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

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EXECUTIVE SUMMARY

Background and Applicable Standards

Crab Creek was placed on the Commonwealth of Virginia's 1996 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 Crab 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 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. The United States Environmental Protection Agency (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 macro-invertebrate community is typically assessed through measurement of 8 biometrics that evaluate 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, Crab 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 are seventeen Virginia Pollutant Discharge Elimination System (VPDES) permitted dischargers in the Crab Creek watershed. Twelve are construction stormwater discharge permits and three are industrial stormwater discharge permits. In addition, there are two Municipal Separate Storm Sewer (MS4) permits; one held by the Town of Christiansburg and one held by the Virginia Department of Transportation.

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). Benthic assessments are very good at determining if a particular stream segment is impaired or not, but generally do not 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 systematically identify the most probable stressor(s) for Crab Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data from ambient monitoring stations 9-CBC001.00, 9-CBC004.38, 9-CBC006.35 and 9-CBC009.81 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 potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature and organic matter.

The results of the stressor analysis for Crab 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).

The results indicate that sediment is the Most Probable Stressor and, therefore, it was used to develop the TMDL due to its interconnection with other possible stressors, *i.e*. organic matter and nutrient enrichment. For example, limiting livestock access to streams allows for streambank vegetation regrowth and reduces inputs of organic matter (manure) and nutrients. Total phosphorus is typically bound to soil particles and enters the aquatic environment by the transport of sediment from the land. Stream buffers can reduce overland flow velocities and decrease the amount of sediment and sediment bound nutrients that reach the stream.

Sediment is delivered to the Crab Creek watershed through surface runoff (rural and urban areas), streambank erosion, point sources, and natural erosive processes. The sediment process is a natural and continual process that is often accelerated by human activity. During runoff events (natural rainfall or irrigation), sediment is transported to streams from land areas (*e.g.*, agricultural fields, lawns, forest, etc.). Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (along stream edge and uncontrolled access to streams), forest harvesting, and construction (roads, buildings, etc.) 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.

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. Over 40 % of the Crab Creek watershed is located within the town limits of Christiansburg. 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).

Fine sediments are included in total suspended solids (TSS) loads that are permitted for wastewater, industrial stormwater and construction stormwater discharge. There are 17 VPDES permits (12 construction stormwater discharge permits, three industrial stormwater discharge permits, and two MS4 permits).

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 Crab 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 Upper Tinker Creek watershed was compared to the Crab 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 the Upper Tinker Creek watershed were used as base input parameters for Crab Creek when calibrating Crab Creek with the flow values from USGS Station #03171170 (Crab Creek at STP near Christiansburg, VA). 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 Crab Creek, were used as initial representation of the watershed. This representation was then refined through calibration to instantaneous flow measurements collected for Crab Creek primarily during base-flow conditions. The representative flow period used for hydrologic calibration covered the period October 1995 through September 2003. While there were no peak flow values in the observed record to verify output during storm events, and only 14 observations in total, the model predicted base flow conditions well, with an R^2 value of 0.66 during modeled base flow events. For purposes of modeling watershed inputs to in-stream water quality, the Crab Creek drainage area was divided into five subwatersheds. The water quality calibration and validation were conducted using monitored data collected at VADEQ monitoring stations between October 1993 and September 2003. Modeled coliform levels matched observed levels during a variety of flow conditions, indicating that the model was well calibrated.

General Standard (benthic) - Sediment

There is no existing in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Crab Creek watershed. This approach pairs two watersheds: one that is supportive of their designated use(s) and one whose streams are impaired. The Toms Creek watershed was selected as the TMDL reference for Crab Creek. The TMDL sediment load was defined as the modeled sediment load for existing conditions from the non-impaired Toms Creek watershed, area-adjusted to the Crab Creek watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling for both Crab Creek and Toms Creek. Sufficient flow rate data was not available within Crab Creek 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 two watersheds.

Existing Conditions

Fecal Coliform

Wildlife populations and ranges, biosolids application rates and practices, the 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 Crab Creek watershed were used to calculate fecal coliform loads from land-based nonpoint sources in the watershed. The estimated fecal coliform production and accumulation rates from 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 of October 1986 through 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) - Sediment

The benthic TMDL for Crab Creek was developed using sediment as the primary stressor and the Toms Creek watershed as the reference watershed. The Toms Creek watershed is slightly larger than the Crab Creek watershed. Landuse categories in the Toms Creek watershed were decreased by a multiple of 0.963 to establish a common basis for comparing loads between the two watersheds. After area-adjustment, the Toms Creek watershed was equal in size to Crab Creek (5,042.1 ha). The average annual sediment load (metric tons per year) from the area-adjusted Toms Creek defined the TMDL sediment load for Crab Creek. The sediment loads for existing conditions were calculated using the period of January 1992 through March 2000 as representative of both wet and dry periods of precipitation. The target sediment TMDL load for existing conditions was **2,551 T/yr**. The existing load from Crab Creek was **6,306 T/yr.** The benthic TMDL for Crab Creek is composed of three components: waste load allocations (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (MOS), which was set to 10% for this study. The load for allocation for existing conditions becomes **2,296 T/yr**.

Since urban development is expected to occur in Crab Creek over the next 20 to 25 years, changes in landuse were estimated by modeling future loads as part of the allocation process. The broad based landuse change that was modeled resulted in the percentage developed land increasing from 8.0% to 11.3%. The sediment load including future development was **7,174 T/yr.**

Load Allocation Scenarios

Fecal Coliform

The next step in the TMDL process was 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 of loading from existing conditions are given in Table ES.1. Scenario four shows the reduction for the targets for Stage I implementation goals.

Table ES.1 Reduction percentages in loading from existing conditions.

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	76.7	27.8
2	0	0	0	0	0	100	73.3	27.8
3	0	0	90	50	50	100	11.7	17.6
4	0	0	100	60	60	100	3.33	16.1
5	0	0	100	99	99	100	0.0	1.92
6	0	99	100	99	99	100	0.0	1.53
7	99	99	100	99	99	100	0.0	1.53
8	0	99	100	99.95	99.95	100	0.0	0.0

General Standard (benthic) - Sediment

The reductions required to meet the TMDL considering future growth are shown in Table ES.2. To aid the development of TMDL allocation scenarios, nonpoint source areas were grouped into agriculture, urban and forestry categories. Sub-categories for agriculture (*i.e.*, hay, pastureland, cropland) and forestry (disturbed forest, undisturbed forest) were also included to provide a more specific allocation. The predominant sediment loads were from agriculture (cropland and pastureland) and the stream channel.

Table ES.2 Required reductions for Crab Creek Watershed.

Load Summary	Crab Creek	Reductions Required	
		(T/yr)	(% of existing load)
Projected Future Load	7,197	4,978	78.9
Existing Load	6,307	4,088	64.8
TMDL	2,551		
Target Modeling Load	2,219		

Two sediment reduction alternatives are presented in Table ES.3. Alternative 1 requires sediment reductions from pastureland (72%), channel erosion (79.1%), and MS4 permitted areas (50%). The reductions could be achieved through riparian buffers, livestock exclusion from streams, stormwater management and improved pasture management. Alternative 2 requires a 41% reduction from cropland, a 51% reduction from pastureland, an 82% reduction of channel erosion, and 50% reductions from MS4 permitted areas. Significant reductions appear feasible through the implementation of aggressive measures to minimize streambank erosion through improved stormwater control in urban areas, installation of riparian buffers, and livestock exclusion from streams.

Table ES.3 TMDL sediment allocation scenarios for the Crab Creek impairment.

Sediment Source Categories	Existing Condition (t/yr)	Allocations Alternative 1 (%)	Alternative 1 (T/yr)	Alternative 2 (%)	Alternative 2 (T/yr)
LDR-PER	14.662	0	14.662	0	14.662
HDR-PER	0.041	0	0.041	0	0.041
COM-PER	3.477	0	3.477	0	3.477
Transitional	31.272	0	31.272	0	31.272
Forest	34.375	0	34.375	0	34.375
Disturbed Forest	114.548	0	114.548	0	114.548
Pastureland	**1,996.801**	**72**	**547.801**	**51**	**978.432**
Cropland	**761.808**	0	761.808	**41**	**449.467**
LDR-IMP	2.686	0	2.686	0	2.686
HDR-IMP	0.016	0	0.016	0	0.016
COM-IMP	3.716	0	3.716	0	3.716
Water	0.000	0	0.000	0	0.000
MS4-Existing	**55.145**	**50**	**27.573**	**50**	**27.573**
MS4-Future	**22.351**	**50**	**11.176**	**50**	**11.176**
NPS Load	3,040.942		1.553.151		1,671.441
Active Ag. BMPs	-281.960		-281.960		-281.960
Channel Erosion	**4,416.561**	**79.1**	**923.061**	**82**	**794.981**
Point Source Loads	21.230		21.230		21.230
Total	**7,196.773**		**2,215.482**		**2.205.692**
Target Allocation Load (TMDL-MOS-WLA)			**2,219.000**		**2219.000**

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 Crab 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 approves 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 direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion. Improved pasture management (including less intensive grazing, minimizing animal concentrations by frequent movement of winter feeding areas, improving pasture forages, etc.) can significantly reduce soil loss from pasture areas. Reducing tillage operations, farming on the contour, strip cropping, maintaining a winter cover crop, etc. have been demonstrated as effective measures to reduce erosion from cropland agriculture. Additionally, in both urban and rural areas, reducing the human bacteria loading from failing septic systems should be a primary implementation focus because of the 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 the opportunity to participate in the development of the TMDL implementation plan. While specific goals for BMP implementation will be established as part of the implementation plan development, the Stage I scenarios targeted controllable, anthropogenic bacteria and sediment sources.

Public Participation

During development of the TMDL for the Crab 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 first public meeting was held on October 14, 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 final public meeting on March 17, 2004. There was a 30 day-public comment period after the first and final public meetings and no written comments were received.

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 the meetings 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 a TMDL for the Crab Creek watershed area is based on provisions of the Clean Water Act. The document, *Guidance for Water Quality-Based Decisions: The TMDL Process* (EPA, 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 Crab Creek watershed in Virginia's Montgomery County is part of the New River basin (Figure 1.1). Crab Creek flows into the New River, which flows into the Ohio River. The Ohio River joins the Mississippi River and eventually flows into the Gulf of Mexico.

According to the 1996 303(d) TMDL Priority List (VADEQ 1996), Crab Creek was listed as impaired. VADEQ has identified this segment as impaired with regard to both fecal coliform and the General Standard (benthic). Crab Creek remained on the 1998 and 2002 303(d) lists.

