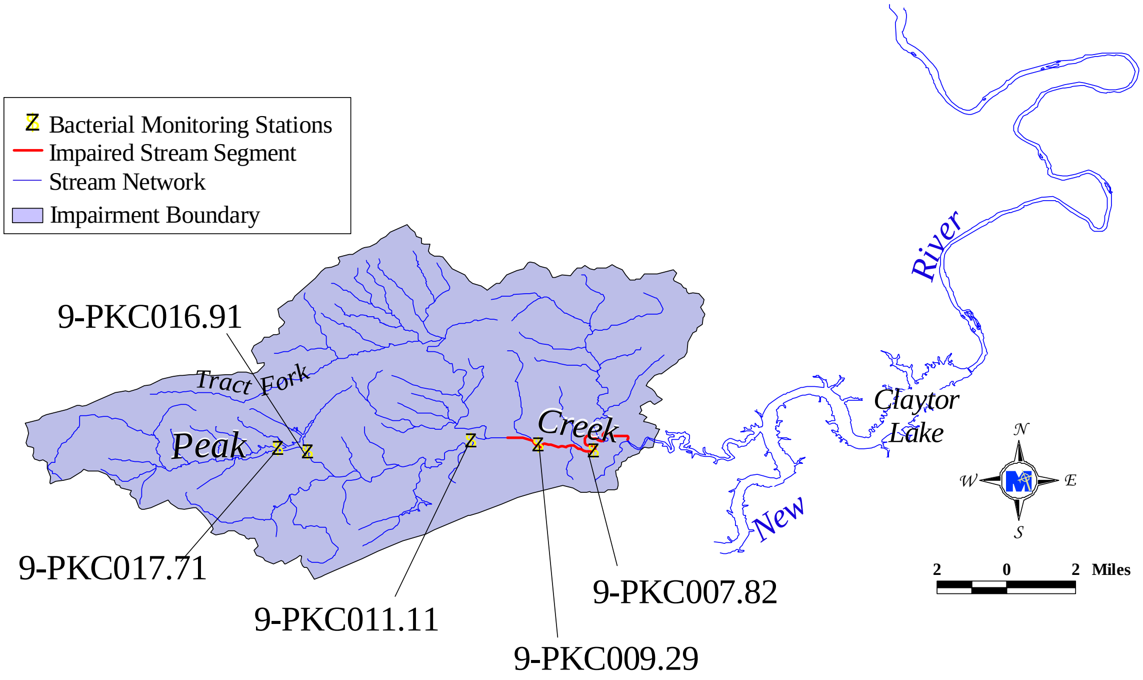

Figure 2.7 **Location of VADEQ water quality monitoring stations used for TMDL assessment in the Peak Creek watershed.**

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for period January 1990 through October 2002.

Impairment	VADEQ Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] %	Violations[2] %
Peak Creek	9-PKC004.65	142	100	8,000	320	100	7	13
Peak Creek	9-PKC007.82	14	100	1,500	479	200	3	5
Peak Creek	9-PKC009.29	47	100	7,400	715	200	9	16
Peak Creek	9-PKC011.11	45	100	1,100	198	100	1	4
Peak Creek	9-PKC016.91	12	25	100	63	63	0	0
Peak Creek	9-PKC017.71	11	25	100	59	25	0	0

[1] Violations are based on the pre-2003 fecal coliform instantaneous standard (i.e., 1,000 cfu/100ml)

[2] Violations are based on the interim fecal coliform instantaneous standard (i.e., 400 cfu/100ml)

2.2.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from November 2002 through October 2003. Specifically, water quality samples were taken at a single station in the Peak Creek watershed (Figure 2.8). All samples were analyzed for fecal coliform and *E. coli* concentrations, and for bacteria source (*i.e.*, human, livestock, pets, wildlife) by the Environmental Diagnostics Laboratory (EDL) at MapTech. Tables 2.2 and 2.3 summarize the fecal coliform and *E. coli* concentration data, respectively, at this station. Bacterial source tracking (BST) is discussed in greater detail in Section 2.2.2.2.

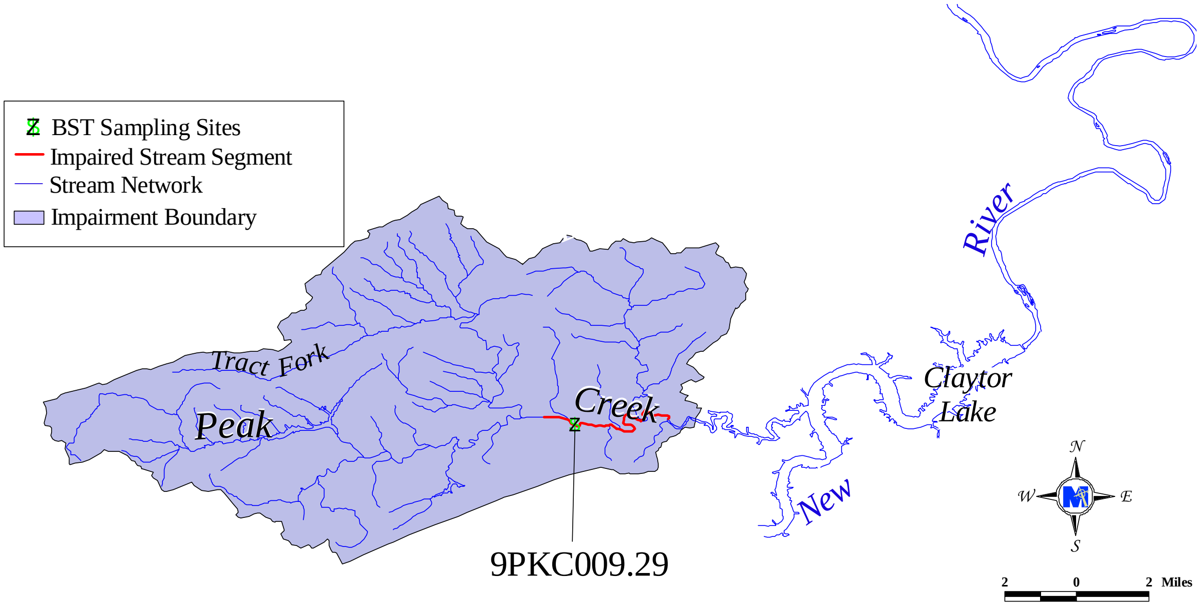

Figure 2.8 Location of the BST water quality monitoring station in the Peak Creek watershed.

Table 2.2 Summary of water quality sampling conducted by VADEQ during TMDL development. Fecal coliform concentrations (cfu/100 ml).

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)	Violations[2] (%)
Peak Creek	9PKC009.29	12	120	18,000	2,192	365	17	42

[1] Violations based on listing fecal coliform instantaneous standard (*i.e.*, 1,000 cfu/100ml)

[2] Violations based on new fecal coliform instantaneous standard (*i.e.*, 400 cfu/100ml)

Table 2.3 Summary of water quality sampling conducted by VADEQ during TMDL development. *E. coli* concentrations (cfu/100 ml).

Impairment	Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] (%)
Peak Creek	9PKC009.29	12	2	10,000	1,295	180	42

[1] Violations based on *E. coli* instantaneous standard (*i.e.*, 235 cfu/100ml)

2.2.1.3 Summary of In-stream Water Quality Monitoring Data

A wide range of fecal coliform concentrations have been recorded in the watershed. Concentrations reported during TMDL development tended to be higher than historical values reported by VADEQ during TMDL assessment. Exceedances of the instantaneous standard were reported in all flow regimes, leaving no apparent relationship between flow and water quality.

2.2.2 Analysis of Water Quality Monitoring Data

The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

2.2.2.1 Summary of Frequency of Violations at the Monitoring Stations

All water quality data were collected at a time-step of at least one month. The state standard of 1,000 cfu/100 ml and 400 cfu/100 ml was used to test for fecal coliform violations. For samples with *E. coli* concentrations, violations of the state standard of 235 cfu/100 ml were calculated. Violation rates are listed in Tables 2.1 through 2.3. A distribution of fecal coliform concentrations at each sampling station in the watershed can be found in Appendix A. Monitoring performed during development of the TMDL indicate a higher frequency of violations than previously measured.

2.2.2.2 Bacterial Source Tracking

MapTech, Inc. was contracted to do analysis of fecal coliform and *E. coli* concentrations as well as bacterial source tracking. Bacterial source tracking is intended to aid in identifying sources (*i.e.*, human, pets, livestock, or wildlife) of fecal contamination in water bodies. Data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing solutions.

Several procedures are currently under study for use in BST. Virginia has adopted the Antibiotic Resistance Analysis (ARA) methodology implemented by MapTech's EDL. This method was selected because it has been demonstrated to be a reliable procedure for confirming the presence or absence of human, pet, livestock and wildlife sources in watersheds in Virginia. The results of sampling were reported as the percentage of isolates acquired from the sample that were identified as originating from either human, pet, livestock, or wildlife sources.

In spite of the high quality of the data collected, care should be taken in using these data. These data represent, at most, 12 instantaneous observations at each station and may not be representative of long-term conditions. The hydrologic conditions during this period were extreme, beginning with drought and ending with some of the wettest seasons on record. Additionally, the dynamics of the bacterial community are not well understood, so care should be taken in extrapolating from the in-stream condition to activities in the watershed. As with any other monitoring program, the data should not be viewed in a vacuum. Local knowledge of the sources involved, historical water quality records, and the hydrologic conditions during sampling should all be considered in any interpretation of this data.

BST results of water samples collected at 1 ambient station in the Peak Creek drainage are reported in Table 2.4. The fecal coliform and *E. coli* enumerations are given to indicate the bacteria concentration at the time of sampling. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The statistical significance was determined through 2 tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations. The BST results indicate the presence of all sources (*i.e.*, human, livestock, wildlife and pets) contributing to the fecal bacteria violations.

Table 2.4 Summary of bacterial source tracking results from water samples collected in the Peak Creek impairment.

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as[1]:			
				Human	Pets	Livestock	Wildlife
9-PKC009.29	11/25/02	230	2	0	0	100	0
	12/17/02	150	23	**56**	0	**33**	11
	1/29/03	200	25	**17**	**22**	**22**	**39**
	2/25/03	220	52	**17**	**21**	**58**	4
	3/31/03	18,000	10,000	**13**	**53**	**13**	**21**
	4/29/03	360	120	**17**	**33**	**25**	**25**
	5/2803	370	130	0	**17**	**83**	0
	6/26/03	640	230	**13**	8	**29**	**50**
	7/22/03	600	510	**8**	**16**	**38**	**38**
	8/27/03	5,000	800	0	**38**	0	**62**
	9/22/03	410	550	**12**	**17**	**17**	**54**
	10/22/03	120	3,100	4	4	**33**	**59**

[1] **BOLD** type indicates a statistically significant value.

2.2.2.3 Trend and Seasonal Analyses

In order to improve TMDL allocation scenarios and, therefore, the success of implementation strategies, trend and seasonal analyses were performed on precipitation, and fecal coliform concentrations. A Seasonal Kendall Test was used to examine long-term trends. The Seasonal Kendall Test ignores seasonal cycles when looking for long-term trends. This improves the chances of finding existing trends in data that are likely to have seasonal patterns. Additionally, trends for specific seasons can be analyzed. For instance, the Seasonal Kendall Test can identify the trend (over many years) in discharge levels during a particular season or month.

A seasonal analysis of precipitation, and fecal coliform concentration data was conducted using the Mood Median Test. This test was used to compare median values of precipitation and fecal coliform concentrations in each month. Significant differences between months within years were reported.

2.2.2.4 Precipitation

Total monthly precipitation measured at NWS Station #446955 in Pulaski County was analyzed and no overall, long-term trend or seasonality was observed.

2.2.2.5 Fecal Coliform Concentrations

Water quality monitoring data collected by VADEQ were described in section 2.2.1.1. The trend analysis was conducted on data, if sufficient, collected at stations used in TMDL assessment. There were no stations with a significant seasonality effect (Table 2.5).

Table 2.5 Summary of trend analysis on fecal coliform (cfu/100 ml).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
PKC004.65	418.71	100	8,000	100	1,084.32	241	No Trend
PKC007.82	1,868.75	300	8,000	100	2,769.72	112	No Trend
PKC009.29	682.04	200	7,400	100	1,344.87	54	No Trend
PKC011.11	205.26	100	1,700	100	274.14	57	No Trend
PKC016.88	100	100	100	100	--	1	--
PKC016.91	100	100	100	100	0	13	--
PKC017.71	100	100	100	100	0	12	--

[1] SD: standard deviation
[2] N: number of sample measurements
[3] A number in the significant trend column represents the Seasonal-Kendall estimated slope, "--" insufficient data

3. FECAL COLIFORM SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential significant sources of fecal coliform in the Peak Creek watershed. The source assessment was used as the basis of water quality model development and ultimate analysis of TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local, state, and federal management agencies. This section documents the available information and interpretation for the TMDL analysis. The source assessment chapter is organized into point and nonpoint sections. The representation of the following sources in the model is discussed in Section 4.

3.1 Assessment of Point Sources

Point sources permitted to discharge in the Peak Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES) are listed in Table 3.1 and shown in Figure 3.1. There are currently no MS4 permitted storm sewer discharges in the watershed. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted dischargers are expected not to exceed the 126 cfu/100ml *E. coli* standard. One method for achieving this goal is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens and fecal coliform bacteria. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. If the concentration is high enough, pathogen concentrations, including fecal coliform bacteria concentrations, are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, fecal coliform concentrations are reduced to levels well below the standard.

Table 3.1 Permitted Point Sources in the Peak Creek Watershed.

Facility	VPDES #	Design Discharge (MGD)	Permitted For Fecal Control	Data Availability
Magnox Pulaski Inc	VA0000281	0.58	No	1976-2003
Residence	VAG402040	0.0005	Yes	No Data
TMD Friction Inc	VAR050139	Stormwater	No	Not Applicable
Bondcote Corporation	VAR050250	Stormwater	No	Not Applicable
Pulaski County Industrial Development Authority	VAR050339	Stormwater	No	Not Applicable
Jefferson Mills Inc	VAR050444	Stormwater	No	Not Applicable
Pulaski Furniture Corporation - Plant No. 5	VAR050454	Stormwater	No	Not Applicable
McCready Lumber Co Inc	VAR050772	Stormwater	No	Not Applicable
VDOT - Salem District - Rte 641 (0641 077 P98 N501)	VAR100264	Stormwater	No	Not Applicable
Pulaski Business Park	VAR101248	Stormwater	No	Not Applicable
VDOT Pulaski Co 0807 077 P01 N501 (58283)	VAR101880	Stormwater	No	Not Applicable
New Pulaski Elementary School	VAR101919	Stormwater	No	Not Applicable
Gem City Iron & Metal Company Incorporated	VAR520118	Stormwater	No	Not Applicable
Pulaski Furniture	VAR520122	Stormwater	No	Not Applicable

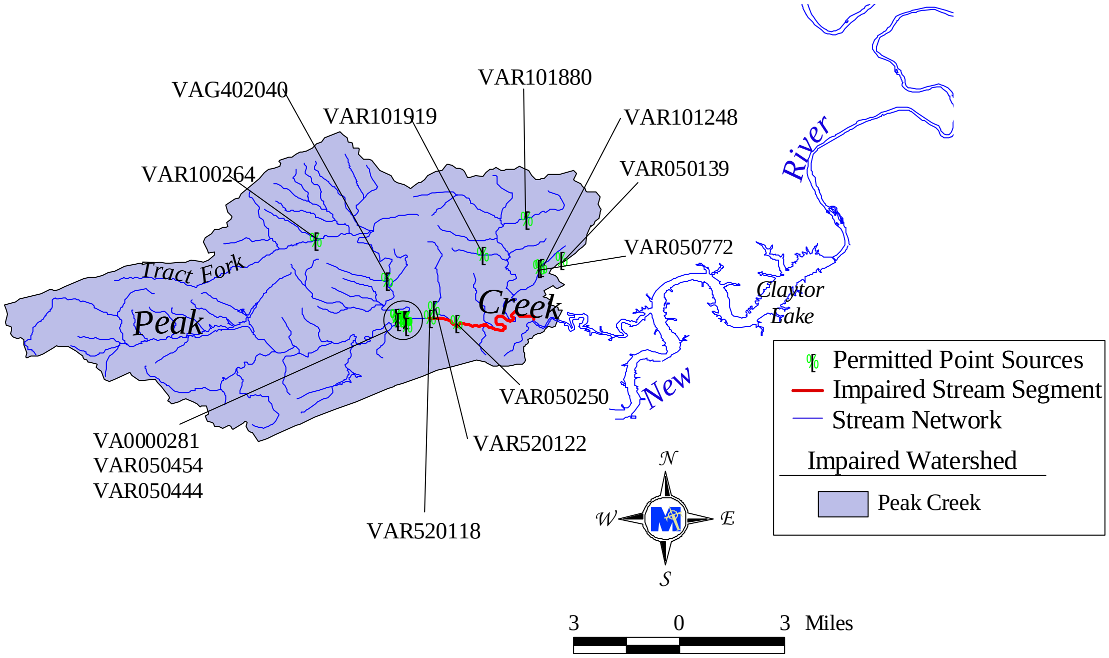

Figure 3.1 **Location of VPDES permitted point sources in the Peak Creek watersheds.**

3.2 Assessment of Nonpoint Sources

In the Peak Creek watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include exfiltration and overflows from municipal sewage systems, residential sewage treatment systems, land application of waste (livestock and biosolids), livestock, wildlife, and pets. Sources were identified and enumerated. Where appropriate, spatial distribution of sources throughout the watershed was also determined.

3.2.1 Private Residential Sewage Treatment

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and should be periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried absorption trenches consisting of perforated pipes enclosed in beds of gravel. This combination of pipe and trenches comprise the drainage field. Once in the soil, the effluent may potentially flow downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily through filtration by the soil matrix and die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters (ground and surface water). Properly designed, installed, and functioning septic systems that are more than 50 feet from a stream are considered to contribute virtually no fecal coliform to surface waters. Reneau (2000) reported that a very small portion of fecal coliform can survive in the soil system for over 50 days. This number might be higher or lower depending on soil moisture, temperature, and physical characteristics such as soil structure and texture.

A septic failure occurs when a drain field has inadequate drainage or a "break", such that effluent flows directly to the soil surface, bypassing travel through the soil profile. In this situation, the effluent is either available to be washed into waterways during runoff events or is directly deposited in-stream due to proximity. A permit from the Virginia Department of Health (VDH) is required for installing or repairing a septic system. A survey of septic pump-out contractors performed by MapTech showed that failures were more likely to occur in the winter to spring months than in the summer to fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed on the surface of the yard.

Table 3.2 indicates the human population contributing to the impairment, projected to current numbers based on 1990 and 2000 Census data. Due to the aggregation of census data from geographical units developed for the census (*i.e.*, census blocks and groups) to subwatersheds, some slight errors occurred (*e.g.,* small numbers of homes with sewer service indicated in subwatersheds where no service is available). These slight errors were controlled based on validation with public review and cross-referencing with other data sources (*e.g.,* public service authorities). The number of households that reported in the 1990 Census a system other than sewer or septic are an indicator of the potential number of households depositing sewage directly to the stream.

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml. An average fecal coliform density for human waste of 13,000,000 cfu/g was reported by Geldreich (1978) and a total wastewater load of 75 gal/day/person for households utilizing septic systems, with typical septic tank effluent having fecal coliform concentrations of 10,000 cfu/100 ml (Metcalf and Eddy, 1991).

Table 3.2 Human population, housing units, houses on sanitary sewer, houses on septic systems, and houses on other treatment systems for 2003 in the Peak Creek watershed.[1]

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other [2]
Peak Creek	14,454	6,858	4,241	2,427	190

[1] U.S. Census Bureau.

[2] Houses with treatment systems other than sanitary sewer and septic systems.

3.2.2 Public Sewage Treatment

Where residents have access to public sewer systems, sewage is collected and transported through a system of pipelines to the treatment facility, where it is treated (*e.g.*, removal of solids, and chlorination/de-chlorination) and discharged. Fecal bacteria remaining in the waste stream after treatment are accounted for as a point source (Section 3.1). However, failure of the collection system can occur through exfiltration (*e.g.*, leaking sewer lines) or overflows (*e.g.*, capacity of system exceeded due to blockage in line, system malfunction, or infiltration).

3.2.3 Livestock

The predominant types of livestock in the Peak Creek watershed are beef and dairy cattle, sheep, and horses, although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Natural Resources Conservation Service (NRCS), Skyline Soil and Water Conservation District (SSWCD), watershed visits, verbal communication with farmers, and review of all publicly available information on animal type and approximate numbers known to exist within Pulaski and Wythe Counties and the TMDL project areas. Table 3.3 gives estimates of livestock populations in the Peak Creek watershed. Values of fecal coliform density for livestock sources were based on sampling performed by MapTech. Reported manure production rates for livestock were taken from ASAE, 1998. A summary of fecal coliform density values and manure production rates is presented in Table 3.4.

Table 3.3 Estimated livestock populations in the Peak Creek watershed.

Watershed	Beef Cattle	Dairy Cattle	Horse	Sheep
Peak Creek	2,824	677	264	542

Table 3.4 Average fecal coliform densities and waste loads associated with livestock.[1]

Type	Waste Load (lb/d/an)	FC Density (cfu/g)
Dairy (1,400 lb)	120.4	258,000
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000
Dairy Separator	N/A	32,000[2]
Dairy Storage Pit	N/A	1,200[2]

[1] American Society of Agricultural Engineers.

[2] units are cfu/100ml

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Second, grazing livestock deposit manure directly on the land, where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

All grazing livestock were expected to deposit some portion of waste on pasture land areas. The percentage of time spent on pasture for dairy and beef cattle was reported by SWCD, NRCS, Virginia Department of Conservation and Recreation (VADCR), and Virginia Cooperative Extension (VCE) personnel (Table 3.6 through Table 3.8). Horses, sheep, beef cattle and goats were assumed to be in pasture 100% of the time. The average amount of time spent by dairy and beef cattle in stream access areas (*i.e.*, within 100 feet of the stream) for each month is given in Table 3.6 through Table 3.8.

Table 3.5 Average percentage of collected dairy waste applied throughout year.[1]

Month	Applied % of Total	Landuse
January	1.50	Cropland
February	1.75	Cropland
March	17.00	Cropland
April	17.00	Cropland
May	17.00	Cropland
June	1.75	Pasture
July	1.75	Pasture
August	1.75	Pasture
September	5.00	Cropland
October	17.00	Cropland
November	17.00	Cropland
December	1.50	Cropland

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD).

Table 3.6 Estimated average time dairy milking cows spend in different areas per day.[1]

Month	Pasture (hr)	Stream (hr)	Loafing Lot (hr)
January	2.5	0.17	21.4
February	2.5	0.17	21.4
March	3.5	0.26	20.2
April	5.4	0.34	18.2
May	6.3	0.34	17.3
June	6.9	0.43	16.7
July	7.6	0.43	16.0
August	7.6	0.43	16.0
September	7.7	0.34	16.0
October	7.3	0.26	16.4
November	6.4	0.26	17.3
December	4.7	0.17	19.1

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD), Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

Table 3.7 Estimated average time dry cows and replacement heifers spend in different areas per day.[1]

Month	Pasture (hr)	Stream (hr)	Loafing Lot (hr)
January	23.3	0.72	0.0
February	23.3	0.72	0.0
March	22.6	1.44	0.0
April	21.8	2.16	0.0
May	21.8	2.16	0.0
June	21.1	2.88	0.0
July	21.1	2.88	0.0
August	21.1	2.88	0.0
September	21.8	2.16	0.0
October	22.6	1.44	0.0
November	22.6	1.44	0.0
December	23.3	0.72	0.0

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD),Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

Table 3.8 Estimated average time beef cows spend in different areas per day.[1]

Month	Pasture (hr)	Stream (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

[1] Natural Resources Conservation Service (NRCS), Soil and Water Conservation District (SWCD),Virginia Department of Conservation and Recreation, and Virginia Cooperative Extension.

3.2.4 Biosolids

The rate of biosolids application in the Peak Creek watershed is relatively small. The Peppers Ferry Regional Wastewater Treatment Authority is the source of biosolids. Table 3.9 shows the amount of biosolids produced and distributed in the affected watersheds by source and year. Table 3.10 shows acreages permitted for biosolids application and the actual application information. The sensitivity analysis (section 4.6) for this study will include modeling application of the maximum permitted level on permitted sites in the watershed.

Table 3.9 Sources of biosolids spread (dry tons) in the Peak Creek watershed.

Source	1994	1995	1997	1999	2000	2001	2002	2003
Peppers Ferry RWTA	13.93	0.60	16.46	6.24	5.20	13.41	5.00	10.28

Table 3.10 Acreages permitted for biosolids applications and actual applications by impairment area in the Peak Creek watershed.

Impairment	Subwatersheds	Acres Permitted	Acres Applied (1994-2003)	Dry Tons Applied (1994-2003)	Fecal Coliform Applied
Peak Creek	PK01	0.00	0.00	0.00	0.00E+00
	PK02	0.00	0.00	0.00	0.00E+00
	PK03	0.00	0.00	0.00	0.00E+00
	PK04	0.00	0.00	0.00	0.00E+00
	PK05	90.00	90.00	20.43	1.25E+12
	PK06	0.00	0.00	0.00	0.00E+00
	PK07	0.00	0.00	0.00	0.00E+00
	PK08	181.00	181.00	26.48	2.97E+12
	PK09	0.00	0.00	0.00	0.00E+00
TOTAL		271.00	271.00	46.91	4.22E+12

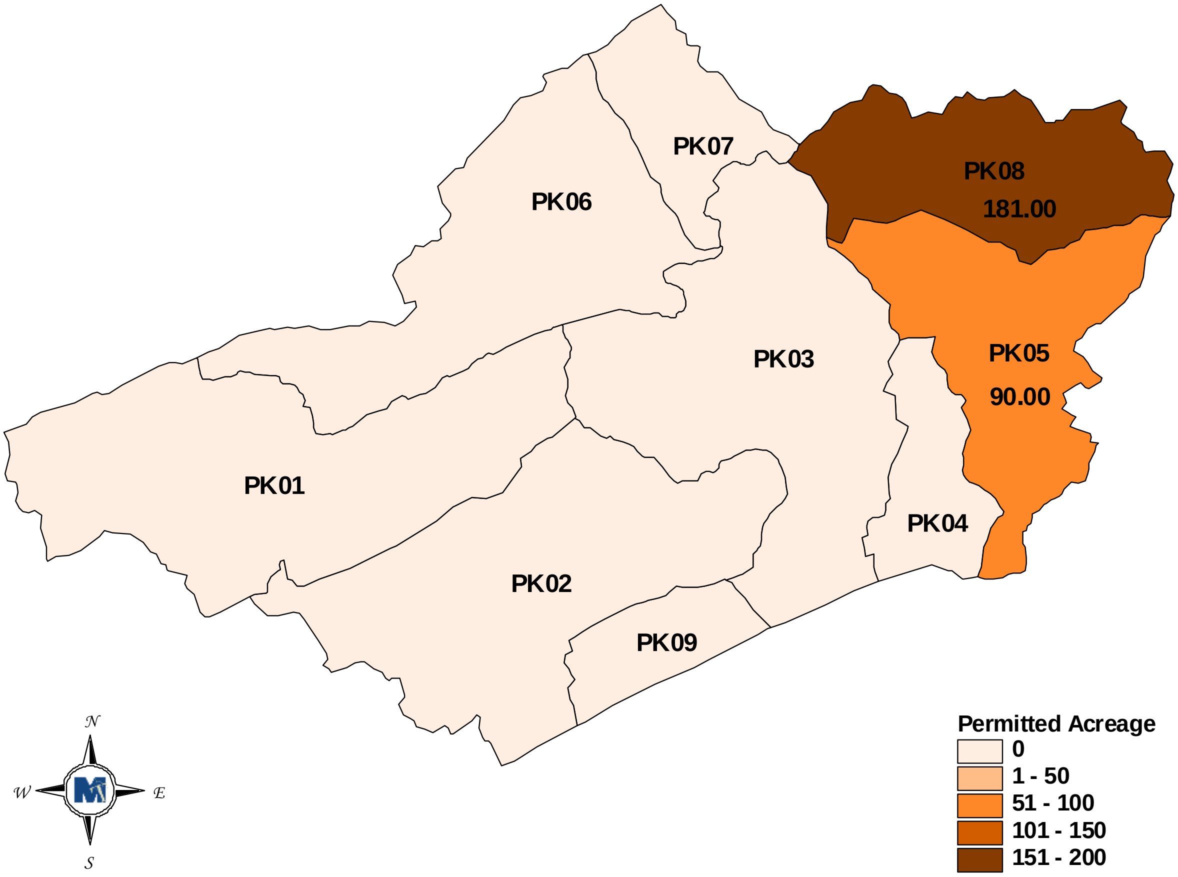

Figure 3.2 Location of acres permitted for biosolids application in the Peak Creek watershed.

3.2.5 Wildlife

The predominant wildlife species in the watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), citizens from the watershed, source sampling, and site visits. Population densities were provided by VDGIF and are listed in Table 3.11 (Bidrowski, 2003; Costanzo, 2003; Farrar, 2003; Knox, 2003; Norman and Lafon, 2002; and Rose and Cranford, 1987). The estimated number of animals in the Peak Creek watershed are reported in Table 3.12. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996; and Yagow, 1999). Table 3.13 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on wildlife waste sampling performed by MapTech. The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999). Percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling for other projects. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.14.

Table 3.11 Wildlife population density.

Wildlife	Pulaski County Density	Wythe County Density	Density Unit
Raccoon	0.0703	0.0703	an/ac of habitat
Muskrat	2.75	2.75	an/ac of habitat
Beaver	4.8	3.8	an/mi of stream
Deer	0.041	0.042	an/ac of habitat
Turkey	0.015	0.018	an/ac of forest
Goose	0.003	0.003	an/ac
Duck	0.015	0.023	an/ac

Table 3.12 Estimated wildlife populations in the Peak Creek watershed.

Watershed	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Peak Creek	2,117	730	17	79	3,685	3,485	303

Table 3.13 Wildlife fecal production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	Primary = region within 600 ft of continuous streams Infrequent = region between 601 and 7,920 ft from continuous streams
Muskrat	100	Primary = region within 66 ft from continuous streams Less frequent = region between 67 and 308 ft
Beaver[1]	200	Continuous stream below 500 ft elevation (defined as distance in feet)
Deer	772	Primary = forested, harvested forest land, orchards, grazed woodland, open urban, cropland, pasture Infrequent = low density residential, medium density residential Seldom/None = rest of landuse codes
Turkey[2]	320	Primary = forested, harvested forest land, grazed woodland Infrequent = open urban, orchards, cropland, pasture Seldom/None = Rest of landuse codes
Goose[3]	225	Primary = region within 0-66 ft from ponds and continuous streams Infrequent = region between 67 and 308 ft from ponds and continuous streams
Duck	150	Primary = region within 0-66 ft from ponds and continuous streams Infrequent = region between 67 and 308 ft from ponds and continuous streams

[1] Beaver waste load was calculated as twice that of muskrat, based on field observations.
[2] Waste load for domestic turkey (ASAE, 1998).
[3] Goose waste load was calculated as 50% greater than that of duck, based on field observations and conversation with Gary Costanzo (Costanzo, 2003)

Table 3.14 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.

Animal Type	Fecal Coliform Density (cfu/g)	Portion of Day in Stream Access Areas (%)
Raccoon	2,100,000	5
Muskrat	1,900,000	90
Beaver	1,000	100
Deer	380,000	5
Turkey	1,332	5
Goose	250,000	50
Duck	3,500	75

3.2.6 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was measured. Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.15. Table 3.16 lists the domestic animal populations for the watershed.

Table 3.15 Domestic animal population density, waste load, and fecal coliform density.

Type	Population Density (an/house)	Waste load (g/an-day)	FC Density (cfu/g)
Dog	0.534	450	480,000
Cat	0.598	19.4	9

Table 3.16 Estimated domestic animal populations in the Peak Creek watershed.

Watershed	Dog	Cat
Peak Creek	3,662	4,101

4. MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of a TMDL for the Peak Creek watershed, the relationship was defined through computer modeling based on data collected throughout the study area. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. In this section, the selection of modeling tools, parameter development, calibration/validation, and model application are discussed.

4.1 Modeling Framework Selection

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions and to perform TMDL allocations. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

The HSPF model simulates a watershed by dividing it up into a network of stream segments (referred to in the model as RCHRES), impervious land areas (IMPLND) and pervious land areas (PERLND). Each subwatershed contains a single RCHRES, modeled as an open channel, and numerous PERLNDs and IMPLNDs, representing the various landuses in that subwatershed. Water and pollutants from the land segments in a given subwatershed flow into the RCHRES in that subwatershed. Point discharges and withdrawals of water and pollutants are simulated as flowing directly to or withdrawing from a particular RCHRES as well. Water and pollutants from a given RCHRES flow into the next downstream RCHRES. The network of RCHRESs is constructed to mirror the configuration of the stream segments found in the physical world. Therefore, activities simulated in one impaired stream segment affect the water quality downstream in the model.

4.2 Model Setup

To adequately represent the spatial variation in the watershed, the Peak Creek drainage areas were divided into nine subwatersheds (Figure 4.1). The rationale for choosing these subwatersheds was based on the availability of water quality data and the limitations of the HSPF model. Water quality data (*i.e.*, fecal coliform concentrations) are available at specific locations throughout the watershed. Subwatershed outlets were chosen to coincide with these monitoring stations, since output from the model can only be obtained at the modeled subwatershed outlets (Figure 4.1 and Table 4.1). In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watershed allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watershed.

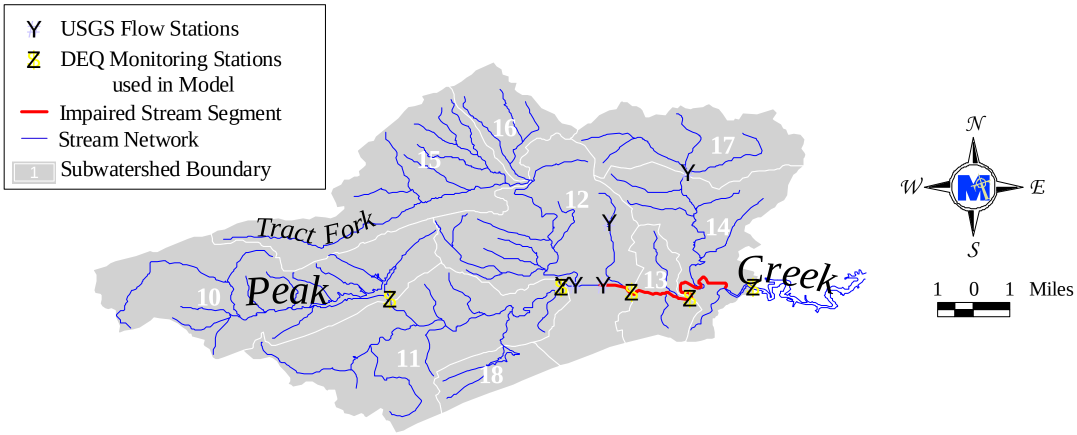

Figure 4.1 **Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Peak Creek watershed.**

Table 4.1 **VADEQ monitoring stations and corresponding reaches in the Peak Creek watershed.**

Station Number	Reach Number
9-PKC016.91	10
9-PKC011.11	11
9-PKC009.29	12
9-PKC007.82	13
9-PKC004.65	14

Using aerial photographs, MRLC identified up to 21 possible landuse types in the watershed. The landuse types were consolidated into 8 categories based on similarities in hydrologic and waste application/production features (Table 4.2). Within each subwatershed, up to the eight landuse categories were represented. Each landuse had parameters associated with it that described the hydrology of the area (*e.g.*, average slope length) and the behavior of pollutants (*e.g.*, fecal coliform accumulation rate). Table 4.3 shows the consolidated landuse types and the area existing in each impairment. These landuse types are represented in HSPF as PERLNDs and IMPLNDs. Impervious areas in the watershed are represented in three IMPLND types, while there are seven PERLND types, each with parameters describing a particular landuse (Table 4.2). Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

Table 4.2 Consolidation of MRLC landuse categories for the Peak Creek watershed.

TMDL Landuse Categories	Pervious / Impervious (Percentage)	MRLC Landuse Classifications (Class No.)
Water	Impervious (100%)	Open Water (11)
Residential/Recreational	Pervious (70%) Impervious (30%)	Low Intensity Residential (21) High Intensity Residential (22) Urban/Recreational Grasses (85)
Commercial and Services	Pervious (70%) Impervious (30%)	Commercial/Industrial/Transportation (23)
Barren	Pervious (100%)	Transitional (33) Quarries/Strip Mines/Gravel Pits (32)
Woodland/Wetland	Pervious (100%)	Evergreen Forest (42) Deciduous Forest (41) Mixed Forest (43) Emergent Herbaceous Wetlands (92) Woody Wetlands (91)
Pasture	Pervious (100%)	Pasture/Hay (81)
Cropland	Pervious (100%)	Row Crops (82)
Livestock Access	Pervious (100%)	Pasture/Hay (81)

Table 4.3 Spatial distribution of landuse types in the Peak Creek drainage area.

Landuse	Peak Creek Acreage
Water	247
Residential/Recreational	1,687
Commercial & Services	653
Barren	200
Woodland/Wetland	35,471
Pasture/Hay	13,446
Livestock Access	695
Cropland	1,577

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (mechanically applied and deposited directly), die-off was addressed implicitly through monitoring and modeling. Samples of collected waste prior to land application (*i.e.*, dairy waste from loafing areas) were collected and analyzed by MapTech. Therefore, die-off is implicitly accounted for through the sample analysis. Die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

4.3 Source Representation

Both point and nonpoint sources can be represented in the model. In general, point sources are added to the model as a time-series of pollutant and flow inputs to the stream. Land-based nonpoint sources are represented as an accumulation of pollutants on land, where some portion is available for transport in runoff. The amount of accumulation and availability for transport vary with landuse type and season. The model allows for a maximum accumulation to be specified. The maximum accumulation was adjusted seasonally to account for changes in die-off rates, which are dependent on temperature and moisture conditions. Some nonpoint sources, rather than being land-based, are represented as being deposited directly to the stream (*e.g.*, animal defecation in stream). These sources are modeled similarly to point sources, as they do not require a runoff event for delivery to the stream. These sources are primarily due to animal activity, which varies with the time of day. Direct depositions by nocturnal animals were modeled as being deposited from 6:00 PM to 6:00 AM, and direct depositions by diurnal animals were modeled as being deposited from 6:00 AM to 6:00 PM. Once in stream, die-off is represented by a first-order exponential equation.

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 1995 were used for the water quality calibration and validation period (1993-2003). Data representing 2003 were used for the allocation runs in order to represent current conditions. Additionally, data projected to 2008 were analyzed to assess the impact of changing populations.

4.3.1 Point Sources

For permitted point dischargers design flow capacities were used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 ml, where discharges were permitted for fecal control, to ensure that compliance with state water quality standards could be achieved even if permitted loads were at maximum levels. For calibration and current condition runs, a lower value of fecal coliform concentration was used, based upon a regression analysis relating Total Residual Chlorine (TRC) levels and fecal coliform concentrations (VADEQ/VADCR, 2000). Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

4.3.2 Private Residential Sewage Treatment

The number of septic systems in the subwatersheds modeled for the Peak Creek watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential landuse types. Each landuse area was assigned a number of septic systems based on census data. A total of 2,242 septic systems were estimated in the Peak Creek watershed in 1995. During allocation runs, the number of households was projected to 2003 (based on current Pulaski County growth rates -- USCB, 2000) resulting in 2,427 septic systems (Table 4.4). The number of septic systems was projected to increase to 2,543 by 2008.

Table 4.4 Estimated failing septic systems (2003).

Impaired Segment	Total Septic Systems	Failing Septic Systems	Straight Pipes
Peak Creek	2,427	679	36

4.3.2.1 Failing Septic Systems

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. In accordance with estimates from Raymond B. Reneau, Jr. of the Crop and Soil Environmental Sciences Department at Virginia Tech, a 40% failure rate for systems designed and installed prior to 1964, a 20% failure rate for systems designed and installed between 1964 and 1984, and a 5% failure rate on all systems designed and installed after 1984 was used in development of a TMDL for the Peak Creek watershed. Total septic systems in each category were calculated using U.S. Census Bureau block demographics. The applicable failure rate was multiplied by each total and summed to get the total failed septic systems per subwatershed. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors (VADEQ/VADCR, 2000) to account for more frequent failures during wet months.

4.3.2.2 Uncontrolled Discharges

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category “other means” were assumed to be disposing sewage via uncontrolled discharges if located within 200 feet of a stream. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. A 200-foot buffer was created from the stream segments. The corresponding buffer and subwatershed areas were intersected resulting in uncontrolled discharges within 200 feet of the stream per subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the waste load for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

4.3.2.3 Sewer System Overflows

During the model calibration/validation period, October 1993 to September 2003, there were 7 reported sewer overflows, leading to a significant input of fecal bacteria into the watershed. It was assumed that additional occurrences of sewer overflows were likely undetected, and a procedure was determined to estimate the quantity of unreported overflows. Overflows were considered to occur during sufficiently wet periods, as based on the average rainfall over a three-day period encompassing a reported overflow event. Additional three day wet periods exceeding this average value were considered to contain an unreported sewer overflow. The concentration of fecal bacteria discharged was considered to be equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events. This estimate of concentration is conservative because some biodegradation occurs in a septic system.

4.3.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The number of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2003 were used for the allocation runs, while these numbers were projected back to 1995 for the calibration and validation runs. The numbers are based on data provided by SWCD and NRCS, as well as taking into account growth rates in Pulaski County as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1995 and VASS, 2003). Similarly, when growth was analyzed, livestock numbers were projected to 2008. For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.4). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

4.3.3.1 Land Application of Collected Manure

Significant collection of livestock manure occurs on dairy farms. For dairy farms in the drainage area, the average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.2.2. The amount of waste collected was first based on proportion of milking cows, as the milking herd represented the only cows subject to confinement and, therefore, waste collection. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. Finally, values for the percentage of loafing lot waste collected were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.5). Stored waste was spread on pastureland. It was assumed that 100% of land-applied waste is available for transport in surface runoff transport unless the waste is incorporated in the soil by plowing during seedbed preparation. Percentage of cropland plowed and amount of waste incorporated was adjusted using calibration for the months of planting.

4.3.3.2 Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering

Department at Virginia Tech and MapTech, Inc. for VADCR. The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

Proportion = [(24 hr) – (time in confinement) – (time in stream access areas)]/(24 hr)

All other livestock (horse and goat) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land-use type was area-weighted.

4.3.3.3 Direct Deposition to Streams

Beef and dairy cattle are the primary sources of direct deposition by livestock in the Peak Creek watershed. The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

For the waste produced on the "stream access" landuse, 30% of the waste was modeled as being directly deposited in the stream and 70% remained on the land segment adjacent to the stream. The 70% was treated as manure deposited on land. However, applying it in a separate land-use area (stream access) allows the model to consider the proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

4.3.4 Biosolids

Investigation of VDH data indicated that biosolids applications have occurred within the Peak Creek watershed. For model calibration, biosolids were modeled at the average reported load and average fecal coliform density. With urban populations growing, the disposal of biosolids will take on increasing importance. Class B biosolids have been measured with 68,467 cfu/g-dry and are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. The sensitivity analysis (see Section 4.6) provided insight into the effects that increased applications of biosolids could have on water quality. During allocation runs, biosolids applications were modeled at the highest permittable loading rate (*i.e.,* 15 dry tons/ac at 1,995,262 cfu/g) applied to all permitted acreages in the month of May each year.

4.3.5 Wildlife

For each species, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.5). An example of one of these layers is shown in Figure 4.2. This layer was overlaid with the landuse layer and the resulting area was calculated for each landuse in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.14). For all animals other than beaver, it was estimated that 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (1995–2008) projections were made to wildlife populations, as there was no available data to support such adjustments.

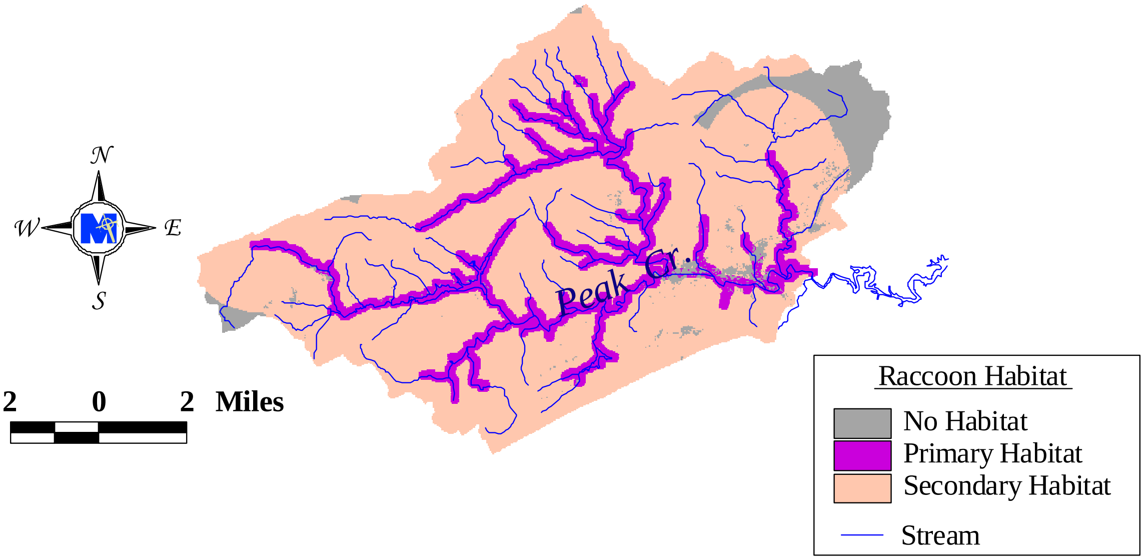

Figure 4.2 **Example of raccoon habitat layer in the Peak Creek watershed as developed by MapTech.**

4.3.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals/house), waste load, and fecal coliform density are reported in Section 3.2.6. Waste from pets was distributed in the residential landuses. The locations of households were taken from census reports from 1990 and 2000 (USCB, 1990, 2000). The landuse and household layers were overlaid, which resulted in number of households per landuse. The number of animals per landuse was determined by multiplying the number of households by the population density. The amount of fecal coliform deposited daily by pets in each landuse segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load was assumed not to vary seasonally. The population figures for cats and dogs were projected from 1990 data to 1995, 2003, and 2008 based on housing growth rates.

4.4 Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). In order to determine a representative stream profile for each stream reach, cross-sections were surveyed at the subwatershed outlets. One outlet was considered the beginning of the next reach, when appropriate. In the case of a confluence, sections were surveyed above the confluence for each tributary and below the confluence on the main stream.

Most of the sections exhibited distinct flood plains with pitch and resistance to flow significantly different from that of the main channel slopes. The streambed, channel banks, and flood plains were identified. Once identified, the streambed width and slopes of channel banks and flood plains were calculated using the survey data. A representative stream profile for each surveyed cross-section was developed, consisting of a trapezoidal channel with pitch breaks at the beginning of the flood plain (Figure 4.3). With this approach, the flood plain can be represented differently from the streambed. To represent the entire reach, profile data collected at each end of the reach were averaged.

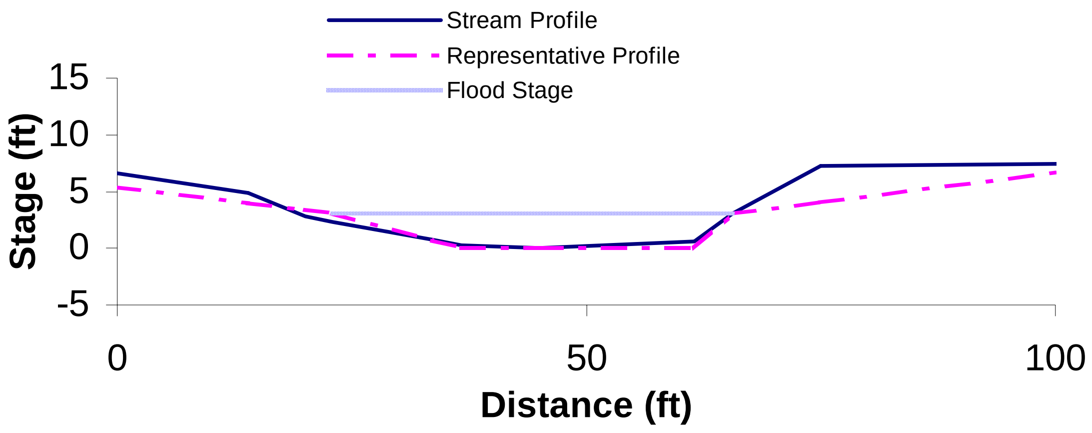

Figure 4.3 Stream profile representation in HSPF.

Conveyance was used to facilitate the calculation of discharge in the reach with different values for resistance to flow (Manning's n) assigned to the flood plains and streambeds. The conveyance was calculated for each of the two flood plains and the main channel, these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in ft^3/s) at a given depth.

A key parameter used in the calculation of conveyance is the Manning's roughness coefficient, n. There are many ways to estimate this parameter for a section. The method first introduced by Cowan (1956) and adopted by the Soil Conservation Service (1963) was used to estimate Manning's n. This procedure involves a 6-step process of evaluating the properties of the reach, which is explained in more detail by Chow (1959). Field data describing the channel bed, bank stability, vegetation, obstructions, and other pertinent parameters were collected. Photographs were also taken of the sections while in the field. Once the field data were collected, they were used to estimate the Manning's roughness for the section observed. The pictures were compared to pictures contained in Chow (1959) for validation of the estimates of the Manning's n for each section.

The result of the field inspections of the reach sections was a set of characteristic slopes (channel sides and field plains), bed widths, heights to flood plain, and Manning's roughness coefficients. Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from Digital Elevation Models (DEMs) and a stream-flow network digitized from USGS 7.5-minute quadrangle maps (scale 1:24,000). These data were used to derive the Hydraulic Function Tables (F-tables) used by the HSPF model (Table 4.5). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and outflow (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. A maximum depth of 50 ft was used in the F-tables. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

Table 4.5 Example of an "F-table" calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0.0	0.00	0.00	0.00
0.2	21.96	4.37	10.87
0.4	22.16	8.78	34.54
0.6	22.36	13.23	67.92
0.8	22.56	17.73	109.75
1.0	22.77	22.26	159.29
1.3	23.07	29.14	246.88
1.7	23.48	38.44	386.59
2.0	23.78	45.53	507.43
2.3	24.08	52.71	641.30
2.7	24.49	62.43	839.20
3.0	24.79	69.82	1,001.68
6.0	29.42	149.62	3,222.35
9.0	37.08	249.37	6,254.60
12.0	44.73	372.08	10,078.05
15.0	52.38	517.75	14,818.37
25.0	77.32	1,163.48	38,629.43
50.0	92.02	2,796.19	103,246.75

4.5 Selection of Representative Modeling Period

Selection of the calibration/validation periods was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Modeling periods were selected for hydrology calibration/validation, water quality calibration/validation, and modeling of allocation scenarios. Special Study data (*i.e.*, instantaneous flow values) at USGS Station #03168450 (Peak Creek at Magnox-Pulaski, Pulaski, VA) were available from 1995 to 2001, while data from USGS Station #03168750 (Thorne Springs Branch near Dublin, VA) were available from 1986 to 2001. Due to the sparse amount of data (*i.e.*, 8 observations over a 6-year period, and 14 observations over a 15-year period), a paired watershed approach was used to set initial parameters for the model, and all available data were used for the hydrology calibration. Water quality data (*i.e.*, fecal coliform concentrations) were available from 1988 through 2003, with more data available in the 2001 to 2003 timeframe. A representative period for water quality calibration and validation was selected with consideration for the hydrology calibration period, availability of water quality data, and the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Peak Creek segment on the 1998 303 (d) Total Maximum Daily Load Priority List and Report.

With these criteria in mind, the modeling periods for water quality calibration and validation were 10/1/93 through 9/30/98 and 10/1/98 through 9/30/2003, respectively.

The period selected for modeling of allocation scenarios represents critical hydrological conditions. The mean daily precipitation for each season was calculated for the period October 1970 through September 2000. This resulted in 30 observations of mean precipitation for each season. The mean and variance of these observations were calculated. Next, a representative period for modeling was chosen and compared to the historical data. The representative period was chosen such that the mean and variance of each season in the modeled period was not significantly different from the historical data (Figure 4.4 and Figure 4.5).

Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for modeling of allocation scenarios was 10/1/1986 through 9/30/1991.

Table 4.6 Comparison of modeled period to historical records.

	Precipitation (in/day)			
	Fall	**Winter**	**Spring**	**Summer**
	Historical Record (1981-1996)			
Mean	0.0905	0.1002	0.1097	0.1113
Variance	0.0008	0.0015	0.0006	0.0013
	Representative Hydrological Period (10/1/86-9/30//91)			
Mean	0.0961	0.0852	0.0975	0.1110
Variance	0.0008	0.0017	0.0005	0.0032
	p-Values			
Mean	0.3487	0.2416	0.1592	0.4954
Variance	0.4289	0.3685	0.5124	0.0832

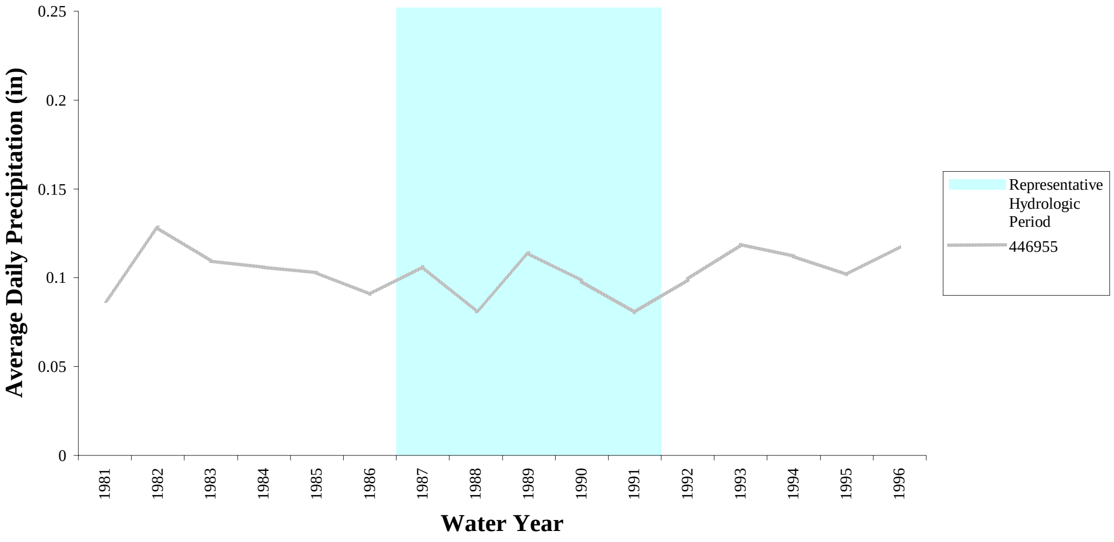

Figure 4.4 **Annual Historical Precipitation (Station 446955) Data.**

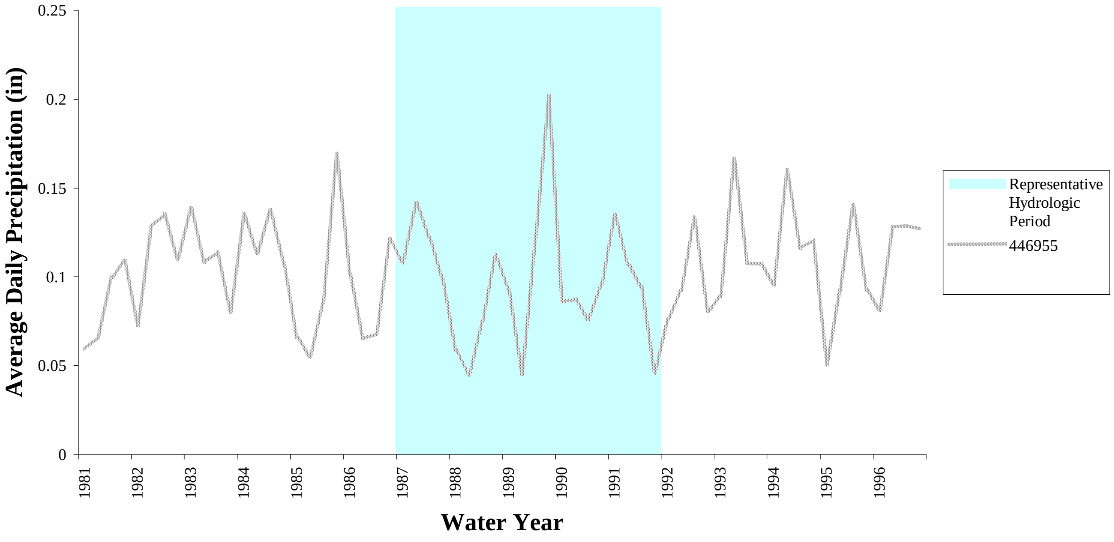

Figure 4.5 **Seasonal Historical Precipitation (Station 446955) Data.**

4.6 Sensitivity Analysis

Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

Sensitivity analyses were run on both hydrologic and water quality parameters. The parameters adjusted for the hydrologic sensitivity analysis are presented in Table 4.7, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value, and the model was run for water years 1994 through 2002. Where an increase of 50% exceeded the maximum value for the parameter, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and LZETP (Lower Zone Evapotranspiration). To a lesser extent peak flows were sensitive to UZSN (Upper Zone Storage) and LZSN (Lower Zone Storage). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the Low Flows and Summer Flow Volume statistics) were AGWRC (Groundwater Recession Rate), INFILT, INTERCEP (interception), LZETP, DEEPFR (Losses to Deep Aquifers) and, to a lesser extent, BASETP (Evapotranspiration from Base Flow). The responses of these and other hydrologic outputs are reported in Table 4.8.

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 1993 through 1998 and model parameters established for 1995 conditions. The three parameters impacting the model’s water quality response (Table 4.9) were increased and decreased by amounts that were consistent with the range of values for the parameter.

Since the water quality standard for fecal coliform bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric-mean fecal coliform concentration. A monthly geometric mean was calculated for all months during the simulation period, and the value for each month was averaged. Deviations from the base run are given in Table 4.10 and plotted by month in Figure 4.6 and through Figure 4.8.

In addition to analyzing the sensitivity of the model response to changes in model parameters, the response of the model to changes in land-based and direct loads was analyzed. The impacts of land-based and direct load changes on the annual load are presented in Figure 4.9, while impacts on the monthly geometric mean are presented in Figure 4.10 and Figure 4.11. It is evident from Figure 4.9 that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs greatly between land applied and direct loadings, however, as a 100% increase in the land applied loads results in an increase of over 80% in stream loads, while a 100% increase in direct loads results in an increase of approximately 10% for in stream loads. The sensitivity analysis of geometric mean concentrations in Figures 4.10 and 4.11 showed that direct loads had the greatest impact, with land-applied loads having a lesser, but measurable impact.