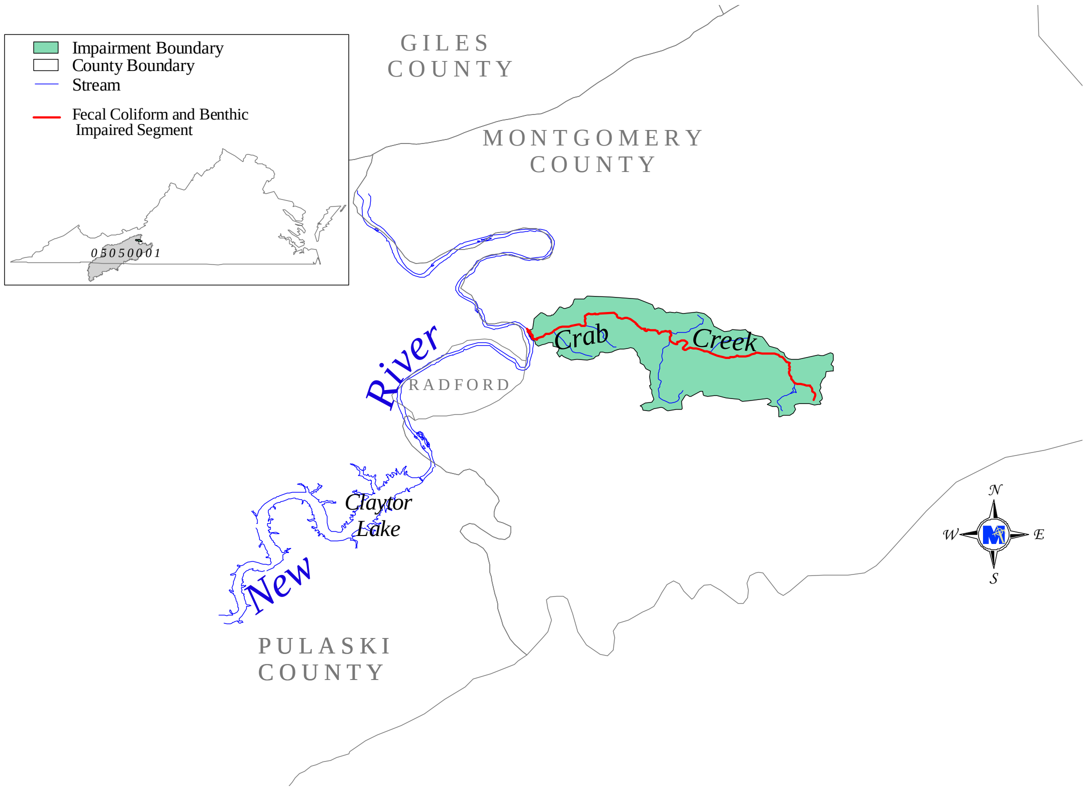


Figure 1.1 Location of impaired stream in the Crab Creek Watershed.

Crab Creek (waterbody ID # VAW-N18R) was listed as impaired for both fecal coliform and benthic impairments. During the 1998 assessment period, 15 of 56 samples taken at river mile 04.38, and 21 of 56 samples taken at river mile 06.35 violated the fecal coliform standard. Subsequently, during the 2002 assessment period, 21 of 60 samples taken at river mile 04.38, and 21 of 59 samples taken at river mile 06.35 violated the standard. Crab Creek had a rating of severely impaired during the 1998 assessment period at benthic monitoring station 9CBC004.38, and was rated as moderately impaired at benthic monitoring station 9CBC006.35. During the 2002 assessment period, Crab Creek was rated as moderately impaired at both benthic monitoring stations (9CBC004.38 and 9CBC006.35). The impairment of Crab Creek extends from the headwaters to the confluence with the New River (12 miles).

The Crab Creek watershed (USGS Hydrologic Unit Code #0505001) is part of the New River basin. The land area of the affected watersheds is approximately 12,400 acres, with pasture and forest as the primary landuses (Figure 1.2).

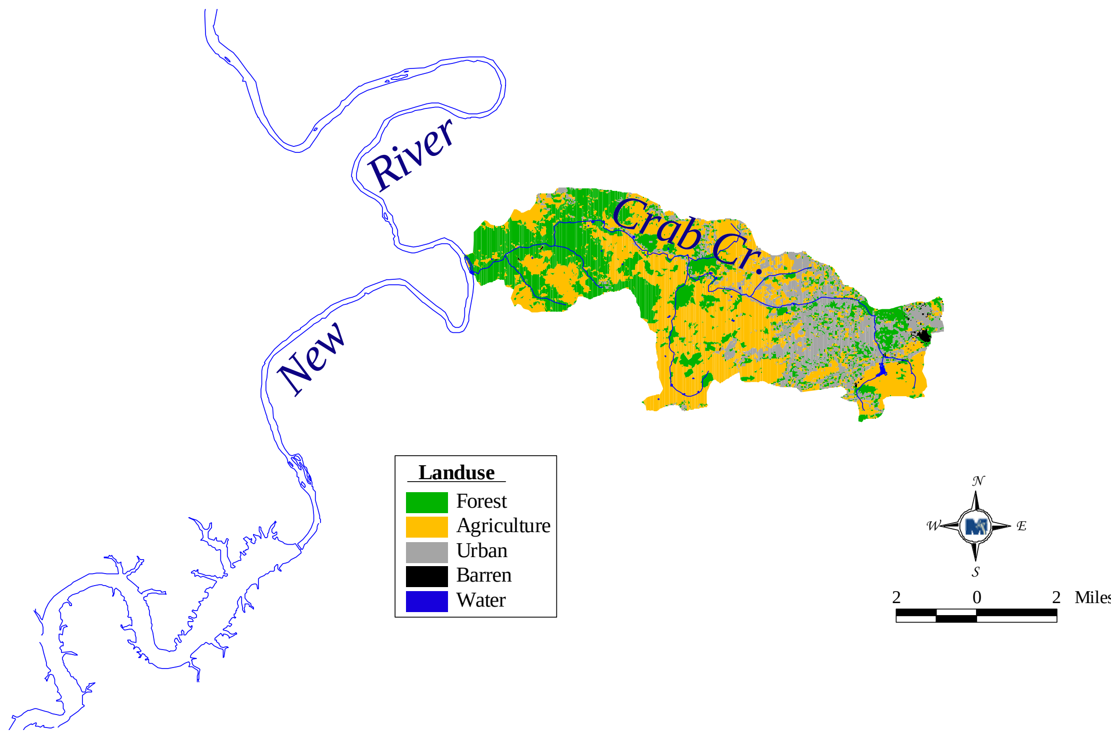


Figure 1.2 Landuses in the Crab Creek Watershed.

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.

Crab Creek	
Landuse	**Acreage**
Water	11
Residential/Recreational	1,591
Commercial & Services	639
Barren	55
Woodland/Wetland	4,096
Pasture/Hay	5,279
Livestock Access	207
Cropland	500

The estimated human population within the drainage area is 15,711 (USCB, 1990, 2000). Among Virginia counties, Montgomery County ranks 9th for the number of dairy cows, 27th for the number of all cattle and calves, 31st for beef cattle, and 14th for production of corn silage (Virginia Agricultural Statistics, 2001). Montgomery County is also home to 543 species of wildlife, including 57 types of mammals (*e.g.*, beaver, raccoon, and white - tailed deer) and 196 types of birds (*e.g.*, wood duck, wild turkey, Canada goose) (VDGIF, 1999).

For the period 1952 to 2000, the Crab Creek watershed received average annual precipitation of approximately 40.43 inches, with 53% of the precipitation occurring during the May through October growing season (SERCC, 2002). Average annual snowfall is 23.1 inches with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 51.5 ºF. The highest average daily temperature of 82.8 ºF occurs in July, while the lowest average daily temperature of 20.5 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., <u>swimming and boating</u>; the propagation and growth of <u>a balanced, indigenous population of aquatic life</u>, 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 has since 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

Crab Creek was initially placed on the Virginia 1996 303(d) TMDL Priority List based on monitoring performed. Crab Creek remained on the 2002 303(d) Report on Impaired Waters. 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 Crab 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.

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 Crab Creek is protected during times when it is most vulnerable.

Critical conditions are important because they describe the factors that combine to cause a violation of water quality standards and help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Crab 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 2.4). That is, the analysis showed no dominance of either nonpoint sources or point sources. High concentrations were recorded in all flow regimes. Based on this analysis, a time period for allocation was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting period was October 1980 through September 1985.

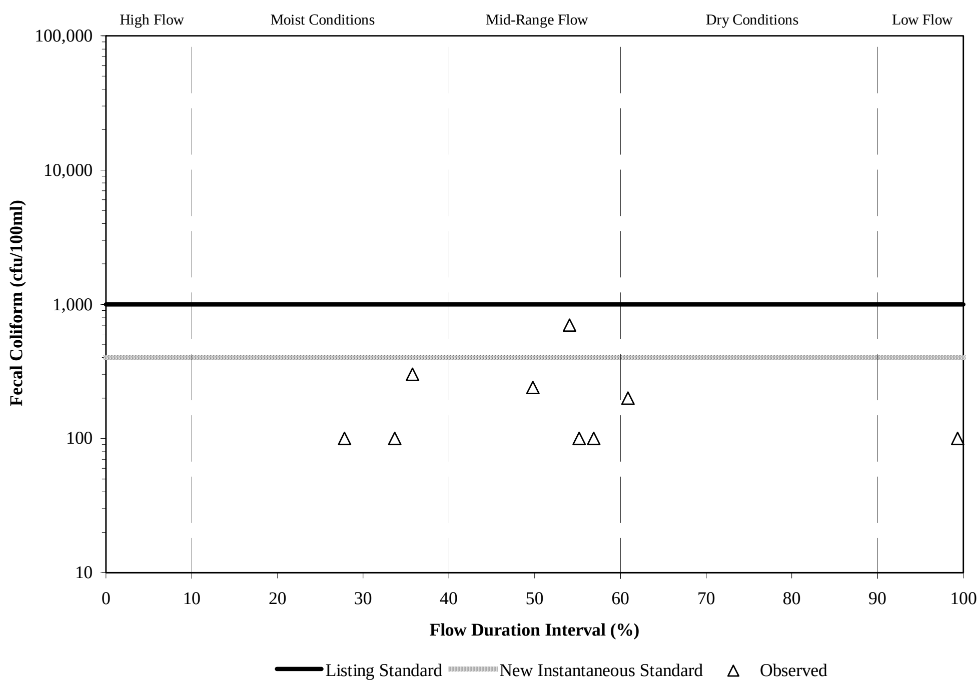


Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 9CBC001.00) and discharge in Crab Creek.

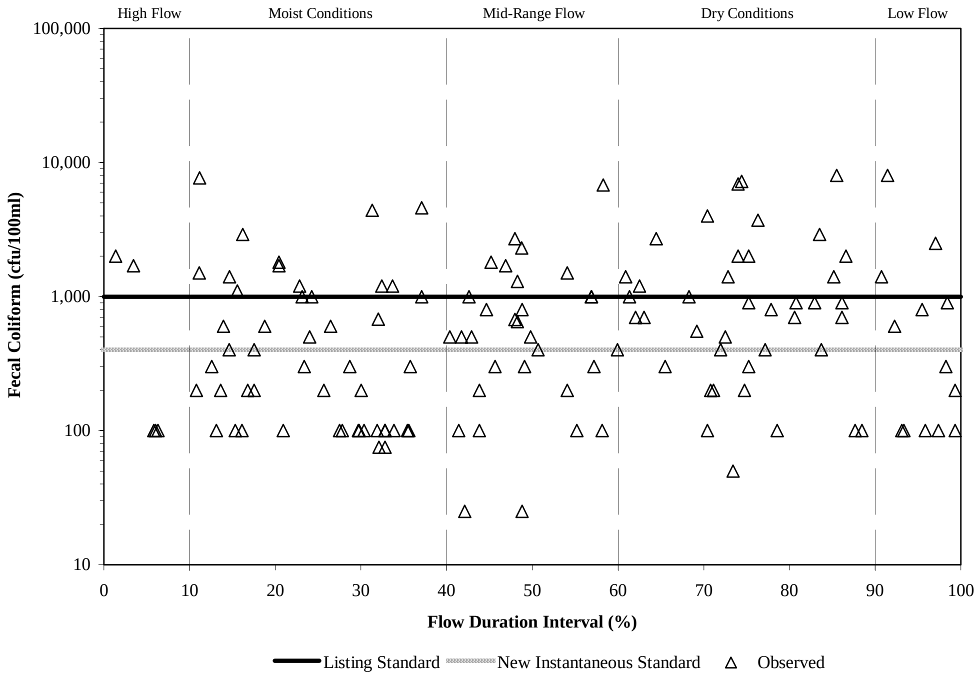


Figure 2.2 Relationship between fecal coliform concentrations (VADEQ Station 9CBC004.38) and discharge in Crab Creek.

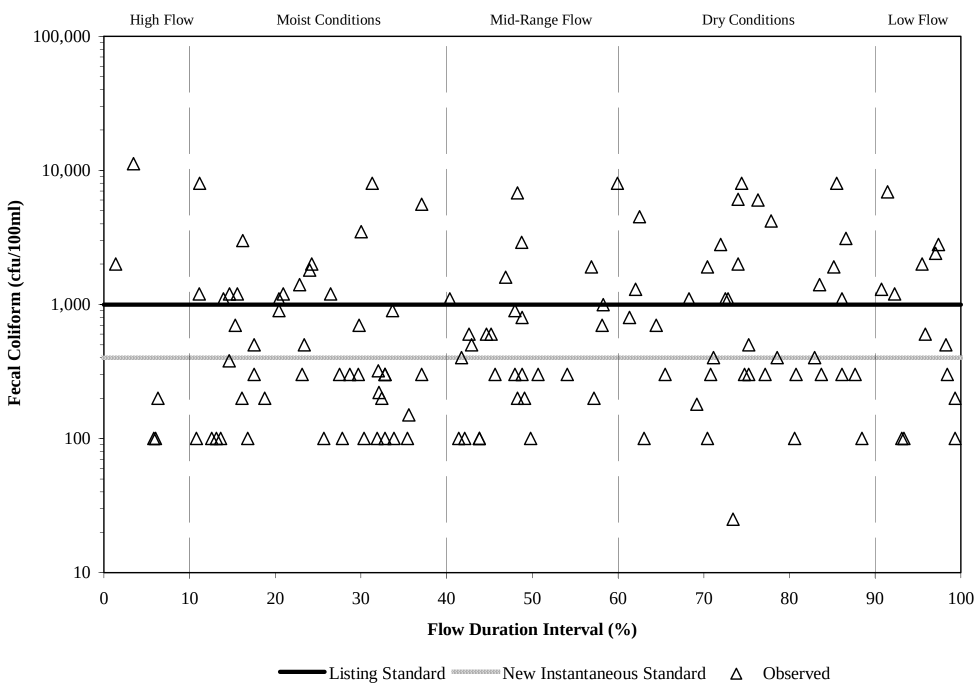


Figure 2.3 Relationship between fecal coliform concentrations (VADEQ Station 9CBC006.35) and discharge in Crab Creek.

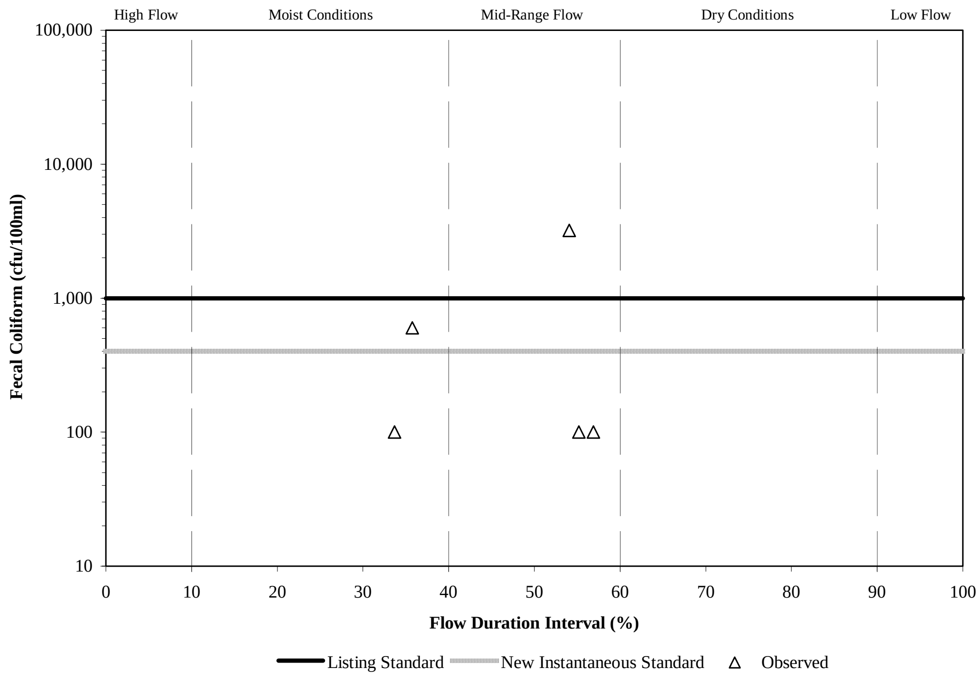


Figure 2.4 Relationship between fecal coliform concentrations (VADEQ Station 9CBC009.81) and discharge in Crab Creek.

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 Crab 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 5 VADEQ in-stream monitoring stations used for TMDL assessment (Figure 2.5), and
- Bacteria enumerations and bacterial source tracking from 2 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 May 2002 (Table 2.1) and are included in the analysis. Samples were taken for the express 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.

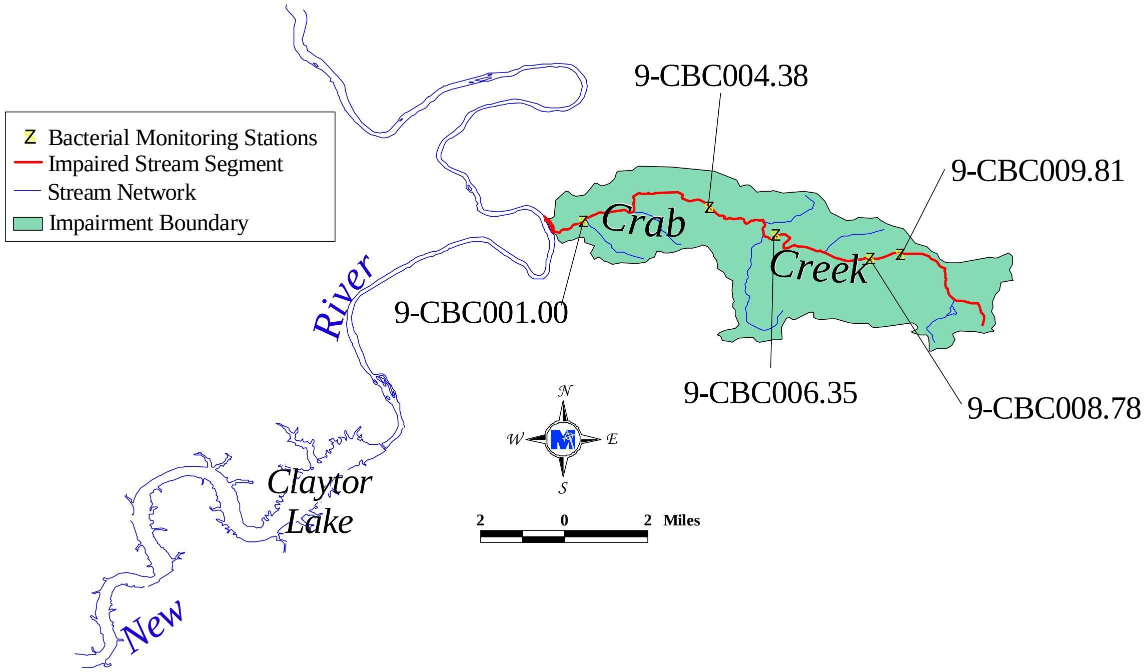


Figure 2.5 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Crab Creek watershed.

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

Impairment	VADEQ Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] %	Violations[2] %
Crab Creek	9-CBC001.00	9	100	700	216	100	0	11
Crab Creek	9-CBC004.38	138	25	8,000	1,081	500	28	53
Crab Creek	9-CBC006.35	132	25	11,200	1,335	400	35	49
Crab Creek	9-CBC008.78	1	2,400	2,400	2,400	2,400	100	100
Crab Creek	9-CBC009.81	5	100	3,200	820	100	20	40

[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 2 sites throughout the Crab Creek watershed (Figure 2.6). 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. Table 2.2 and Table 2.3 summarize the fecal coliform and *E. coli* concentration data, respectively, at the ambient stations. Bacterial source tracking (BST) is discussed in greater detail in Section 2.2.2.2.

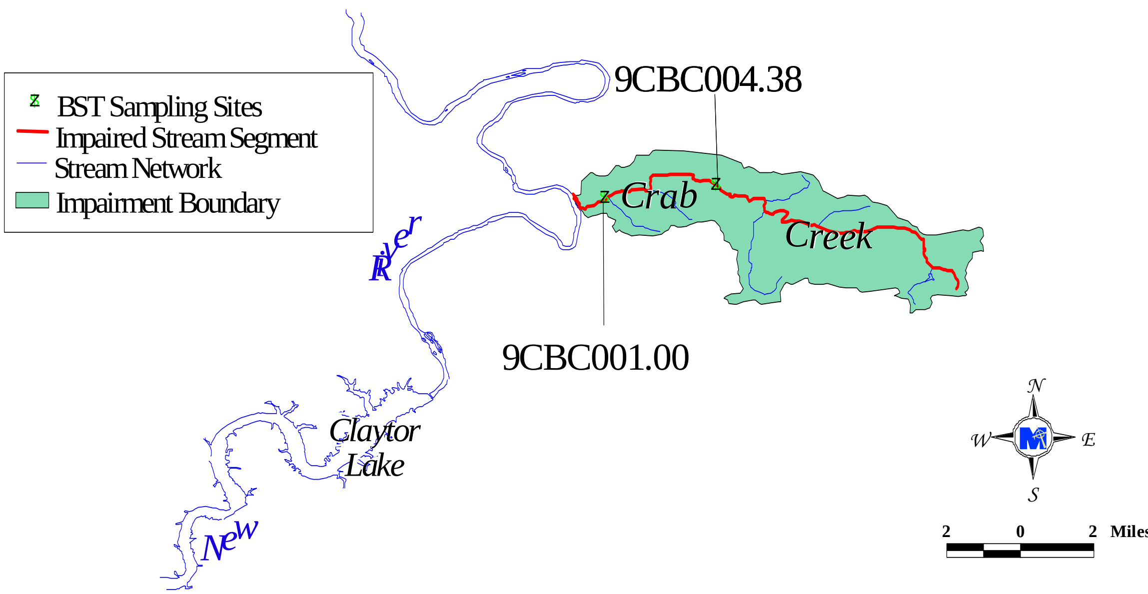


Figure 2.6 Location of BST water quality monitoring stations in the Crab Creek watershed.