Table 4.7 Base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
AGWRC	Active Groundwater Coefficient	1/day	0.989-0.994
BASETP	Base Flow Evapotranspiration	---	0.0315-0.0325
CEPSC	Interception Storage Capacity	in	0.01-0.4
DEEPFR	Fraction of Deep Groundwater	---	0.0
INFILT	Soil Infiltration Capacity	in/hr	0.006-0.296
INTFW	Interflow Inflow	---	1.0
KVARY	Groundwater Recession Coefficient	1/day	0.05-0.12
LZSN	Lower Zone Nominal Storage	in	2.0-3.0
MON-LZETPARM	Monthly Lower Zone Evapotranspiration	---	0.10-0.90
NSUR	Manning's *n* for Overland Flow	---	0.10-0.48
UZSN	Upper Zone Storage Capacity	in	0.05-2.0

Table 4.8 Sensitivity analysis results for hydrologic model parameters.

Model Parameter	Parameter Change (%)	Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC**	-50	2.35%	170.56%	-86.64%	15.55%	-17.81%	-16.14%	28.47%	64.49%
AGWRC	-10	1.32%	62.81%	-51.03%	12.09%	-13.74%	-17.29%	24.34%	58.91%
AGWRC[1]	1	-0.14%	-1.44%	1.42%	-0.91%	-0.26%	1.10%	-0.19%	-4.03%
BASETP	-50	1.27%	-0.74%	2.78%	-0.21%	2.66%	3.03%	-0.28%	-1.08%
BASETP	-10	0.26%	-0.14%	0.58%	-0.05%	0.56%	0.64%	-0.07%	-0.18%
BASETP	10	-0.26%	0.12%	-0.59%	0.04%	-0.56%	-0.63%	0.08%	0.29%
BASETP	50	-1.21%	0.77%	-2.80%	0.22%	-2.64%	-2.96%	0.42%	1.18%
DEEPFR	-50	5.60%	4.68%	5.69%	5.32%	5.48%	5.28%	6.44%	5.57%
DEEPFR	-10	1.12%	0.94%	1.14%	1.06%	1.10%	1.06%	1.29%	1.12%
DEEPFR	10	-1.12%	-1.08%	-1.14%	-1.06%	-1.10%	-1.06%	-1.29%	-1.12%
DEEPFR	50	-5.60%	-5.04%	-5.72%	-5.30%	-5.48%	-5.30%	-6.43%	-5.57%
INFILT	-50	-1.07%	33.02%	-10.58%	0.66%	-7.57%	-1.83%	5.56%	3.97%
INFILT	-10	-0.31%	3.11%	-1.20%	-0.40%	-0.95%	-0.19%	0.49%	0.17%
INFILT	10	0.33%	-2.25%	0.95%	0.45%	0.84%	0.16%	-0.32%	0.00%
INFILT	50	1.69%	-6.24%	3.50%	2.27%	3.79%	0.66%	-0.68%	0.67%
INTFW	-50	-0.35%	-2.33%	0.50%	-0.53%	-0.13%	-0.58%	-0.18%	-0.85%
INTFW	-10	-0.04%	-0.33%	0.07%	-0.05%	-0.02%	-0.08%	-0.02%	-0.10%
INTFW	10	0.04%	0.29%	-0.06%	0.04%	0.02%	0.08%	0.02%	0.08%
INTFW	50	0.14%	1.13%	-0.23%	0.14%	0.07%	0.32%	0.07%	0.34%
LZSN	-50	2.52%	10.47%	-0.11%	4.12%	0.14%	-0.62%	6.49%	4.75%
LZSN	-10	0.35%	1.44%	-0.14%	0.66%	0.11%	-0.19%	0.77%	0.61%
LZSN	10	-0.31%	-1.35%	0.13%	-0.60%	-0.14%	0.18%	-0.63%	-0.79%
LZSN	50	-1.34%	-5.05%	0.51%	-2.57%	-0.91%	0.66%	-2.22%	-3.83%
MON-INTERCEP	-50	4.07%	-1.18%	6.86%	1.95%	5.19%	6.59%	2.96%	1.06%
MON-INTERCEP	-10	0.70%	-0.37%	1.30%	0.28%	1.01%	1.19%	0.40%	-0.01%
MON-INTERCEP	10	-0.65%	0.29%	-1.21%	-0.27%	-0.99%	-1.00%	-0.37%	-0.05%
MON-INTERCEP	50	-2.81%	2.04%	-5.66%	-0.93%	-4.44%	-5.04%	-1.02%	-0.12%
MON-LZETP	-50	12.03%	15.28%	16.84%	8.03%	4.86%	13.38%	24.84%	3.96%
MON-LZETP	-10	1.75%	1.56%	2.66%	1.20%	0.65%	1.67%	3.94%	0.05%
MON-LZETP	10	-1.55%	-1.37%	-2.44%	-1.04%	-0.57%	-1.48%	-3.48%	-0.43%
MON-LZETP	50	-7.94%	-5.81%	-12.47%	-5.17%	-4.21%	-10.00%	-14.18%	-1.69%
MON-MANNING	-50	0.10%	1.37%	-0.16%	-0.14%	0.01%	0.30%	0.32%	0.20%
MON-MANNING	-10	0.01%	0.15%	-0.02%	-0.01%	0.00%	0.04%	0.03%	0.02%
MON-MANNING	10	-0.01%	-0.12%	0.01%	0.01%	0.00%	-0.03%	-0.02%	-0.02%
MON-MANNING	50	-0.04%	-0.49%	0.06%	0.03%	-0.01%	-0.15%	-0.08%	-0.09%
MON-UZSN	-50	4.46%	15.59%	1.16%	3.86%	6.28%	7.91%	-0.43%	8.55%
MON-UZSN	-10	0.64%	2.36%	0.10%	0.44%	1.06%	1.54%	-0.51%	1.14%
MON-UZSN	10	-0.54%	-2.09%	-0.07%	-0.36%	-0.93%	-1.45%	0.60%	-1.02%
MON-UZSN	50	-2.06%	-7.17%	-0.09%	-1.20%	-3.26%	-5.73%	1.92%	-4.14%

[1] Maximum value used corresponds to the maximum allowable value for the parameter.

** Decreasing AGWRC, was shown to greatly influence the upper 50% flow values, however, this is a result of this parameters impact on low flows, with the result that the storm flows appear higher in comparison to base flow values, and should not be interpreted as influencing runoff producing events.

Table 4.9 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0.0E+00 – 1.7E+11
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0-1.8
FSTDEC	In-stream First Order Decay Rate	1/day	1.15

Table 4.10 Percent change in average monthly *E. coli* geometric mean for the years 1993-1998.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	68.49	71.71	53.96	45.28	46.07	50.29	43.07	42.49	40.55	45.15	42.05	56.70
FSTDEC	-10	8.72	8.72	6.63	5.86	6.01	6.34	5.84	5.62	5.48	5.83	5.66	6.87
FSTDEC	10	-7.78	-7.68	-5.93	-5.34	-5.48	-5.72	-5.40	-5.15	-5.06	-5.31	-5.21	-6.11
FSTDEC	50	-29.75	-28.88	-23.07	-21.36	-21.97	-22.60	-21.93	-20.84	-20.65	-21.22	-21.12	-23.53
SQOLIM	-50	-17.40	-14.42	-12.06	-9.12	-10.17	-11.74	-5.31	-4.41	-4.11	-4.83	-7.69	-8.71
SQOLIM	-25	-7.75	-6.78	-5.28	-4.39	-4.94	-5.42	-2.63	-2.36	-1.82	-2.14	-3.79	-3.87
SQOLIM	50	14.85	11.83	9.30	7.22	8.18	8.48	3.93	3.71	3.59	4.53	7.51	7.59
SQOLIM	100	25.81	19.97	16.16	12.30	13.65	12.94	5.63	5.73	6.22	7.55	11.98	12.54
WSQOP	-50	19.15	20.77	14.87	11.60	10.69	11.55	4.67	4.33	4.87	5.52	8.14	10.79
WSQOP	-10	2.64	2.73	2.01	1.55	1.49	1.59	0.67	0.59	0.64	0.73	1.12	1.43
WSQOP	10	-2.31	-2.35	-1.75	-1.35	-1.31	-1.39	-0.60	-0.52	-0.56	-0.63	-0.98	-1.24
WSQOP	50	-9.29	-9.24	-6.98	-5.39	-5.31	-5.60	-2.50	-2.10	-2.20	-2.50	-3.94	-4.93

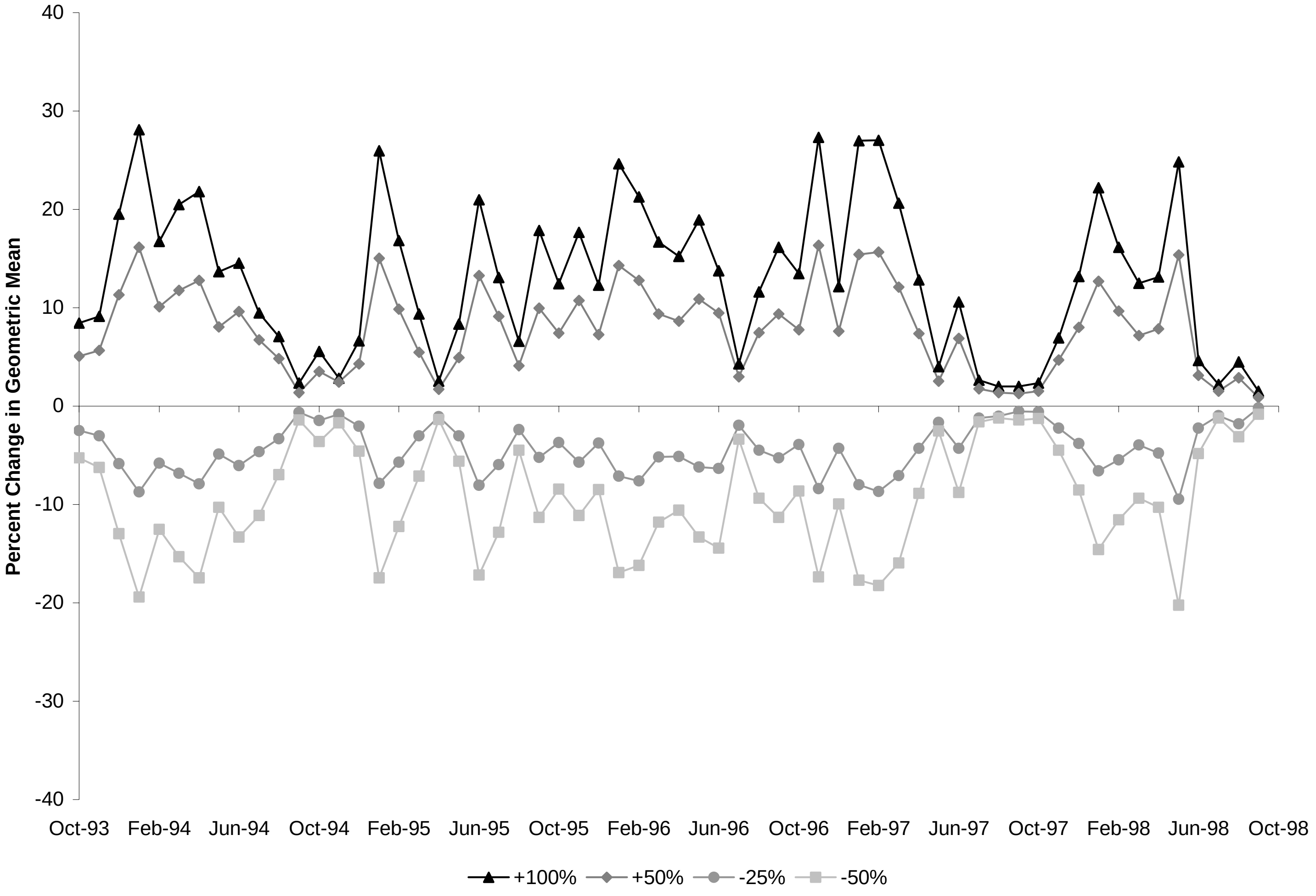

Figure 4.6 Results of sensitivity analysis on monthly geometric-mean concentrations in the Peak Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).

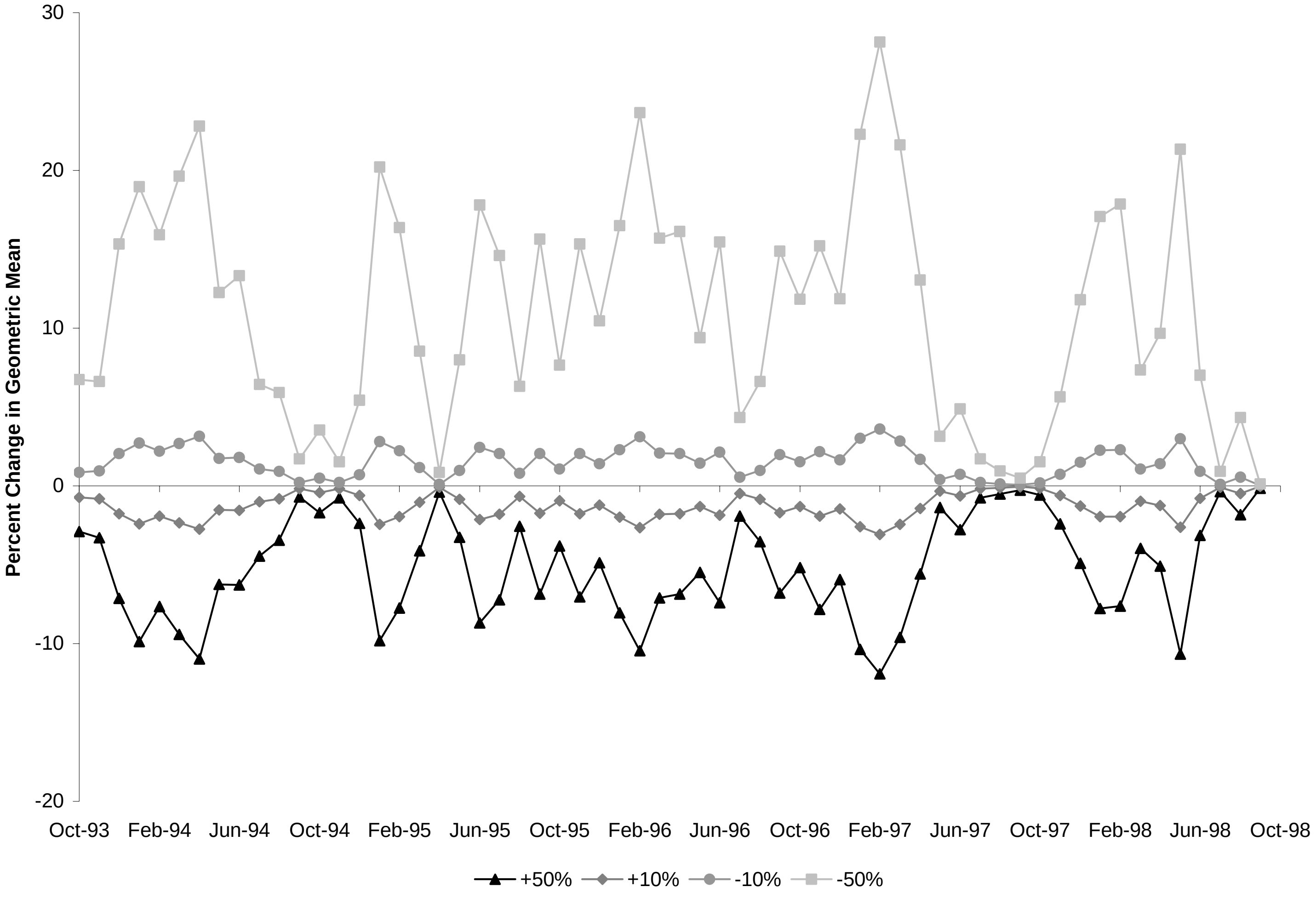

Figure 4.7 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Peak Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).**

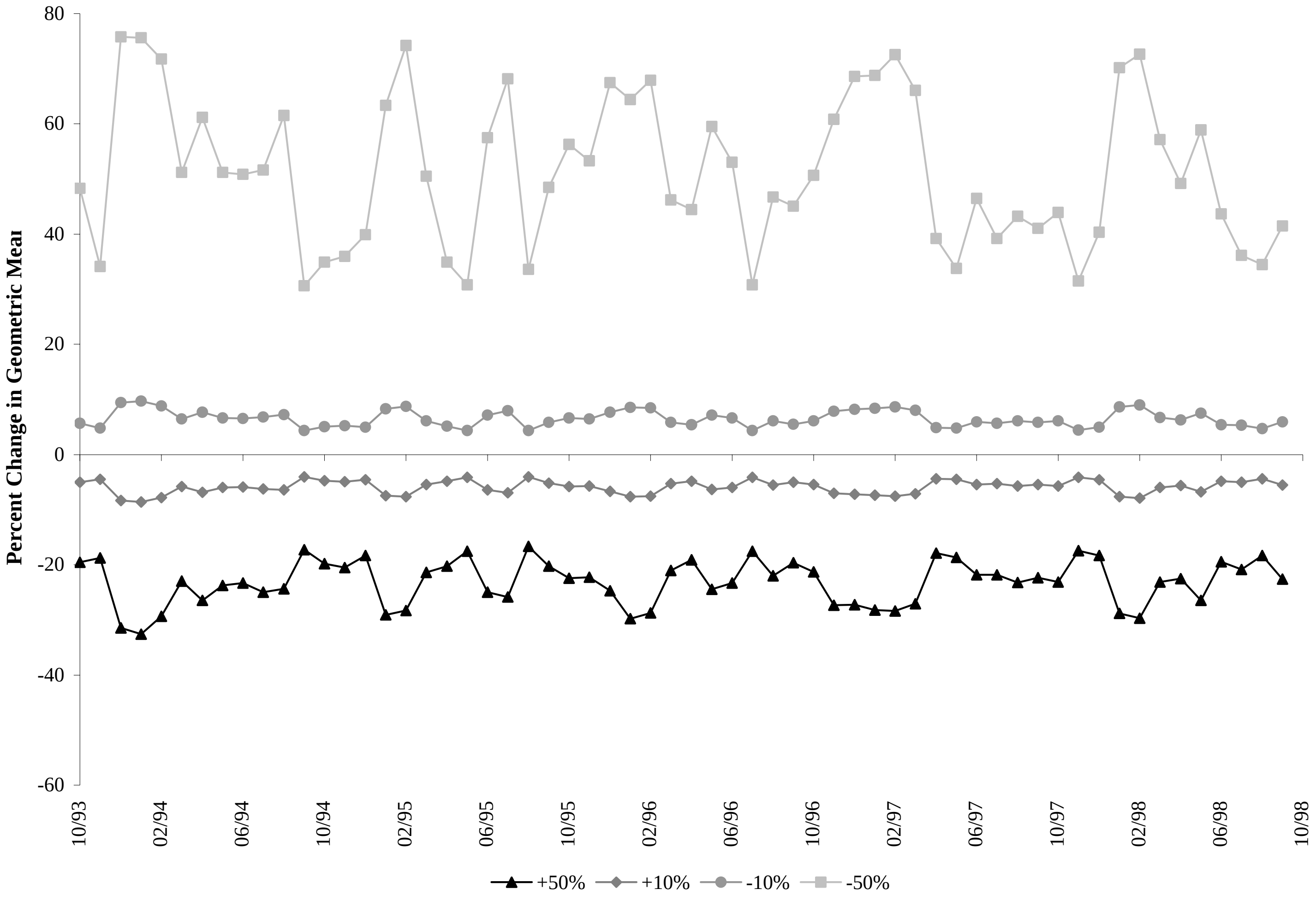

Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations in the Peak Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).

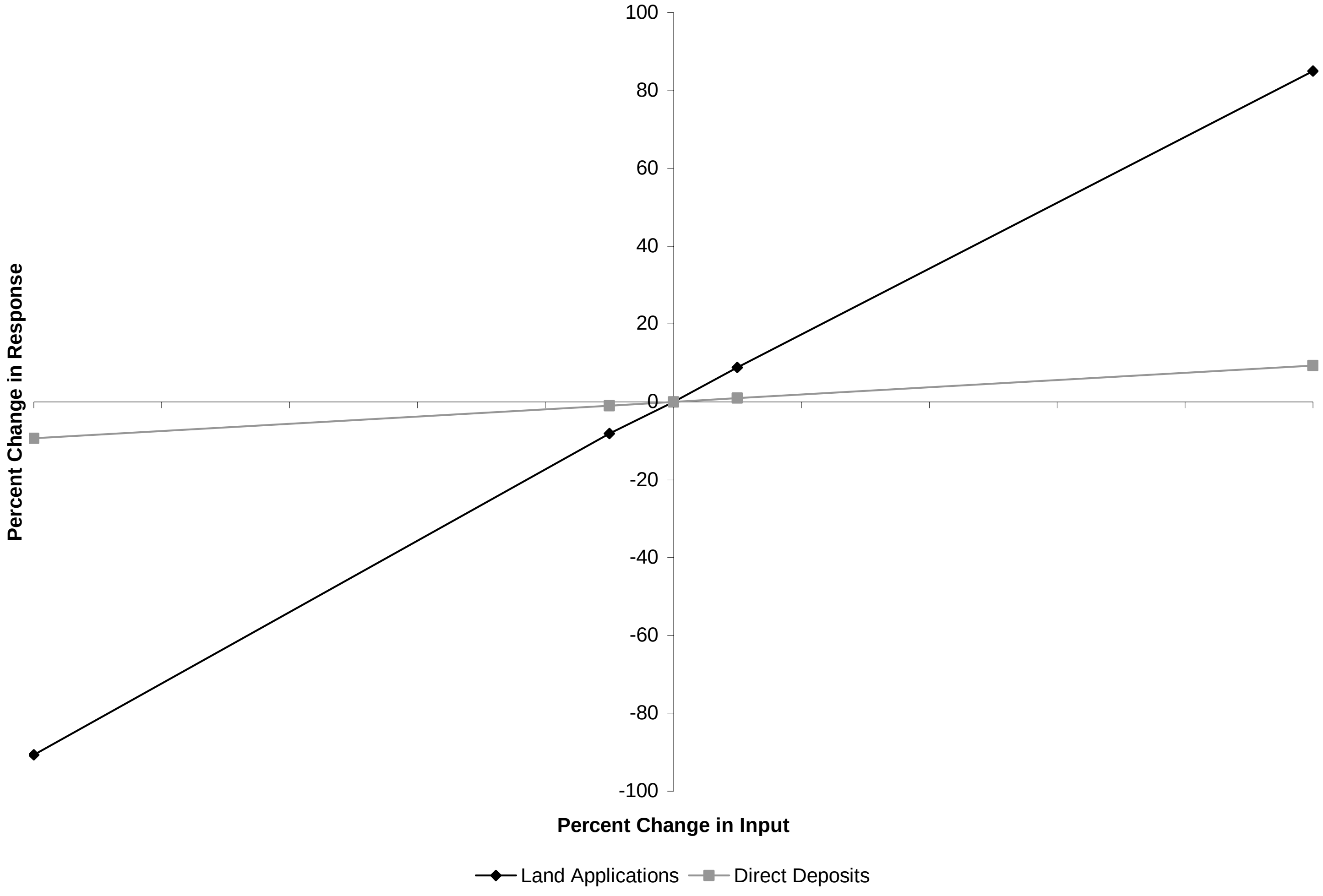

Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Peak Creek watershed.

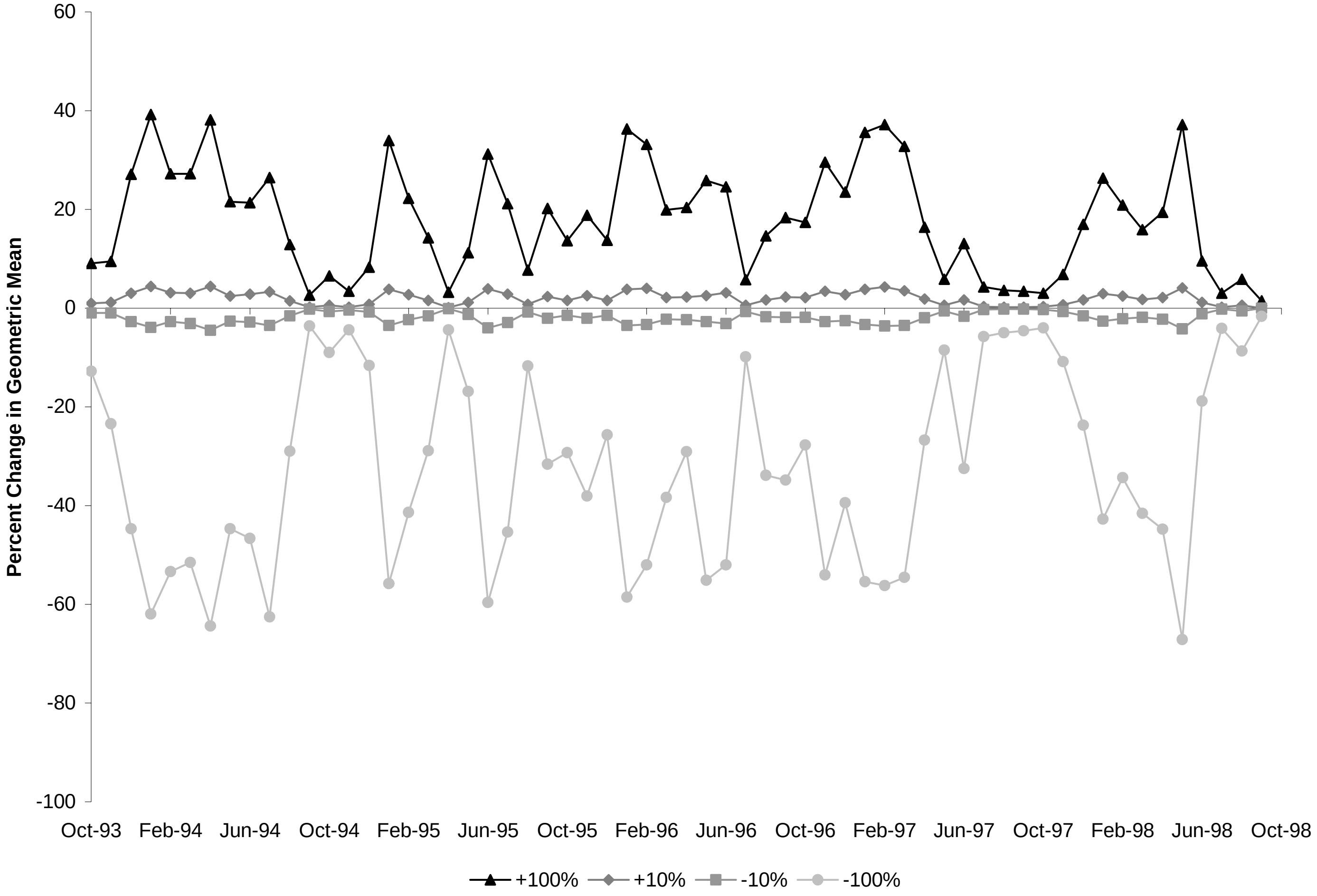

Figure 4.10 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Peak Creek watershed, as affected by changes in land-based loadings.**

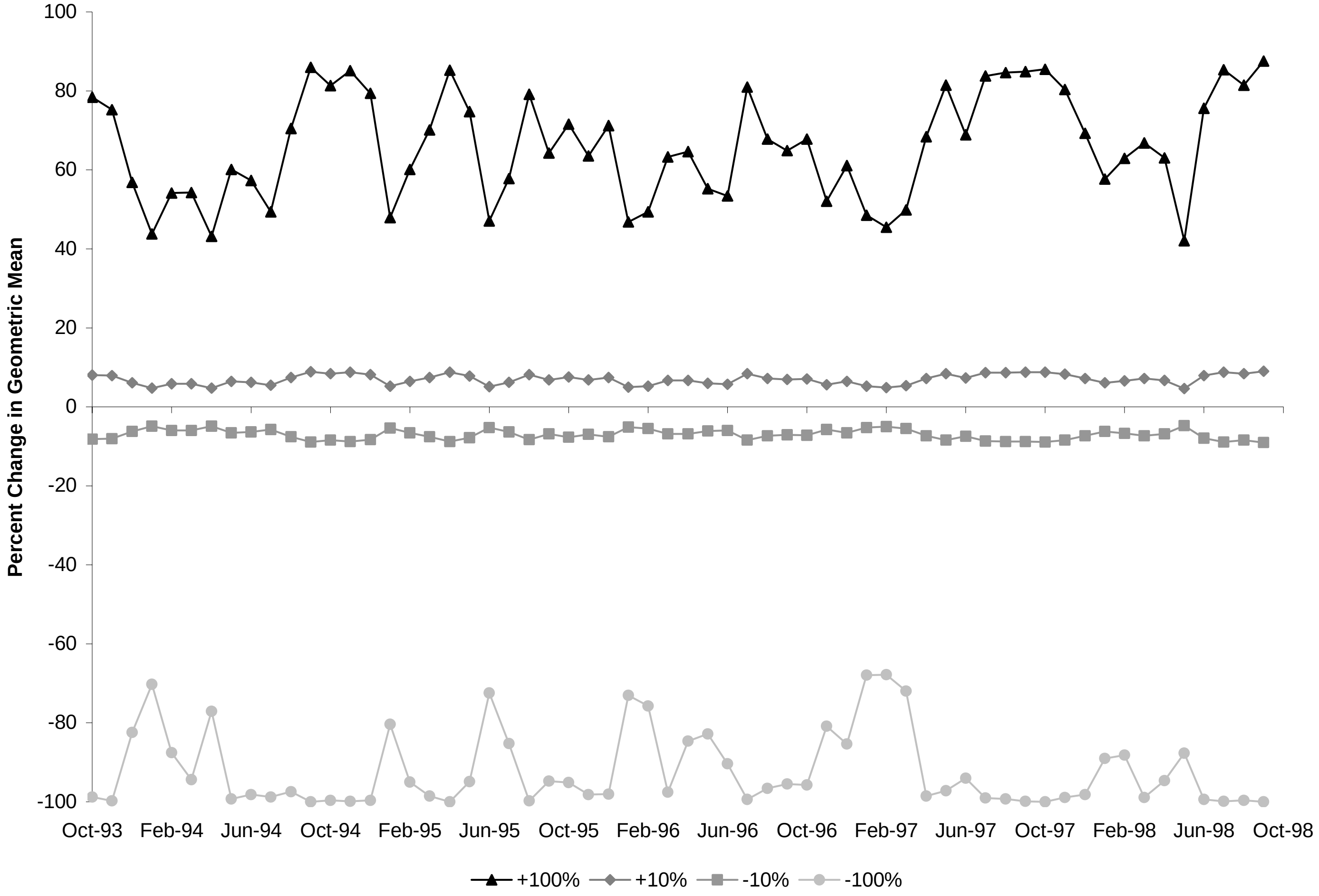

Figure 4.11 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Peak Creek watershed, as affected by changes in loadings from direct nonpoint sources.**

4.7 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, landuse, and topographic data. Qualities of fecal coliform sources were modeled as described in chapters 3 and 4. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Using observed data that is reported at a shorter time-step improves this process and subsequently the performance of a time-dependent model. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration. During validation, no adjustments are made to model parameters. The goal of validation is to assess the capability of the model in hydrologic conditions other than those used during calibration.

4.7.1 Hydrologic Calibration and Validation

Due to the lack of continuous stream flow data for Peak Creek, the paired watershed approach, with additional refinement using instantaneous flow measurements was used to calibrate the HSPF model. Through this approach, the HSPF model is calibrated using data from a hydrologically similar watershed, where continuous stream flow is available. The calibrated parameters from the model (*e.g.*, lower zone storage), in conjunction with physically derived parameters (*e.g.*, land slope and slope length) specific to Peak Creek, are then used as an initial representation of the watershed. In the case of Peak Creek, this representation was then refined through calibration to instantaneous flow measurements collected primarily during base-flow conditions.

Upper Tinker Creek was compared to the Peak Creek watershed and chosen as an appropriate watershed for a paired-watershed calibration. The hydrologic comparison of the watersheds was established by examining the landuse distribution, total drainage area, channel and watershed characteristics, and hydrologic soil group.

The first action taken to implement the paired watershed was examining the similarities between the Upper Tinker Creek and Peak Creek watersheds. The landuse distribution is shown in Table 4.11. The four landuse categories were agricultural, urban, natural and other. The agricultural landuses category included barren land, pasture, cropland, and livestock access areas; these accounted for 56% of the Upper Tinker Creek watershed and 29% of the Peak Creek watershed.

Table 4.11 Landuse distribution for Peak Creek and Upper Tinker Creek watersheds.

Landuse Categories	Landuse	Peak Creek		Upper Tinker Creek	
		acres	%	acres	%
Agricultural	Barren	200	0.37	23	0.31
	Cropland/Row Crops	1,577	2.92	78	1.00
	Livestock Access	695	1.29	276	3.70
	Pasture	13,446	24.91	3,793	50.80
Total Agricultural		15,919	29.49	4,170	55.80
Urban	Commercial	653	1.21	4	0.05
	Residential	1,687	3.13	91	1.20
Total Urban		2,340	4.34	95	1.30
Natural	Forest and Wetlands	35,471	65.72	3,173	42.50
Other	Water	247	0.46	30	0.41
Total		53,976	100.00	7,468	100.00

The soil hydrologic groups in both watersheds were examined. The soils series present in both the Upper Tinker Creek and Peak Creek watersheds consist of well-drained soils. Based on the hydrologic soil group classification, the soil series present in the two watersheds predominantly range from “B” to “C” (Table 4.12).

Table 4.12 Soil distribution in Tinker Creek and Peak Creek.

Statsgo ID	Hydrologic Soil Group	Percent of Watershed	
		Tinker Creek	Peak Creek
VA001	B	0%	59%
VA002	B/C	50%	20%
VA003	B/C	40%	17%
VA004	C	0%	1%
VA005	B/C	10%	0%
VA017	C	0%	2%

Additional watershed characteristics of Tinker Creek and Peak Creek, including the drainage area, main channel slope, main channel length, and the drainage density, were compared. The data, presented in Table 4.13 indicates that these physical characteristics of the watershed are similar.

Table 4.13 Comparison of Tinker Creek and Peak Creek Watershed Characteristics

Watershed	Drainage Area (acre)	Main Channel Slope	Main Channel Length (ft)	Drainage Density (ft/acre)
Tinker Creek	7,482.00	0.08	2,162.00	14.24
Peak Creek	54,083.96	0.01	198,541.26	12.16

Based on the landuse distribution, soil types, and the watershed physical characteristics, the Upper Tinker Creek watershed is hydrologically similar to the Peak Creek watershed. The HSPF model was calibrated and validated for the Upper Tinker Creek watershed (VADEQ, 2003), where continuous flow data was available. The HSPF input parameters for the Upper Tinker Creek watershed were used as base input parameters for Peak Creek when calibrating Peak Creek with flow values from USGS station #03168450 (Peak Creek at Magnox-Pulaski, Pulaski, VA) and USGS station #03168750 (Thorne Springs Branch near Dublin, VA). Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZE), the recession rates for groundwater (AGWRC), the amount of soil moisture storage in the upper zone (MON-UZS) and lower zone (MON-LZE), the infiltration capacity (INFILT), baseflow PET (BASETP), forest coverage (FOREST), and Manning’s n for overland flow plane (MON-MAN). Table 4.14 contains the typical range for the above parameters along with the initial estimate and final calibrated value. Although HSPF is not a physically based model, and thus parameters are adjusted during calibration in order to match observed data, guidelines are provided by E.P.A as to typically encountered values. Final calibrated parameters did not go outside of typical values, except in the case of SLSUR, which ranged just outside the high value of 0.30, with a peak value of 0.366 for the forest land-use during the summer months, which coincided with periods of lower than expected flows in the observed record. Specific values for each calibrated parameter are given in the excerpt from the calibrated UCI in Appendix C.

The results of calibration for Peak Creek are presented in Figure 4.12 and Figure 4.13. The model was calibrated for hydrologic accuracy using instantaneous flow data from USGS Station #03168450 (Peak Creek at Magnox-Pulaski, Pulaski, VA) and USGS Station #03168750 (Thorne Springs Branch near Dublin, VA). The distribution of flow volume between surface runoff, interflow, and groundwater was 11%, 29%, and 60%, respectively. While there were no peak flow values in the observed record to verify output during storm events, and only 22 observations in total, the model predicted base flow conditions well.

Table 4.14 Model parameters utilized for hydrologic calibration of Peak Creek.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	0.0	0.0 – 1.0
LZSN	in	2.0 – 15.0	2.0 – 3.0	2.0
INFILT	in/hr	0.001 – 0.50	0.006 – 0.296	0.168 - 0.275
LSUR	ft	100 – 700	100 – 700	100 – 800
SLSUR	---	0.001 – 0.30	0.001 – 0.155	0.001 – 0.366
KVARY	1/in	0.0 – 5.0	0.05 – 0.12	0.0
AGWRC	1/day	0.85 – 0.999	0.989 – 0.994	0.90
PETMAX	deg F	32.0 – 48.0	40.0	40.0
PETMIN	deg F	30.0 – 40.0	35.0	35.0
INFEXP	---	1.0 – 3.0	2.0	2.0
INFILD	---	1.0 – 3.0	2.0	2.0
DEEPFR	---	0.0 – 0.50	0.0	0.50
BASETP	---	0.0 – 0.20	0.0315 – 0.0325	0.20
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	1.0	1.0
IRC	1/day	0.30 – 0.85	0.30 – 0.85	0.30
MON-INT	in	0.01 - 0.40	0.01 – 0.40	0.01 – 0.40
MON-UZS	in	0.05 – 2.0	0.05 – 2.0	0.032 – 0.82
MON-LZE	---	0.10 – 0.90	0.10 – 0.90	0.10 – 0.90
MON-MAN		0.10 – 0.50	0.10 – 0.48	0.10 – 0.42
RETSC	in	0.0 – 1.0	0.10	0.10
KS	---	0.0 – 0.9	0.50	0.50

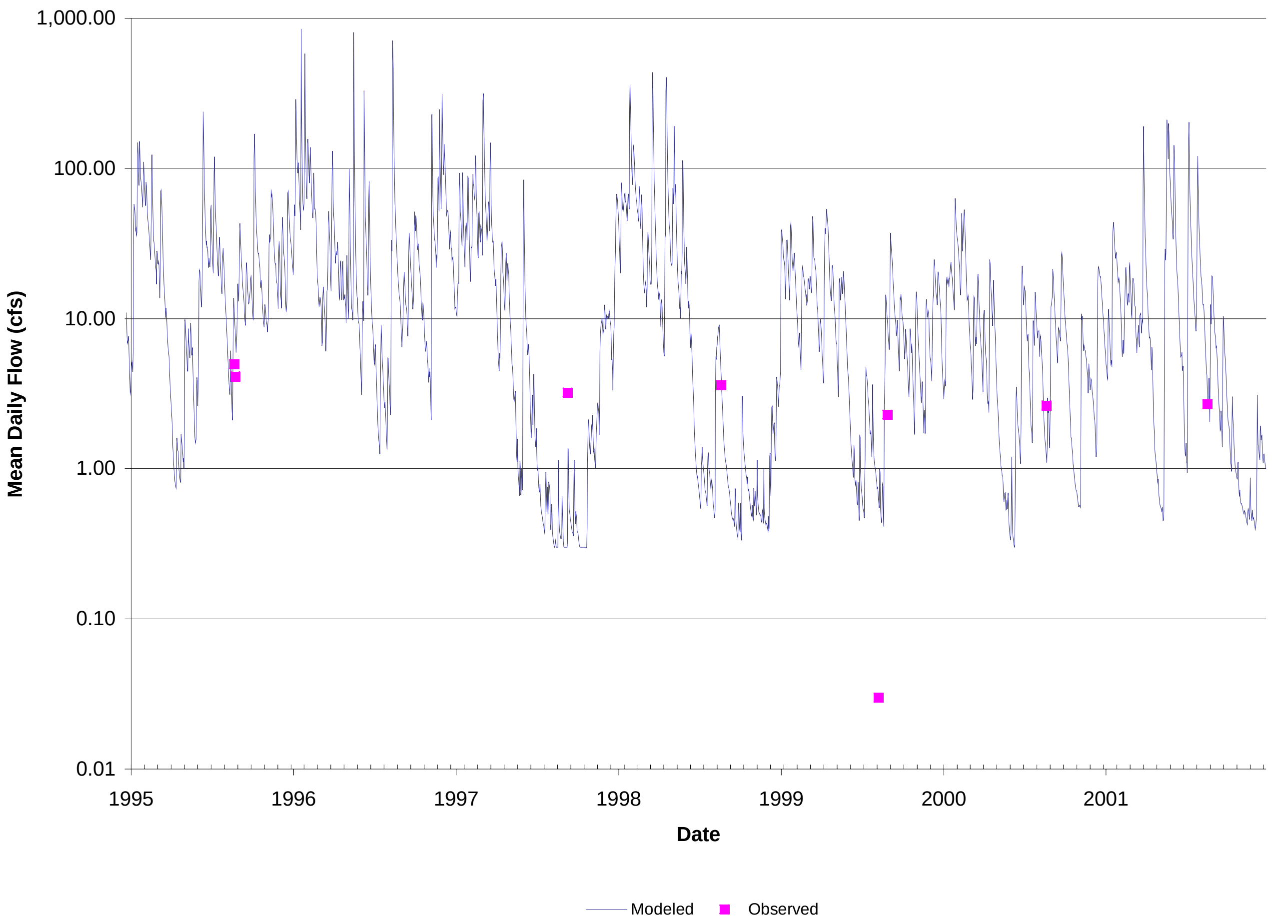

Figure 4.12 Calibration results for subwatershed 2 of Peak Creek for the period 8/21/1995 through 8/21/2001.

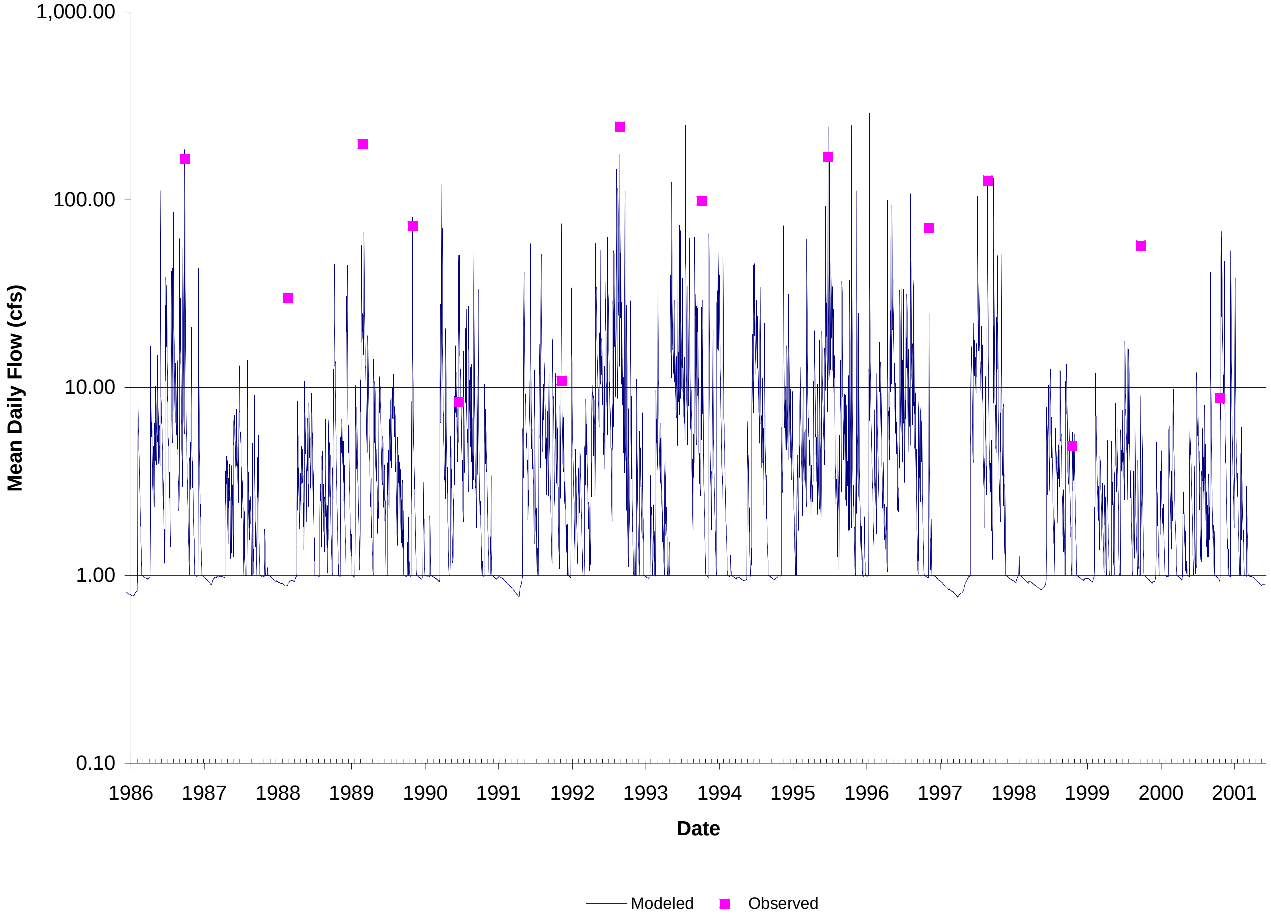

Figure 4.13 Calibration results for subwatershed 8 of Peak Creek for the period 7/27/1986 through 5/17/2001.

4.7.2 Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors, some of which are described here. First, water quality concentrations (*e.g.*, fecal coliform concentrations) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters such as fecal coliform concentration. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the limited amount of measured data for use in calibration and the practice of censoring both high (typically 8,000 or 16,000 cfu/100 ml) and low (under 100 cfu/100 ml) concentrations impede the calibration process.

The water quality calibration was conducted using monitored data from 10/1/93 through 9/30/98. Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4. 15). Specific values for each calibrated parameter are given in the excerpt from the calibrated UCI in Appendix C. Figure 4.14 through Figure 4.17 show the results of calibration. Modeled coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

Table 4.15 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
MON-ACCUM	FC/ac*day	0.0E+00 – 1.0E+20	0.0E+00 – 3.0E+10	0.0E+00 – 3.0E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0E+00 – 1.7E+11	0.0E+00 – 1.0E+12
WSQOP	in/hr	0.05 – 3.00	0-1.8	0.01- 0.9
IOQC	FC/ft^3	0.0E+00 – 1.0E+06	0	0
AOQC	FC/ft^3	0 – 10	0	0
DQAL	FC/100ml	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.00	1.15	0.2 – 2.5
THFST	---	1.0 – 2.0	1.07	1.07

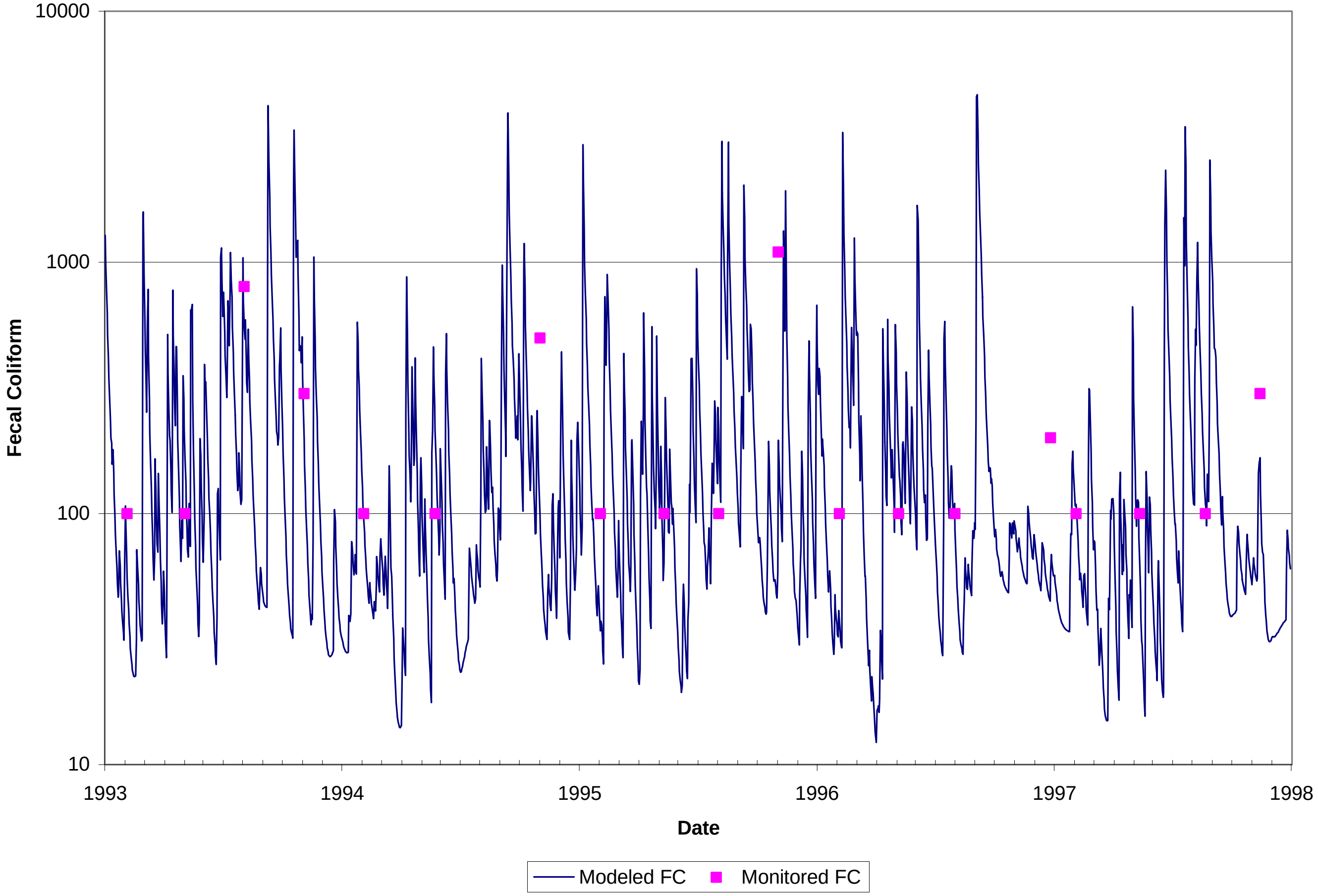

Figure 4.14 **Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Peak Creek impairment, during the calibration period.**

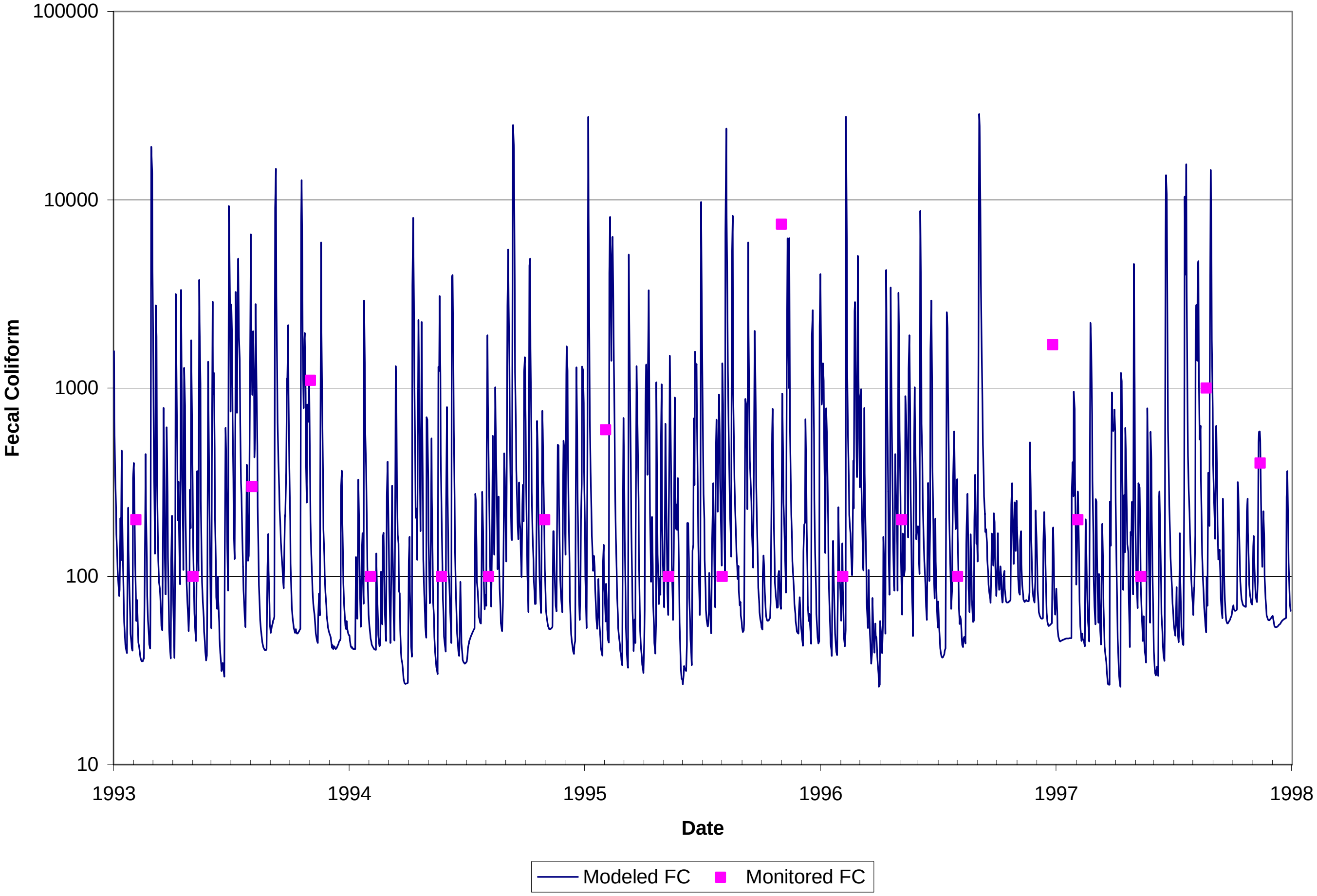

Figure 4.15 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 3 in the Peak Creek impairment, during the calibration period.

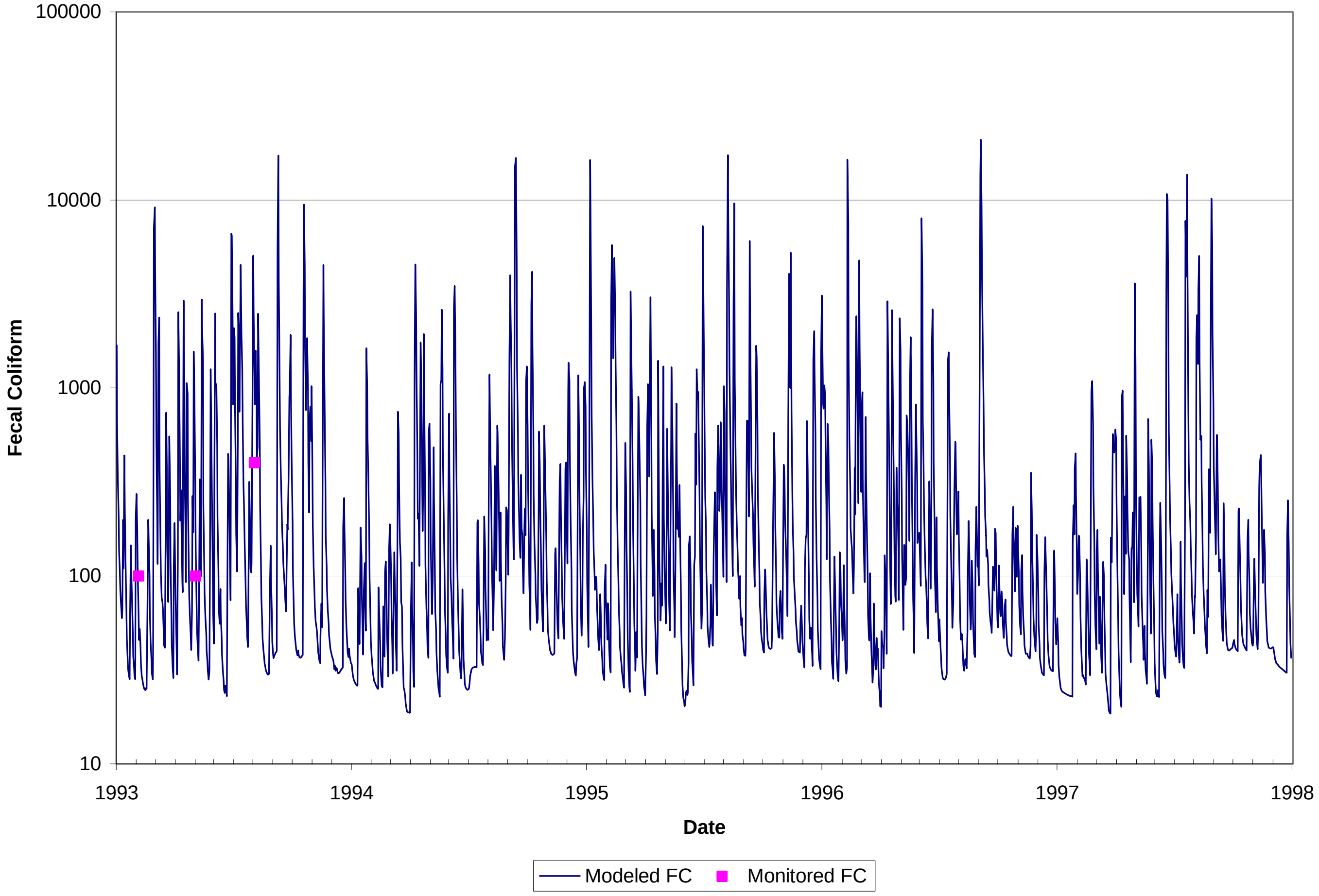

Figure 4.16 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 4 in the Peak Creek impairment, during the calibration period.