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] (%)
Crab Creek	9CBC001.00	12	80	8,100	998	315	8	42
Crab Creek	9CBC004.38	12	210	5,200	918	360	17	50

[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] (%)
Crab Creek	9CBC001.00	12	1	400	176	110	33
Crab Creek	9CBC004.38	12	88	490	248	175	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 were within the range of 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. Violations were persistent throughout the monitored period.

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. These isolates were identified as originating from either human, pet, livestock, or wildlife sources.

BST results of water samples collected at two ambient stations in the Crab Creek drainage are reported in Table 2.4. The BST results indicate the presence of all sources (*i.e.,* human, wildlife, livestock, and pets) contributing to the fecal bacteria violations. The *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 two 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.

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

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as[1]: Human	Pets	Livestock	Wildlife
9-CBC001.00	11/25/02	80	4	0	50	0	50
	12/1702	200	110	**46**	4	**46**	4
	1/29/03	280	<1	--	--	--	--
	2/25/03	280	110	0	**58**	**42**	0
	3/31/03	200	110	**17**	**29**	**29**	**25**
	4/29/03	270	80	29	29	0	42
	5/28/03	700	380	**17**	**37**	**13**	**33**
	6/26/03	600	200	**55**	4	**33**	8
	7/22/03	490	260	**25**	**33**	9	**33**
	8/27/03	8,100	400	**21**	**29**	**21**	**17**
	9/22/03	430	350	**25**	0	**46**	**29**
	10/22/03	350	110	0	0	88	12
9-CBC004.38	11/25/02	300	100	**29**	**25**	**46**	0
	12/17/02	2,500	450	**41**	8	**38**	**13**
	1/29/03	240	130	**26**	**30**	9	**35**
	2/25/03	240	120	**17**	**49**	**13**	**21**
	3/31/03	210	88	0	**38**	**45**	**17**
	4/29/03	230	90	**38**	**29**	**25**	8
	5/28/03	500	380	**21**	**17**	**21**	**41**
	6/26/03	250	110	**17**	**13**	4	**66**
	7/22/03	460	380	**13**	**25**	**29**	**33**
	8/27/03	5,200	420	**13**	0	8	**79**
	9/22/03	470	490	**12**	**17**	8	**63**
	10/22/03	420	220	0	0	**88**	**12**

[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. No 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. An overall trend in fecal coliform concentrations was detected at station 9CBC004.38. The slope of this increase was estimated at 2.5 cfu/100ml/yr. The remaining stations had no overall trend (Table 2.5). Differences in mean monthly fecal coliform concentration for station 9CBC004.38 are indicated in Table 2.6. Fecal coliform concentrations in months with the same median group letter are not significantly different from each other at the 95% significance level. For example, March, May, June, July, August and September are all in median group "B" and are not significantly different from each other. Flows in months with multiple groups are the result of the 95% confidence interval for that month, overlapping more than one median group. For example, March is in both median group "A" and "B" and is not significantly different than either group. The remaining stations had no seasonality effect.

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]
CBC001.00	316.32	220	790	100	261.52	19	--
CBC004.38	1,014.39	500	8,000	100	1,528.29	165	2.5
CBC006.35	1,250.67	400	8,000	100	1,935.51	149	No Trend
CBC008.78	2,400.00	2,400	2,400	2,400	--	1	--
CBC009.81	1,050.00	415	3,500	100	1,212.02	14	--

[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

Table 2.6 Summary of Mood Median Test on mean monthly fecal coliform at Station 9CBC004.38 (p=0.001).

Month	Mean (cfu/100 ml)	Minimum (cfu/100 ml)	Maximum (cfu/100ml)	Median Groups	
January	280.71	100	600	A	
February	469.23	100	2,900	A	
March	1,110.00	100	8,000	A	B
April	536.92	100	1,700	A	
May	1,507.14	100	7,700	A	B
June	1,689.58	500	4,400		B
July	968.46	100	2,500	A	B
August	1,095.83	400	4,000	A	B
September	1,685.00	150	6,900	A	B
October	1,295.83	100	7,200	A	
November	666.00	100	2,200	A	
December	1,100.00	100	8,000	A	

3. FECAL COLIFORM SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential significant sources of fecal coliform in the Crab 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 currently permitted to discharge in the Crab Creek watershed through the Virginia Pollutant Discharge Elimination System (VPDES) are listed in Table 3.1 and shown in Figure 3.1. After 1998, the Town of Christiansburg STP, Permit VA0061751, no longer discharged to Crab Creek. There is currently one Municipal Separate Storm Sewer System (MS4) permit held by the Town of Christiansburg (VAR040025) and one held by the Virginia Department of Transportation (VDOT – VAR040016).

Table 3.1 Permitted Point Sources in the Crab Creek Watershed.

Facility	VPDES #	Design Discharge (MGD)	Permitted For Fecal Control	Data Availability
Marshall Concrete Products Inc - Christiansburg	VAG110015	.001	No	No Data
Town of Christiansburg	VAR051370	Stormwater	No	Not Applicable
VDOT - Salem District - Rte 81 0081-060-119 C501	VAR100229	Stormwater	No	Not Applicable
VDOT - Christiansburg (4541)	VAR101126	Stormwater	No	Not Applicable
Depot Street School Residence	VAR102138	Stormwater	No	Not Applicable
Oaktree Townhomes Phase VI	VAR102140	Stormwater	No	Not Applicable
Holy Spirit Catholic Church	VAR102148	Stormwater	No	Not Applicable
New River Medical Assoc. Medical Office Park	VAR102164	Stormwater	No	Not Applicable
Edgemont of Diamond Hill	VAR102279	Stormwater	No	Not Applicable
Lions Gate	VAR102308	Stormwater	No	Not Applicable
Hunters Ridge Phase III	VAR103014	Stormwater	No	Not Applicable
Oak Tree Professional Park	VAR103064	Stormwater	No	Not Applicable
Hans Meadow Drainage Improvements	VAR103090	Stormwater	No	Not Applicable
Oak Tree Townhouses	VAR103349	Stormwater	No	Not Applicable
Federal Express Corp - WALA Station	VAR520312	Stormwater	No	Not Applicable
MS4 – Town of Christiansburg	VAR040025	Stormwater	Not Currently	No Data
MS4 – VDOT	VAR040016	Stormwater	Not Currently	No Data

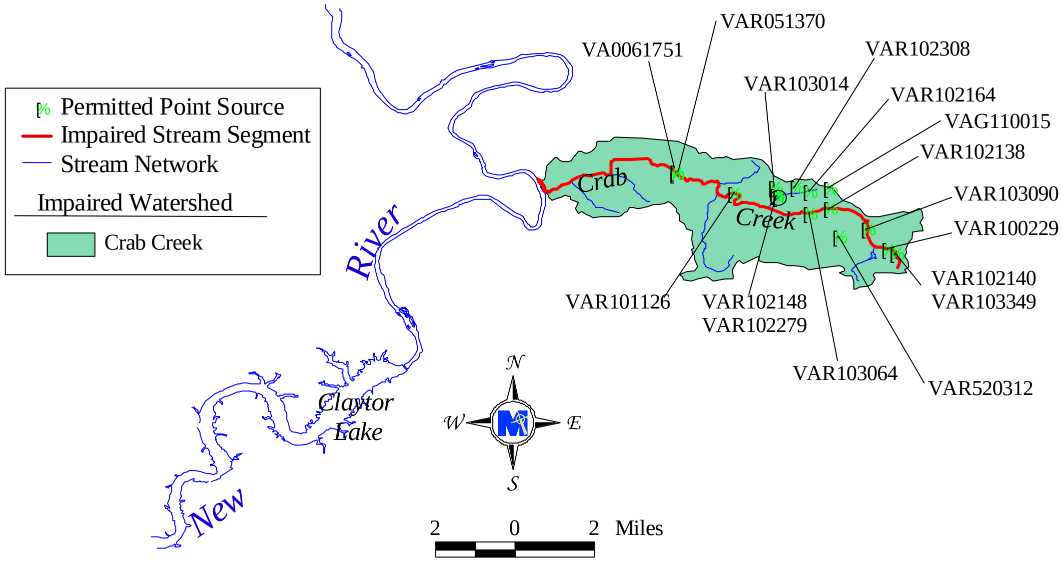


Figure 3.1 Location of VPDES permitted point sources in the Crab Creek watershed.

3.2 Assessment of Nonpoint Sources

In the Crab 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 Crab Creek watershed.[1]

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other [2]
Crab Creek	15,711	6,950	5,187	1,713	50

[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 Crab Creek watershed are beef and dairy cattle, horses, and sheep; however, 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 Montgomery County and the TMDL project areas. Table 3.3 gives estimates of livestock populations in the Crab 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 Crab Creek watershed.

Watershed	Beef Cattle	Dairy Cattle	Horse	Sheep
Crab Creek	1,467	100	290	100

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, VADCR, and VCE personnel (Table 3.6 through Table 3.8). Horses, sheep, and beef cattle 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 Crab Creek watershed is relatively small. The Town of Christiansburg Sewage Treatment Plant is the source of biosolids. Table 3.9 shows the amount of biosolids produced and distributed in the affected watershed by source and year. Table 3.10 and Figure 3.2 show acreages permitted for biosolids application and the actual application information. The sensitivity analysis (see 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 Crab Creek watershed.

Source	1996	1997	1998	1999	2001	2002	2003
Christiansburg STP	43.56	98.79	48.44	22.33	53.90	93.20	100.62

Table 3.10 Acreages permitted for biosolids applications and actual applications by subwatershed in the Crab Creek watershed.

Impairment	Subwatersheds	Acres Permitted	Acres Applied (1994-2003)	Dry Tons Applied (1994-2003)	Fecal Coliform Applied
Crab Creek	CB01	0.00	0.00	0.00	0.00E+00
	CB02	122.21	122.21	59.47	2.28E+12
	CB03	251.23	251.23	401.37	9.28E+12
	CB04	0.00	0.00	0.00	0.00E+00
	CB05	0.00	0.00	0.00	0.00E+00
TOTAL		373.44	373.44	460.84	1.16E+13

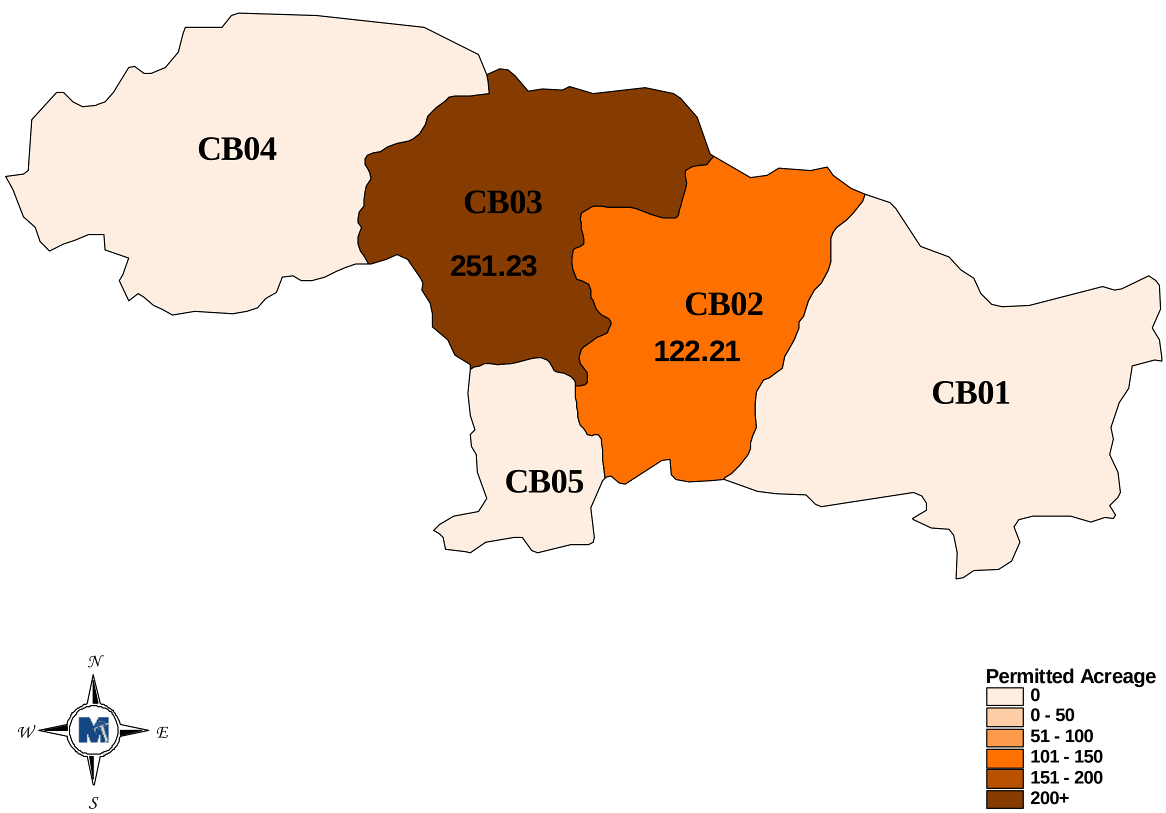


Figure 3.2 Location of acres permitted for biosolids application in Crab Creek.

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 numbers of animals in the Crab 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	Montgomery County Density	Density Unit
Raccoon	0.0703	an/ac of habitat
Muskrat	2.75	an/ac of habitat
Beaver	4.8	an/mi of stream
Deer	0.047	an/ac of habitat
Turkey	0.014	an/ac of forest
Goose	0.003	an/ac
Duck	0.011	an/ac

Table 3.12 Estimated wildlife populations in the Crab Creek watershed.

Watershed	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Crab Creek	550	131	3	10	617	781	48

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 Crab Creek watershed.

Watershed	Dog	Cat
Crab Creek	3,712	4,156

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 Crab 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 Crab Creek drainage areas were divided into five 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.

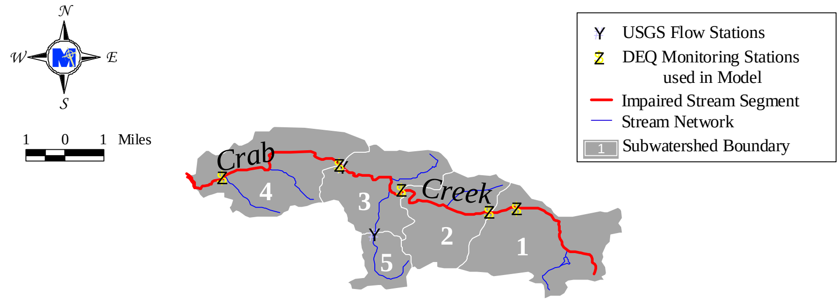


Figure 4.1 Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Crab Creek watershed.

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

Station Number	Reach Number
9-CBC009.81	1
9-CBC006.35	2
9-CBC004.38	3
9-CBC001.00	4

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 the 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). The percentages of impervious and pervious area were estimated from data provided in VADCR's online 2002 NPS Assessment Database (VADCR, 2002) (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 Crab 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 Crab Creek drainage area.

Landuse	Crab Creek Acreage
Water	11
Residential/Recreational	1,591
Commercial & Services	639
Barren	55
Woodland/Wetland	4,096
Pasture/Hay	5,279
Livestock Access	207
Cropland	500

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 met 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 Crab 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 1,443 septic systems were estimated in the Crab Creek watershed in 1995. During allocation runs, the number of households was projected to 2003, based on current Montgomery County growth rates (USCB, 2000) resulting in 1,713 septic systems (Table 4.4). The number of septic systems was projected to increase to 1,882 by 2008.

Table 4.4 Estimated failing septic systems (2003).

Impaired Segment	Total Septic Systems	Failing Septic Systems	Straight Pipes
Crab Creek	1,713	359	4

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 Crab 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 9 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 Montgomery 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 landuse 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 Crab 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% remaining was treated as manure deposited on land. However, applying it in a separate landuse 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 Crab 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. No seasonal variation was assumed for the remaining species. 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). It was estimated, for all animals other than beaver, 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 developed by MapTech in the Crab Creek watershed.

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 the 1990 and 2000 Census (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 populations of 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 and consisted 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.

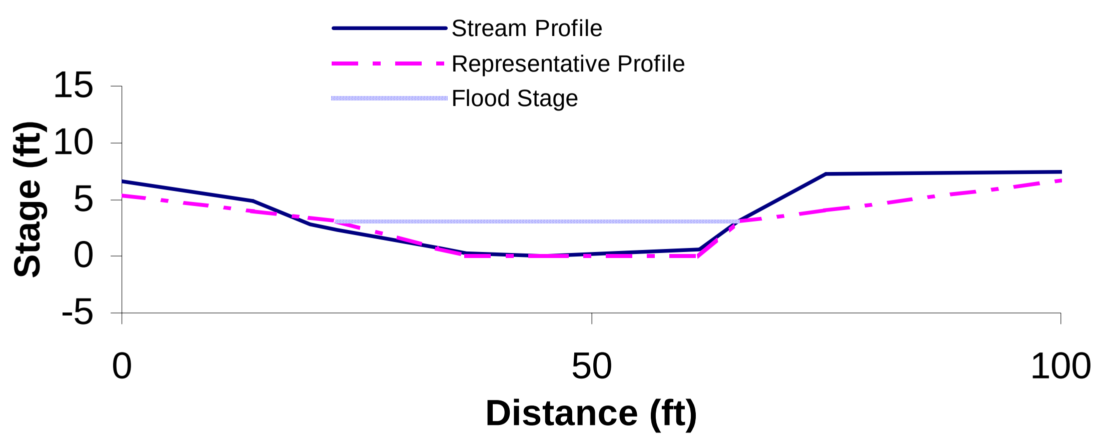


Figure 4.3 Stream profile representation in HSPF.

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, and 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 representative modeling 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 #03171170 (Crab Creek at STP near Christiansburg, VA) were available from 1995 to 2003. Due to the sparse amount of data (*i.e.*, 14 observations over an 8-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 Crab Creek segment on the 1998 303(d) list. 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 were not significantly different from the historical data (Table 4.6, Figures 4.4 and 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