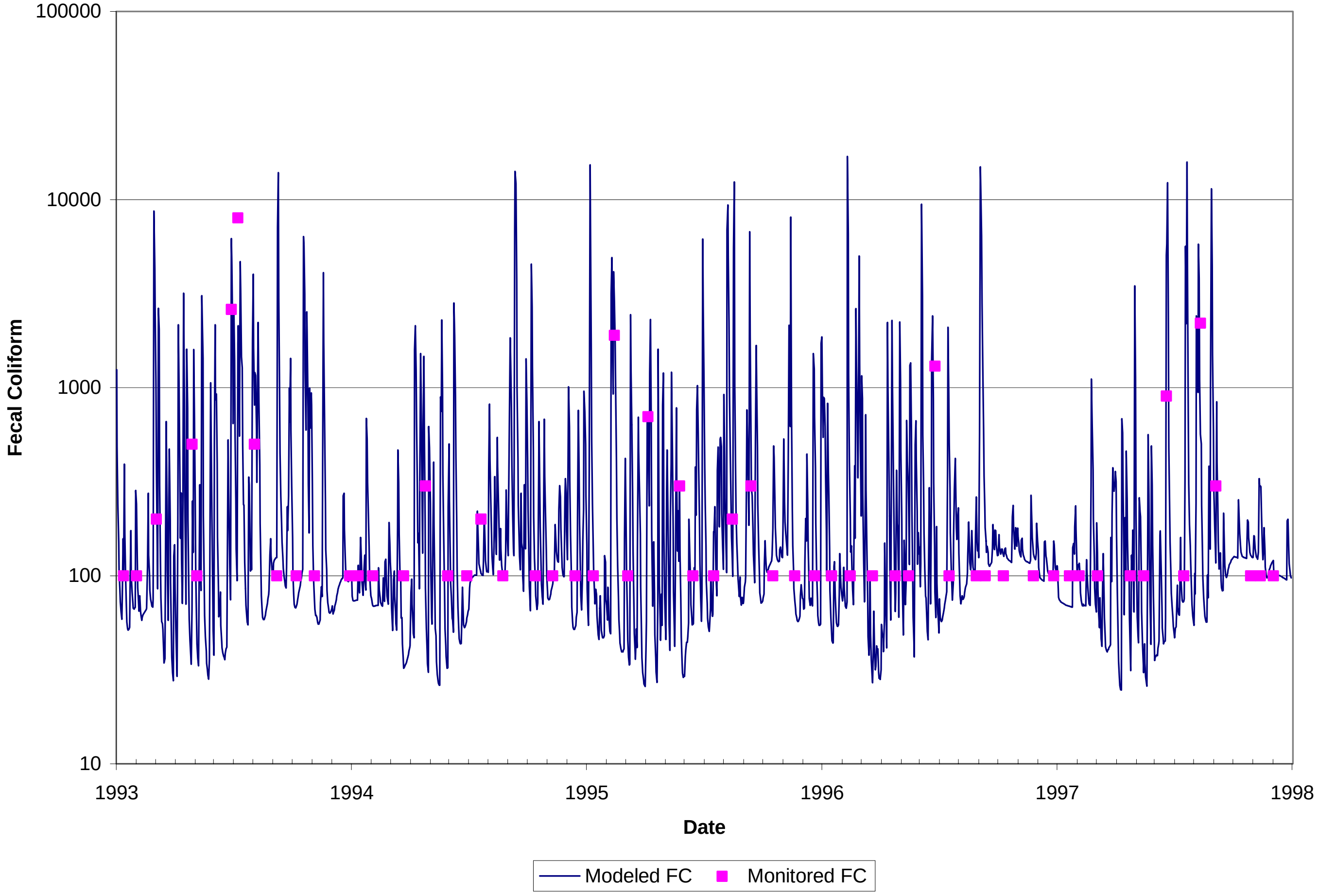

Figure 4.17 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 5 in the Peak Creek impairment, during the calibration period.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. To provide a quantitative measure of the agreement between modeled and measured data while taking the inherent variability of fecal coliform concentrations into account, each observed value was compared with modeled concentrations in a 2-day window surrounding the observed data point. Standard error in each observation window was calculated as follows:

$$Standard\ Error = \frac{\sqrt{\dfrac{\sum_{i=1}^{n}\left(observed - modeled_i\right)^2}{\left(n-1\right)}}}{\sqrt{n}}$$

where

$observed$ = an observed value of fecal coliform
$modeled_i$ = a modeled value in the 2 - day window surrounding the observation
n = the number of modeled observations in the 2 - day window

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data and found to be at reasonable levels (Table 4.16).

Table 4.16 Results of analyses on calibration runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-PKC004.65	57.6	66,034
9-PKC007.82	67.2	31,888
9-PKC009.29	85.2	63,444
9-PKC011.11	15.8	10,893

The water quality validation was conducted using data for the time period from 10/1/98 to 9/20/03. The relationship between observed values and modeled values is shown in Figures 4.18 through 4.21. The results of standard error and maximum value analyses are reported in Table 4.17. Standard errors calculated from validation runs were comparable to standard errors calculated from calibration runs. Maximum simulated values were comparable to observed values in the area (Section 2).

Table 4.17 Results of analyses on validation runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-PKC004.65	26	62,989
9-PKC009.29	95	61,290
9-PKC011.11	24	9,129
9-PKC016.91	8	2,923

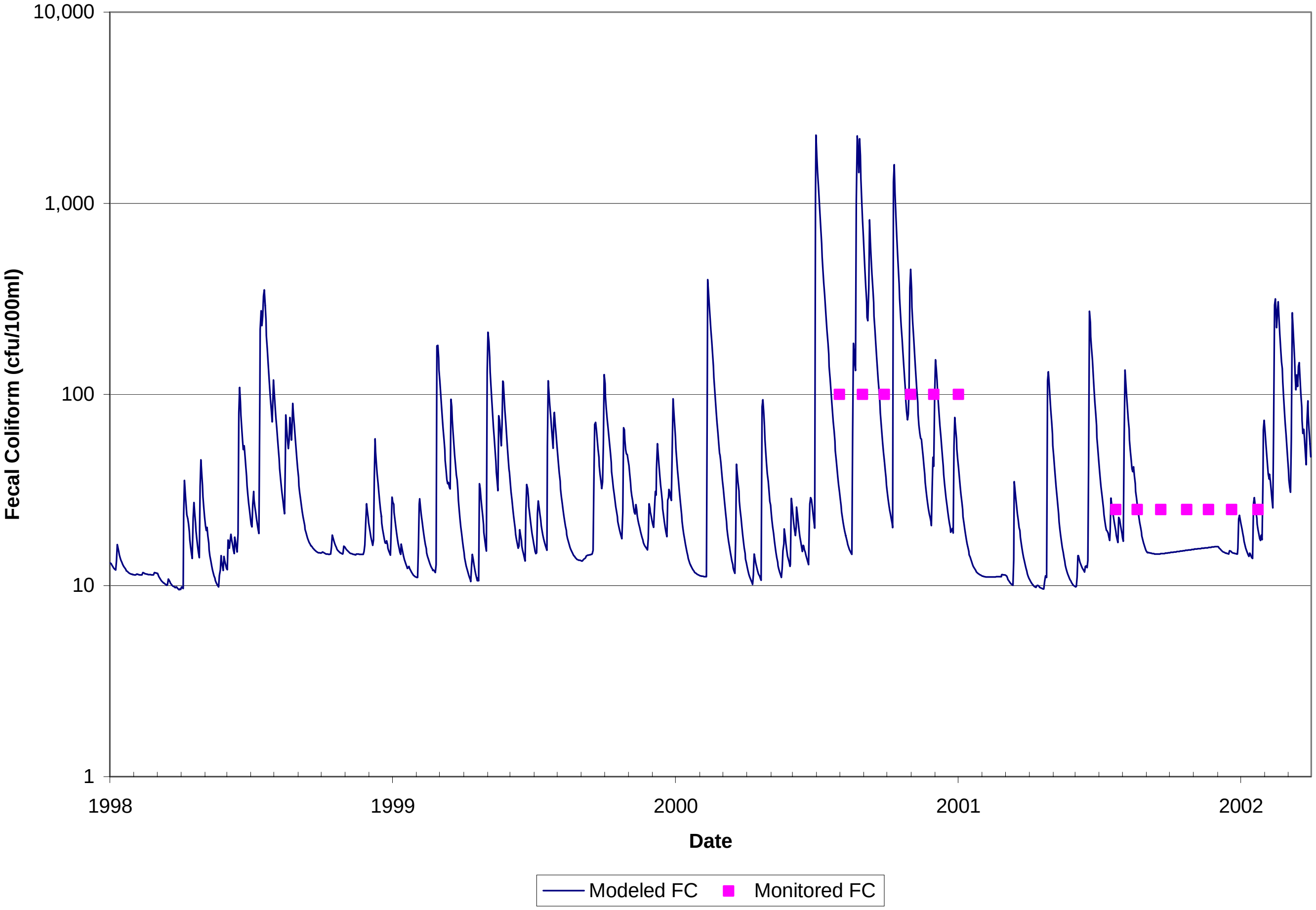

Figure 4.18 **Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 1 in the Peak Creek impairment, during the validation period.**

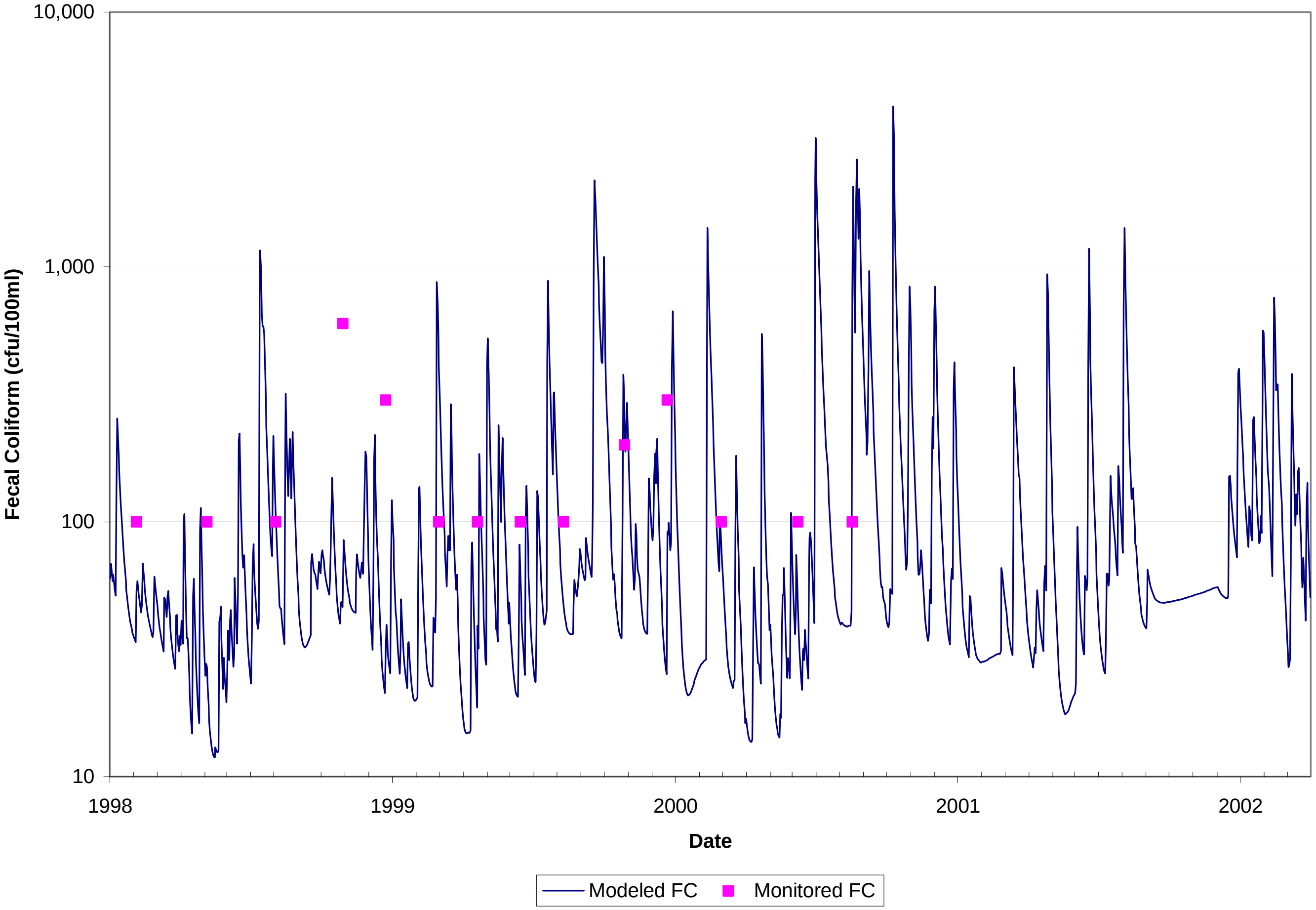

Figure 4.19 **Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Peak Creek impairment, during the validation period.**

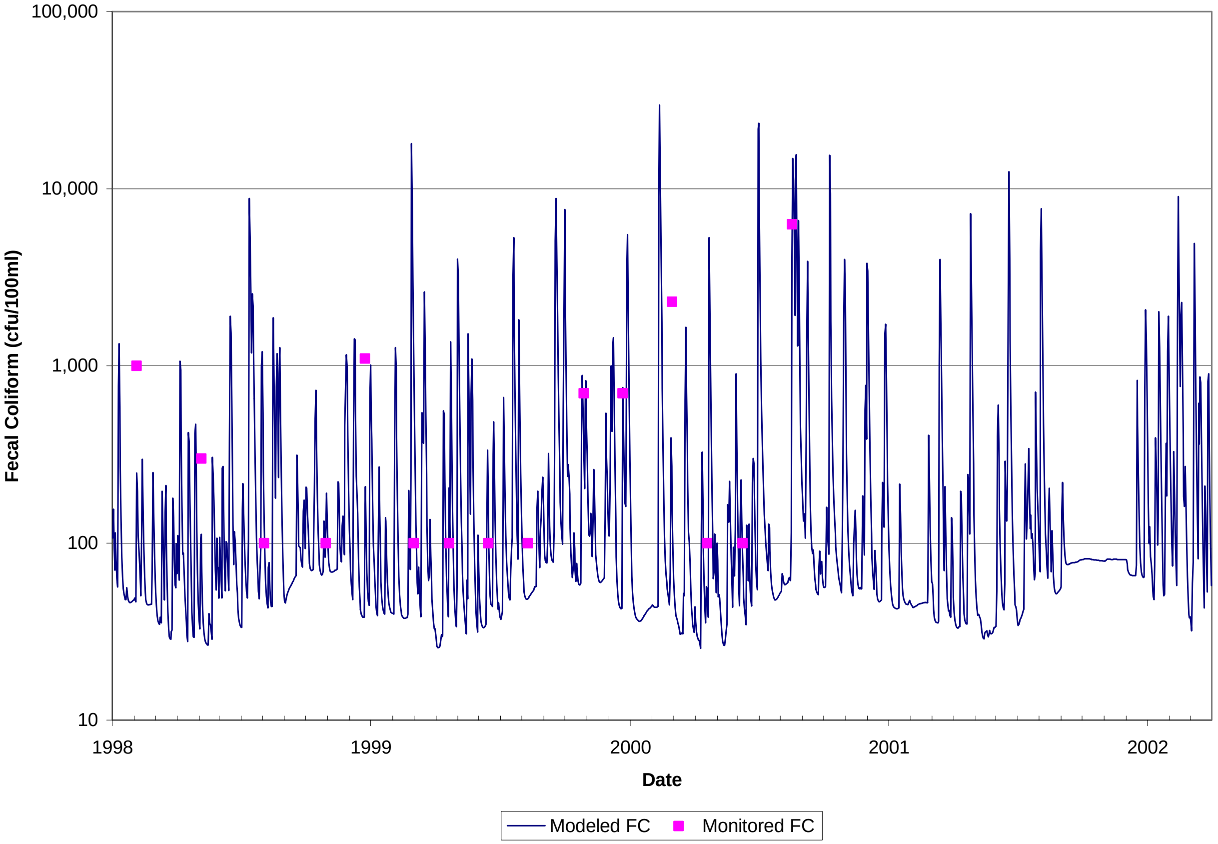

Figure 4.20 **Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 3 in the Peak Creek impairment, during the validation period.**

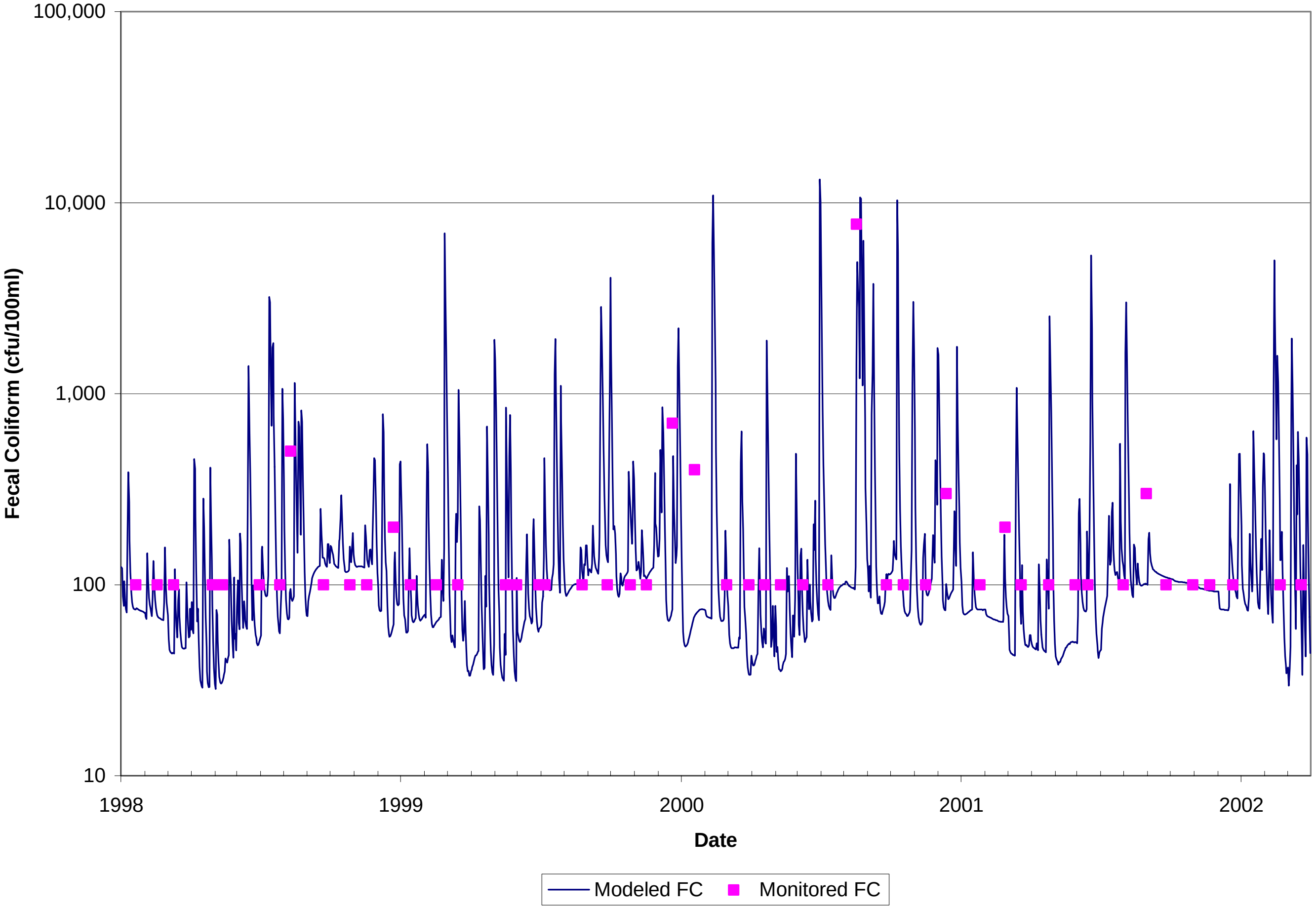

Figure 4.21 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 5 in the Peak Creek impairment, during the validation period.

4.8 Existing Loadings

All appropriate inputs were updated to 2003 conditions, as described in Section 4. All model runs were conducted using precipitation data for the representative period used for hydrologic calibration (10/1/86 through 9/30/91). Figure 4.22 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126 cfu/100 ml standard. Figure 4.23 shows the instantaneous values of *E. coli* concentrations in relation to the 235 cfu/100 ml standard. Appendix B contains tables with monthly loadings to the different landuse areas in each subwatershed.

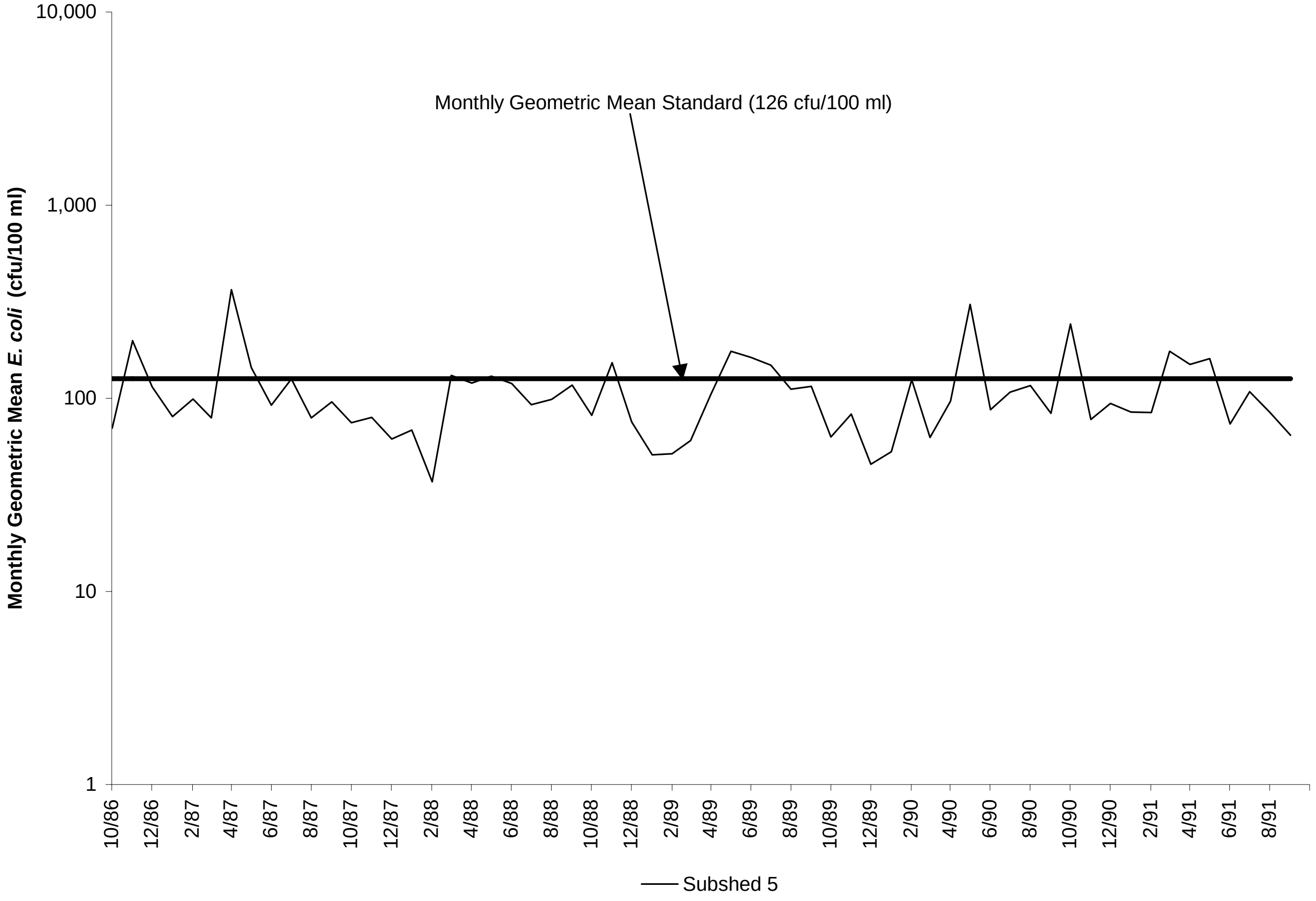

Figure 4.22 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Peak Creek impairment.

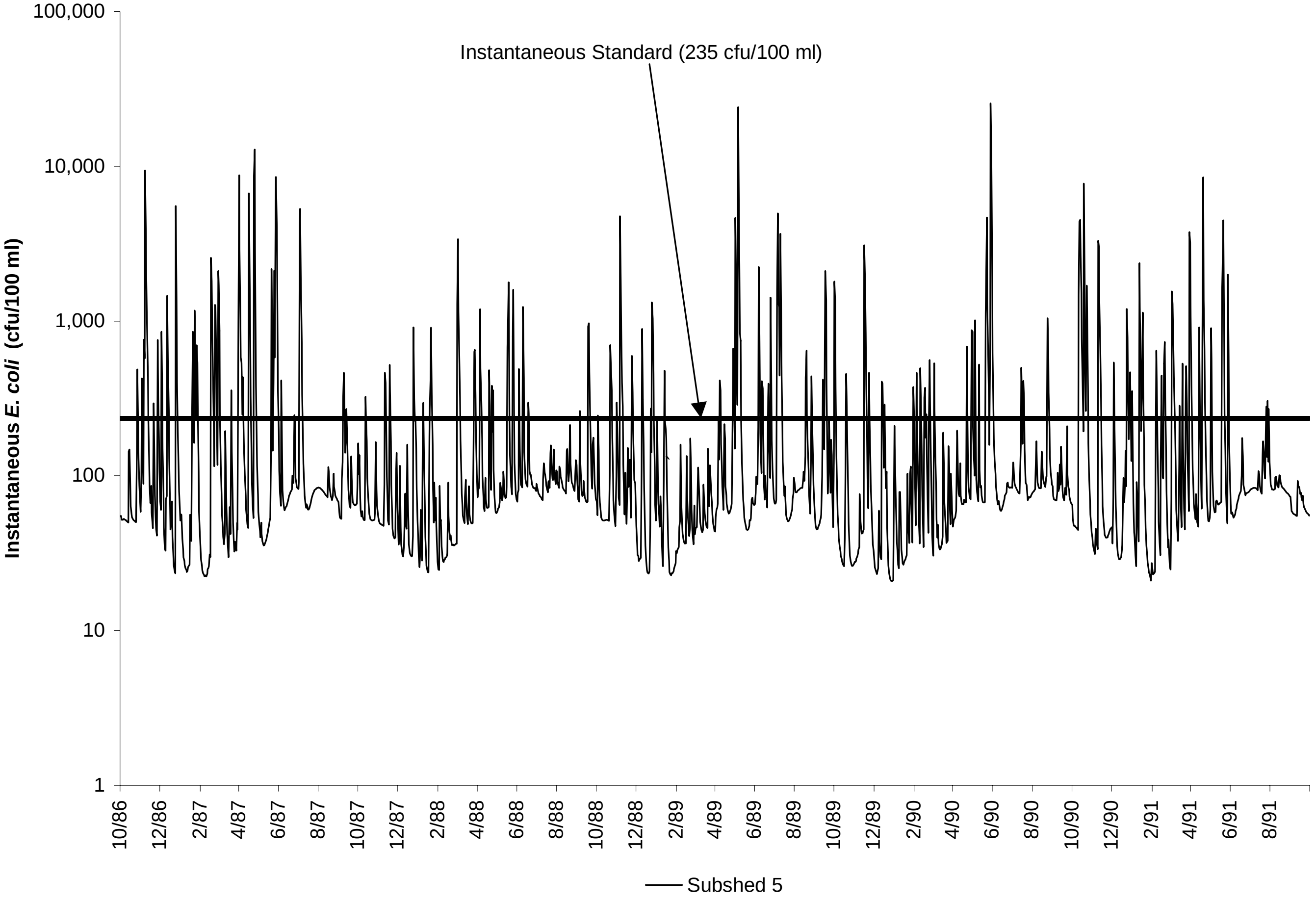

Figure 4.23 Existing conditions (***i.e.***, mean daily) of ***E. coli*** concentrations at the outlet of the Peak Creek impairment.

5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, point sources) and load allocations (LAs, nonpoint sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

$$TMDL = WLAs + LAs + MOS$$

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving water body and still achieve water quality standards. For fecal bacteria, TMDL is expressed in terms of colony forming units (or resulting concentration). A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

5.1 Incorporation of a Margin of Safety

In order to account for uncertainty in modeled output, a margin of safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A margin of safety can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of a MOS in the development of a fecal coliform TMDL is to ensure that the modeled loads do not under-estimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of this TMDL. By adopting an implicit MOS in estimating the loads in the watershed, it is insured that the recommended reductions will, in fact, succeed in meeting the water quality standard. Examples of implicit MOS used in the development of this TMDL were:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed

- Modeling biosolids applications at the maximum allowable rate and fecal coliform concentration in all permitted fields

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standard was attained. The TMDL developed for the Peak Creek watershed was based on the Virginia State Standard for *E. coli*. As detailed in Section 1.2, the *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* not exceed 235 cfu/100 ml. According to the guidelines put forth by VADEQ (VADEQ, 2003) for modeling *E. coli* with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* through the use of the following equation (developed from a dataset containing n-493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

Where C_{ec} is the concentration of *E. coli* in cfu/100 ml, and C_{fc} is the concentration of fecal coliform in cfu/100 ml.

Pollutant concentrations were modeled over the entire duration of a representative modeling period, and pollutant loads were adjusted until the standard was met (Figures 5.7 through 5.8). The development of the allocation scenario was an iterative process that required numerous runs with each followed by an assessment of source reduction against the water quality target.

5.2.1 Wasteload Allocations

There are thirteen point sources currently permitted to discharge in the Peak Creek watershed (Figure 3.1 and Table 3.1). Of these sources, only one is permitted for fecal control in the impairment areas. For allocation runs, sources without fecal control permits were modeled as discharging the average recorded value of water, with no *E.*

coli. The allocation for these sources is zero cfu/100 ml. The allocation for the sources permitted for fecal control is equivalent to their current permit levels (*i.e.*, design flow and 126 cfu/100 ml).

5.2.2 Load Allocations

Load allocations to nonpoint sources are divided into land-based loadings from landuses and directly applied loads in the stream (*e.g.,* livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Within this framework, however, initial criteria that influenced developing load allocations included how sources were linked for representing existing conditions, and results from bacterial source tracking in the area. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. Bacterial source tracking during 2002-2003 sampling periods confirmed the presence of human, pets, livestock and wildlife contamination.

Allocation scenarios for Peak Creek are shown in Table 5.1. Scenario 1 describes a baseline scenario that corresponds to the existing conditions in the watershed. Model results indicate that human, livestock, and in-stream depositions by wildlife are significant in all areas of the watershed. This is in agreement with the results of BST analysis presented in Appendix C.

The first objective in running reduction scenarios was to explore the role of anthropogenic sources in standards violations. Scenarios were explored first to determine the feasibility of meeting standards without wildlife reductions. Following this theme, Scenario 3 resulted from 100% reductions in sewer overflows and uncontrolled residential discharges (*i.e.*, straight pipes), 90% reduction in direct livestock deposition, and 50% reductions to land loads from urban and agricultural lands. Direct loads from wildlife were not addressed. This scenario improved conditions in the stream, but failed to eliminate exceedances.

With reduction iterations leading to Scenario 4, attention continued with reductions to anthropogenic sources with additional reductions to land loads from urban and agricultural lands; however, exceedances still persisted with both water quality standards. With an additional 99 % reduction in wildlife land loads, the geometric mean standard was met (Scenario 4, Table 5.1). Additional scenarios were made by first exhausting options related to anthropogenic sources, then iteratively making reductions in wildlife until a reduction scenario was found that resulted in zero exceedances of both standards (Scenario 6, Table 5.1).

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Peak Creek impairment.

	Percent Reduction in Loading from Existing Condition						Percent Violations	
Scenario Number	**Direct Wildlife**	**NPS Wildlife**	**Direct Livestock**	**NPS Pasture / Livestock**	**Res./ Urban**	**Straight Pipe/ Sewer Overflow**	**GM > 126 cfu/ 100ml**	**Single Sample Exceeds 235 cfu/ 100ml**
1	0	0	0	0	0	0	21.7	17.5
2	0	0	0	0	0	100	20.0	17.4
3	0	0	90	50	50	100	1.67	9.53
4	0	0	100	99	99	100	0.0	1.04
5	0	99	100	99	99	100	0.0	0.11
6	0	68	100	99.5	99.5	100	0.0	0.0

Figures 5.1 and 5.2 show graphically the existing and allocated conditions for the geometric-mean concentrations and instantaneous concentrations in the impairment. Table 5.2 indicates the land-based and direct load reductions resulting from the final allocation. Table 5.3 shows the final TMDL loads for the impairment.

To determine if the allocation scenario presented (Table 5.1, scenario 6) will be applicable in the future, the same scenario was evaluated with an increase in permitted loads. The permitted loads were increased by a factor of 5 to simulate a population growth. This future scenario resulted in no violations of the geometric or instantaneous *E. coli* standard. The TMDL table that reflects this future scenario is in Appendix E.

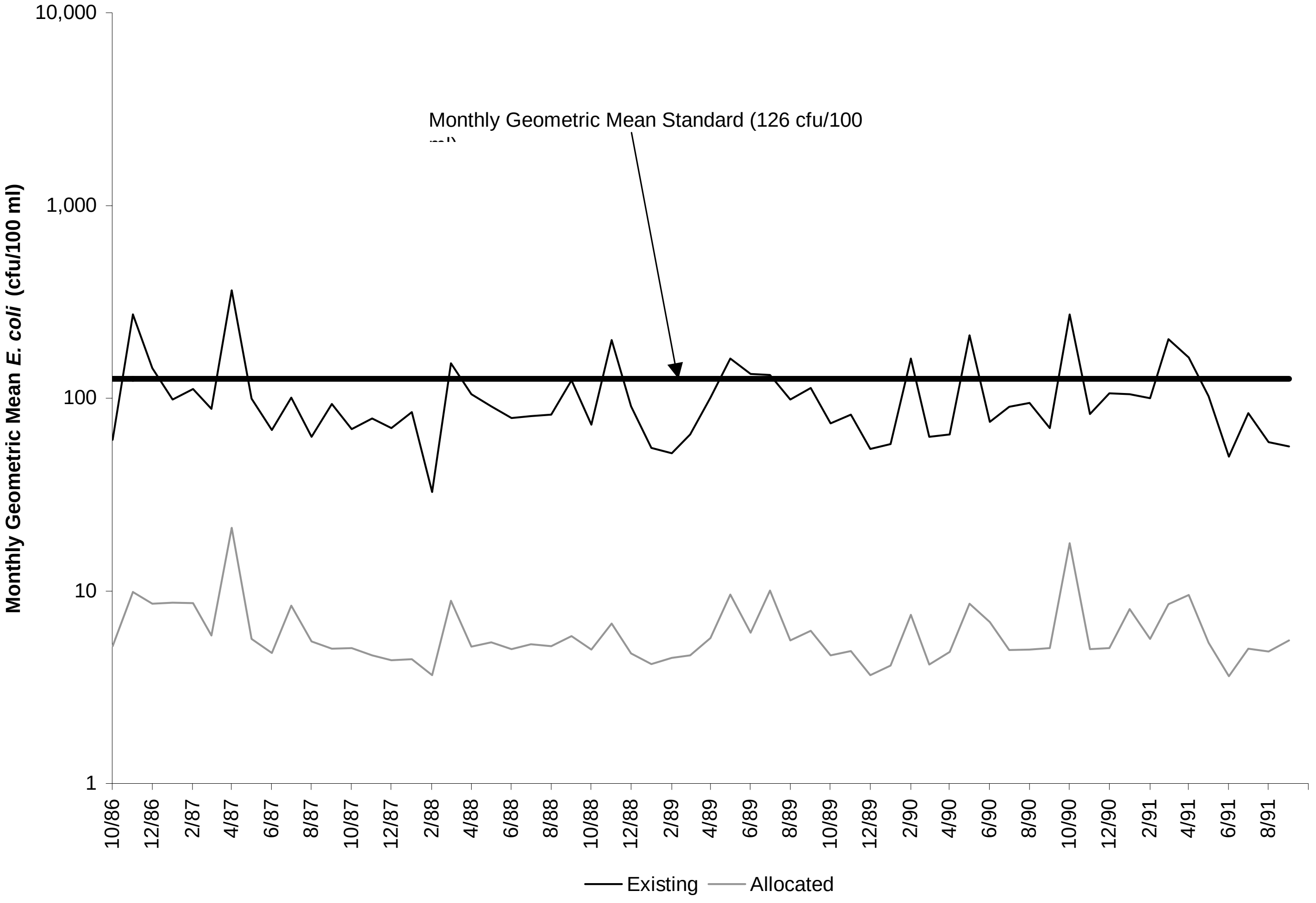

Figure 5.1 Monthly geometric mean *E. coli* concentrations for the Peak Creek impairment, under existing and allocated conditions.

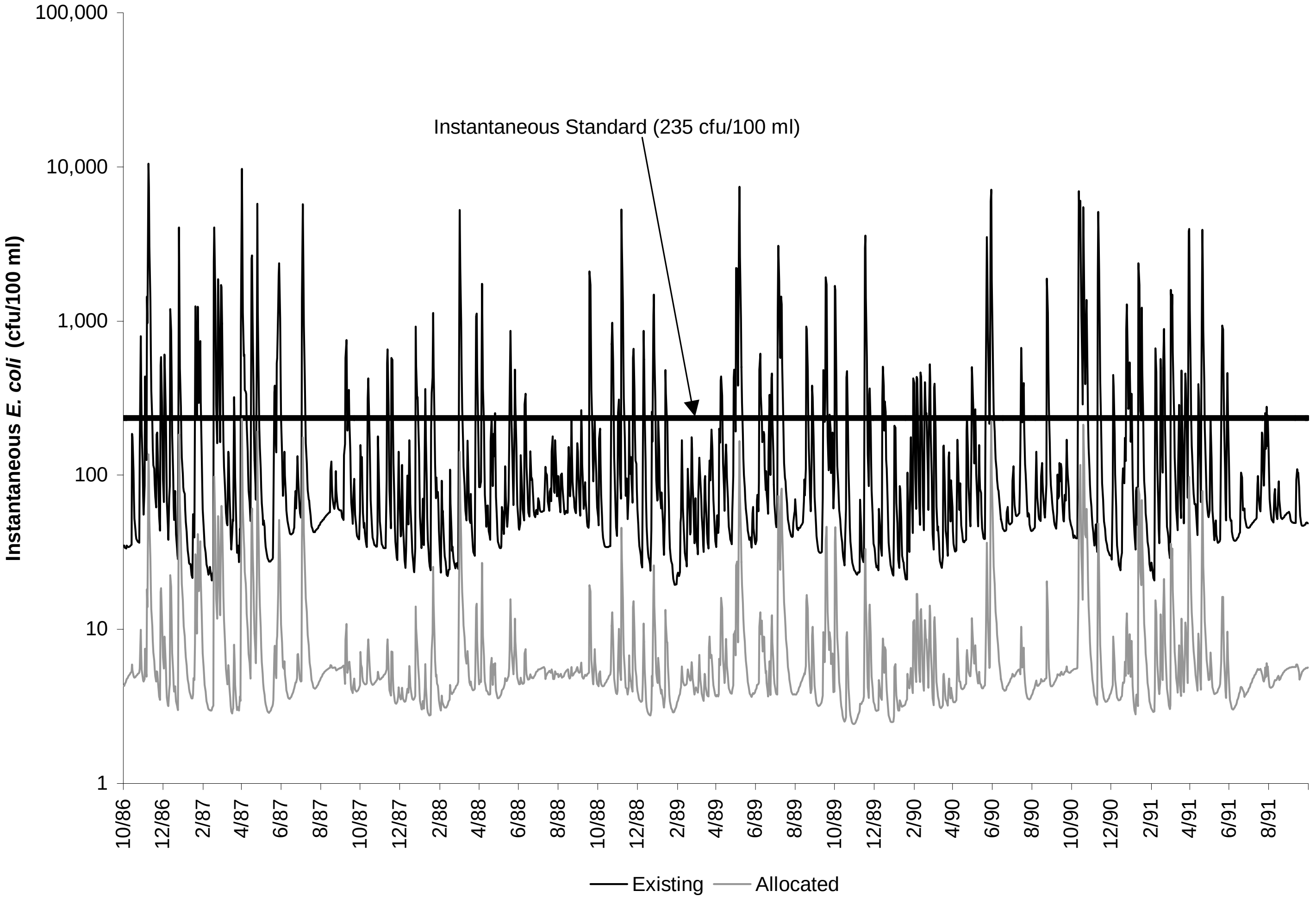

Figure 5.2 Instantaneous *E. coli* concentrations for the Peak Creek impairment, under existing and allocated conditions.

Table 5.2 Land-based and Direct nonpoint source load reductions in the Peak Creek impairment for final allocation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Residential	4.64E+14	2.32E+12	99.5
Commercial	7.43E+12	3.72E+10	99.5
Barren	6.93E+12	3.47E+10	99.5
Cropland	5.02E+15	2.51E+13	99.5
Livestock Access	2.36E+14	1.18E+12	99.5
Pasture	3.20E+15	1.60E+13	99.5
Forest	5.70E+13	1.71E+13	68
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	3.36E+15	0.00E+00	100
Wildlife	1.46E+13	1.46E+13	0
Straight Pipes and Sewer Overflows	2.99E+13	0.00E+00	100

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after TMDL in the Peak Creek watershed.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Peak Creek (FC) *VAG402040*[1]	8.70E+08 *8.70E+08*	4.26E+12	*Implicit*	4.26E+12

[1] General permits – single family home

PART III: GENERAL WATER QUALITY (BENTHIC) TMDL

6. WATER QUALITY ASSESSMENT

6.1 Benthic Assessment

Peak Creek was first listed in 1996 as being moderately impaired based on the RBP II assessment method. Table 6.1 through Table 6.3 show the RBP II assessments for Peak Creek stations 9-PKC007.80, 9-PKC09.29, and 9-PKC011.11.

Table 6.1 The RBPII biological assessment for the last 5 years for Peak Creek at station 9-PKC007.80.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998	65.27	Severely Impaired (BPJ)	40.91	Moderately Impaired
1999	8.33	Severely Impaired	39.13	Severely Impaired (BPJ)
2000	17.39	Severely Impaired (BPJ)		(not sampled)
2001		(not sampled)		(not sampled)
2002	56.52	Slightly Impaired	50.00	Moderately Impaired
Seasonal 5-yr average	36.88		43.35	
Seasonal last 2-yr average	56.52		50.00	
Final 5-yr average			39.65	
Final 2-yr average			53.26	

Table 6.2 The RBPII biological assessment for the last 5 years for Peak Creek at station 9-PKC009.29.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998	73.91	Severely Impaired (BPJ)	45.45	Moderately Impaired
1999	29.17	Severely Impaired (BPJ)	47.83	Severely Impaired (BPJ)
2000	60.87	Severely Impaired (BPJ)		(not sampled)
2001		(not sampled)		(not sampled)
2002	43.48	Moderately Impaired	36.36	Moderately Impaired
Seasonal 5-yr average	51.86		43.21	
Seasonal last 2-yr average	43.48		36.36	
Final 5-yr average			48.15	
Final 2-yr average			39.92	

Table 6.3 The RBPII biological assessment for the last 5 years for Peak Creek at station 9-PKC011.11.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998	91.30	Non-Impaired	72.73	Non-Impaired (BPJ)
1999	66.67	Non-Impaired (BPJ)	52.17	Non-Impaired (BPJ)
2000	52.17	Non-Impaired (BPJ)		(not sampled)
2001		(not sampled)		(not sampled)
2002	100.00	Non-Impaired	100.00	Non-Impaired
Seasonal 5-yr average	77.54		74.97	
Seasonal last 2-yr average	100.00		100.00	
Final 5-yr average			76.44	
Final 2-yr average			100.00	

The General Standard is evaluated by VADEQ through application of the Rapid Bioassessment Protocol II (RBP II). VADEQ is also using an additional assessment tool, the Stream Condition Index (SCI), for calculating benthic assessment scores. The SCI does not require a reference station for non coastal streams, allowing the benthic condition of different streams to be more directly compared. The SCI is also useful for trend analysis for streams in which more than one reference station has been used.

Data from benthic surveys completed on Peak Creek are summarized in Tables 6.4 through 6.6. Because the Stream Condition Index (SCI) score does not depend on values from a reference station, the scores have been calculated for both of the biological monitoring stations (PKC007.80 and PKC009.29) and reference station 9-PKC011.11. Benthic assessments indicate impaired conditions at the two biological monitoring stations and non-impaired conditions at the reference site. In Virginia, streams with an SCI of less than 61.3 are approaching conditions unlike reference sites.

Table 6.4 Summary of biological monitoring data for Station PKC007.80.

Date	Taxa	EPT	% Ephem	% PT-H	% Scraper	% Chiron	%2 Dom	%MFBI	SCI
6/4/02	63.6	36.4	4.3	2.5	80.6	93.9	32.9	77.0	48.9
3/28/00	36.4	9.1	0.0	0.0	29.1	74.8	63.7	62.0	34.4
11/3/99	45.5	9.1	0.0	0.0	13.3	0.0	31.8	61.1	20.1
3/1/99	31.8	9.1	0.0	0.0	16.1	68.2	36.7	64.4	28.3
10/13/98	36.4	9.1	0.0	0.0	25.6	97.9	29.9	69.0	33.5
4/6/98	59.1	45.5	7.1	12.2	35.1	77.2	83.1	72.1	48.9
10/9/97	18.2	9.1	0.0	0.0	27.4	0.0	24.5	69.4	18.6
5/1/97	63.6	45.5	2.0	71.9	33.4	91.5	95.0	79.4	60.3
10/23/96	27.3	9.1	0.0	0.0	15.1	98.1	20.2	62.4	29.0
5/1/96	59.1	54.5	24.8	32.0	28.6	78.5	74.9	77.6	53.7
10/18/95	18.2	9.1	0.0	0.0	22.8	0.0	12.8	63.9	15.8
5/3/95	22.7	9.1	0.0	0.0	16.4	0.0	9.8	62.2	15.0
10/7/94	31.8	18.2	1.7	0.0	3.3	0.0	13.4	63.7	16.5
Mean	39.5	21.0	3.1	9.1	26.7	52.3	40.7	68.0	32.5
Median	36.4	9.1	0.0	0.0	25.6	74.8	31.8	64.4	29.0

Table 6.5 Summary of biological monitoring data for Station PKC009.29.

Date	Taxa	EPT	% Ephem	% PT-H	% Scraper	% Chiron	%2 Dom	%MFBI	SCI
6/4/02	63.6	36.4	3.2	2.7	20.4	85.4	40.6	61.7	39.2
3/28/00	54.5	18.2	1.6	0.0	32.3	68.6	70.1	58.8	38.0
11/3/99	72.7	18.2	1.3	0.0	31.2	99.2	47.7	65.8	42.0
3/1/99	50.0	27.3	2.8	2.4	6.8	57.6	24.5	60.6	29.0
10/13/98	45.5	18.2	2.8	0.0	40.3	0.0	39.8	64.0	26.3
4/6/98	63.6	63.6	14.1	5.4	40.3	77.9	59.7	69.9	49.3
10/9/97	45.5	27.3	0.0	8.7	41.6	96.9	35.7	68.4	40.5
5/1/97	59.1	45.5	14.5	30.6	46.3	81.2	87.2	76.4	55.1
10/23/96	22.7	9.1	0.0	0.0	28.0	0.0	25.0	65.1	18.7
5/1/96	72.7	72.7	29.0	21.8	50.2	87.8	78.6	76.8	61.2
10/18/95	36.4	18.2	2.9	0.0	15.7	0.0	16.6	61.7	18.9
5/3/95	45.5	27.3	1.6	2.7	40.3	89.4	54.1	60.7	40.2
10/7/94	31.8	9.1	0.0	0.0	13.7	99.2	13.5	60.1	28.4
Mean	51.0	30.1	5.7	5.7	31.3	64.9	45.6	65.4	37.5
Median	50.0	27.3	2.8	2.4	32.3	81.2	40.6	64.0	39.2

Table 6.6 Summary of biological monitoring data for Station PKC011.11 (reference).

Date	Taxa	EPT	% Ephem	% PT-H	% Scraper	% Chiron	%2 Dom	%MFBI	SCI
6/4/02	81.8	72.7	27.4	36.0	23.4	76.8	78.5	78.9	60.1
3/28/00	63.6	45.5	100.0	5.2	65.1	96.3	47.7	89.0	64.0
11/3/99	31.8	36.4	92.1	69.5	35.1	99.0	58.6	96.8	64.9
3/1/99	68.2	54.5	40.4	100.0	20.0	92.0	89.4	89.7	69.3
10/13/98	50.0	45.5	68.1	100.0	25.1	99.0	43.4	99.9	66.4
4/6/98	72.7	72.7	46.6	47.2	56.9	85.7	98.2	82.1	70.3
10/9/97	50.0	45.5	79.0	50.5	70.6	99.2	63.1	88.4	68.3
5/1/97	77.3	90.9	58.0	65.5	64.5	94.4	89.8	93.6	79.3
10/23/96	50.0	54.5	77.8	36.1	35.5	97.2	62.2	87.2	62.6
5/1/96	68.2	81.8	51.7	68.5	53.1	95.1	88.0	90.4	74.6
10/18/95	45.5	54.5	100.0	9.9	32.5	0.0	41.8	99.8	48.0
5/3/95	81.8	63.6	40.4	86.4	33.1	98.3	87.6	91.1	72.8
10/7/94	50.0	45.5	91.3	23.2	26.6	0.0	50.3	98.1	48.1
Mean	60.8	58.7	67.1	53.7	420	79.5	69.1	91.2	65.3
Median	63.6	54.5	68.1	50.5	35.1	95.1	63.1	90.4	66.4

Plots of the SCI scores were prepared for Peak Creek (Figure 6.1) to show variation of the benthic condition with location and over time. Although it is not proper to connect discrete data points with lines, it has been done in Figure 6.1 to more clearly show seasonality and to help distinguish among stations. The benthic community in Peak Creek displays seasonality with SCI scores generally lower in the fall than in the spring. Mood's Median Test was run on all data from Peak Creek and seasonal variation in SCI scores is significant ($p = 0.015$). Beginning in 2000, seasonality is less pronounced and there is a decline in SCI scores at most stations. When data from 2000-2003 was deleted from the data set the seasonality became even more pronounced ($p = 0.009$), implying that the drought decreased the degree of seasonality. These two trends are most easily seen at the Peak Creek reference station (PKC011.11) in Figure 6.1 and are attributed to the drought of 2000-2003. However, the drought-related decline in SCI observed at the two upper stations did not occur at the lower station where SCI scores actually improved. (On Crab Creek, also in the New River watershed, the drought-related decline occurred at all three biological monitoring stations.) Monitoring site PKC007.80 may not exhibit the same drought response pattern as the upstream stations because the drought prevents contaminated storm water from entering the stream at this location. Drought conditions would decrease input from the site as well as leaving the sediment relatively undisturbed, both of which would decrease benthic exposure to toxic metals

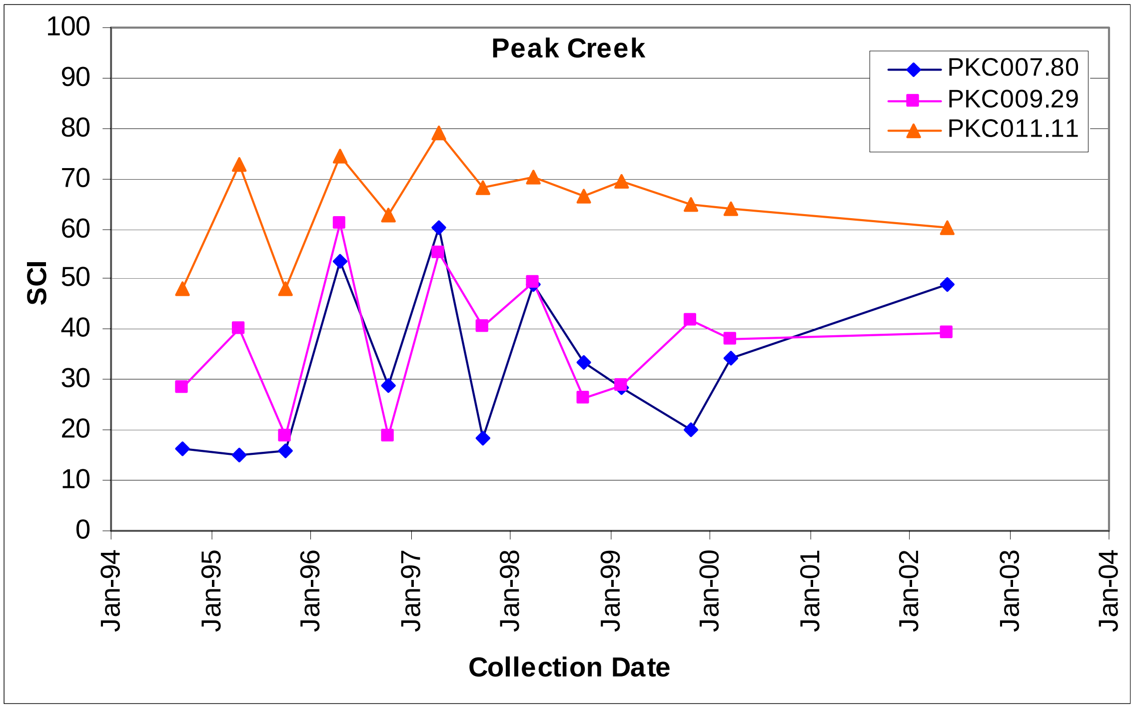

Figure 6.1 Biological assessment scores over time for Peak Creek.

Peak Creek bioassessment scores have improved since the early 1990s and VADEQ regional biologists attribute the improvement to voluntary capping of the Allied site. However, the cap is showing signs of wear and there is still no vegetative buffer to mitigate erosion from the site.

There are data from 13 benthic samples at all three stations and the data for each of the eight metrics has been summarized using “box and whisker” plots. Interpretation of the plots is illustrated in Figure 6.2, in which the data range for a given metric is displayed as four quartiles. The “box” of two colors shows the two inner quartiles with the dividing line between the colors representing the median value. The “whiskers” above and below each box show the outer quartiles with the upper quartile extending above the box and the lower quartile extending below the box. Finally, the mean value is displayed as a square within one of the two inner-quartile boxes.

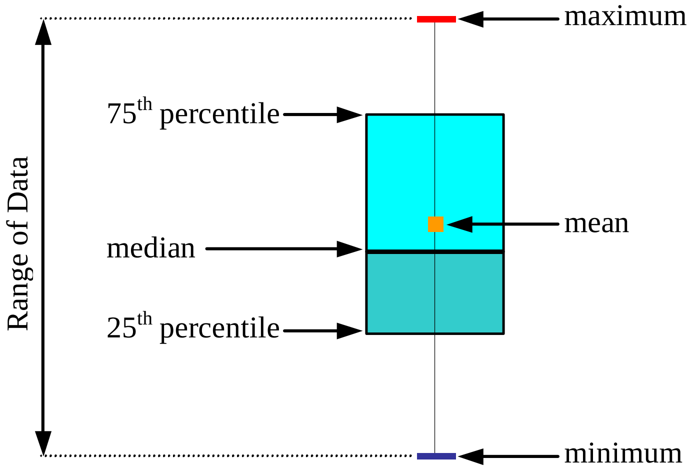

Figure 6.2 Interpretation of Box and Whisker plots.

The summaries for each station are displayed in Figures 6.3 - 6.5 and they display the same general pattern. The metric score increases from %2Dom to %Chiron, followed by a large drop in score for the next four metrics (%Ephem, %PT-H, %Scraper, %EPT) and then increases in the scores for Taxa Richness and %MFBI. The last metric displayed is the SCI score, obtained by averaging the eight individual metric scores. The pattern persists in an attenuated form, even at the reference station on Peak Creek, and indicates that conditions must be optimal for the sensitive invertebrate families found in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) to flourish. The %PT-H scores at the reference watershed are significantly higher than at the two stations downstream, indicating that the Plecoptera order is less dominated by those hydropsychid species adapted to higher levels of fine particulate organic matter.

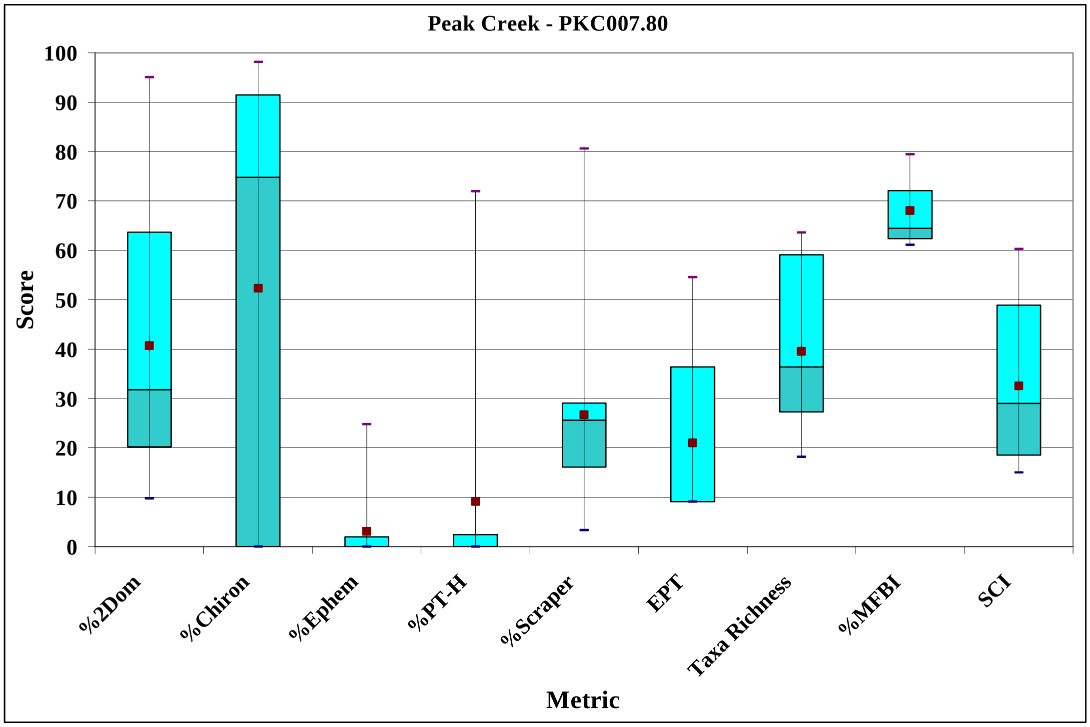

Figure 6.3 SCI metric scores for Peak Creek at Station 9-PKC007.80.

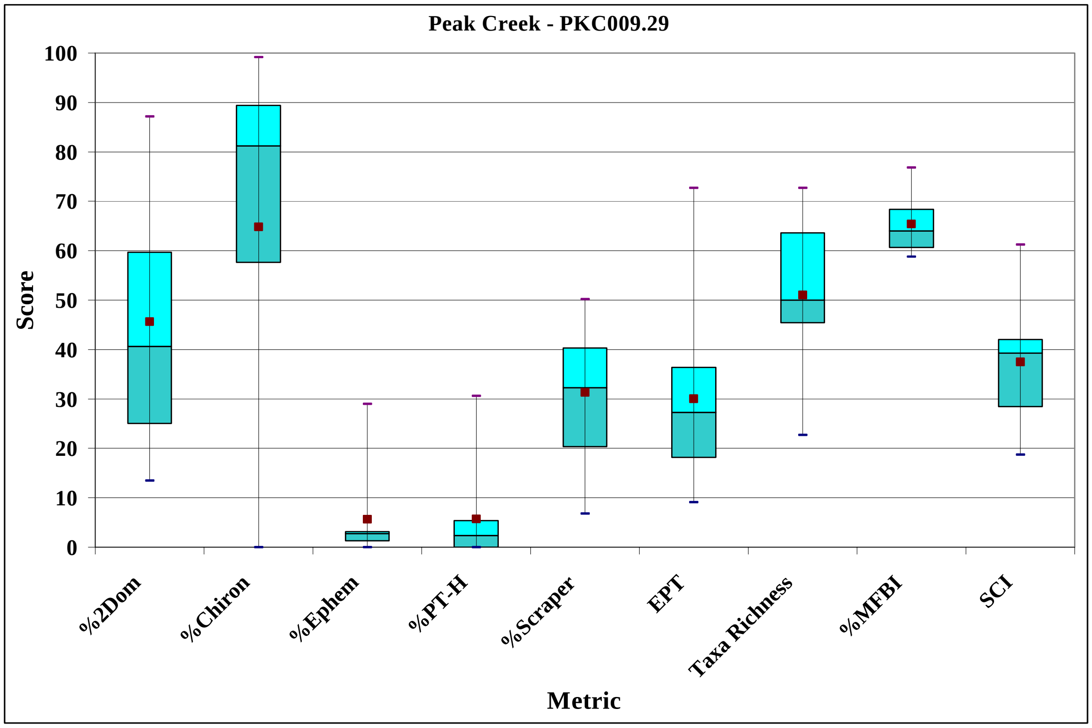

Figure 6.4 SCI metric scores for Peak Creek at Station 9-PKC009.29.

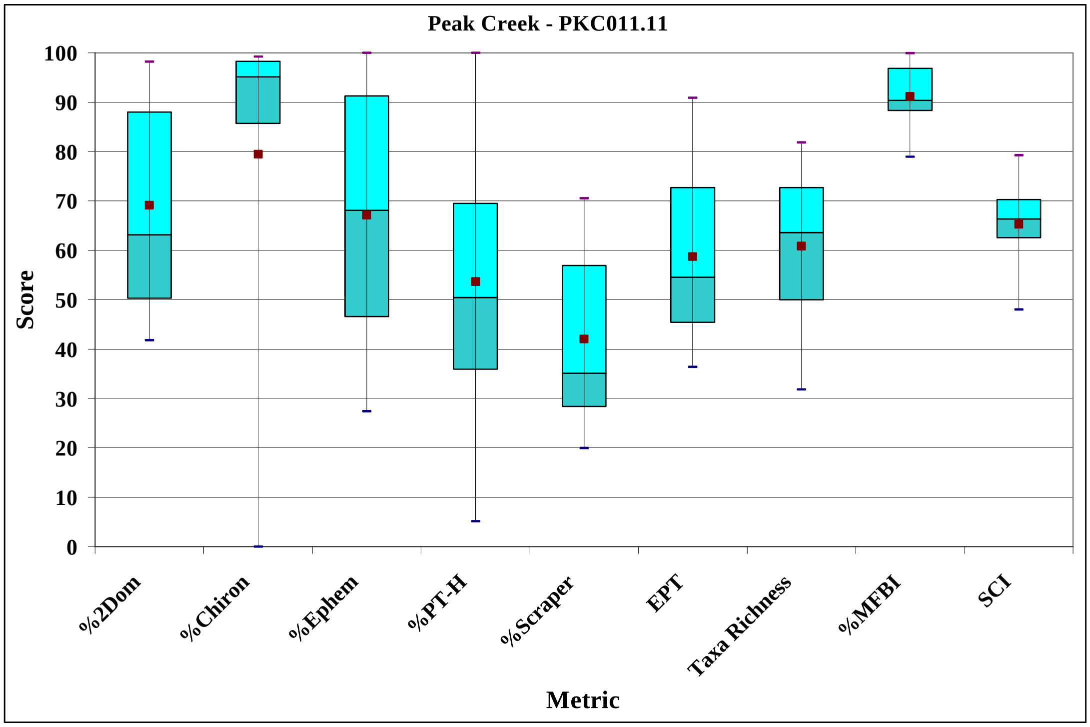

Figure 6.5 **SCI metric scores for Peak Creek at Station 9-PKC011.11 (Reference Station).**

6.2 Habitat Assessment

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.*, by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.*, due to landuse changes in the watershed such as increasing the area of impervious surfaces). Habitat assessment for Peak Creek will include an analysis of habitat scores recorded by VADEQ biologists.

6.2.1 Habitat assessment at biological monitoring stations

Habitat assessments are normally carried out as part of the benthic sampling. The overall habitat score is the sum of nine individual metrics, each metric ranging from 0 to 20. The classification schemes for both the individual habitat metrics and the overall habitat score for a sampling site are shown in Table 6.7.

Table 6.7 Classification of habitat metrics based on score.

Metric Score	Combined Score	Classification
16-20	151-200	Optimal
11-15	101-150	Suboptimal
6-10	51-100	Marginal
0-5	0-50	Poor

Habitat assessments on Peak Creek are displayed in Figure 6.6 through Figure 6.8 and indicate suboptimal conditions. Lack of riparian vegetation is the metric with the lowest score at each station, marginal at the upper and lower stations and poor at the middle station. Both the upper and lower stations have riffles and substrate in the optimal range. While decreasing habitat downstream from the reference station produces a measurable difference in the benthic community, habitat quality does not appear to play a critical role in the Peak Creek benthic impairment.

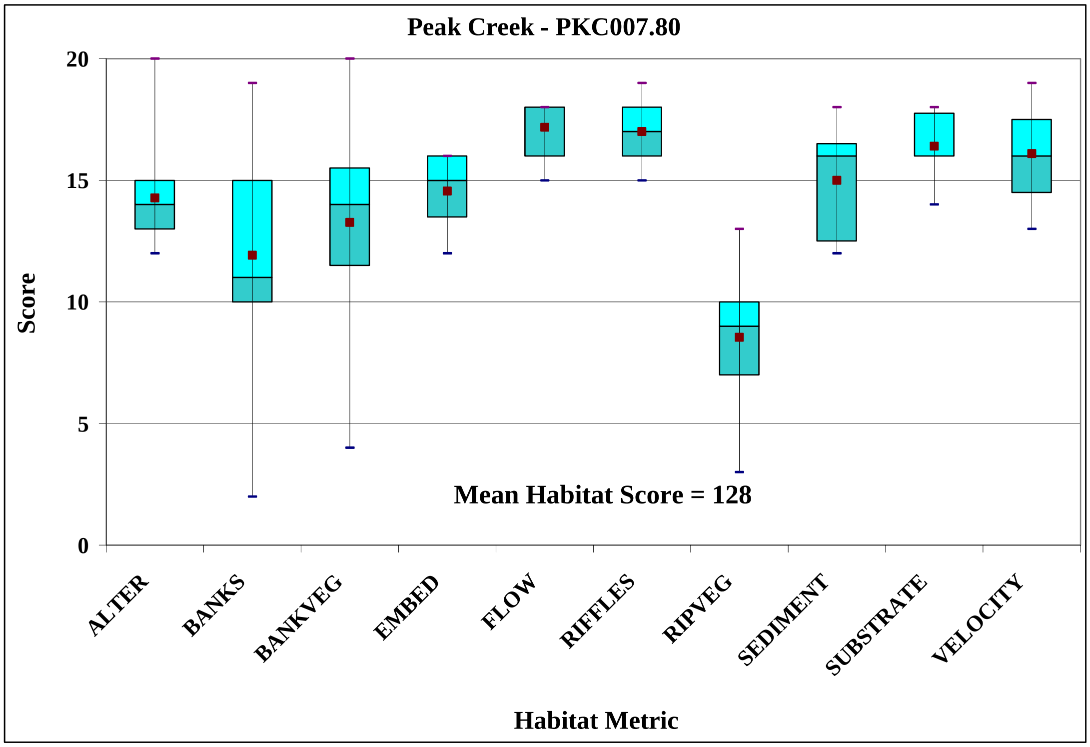

Figure 6.6 Habitat scores for Peak Creek at Station 9-PKC007.80.

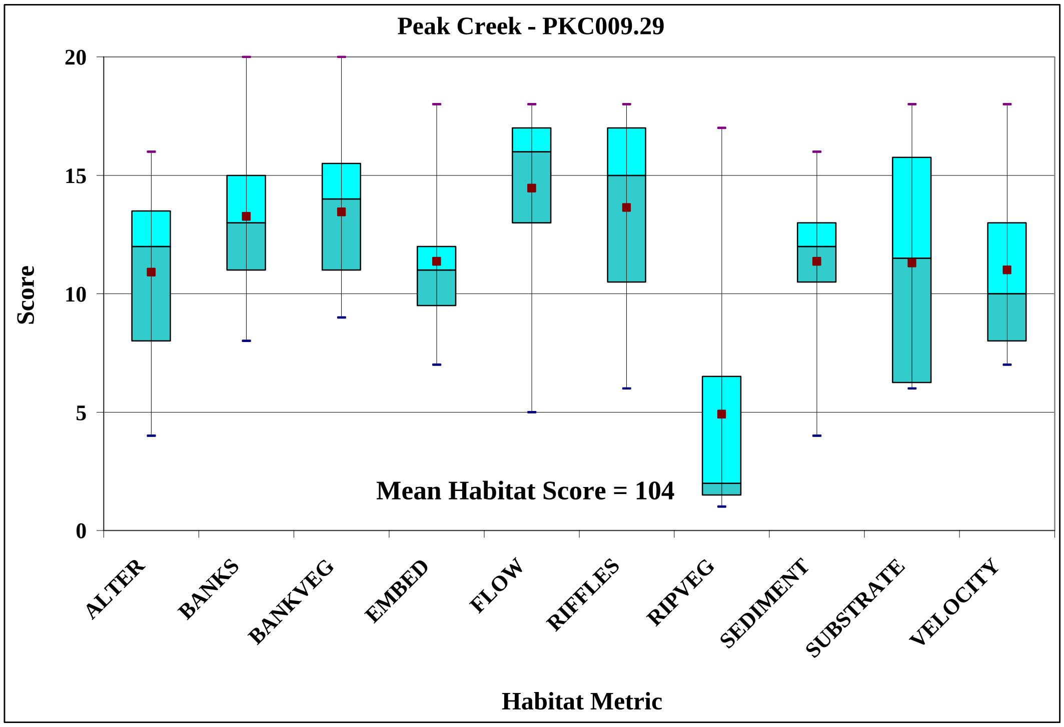

Figure 6.7 Habitat scores for Peak Creek at Station 9-PKC009.29.

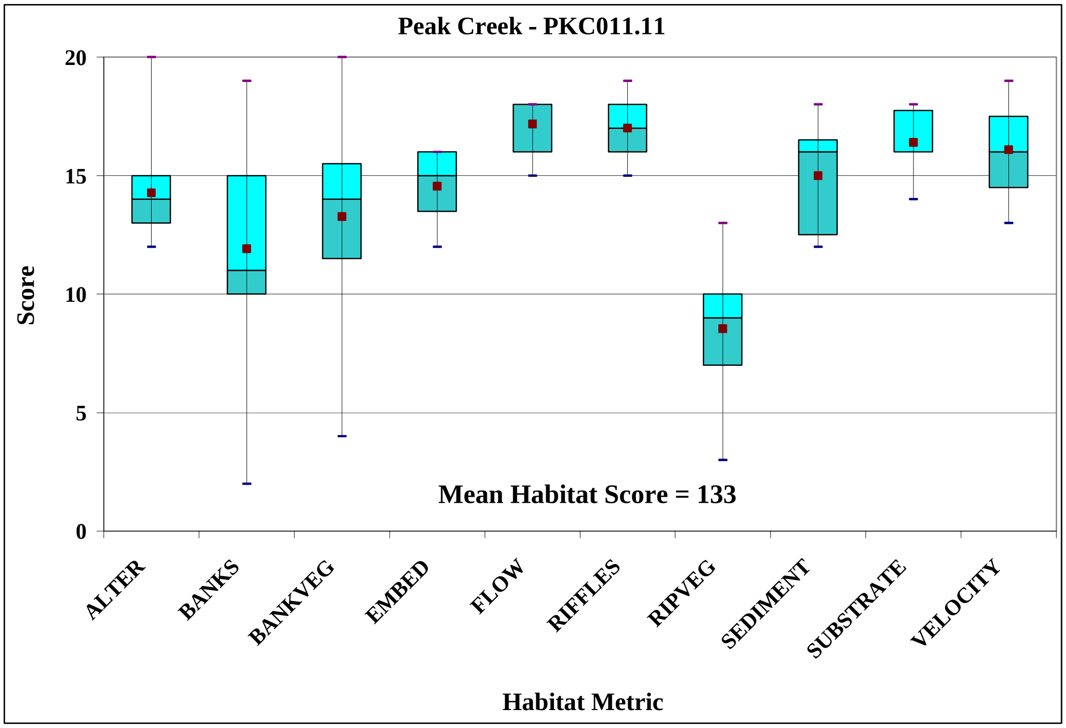

Figure 6.8 Habitat scores for Peak Creek at Station 9-PKC011.11 (Reference Station).

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION AND REFERENCE WATERSHED SELECTION

7.1 Stressor Identification

Peak Creek begins in the George Washington/Jefferson National Forest in Wythe County. It flows east through Gatewood Reservoir and the Town of Pulaski before it confluences with Claytor Lake. It is a third order stream upstream of Pulaski and becomes a fourth order stream after its confluence with Tract Fork in Pulaski. The geology of the watershed in the vicinity of Pulaski is limestone and dolomite. The landuse is a mix of urban/suburban and forest with some pasture and hay. There is currently one VPDES permitted facility, Magnox (river mile 10.1), a magnetic tape manufacturer (VA0000281) that discharges to Peak Creek as it enters the Town of Pulaski. In 1998, Magnox began sending the majority of its process wastewater to the Peppers Ferry Regional STP. This eliminated the discharge of significant quantities of lead, sulphates, and sodium. Table 7.1 summarizes the copper and zinc discharged from Magnox from July 1999 through February 2004; copper and zinc are sampled once per week. VADEQ considers Magnox to be in compliance with its VPDES permit.

Table 7.1 Copper (Cu) and Zinc (Zn) Discharged to Peak Creek From Magnox from 7/99 to 2/04.

Parameter	Total Copper Avg (ug/L)	Total Copper Avg (g/d)	Total Zinc Avg (ug/L)	Total Zinc Avg (g/d)
VPDES Permit Limit	11	50.5	50	230
MAX	9	12.94	258	790.99
AVG	0.32	0.64	12.98	39.79
MIN	NQ	NQ	NQ	NQ

Until 1996, the Town of Pulaski discharged treated sewage to Peak Creek from a municipal sewage treatment plant on the east side of town (near the Radio Tower). Table 7.2 summarizes the permitted discharges, including small discharges permitted under VADEQ's VPDES general permit program.

Table 7.2 VADEQ Permits in the Peak Creek Watershed.

Permit Number	Type	Facility Name	Receiving Stream
VA0000281	Individual Permit	Magnox Pulaski Inc	Peak Creek
VAG402040	Single Family Home	Dalton, Ricky Residence	Tract Fork Creek
VAR050139	Stormwater	TMD Friction Inc	Thorne Springs Branch UT
VAR050339	Stormwater	Pulaski County Industrial Development Authority	Peak Creek
VAR050250	Stormwater	Bondcote Corporation	Peak Creek UT
VAR050339	Stormwater	Pulaski County Industrial Development Authority	Peak Creek
VAR050444	Stormwater	Jefferson Mills Inc	Peak Creek
VAR050454	Stormwater	Pulaski Furniture Corporation - Plant No. 5	Peak Creek UT
VAR050772	Stormwater	McCready Lumber Co Inc	Thorne Springs Branch UT
VAR100264	Stormwater	VDOT - Salem District - Rte 641 (0641 077 P98 N501)	Tract Fork Creek
VAR101248	Stormwater	Pulaski Business Park	Thorne Springs Branch UT
VAR101880	Stormwater	VDOT Pulaski Co 0807 077 P01 N501 (58283)	Thorne Springs Branch UT
VAR101919	Stormwater	New Pulaski Elementary School	Thorne Springs Branch UT
VAR520118	Stormwater	Gem City Iron & Metal Company Inc.	Peak Creek
VAR520122	Stormwater	Pulaski Furniture	Peak Creek

Peak Creek has been channelized for about one mile through the Town of Pulaski to minimize the impact of flooding. The former Allied Chemical Plant (currently Allied Signal) is one major source of metals to Peak Creek. The site is located just downstream of the Town of Pulaski around monitoring station PKC007.80. EPA Region III’s Hazardous Site Cleanup Division is working with the Honeywell Corporation to remediate the site under EPA’s Removal Program. The plant manufactured sulfuric acid and ferric sulfide until it ceased operations in 1976. Extensive piles of spoils were left exposed, and runoff from the site contained cadmium, lead, chromium, zinc, selenium, nickel and low pH. The situation was further strained by the construction of a shopping center up gradient from the spoils. Stormwater runoff from the parking lot was funneled directly through the pile of spoils and then flowed directly into Peak Creek. In 1989, staff from the State Water Control Board’s (now VADEQ) Roanoke office found virtually no benthic organisms downstream of the exposed spoils. As a result of this finding, the spoils were capped with soil in 1993 and 1996 resulting in significant improvement in the biological community. However, stormwater runoff from the shopping center parking lot has breached the caps in several places. The old Allied Signal property is now an EPA Superfund site. The shopping center recently put in a collection system to route parking lot stormwater runoff away from the old spoils site and prevent further damage. However, multiple site visits (including one in 2002) documented the absence of a vegetative cover in several places (VADEQ personal communication 3/1/2004). The pictures in Figure 7.1 were taken in 2002 and show the lack of vegetation as well as erosion taking place at the site; the top photo shows the view looking down on Peak Creek and the bottom photo shows the view looking upward at the site. Historically, both iron and coal were mined in the watershed. There were three iron furnaces in the Town of Pulaski which were used to remove impurities from iron. This process resulted in the production of a waste product called “slag”. Waste slag was used as fill for construction projects and road building throughout the town. Iron slag typically consists of calcium, magnesium, and aluminum silicates. Figure 7.2 shows the benthic-impaired segment in Peak Creek.

Figure 7.1 Two views of Peak Creek; the top photo shows the perspective looking down on Peak Creek, the bottom photo shows the perspective looking up.

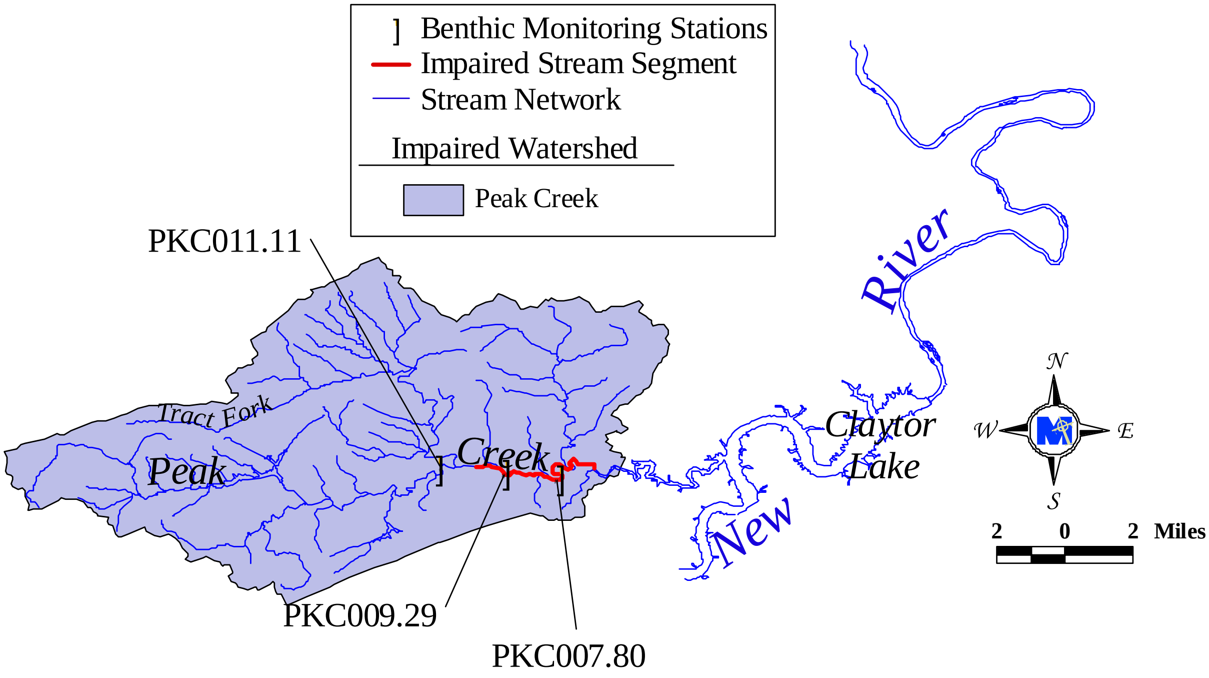

Figure 7.2 Peak Creek benthic impairments and benthic monitoring stations.

Figure 7.3 summarizes the rapid bioassessment protocol II (RBP II) results for the benthic impairments in Peak Creek. Scores for both of the Peak Creek monitoring stations are at the mid to upper end of the range for moderate impairments. Benthic and habitat assessments were carried out at two stations in the impaired reach (9-PKC009.29 and 9-PKC007.80). 9-PKC009.29 is located parallel to the Allied Signal site. There is virtually no riparian vegetation and obvious signs of erosion. Red, yellow and orange stains on the exposed soil attest to the fact that leachate from the site has been washed into the stream. 9-PKC007.80 is located downstream from the Allied Signal site near Rt. 99. There were a total of 14 benthic surveys for Peak Creek at the two impaired biological monitoring stations (9-PKC009.29 and 9-PKC007.80) between October of 1994 and December of 2002. The primary reference station used for the benthic surveys was a station on Peak Creek just upstream from the Town of Pulaski: 9-PKC011.11.

RBP II scores for the two impaired stations are displayed graphically in Figure 7.3, and the individual scores can be found in Table 7.3.

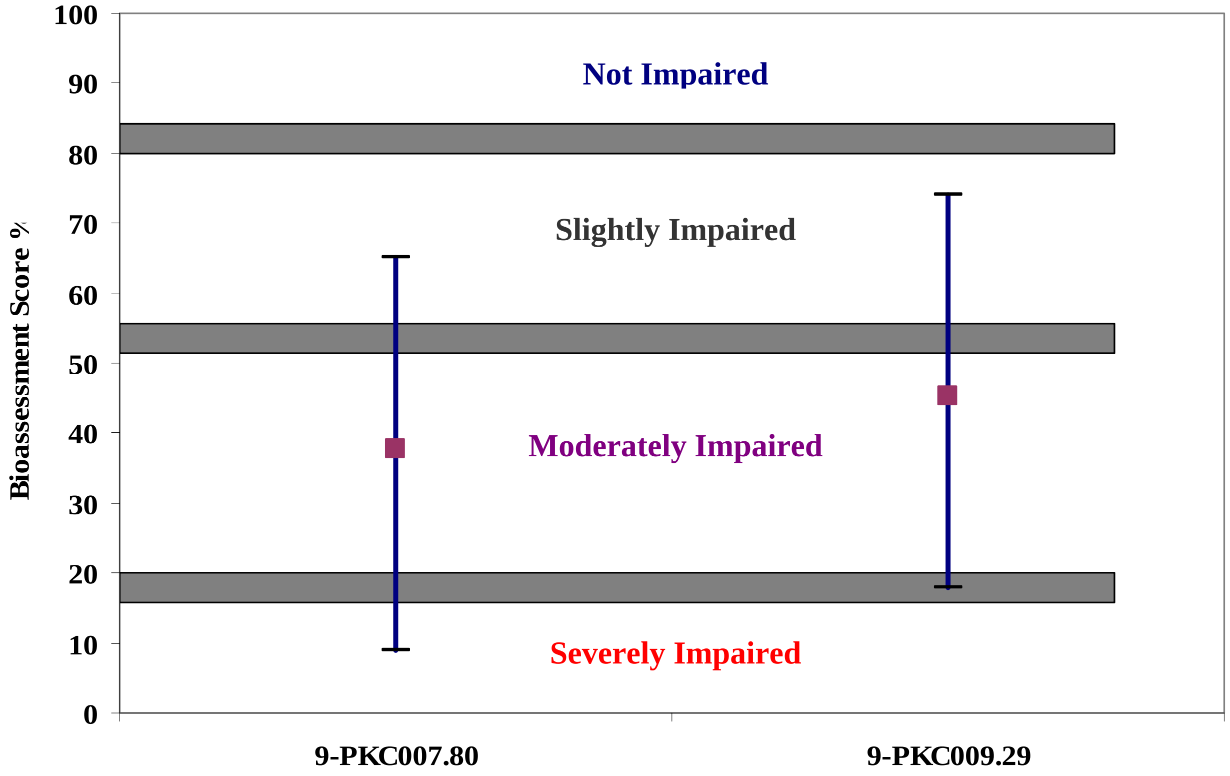

Figure 7.3 Bioassessment scores for benthic impairments in Peak Creek.

Table 7.3 RBP II Scores for Peak Creek (PKC007.80) (PKC009.29)

Station	10/94	5/95	10/95	5/96	10-/96	5/97	10/97	4/98	10/98	3/99	11/99	3/00	6/02	12/02	Mean
9-PKC007.80	38	21	9	57	32	62	9	65	45	17	26	36	57	55	38
9-PKC009.29	48	29	23	65	18	57	43	74	55	30	48	55	43	45	45

Additional information for this analysis was obtained from dissertations submitted to the faculty of Virginia Polytechnic Institute and State University. They are Studies of Benthic Macroinvertebrate Use for Biomonitoring of Mid-Atlantic Highland Streams by Michael D. Moeykens, May 2002, and Site-specific Validation of a Chronic Toxicity Test with the Amphipod Hyalella azteca: An Integrated Study of Heavy Metal Contaminated Sediments in Peak Creek, Virginia by John Cairns et al., August 2000.

Table 7.4 shows the VADEQ monitoring stations that had recent data.

Table 7.4 VADEQ Monitoring Stations on Peak Creek

Station	Description	Type	Period of Record
9-PKC004.65	Rt. 100	Ambient/Fish Tissue	1970-2003
9-PKC007.82	Rt. 99	Ambient/Fish Tissue	1976-1994
9-PKC009.29	Near Radio Tower	Ambient	1988-2003
9-PKC011.11	Rt. 610	Ambient	1972-2003

Ambient monitoring data from 9-PKC007.82, 9-PKC009.29 and 9-PKC011.11 were used in the analysis. In cases where the results were similar among all three stations, only data from 9-PKC009.29 is shown in the graphs. However, a separate graph for each parameter shown can be found for all three monitoring stations in Appendix D. Data from station 9-PKC004.65 was not used (except in the discussion about fish tissue sampling) because it is located in the beginning of an arm of Claytor Lake and exhibits characteristics similar to a low gradient stream.

TMDLs must be developed for a specific pollutant(s). Benthic assessments are very good at determining if a particular stream segment is impaired or not but they usually don't provide enough information to determine the cause(s) of the impairment. The process outlined in the Stressor Identification Guidance Document (EPA, 2000) was used to separately identify the most probable stressor(s) for Peak Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Landuse data as well as a visual assessment of conditions along the stream provided additional information to eliminate or support candidate stressors. The list of potential stressors is: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature, and organic matter.

The results of the stressor analysis for Peak Creek are divided into three categories:

> **Non-Stressors**: Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

Possible Stressors: Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.

Most Probable Stressor: The stressor(s) with the most consistent information linking it with the poorer benthic and habitat metrics was considered to be the most probable stressor(s).

7.1.1 Non-Stressors

7.1.1.1 Dissolved Oxygen

Dissolved oxygen concentrations remained well above the water quality standard at both Peak Creek monitoring stations and concentrations for 9-PKC009.29 are shown in (Figure 7.4). In addition, low dissolved oxygen was found not to be an issue in the studies referenced in Section 1. Low dissolved oxygen was eliminated as a possible stressor.

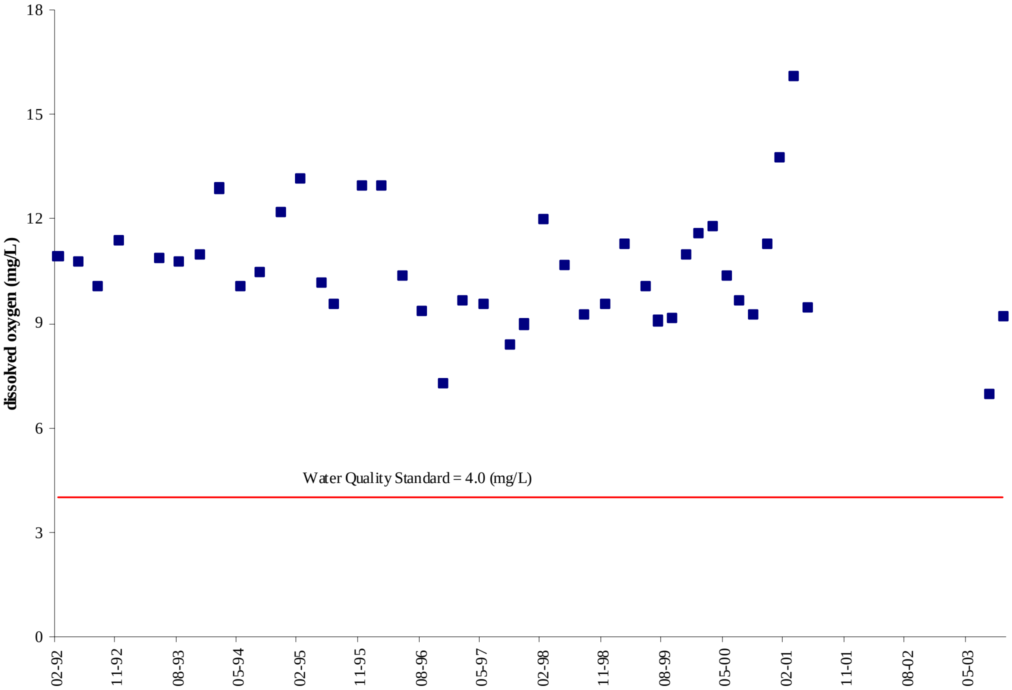

Figure 7.4 Dissolved Oxygen Concentrations at 9-PKC009.29.

7.1.1.2 Temperature

The maximum temperature recorded in Peak Creek at monitoring station 9-PKC009.29 was 28 ^{o}C, which is below the specific state standard of 29 ^{o}C for the New River Basin. Median temperature measurements were consistent among the three Peak Creek monitoring stations ranging from 12.85 ^{o}C to 13 ^{o}C (Figure 7.5). Therefore, temperature was eliminated as a possible stressor.

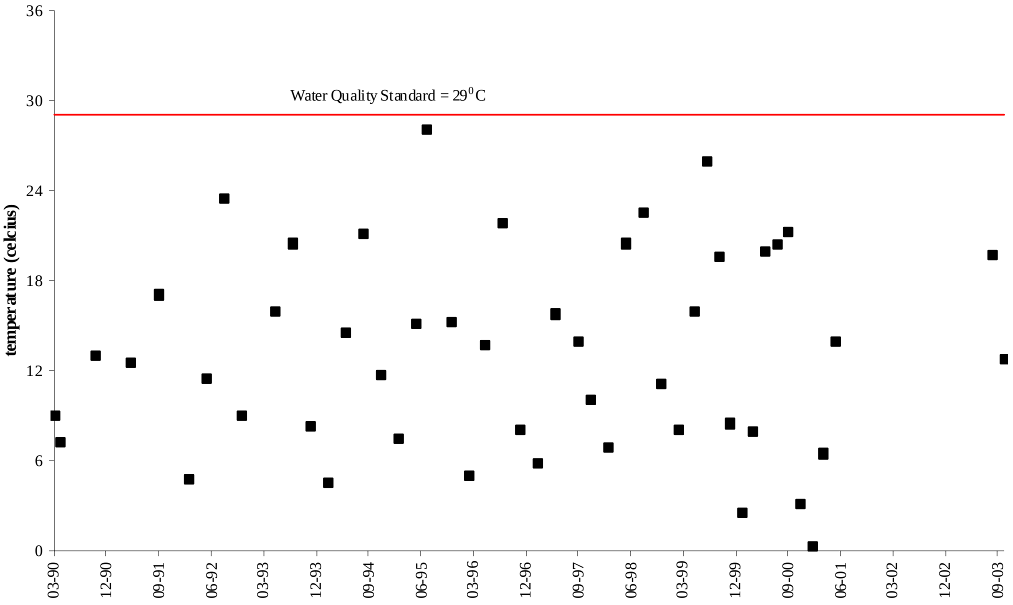

Figure 7.5 Water Temperature at 9-PKC009.29.

7.1.1.3 pH

The maximum and minimum pH values were within the state standard range (6≤ pH ≤9) at the three Peak Creek monitoring stations, with one exception (Figure 7.6). The exception was above the upper standard of 9.0 and the maximum value recorded was 9.3 in July of 1995 at 9-PKC009.29. This is reasonable since the geology of the drainage area is limestone and occasional values at this level do not adversely impact benthic communities. The median pH value at the three monitoring stations was 8.2. Alkalinity concentrations were within the expected normal range of 30 to 500 mg/l for this ecoregion (Figure 7.7). However, there was a significant difference between the median values for 9-PKC011.11 (20.3 mg/l) and 9-PKC009.29 (81.5 mg/l). There was also considerable variation in alkalinity at 9-PKC009.29, with values ranging from 18.1 - 168 mg/l. This is noteworthy because hardness diminishes the toxicity of heavy metals to aquatic organisms. The headwaters of Peak Creek in the National Forest are underlain by shale, and lower alkalinities are expected at the reference station. Based on the available data, pH was eliminated as a possible stressor.

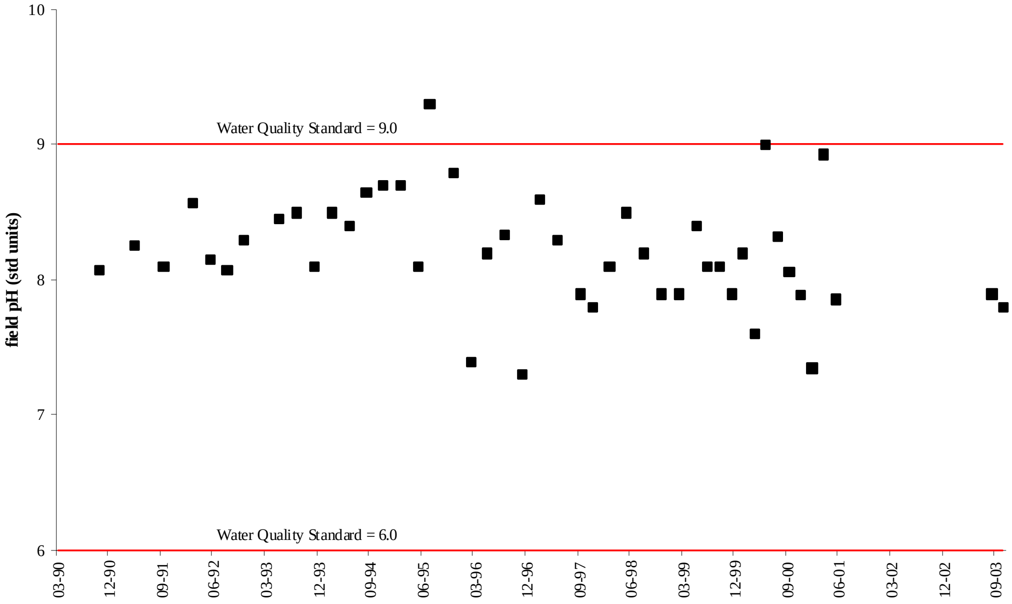

Figure 7.6 Field pH Data at 9-PKC009.29.

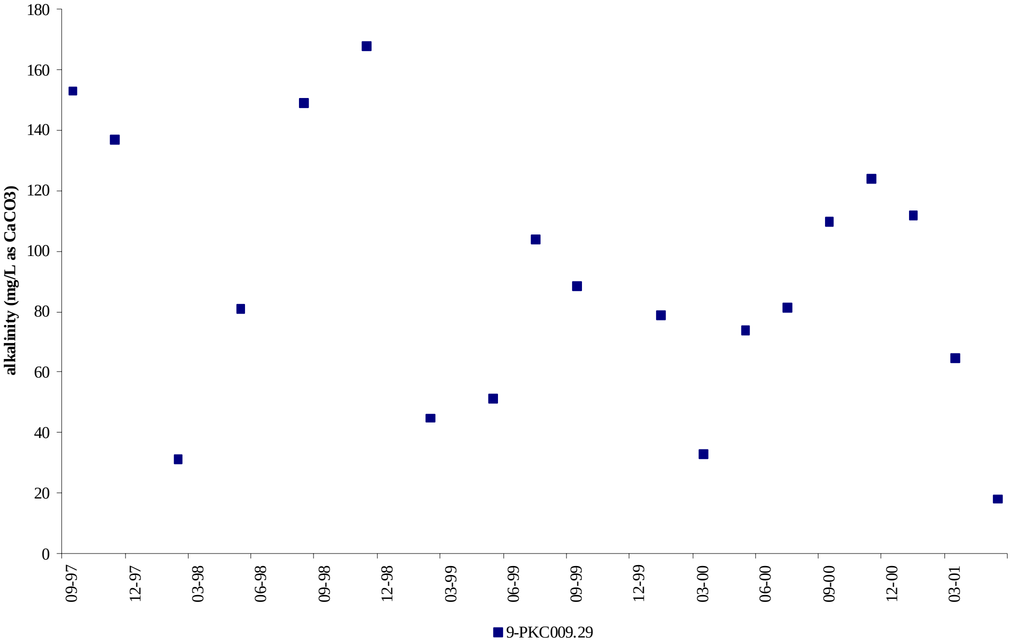

Figure 7.7 Alkalinity Concentrations at two VADEQ Peak Creek Monitoring Stations.

7.1.1.4 Nutrients

Median Total Phosphorus (TP) concentrations were below the VADEQ assessment screening value of 0.2 mg/l at the three monitoring stations (Figure 7.8). Nitrate Nitrogen (NO_3-N) values showed the same pattern as the TP values, being slightly higher downstream of Pulaski but below acceptable levels (1.0 mg/l) (Figure 7.9). Therefore, nutrients are eliminated as a possible stressor.

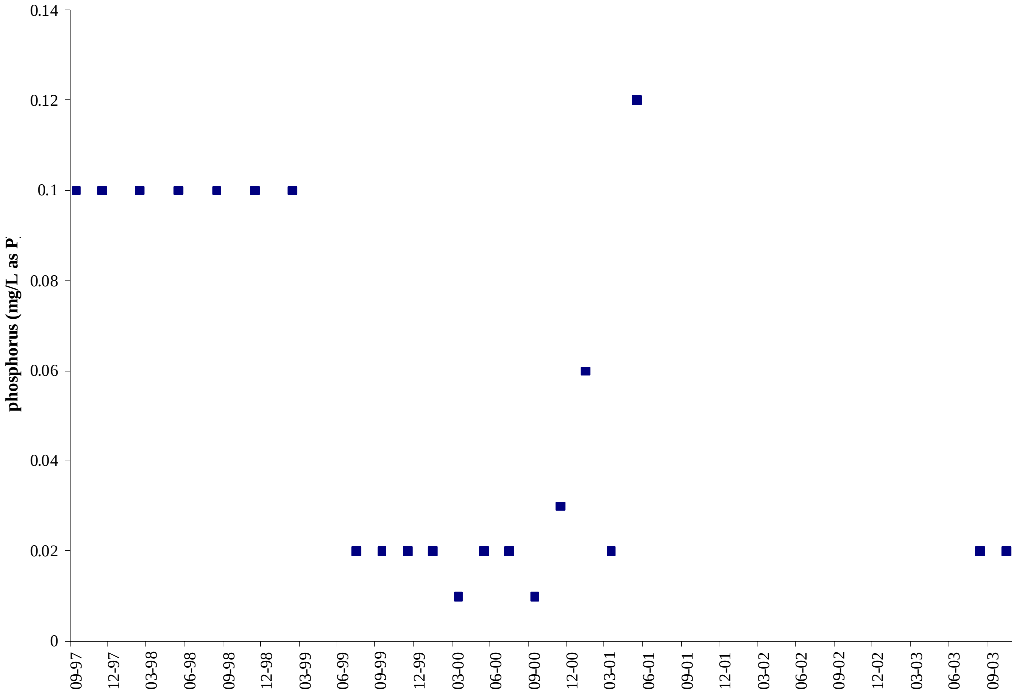

Figure 7.8 Total Phosphorus Concentrations at 9-PKC009.29.

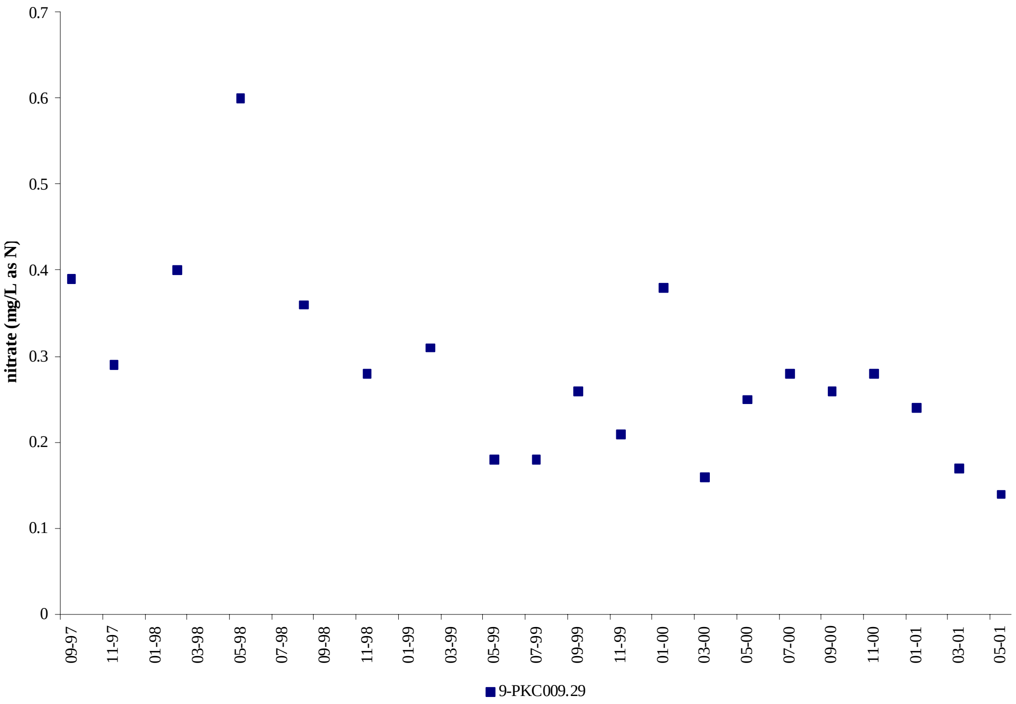

Figure 7.9 Nitrate Nitrogen Concentrations at 9-PKC009.29.

7.1.1.5 Toxics

Water column toxics data did not exceed any water quality standards; in fact, many parameters were below minimum detection levels. Sediment toxics values were also below the minimum detection level or consensus based Probable Effect Concentration sediment screening values, with the exception of polyaromatic hydrocarbons (PAHs) and DDT metabolites DDD and DDE (PEC; MacDonald et al., 2000). Fish tissue and sediment were sampled at 9-PKC007.82 on September 13, 2000. Five PAHs exceeded PEC sediment screening levels and they are discussed in Section 7.3. PCBs exceeded the VADEQ standard of 54 ppb in smallmouth bass (71.4 ppb), but sediment PCB levels were well below the PEC sediment screening value (676 ug/kg). Fish tissue and sediment data were also collected at 9-PKC004.65 (located at the beginning of an arm of Claytor Lake) on September 12, 2000, and no toxic values exceeded PEC sediment screening levels. However, a PCB value of 150 ppb was found in carp. DDT and metabolites DDD and DDE were sampled on nine different occasions throughout the 1990s at the non-impaired reference station 9-PKC011.11. Two DDE values and one DDD value were above the minimum detection level. DDD and DDE values collected in May of 1999 exceeded PEC sediment screening values (DDD PEC value 28 ug/kg, sample value 30 ug/kg and DDE PEC value 31.3 ug/kg, sample value 40 ug/kg). DDD and DDE did not exceed PEC levels in the impaired section of Peak Creek.

All of the available ammonia data was below the detection level at both stations with only two exceptions at 9-PKC009.29. A value of 0.13 mg/l was recorded in July of 1999 and a value of 0.04 mg/l was recorded in May of 2001. Chloride values at 9-PKC009.29 are below 230 mg/l, which is EPA's chronic water quality criteria (Figure 7.10). With the exception of polyaromatic hydrocarbons, the toxics that were evaluated are not considered possible stressors.

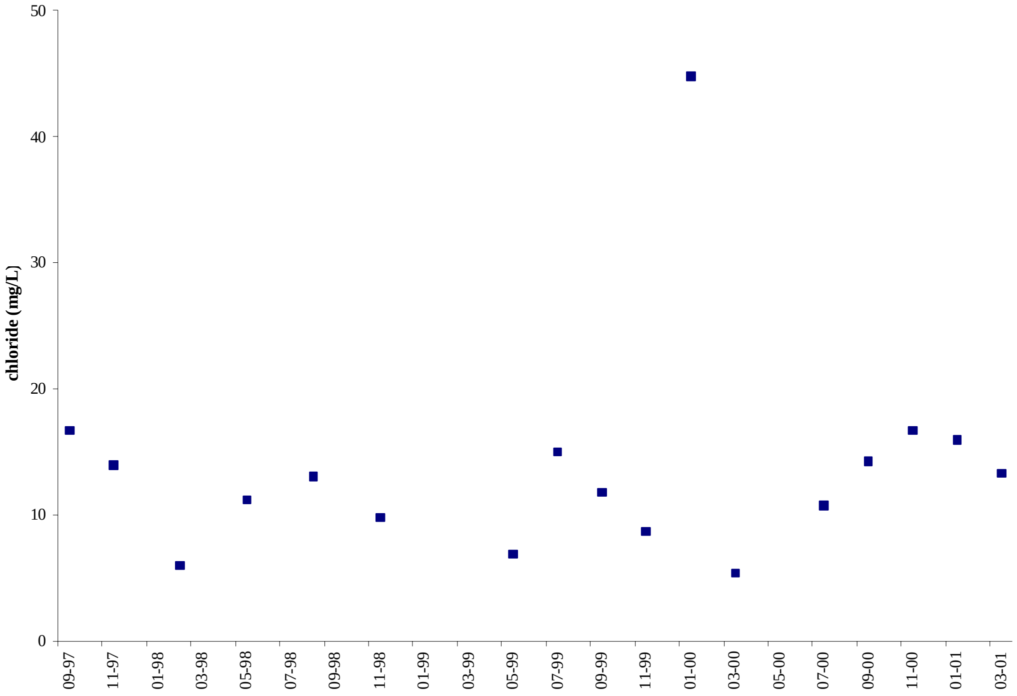

Figure 7.10 Chloride concentrations at 9-PKC009.29.

7.1.1.6 Sediment

The median habitat scores for metrics that indicate sediment problems (embeddedness, sediment deposition, and epifaunal substrate characterization) were in suboptimal to optimal ranges for Peak Creek at both downstream monitoring stations. However, at monitoring station 9-PKC009.29, sediment deposition scores fell into the poor category during one survey and the marginal category in another four surveys. Epifaunal substrate characterization and embeddedness also fell into the marginal category during four surveys. Ambient monitoring data supports the habitat assessment. Total suspended solids (Figure 7.11) and turbidity data (Figure 7.12) do not indicate excessive values on a frequent basis. The benthic metrics and dominant benthic organisms also support the habitat and chemical data. One of the most dominant organisms at station 9-PKC009.29 was Psephenidae. These organisms commonly known as “water pennies” are very sensitive to inorganic sediment deposition (Voshell, 2002). In addition, the Macroinvertebrate Aggregated Index for Streams (MAIS) metric percent Haptobenthos can be used as an indicator of sediment deposition because it measures the abundance of organisms that require a coarse, clean bottom substrate. The median scores for this metric were considerably better at both downstream stations (9-PKC007.80 – 85% and 9-PKC009.29 – 78%) relative to the upstream reference station (9-PKC011.11 – 63%). Based on this information, sediment was eliminated as a possible stressor.

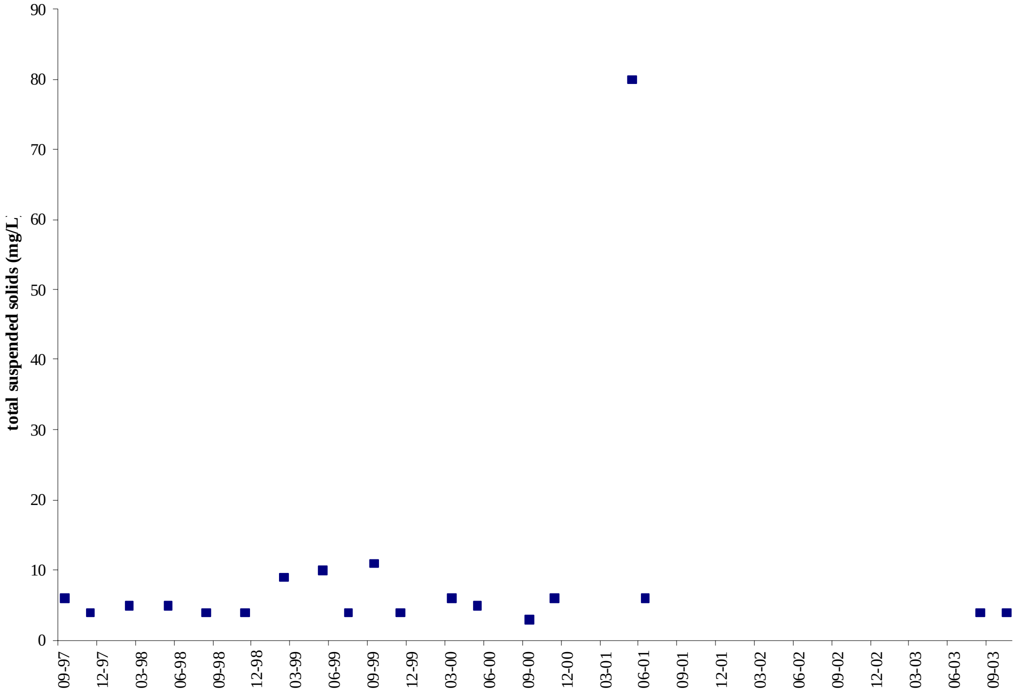

Figure 7.11 TSS Concentrations at 9-PKC009.29.

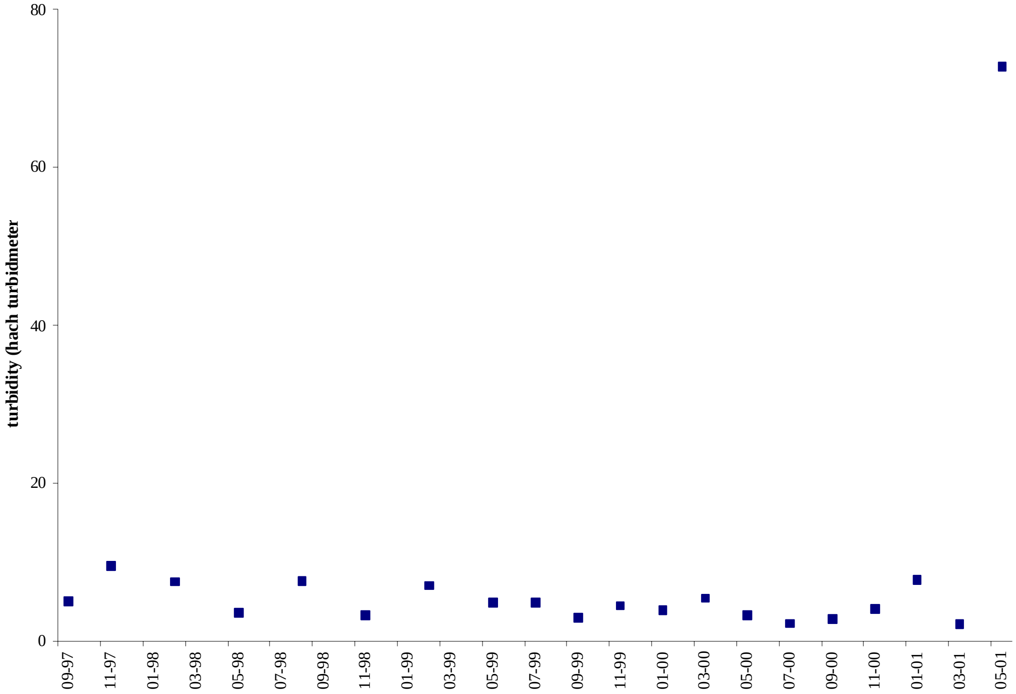

Figure 7.12 Turbidity Values at 9-PKC009.29.

7.1.2 Possible Stressors

7.1.2.1 Conductivity

There was a substantial difference in conductivity values before and after the Town of Pulaski, *i.e.*, conductivity values were very low in Peak Creek before the stream reaches Pulaski, and extremely high after it passes through Pulaski (Figure 7.13). Median conductivity values were six times greater at 9-PKC009.29 than at 9-PKC011.11. There was one extreme value of 1,051 at 9-PKC009.29 in September 1997. Mean and median values at 9-PKC009.29 were in the good range -- below 500 -- but there were other spikes above 700. Extremely high or wide swings in conductivity can contribute to environmental stress for benthic macroinvertebrates. Conductivity should be considered a possible stressor.

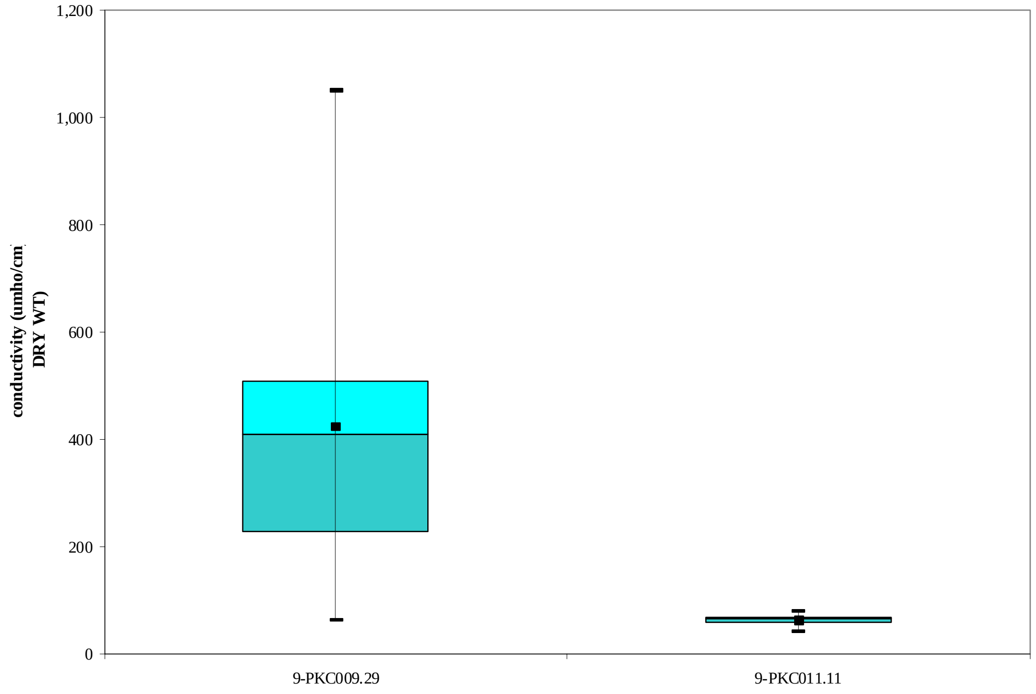

Figure 7.13 Box & Whisker Plot of Conductivity at 9-PKC009.29 & 9-PKC011.11.

7.1.2.2 Polyaromatic Hydrocarbons (PAHs)

Fish tissue and sediment sampling was performed at monitoring station 9-PKC007.82 on September 13, 2000. Five PAH parameters had levels that exceeded PEC screening values (Figure 7.14). Interestingly, these parameters had very low values in fish tissue collected at the same time. Fish tissue and sediment data were also collected at 9-PKC004.65 on September 12, 2000, and no toxic sediment values exceeded PEC screening values. Fish tissue values were also below VADEQ water quality standards, with the exception of PCBs previously discussed. The five PAHs are considered possible stressors.

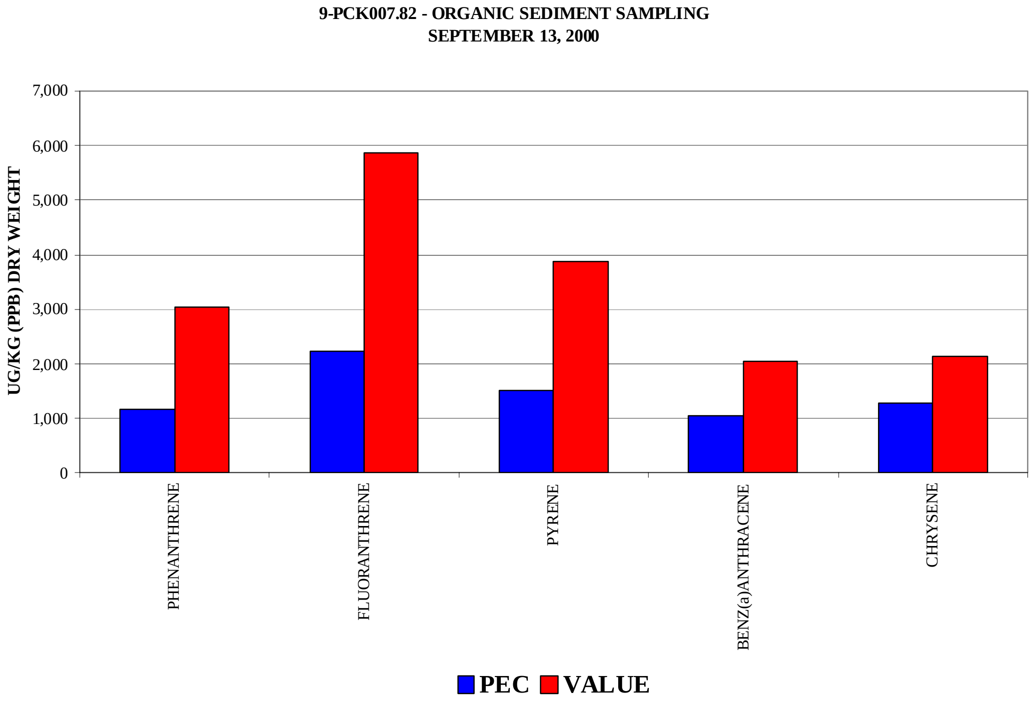

Figure 7.14 Sediment PAHs at 9-PKC007.82 September 13, 2000.