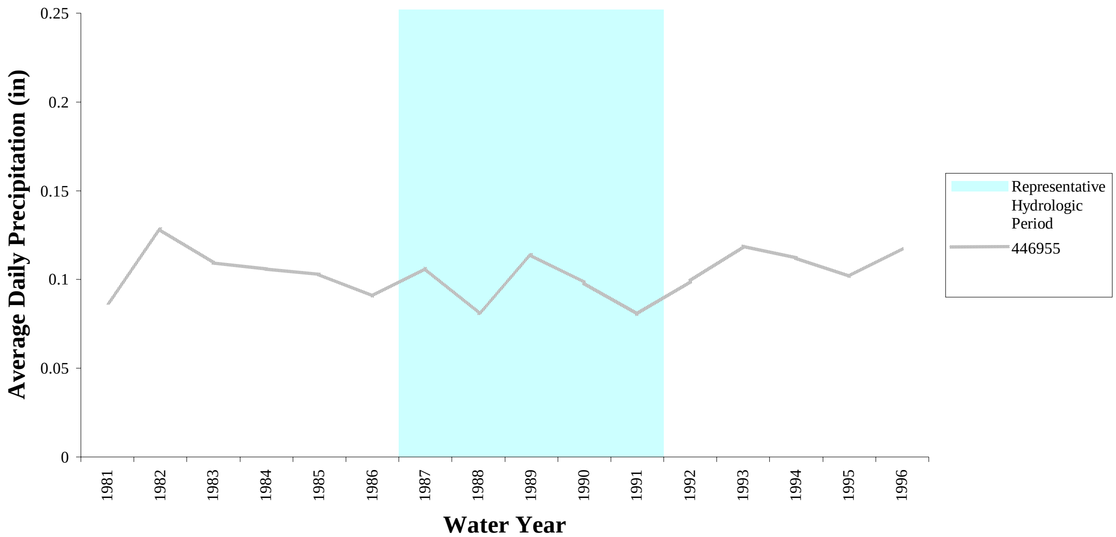


Figure 4.4 Annual Historical Precipitation (Station 446955) Data

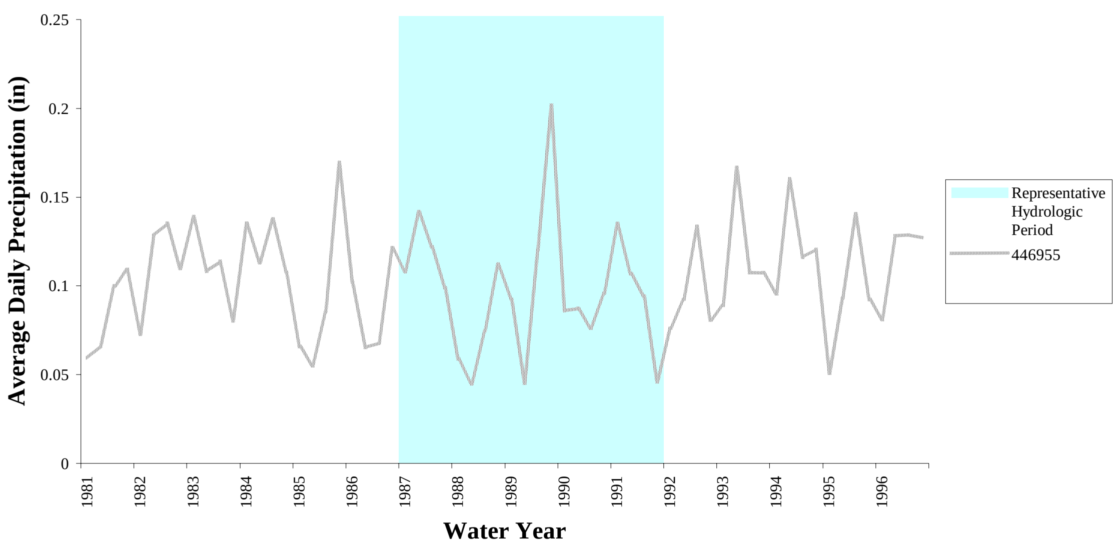


Figure 4.5 Seasonal Historical Precipitation (Station 446955) Data

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 UZSN (Upper Zone Storage) which govern surface transport, and by LZETP (Lower Zone Evapotranspiration) which affects soil moisture. To a lesser extent the model was affected by LZSN (Lower Zone Storage) which also affects soil moisture. 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, CEPSC (interception), 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.

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	---	0.1-0.9
NSUR	Manning's *n* for Overland Flow	---	0.1-0.48
UZSN	Upper Zone Storage Capacity	in	0.5-2.0

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	1.82%	108.62%	-84.45%	7.46%	-15.54%	-3.28%	15.01%	59.74%
AGWRC**	-10	0.78%	32.98%	-42.62%	4.72%	-12.54%	-9.02%	15.60%	52.15%
AGWRC[1]	1	-21.44%	-11.54%	-24.32%	-25.54%	-24.41%	-9.71%	-23.57%	-3.17%
BASETP	-50	1.05%	-1.56%	3.42%	0.01%	3.27%	3.13%	-1.37%	-3.01%
BASETP	-10	0.21%	-0.33%	0.70%	0.00%	0.66%	0.62%	-0.28%	-0.61%
BASETP	10	-0.21%	0.34%	-0.70%	-0.01%	-0.66%	-0.61%	0.29%	0.60%
BASETP	50	-1.01%	1.77%	-3.57%	-0.03%	-3.28%	-3.02%	1.49%	3.37%
DEEPFR	-50	4.54%	2.35%	5.69%	4.54%	4.95%	4.50%	4.23%	3.58%
DEEPFR	-10	0.91%	0.47%	1.14%	0.91%	0.99%	0.90%	0.85%	0.69%
DEEPFR	10	-0.91%	-0.47%	-1.14%	-0.91%	-0.99%	-0.90%	-0.85%	-0.69%
DEEPFR	50	-4.54%	-2.33%	-5.73%	-4.54%	-4.95%	-4.52%	-4.22%	-3.43%
INFILT	-50	-1.85%	33.71%	-17.44%	-5.25%	-15.71%	-1.06%	12.75%	11.82%
INFILT	-10	-0.49%	4.05%	-2.38%	-1.08%	-2.53%	-0.46%	1.82%	1.21%
INFILT	10	0.52%	-3.17%	2.02%	1.02%	2.27%	0.60%	-1.54%	-0.97%
INFILT	50	2.58%	-10.55%	7.78%	4.51%	9.39%	3.55%	-5.84%	-2.33%
INTFW	-50	-0.63%	-2.03%	0.86%	-0.76%	-0.40%	-1.01%	-0.41%	-1.93%
INTFW	-10	-0.08%	-0.30%	0.12%	-0.08%	-0.06%	-0.16%	-0.04%	-0.25%
INTFW	10	0.07%	0.27%	-0.11%	0.07%	0.06%	0.14%	0.03%	0.21%
INTFW	50	0.27%	1.09%	-0.41%	0.23%	0.23%	0.58%	0.12%	0.85%
LZSN	-50	1.20%	7.77%	-0.50%	1.21%	-1.51%	-0.62%	4.84%	2.94%
LZSN	-10	0.17%	1.07%	-0.13%	0.26%	-0.22%	-0.22%	0.71%	0.68%
LZSN	10	-0.16%	-0.90%	0.11%	-0.26%	0.17%	0.20%	-0.60%	-0.56%
LZSN	50	-0.65%	-3.48%	0.39%	-1.20%	0.55%	0.89%	-2.29%	-3.06%
MON-INTERCEP	-50	3.00%	-2.62%	6.67%	2.04%	6.00%	6.05%	-0.90%	-0.74%
MON-INTERCEP	-10	0.52%	-0.61%	1.32%	0.35%	1.15%	1.11%	-0.28%	-0.29%
MON-INTERCEP	10	-0.50%	0.64%	-1.30%	-0.35%	-1.16%	-1.01%	0.29%	0.37%
MON-INTERCEP	50	-2.13%	3.25%	-6.14%	-1.40%	-5.05%	-4.76%	1.61%	1.68%
MON-LZETP	-50	7.77%	16.55%	6.31%	3.33%	1.47%	9.28%	16.33%	6.06%
MON-LZETP	-10	1.26%	2.18%	1.37%	0.68%	0.31%	1.28%	2.64%	0.78%
MON-LZETP	10	-1.08%	-1.73%	-1.25%	-0.59%	-0.28%	-1.03%	-2.29%	-0.63%
MON-LZETP	50	-5.24%	-7.27%	-6.67%	-2.63%	-2.10%	-6.29%	-9.69%	-2.70%
MON-MANNING	-50	0.20%	1.72%	-0.37%	-0.07%	0.15%	0.61%	0.21%	0.53%
MON-MANNING	-10	0.03%	0.27%	-0.05%	-0.02%	0.02%	0.08%	0.04%	0.08%
MON-MANNING	10	-0.03%	-0.23%	0.05%	0.01%	-0.02%	-0.08%	-0.03%	-0.07%
MON-MANNING	50	-0.10%	-0.99%	0.19%	0.06%	-0.05%	-0.31%	-0.15%	-0.27%
MON-UZSN	-50	3.46%	11.68%	-0.31%	5.60%	8.08%	9.90%	-7.30%	4.44%
MON-UZSN	-10	0.38%	1.39%	-0.06%	0.78%	0.99%	1.38%	-1.26%	0.58%
MON-UZSN*	10	-0.30%	-1.17%	0.02%	-0.67%	-0.81%	-1.18%	1.14%	-0.45%
MON-UZSN*	50	-1.06%	-4.45%	0.02%	-2.57%	-2.96%	-4.68%	4.69%	-1.91%

[1]Maximum value used corresponds to the maximum allowable value for the parameter.
*Where maximum value exceeds allowable maximum, variable is assigned maximum allowable value.
** 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.

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. FSTDEC (First Order Decay) was the parameter with the greatest influence on monthly geometric mean concentration, although MON-SQOLIM and WSQOP also showed significant potential to influence this value (Table 4.10). The results of this analysis are also plotted in Figures 4.6 through 4.8.

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 – 3.6E+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

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 through Figure 4.8.

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	36.8	36.1	36.4	39.9	44.8	47.2	46.7	46.3	47.0	38.9	38.4	38.0
FSTDEC	-10	5.7	5.6	5.7	6.1	6.7	6.9	6.9	6.8	6.9	5.9	5.9	5.9
FSTDEC	10	-5.2	-5.0	-5.1	-5.5	-6.0	-6.1	-6.1	-6.0	-6.1	-5.3	-5.4	-5.3
FSTDEC	50	-21.8	-21.0	-21.5	-22.9	-24.4	-24.9	-24.7	-24.5	-24.7	-22.1	-22.3	-22.2
SQOLIM	-50	-14.7	-14.1	-10.4	-7.2	-9.3	-12.9	-8.2	-5.2	-7.1	-6.2	-7.8	-7.5
SQOLIM	-25	-6.7	-6.5	-4.7	-3.1	-4.1	-5.5	-3.3	-2.1	-3.2	-2.8	-3.5	-3.4
SQOLIM	50	13.8	12.0	8.3	6.0	7.8	11.1	6.8	4.6	5.9	5.1	7.4	6.7
SQOLIM	100	22.5	20.3	13.8	9.5	12.4	16.9	10.0	6.9	10.1	9.2	12.0	11.0
WSQOP	-50	18.9	21.1	14.2	10.1	11.3	14.9	8.1	5.5	8.9	8.0	8.7	10.3
WSQOP	-10	2.5	2.7	1.9	1.3	1.5	2.0	1.2	0.8	1.2	1.1	1.2	1.4
WSQOP	10	-2.2	-2.4	-1.6	-1.1	-1.3	-1.8	-1.1	-0.7	-1.0	-0.9	-1.0	-1.2
WSQOP	50	-8.6	-9.2	-6.4	-4.4	-5.3	-7.2	-4.4	-2.6	-4.1	-3.6	-4.2	-4.7

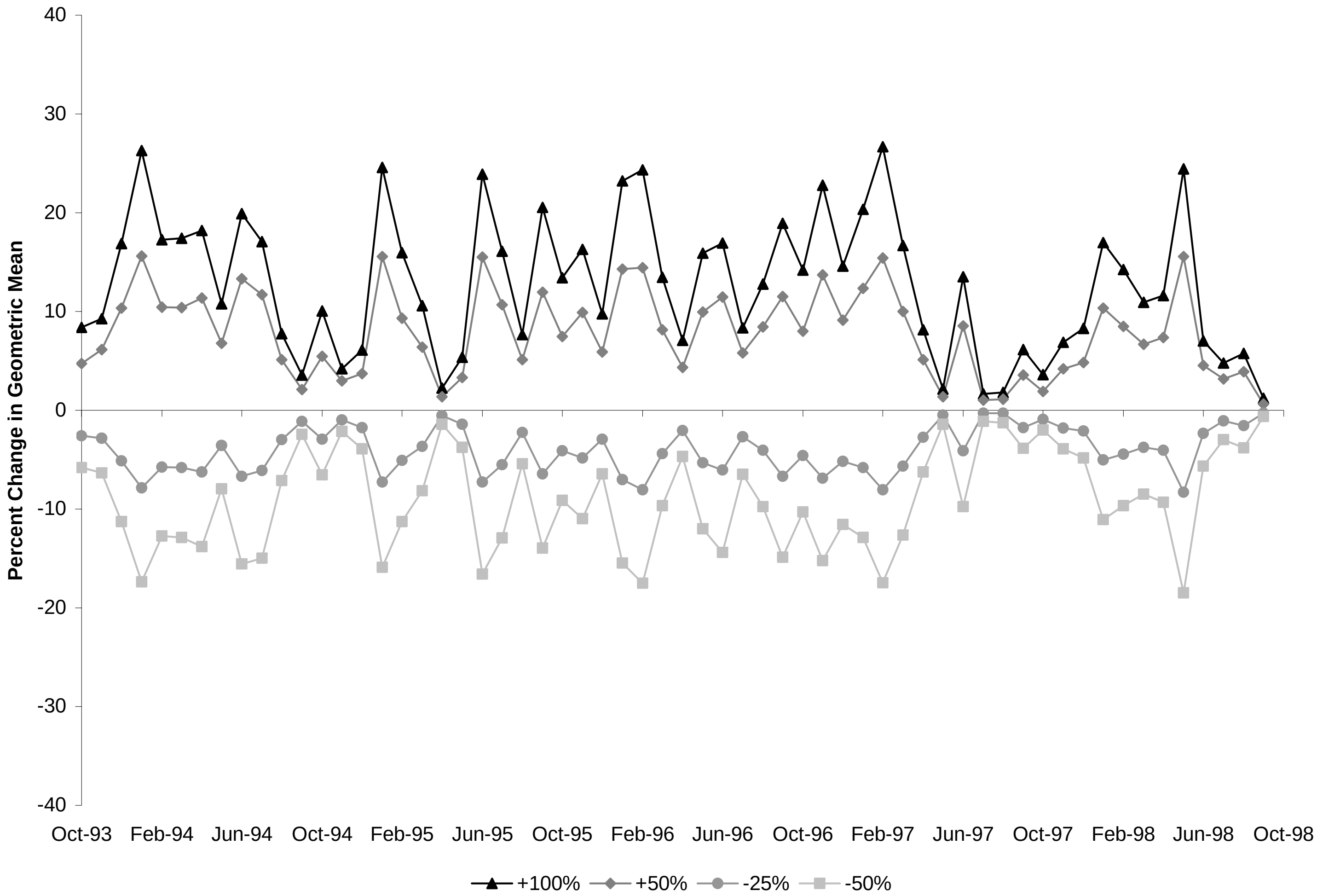


Figure 4.6 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Crab Creek watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).**

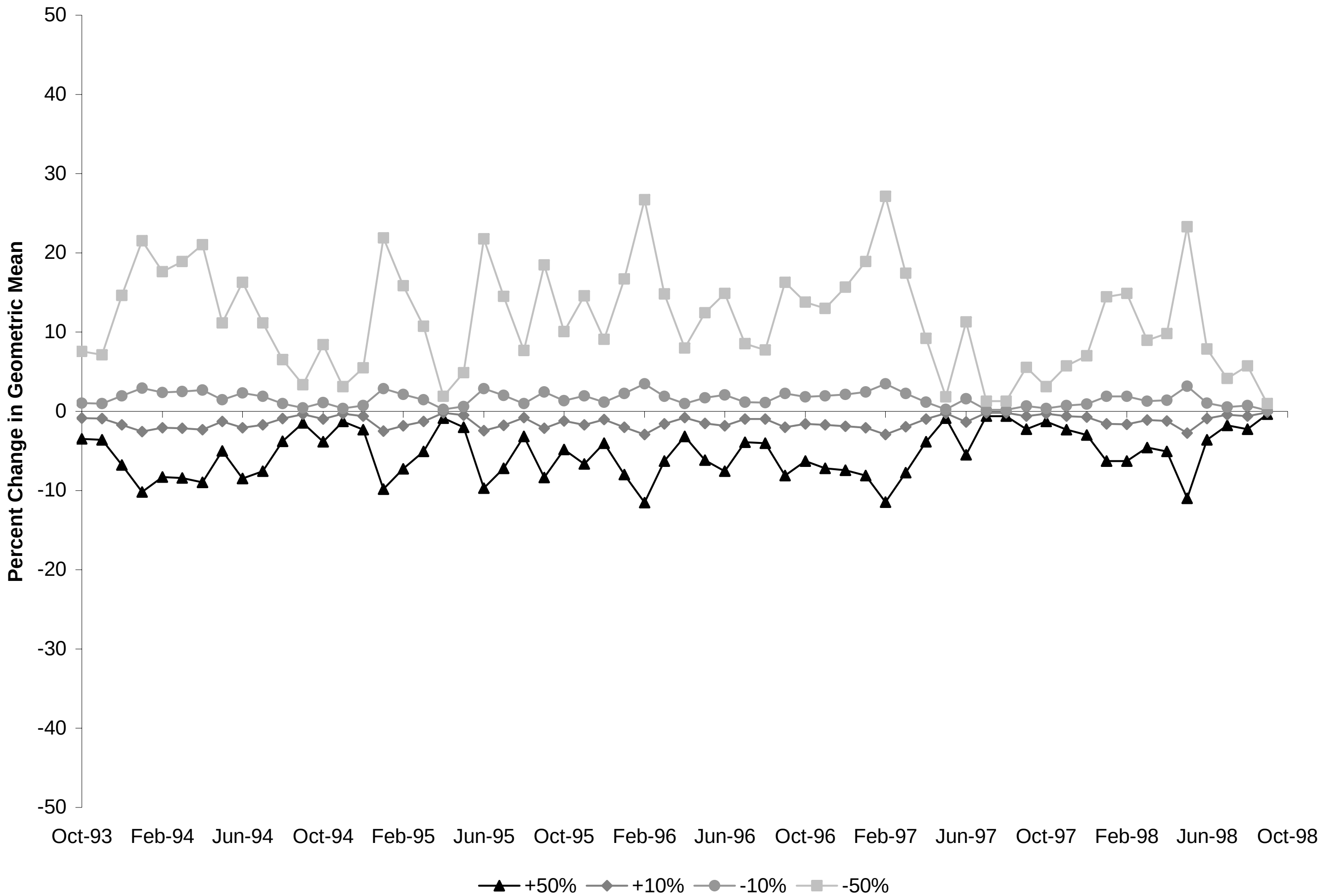


Figure 4.7 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Crab Creek watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).**

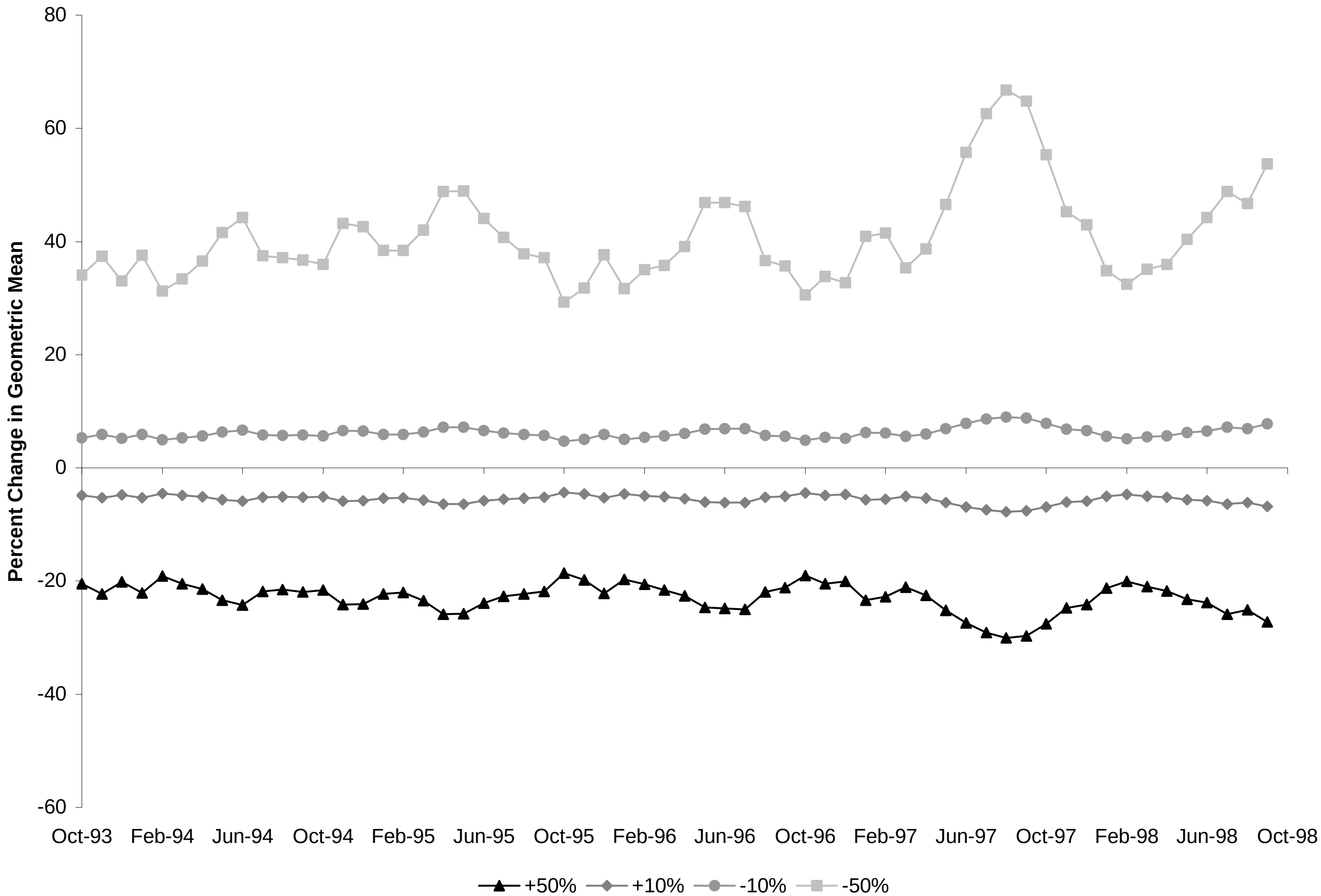


Figure 4.8 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Crab Creek watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

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.