7.1.2.3 Organic Matter

Several different parameters were used to determine if organic matter in the stream was impacting the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) provides an indication of how much dissolved organic matter might be present. Total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS) provide an indication of particulate organic matter in a stream. Few data were collected, and some was below the minimum detection level. One BOD_5 value was collected at 9-PCK007.80 in the 1990s. Most of the BOD_5 concentrations were at the minimum detection value of 2.0 mg/l, but there was one spike of 7.0 mg/l in July 1999 at monitoring station 9-PKC009.29 (Figure 7.15). COD (Figure 7.16) and TOC (Figure 7.17) concentrations were also low. Median values at 9-PKC009.29 were 8.1 mg/l and 2.5 mg/l respectively. There was a spike in both parameters in February 1996; TOC was 19.5 mg/l and COD was 60 mg/l. Volatile Solids concentrations were relatively low as well, with a spike of 68 mg/l in September 1997 (Figure 7.18).

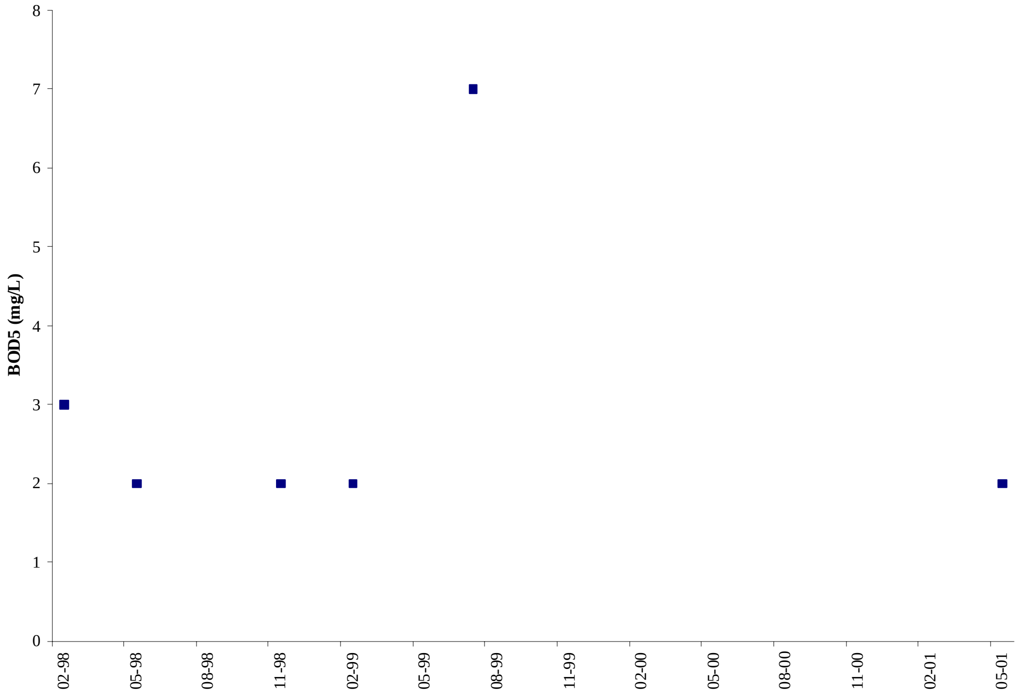

Figure 7.15 BOD5 Concentrations at 9-PKC009.29.

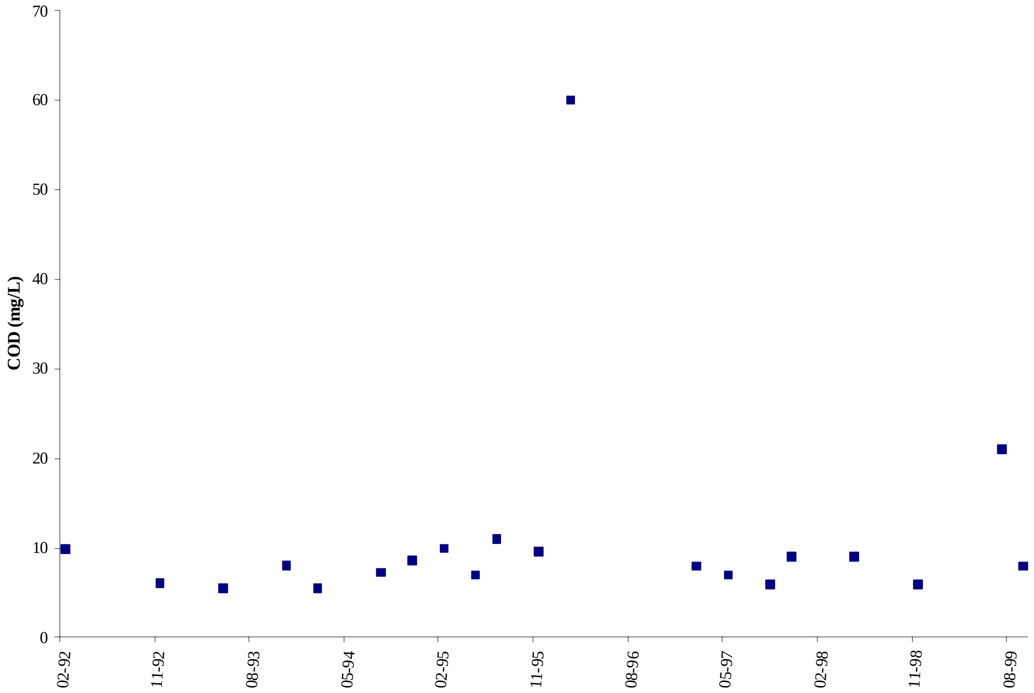

Figure 7.16 COD concentrations at 9-PKC009.29.

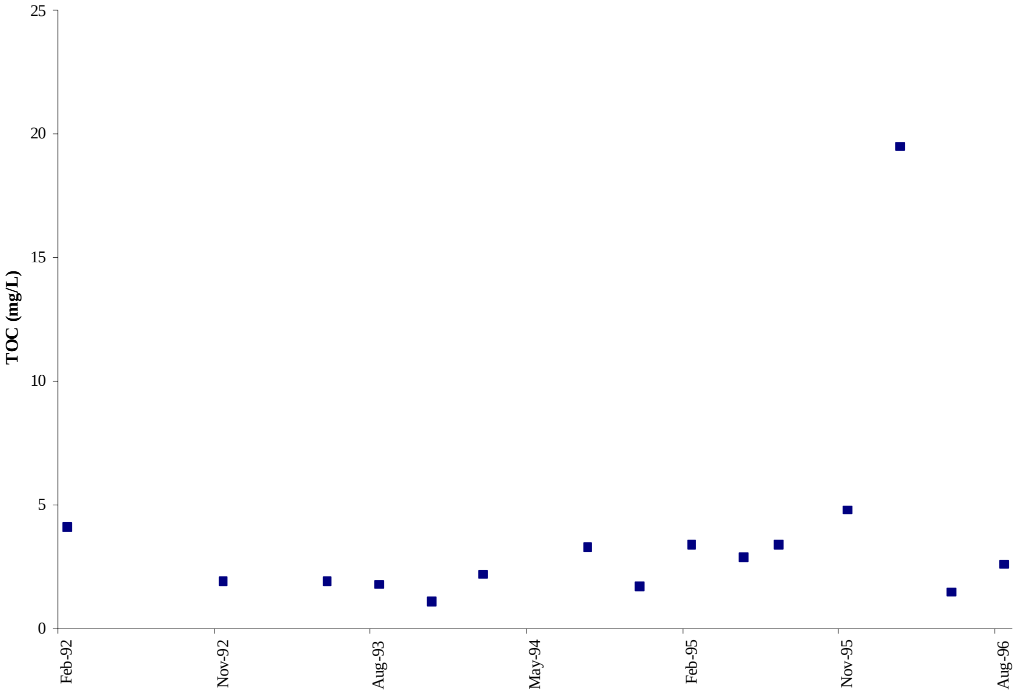

Figure 7.17 TOC concentrations at 9-PKC009.29.

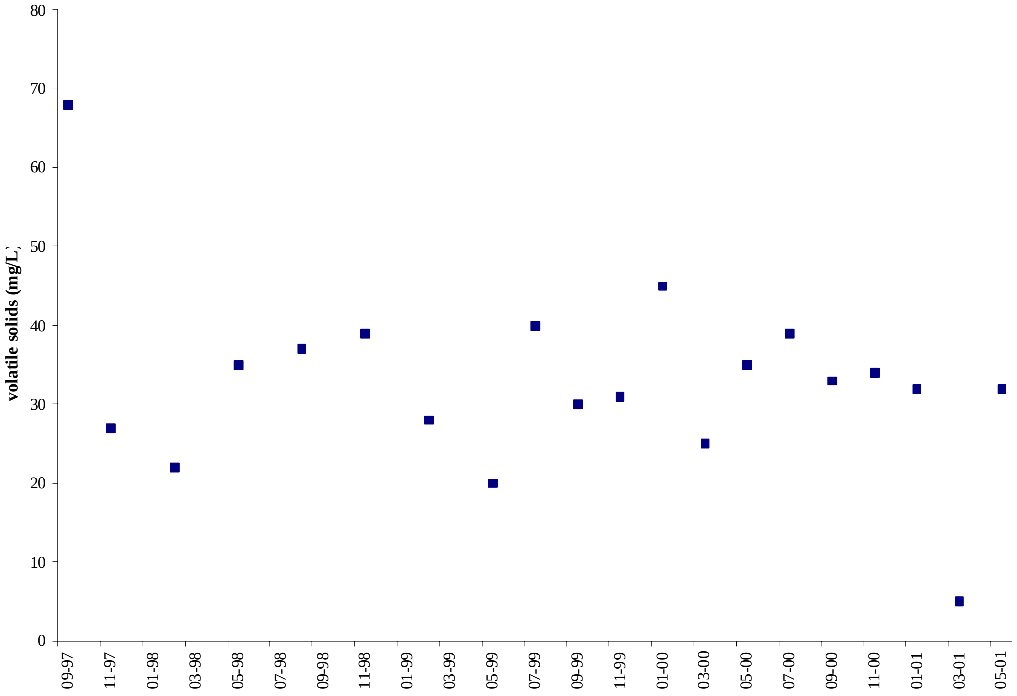

Figure 7.18 VS concentrations at 9-PKC009.29.

Although the chemical data was inconclusive, the benthic metrics indicate that organic matter may be a problem in Peak Creek; the benthic metric MFBI can be an indicator of excessive organic solids. The average MFBI score was found to be significantly higher at the impaired stations relative to the upstream reference station (Figure 7.19). MFBI scores range from 0 to 10 and increasing values have been correlated with increasing organic matter. Average scores at 9-PKC009.29 and 9-PKC007.80 were 5.57 and 5.3, respectively. The upstream reference station had an average score of 3.77. The assemblages for both of the impaired benthic stations from the VADEQ Ecological Data Application System (EDAS) database were examined, and hydropsychidae (netspinning caddisflies) were found to be the dominant family at both of these stations (9-PKC007.80, 52% and 9-PKC009.29, 53%). In contrast, the assemblage at 9-PKC011.11 was dominated by mayflies, sensitive caddisflies, and stoneflies (62%). According to Voshell (2002), “If common netspinners account for the majority of the community that is a reliable indicator of organic or nutrient pollution.” Based on this information, organic matter should be considered a possible stressor. It is anticipated that there will be reductions in the primary sources of organic matter via implementation of the fecal bacteria TMDL being developed for Peak Creek.

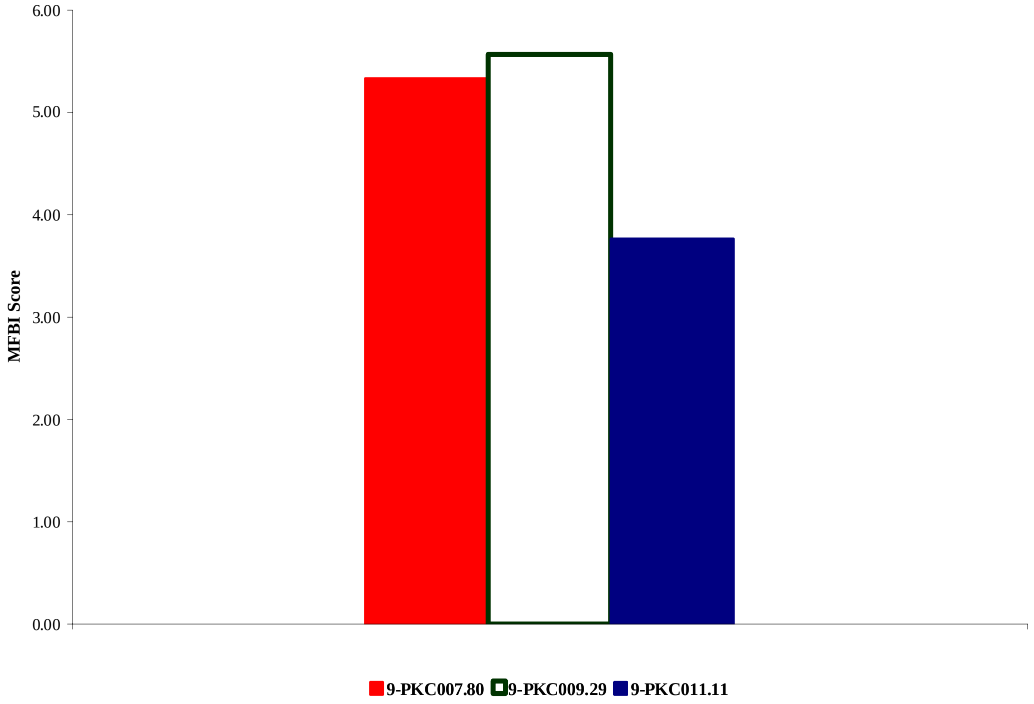

Figure 7.19 MFBI Metric at all three Peak Creek stations.

7.1.3 Most Probable Stressors

7.1.3.1 Metals

VADEQ water column metals data was either at the minimum detection level or below the appropriate water quality standard. The following dissolved metals were sampled by VADEQ; aluminum, antimony, arsenic, beryllium, cadmium, chromium, copper, iron, lead, manganese, mercury, nickel selenium, silver thallium and zinc. Quarterly sampling was conducted at six sites on Peak Creek by Michael Moeykens (2002) between August 1988 and August 1999 as part of a Ph.D. dissertation (Table 7.5 and Figure 7.20). Moeykens sampled cadmium, copper, cobalt, iron, magnesium, nickel, sodium, lead, and zinc. His report, which documents the concentrations found in tables 4.1 through 4.4, can be found at http://scholar.lib.vt.edu/theses/available/etd-05222002-174758/unrestricted/MoeyDisNew.pdf **.**

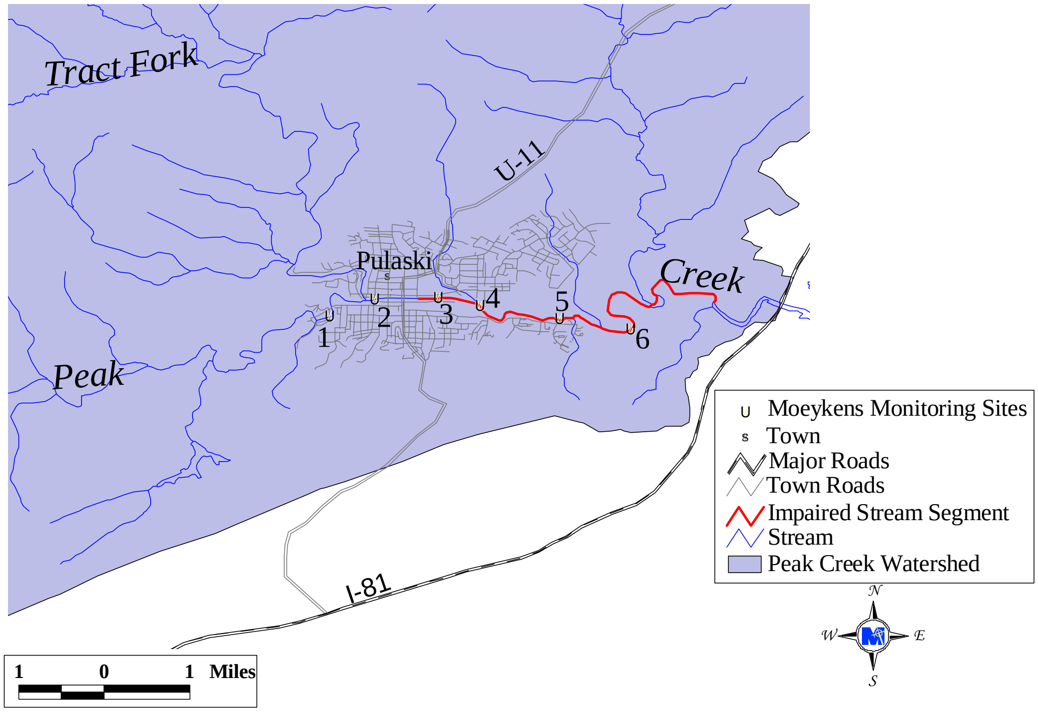

Figure 7.20 Monitoring sites sampled by Moeykens August 1998 through August 1999.

Table 7.5 Sites Sampled by Moeykens August 1998 – August 1999.

Site	Location	River Mile
1*	Commerce Street Bridge	11.11
2	Randolph Street Bridge	10.28
3	Duncan Street Bridge	9.66
4*	Railway Trestle	9.29
5	Bentley Hollow Road	8.48
6*	Rt. 99	7.82

*Same location as a VADEQ benthic and ambient monitoring station.

Dissolved concentrations of lead (Pb) exceeded EPA's hardness adjusted chronic criteria once at sites 1 and 3, while zinc (Zn) exceeded the chronic criteria once at sites 1 and 2.

Table 7.6 Dissolved metals concentrations at sites sampled by Moeykens 8/98 – 8/99, all values ug/L.

Site	Cd	Co	Cu	Fe	Mn	Na	Ni	Pb	Zn
PC1	BDL	BDL	BDL	60 - 354	1.1 - 5.7	1,189 - 1,904	14	1.3*	73*
PC2	BDL	BDL	BDL	11 - 129	4.2 - 17	17,030 - 92,200	11	1.1 - 5.7	50 - 178*
PC3	BDL	BDL	BDL	41 – 73	6.7 - 22.7	18,260 - 85,030	12	1.8	49 - 66
PC4	BDL	BDL	BDL	25 – 67	8 - 30.8	18,580 - 80,750	11	BDL	47 - 50
PC5	BDL	BDL	BDL	38 – 83	21.1 - 45.3	18,270 - 66,500	16 - 24	1.6	39 - 82
PC6	BDL	4.59	BDL	52 – 78	5.7 - 17.9	18,700 - 68,500	19 - 27	BDL	52 - 85

BDL = Below Detection Level

*** Exceeds EPA's hardness adjusted chronic criteria**

VADEQ sediment sampling indicated elevated metals values above and below the Town of Pulaski. Table 7.7 documents the percentage of time that sediment metals exceeded the PEC screening value at all three VADEQ Peak Creek monitoring stations; separate graphs for each parameter at each station can be found in Appendix D. The reason that PEC values were exceeded at the reference station (9-PKC011.11) is believed to be due to historic mining in the area and material from the former Allied Signal site was used as fill for construction and road building projects throughout the Town of Pulaski and surrounding county.

Table 7.7 Percent sediment metal exceedance of PEC values in Peak Creek.

	9-PKC007.82	**9-PKC009.29**	**9-PKC011.11**
Cu (N)	100% (6)	22% (9)	20% (10)
Pb (N)	67% (6)	44% (9)	70% (10)
Zn (N)	83% (6)	100% (8)	70% (10)

Box and whisker plots for VADEQ sediment monitored copper (Cu), Pb, and Zn are presented below (Figure 7.21 through Figure 7.23). VADEQ sediment data was collected throughout the 1990s at monitoring stations 9-PKC007.82 (four values), 9-PKC009.29 (eight values), and 9-PKC011.11 (nine values). Data was also used from a VADEQ special study, *Peak Creek Sediment Metals* (Willis, 1989). Median values for all three metals were highest at station 9-PKC007.82, which is downstream from the Allied Signal site. VADEQ nickel and chromium sediment values were all below the appropriate PEC screening value. Other sediment metals sampled by VADEQ were aluminum, antimony, arsenic, beryllium, cadmium, iron, manganese, mercury, selenium, silver, and thallium. When VADEQ sampled for arsenic in the sediment at stations 9-PKC007.82, 9-PKC009.29, and 9-PKC011.11, arsenic was never found to be above the detection limit of 10 mg/kg.

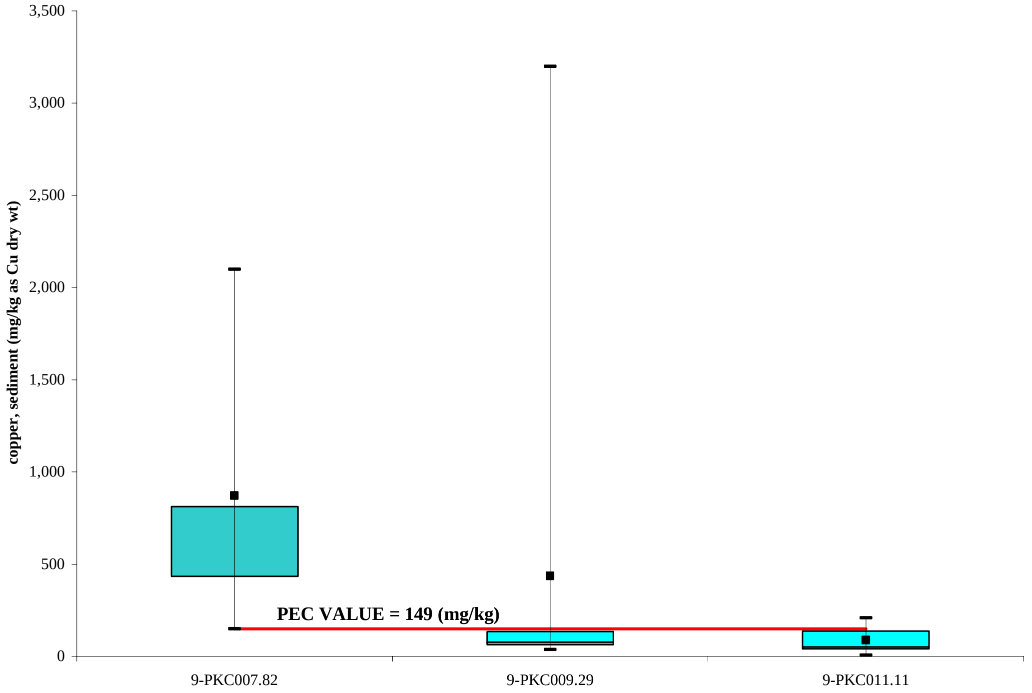

Figure 7.21 Sediment Cu. PEC Screening Value 149 mg/kg.

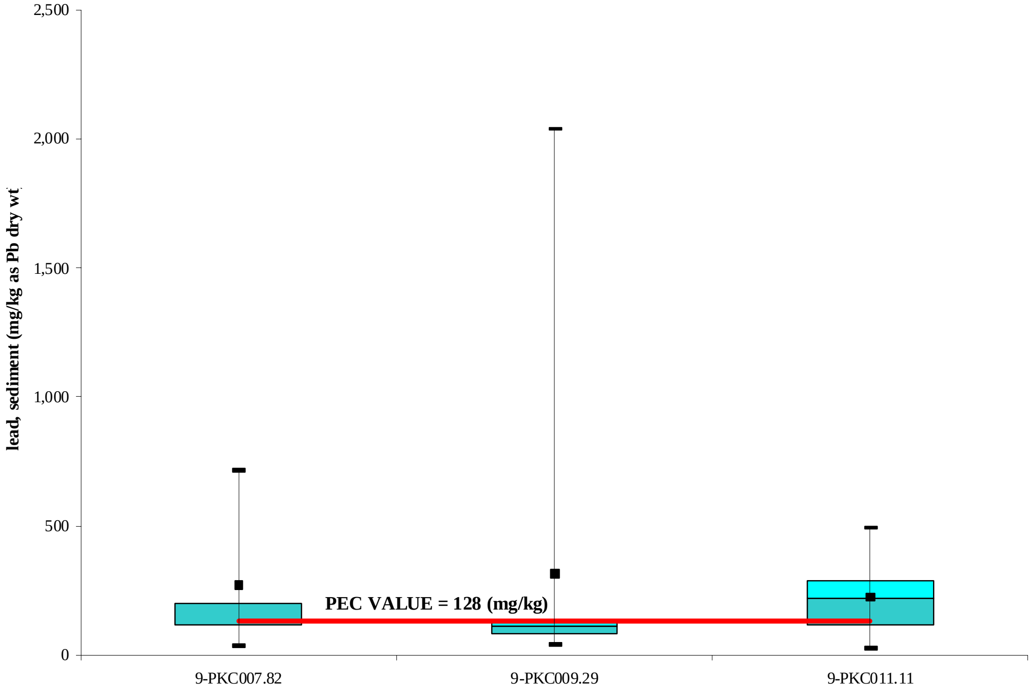

Figure 7.22 Sediment Pb. PEC Screening Value 128 mg/kg.

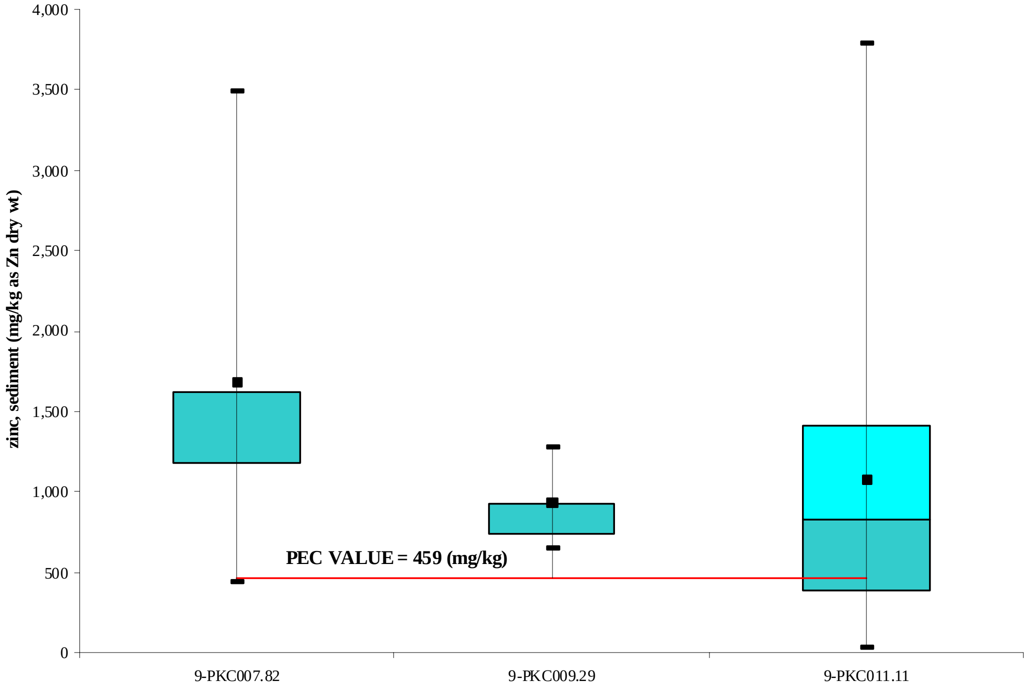

Figure 7.23 Sediment Zn. PEC Screening Value 459 mg/kg.

Sediment pore samples were collected quarterly by Moeykens (2002) in his study of Peak Creek. Two types of results were reported: simultaneously extracted metals (SEM, µg/g) and dissolved metal concentrations from pore water (µg/l). The presence of metals in pore water is considered an indicator of bioavailability. The SEM data exceeded PEC values in 24 samples, 3 for Cu, 6 for Pb, and 21 for Zinc, Table 7.8. There was one exceedance for Zn and Pb at the reference site. Pore water concentrations of Pb exceeded EPA's hardness adjusted chronic criteria once at sites 1 and 3, and Zn once at sites 1 and 2. These results demonstrate that heavy metals were detected at elevated levels in water less frequently as in sediment. This indicates that these metals may be bioavailable on an infrequent basis.

Table 7.8 SEM values at sites sampled by Moeykens 8/98 – 8/99, all values ug/g dry wt.

Site	Cd	Co	Cu	Fe	Mn	Ni	Pb	Zn
PEC Value	**4.98**	**NA**	**149**	**NA**	**NA**	**48.6**	**128**	**459**
PC1	0.54 - 1.9	1.6 - 8.0	1.9 - 36	2,696 - 10,409	273 - 461	2 - 9	8 - 176	49 - 1,811
PC2	0.48 - 1.5	3.6 - 8.9	4.1 - 17.3	2,400 - 8,320	340 - 582	2 - 6	44 - 98	1,015 - 6,413
PC3	0.81 - 1.20	3.5 - 8.2	4.9 - 21.1	2,652 - 4,045	423 - 724	2 - 8	29 - 89	2,095 - 11,367
PC4	1.14 - 2.1	3.9 - 9.7	132.5 - 462.3	610 - 9,454	251 - 319	4 - 6	60 - 125	935 - 3,872
PC5	0.88 - 2.5	7.7 - 31.1	50 - 135.5	6,381 - 10,320	427 - 667	4 - 8	74 - 296	960 - 6,288
PC6	0.61 - 2.5	4.6 - 10	75.1 - 121.6	7,303 - 9,952	346 - 566	4 - 5	82 - 324	798 - 1,446

In a related study (referred to in Section 7.1), Cairns et al. performed body burden examinations of Hydropsychidae collected in Peak Creek. Elevated levels of Cu and Zn were found at the contaminated sites downstream from the reference station 9-PKC011.11. This appears to confirm the results from the pore water sampling that heavy metals in Peak Creek sediment are periodically bioavailable. However, it is not clear how the contaminants are getting into the organisms, from the water or ingested through the food chain. Although the exposure route is not known, the detrimental effect of Cu and Zn on the benthic community has been well established. In a study on the Clinch River investigators found that sampling stations impacted by Cu and Zn were characterized by reduced taxa richness, reduced abundance, and a shift in community composition from sensitive to tolerant taxa (Clements, et al. 1992). A New Zealand study made use of a stream mesocosm in order to control environmental factors and provide a causal link between a contaminant and a biological response. The investigators found that all five mayfly species were very sensitive to Cu and Zn, whereas four of the seven caddisfly species showed stimulation and three were reduced (Hickey and Golding 2002). In an earlier study investigators also found upstream reference sites dominated by mayflies while sites impacted by Cu and Zn were dominated by caddisflies (Clements, et al. 1988).

An examination of the benthic assemblages at all three Peak Creek benthic monitoring stations (in the VADEQ EDAS database) revealed an interesting anomaly. Psephenidae, commonly known as water pennies, was one of the most dominant family groups at station 9-PKC009.29 (10%). Psephenidae are somewhat tolerant of metal pollution (Voshell, 2002). The percentage of this family group at 9-PKC007.80 and 9-PKC011.11 was 3%, which is typical of other reference stations in this ecoregion. In addition, some species of Hydropsychidae are relatively tolerant to pollution from heavy metals (VADEQ personal communication, 3/1/2004). This could also be factor in their abundance in Peak Creek.

Sampling by VADEQ and others (referenced in Section 1) provide conclusive evidence that elevated metals are present throughout Peak Creek, even at the non-impaired reference station. Therefore, multiple sources of metals exist in the watershed. Based upon the information described above, Zn and Cu are considered significant stressors and will be used as target pollutants in the benthic TMDL for Peak Creek.

In summary, the selected stressors were the ones that had the most chemical and biological evidence. MapTech personnel met with VADEQ regional and headquarters staff on March 1, 2004 and it was collectively decided that metals were the single most important stressor in Peak Creek. It is recognized that there are other contributing factors to the impairments such as the channelization of Peak Creek through the Town of Pulaski. VADEQ should continue regular chemical and biological sampling in this watershed. Special studies should also be periodically employed. It will be necessary to identify all of the significant sources of heavy metals in the watershed and also collect the information necessary to determine if any other stressors need to be addressed in the future.

8. MODELING PROCEDURE

As noted in Section 7, high concentrations of metals in stream sediment were identified as primary stressors for the Peak Creek watershed. The Peak Creek General Standard TMDL was based on reductions of copper (Cu) and zinc (Zn) loads to the stream. The TMDL endpoint was based on metal concentrations observed in sediment at the non-impaired upstream station (9-PKC011.11). The TMDL loads (reported in Section 9) are the loads of Cu and Zn that resulted in sediment concentrations (*i.e.*, mg-metal/kg-sediment) equivalent to those observed at the reference site (Table 8.1). TMDL loads are expressed in terms of kg/y permissible from point and nonpoint sources. The TMDL Margin of Safety (MOS) was addressed implicitly since implementation efforts aimed at reducing the target pollutants to acceptable levels will reduce other pollutant levels as well.

Table 8.1 Observed median concentrations of Cu and Zn in sediments at stations in Peak Creek.

Pollutant	Reference Site (9-PKC011.11)	Adjacent to Allied Signal (9-PKC009.29)	Below Allied Signal (9-PKC007.82)
Sediment Cu (mg/kg)	50	76	983
Sediment Zn (mg/kg)	587	933	1620

8.1 Copper and Zinc Model Framework

Dissolved Metals

In order to address the possibility of dissolved metals (*i.e.*, Cu and Zn) reaching an acute toxicity level, preliminary modeling included examination of the impact from acidic runoff from contaminated sites during storm events, and point sources during low-flow conditions.

There is one area of well-documented contaminated soils in the Peak Creek watershed, Allied Signal. The potential for stormwater from this site raising the concentration of dissolved Cu or Zn in the water column to acutely toxic levels, 13 μg/l and 120 μg/l, respectively, was considered through the application of an equilibrium model. An equilibrium speciation model (MINTEQA2 for Windows, Allison Geoscience

Consultants, Inc. and HydroGeoLogic, Inc., version 1.50) was used to support water quality modeling in Peak Creek. The primary concern was to complete a sensitivity study of metal solubility with varying pH. Sorption and chelation/complexation were not incorporated into the model.

Total concentrations of substances used in the model were taken from two sources. Metal concentrations (other than calcium and magnesium) were taken from the 2002 Honeywell Report and were the highest values measured in stormwater runoff on July 26, 2002. Hardness and alkalinity values, as well as anion concentrations, approximated the mean values from ambient water quality monitoring stations. Input species and their concentrations are displayed in Table 8.2.

Table 8.2 Initial concentration of species used in the MINTEQ speciation model.

Species	Concentration	
	mol/L	mg/L
Al+3	3.72E-04	10.02
Ca+2	7.41E-04	29.65
Cd+2	1.78E-07	0.00
Cl-1	5.62E-04	19.94
CO3-2	1.00E-03	60.00
Cr(OH)2+	3.47E-07	0.02
Cu+2	1.91E-04	12.11
Fe+3	3.55E-04	19.81
Mg+2	4.07E-04	9.90
Ni+2	8.51E-07	0.05
NO3-1	3.24E-06	0.20
Pb+2	4.79E-07	0.10
PO4-3	4.17E-07	0.04
SO4-2	8.32E-04	81.52
Zn+2	1.38E-04	9.02

The first model run was a sensitivity analysis with pH ranging from 2.0 to 10.0; the results are displayed in Table 8.3 and Figure 8.1. Iron, aluminum, lead, and copper all fall from solution by pH =7. Aqueous lead carbonate increases the level of lead in solution and reaches a local maximum near pH = 8.5. Zinc is more soluble and does not begin precipitating until the pH exceeds 7, and a few percent remains in solution at pH = 8.5.

Table 8.3 Solubility of selected metals as a function of pH.

pH	Percent Metal in Solution				
	Fe	Al	Pb	Cu	Zn
2.0	0.1	100.0	100.0	100.0	100.0
2.5	0.0	100.0	100.0	100.0	100.0
3.0	0.0	100.0	100.0	100.0	100.0
3.5	0.0	100.0	100.0	100.0	100.0
4.0	0.0	12.8	100.0	100.0	100.0
4.5	0.0	0.4	100.0	100.0	100.0
5.0	0.0	0.0	85.2	100.0	100.0
5.5	0.0	0.0	31.2	100.0	100.0
6.0	0.0	0.0	10.8	16.4	100.0
6.5	0.0	0.0	4.0	2.8	100.0
7.0	0.0	0.0	2.0	0.8	100.0
7.5	0.0	0.0	1.5	0.2	53.3
8.0	0.0	0.0	3.0	0.1	19.6
8.5	0.0	0.0	6.5	0.0	2.8
9.0	0.0	0.0	2.5	0.0	0.6
9.5	0.0	0.1	0.7	0.0	0.3
10.0	0.0	0.4	0.4	0.0	0.3

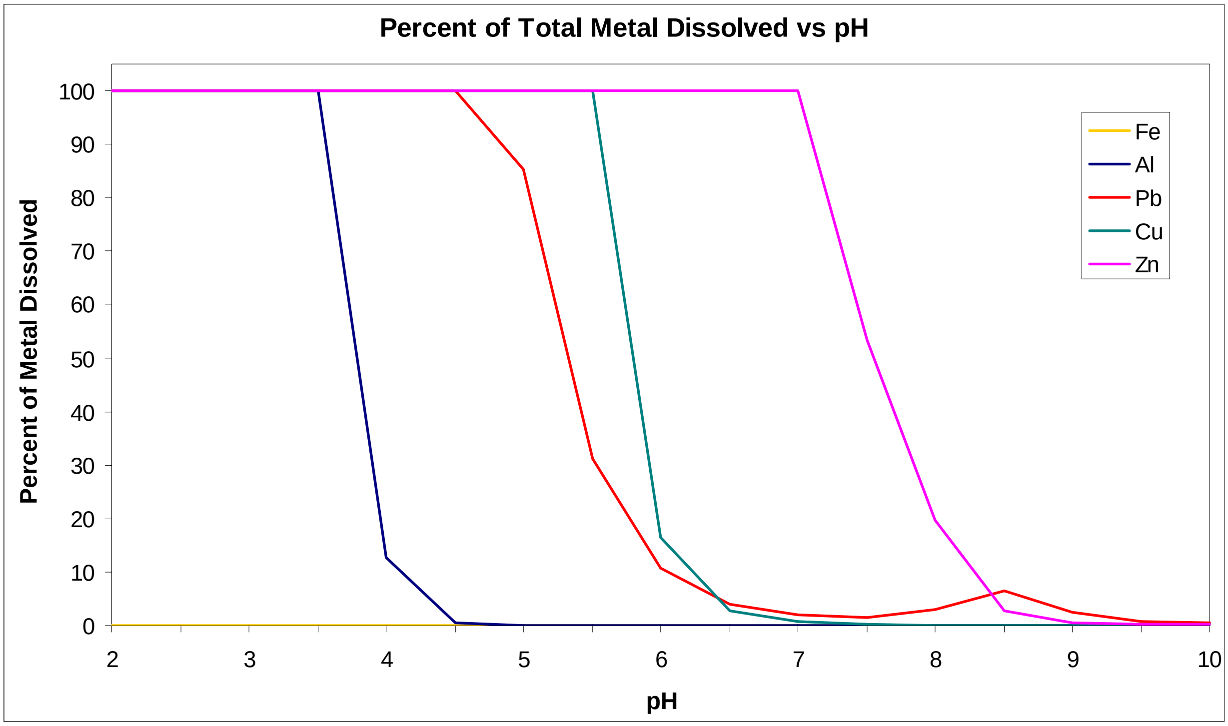

Figure 8.1 Variation of solubility with pH for selected metals.

The model was then run at two pH values. The first value represents a “worst case” scenario with pH = 5, the lowest pH recorded in the stormwater runoff study conducted in 2002. The second value, pH = 8.2, is the median pH value from ambient water quality stations on Peak Creek. The results are displayed in Table 8.4. At pH = 5, the solubility of copper and zinc are high enough to give toxic concentrations, based on maximum total metal concentrations in the stormwater runoff. However, at pH = 8.2, equilibrium concentrations of all metals, with the exception of Zn, appear to be below acutely toxic levels. Average annual runoff volume from the site is approximately 47 cm-ha, while the average annual runoff volume from upstream areas is approximately 46,000 cm-ha. This represents a dilution factor of almost 1,000 times, which would result in concentrations well below the acute toxicity level for all metals. It does seem plausible that toxic spikes of soluble metals might be generated under the right conditions, but dilution of the runoff and mixing with less acidic stream water would make the occurrence improbable. It is more likely that colloidal particles containing metals and ingested by benthic organisms is the principal exposure mechanism.

Table 8.4 Comparison of metal speciation at two pH values.

	pH=5					**pH=8.2**				
	Dissolved			**Pecipitated**		**Dissolved**			**Precipitated**	
Species	**mol/L**	**mg/L**	**%**	**mol/L**	**%**	**mol/L**	**mg/L**	**%**	**mol/L**	**%**
Al+3	6.45E-08	0.002	0	3.71E-04	100	2.62E-08	0.001	0	3.71E-04	100
Cd+2	1.78E-07	0.020	100	0.00E+00	0	1.78E-07	0.020	100	0.00E+00	0
Cr+3	3.49E-07	0.018	100	0.00E+00	0	7.40E-10	0.000	0.2	3.48E-07	99.8
Cu+2	1.89E-04	11.987	100	0.00E+00	0	8.50E-08	0.005	0	1.89E-04	100
Fe+3	5.37E-11	0.000	0	3.58E-04	100	7.31E-14	0.000	0	3.58E-04	100
Ni+2	8.52E-07	0.050	100	0.00E+00	0	8.52E-07	0.050	100	0.00E+00	0
Pb+2	4.11E-07	0.085	85.2	7.15E-08	14.8	2.61E-08	0.005	5.4	4.57E-07	94.6
Zn+2	1.38E-04	9.001	100	0.00E+00	0	1.28E-05	0.835	9.3	1.25E-04	90.7

Magnox Pulaski (VA0000281) is the only permitted discharge controlling discharges of Cu and Zn. Discharges from the site include one process water outfall and three stormwater outfalls. Average concentrations of Cu and Zn from the process water outfall are 6.90 μg/l and 24.88 μg/l, respectively. Permit levels for Cu and Zn from the process water outfall are 11 μg/l and 50 μg/l, respectively. Average concentrations of Cu and Zn from the stormwater outfalls are 10.5 μg/l and 1,274 μg/l, respectively. Permit benchmarks for these constituents in the stormwater discharges are 30 μg/l and 203 μg/l for Cu and Zn, respectively.

Although the analysis of metal speciation described earlier indicated that most of the dissolved Cu and Zn would precipitate out when it reached the stream, an additional analysis is presented here to examine the potential for dissolved Cu or Zn reaching an acute level in the stream. The permit for Magnox includes wording describing a contingency plan designed to prevent the discharge from exceeding 45% of the stream flow. In a worst-case, low-flow condition, stormwater would not be contributing, but process water would make up 45% of the flow in Peak Creek. Given the chemistry of the stream, virtually no dissolved Cu or Zn would be expected in the stream. At the permit levels (*i.e.*, 11 μg-Cu/l and 50 μg-Zn/l), the resulting in-stream concentrations, assuming all constituents remained dissolved, would be 4.95 μg-Cu/l and 22.5 μg-Zn/l. These values are well below the acute criteria for Cu and Zn, 13 μg-Cu/l and 120 μg-Zn/l.

8.1.1 Metals in Sediment

A mass-balance model for predicting the concentration of metals in stream sediment, in combination with a watershed model used to simulate sediment loads from potential sources in the Peak Creek watershed, was used to develop this TMDL. The sediment-delivery model used in this study was the Visual *Basic*^{TM} version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow et al., (2002), and BSE (2003).

Because pH in the stream has always been recorded as neutral to basic, all metals delivered to the stream (*i.e.*, dissolved or particulate) were modeled as eventually becoming part of the stream sediment load, whether by being associated with sediment delivered to the stream or by precipitating out of solution upon reaching the stream. Since the TMDL endpoint is based on the concentration of metals in stream sediment, this assumption adds to the implicit MOS. Sediment delivery was modeled at 4 locations (contributing subwatersheds delineated in Figure 8.2), as follows:

Outlet of Model Segment 1: Reference site (9-PKC011.11)
Outlet of Model Segment 2: Adjacent to the Allied Signal (9-PKC009.29)
Outlet of Model Segment 3: Below the Allied site (9-PKC007.82)
Outlet of Model Segment 4: At the impairment outlet.

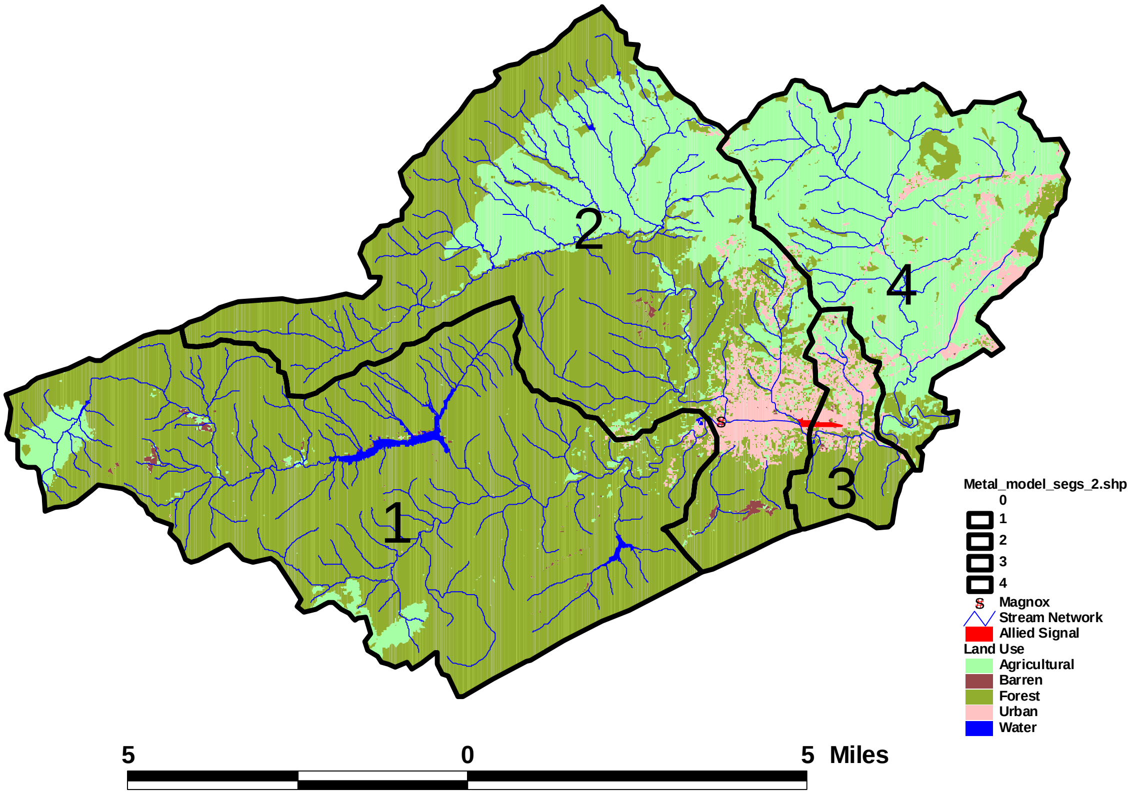

Figure 8.2 Subwatersheds used to model sediment delivery in Peak Creek.

Sources of metals included background loads associated with sediment delivered to the stream, loads in runoff from urban areas, permitted point sources, and loads from known areas of contaminated soils. For the sediment-associated loads from the area upstream of the reference site (*i.e.*, Model Segment 1) and forested areas in the headwaters of the Tract Fork drainage (*i.e.*, forested areas in Model Segment 2), sediment concentrations equal to those measured in sediment at the reference station (*i.e.*, 50 mg-Cu/kg and 587 mg-Zn/kg) were used. These areas are known to be impacted by historical coal and iron mine activities.

For the remaining pervious areas, more generalized concentrations were used, based on literature values (*i.e.*, 26 mg-Cu/kg and 60 mg-Zn/kg – Novotny and Olem, 1994). For loads associated with runoff from urban areas, median Event-Mean-Concentrations (EMCs) observed during the National Urban Runoff Program (EPA, 1983) were used. These concentrations (*i.e.*, 43 μg-Cu/l and 228 μg-Zn/l) were combined with average annual runoff volumes from urban impervious surfaces to calculate an annual load. For calibration purposes, loads from permitted point sources were based on Discharge Monitoring Reports (DMRs). These loads were increased to permitted maximums for allocation purposes.

The concentration of metals in soils at the Allied Signal site were calculated based on soil and stormwater sampling done on site and described in the report titled *Draft Site Characterization Report, Allied-Pulaski Site*, prepared by Parsons for Honeywell (October 2002). In this report, extensive sampling of lead (Pb) in soils was reported. Specifically, 54 samples were collected and analyzed as part of the report development and 19 historical values were reported. Historical values ranged from 28 to 1,650 mg/kg, with a median value of 519 mg/kg. The values observed to support the study ranged from <11.7 to 2,040 mg/kg, with a median value of 221.5 mg/kg. The overall median for the data was 250 mg/kg. One sample of stormwater collected from the site was analyzed for total and dissolved Pb, Cu, and Zn (Table 8.5). Total metal values from this sample were used to determine the ratio of the Cu and Zn relative to Pb for the soils on the site. Using these ratios and the overall median Pb concentration, the expected Cu and Zn concentrations were 28,810 and 20,810 mg/kg, respectively. These values seem reasonable in view of the high stream-sediment concentrations observed downstream of the site in Peak Creek.

Table 8.5 Results of stormwater sampling conducted at Allied Signal (7/26/02).

	Pb (mg/l)	Cu (mg/l)	Zn (mg/l)
Total	0.105	12.1	8.74
Dissolved	<0.100	12.2	8.17

Stormwater runoff was modeled for sites with general permits specifying Cu or Zn and the monitoring cutoffs were used. Inputs from those facilities were very small compared with other inputs.

The governing equations (below) for calculating the metal concentrations in stream sediment assume an equilibrium condition reached over time, where sediments in the stream reflect a proportional mix of the sediment conditions delivered from the land with additional metal loads from urban runoff and permitted point sources.

$$C_M = \frac{L_M}{L_S} \qquad \textit{and} \qquad L_M = L_{M,S} + L_{M,U} + L_{M,PS} + L_{M,CS}$$

where,

C_M = The concentration (*C*) of metal *M* in stream sediment at the point of interest.

L_M = The load (*L*) of metal *M* delivered to the stream at the point of interest.

L_S = The load (*L*) of sediment *S* delivered to the stream at the point of interest.

$L_{M,S}$ = The load of metal *M* associated with sediment delivered to the stream, based on the sediment load from specific source areas modeled using GWLF and corresponding metal concentrations.

$L_{M,U}$ = The load of metal *M* associated with urban runoff, based on annual runoff from urban impervious land segments and the concentration of metal in the runoff.

$L_{M,PS}$ = The load of metal *M* from permitted point sources, based on monitored data for calibration purposes and permitted loads for allocation purposes.

$L_{M,CS}$ = The load of metal *M* from land areas known to be contaminated, based on the sediment load modeled using GWLF and corresponding metal concentrations.

Enrichment ratios were used as calibration parameters applied to the contaminated sediment source area in Model Segments 2 and 3. This allowed adjustment of loads to account for uncertainties in source area concentrations, and to account for preferential delivery of metals attached to smaller sediment particles. Additionally, values of pH as low as 2 have been observed in surface water at the contaminated site. Acidic runoff has the capacity to carry dissolved metals in addition to the sediment-associated metals. The use of enrichment ratios allowed this delivery mechanism to be considered.

Upon calibration of the enrichment ratios, the point source loads were increased to the maximum permitted loads, and allocations were developed based on reducing loads from the known contaminated site.

8.2 Sediment Model Framework

The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith et al., 1992) for use in ungaged watersheds. It was chosen for this study as the model framework for simulating sediment. GWLF is a continuous simulation spatially-lumped model that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources (NPS) of pollution. The model considers flow input from both surface and groundwater and it uses landuse classes as the basic unit for representing variable source areas. It supports the calculation of nutrient loads from septic systems and streambank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources. Runoff is simulated based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (Schwab et al., 1983; Wischmeier and Smith, 1978). Sediment estimates use a delivery ratio based on a function of watershed area and erosion estimates from the modified USLE. The sediment transported depends on the transport capacity of runoff.

For execution, GWLF uses three input files (*i.e.*, weather, transport, and nutrient loads). The weather file contains daily temperature and precipitation for the period of record. Data are based on a water year typically starting in October and ending in September. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains primarily nutrient values for the various landuses, point sources, and septic system types, but does include urban sediment buildup rates.

8.2.1 Model Setup

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverages, local weather data, streamflow data, literature values, and other data. Watershed boundaries for the three impaired stream segments and selected reference watersheds were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The impaired watershed was delineated from the downstream extent of the impairment. The Peak Creek watershed was sub-divided into four sub-watersheds to facilitate analysis.

8.2.2 Source Assessment

Three source areas were identified as the primary contributors to sediment loading in the Peak Creek watershed: surface runoff, point sources, and streambank erosion. Sediment erosion is a continual process but is often accelerated by human activity. This section describes the predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

8.2.2.1 Surface Runoff

During runoff events (natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.*, agricultural fields, lawns, forest, etc.). The magnitude of sediment loading is affected by rainfall energy, soil cover, soil characteristics, topography, and land management. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations along the stream edge, uncontrolled access to streams, forest harvesting, and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by, among other factors, the level of wind erosion from which deposition will occur. Sediment loading is also affected by sediment deposited from vehicular traffic. This load can be reduced by street sweeping and/or other street maintenance operations.

8.2.2.2 Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks and leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour, et al., 1991; Clary and Webster, 1989; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998).

8.2.2.3 Point Sources TSS Loads

Fine sediments are included in total suspended solids (TSS) loads that are permitted for various facilities with wastewater and industrial stormwater VPDES permits within the Peak Creek watershed. There are 7 permitted industrial construction, one single family wastewater, and one industrial wastewater discharger permitted within the watershed. There were no MS4 permits located in the watershed.

8.2.3 Source Representation – Input Requirements

As described in Section 8.1, the GWLF was developed to simulate runoff, sediment, and nutrients in ungaged watersheds based on landscape conditions such as landuse/landcover, topography, and soils. In essence, the model uses a form of the hydrologic units (HU) concept (Li, 1972; England, 1970) to estimate runoff and sediment from different pervious areas (HUs) in the watershed. In the GWLF model, the nonpoint source load calculation for sediment is affected by landuse activity (*e.g.*, farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses landuse categories as the mechanism for defining homogeneity of source areas. This is a variation of the HU concept, where homogeneity in hydrologic response or nonpoint source pollutant response would typically involve the identification of soil/landuse/topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the effect of varying soil-topographic conditions by landuse entities. A description of model parameters is given in Section 8.4.1 followed by a description of how parameters and other data were calculated and/or assembled.

8.2.3.1 Description of Model Input Parameters

The following description of GWLF model input parameters was taken from a TMDL Draft report prepared by BSE, 2003.

Hydrologic Parameters

Watershed Related Parameter Descriptions

- *<u>Unsaturated Soil Moisture Capacity (SMC):</u> The amount of moisture in the root zone, evaluated as a function of the area-weighted soil type attribute – available water capacity.*

- *<u>Recession Coefficient (/day):</u> The recession coefficient is a measure of the rate at which streamflow recedes following the cessation of a storm, and is approximated by averaging the ratios of streamflow 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.*

- *<u>Seepage Coefficient (/day):</u> The seepage coefficient represents the amount of flow lost to deep seepage.*

The following parameters were initialized by running the model for a 3-month period prior to the chosen period during which loads were calculated.

- *<u>Initial unsaturated storage (cm):</u> 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.*

- *<u>Antecedent Rainfall for each of 5 previous days (cm):</u> The amount of rainfall on each of the five days preceding the first day in the weather file.*

Month Related Parameter Descriptions

- *<u>Month</u>: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*

- *<u>ET CV:</u> Composite evap-transpiration cover coefficient, calculated as an area-weighted average from landuses within each watershed.*

- *<u>Hours per Day:</u> mean number of daylight hours.*

- *<u>Erosion Coefficient:</u> This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned* *separate coefficients for the months October-March, and for April-September.*

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 the inverse function of watershed size (Evans et al., 2001).*

Landuse- 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.*
- *USLE C-factor: The vegetative cover factor for each landuse was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*
- *Daily sediment build-up 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, 2002)

- *% Developed Land: Percentage of the watershed with urban-related landuses- 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 watershed area in acres.*
- *Stream length: Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*
- *Stream length with livestock access: calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling in meters.*

8.2.3.2 Streamflow and Weather data

The GWLF model was not calibrated for hydrology as no appropriate streamflow data existed within or near the watershed. Precipitation and temperature data were obtained from the National Climatic Data Center (NCDC). A weather station was identified in Pulaski (Table 8.6).

Table 8.6 Weather station used in GWLF model for Peak Creek watershed.

Watershed	Weather Stations (station id, location)	Data Type	Data Period
Peak Creek	Station id: 446955 Location: Pulaski, VA	Daily Precipitation & Temperature	1/1/1986–12/31/1991

8.2.3.3 Landuse/landcover classes

Landuse classes are used as the basic response unit for performing runoff and erosion calculations and summarizing sediment transport. Landuse coverages were obtained from Multi-Resolution Land Characteristics (MRLC) data (EPA, 1992) for all impaired and reference watersheds. The landuse categories were consolidated from MRLC classifications as given in Table 8.7. Urban landuse categories (*i.e.*, low density residential – LDR, high density residential – HDR, and commercial/industrial/ transportation/mining – COM) were further subdivided into a pervious (PER) and an impervious (IMP) component. The percentage of impervious and pervious area was assigned from data provided in VADCR's online 2002 NPS Assessment Database (VADCR, 2002). The pasture/hay category was subdivided into five sub-categories (*i.e.*, hay, overgrazed pasture, unimproved pasture, improved pasture, and stream edge). The percentages of the pasture/hay acreage that were assigned to each category were obtained from local sources and VADCR's online 2002 NPS Assessment. Cropland was also subdivided into two sub-categories: low tillage and high tillage. The percentage assigned to each cropland sub-category was obtained from VADCR's online database (VADCR, 2002), Boring (2004), and local information. Landuse distributions for Peak Creek are given in Table 8.8.

Table 8.7 Landuse-Categories for TMDL Analysis.

TMDL Landuse Categories	MRLC Landuse Categories
Low Density Residential	Low Density Residential (21)
High Density Residential	High Density Residential (22)
Commercial	Commercial (23) Industrial (23) Transportation (23)
Transitional	Barren – transitional (33) Barren/Bare Rock (31) Barren Gravel Pits (32)
Forest	Deciduous Forest (41) Evergreen Forest (42) Upland – Mixed Forest (43) Woody Wetlands (91) Shrubland (51)
Urban Grass	Urban Grass (85)
Pasture/Hay	Pasture/Hay (81) Grasslands (71) Pasture/Hay (81) Herbaceous Wetlands(92) Orchards/vineyards (61)
Cropland	Row Crops (82) Small grain (83) Cultivated Fallow (84)
Water	Water (5)

The weighted C-factor for each landuse category was estimated following guidelines given in Wischmeier and Smith, 1978, GWLF User's Manual (Haith et al., 1992), and Kleene, 1995. Where multiple landuse classifications were included in the final TMDL classification (*e.g.*, pasture/hay), each classification was assigned a C-factor and an area weighted C-factor calculated.

Table 8.8 Landuse distributions by sub-watershed (ha).

Landuse Category	Model Segment			
	1	2	3	4
Low Density Residential (pervious)	25	295	82	103
High density Residential (pervious)	0	1	4	0
Commercial (pervious)	1	22	28	38
Transitional	33	38	6	1
Forest				
Disturbed Forest	67	44	4	3
Forest	7892	5167	528	410
Pasture/Hay				
Hay	22	145	9	209
Overgrazed	30	188	12	250
Unimproved	119	753	46	1000
Improved	148	941	58	1250
Stream Edge	2	102	1	362
Cropland				
High Tillage	0	0	0	0
Low Tillage	83	266	17	261
Low Density Residential (impervious)	8	98	27	34
High density Residential (impervious)	0	0	3	0
Commercial (impervious)	2	41	52	71
Water	111	4	0	2

8.2.3.4 Sediment Parameters

Sediment parameters include USLE parameters K, LS, C, and P, sediment delivery ratio, and a buildup and loss functions for impervious surfaces. The product of the USLE parameters, KLSCP, is entered as input to GWLF. The K factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. Soils data for Peak Creek was obtained from VADCR’s VirGIS database for Pulaski County, Virginia (VADCR, 1992), the Pulaski County soil survey manual (SCS, 1985b), and the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004). The area-weighted K-factor by landuse category was calculated using GIS procedures. Land slope was calculated from USGS Digital Elevation Models (DEMs) using GIS techniques. The length-of-slope was based on VirGIS procedures given in VirGIS Interim Reports (*e.g.,* Shanholtz et al., 1988). The VirGIS length-of-slope values were developed in cooperation with local SCS Office personnel for much of Virginia. The area-weighted slope and length-of-slope were calculated by landuse category using GIS procedures. The area-weighted LS factor was calculated for each landuse category using procedures recommended by Wischmeier and Smith (1978). The average soil solum thickness and corresponding available soil moisture capacity were obtained from soils data and used to estimate the unsaturated soil moisture capacity.

8.2.3.5 Pervious and Impervious Surfaces

Four TMDL categories define urban landuse/landcover (Table 8.8). Each urban area was sub-divided into pervious areas (USLE sediment algorithm applies) and impervious areas where an exponential buildup-washoff algorithm applies. The percentage of pervious and impervious area was calculated from data obtained from VADCR’s 2002 NPS Assessment Landuse/Landcover Database (VADCR, 2002).

The daily sediment build-up rate on impervious surfaces, which represents the daily amount of dry deposition from the air on days without rainfall, was assigned using GWLF manual (Haith et al. 1992) guidance. For this study, the values used by BSE, 2003 were assigned as the daily build up rate for the impairment.

8.2.3.6 Sediment Delivery Ratio

The sediment delivery ratio specifies the percentage of eroded sediment delivered to surface water and is empirically based on watershed size. The sediment delivery ratios for impaired and reference watersheds were calculated as an inverse function of watershed size (Evans et al., 2001).

8.2.3.7 SCS Runoff Curve

The runoff curve number is a function of soil type, antecedent moisture conditions, and cover and management practices. The runoff potential of a specific soil type is indexed by the Soil Hydrologic Group (HG) code. Each soil-mapping unit is assigned HG codes that range in increasing runoff potential from A to D. The soil HG code was given a numerical value of 1 to 4 to index HG codes A to D, respectively. An area-weighted average HG code was calculated for each landuse/land cover from soil survey data using GIS techniques. Runoff curve numbers (CN) for soil HG codes A to D were assigned to each landuse/land cover condition for antecedent moisture condition II following GWLF guidance documents and SCS 1986 recommended procedures. The runoff CN for each landuse/land cover condition was then adjusted based on the numerical area-weighted soil HG codes.

8.2.3.8 Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of streams with livestock access, total length of natural stream channel, % developed land, mean stream depth, and watershed area. The number of dairy and beef animals for Peak Creek watershed was obtained from information provided by the Soil and Water Conservation District. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The length of harden channel was estimated as the length of stream flowing through commercial areas using GIS techniques. The mean stream depth was estimated as a function of watershed area.

8.2.4 Point Source TSS Loads

Nine point sources were identified in the Peak Creek watershed and are listed in Table 8.9. In the case of this TMDL, TSS loads from permitted point sources were modeled in order to accurately reflect the equilibrium concentration of Cu and Zn in sediment. Sediment itself was not identified as a stressor. As a result, anticipated TSS loads (based on monitored data where available) were modeled rather than permit levels. Increasing the TSS load to permit levels would actually serve to dilute the metal concentrations in sediment. Loads from stormwater sources were accounted for in the model through erosion and washoff from the various source areas. The load from the general permit was modeled based on maximum permitted levels because no additional data was available; however, the load from this source was negligible. The load from the industrial wastewater discharge was modeled based on monitored data (*i.e.*, average flow and TSS concentration).

Table 8.9 VPDES point source facilities and permitted TSS load.

Peak Creek Point Sources		Existing Conditions		
VPDES ID	**Name**	**Permit Discharge (MGD)**	**Concentration (mg/L)**	**TSS (T/yr)**
Industrial Stormwater Discharge Permits				
VAR050139	TMD Friction	N/A	N/A	N/A
VAR050250	Bondcote Corporation	N/A	N/A	N/A
VAR050339	Pulaski County Industrial Dev. Authority	N/A	N/A	N/A
VAR050444	Jefferson Mills Inc	N/A	N/A	N/A
VAR050454	Pulaski Furniture Corp. Plant # 5	N/A	N/A	N/A
VAR050772	McCready Lumber Company, Inc	N/A	N/A	N/A
VAR100264	VDOT - Salem District - Rte 641	N/A	N/A	N/A
VAR101248	Pulaski Business Park	N/A	N/A	N/A
VAR101880	VDOT Pulaski Co 0807 077 P01 N501	N/A	N/A	N/A
VAR101919	New Pulaski Elementary School	N/A	N/A	N/A
VAR520118	Gem City Iron & Metal Company, Inc	N/A	N/A	N/A
VAR520122	Pulaski Furniture	N/A	N/A	N/A
Single Family Watewater Discharge Permits				
VAG402040	Residence	0.0005	30	0.021
Industrial Wastewater Discharge Permits				
VA0000281	Magnox Pulaski, Inc.	0.84	4.19	4.866
Total				**4.887**

8.2.5 Stream Characteristics

The GWLF model does not support in-stream flow routing. An empirical relationship developed by Evans et al., 2001 and modified by BSE, 2003 requires total watershed stream length of the natural channel and the average mean depth for making estimates of channel erosion. This calculation excludes the non-erosive hardened and piped sections of the stream.

8.2.6 Selection of a Representative Modeling Period

The selection of the modeling period was based on the need to represent critical hydrological conditions and seasonal variability. A discussion of analysis conducted to select a representative period is given in Section 4.

8.2.7 Hydrologic Model Calibration Process

Hydrologic calibration was not performed for Peak Creek, as no suitable stream flow data existed within or nearby the watershed. The GWLF model was originally developed for use in ungaged watersheds and this was considered an acceptable alternative since both the impaired segment and the reference watershed are located within the same drainage (allowing the use of the same weather data). The model's parameters were carefully assigned based on available soils, landuse, topographic data, and with guidance from the GWLF manual to adequately account for differences in watershed characteristics that affect hydrology, erosion, and sediment transport.

8.3 Existing Conditions

Combining the results of the sediment-loading model with anticipated concentrations of Cu and Zn from the sources discussed in Section 8.1, concentrations of Cu and Zn in the stream sediments were modeled and calibrated to the median concentrations observed at ambient monitoring stations that coincide with the outlets of Model Segments 2 and 3 (Table 8.10). The resulting calibrated enrichment ratios for Cu and Zn delivered from the contaminate site at Allied Signal were 3.7 and 4.2, respectively. These values are consistent with those reported by Novotny and Olem (1994) (*i.e.*, 1.8 and 4.0 for Cu and Zn, respectively). The loads modeled as being delivered from the Allied Signal site are an order of magnitude greater than the loads from any other site.

Table 8.10 Existing conditions of Cu and Zn in sediment, as modeled, at four points in the Peak Creek drainage.

Pollutant Source	Sediment (Mg/yr)	Cu (g/yr)	Zn (g/yr)
Segment 1 (Reference)			
Background	578	28,916	339,476
Resulting Concentration (mg/kg)		**50**	**587**
Segment 2			
Background	1,760	52,514	253,956
Urban Stormwater	30	36,560	193,851
Allied Signal Stormwater	16	56,405	1,405,621
Magnox Process Water	4.89	8,037	28,970
Magnox Stormwater	0.09	49	6,003
Resulting Concentration (mg/kg)		**76**	**933**
Segment 3			
Background	289	8,166	31,566
Urban Stormwater	16	20,357	107,939
Allied Signal Stormwater	23	2,459,282	2,035,641
Resulting Concentration (mg/kg)		**983**	**1,620**
Segment 4			
Background	2,143	55,093	127,138
Urban Stormwater	21	25,832	136,968
Resulting Concentration (mg/kg)		**564**	**956**

9. ALLOCATIONS

For modeling allocations, loads from permitted sources were adjusted to permitted levels. Reductions were then made to the loads from specific sources, starting with the Allied Signal site and including additional sites as warranted. Two allocation scenarios are presented here. The targeted value for Zn can be achieved through an 83% reduction in the load from the Allied Signal site. For Cu, the first scenario focuses on reductions from the Allied site and urban stormwater (Table 9.1). This scenario includes a 99% reduction from the Allied Signal site and an 83% reduction in loads associated with urban stormwater. The second scenario distributes the reduction in Cu loads between the Allied Signal site, urban stormwater, and background sources (Table 9.2). This scenario is potentially more achievable because it calls for only a 40% reduction of the loads from urban stormwater and background sources.

Table 9.1 Allocation scenario 1, focusing on load reductions from the Allied Signal site and urban stormwater.

Pollutant Source	Cu Reduction	Cu (g/yr)	Zn Reduction	Zn (g/yr)
Segment 1 (Reference)				
Background	0%	28,916	0%	339,476
Resulting Concentration (mg/kg)		**50**		**587**
Segment 2				
Background	0%	52,514	0%	253,956
Urban Stormwater	83%	6,215	0%	193,851
Allied Signal Stormwater	99%	564	83%	238,956
Magnox Process Water	0%	12,322	0%	56,008
Magnox Stormwater	0%	141	0%	957
Resulting Concentration (mg/kg)		**42**		**453**
Segment 3				
Background	0%	8,166	0%	31,566
Urban Stormwater	83%	3,461	0%	107,939
Allied Signal Stormwater	99%	24,593	83%	346,059
Resulting Concentration (mg/kg)		**50**		**577**
Segment 4				
Background	0%	55,093	0%	127,138
Urban Stormwater	0%	25,832	0%	136,968
Resulting Concentration (mg/kg)		**45**		**375**

Table 9.2 Allocation scenario 2, focusing on load reductions from the Allied Signal site and a combination of urban stormwater and background loads.

Pollutant Source	Cu Reduction	Cu (g/yr)	Zn Reduction	Zn (g/yr)
Segment 1 (Reference)				
Background	0%	28,916	0%	339,476
Resulting Concentration (mg/kg)		**50**		**587**
Segment 2				
Background	40%	31,508	0%	253,956
Urban Stormwater	40%	21,936	0%	193,851
Allied Signal Stormwater	99%	564	83%	238,956
Magnox Process Water	0%	12,322	0%	56,008
Magnox Stormwater	0%	141	0%	957
Resulting Concentration (mg/kg)		**40**		**453**
Segment 3				
Background	40%	4,900	0%	31,566
Urban Stormwater	40%	12,214	0%	107,939
Allied Signal Stormwater	99%	24,593	83%	346,059
Resulting Concentration (mg/kg)		**50**		**577**
Segment 4				
Background	0%	55,093	0%	127,138
Urban Stormwater	0%	25,832	0%	136,968
Resulting Concentration (mg/kg)		**45**		**375**

The final TMDL is presented in Table 9.3 as 12 kg/year and 218 kg/year for Cu and Zn, respectively. Of these TMDLs, the remaining loads from the Allied Signal site are allocated at 25 kg/year and 585 kg/year for Cu and Zn, respectively.

Table 9.3 Average annual Cu and Zn loads (kg/year) modeled based on TMDL in the Peak Creek watershed.

Impairment*	WLA (kg/year)	LA (kg/year)	MOS	TMDL (kg/year)
Peak Creek (Cu)	12.7	206	*Implicit*	218.7
VA0000281 – Magnox	*12.0*			
VAR050772 – McCready	*0.6*			
VAR520118 – Gem City	*0.1*			
Peak Creek (Zn)	57.6	1,776		1,833.6
VA0000281 – Magnox	*57.0*			
VAR050772 – McCready	*0.6*			

* The WLAs for affected permits are detailed in this table.

PART IV: IMPLEMENTATION AND PUBLIC PARTICIPATION

10. IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to 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 Peak Creek. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL has been approved by the civilian State Water Control Board and then EPA, measures must be taken to reduce pollution levels in the stream. These measures, 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 recent *Guidance Manual for Total Maximum Daily Load Implementation Plans,* published in July 2003 and available upon request from the VADEQ and VADCR TMDL project staff or at http://www.deq.state.va.us/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, Virginia will be well on the way to restoring impaired waters and enhancing the value of this important resource. Additionally, development of an approved implementation plan will improve a locality's chances for obtaining financial and technical assistance during implementation.

10.1 Staged Implementation

In general, Virginia intends for the required 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 to control bacteria and minimize streambank erosion 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. Reduced trampling and soil shear on streambanks by livestock hooves has been shown to reduce bank erosion.

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 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 I scenarios are targeted at controllable, anthropogenic bacteria and sediment sources.

Stage I scenarios - Bacteria

The goal of the Stage I scenarios is to reduce the bacteria loadings from controllable sources, excluding wildlife. The Stage I scenarios were generated with the same model setup as was used for the TMDL allocation scenarios.

As presented in Chapter 5, scenarios were devised assuming reductions of 50% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, 90% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. With this scenario, the model predicted 10% violations of the instantaneous water quality standard and 2% violations of the geometric mean standard.

The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the main stem of Peak Creek to less than 10%. Table 10.1 contains a set of reductions in land-based and direct loads that are projected to achieve this goal, along with a projected percent of violation occurrence. The Stage I allocation requires a 100% reduction in loads from sewer overflows and uncontrolled residential discharges (straight pipes), a 90% reduction in direct in-stream loads from livestock, a 50% reduction in land-based loads from urban and agricultural sources, and a 0% reduction in all wildlife loads (Table 10.1, scenario 3).

Table 10.1 Reduction percentages for the Stage I implementation.

Scenario Number	Percent Reduction in Loading from Existing Condition						Percent Violations	
	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	21.7	17.5
2	0	0	0	0	0	100	20.0	17.4
3[1]	0	0	90	50	50	100	1.67	9.53
4	0	0	100	99	99	100	0.0	1.04
5	0	99	100	99	99	100	0.0	0.11
6[2]	0	65	100	99.5	99.5	100	0.0	0.0

[1] Stage I implementation scenario.

[2] Final TMDL allocation.

Table 10.2 details the load reductions required for meeting the Stage I Implementation.

Table 10.2 Nonpoint source allocations in the Peak Creek impairment for Stage I implementation.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Residential	4.64E+14	1.85E+14	60
Commercial	7.43E+12	2.97E+12	60
Barren	6.93E+12	2.77E+12	60
Cropland	5.02E+15	2.01E+15	60
Livestock Access	2.36E+14	9.43E+13	60
Pasture	3.20E+15	1.28E+15	60
Forest	5.70E+13	5.70E+13	0
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	3.36E+15	0.00E+00	100
Wildlife	1.46E+13	1.46E+13	0
Straight Pipes and Sewer Overflows	2.99E+13	0.00E+00	100

Stage I Scenarios – Cu and Zn

The Honeywell Corporation is presently working with the EPA under a unilateral order to remediate the lead contaminated soils of the Allied Signal site. Based on the TMDL analysis, Virginia believes that metals migrating from this site are one of the primary reasons for the benthic impairment on Peak Creek. If the work associated with the removal order adequately prevents further migration of metals, specifically copper (Cu) and zinc (Zn), to the stream, and the benthic community remains impaired, the Commonwealth may need to investigate other sources and/or pathways of metals and other contaminants to Peak Creek. If the site is no longer a source of those pollutants to the stream, another significant source of contamination is likely.

The Honeywell Corporation has submitted a workplan for the corrective actions planned for the site, and the workplan is currently under review. The EPA has asked VADEQ for comments on the workplan, and VADEQ has provided comments which include the following:

- excavated contaminated soils may be considered newly generated wastes that should be characterized and managed at an off-site permitted solid or hazardous waste landfill as appropriate;
- a new cap that meets modern design criteria for non-hazardous industrial landfills should be constructed over the area that was previously capped and where that cap has since eroded;
- information on how storm water will be managed on and around the cap should be provided; and
- information should be provided on how post-closure maintenance of the cap will be addressed.

10.2 Link to Ongoing Restoration Efforts

Implementation of this TMDL will be integrated into on-going water quality improvement efforts aimed at restoring water quality in Peak Creek and the New River basin. Several BMPs known to be effective in controlling bacteria have also been identified for implementation as part of this effort. For example, management of on-site waste management systems, management of livestock and manure, and pet waste management are among the components of a nonpoint source implementation strategy.

10.3 Reasonable Assurance for Implementation

10.3.1 Follow-up Monitoring

VADEQ will continue monitoring the Peak Creek watershed in accordance with its ambient watershed monitoring program to evaluate reductions in fecal bacteria counts and the effectiveness of TMDL implementation in attainment of water quality standards.

Monitoring station(s) on Peak Creek will continue to be monitored. Watershed monitoring stations are designed to provide complete, census-based coverage of every watershed in Virginia. Two of the major data users in the Commonwealth (VADEQ and VADCR) have indicated that this is an important function for ambient water quality monitoring.

Watershed stations are located at the mouth and within the watershed, based on a census siting scheme. The number of stations in the watershed is determined by the NPS priority ranking, thus focusing our resources on known problem areas. Watersheds are monitored on a rotating basis such that, in the 6-year assessment cycle, all 493 watersheds are monitored. These stations will be sampled at a frequency of once every other month for a two-year period on a 6-year rotating basin basis.

10.3.2 Regulatory Framework

While section 303(d) of the Clean Water Act and current EPA 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. 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. EPA 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.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the implementation plan, which will also be supported by the regional and local offices of VADEQ, VADCR, and other cooperating agencies.

Once developed, VADEQ will take TMDL implementation plans to the State Water Control Board (SWCB) for approval as the plan for implementing the pollutant allocations and reductions contained in the TMDLs. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP) in accordance with the CWA's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA 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.

10.3.3 Stormwater Permits

It is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs. One of these regulations is the VPDES Permit Regulation (9 VAC 25-31-10 et seq.). Section 9 VAC 25-31-120 describes the requirements for stormwater discharges. Also, federal regulations state in 40 CFR §122.44(k) that National Pollutant Discharge Elimination System (NPDES) permit conditions may consist of *"Best management practices to control or abate the discharge of pollutants when:… (2) Numeric effluent limitations are infeasible…"*.

Currently, there are no MS4 permits in the Peak Creek watershed held by the Town of Pulaski (VAR015370) or the Virginia Department of Transportation.

For MS4/VPDES general permits, VADEQ expects revisions to the permittee's Stormwater Pollution Prevention Plans to specifically address the TMDL pollutants of concern. VADEQ anticipates that BMP effectiveness would be determined through ambient in-stream monitoring. This is in accordance with recent EPA guidance (EPA Memorandum on TMDLs and Stormwater Permits, dated November 22, 2002). If future monitoring indicates no improvement in stream water quality, the permit could require the MS4 to expand or better tailor its BMPs to achieve the TMDL reductions. However, only failing to implement the required BMPs would be considered a violation of the permit. VADEQ acknowledges that it may not be possible to meet the existing water quality standard because of the wildlife issue associated with a number of bacteria TMDLs (see section 10.3.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from a water quality standards change on Peak Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Storm Water Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.deq.state.va.us/water/bmps.html.

10.3.4 Implementation Funding Sources

One potential source of funding for TMDL implementation is Section 319 of the Clean Water Act. Section 319 funding is a major source of funds for Virginia's Nonpoint Source Management Program. Other funding sources for implementation include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, the Virginia State Revolving Loan Program, and the Virginia Water Quality Improvement Fund. The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

10.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that, even after removal of all bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for Peak Creek, these streams may not be able to attain standards without some reduction in wildlife load. **Virginia and EPA are not proposing the elimination of wildlife to allow for the attainment of water quality standards.**

Although previous TMDLs for the Commonwealth have not addressed wildlife reductions in first stage goals, some localities have already introduced wildlife management practices. While managing overpopulations of wildlife remains as an option to local stakeholders, the reduction of wildlife or changing a natural background condition is not the intended goal of a TMDL.

To address this issue, Virginia proposed (during its recent triennial water quality standards review) a new "secondary contact" category for protecting the recreational use in state waters. On March 25, 2003, the Virginia State Water Control Board adopted criteria for "secondary contact recreation" which means "a water-based form of recreation, the practice of which has a low probability for total body immersion or ingestion of waters (examples include but are not limited to wading, boating and fishing)". These new criteria were approved by EPA and became effective in February 2004. Additional information can be found at http://www.deq.state.va.us/wqs/rule.html.

In order for the new criteria to apply to a specific stream segment, the primary contact recreational use must be removed. To remove a designated use, the state must demonstrate: 1) that the use is not an existing use, 2) that downstream uses are protected, and 3) that the source of bacterial contamination is natural and uncontrollable by effluent limitations and by implementing cost-effective and reasonable best management practices for nonpoint source control (9 VAC 25-260-10). This, and other, information is collected through a special study called a Use Attainability Analysis (UAA). All site-specific criteria or designated use changes must be adopted as amendments to the water quality standards regulations. Watershed stakeholders and EPA will be able to provide comment during this process. Additional information can be obtained at http://www.deq.state.va.us/wqs/WQS03AUG.pdf.

Based on the above, EPA and Virginia have developed a process to address the wildlife issue. First in this process is the development of a Stage I scenario such as those presented previously in this chapter. The pollutant reductions in the Stage I 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 I scenario, all controllable sources would be reduced to the maximum extent practicable using the iterative approach described in section 10.1 above. VADEQ will reassess water quality in the stream during and subsequent to the implementation of the Stage I 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 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.

11. PUBLIC PARTICIPATION

The development of the Peak Creek TMDL greatly benefited from public involvement. Table 11.1 details the public participation throughout the project. The government kickoff meeting for the study of the Back Creek, Crab Creek, and Peak Creek watersheds took place on May 29, 2003 at the Dublin Library in Dublin, Virginia with 24 people (4 consultants, 14 government agents, 2 industry representatives, 2 from citizens' groups, and 2 farmers) attending. The kickoff meeting was publicized through direct mailing to local government agencies and a notice in the *Virginia Register*.

Stakeholders (12 area farmers), VADEQ and MapTech personnel met at the New River Roundtable Agricultural subcommittee on August 9, 2003.

The first public meeting was held at the Pulaski Town Hall in Pulaski, Virginia on September 30, 2003 to discuss the process for TMDL development; 13 people (5 farmers/general public, 5 government agents and 3 consultants) attended. The meeting was published in the *Virginia Register* and copies of the presentation materials were available for public distribution. There was a 30 day-public comment period and no written comments were received.

A "Field Day" was offered on November 18, 2003 to all stakeholders in the Back Creek, Crab Creek, and Peak Creek watershed areas. There were 9 participants, including 5 citizens from the Back Creek area, 3 government agents, and 1 MapTech representative. Participants were shown examples of aquatic life from a nearby reference stream, then looked at 2 sites on Back Creek to contrast the differences and discuss potential implementation strategies. Field Day was announced at the 1st public meeting. Those that signed up for the field day were contacted by phone and email.

The final public meeting for the Back Creek, Crab Creek, and Peak Creek watersheds was held on March 17, 2004 at the New River Valley Competitiveness Center in Radford, Virginia. The meeting was publicized through 400 mailings to residents, in the *Virginia Register,* and on the VADEQ and MyChristiansburg.com websites. There were 24 attendees, including, 10 government agents, 10 MapTech representatives, and 4 from the general public. There was a 30 day-public comment period and no written comments were received.

Table 11.1 Public participation during TMDL development for the Peak Creek watershed.

Date	Location	Attendance[1]	Type	Format
5/29/03	Dublin Library 300 Giles Avenue Dublin, VA	24	Kickoff Meeting[2]	Open to public at large
9/30/03	Pulaski Town Hall 42 First Street, NW Pulaski, VA	13	1st public	Open to public at large
11/18/03	Back Creek	9	Field Day[2]	Open to public at large
3/17/04	New River Valley Competitiveness Center 6580 Valley Center Drive Radford, VA	24	Final public[2]	Open to public at large

[1] The number of attendants is estimated from sign up sheets provided at each meeting. These numbers are known to underestimate the actual attendance.

[2] Combined meetings for Back Creek, Crab Creek, and Peak Creek.

Public participation during the implementation plan development process will include the formation of stakeholders' committee and open public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the expressed purpose of formulating the TMDL implementation plan. The major stakeholders were identified during the development of this TMDL. The committee will consist of, but not be limited to, representatives from VADEQ, VADCR, VDH, local agricultural community, local urban community, and local governments. This committee will have responsibility for identifying corrective actions that are founded in practicality, establish a time line to insure expeditious implementation, and set measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from EPA (1998).

303(d). A section of the Clean Water Act of 1972 requiring states to identify and list water bodies that do not meet the states' water quality standards.

Allocations. *That portion of a receiving water's loading capacity attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources. (A wasteload allocation [WLA] is that portion of the loading capacity allocated to an existing or future point source, and a load allocation [LA] is that portion allocated to an existing or future nonpoint source or to natural background levels. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting loading.)*

Ambient water quality. *Natural concentration of water quality constituents prior to mixing of either point or nonpoint source load of contaminants. Reference ambient concentration is used to indicate the concentration of a chemical that will not cause adverse impact on human health.*

Anthropogenic. *Pertains to the [environmental] influence of human activities.*

Antidegradation Policies. *Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity. *The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

Background levels. *Levels representing the chemical, physical, and biological conditions that would result from natural geomorphological processes such as weathering or dissolution.*

Bacteria. *Single-celled microorganisms. Bacteria of the coliform group are considered the primary indicators of fecal contamination and are often used to assess water quality.*

Bacterial decomposition. *Breakdown by oxidation, or decay, of organic matter by heterotrophic bacteria. Bacteria use the organic carbon in organic matter as the energy source for cell synthesis.*

Bacterial source tracking (BST). A collection of scientific methods used to track sources of fecal contamination.

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

Best management practices (BMPs). *Methods, measures, or practices determined to be reasonable and cost-effective means for a landowner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.*

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota. (2)

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

Calibration. *The process of adjusting model parameters within physically defensible ranges until the resulting predictions give a best possible good fit to observed data.*

Causal analysis. A process in which data and other information are organized and evaluated using quantitative and logical techniques to determine the likely cause of an observed condition. (2)

Causal association. A correlation or other association between measures or observations of two entities or processes which occurs because of an underlying causal relationship. (2)

Causal mechanism. The process by which a cause induces an effect. (2)

Causal relationship. The relationship between a cause and its effect. (2)

Cause.
1. That which produces an effect (a general definition).
2. A stressor or set of stressors that occur at an intensity, duration and frequency of exposure that results in a change in the ecological condition (a SI-specific definition). (2)

Channel. *A natural stream that conveys water; a ditch or channel excavated for the flow of water.*

Chloride. *An atom of chlorine in solution; an ion bearing a single negative charge.*

Clean Water Act (CWA). *The Clean Water Act (formerly referred to as the Federal Water Pollution Control Act or Federal Water Pollution Control Act Amendments of 1972), Public Law 92-500, as amended by Public Law 96-483 and Public Law 97-117, 33 U.S.C. 1251 et seq. The Clean Water Act (CWA) contains a number of provisions to restore and maintain the quality of the nation's water resources. One of these provisions is Section 303(d), which establishes the TMDL program.*

Coefficient of determination. Represents the proportion of the total sample variability around y that is explained by the linear relationship between *y* and *x*. (In simple linear regression, it may also be computed as the square of the coefficient of correlation *r.)* (3)

Concentration. *Amount of a substance or material in a given unit volume of solution; usually measured in milligrams per liter (mg/L) or parts per million (ppm).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

Confluence. The point at which a river and its tributary flow together.

Contamination. *The act of polluting or making impure; any indication of chemical, sediment, or biological impurities.*

Continuous discharge. *A discharge that occurs without interruption throughout the operating hours of a facility, except for infrequent shutdowns for maintenance, process changes, or other similar activities.*

Conventional pollutants. *As specified under the Clean Water Act, conventional contaminants include suspended solids, coliform bacteria, high biochemical oxygen demand, pH, and oil and grease.*

Conveyance. A measure of the of the water carrying capacity of a channel section. It is directly proportional to the discharge in the channel section.

Cost-share program. *A program that allocates project funds to pay a percentage of the cost of constructing or implementing a best management practice. The remainder of the costs is paid by the producer(s).*

Cross-sectional area. *Wet area of a waterbody normal to the longitudinal component of the flow.*

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

Decay. *The gradual decrease in the amount of a given substance in a given system due to various sink processes including chemical and biological transformation, dissipation to other environmental media, or deposition into storage areas.*

Decomposition. *Metabolic breakdown of organic materials; the formation of by-products of decomposition releases energy and simple organic and inorganic compounds. See also Respiration.*

Designated uses. *Those uses specified in water quality standards for each waterbody or segment whether or not they are being attained.*

Deterministic model. *A model that does not include built-in variability: same input will always result in the same output.*

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

Direct runoff. *Water that flows over the ground surface or through the ground directly into streams, rivers, and lakes.*

Discharge. *Flow of surface water in a stream or canal, or the outflow of groundwater from a flowing artesian well, ditch, or spring. Can also apply to discharge of liquid effluent from a facility or to chemical emissions into the air through designated venting mechanisms.*

Discharge Monitoring Report (DMR). *Report of effluent characteristics submitted by a municipal or industrial facility that has been granted an NPDES discharge permit.*

Discharge permits (under NPDES). *A permit issued by the U.S. EPA or a state regulatory agency that sets specific limits on the type and amount of pollutants that a municipality or industry can discharge to a receiving water; it also includes a compliance schedule for achieving those limits. The permit process was established* *under the National Pollutant Discharge Elimination System, under provisions of the Federal Clean Water Act.*

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

Diurnal. *Actions or processes that have a period or a cycle of approximately one tidal-day or are completed within a 24-hour period and that recur every 24 hours. Also, the occurrence of an activity/process during the day rather than the night.*

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

Domestic wastewater. *Also called sanitary wastewater, consists of wastewater discharged from residences and from commercial, institutional, and similar facilities.*

Drainage basin. *A part of a land area enclosed by a topographic divide from which direct surface runoff from precipitation normally drains by gravity into a receiving water. Also referred to as a watershed, river basin, or hydrologic unit.*

Dynamic model. *A mathematical formulation describing and simulating the physical behavior of a system or a process and its temporal variability.*

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

Effluent. *Municipal sewage or industrial liquid waste (untreated, partially treated, or completely treated) that flows out of a treatment plant, septic system, pipe, etc.*

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

Empirical model. *Use of statistical techniques to discern patterns or relationships underlying observed or measured data for large sample sets. Does not account for physical dynamics of waterbodies.*

Endpoint. *An endpoint (or indicator/target) is a characteristic of an ecosystem that may be affected by exposure to a stressor. Assessment endpoints and measurement endpoints are two distinct types of endpoints commonly used by resource managers. An assessment endpoint is the formal expression of a valued environmental characteristic and should have societal relevance (an indicator). A measurement endpoint is the expression of an observed or measured response to a stress or disturbance. It is a measurable environmental characteristic that is related to the valued environmental characteristic chosen as the assessment endpoint. The numeric criteria that are part of traditional water quality standards are good examples of measurement endpoints (targets).*

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undersirable for recreation, and may not support normal fish populations.

Evapotranspiration. The combined effects of evaporation and transpiration on the water balance. Evaporation is water loss into the atmosphere from soil and water surfaces. Transpiration is water loss into the atmosphere as part of the life cycle of plants.

Existing use. *Use actually attained in the waterbody on or after November 28, 1975, whether or not it is included in the water quality standards (40 CFR 131.3).*

Fate of pollutants. *Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

Fecal Coliform. Indicator organisms (organisms indicating presence of pathogens) associated with the digestive tract.

Feedlot. *A confined area for the controlled feeding of animals. Tends to concentrate large amounts of animal waste that cannot be absorbed by the soil and, hence, may be carried to nearby streams or lakes by rainfall runoff.*

First-order kinetics. *The type of relationship describing a dynamic reaction in which the rate of transformation of a pollutant is proportional to the amount of that pollutant in the environmental system.*

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

Geometric mean. A measure of the central tendency of a data set that minimizes the effects of extreme values.

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

Ground water. *The supply of fresh water found beneath the earths surface, usually in aquifers, which supply wells and springs. Because ground water is a major source of drinking water, there is growing concern over contamination from leaching agricultural or industrial pollutants and leaking underground storage tanks.*

HSPF. Hydrological Simulation Program – Fortran. A computer simulation tool used to mathematically model nonpoint source pollution sources and movement of pollutants in a watershed.

Hydrograph. *A graph showing variation of stage (depth) or discharge in a stream over a period of time.*

Hydrologic cycle. *The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

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.*

Hyetograph. *Graph of rainfall rate versus time during a storm event.*

IMPLND. An impervious land segment in HSPF. It is used to model land covered by impervious materials, such as pavement.

Indicator. *A measurable quantity that can be used to evaluate the relationship between pollutant sources and their impact on water quality.*

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause. (2)

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor. (2)

Infiltration capacity. *The capacity of a soil to allow water to infiltrate into or through it during a storm.*

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

Interflow. Runoff that travels just below the surface of the soil.

Isolate. An inbreeding biological population that is isolated from similar populations by physical or other means.

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

Loading, Load, Loading rate. *The total amount of material (pollutants) entering the system from one or multiple sources; measured as a rate in weight per unit time.*

Load allocation (LA). *The portion of a receiving waters loading capacity attributed either to one of its existing or future nonpoint sources of pollution or to natural background sources. Load allocations are best estimates of the loading, which can range from reasonably accurate estimates to gross allotments, depending on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished (40 CFR 130.2(g)).*

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

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 (CWA Section 303(d)(1)(C)). The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models) and approved by EPA either individually or in state/EPA agreements. If the MOS needs to be larger than that which is allowed through the* *conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).*

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

Mathematical model. *A system of mathematical expressions that describe the spatial and temporal distribution of water quality constituents resulting from fluid transport and the one or more individual processes and interactions within some prototype aquatic ecosystem. A mathematical water quality model is used as the basis for waste load allocation evaluations.*

Mean. The sum of the values in a data set divided by the number of values in the data set.

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

MGD. Million gallons per day. A unit of water flow, whether discharge or withdraw.

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

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

Monitoring. *Periodic or continuous surveillance or testing to determine the level of compliance with statutory requirements and/or pollutant levels in various media or in humans, plants, and animals.*

Mood's Median Test. *A nonparametric (distribution-free) test used to test the equality of medians from two or more populations.*

Multivariate Regression. A functional relationship between 1 dependent variable and multiple independent variables that are often empirically determined from data and are used especially to predict values of one variable when given values of the others.

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

National Pollutant Discharge Elimination System (NPDES). *The national program for issuing, modifying, revoking and re-issuing, terminating, monitoring, and enforcing permits, and imposing and enforcing pretreatment requirements, under sections 307, 402, 318, and 405 of the Clean Water Act.*

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Nonpoint source. *Pollution that 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.*

Numeric targets. *A measurable value determined for the pollutant of concern, which, if achieved, is expected to result in the attainment of water quality standards in the listed waterbody.*

Numerical model. *Model that approximates a solution of governing partial differential equations, which describe a natural process. The approximation uses a numerical discretization of the space and time components of the system or process.*

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

Parameter. A numerical descriptive measure of a population. Since it is based on the observations of the population, its value is almost always unknown.

Peak runoff. *The highest value of the stage or discharge attained by a flood or storm event; also referred to as flood peak or peak discharge.*

PERLND. A pervious land segment in HSPF. It is used to model a particular landuse segment within a subwatershed (e.g. pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by EPA or an approved federal, state, or local agency to implement the requirements of an environmental regulation; e.g., a permit to operate a wastewater treatment plant or to operate a facility that may generate harmful emissions.*

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.*

Phased/staged approach. *Under the phased approach to TMDL development, load allocations and wasteload allocations are calculated using the best available data and information recognizing the need for additional monitoring data to accurately characterize sources and loadings. The phased approach is typically employed when nonpoint sources dominate. It provides for the implementation of load reduction strategies while collecting additional data.*

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

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.*

Pollutant. *Dredged spoil, solid waste, incinerator residue, sewage, garbage, sewage sludge, munitions, chemical wastes, biological materials, radioactive materials, heat, wrecked or discarded equipment, rock, sand, cellar dirt, and industrial, municipal, and agricultural waste discharged into water. (CWA section 502(6)).*

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.*

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

Public comment period. *The time allowed for the public to express its views and concerns regarding action by EPA or states (e.g., a Federal Register notice of a proposed rule-making, a public notice of a draft permit, or a Notice of Intent to Deny).*

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

Quartile. The 25th, 50th, and 75th percentiles of a data set. A percentile (p) of a data set ordered by magnitude is the value that has at most p% of the measurements in the data set below it, and (100-p)% above it. The 50th quartile is also known as the median. The 25th and 75th quartiles are referred to as the lower and upper quartiles, respectively.

Raw sewage. *Untreated municipal sewage.*

Rapid Bioassessment Protocol (RBP). A suite of measurements based on a quantitative assessment benthic macroinvertebrates and a qualititative assessment of their habitat. RBP scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

Receiving waters. *Creeks, streams, rivers, lakes, estuaries, ground water formations, or other bodies of water into which surface water and/or treated or untreated waste are discharged, either naturally or in man-made systems.*

Reference Conditions. The chemical, physical, or biological quality or condition exhibited at either a single site or an aggregation of sites that are representative of non-impaired conditions for a watershed of a certain size, landuse distribution, and other related characteristics. Reference conditions are used to describe reference sites.

Reserve capacity. *Pollutant loading rate set aside in determining stream waste load allocation, accounting for uncertainty and future growth.*

Residence time. *Length of time that a pollutant remains within a section of a stream or river. The residence time is determined by the streamflow and the volume of the river reach or the average stream velocity and the length of the river reach.*

Restoration. *Return of an ecosystem to a close approximation of its presumed condition prior to disturbance.*

Riparian areas. *Areas bordering streams, lakes, rivers, and other watercourses. These areas have high water tables and support plants that require saturated soils during all or part of the year. Riparian areas include both wetland and upland zones.*

Riparian zone. *The border or banks of a stream. Although this term is sometimes used interchangeably with floodplain, the riparian zone is generally regarded as relatively narrow compared to a floodplain. The duration of flooding is generally much shorter, and the timing less predictable, in a riparian zone than in a river floodplain.*

Roughness coefficient. *A factor in velocity and discharge formulas representing the effects of channel roughness on energy losses in flowing water. Manning's "n" is a commonly used roughness coefficient.*

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

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles.

Sediment. In the context of water quality, soil particles, sand, and minerals dislodged from the land and deposited into aquate systems as a result of erosion.

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

Sewer. *A channel or conduit that carries wastewater and storm water runoff from the source to a treatment plant or receiving stream. Sanitary sewers carry household, industrial, and commercial waste. Storm sewers carry runoff from rain or snow. Combined sewers handle both.*

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.*

Slope. *The degree of inclination to the horizontal. Usually expressed as a ratio, such as 1:25 or 1 on 25, indicating one unit vertical rise in 25 units of horizontal distance, or in a decimal fraction (0.04), degrees (2 degrees 18 minutes), or percent (4 percent).*

Source. An origination point, area, or entity that releases or emits a stressor. A source can alter the normal intensity, frequency, or duration of a natural attribute, whereby the attribute then becomes a stressor. (2)

Spatial segmentation. *A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

Staged Implementation. A process that allows for the evaluation of the adequacy of the TMDL in achieving the water quality standard. As stream monitoring continues to occur, staged or phased implementation allows for water quality improvements to be recorded as they are being achieved. It also provides a measure of quality control, and it helps to ensure that the most cost-effective practices are implemented first.

Stakeholder. Any person with a vested interest in the TMDL development.

Standard. In reference to water quality (e.g. 200 cfu/100 ml geometric mean limit).

Standard deviation. A measure of the variability of a data set. The positive square root of the variance of a set of measurements.

Standard error. The standard deviation of a distribution of a sample statistic, esp. when the mean is used as the statistic.

Statistical significance. An indication that the differences being observed are not due to random error. The p-value indicates the probability that the differences are due to random error (i.e. a low p-value indicates statistical significance).

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

Stepwise regression. All possible one-variable models of the form $E(y) = B_{()} + B_1 x_1$ are fit and the "best" x_1 is selected based on the t-test for B_1. Next, two-variable models of the form $E(y) = B_{()} + B_1 x_1 + B_2 x_i$ are fit (where x_i is the variable selected in the first step): the "second best" x_i is selected based on the test for B_2. The process continues in this fashion until no more "important" x's can be added to the model. (3)

Storm runoff. *Storm water runoff, snowmelt runoff, and surface runoff and drainage; rainfall that does not evaporate or infiltrate the ground because of impervious land surfaces or a soil infiltration rate lower than rainfall intensity, but instead flows onto adjacent land or into waterbodies or is routed into a drain or sewer system.*

Streamflow. *Discharge that occurs in a natural channel. Although the term "discharge" can be applied to the flow of a canal, the word "streamflow" uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than "runoff" since streamflow may be applied to discharge whether or not it is affected by diversion or regulation.*

Stream Reach. A straight portion of a stream.

Stream restoration. *Various techniques used to replicate the hydrological, morphological, and ecological features that have been lost in a stream because of urbanization, farming, or other disturbance.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. (2)

Surface area. *The area of the surface of a waterbody; best measured by planimetry or the use of a geographic information system.*

Surface runoff. *Precipitation, snowmelt, or irrigation water in excess of what can infiltrate the soil surface and be stored in small surface depressions; a major transporter of nonpoint source pollutants.*

Surface water. *All water naturally open to the atmosphere (rivers, lakes, reservoirs, ponds, streams, impoundments, seas, estuaries, etc.) and all springs, wells, or other collectors directly influenced by surface water.*

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

Timestep. An increment of time in modeling terms. The smallest unit of time used in a mathematical simulation model (e.g. 15-minutes, 1-hour, 1-day).

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

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

TMDL Implementation Plan. A document required by Virginia statute detailing the suite of pollution control measures needed to renediate an impaired stream segment. The plans are also required to include a schedule of actions, costs, and monitoring. Once implemented, the plan should result in the previously impaired water meeting water quality standards and achieving a "fully supporting" use support status.

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

TRC. Total Residual Chlorine. A measure of the effectiveness of chlorinating treated waste water effluent.

Tributary. A lower order-stream compared to a receiving waterbody. "Tributary to" indicates the largest stream into which the reported stream or tributary flows.

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

Validation (of a model). *Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical processes under investigation. A validated model will have also been tested to ascertain whether it accurately and correctly solves the equations being used to define the system simulation.*

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

Wasteload allocation (WLA). *The portion of a receiving waters' 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 (40 CFR 130.2(h)).*

Wastewater. *Usually refers to effluent from a sewage treatment plant. See also* **Domestic wastewater***.*

Wastewater treatment. *Chemical, biological, and mechanical procedures applied to an industrial or municipal discharge or to any other sources of contaminated water to remove, reduce, or neutralize contaminants.*

Water quality. *The biological, chemical, and physical conditions of a waterbody. It is a measure of a waterbody's ability to support beneficial uses.*

Water quality-based effluent limitations (WQBEL). *Effluent limitations applied to dischargers when technology-based limitations alone would cause violations of water quality standards. Usually WQBELs are applied to discharges into small streams.*

Water quality-based permit. *A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria. *Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by EPA or states for various pollutants of concern to protect human health and aquatic life. Narrative criteria are statements that describe the desired water quality goal. Criteria are based on specific levels of pollutants that would make the water harmful if used for drinking, swimming, farming, fish production, or industrial processes.*

Water quality standard. *Law or regulation that consists of the beneficial designated use or uses of a waterbody, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular waterbody, and an antidegradation 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.*

WQIA. Water Quality Improvement Act.

APPENDIX A

FREQUENCY ANALYSIS OF WATER QUALITY SAMPLING DATA

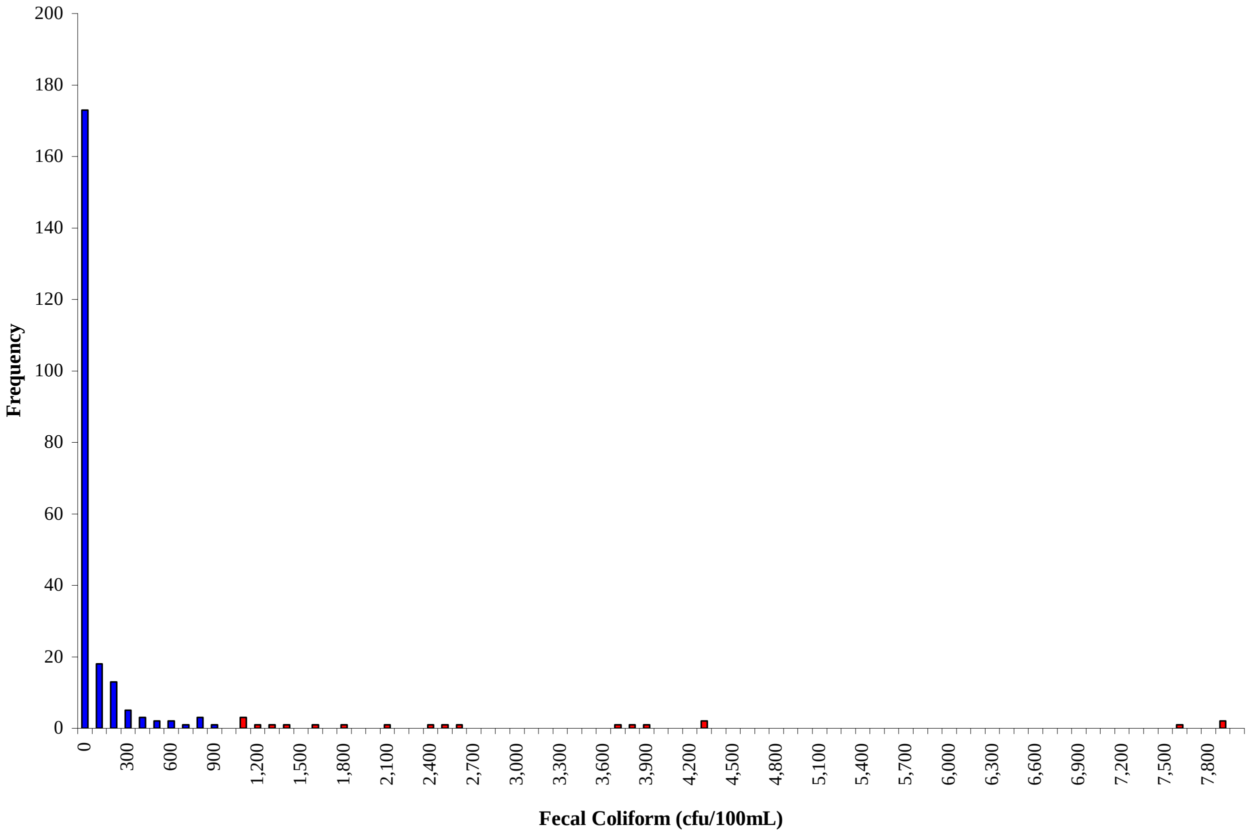

Figure A.1 Frequency analysis of fecal coliform concentrations at station 9-PKC004.65 in the Peak Creek impairment for period January 1980 to August 2003.

* Red indicates a value, which violates the listing standard of 1,000 cfu/100ml.

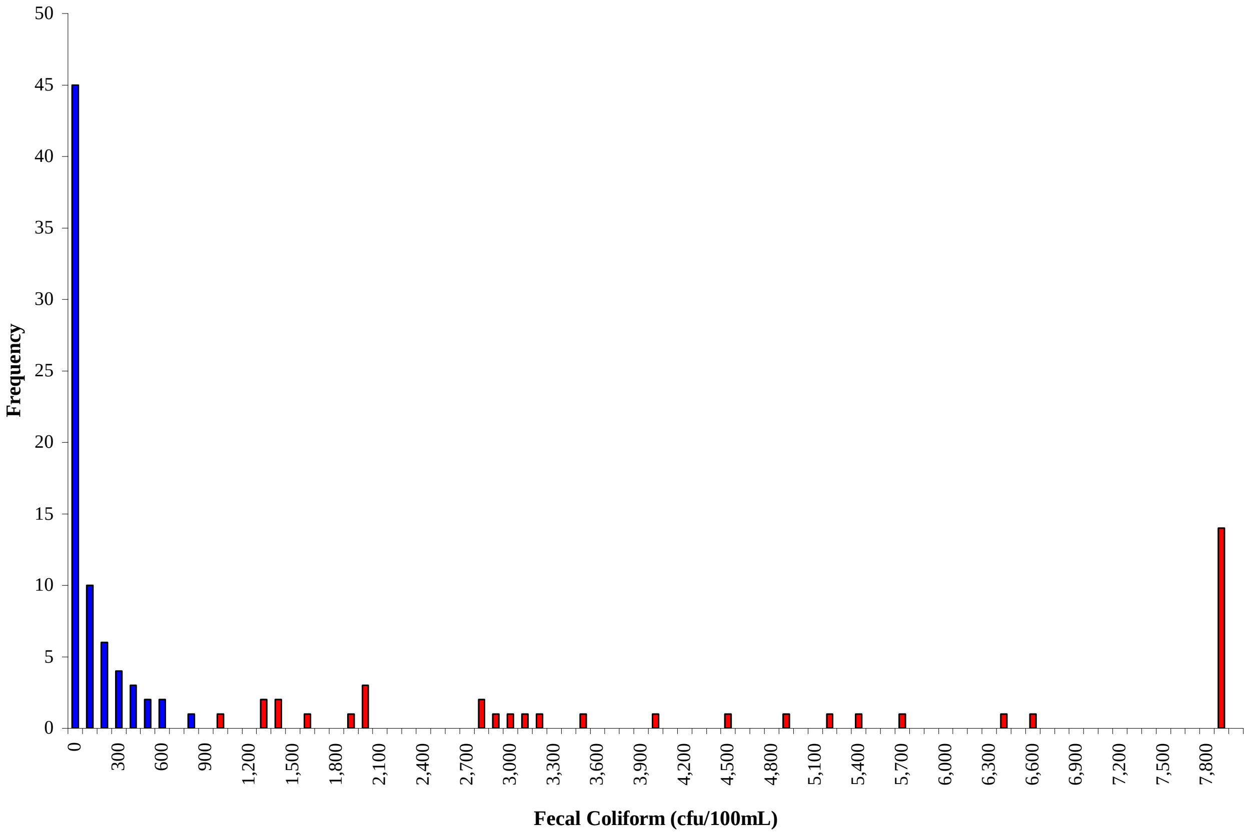

Figure A.2 **Frequency analysis of fecal coliform concentrations at station 9-PKC007.82 in the Peak Creek impairment for period January 1980 to May 1994.**

* Red indicates a value, which violates the listing standard of 1,000 cfu/100ml.

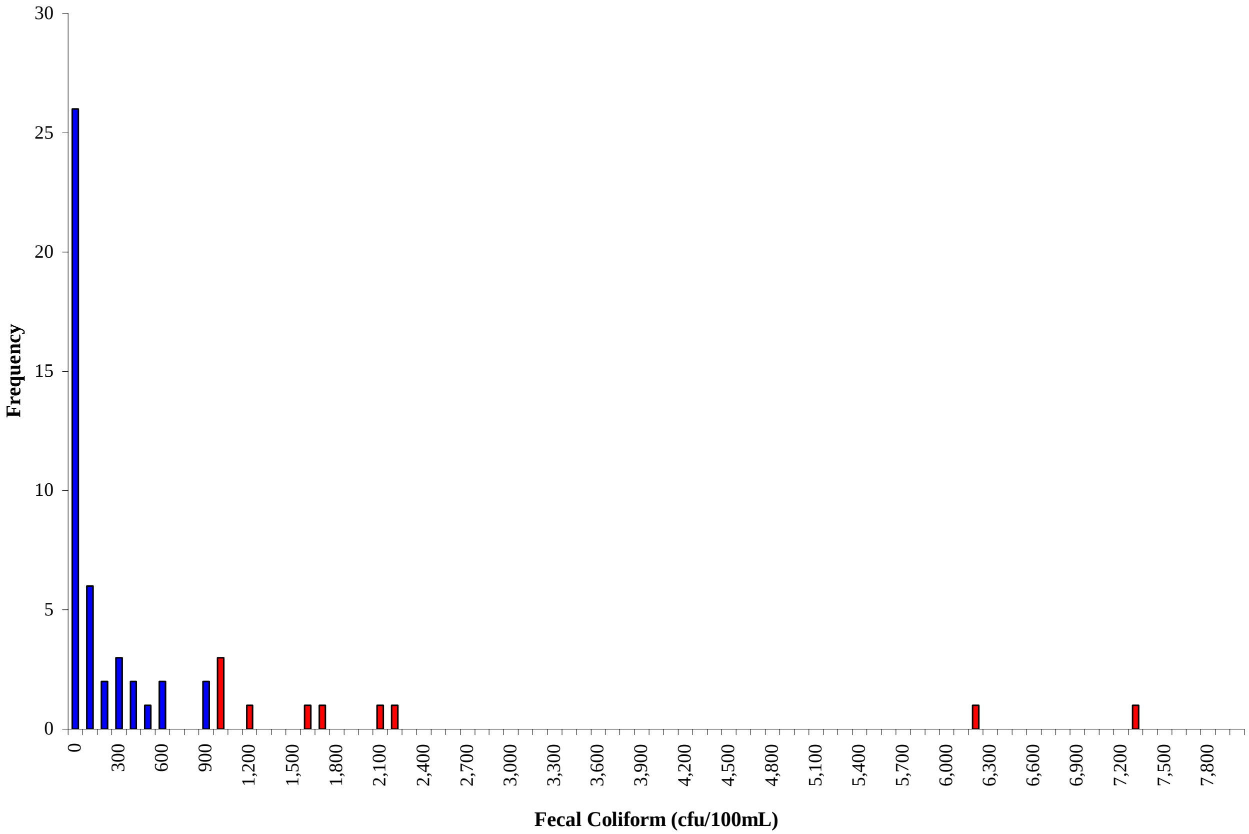

Figure A.3 **Frequency analysis of fecal coliform concentrations at station 9-PKC009.29 in the Peak Creek impairment for period September 1988 to October 2003.**

* Red indicates a value, which violates the listing standard of 1,000 cfu/100ml.

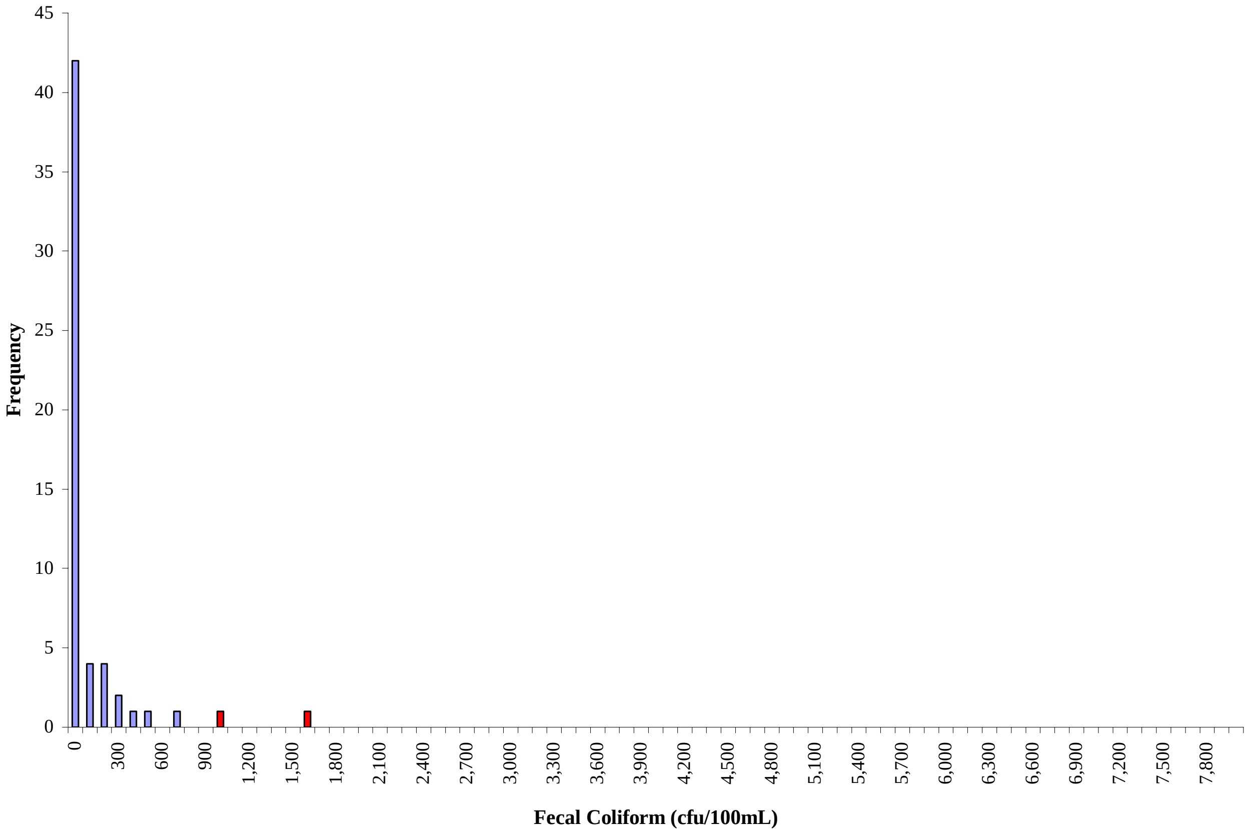

Figure A.4 **Frequency analysis of fecal coliform concentrations at station 9-PKC011.11 in the Peak Creek impairment for period April 1980 to October 2003.**

* Red indicates a value, which violates the listing standard of 1,000 cfu/100ml.

Figure A.5 Frequency analysis of fecal coliform concentrations at station 9-PKC016.91 in the Peak Creek impairment for period April 2001 to October 2002.

* Red indicates a value, which violates the listing standard of 1,000 cfu/100ml.

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions (2003) of land applied fecal coliform load for Peak Creek impairment (Subsheds 10-18).

	Barren (cfu/ac*day)	Commercial (cfu/ac*day)	Forest (cfu/ac*day)	Pasture (cfu/ac*day)
January	1.30E+09	2.44E+08	6.52E+08	6.04E+09
February	1.30E+09	2.44E+08	6.52E+08	6.53E+09
March	1.30E+09	2.44E+08	6.52E+08	6.57E+09
April	1.30E+09	2.44E+08	6.52E+08	6.71E+09
May	1.30E+09	2.44E+08	6.52E+08	2.19E+12
June	1.30E+09	2.44E+08	6.52E+08	9.54E+09
July	1.30E+09	2.44E+08	6.52E+08	9.63E+09
August	1.30E+09	2.44E+08	6.52E+08	9.63E+09
September	1.30E+09	2.44E+08	6.52E+08	7.01E+09
October	1.30E+09	2.44E+08	6.52E+08	7.08E+09
November	1.30E+09	2.44E+08	6.52E+08	6.52E+09
December	1.30E+09	2.44E+08	6.52E+08	6.34E+09

Table B.1 Current conditions (2003) of land applied fecal coliform load for Peak Creek impairment (Subsheds 10-18) (continued).

	Livestock Access (cfu/ac*day)	Residential (cfu/ac*day)	Row Crops (cfu/ac*day)	Water (cfu/ac*day)
January	6.11E+09	1.29E+10	1.77E+10	0.00E+00
February	6.33E+09	1.27E+10	2.06E+10	0.00E+00
March	8.03E+09	1.23E+10	1.93E+11	0.00E+00
April	9.90E+09	1.20E+10	1.93E+11	0.00E+00
May	9.90E+09	1.18E+10	1.93E+11	0.00E+00
June	1.16E+10	1.16E+10	7.46E+08	0.00E+00
July	1.16E+10	1.11E+10	7.46E+08	0.00E+00
August	1.16E+10	1.11E+10	7.46E+08	0.00E+00
September	9.90E+09	1.11E+10	5.74E+10	0.00E+00
October	8.03E+09	1.09E+10	1.93E+11	0.00E+00
November	7.73E+09	1.11E+10	1.93E+11	0.00E+00
December	6.11E+09	1.20E+10	1.77E+10	0.00E+00

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Peak Creek impairment (Subsheds 10-18).

Reach	Source	Jan cfu/day	Feb cfu/day	Mar cfu/day	Apr cfu/day	May cfu/day	Jun cfu/day
10	Human	1.01E+08	1.01E+08	1.01E+08	1.01E+08	1.01E+08	1.01E+08
	Livestock	2.96E+09	3.15E+09	5.39E+09	7.76E+09	7.76E+09	9.99E+09
	Wildlife	1.02E+10	1.02E+10	1.02E+10	1.02E+10	1.02E+10	1.02E+10
11	Human	6.85E+08	6.85E+08	6.85E+08	6.85E+08	6.85E+08	6.85E+08
	Livestock	1.96E+09	2.13E+09	3.56E+09	5.12E+09	5.12E+09	6.55E+09
	Wildlife	2.29E+09	2.29E+09	2.29E+09	2.29E+09	2.29E+09	2.29E+09
12	Human	4.83E+09	4.83E+09	4.83E+09	4.83E+09	4.83E+09	4.83E+09
	Livestock	1.11E+10	1.22E+10	2.01E+10	2.88E+10	2.88E+10	3.66E+10
	Wildlife	3.77E+09	3.77E+09	3.77E+09	3.77E+09	3.77E+09	3.77E+09
13	Human	7.08E+08	7.08E+08	7.08E+08	7.08E+08	7.08E+08	7.08E+08
	Livestock	1.70E+09	1.86E+09	3.07E+09	4.40E+09	4.40E+09	5.60E+09
	Wildlife	6.02E+08	6.02E+08	6.02E+08	6.02E+08	6.02E+08	6.02E+08
14	Human	4.19E+08	4.19E+08	4.19E+08	4.19E+08	4.19E+08	4.19E+08
	Livestock	2.12E+10	2.33E+10	3.82E+10	5.47E+10	5.47E+10	6.95E+10
	Wildlife	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09
15	Human	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08
	Livestock	3.45E+11	3.79E+11	3.82E+11	3.90E+11	3.98E+11	5.70E+11
	Wildlife	1.01E+10	1.01E+10	1.01E+10	1.01E+10	1.01E+10	1.01E+10
16	Human	6.03E+07	6.03E+07	6.03E+07	6.03E+07	6.03E+07	6.03E+07
	Livestock	7.18E+09	7.89E+09	1.29E+10	1.85E+10	1.85E+10	2.35E+10
	Wildlife	4.34E+09	4.34E+09	4.34E+09	4.34E+09	4.34E+09	4.34E+09
17	Human	3.50E+08	3.50E+08	3.50E+08	3.50E+08	3.50E+08	3.50E+08
	Livestock	2.21E+10	2.43E+10	3.98E+10	5.70E+10	5.70E+10	7.25E+10
	Wildlife	3.53E+08	3.53E+08	3.53E+08	3.53E+08	3.53E+08	3.53E+08
18	Human	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.89E+09	1.89E+09	1.89E+09	1.89E+09	1.89E+09	1.89E+09

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Peak Creek impairment (Subsheds 10-18). (Continued).

Reach	Source	Jul cfu/day	Aug cfu/day	Sep cfu/day	Oct cfu/day	Nov cfu/day	Dec cfu/day
10	Human	1.01E+08	1.01E+08	1.01E+08	1.01E+08	1.01E+08	1.01E+08
	Livestock	9.99E+09	9.99E+09	7.76E+09	5.39E+09	5.39E+09	2.96E+09
	Wildlife	1.02E+10	1.02E+10	1.02E+10	1.02E+10	1.02E+10	1.02E+10
11	Human	6.85E+08	6.85E+08	6.85E+08	6.85E+08	6.85E+08	6.85E+08
	Livestock	6.55E+09	6.55E+09	5.12E+09	3.56E+09	3.32E+09	1.96E+09
	Wildlife	2.29E+09	2.29E+09	2.29E+09	2.29E+09	2.29E+09	2.29E+09
12	Human	4.83E+09	4.83E+09	4.83E+09	4.83E+09	4.83E+09	4.83E+09
	Livestock	3.66E+10	3.66E+10	2.88E+10	2.01E+10	1.85E+10	1.11E+10
	Wildlife	3.77E+09	3.77E+09	3.77E+09	3.77E+09	3.77E+09	3.77E+09
13	Human	7.08E+08	7.08E+08	7.08E+08	7.08E+08	7.08E+08	7.08E+08
	Livestock	5.60E+09	5.60E+09	4.40E+09	3.07E+09	2.84E+09	1.70E+09
	Wildlife	6.02E+08	6.02E+08	6.02E+08	6.02E+08	6.02E+08	6.02E+08
14	Human	4.19E+08	4.19E+08	4.19E+08	4.19E+08	4.19E+08	4.19E+08
	Livestock	6.95E+10	6.95E+10	5.47E+10	3.82E+10	3.52E+10	2.12E+10
	Wildlife	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09	6.40E+09
15	Human	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08	1.03E+08
	Livestock	5.76E+11	5.76E+11	4.09E+11	4.14E+11	3.73E+11	3.64E+11
	Wildlife	1.01E+10	1.01E+10	1.01E+10	1.01E+10	1.01E+10	1.01E+10
16	Human	6.03E+07	6.03E+07	6.03E+07	6.03E+07	6.03E+07	6.03E+07
	Livestock	2.35E+10	2.35E+10	1.85E+10	1.29E+10	1.19E+10	7.18E+09
	Wildlife	4.34E+09	4.34E+09	4.34E+09	4.34E+09	4.34E+09	4.34E+09
17	Human	3.50E+08	3.50E+08	3.50E+08	3.50E+08	3.50E+08	3.50E+08
	Livestock	7.25E+10	7.25E+10	5.70E+10	3.98E+10	3.67E+10	2.21E+10
	Wildlife	3.53E+08	3.53E+08	3.53E+08	3.53E+08	3.53E+08	3.53E+08
18	Human	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.89E+09	1.89E+09	1.89E+09	1.89E+09	1.89E+09	1.89E+09

Table B.3 Existing annual loads from land-based sources for the Peak Creek impairment (Subsheds 10-18).

Source	Barren (cfu/yr)	Commercial (cfu/yr)	Forest (cfu/yr)	Pasture (cfu/yr)	Livestock Access (cfu/yr)	Residential (cfu/yr)	Row Crop (cfu/yr)	Water (cfu/yr)
Pets								
Dogs	0.00E+00	0.00E+00	0.00E+00	3.51E+12	0.00E+00	2.89E+14	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	9.08E+06	0.00E+00	7.46E+08	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	3.51E+12	0.00E+00	2.89E+14	0.00E+00	0.00E+00
Human								
Failed Septic	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+14	0.00E+00	0.00E+00
Livestock								
Dairy	0.00E+00	0.00E+00	0.00E+00	1.39E+15	8.18E+13	0.00E+00	4.96E+15	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	1.19E+15	6.39E+13	0.00E+00	0.00E+00	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	6.49E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Goat	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	1.47E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	2.74E+15	1.46E+14	0.00E+00	4.96E+15	0.00E+00
Wildlife								
Raccoon	3.37E+12	5.92E+12	7.81E+14	2.71E+14	2.86E+13	4.00E+13	3.31E+13	0.00E+00
Muskrat	2.92E+12	8.26E+11	1.90E+13	9.24E+13	4.97E+13	1.02E+12	1.14E+13	0.00E+00
Deer	0.00E+00	0.00E+00	1.20E+14	4.82E+13	3.20E+12	1.50E+12	5.46E+12	0.00E+00
Turkey	1.13E+08	8.39E+07	5.04E+10	5.58E+09	5.36E+08	6.44E+08	3.89E+08	0.00E+00
Goose	1.59E+09	5.95E+09	1.41E+11	3.76E+10	2.74E+10	1.01E+10	5.77E+09	0.00E+00
Duck	5.76E+07	1.93E+08	5.34E+09	1.30E+09	8.73E+08	3.92E+08	2.08E+08	0.00E+00
Total	6.30E+12	6.75E+12	9.21E+14	3.15E+15	2.27E+14	4.59E+14	5.01E+15	0.00E+00

Table B. 4 Existing annual loads from direct-deposition sources for the Peak Creek impairment (Subsheds 10-18).

Source	Fecal Coliform Load (cfu/yr)
Human	
Straight Pipes	2.65E+12
Total	2.65E+12
Livestock	
Dairy	2.76E+15
Beef	5.39E+14
Swine	0.00E+00
Sheep	2.78E+12
Goat	0.00E+00
Horse	6.31E+13
Poultry	0.00E+00
Total	3.36E+15
Wildlife	
Raccoon	3.04E+12
Muskrat	1.14E+13
Beaver	2.23E+06
Deer	9.24E+10
Turkey	3.02E+07
Goose	6.50E+09
Duck	3.63E+08
Total	1.46E+13

APPENDIX C

UCI FILE USED FOR MODELING

```
PERLND

  ACTIVITY
*** <PLS >               Active Sections                               ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  906    0    0    1    0    0    0    1    0    0    0    0    0
  END ACTIVITY

  PRINT-INFO
*** < PLS>                       Print-flags                           PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
  101  906    6    6    6    6    6    6    6    6    6    6    6    6    1    9
  END PRINT-INFO

  GEN-INFO
***             Name                  Unit-systems   Printer BinaryOut
*** <PLS >                                t-series Engl Metr Engl Metr
*** x -  x                                 in  out
  101     ResidRecr                         1    1    0    0    0    0
  102     Barren                            1    1    0    0    0    0
  103     ForestWet                         1    1    0    0    0    0
  104     RowCrops                          1    1    0    0    0    0
  105     PastureHay                        1    1    0    0    0    0
  106     PotLivAcc                         1    1    0    0    0    0
  201     ResidRecr                         1    1    0    0    0    0
  202     Barren                            1    1    0    0    0    0
  203     ForestWet                         1    1    0    0    0    0
  204     RowCrops                          1    1    0    0    0    0
  205     PastureHay                        1    1    0    0    0    0
  206     PotLivAcc                         1    1    0    0    0    0
  207     Water                             1    1    0    0    0    0
  208     Commercial                        1    1    0    0    0    0
  301     ResidRecr                         1    1    0    0    0    0
  302     Barren                            1    1    0    0    0    0
  303     ForestWet                         1    1    0    0    0    0
  304     RowCrops                          1    1    0    0    0    0
  305     PastureHay                        1    1    0    0    0    0
  306     PotLivAcc                         1    1    0    0    0    0
  307     Water                             1    1    0    0    0    0
  308     Commercial                        1    1    0    0    0    0
  401     ResidRecr                         1    1    0    0    0    0
  402     Barren                            1    1    0    0    0    0
  403     ForestWet                         1    1    0    0    0    0
  404     RowCrops                          1    1    0    0    0    0
  405     PastureHay                        1    1    0    0    0    0
  406     PotLivAcc                         1    1    0    0    0    0
  407     Water                             1    1    0    0    0    0
  408     Commercial                        1    1    0    0    0    0
  501     ResidRecr                         1    1    0    0    0    0
  502     Barren                            1    1    0    0    0    0
  503     ForestWet                         1    1    0    0    0    0
  504     RowCrops                          1    1    0    0    0    0
  505     PastureHay                        1    1    0    0    0    0
  506     PotLivAcc                         1    1    0    0    0    0
  507     Water                             1    1    0    0    0    0
  508     Commercial                        1    1    0    0    0    0
  602     Barren                            1    1    0    0    0    0
  603     ForestWet                         1    1    0    0    0    0
  604     RowCrops                          1    1    0    0    0    0
  605     PastureHay                        1    1    0    0    0    0
  606     PotLivAcc                         1    1    0    0    0    0
  607     Water                             1    1    0    0    0    0
  701     ResidRecr                         1    1    0    0    0    0
  702     Barren                            1    1    0    0    0    0
  703     ForestWet                         1    1    0    0    0    0
  704     RowCrops                          1    1    0    0    0    0
  705     PastureHay                        1    1    0    0    0    0
  706     PotLivAcc                         1    1    0    0    0    0
  707     Water                             1    1    0    0    0    0
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  708     Commercial                        1    1    0    0    0    0
  801     ResidRecr                         1    1    0    0    0    0
  802     Barren                            1    1    0    0    0    0
  803     ForestWet                         1    1    0    0    0    0
  804     RowCrops                          1    1    0    0    0    0
  805     PastureHay                        1    1    0    0    0    0
  806     PotLivAcc                         1    1    0    0    0    0
  807     Water                             1    1    0    0    0    0
  808     Commercial                        1    1    0    0    0    0
  902     Barren                            1    1    0    0    0    0
  903     ForestWet                         1    1    0    0    0    0
  905     PastureHay                        1    1    0    0    0    0
  906     PotLivAcc                         1    1    0    0    0    0
  END GEN-INFO

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
  101  906    0    1    1    1    1    1    0    0    1    1    0    0
  END PWAT-PARM1



  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101             1.       2.0   0.27500       305  0.124146      0.00     0.900
  102             0.       2.0   0.27500       255  0.077983      0.00     0.900
  103             1.       2.0   0.27516       397  0.142129      0.00     0.900
  104             1.       2.0   0.27410       318   0.06123      0.00     0.900
  105             0.       2.0   0.27369       330  0.048948      0.00     0.900
  106             1.       2.0   0.27420       100     0.001      0.00     0.900
  201             1.       2.0   0.20968       397  0.086877      0.00     0.900
  202             0.       2.0   0.24489       798  0.081747      0.00     0.900
  203             1.       2.0   0.27320       450  0.133375      0.00     0.900
  204             1.       2.0   0.27144       624  0.043071      0.00     0.900
  205             0.       2.0   0.26406       589  0.062398      0.00     0.900
  206             1.       2.0   0.25963       100     0.001      0.00     0.900
  207             0.       2.0   0.17642       100     0.001      0.00     0.900
  208             1.       2.0   0.16800       176  0.037582      0.00     0.900
  301             1.       2.0   0.18329       592  0.056151      0.00     0.900
  302             0.       2.0   0.25659       464  0.131191      0.00     0.900
  303             1.       2.0   0.25155       518  0.132771      0.00     0.900
  304             1.       2.0   0.20798       533  0.054086      0.00     0.900
  305             0.       2.0   0.19683       500  0.053024      0.00     0.900
  306             1.       2.0   0.19934       100     0.001      0.00     0.900
  307             0.       2.0   0.20210       100     0.001      0.00     0.900
  308             1.       2.0   0.16824       435  0.021084      0.00     0.900
  401             1.       2.0   0.16813       519   0.05441      0.00     0.900
  402             0.       2.0   0.16924       407  0.052961      0.00     0.900
  403             1.       2.0   0.23990       572  0.129269      0.00     0.900
  404             1.       2.0   0.17329       475  0.061655      0.00     0.900
  405             0.       2.0   0.16902       561  0.055139      0.00     0.900
  406             1.       2.0   0.16839       100     0.001      0.00     0.900
  407             0.       2.0   0.16800       100     0.001      0.00     0.900
  408             1.       2.0   0.17001       531   0.05636      0.00     0.900
  501             1.       2.0   0.21611       757  0.034548      0.00     0.900
  502             0.       2.0   0.18007       800   0.03951      0.00     0.900
  503             1.       2.0   0.18917       581  0.067136      0.00     0.900
  504             1.       2.0   0.20307       491  0.061175      0.00     0.900
  505             0.       2.0   0.20060       502  0.057284      0.00     0.900
  506             1.       2.0   0.18370       100     0.001      0.00     0.900
  507             0.       2.0   0.22481       100     0.001      0.00     0.900
  508             1.       2.0   0.23292       443   0.04001      0.00     0.900
  602             0.       2.0   0.27500       800  0.227996      0.00     0.900
  603             1.       2.0   0.27158       473  0.163082      0.00     0.900
  604             1.       2.0   0.26109       350   0.04858      0.00     0.900
  605             0.       2.0   0.26731       367  0.057686      0.00     0.900
  606             1.       2.0   0.26127       100     0.001      0.00     0.900
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  607             0.       2.0   0.27300       100     0.001      0.00     0.900
  701             1.       2.0   0.16800       587  0.048684      0.00     0.900
  702             0.       2.0   0.27300       101      0.01      0.00     0.900
  703             1.       2.0   0.26839       507  0.127642      0.00     0.900
  704             1.       2.0   0.24731       467  0.043674      0.00     0.900
  705             0.       2.0   0.24851       360  0.045837      0.00     0.900
  706             1.       2.0   0.25411       100     0.001      0.00     0.900
  707             0.       2.0   0.26862       100     0.001      0.00     0.900
  708             1.       2.0   0.16800       287   0.06281      0.00     0.900
  801             1.       2.0   0.25214       800  0.043389      0.00     0.900
  802             0.       2.0   0.16800       800    0.0345      0.00     0.900
  803             1.       2.0   0.24089       800  0.049674      0.00     0.900
  804             1.       2.0   0.19132       649  0.049363      0.00     0.900
  805             0.       2.0   0.20638       534  0.046213      0.00     0.900
  806             1.       2.0   0.19612       100     0.001      0.00     0.900
  807             0.       2.0   0.19434       100     0.001      0.00     0.900
  808             1.       2.0   0.24492       800  0.040972      0.00     0.900
  902             0.       2.0   0.27500       764  0.225181      0.00     0.900
  903             1.       2.0   0.27499       552  0.163921      0.00     0.900
  905             0.       2.0   0.27500       464  0.365915      0.00     0.900
  906             1.       2.0   0.27500       100     0.001      0.00     0.900
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101  906       40.       35.        2.        2.       0.5     0.200        0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                         (1/day)
  101            0.1   0.96400       0.2      1.00       0.3      0.10
  102            0.1   0.96400       0.2      1.00       0.3      0.10
  103            0.1   0.96794       0.2      1.00       0.3      0.70
  104            0.1   1.15880       0.2      1.00       0.3      0.60
  105            0.1   1.25946       0.2      1.00       0.3      0.50
  106            0.1   1.13562       0.2      1.00       0.3      0.50
  201            0.1   1.07946       0.2      1.00       0.3      0.10
  202            0.1   1.01177       0.2      1.00       0.3      0.10
  203            0.1   1.01967       0.2      1.00       0.3      0.70
  204            0.1   1.33396       0.2      1.00       0.3      0.60
  205            0.1   1.27397       0.2      1.00       0.3      0.50
  206            0.1   1.12461       0.2      1.00       0.3      0.50
  207            0.1   1.18391       0.2      1.00       0.3      0.01
  208            0.1   1.18400       0.2      1.00       0.3      0.10
  301            0.1   1.14178       0.2      1.00       0.3      0.10
  302            0.1   0.99227       0.2      1.00       0.3      0.10
  303            0.1   1.00059       0.2      1.00       0.3      0.70
  304            0.1   1.08314       0.2      1.00       0.3      0.60
  305            0.1   1.11093       0.2      1.00       0.3      0.50
  306            0.1   1.10247       0.2      1.00       0.3      0.50
  307            0.1   1.09616       0.2      1.00       0.3      0.01
  308            0.1   1.18329       0.2      1.00       0.3      0.10
  401            0.1   1.18360       0.2      1.00       0.3      0.10
  402            0.1   1.18037       0.2      1.00       0.3      0.10
  403            0.1   1.02172       0.2      1.00       0.3      0.70
  404            0.1   1.16880       0.2      1.00       0.3      0.60
  405            0.1   1.18269       0.2      1.00       0.3      0.50
  406            0.1   1.19478       0.2      1.00       0.3      0.50
  407            0.1   1.18400       0.2      1.00       0.3      0.01
  408            0.1   1.17999       0.2      1.00       0.3      0.10
  501            0.1   1.27823       0.2      1.00       0.3      0.10
  502            0.1   1.21902       0.2      1.00       0.3      0.10
  503            0.1   1.54635       0.2      1.00       0.3      0.70
  504            0.1   1.30797       0.2      1.00       0.3      0.60
  505            0.1   1.28812       0.2      1.00       0.3      0.50
  506            0.1   1.26296       0.2      1.00       0.3      0.50
  507            0.1   1.33820       0.2      1.00       0.3      0.01
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  508            0.1   1.36853       0.2      1.00       0.3      0.10
  602            0.1   0.96400       0.2      1.00       0.3      0.10
  603            0.1   1.00345       0.2      1.00       0.3      0.70
  604            0.1   1.43175       0.2      1.00       0.3      0.60
  605            0.1   1.43196       0.2      1.00       0.3      0.50
  606            0.1   1.38084       0.2      1.00       0.3      0.50
  607            0.1   1.45200       0.2      1.00       0.3      0.01
  701            0.1   1.18400       0.2      1.00       0.3      0.10
  702            0.1   1.45200       0.2      1.00       0.3      0.10
  703            0.1   1.13402       0.2      1.00       0.3      0.70
  704            0.1   1.42399       0.2      1.00       0.3      0.60
  705            0.1   1.41407       0.2      1.00       0.3      0.50
  706            0.1   1.42893       0.2      1.00       0.3      0.50
  707            0.1   1.44216       0.2      1.00       0.3      0.01
  708            0.1   1.18400       0.2      1.00       0.3      0.10
  801            0.1   1.40430       0.2      1.00       0.3      0.10
  802            0.1   1.18400       0.2      1.00       0.3      0.10
  803            0.1   1.37763       0.2      1.00       0.3      0.70
  804            0.1   1.24864       0.2      1.00       0.3      0.60
  805            0.1   1.28969       0.2      1.00       0.3      0.50
  806            0.1   1.26359       0.2      1.00       0.3      0.50
  807            0.1   1.25874       0.2      1.00       0.3      0.01
  808            0.1   1.38726       0.2      1.00       0.3      0.10
  902            0.1   0.96400       0.2      1.00       0.3      0.10
  903            0.1   0.96405       0.2      1.00       0.3      0.70
  905            0.1   0.96400       0.2      1.00       0.3      0.50
  906            0.1   0.96400       0.2      1.00       0.3      0.50
  END PWAT-PARM4

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  906      0.01      0.01       0.3      0.01       1.5      0.01      0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  102     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  103     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  104     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  105     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  106     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  201     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  202     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  203     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  204     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  205     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  206     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  207     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  208     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  301     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  302     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  303     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  304     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  305     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  306     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  307     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  308     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  401     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  402     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  403     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  404     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  405     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  406     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  407     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  408     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  501     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
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  502     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  503     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  504     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  505     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  506     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  507     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  508     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  602     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  603     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  604     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  605     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  606     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  607     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  701     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  702     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  703     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  704     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  705     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  706     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  707     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  708     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  801     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  802     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  803     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  804     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  805     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  806     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  807     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  808     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  902     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  903     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  905     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  906     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  END MON-INTERCEP

  MON-UZSN
*** <PLS >  Upper zone storage at start of each month  (inches)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.2310.2310.2380.4290.4420.4420.3690.3690.3690.1190.1160.116
  102     0.1990.1990.2070.3730.4860.4860.4060.4060.4060.1040.1000.100
  103     0.1990.1990.2090.3750.4890.4890.4070.4080.4080.1040.1000.100
  104     0.0450.0440.1490.3920.6250.6670.6310.6310.6310.2030.1210.034
  105     0.2990.2990.3110.5590.5800.5800.4840.4840.4840.1550.1500.150
  106     0.2700.2700.2800.5030.5230.5230.4360.4360.4360.1400.1350.135
  201     0.2580.2580.2670.4800.4950.4950.4130.4140.4140.1340.1300.130
  202     0.2090.2090.2180.3920.5110.5110.4260.4260.4260.1090.1040.104
  203     0.2100.2100.2200.3950.5150.5150.4290.4290.4290.1100.1050.105
  204     0.0520.0500.1710.4510.7190.7670.7270.7270.7270.2330.1390.039
  205     0.3030.3030.3140.5650.5870.5870.4890.4890.4890.1570.1520.152
  206     0.2670.2670.2780.4990.5180.5180.4320.4320.4320.1390.1340.134
  207     0.2910.2910.2910.5180.5180.5180.4340.4380.4380.1750.1750.175
  208     0.2830.2830.2930.5270.5430.5430.4540.4540.4540.1460.1420.142
  301     0.2730.2730.2820.5080.5230.5230.4370.4380.4380.1410.1370.137
  302     0.2040.2040.2140.3840.5010.5010.4170.4180.4180.1070.1020.102
  303     0.2060.2060.2150.3870.5050.5050.4210.4220.4220.1070.1030.103
  304     0.0420.0410.1390.3660.5840.6230.5900.5900.5900.1890.1130.032
  305     0.2640.2640.2740.4930.5120.5120.4270.4270.4270.1370.1320.132
  306     0.2620.2620.2720.4890.5080.5080.4230.4240.4240.1360.1310.131
  307     0.2690.2690.2690.4800.4800.4800.4020.4050.4050.1620.1620.162
  308     0.2830.2830.2930.5260.5430.5430.4530.4530.4530.1460.1420.142
  401     0.2830.2830.2930.5270.5420.5420.4520.4540.4540.1460.1420.142
  402     0.2430.2430.2540.4570.5960.5960.4970.4970.4970.1270.1220.122
  403     0.2100.2100.2200.3950.5160.5160.4300.4300.4300.1100.1050.105
  404     0.0450.0440.1500.3950.6300.6720.6370.6370.6370.2040.1220.034
  405     0.2810.2810.2920.5250.5450.5450.4540.4540.4540.1460.1410.141
  406     0.2840.2840.2950.5300.5510.5510.4580.4590.4590.1470.1420.142
  407     0.2910.2910.2910.5180.5180.5180.4340.4380.4380.1750.1750.175
  408     0.2820.2820.2920.5250.5410.5410.4520.4520.4520.1460.1410.141
  501     0.3060.3060.3160.5690.5860.5860.4890.4900.4900.1580.1540.154
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  502     0.2510.2510.2620.4720.6150.6150.5130.5130.5130.1310.1260.126
  503     0.3180.3180.3330.5990.7810.7810.6500.6510.6510.1660.1590.159
  504     0.0510.0500.1680.4420.7050.7520.7130.7130.7130.2290.1360.038
  505     0.3060.3060.3180.5720.5930.5930.4950.4950.4950.1590.1530.153
  506     0.3000.3000.3110.5600.5820.5820.4850.4850.4850.1550.1500.150
  507     0.3290.3290.3290.5860.5860.5860.4910.4950.4950.1980.1980.198
  508     0.3270.3270.3380.6090.6280.6280.5240.5240.5240.1690.1640.164
  602     0.1990.1990.2070.3730.4860.4860.4060.4060.4060.1040.1000.100
  603     0.2070.2070.2160.3890.5070.5070.4220.4230.4230.1080.1030.103
  604     0.0560.0540.1840.4840.7720.8240.7800.7800.7800.2500.1490.042
  605     0.3410.3410.3530.6350.6590.6590.5500.5500.5500.1770.1700.170
  606     0.3280.3280.3410.6120.6360.6360.5300.5300.5300.1700.1640.164
  607     0.3560.3560.3560.6360.6360.6360.5330.5370.5370.2150.2150.215
  701     0.2830.2830.2930.5270.5430.5430.4530.4540.4540.1460.1420.142
  702     0.2990.2990.3120.5620.7330.7330.6110.6110.6110.1560.1500.150
  703     0.2330.2330.2440.4390.5720.5720.4770.4780.4780.1220.1170.117
  704     0.0550.0540.1830.4820.7680.8190.7760.7760.7760.2490.1490.041
  705     0.3360.3360.3490.6280.6510.6510.5430.5430.5430.1750.1680.168
  706     0.3400.3400.3530.6340.6590.6590.5480.5490.5490.1760.1700.170
  707     0.3540.3540.3540.6320.6320.6320.5290.5330.5330.2130.2130.213
  708     0.2830.2830.2930.5270.5430.5430.4540.4540.4540.1460.1420.142
  801     0.3360.3360.3470.6250.6440.6440.5370.5380.5380.1740.1690.169
  802     0.2440.2440.2550.4580.5970.5970.4980.4990.4990.1270.1220.122
  803     0.2840.2840.2970.5330.6950.6950.5800.5800.5800.1480.1420.142
  804     0.0490.0470.1600.4220.6740.7180.6800.6800.6800.2180.1300.036
  805     0.3070.3070.3180.5720.5940.5940.4950.4950.4950.1590.1530.153
  806     0.3000.3000.3120.5600.5820.5820.4850.4850.4850.1560.1500.150
  807     0.3090.3090.3090.5510.5510.5510.4620.4650.4650.1860.1860.186
  808     0.3320.3320.3430.6170.6360.6360.5320.5320.5320.1710.1660.166
  902     0.1990.1990.2070.3730.4860.4860.4060.4060.4060.1040.1000.100
  903     0.1990.1990.2080.3730.4870.4870.4060.4060.4060.1040.0990.099
  905     0.2290.2290.2380.4280.4440.4440.3700.3700.3700.1190.1150.115
  906     0.2290.2290.2380.4280.4440.4440.3700.3700.3700.1190.1150.115
  END MON-UZSN

  MON-MANNING
*** <PLS >  Manning's n at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  102     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  103     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  104     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  105     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  106     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  201     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  202     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  203     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  204     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  205     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  206     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  207     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  208     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  301     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  302     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  303     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  304     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  305     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  306     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  307     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  308     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  401     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  402     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  403     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  404     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  405     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  406     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  407     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  408     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  501     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
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  502     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  503     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  504     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  505     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  506     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  507     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  508     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  602     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  603     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  604     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  605     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  606     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  607     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  701     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  702     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  703     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  704     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  705     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  706     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  707     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  708     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  801     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  802     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  803     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  804     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  805     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  806     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  807     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  808     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  902     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  903     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  905     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  906     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  END MON-MANNING

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  102     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  103     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  104     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  105     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  106     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  201     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  202     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  203     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  204     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  205     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  206     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  207     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  208     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  301     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  302     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  303     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  304     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  305     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  306     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  307     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  308     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  401     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  402     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  403     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  404     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  405     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  406     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  407     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  408     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  501     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
```

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  502     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  503     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  504     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  505     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  506     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  507     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  508     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  602     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  603     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  604     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  605     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  606     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  607     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  701     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  702     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  703     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  704     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  705     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  706     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  707     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  708     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  801     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  802     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  803     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  804     0.2870.2870.3260.4280.6140.9000.3800.3800.3790.6220.2870.287
  805     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  806     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  807     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  808     0.1000.1000.1000.1440.1440.1920.1000.1000.1000.1000.1000.100
  902     0.1000.1000.1000.1060.1240.1390.1000.1000.1000.1160.1000.100
  903     0.6400.6400.6490.7900.9000.9000.4360.4360.4360.8720.6400.640
  905     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  906     0.4880.4880.5070.6300.7510.8630.3640.3640.3640.4880.4880.488
  END MON-LZETPARM

  NQUALS
*** x -  xNQUAL
  101  906    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  906   FECAL COLIFO    #    0    0    0    1    1    1    0    0    0
  END QUAL-PROPS

  QUAL-INPUT
***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC    AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3 qty/ft3
*** x -  x                         ac.day
  101         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  102         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  103         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  104         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  105         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  106         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  201         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  202         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  203         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  204         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  205         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  206         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  207         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  208         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  301         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  302         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  303         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  304         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  305         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
```

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  306         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  307         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  308         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  401         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  402         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  403         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  404         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  405         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  406         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  407         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  408         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  501         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  502         0.00    0.00    0.00    0.00    0.00   0.200  000.00    0.00
  503         0.00    0.00    0.00    0.00    0.00   0.900  000.00    0.00
  504         0.00    0.00    0.00    0.00    0.00   0.500  000.00    0.00
  505         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  506         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  507         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  508         0.00    0.00    0.00    0.00    0.00   0.200  000.00    0.00
  602         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  603         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  604         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  605         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  606         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  607         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  701         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  702         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  703         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  704         0.00    0.00    0.00    0.00    0.00   0.125  000.00    0.00
  705         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  706         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  707         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  708         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  801         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  802         0.00    0.00    0.00    0.00    0.00   0.200  000.00    0.00
  803         0.00    0.00    0.00    0.00    0.00   0.900  000.00    0.00
  804         0.00    0.00    0.00    0.00    0.00   0.500  000.00    0.00
  805         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  806         0.00    0.00    0.00    0.00    0.00   0.250  000.00    0.00
  807         0.00    0.00    0.00    0.00    0.00   0.000  000.00    0.00
  808         0.00    0.00    0.00    0.00    0.00   0.200  000.00    0.00
  902         0.00    0.00    0.00    0.00    0.00   0.050  000.00    0.00
  903         0.00    0.00    0.00    0.00    0.00   0.225  000.00    0.00
  905         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  906         0.00    0.00    0.00    0.00    0.00   0.063  000.00    0.00
  END QUAL-INPUT

  MON-ACCUM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     63E0862E0860E0858E0857E0856E0853E0853E0853E0852E0853E0858E08
  102     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  103     83E0683E0683E0683E0683E0683E0683E0683E0683E0683E0683E0683E06
  104     25E0829E0803E1003E1003E1064E0664E0664E0682E0803E1003E1025E08
  105     08E0808E0809E0809E0809E0814E0814E0814E0809E0809E0809E0808E08
  106     03E0803E0805E0806E0806E0807E0807E0807E0806E0805E0805E0803E08
  201     20E0820E0819E0819E0818E0818E0817E0817E0817E0817E0817E0819E08
  202     75E0675E0675E0675E0675E0675E0675E0675E0675E0675E0675E0675E06
  203     88E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E06
  204     08E0809E0884E0884E0884E0874E0674E0674E0625E0884E0884E0808E08
  205     07E0808E0808E0808E0808E0812E0812E0812E0808E0809E0808E0808E08
  206     19E0820E0824E0830E0830E0835E0835E0835E0830E0824E0824E0819E08
  207     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  208     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  301     10E0810E0810E0810E0810E0810E0809E0809E0809E0809E0809E0810E08
  302     34E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E06
  303     91E0691E0691E0691E0691E0691E0691E0691E0691E0691E0691E0691E06
  304     25E0828E0803E1003E1003E1085E0685E0685E0680E0803E1003E1025E08
  305     07E0808E0808E0808E0808E0811E0811E0811E0808E0808E0808E0807E08
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  306     06E0807E0809E0811E0811E0813E0813E0813E0811E0809E0808E0806E08
  307     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  308     51E0651E0651E0651E0651E0651E0651E0651E0651E0651E0651E0651E06
  401     09E0809E0809E0809E0809E0809E0808E0808E0808E0808E0808E0809E08
  402     88E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E06
  403     78E0678E0678E0678E0678E0678E0678E0678E0678E0678E0678E0678E06
  404     18E0821E0802E1002E1002E1054E0654E0654E0660E0802E1002E1018E08
  405     07E0808E0808E0808E0808E0811E0811E0811E0808E0809E0808E0808E08
  406     06E0806E0808E0810E0810E0812E0812E0812E0810E0808E0807E0806E08
  407     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  408     56E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E06
  501     11E0810E0810E0810E0809E0809E0809E0809E0809E0809E0809E0810E08
  502     16E0616E0616E0616E0616E0616E0616E0616E0616E0616E0616E0616E06
  503     52E0652E0652E0652E0652E0652E0652E0652E0652E0652E0652E0652E06
  504     30E0835E0803E1003E1003E1065E0665E0665E0698E0803E1003E1030E08
  505     07E0808E0808E0808E0808E0811E0811E0811E0808E0808E0808E0807E08
  506     07E0807E0809E0811E0811E0814E0814E0814E0811E0809E0809E0807E08
  507     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  508     30E0630E0630E0630E0630E0630E0630E0630E0630E0630E0630E0630E06
  602     34E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E06
  603     76E0676E0676E0676E0676E0676E0676E0676E0676E0676E0676E0676E06
  604     25E0829E0803E1003E1003E1003E0803E0803E0878E0803E1003E1025E08
  605     08E0809E0809E0809E0809E0812E0813E0813E0809E0809E0809E0809E08
  606     10E0810E0812E0814E0814E0815E0815E0815E0814E0812E0812E0810E08
  607     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  701     28E0827E0825E0825E0824E0823E0822E0822E0822E0821E0822E0825E08
  702     07E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E08
  703     66E0666E0666E0666E0666E0666E0666E0666E0666E0666E0666E0666E06
  704     16E0819E0802E1002E1002E1092E0692E0692E0651E0802E1002E1016E08
  705     08E0808E0809E0809E0809E0812E0812E0812E0809E0809E0808E0808E08
  706     06E0806E0808E0809E0809E0810E0810E0810E0809E0808E0807E0806E08
  707     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  708     45E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E06
  801     14E0813E0813E0812E0812E0812E0811E0811E0811E0811E0811E0812E08
  802     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  803     34E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E0634E06
  804     30E0835E0803E1003E1003E1045E0645E0645E0699E0803E1003E1030E08
  805     07E0807E0807E0807E0808E0811E0811E0811E0808E0808E0807E0807E08
  806     03E0804E0806E0808E0808E0810E0810E0810E0808E0806E0805E0803E08
  807     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  808     10E0610E0610E0610E0610E0610E0610E0610E0610E0610E0610E0610E06
  902     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  903     85E0685E0685E0685E0685E0685E0685E0685E0685E0685E0685E0685E06
  905     35E0635E0635E0635E0635E0635E0635E0635E0635E0635E0635E0635E06
  906     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     06E1006E1009E1015E1014E1014E1013E1013E1013E1008E1005E1006E10
  102     17E0817E0826E0843E0843E0843E0843E0843E0843E0826E0817E0817E08
  103     08E0808E0812E0821E0821E0821E0821E0821E0821E0812E0808E0808E08
  104     03E1003E1042E1069E1069E1016E0816E0816E0821E1042E1028E1003E10
  105     79E0884E0801E1002E1002E1004E1004E1004E1002E1001E1092E0885E08
  106     33E0834E0869E0801E1001E1002E1002E1002E1001E1069E0846E0833E08
  201     02E1002E1003E1005E1005E1004E1004E1004E1004E1003E1002E1002E10
  202     07E0807E0811E0819E0819E0819E0819E0819E0819E0811E0807E0807E08
  203     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  204     81E0893E0813E1021E1021E1019E0819E0819E0806E1013E1008E1081E08
  205     73E0878E0801E1002E1002E1003E1003E1003E1002E1001E1078E0877E08
  206     02E1002E1004E1007E1007E1009E1009E1009E1007E1004E1002E1002E10
  207     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  208     15E0815E0822E0837E0837E0837E0837E0837E0837E0822E0815E0815E08
  301     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  302     07E0807E0810E0817E0817E0817E0817E0817E0817E0810E0807E0807E08
  303     18E0818E0827E0845E0845E0845E0845E0845E0845E0827E0818E0818E08
  304     05E1006E1081E1001E1201E1243E0843E0843E0840E1081E1054E1005E10
  305     01E1002E1002E1004E1004E1006E1006E1006E1004E1003E1002E1001E10
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  306     01E1001E1003E1005E1005E1006E1006E1006E1005E1003E1002E1001E10
  307     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  308     10E0810E0815E0825E0825E0825E0825E0825E0825E0815E0810E0810E08
  401     91E0890E0801E1002E1002E1002E1002E1002E1002E1001E1085E0888E08
  402     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  403     08E0808E0812E0819E0819E0819E0819E0819E0819E0812E0808E0808E08
  404     02E1002E1031E1051E1051E1014E0814E0814E0815E1031E1020E1002E10
  405     73E0879E0801E1002E1002E1003E1003E1003E1002E1001E1078E0876E08
  406     57E0860E0801E1002E1002E1003E1003E1003E1002E1001E1074E0857E08
  407     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  408     06E0806E0808E0814E0814E0814E0814E0814E0814E0808E0806E0806E08
  501     01E1001E1001E1002E1002E1002E1002E1002E1002E1001E1089E0897E08
  502     02E0802E0802E0804E0804E0804E0804E0804E0804E0802E0802E0802E08
  503     05E0805E0808E0813E0813E0813E0813E0813E0813E0808E0805E0805E08
  504     03E1003E1050E1083E1083E1016E0816E0816E0825E1050E1033E1003E10
  505     71E0877E0801E1002E1002E1003E1003E1003E1002E1001E1076E0875E08
  506     68E0871E0801E1003E1003E1003E1003E1003E1003E1001E1088E0868E08
  507     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  508     03E0803E0804E0807E0807E0807E0807E0807E0807E0804E0803E0803E08
  602     07E0807E0810E0817E0817E0817E0817E0817E0817E0810E0807E0807E08
  603     15E0815E0823E0838E0838E0838E0838E0838E0838E0823E0815E0815E08
  604     05E1006E1078E1001E1201E1201E1001E1001E1039E1078E1052E1005E10
  605     02E1002E1003E1005E1005E1006E1006E1006E1005E1003E1002E1002E10
  606     02E1002E1004E1007E1007E1008E1008E1008E1007E1004E1002E1002E10
  607     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  701     06E1005E1008E1012E1012E1012E1011E1011E1011E1006E1004E1005E10
  702     01E1001E1002E1004E1004E1004E1004E1004E1004E1002E1001E1001E10
  703     13E0813E0820E0833E0833E0833E0833E0833E0833E0820E0813E0813E08
  704     03E1004E1052E1086E1086E1046E0846E0846E0826E1052E1035E1003E10
  705     02E1002E1003E1004E1004E1006E1006E1006E1005E1003E1002E1002E10
  706     01E1001E1002E1005E1005E1005E1005E1005E1005E1002E1001E1001E10
  707     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  708     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  801     01E1001E1002E1003E1003E1003E1003E1003E1003E1002E1001E1001E10
  802     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  803     03E0803E0805E0809E0809E0809E0809E0809E0809E0805E0803E0803E08
  804     03E1003E1050E1084E1084E1011E0811E0811E0825E1050E1033E1003E10
  805     66E0873E0801E1002E1002E1003E1003E1003E1002E1001E1071E0870E08
  806     33E0836E0884E0802E1002E1002E1002E1002E1002E1084E0852E0833E08
  807     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  808     95E0695E0601E0802E0802E0802E0802E0802E0802E0801E0895E0695E06
  902     15E0815E0822E0837E0837E0837E0837E0837E0837E0822E0815E0815E08
  903     09E0809E0813E0821E0821E0821E0821E0821E0821E0813E0809E0809E08
  905     04E0804E0805E0809E0809E0809E0809E0809E0809E0805E0804E0804E08
  906     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  END MON-SQOLIM

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  802    0    0    1    0    0    1
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  802    6    6    6    6    6    6    1    9
  END PRINT-INFO

  GEN-INFO
***             Name             Unit-systems   Printer BinaryOut
*** <ILS >                           t-series Engl Metr Engl Metr
*** x -  x                            in  out
  101     Resid./Recr                  1    1    0    0    0    0
  201     Resid./Recr                  1    1    0    0    0    0
  202     Comm./Ind./Tr                1    1    0    0    0    0
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  301     Resid./Recr                 1    1    0    0    0    0
  302     Comm./Ind./Tr               1    1    0    0    0    0
  401     Resid./Recr                 1    1    0    0    0    0
  402     Comm./Ind./Tr               1    1    0    0    0    0
  501     Resid./Recr                 1    1    0    0    0    0
  502     Comm./Ind./Tr               1    1    0    0    0    0
  701     Resid./Recr                 1    1    0    0    0    0
  702     Comm./Ind./Tr               1    1    0    0    0    0
  801     Resid./Recr                 1    1    0    0    0    0
  802     Comm./Ind./Tr               1    1    0    0    0    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  802    0    1    0    0    0
  END IWAT-PARM1


  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  101            305  0.124146      0.05       0.1
  201            397  0.086877      0.05       0.1
  202            176  0.037582      0.05       0.1
  301            592  0.056151      0.05       0.1
  302            435  0.021084      0.05       0.1
  401            519   0.05441      0.05       0.1
  402            531   0.05636      0.05       0.1
  501            757  0.034548      0.05       0.1
  502            443   0.04001      0.05       0.1
  701            587  0.048684      0.05       0.1
  702            287   0.06281      0.05       0.1
  801            800  0.043389      0.05       0.1
  802            800  0.040972      0.05       0.1
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  802       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  802      0.01      0.01
  END IWAT-STATE1

  NQUALS
*** x -  xNQUAL
  101  802    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
  101  802   FECAL COLIFO    #    0    0    1    1
  END QUAL-PROPS

  QUAL-INPUT
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
  101         0.00    0.00    0.00    0.00    0.10
  201         0.00    0.00    0.00    0.00    0.10
  202         0.00    0.00    0.00    0.00    0.10
  301         0.00    0.00    0.00    0.00    0.10
  302         0.00    0.00    0.00    0.00    0.10
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  401         0.00    0.00    0.00    0.00    0.10
  402         0.00    0.00    0.00    0.00    0.10
  501         0.00    0.00    0.00    0.00    0.10
  502         0.00    0.00    0.00    0.00    0.10
  701         0.00    0.00    0.00    0.00    0.10
  702         0.00    0.00    0.00    0.00    0.10
  801         0.00    0.00    0.00    0.00    0.10
  802         0.00    0.00    0.00    0.00    0.10
  END QUAL-INPUT

  MON-ACCUM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     05E0804E0804E0804E0804E0804E0804E0804E0804E0804E0804E0804E08
  201     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  202     11E0611E0611E0611E0611E0611E0611E0611E0611E0611E0611E0611E06
  301     75E0674E0672E0671E0671E0670E0668E0668E0668E0667E0668E0671E06
  302     04E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E06
  401     65E0665E0664E0663E0663E0662E0661E0661E0661E0661E0661E0663E06
  402     04E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E06
  501     76E0674E0671E0670E0668E0667E0664E0664E0664E0662E0664E0670E06
  502     02E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E06
  701     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  702     03E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E06
  801     99E0697E0692E0690E0687E0685E0680E0680E0680E0678E0680E0690E06
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  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
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  201     14E0814E0820E0833E0833E0832E0831E0831E0831E0818E0812E0813E08
  202     01E0801E0802E0803E0803E0803E0803E0803E0803E0802E0801E0801E08
  301     15E0815E0822E0836E0835E0835E0834E0834E0834E0820E0814E0814E08
  302     73E0673E0601E0802E0802E0802E0802E0802E0802E0801E0873E0673E06
  401     07E0806E0810E0816E0816E0816E0815E0815E0815E0809E0806E0806E08
  402     40E0640E0660E0601E0801E0801E0801E0801E0801E0860E0640E0640E06
  501     08E0807E0811E0817E0817E0817E0816E0816E0816E0809E0806E0807E08
  502     21E0621E0632E0654E0654E0654E0654E0654E0654E0632E0621E0621E06
  701     40E0839E0855E0889E0886E0884E0878E0878E0878E0846E0831E0836E08
  702     64E0664E0696E0602E0802E0802E0802E0802E0802E0896E0664E0664E06
  801     10E0810E0814E0822E0822E0821E0820E0820E0820E0812E0808E0809E08
  802     07E0607E0610E0617E0617E0617E0617E0617E0617E0610E0607E0607E06
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END IMPLND
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APPENDIX D

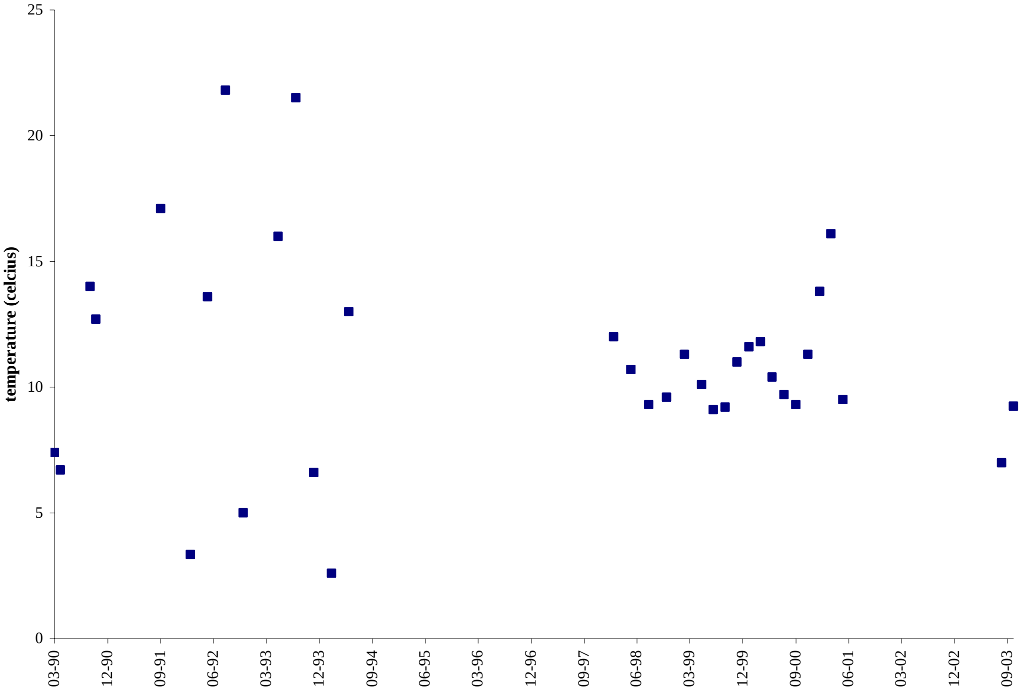

Figure D.1 **Temperature measurements at 9-PKC007.82.**

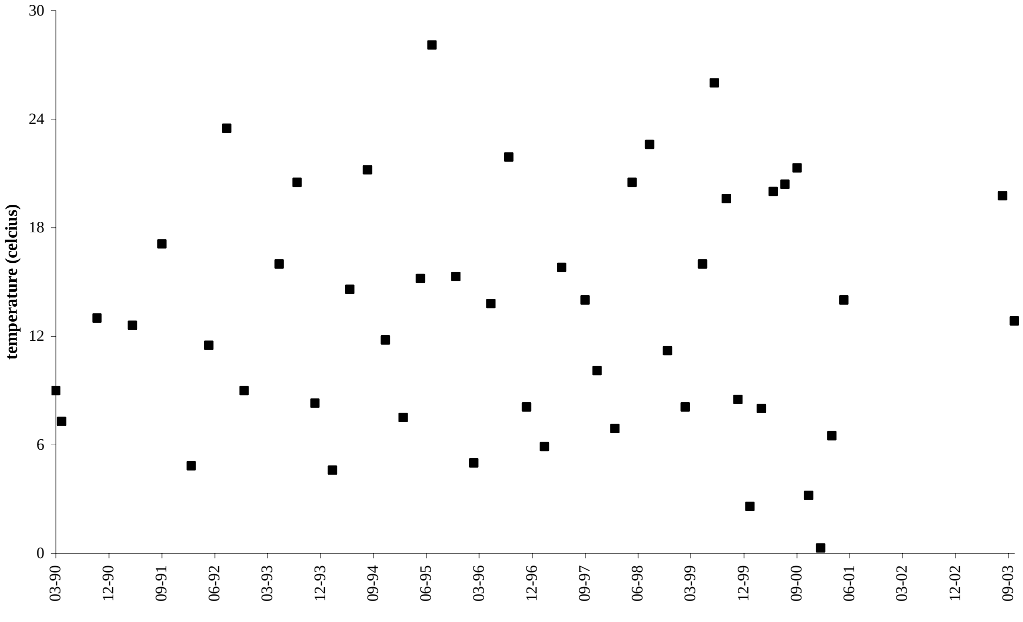

Figure D.2 **Temperature measurements at 9-PKC009.29.**

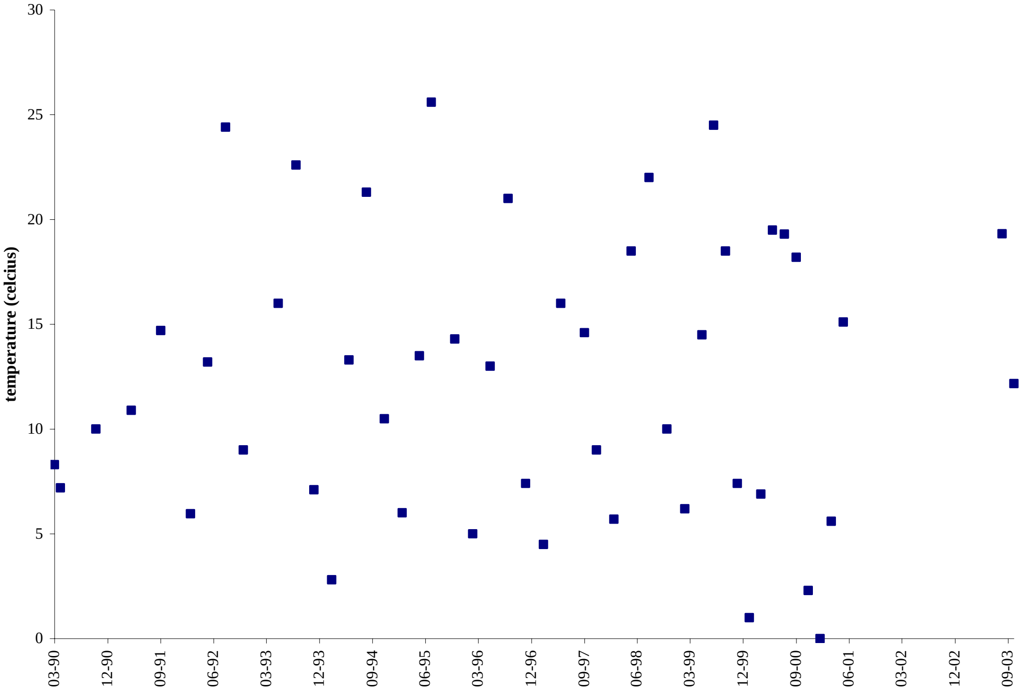

Figure D.3 **Temperature measurements at 9-PKC011.11.**

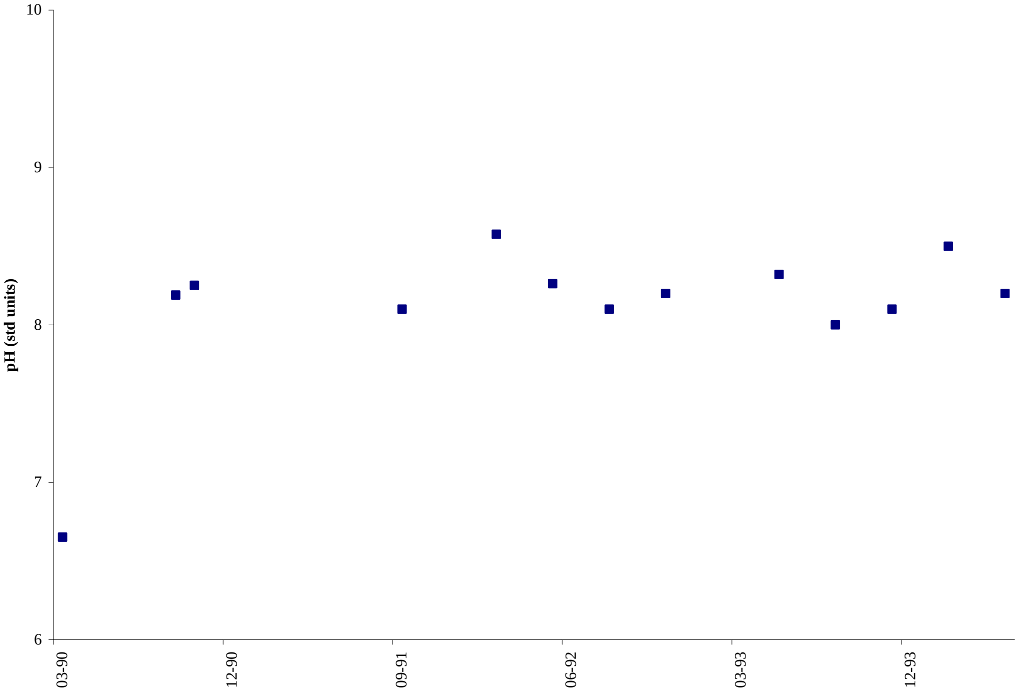

Figure D.4 **pH measurements at 9-PKC007.82.**

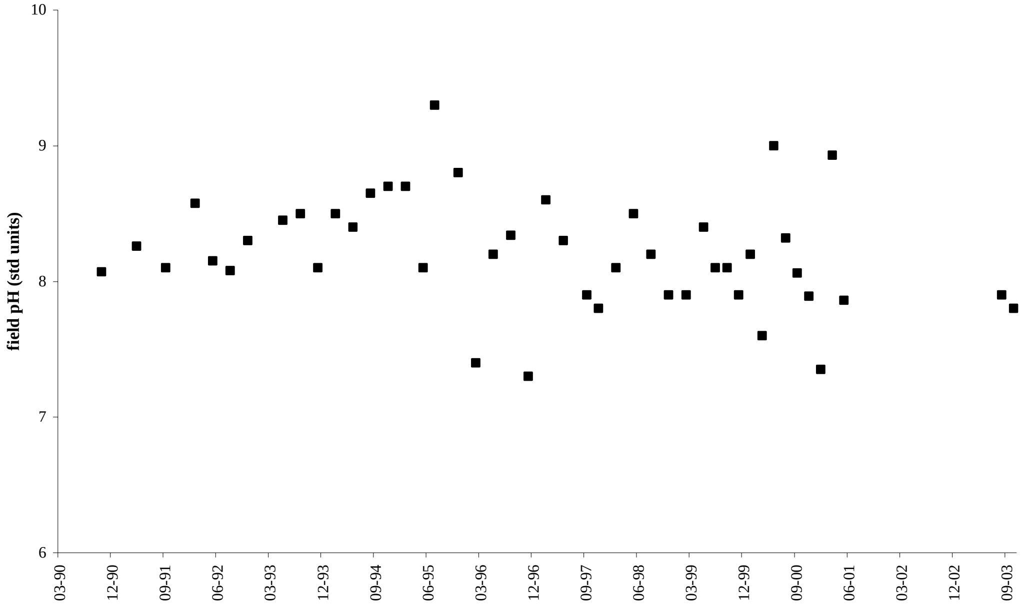

Figure D.5 **pH measurements at 9-PKC009.29.**

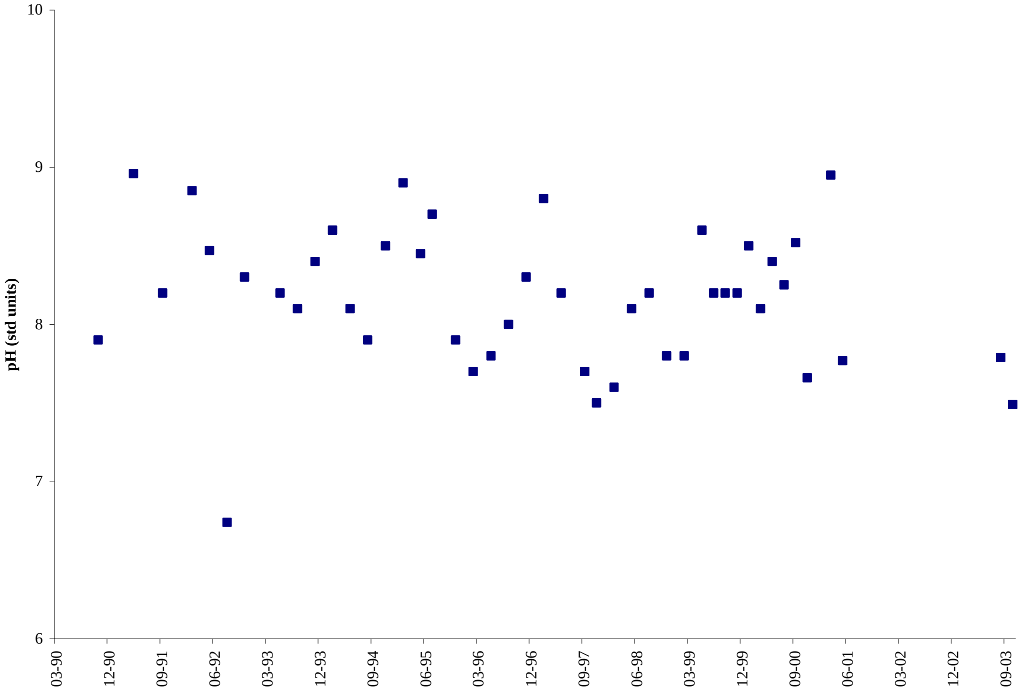

Figure D.6 **pH measurements at 9-PKC011.11.**

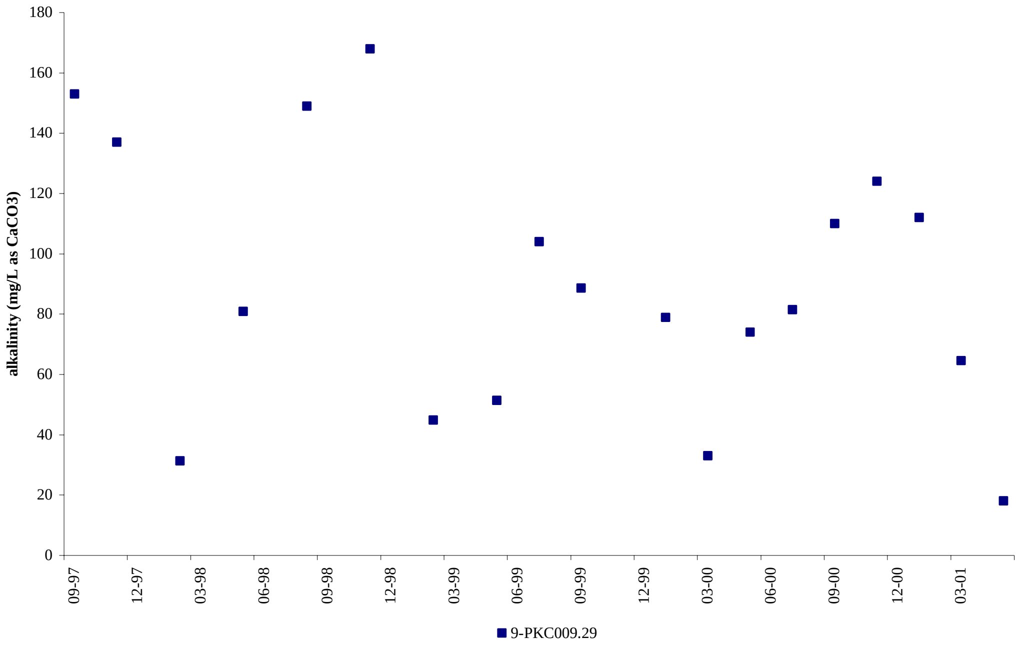

Figure D.7 Alkalinity concentrations at 9-PKC009.29.

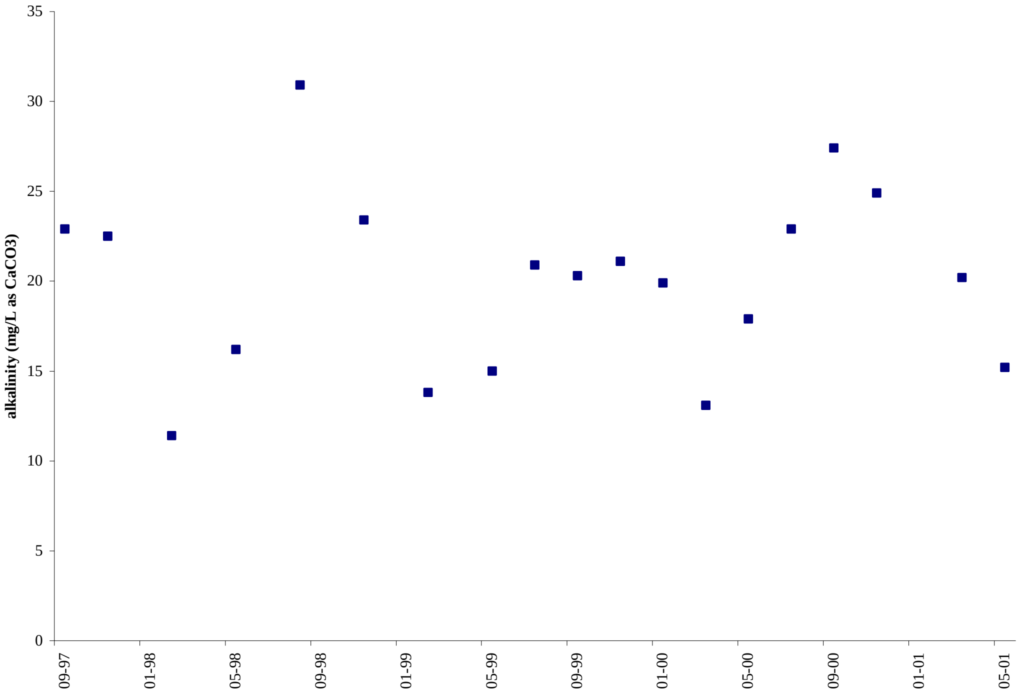

Figure D.8 Alkalinity concentrations at 9-PKC011.11.

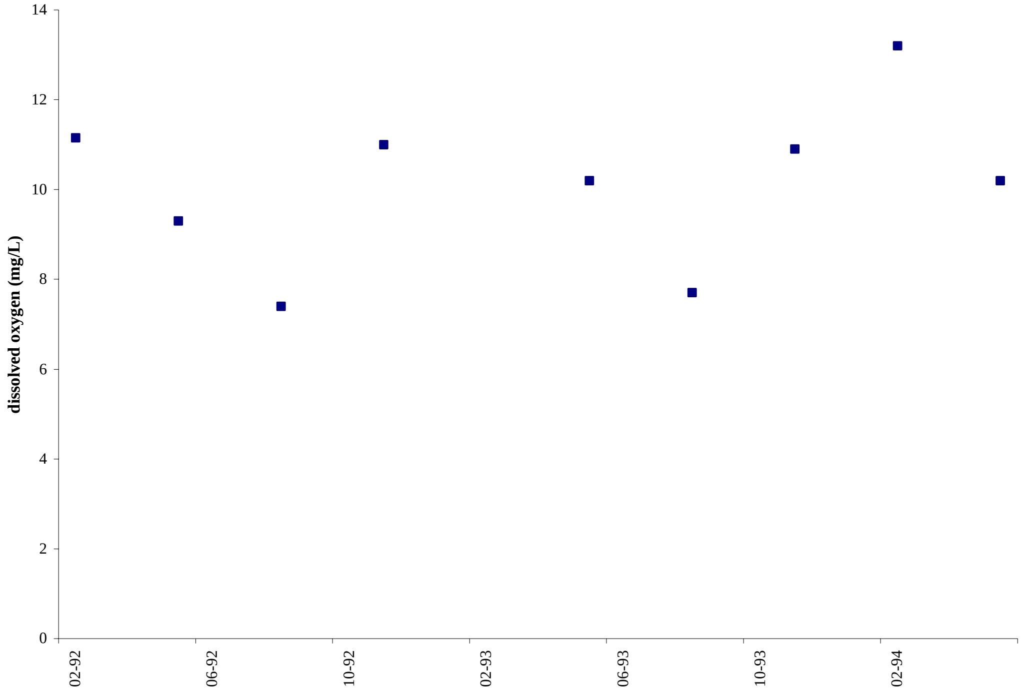

Figure D.9 Dissolved oxygen concentrations at 9-PKC007.82.

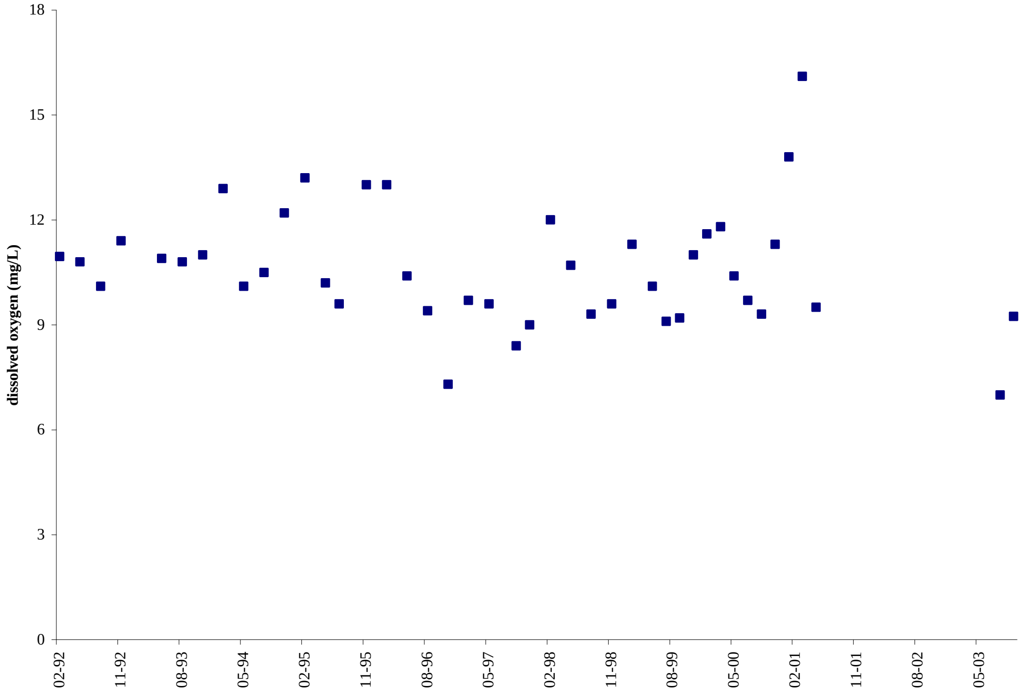

Figure D.10 Dissolved oxygen concentrations at 9-PKC009.29.

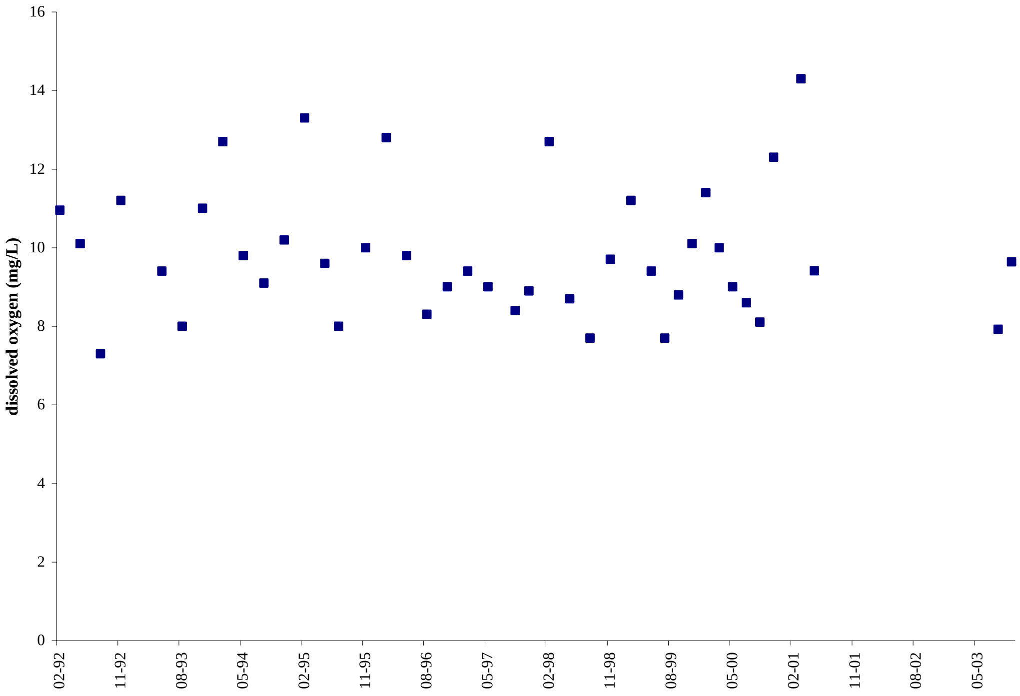

Figure D.11 Dissolved oxygen concentrations at 9-PKC011.11.

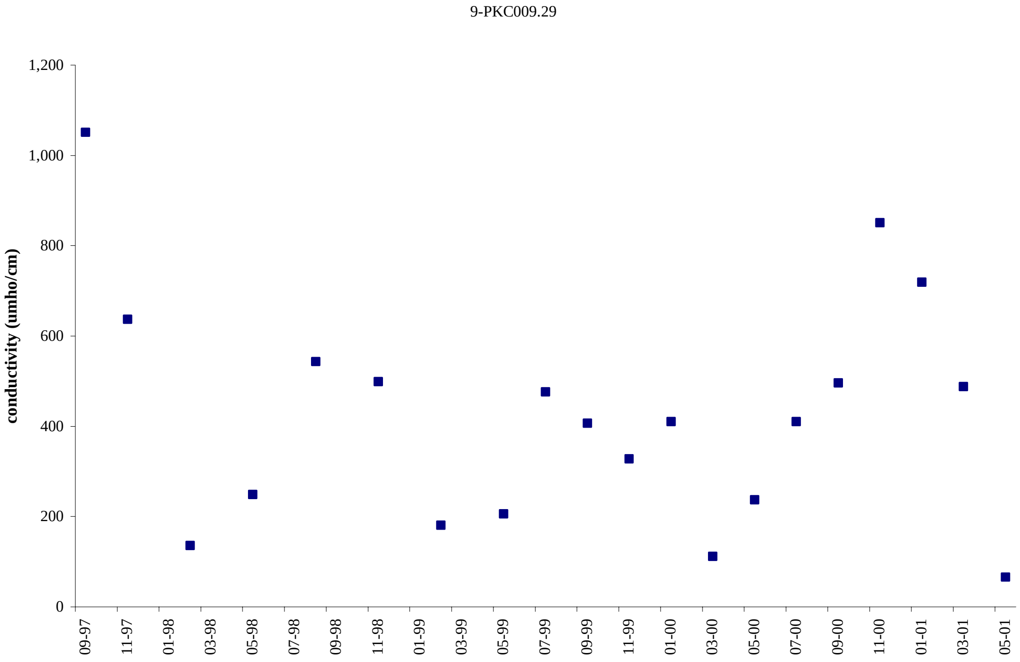

Figure D.12 Conductivity at 9-PKC009.29.

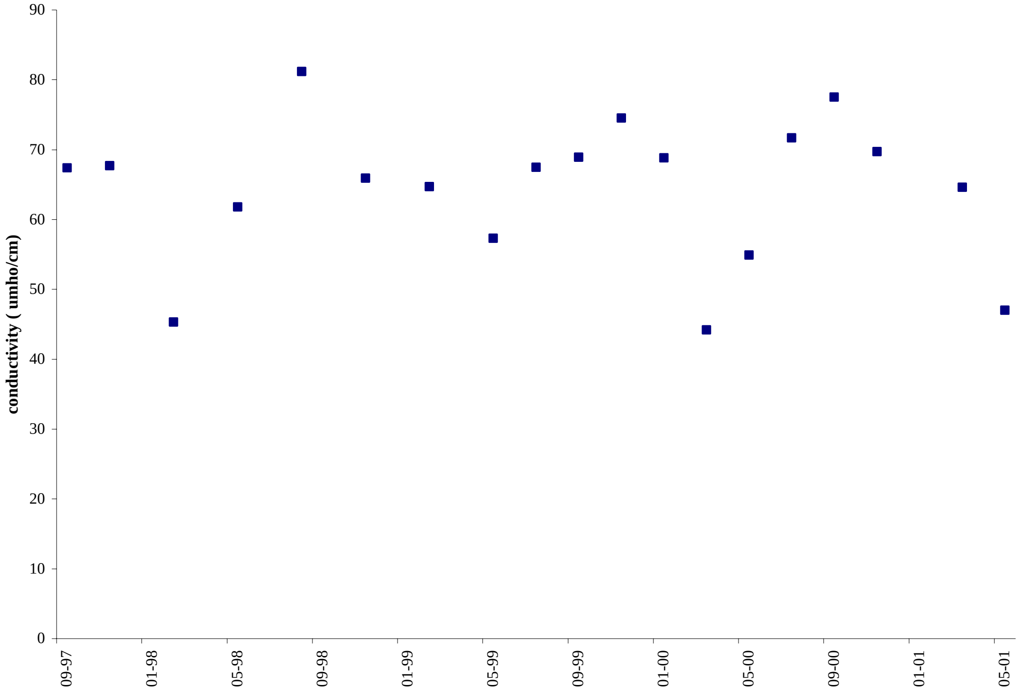

Figure D.13 Conductivity at 9-PKC011.11.

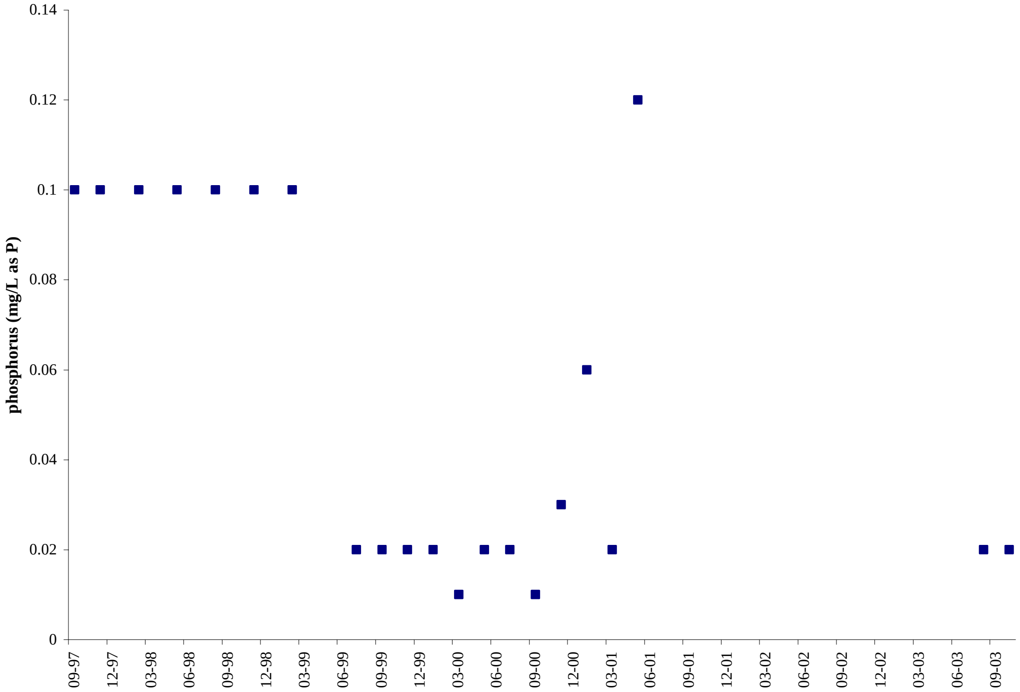

Figure D.14 Total phosphorus concentrations at 9-PKC009.29.

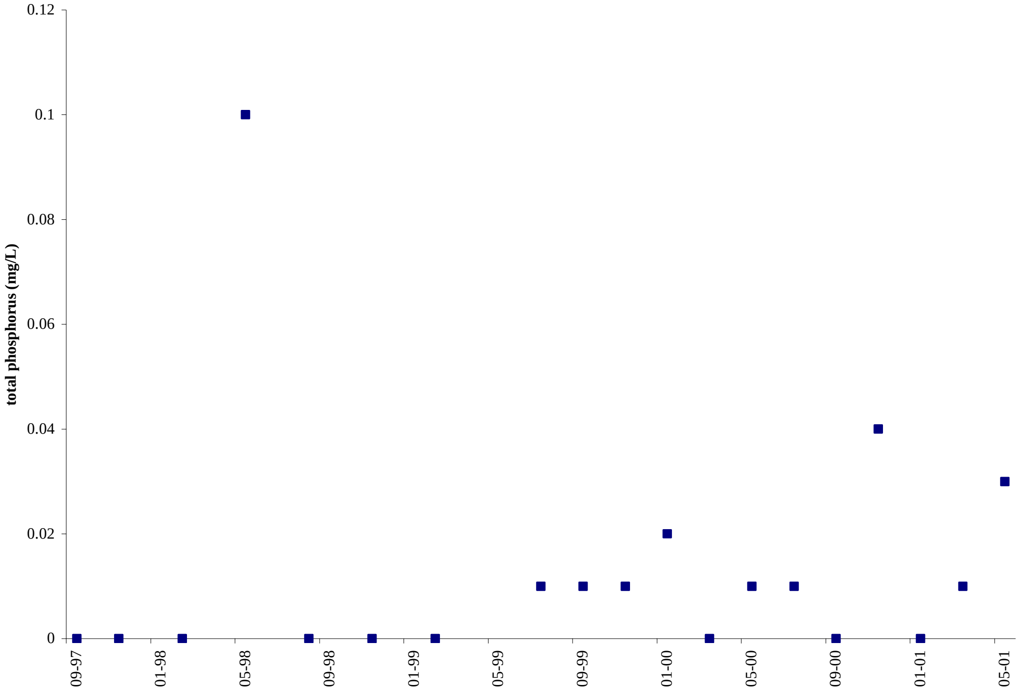

Figure D.15 Total phosphorus concentrations at 9-PKC011.11.

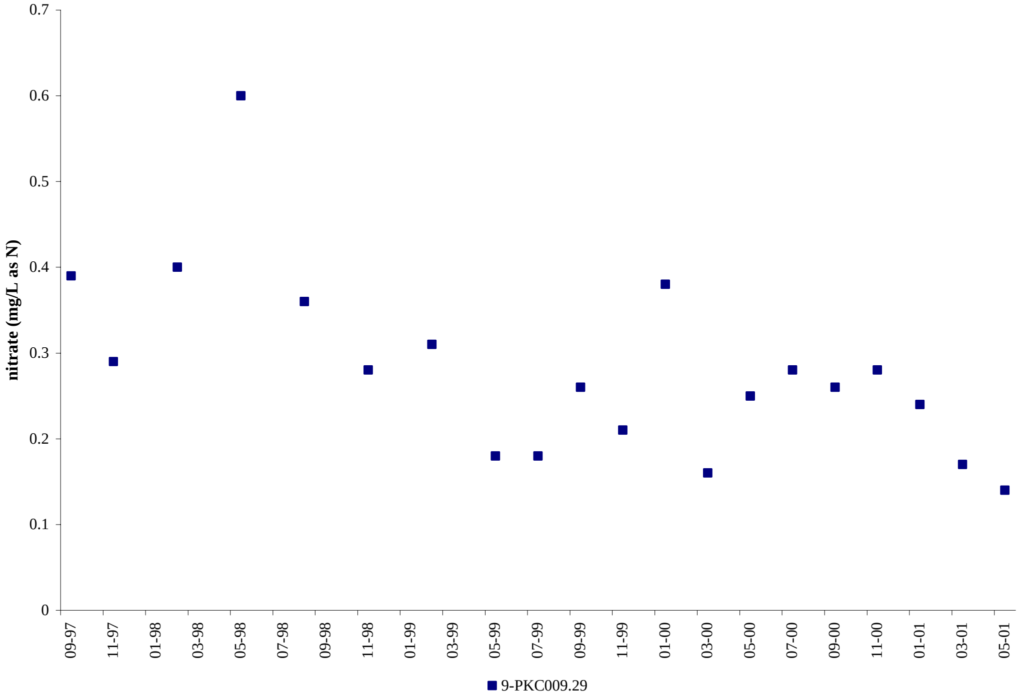

Figure D.16 Nitrate nitrogen concentrations at 9-PKC009.29.

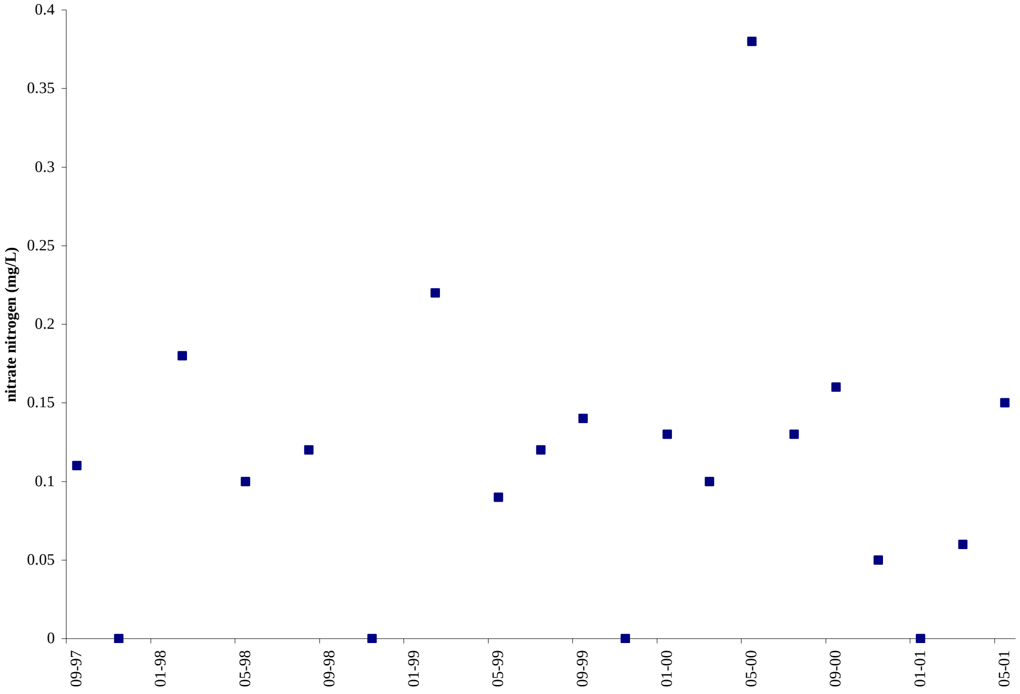

Figure D.17 Nitrate nitrogen concentrations at 9-PKC011.11.

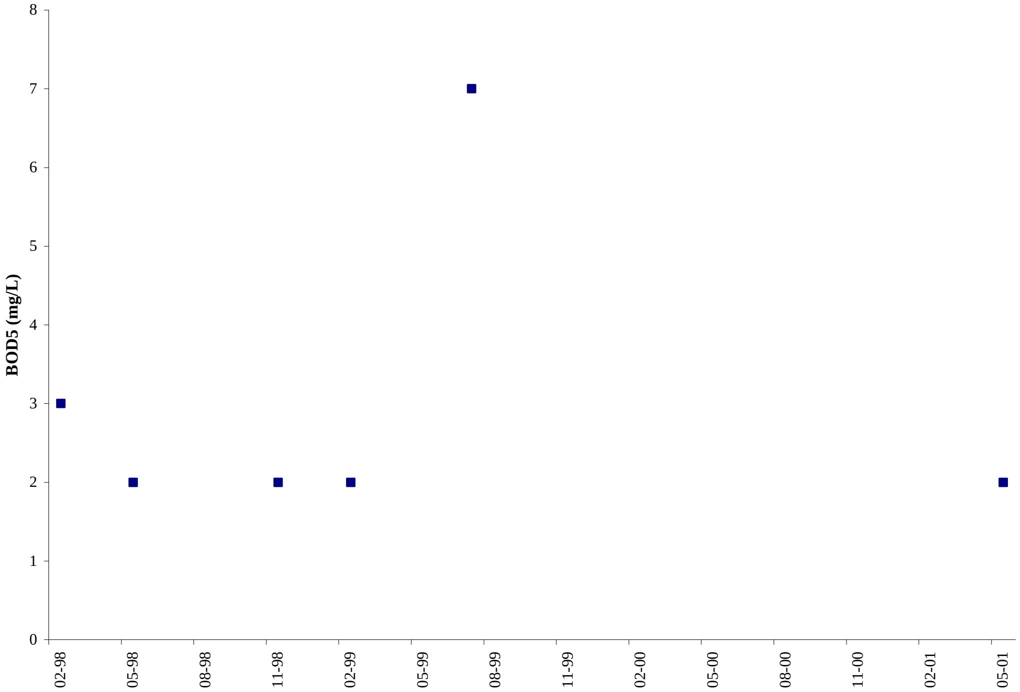

Figure D.18 BOD_5 concentrations at 9-PKC009.29.

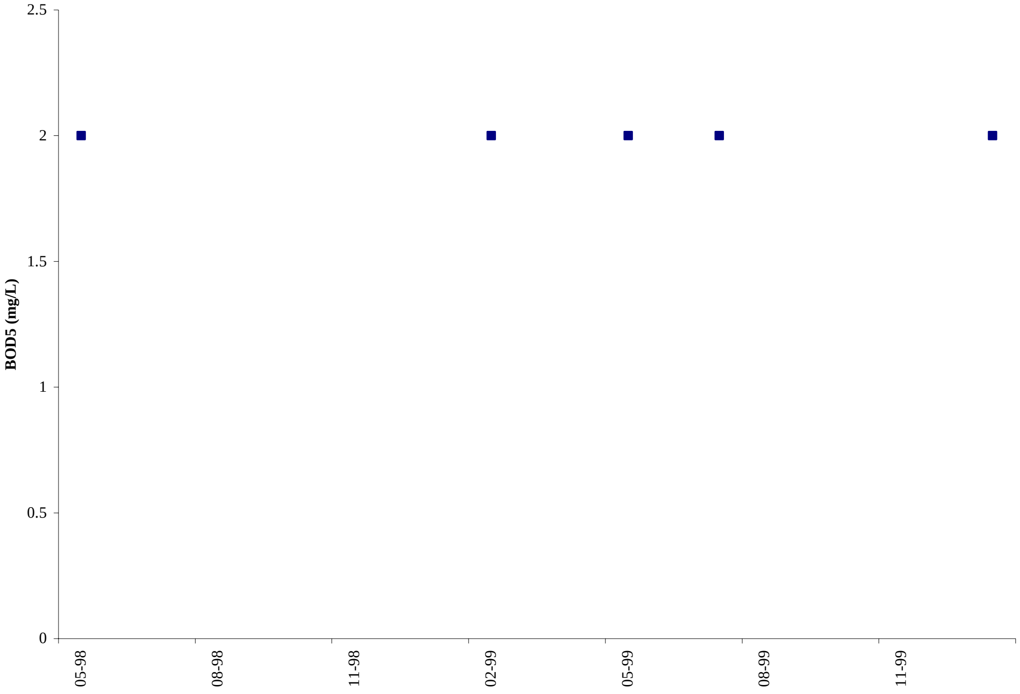

Figure D.19 BOD$_5$ concentrations at 9-PKC011.11.

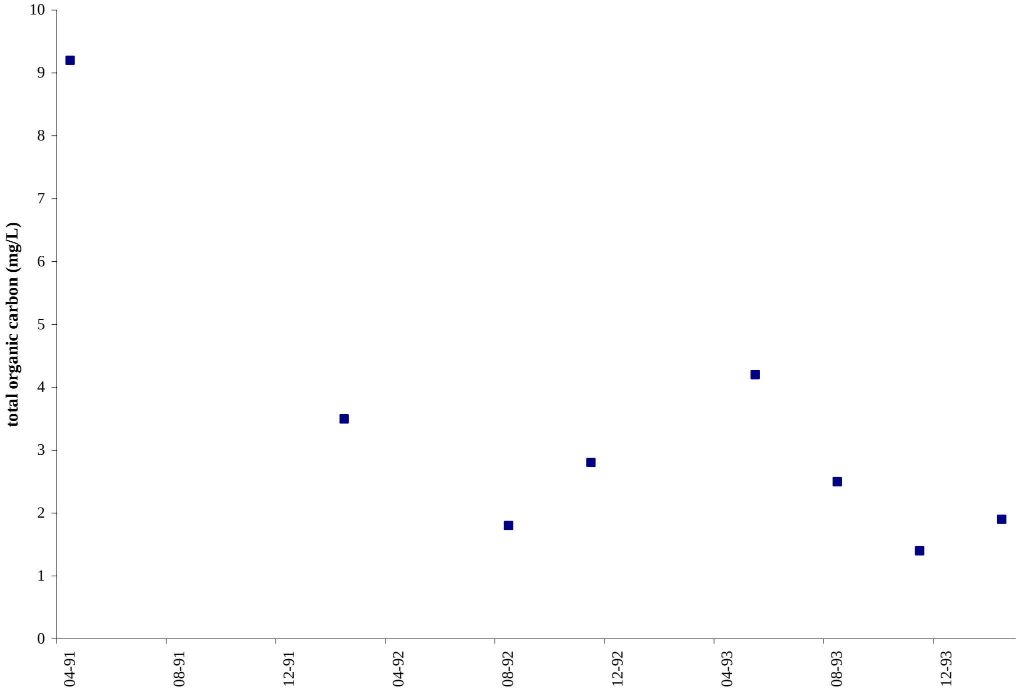

Figure D.20 Total organic carbon at 9-PKC007.82.

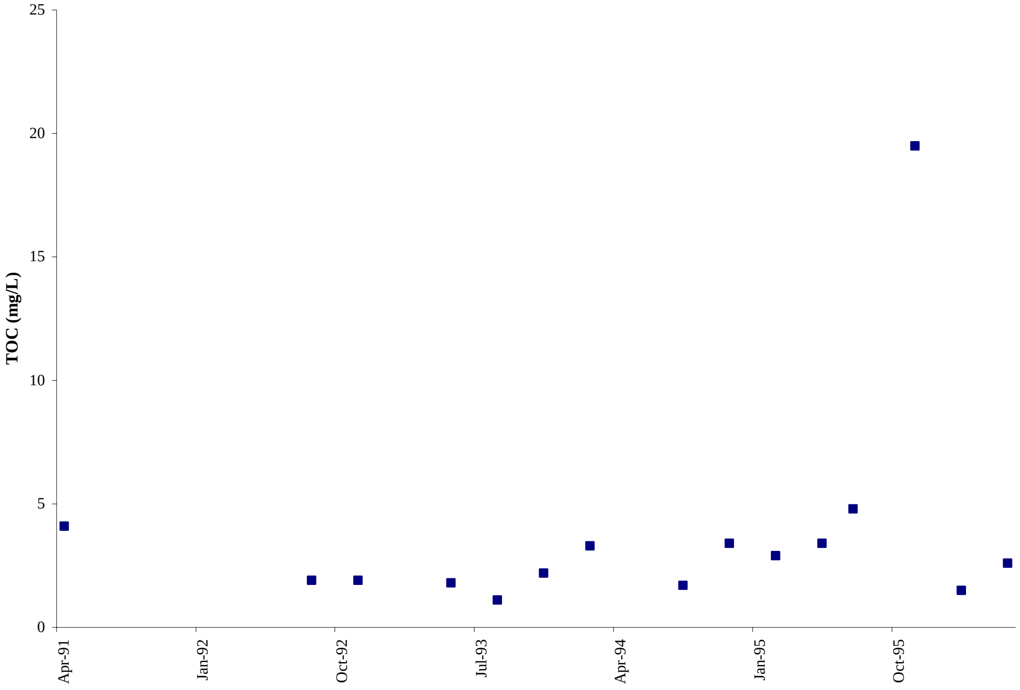

Figure D.21 Total organic carbon concentrations at 9-PKC009.29.

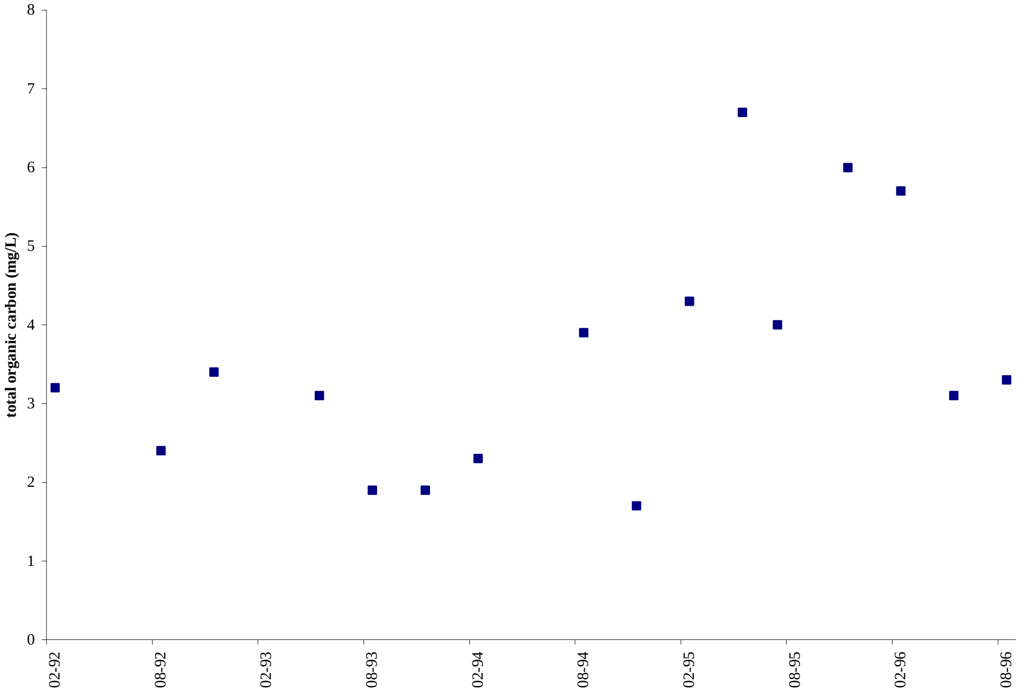

Figure D.22 Total organic carbon concentrations at 9-PKC011.11.

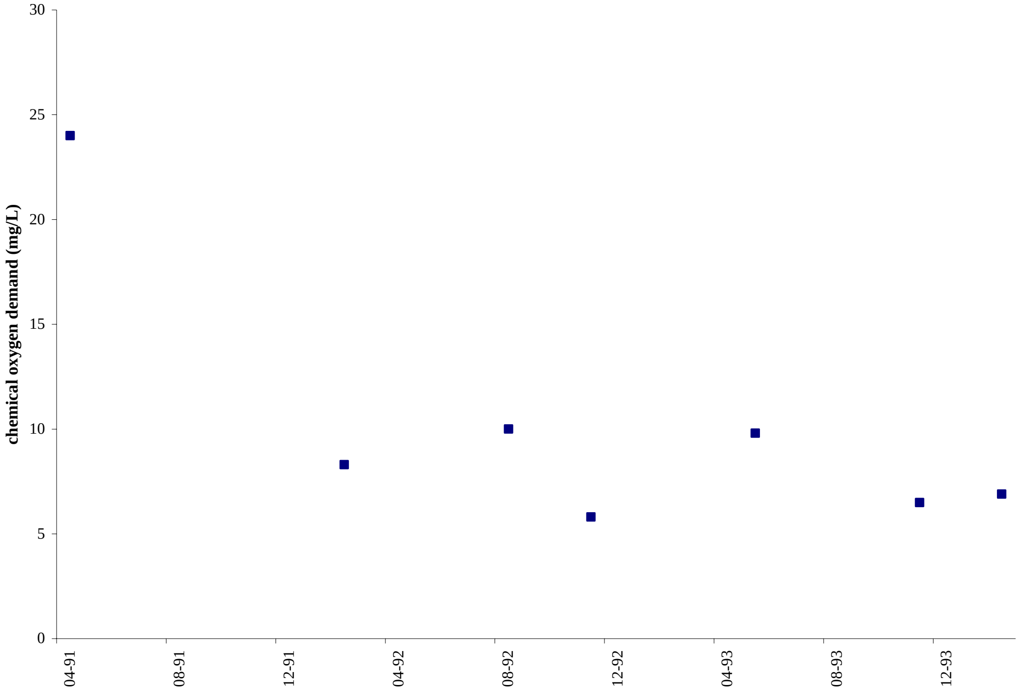

Figure D.23 Chemical oxygen demand concentrations at 9-PKC007.82.

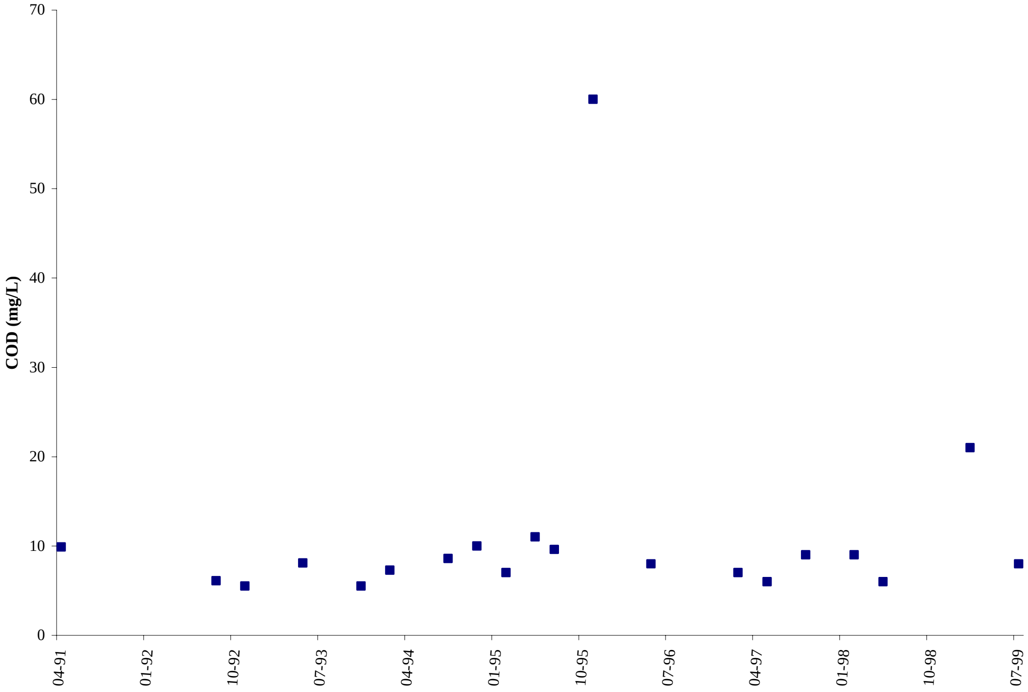

Figure D.24 Chemical oxygen demand concentrations at 9-PKC009.29

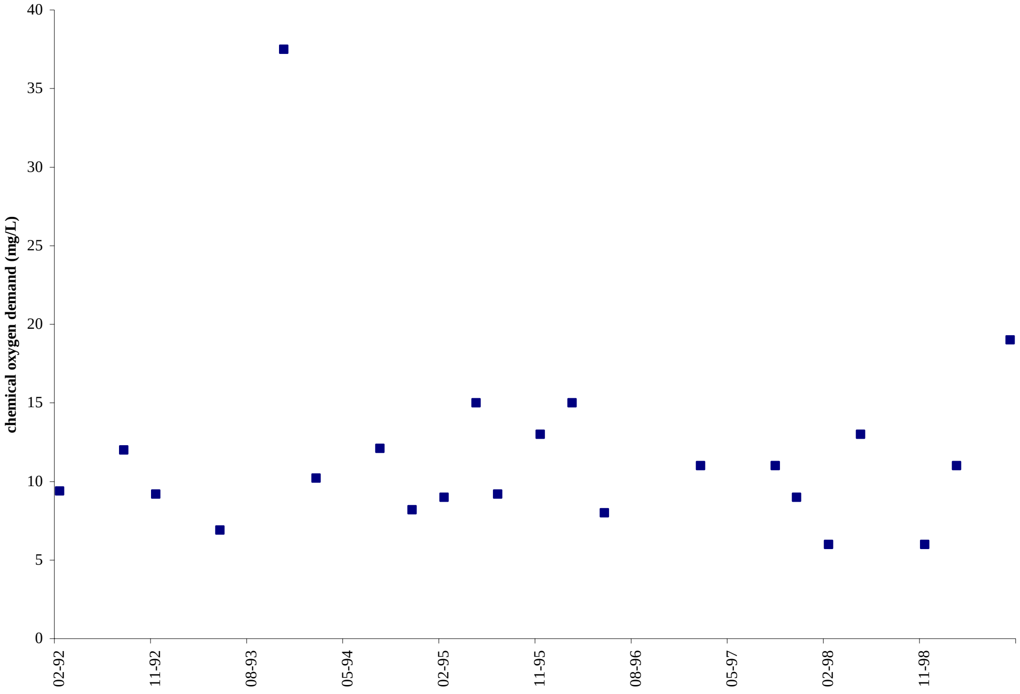

Figure D.25 Chemical oxygen demand concentrations at 9-PKC011.11.

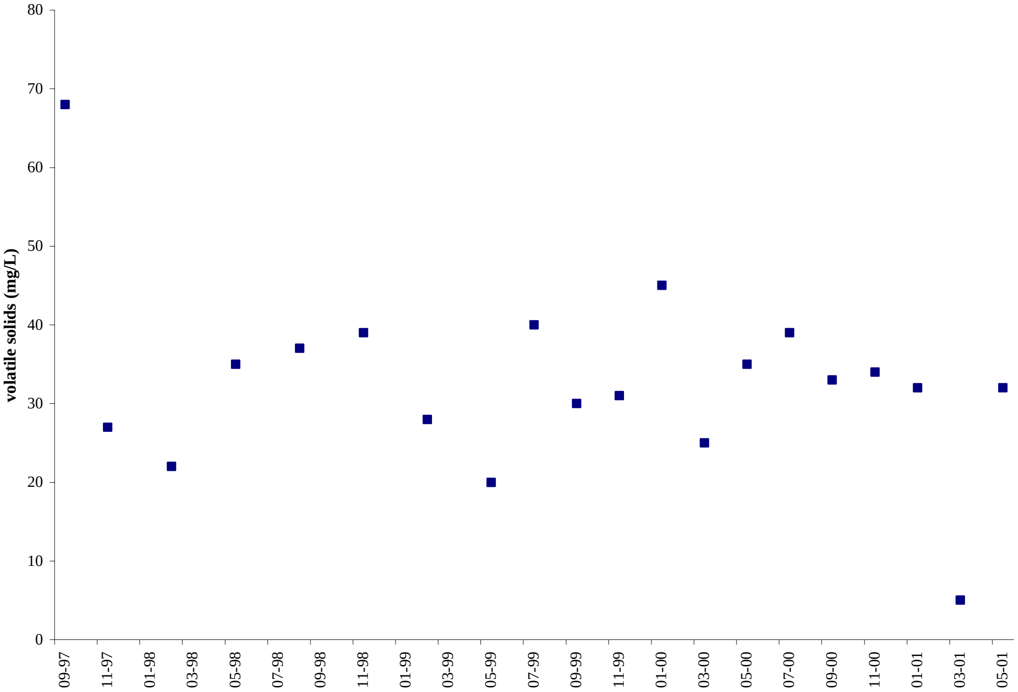

Figure D.26 Volatile solids concentrations at 9-PKC009.29.

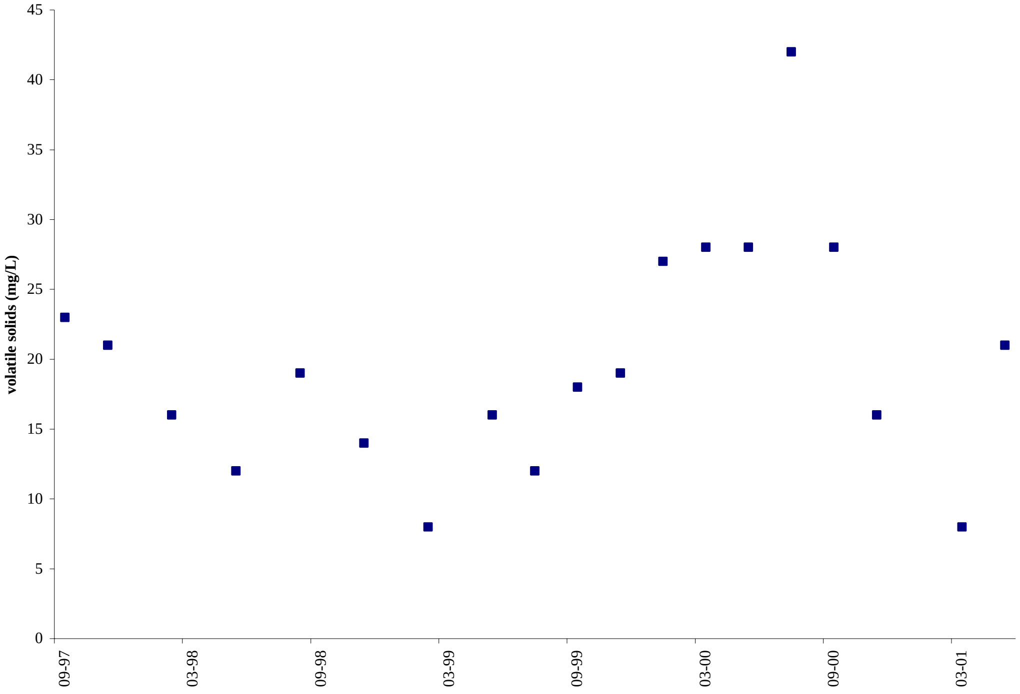

Figure D.27 Volatile solids concentrations at 9-PKC011.11.

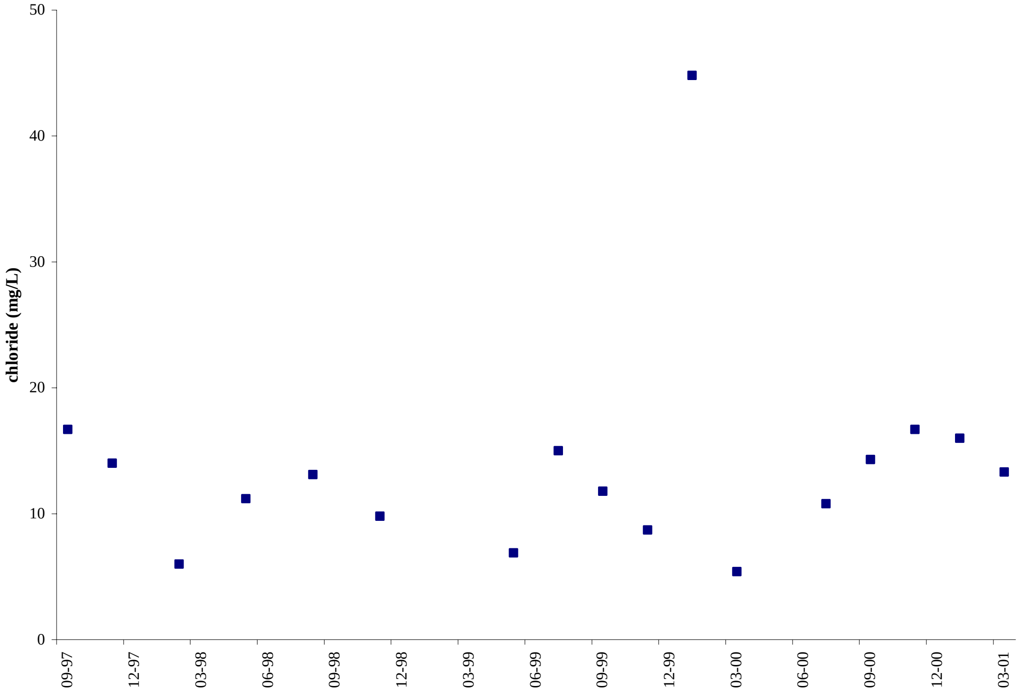

Figure D.28 Chloride concentrations at 9-PKC009.29.

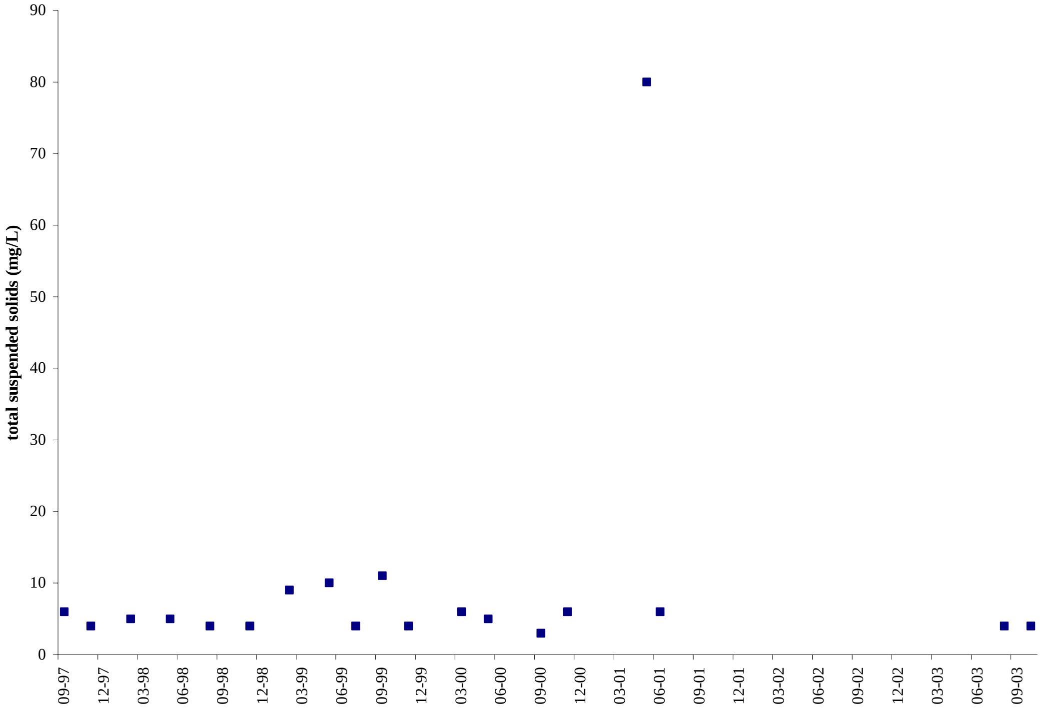

Figure D.29 Total suspended solids concentrations at 9-PKC009.29.

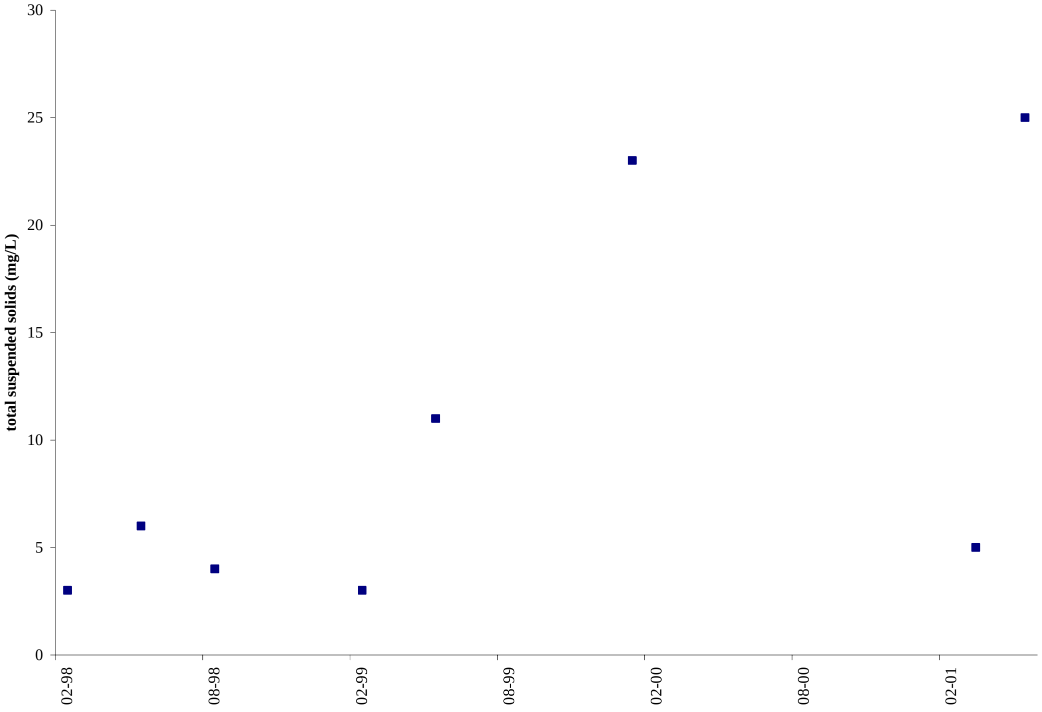

Figure D.30 Total suspended solids concentrations at 9-PKC011.11.

APPENDIX E

Table E.1 Average annual *E. coli* loads (cfu/year) modeled for the Peak Creek watershed impairment after TMDL allocation with permitted point source loads increased five times.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Peak Creek (FC)	4.35E+09	4.62E+12	*Implicit*	4.62E+12
VAG402040[1]	*4.35E+09*			

[1] General permits – single family home