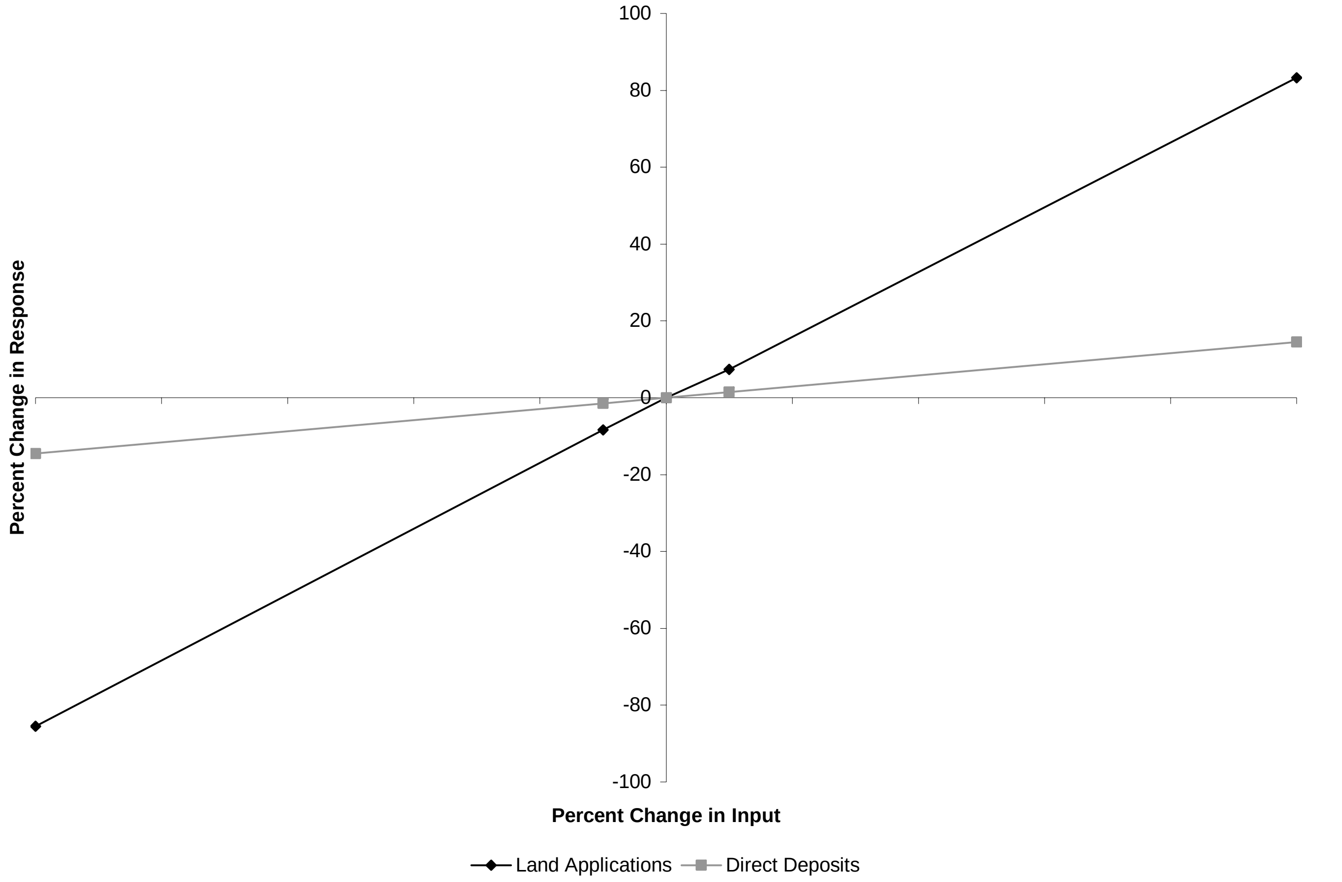


Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Crab Creek watershed.

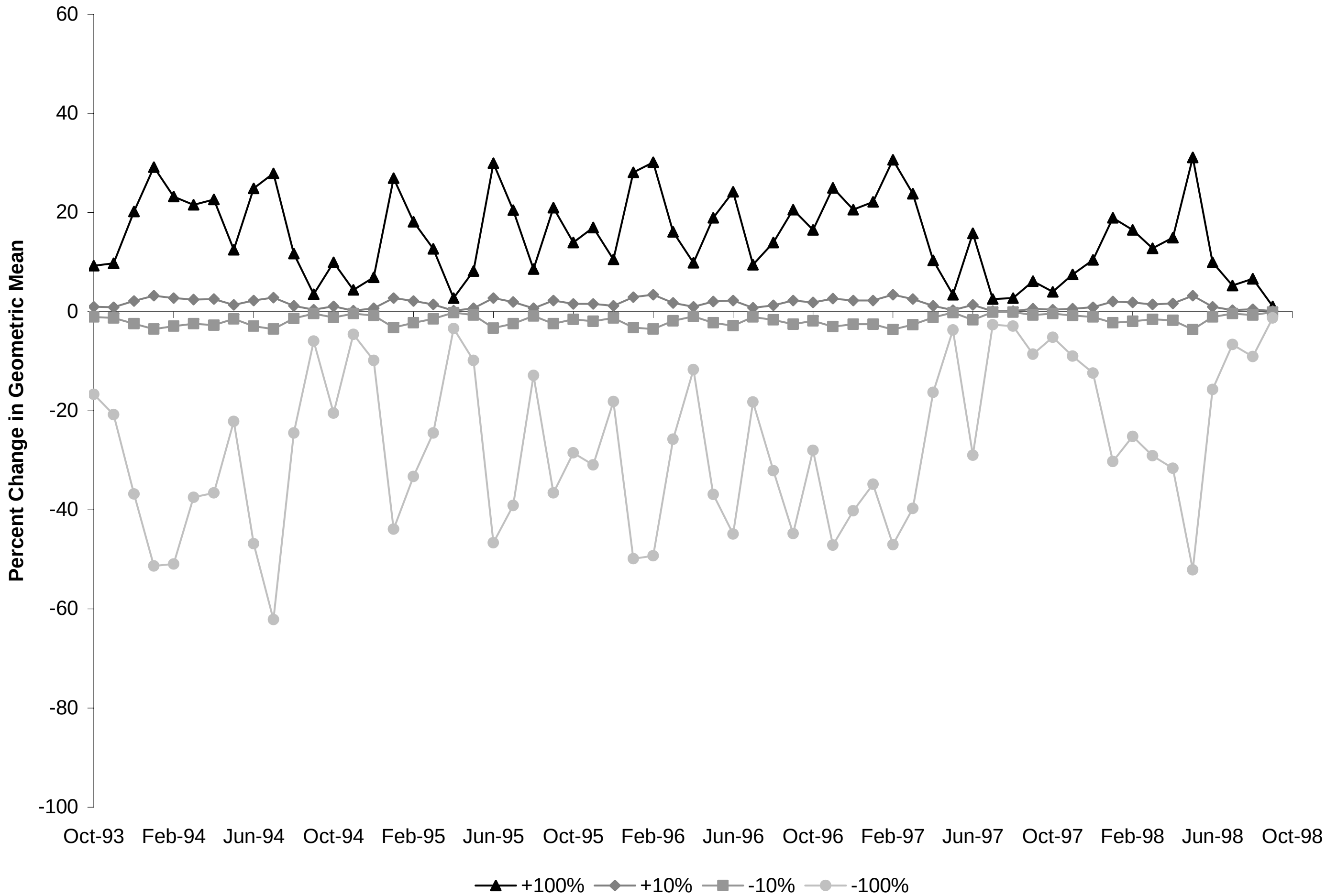


Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations in the Crab Creek watershed, as affected by changes in land-based loadings.

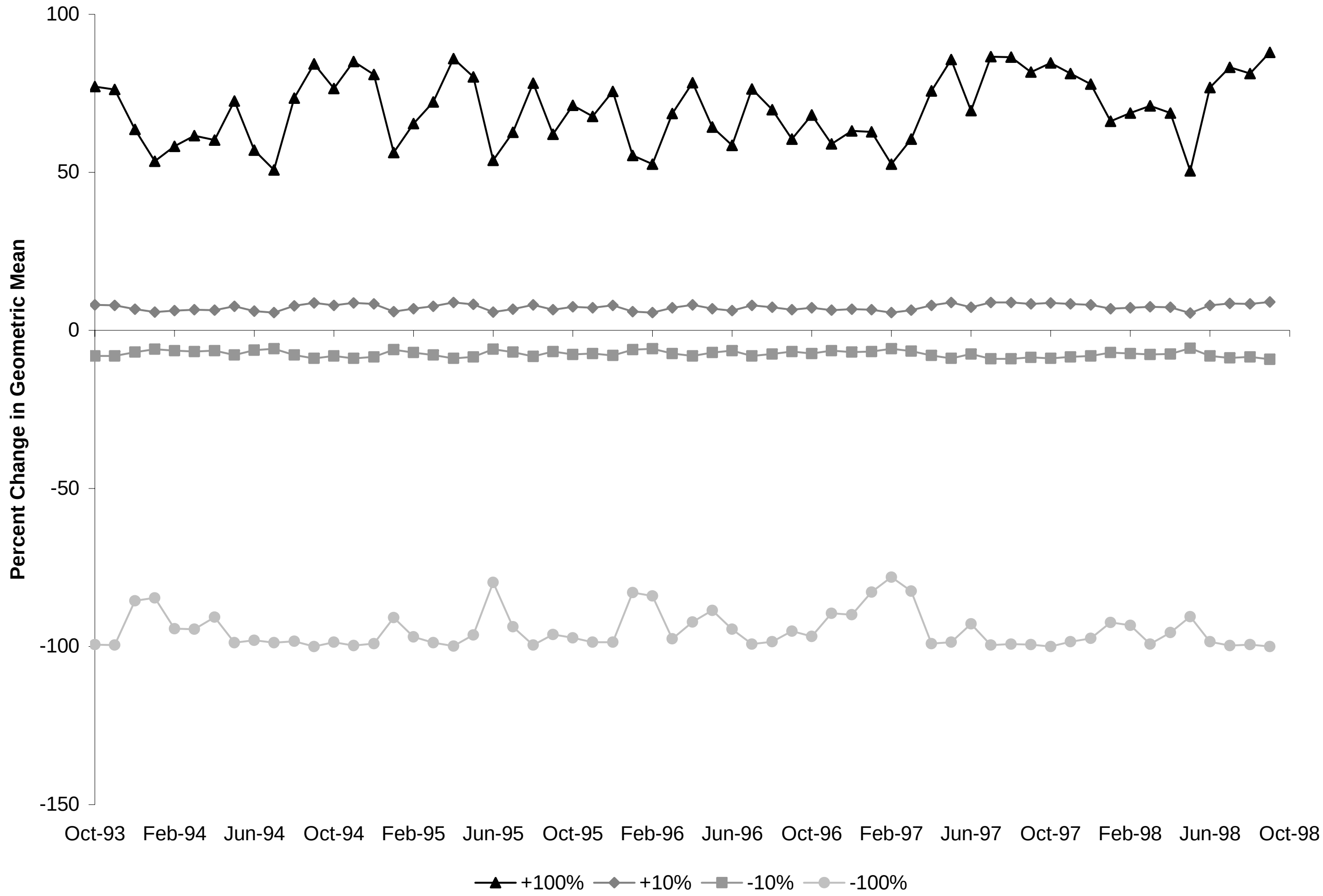


Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations in the Crab Creek watershed, as affected by changes in loadings from direct nonpoint sources.

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 a paired-watershed analysis, with consideration for 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. 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 Crab 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 Crab Creek, are then used as an initial representation of the watershed. In the case of Crab 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 Crab 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 Crab 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, which accounted for 56% of the Upper Tinker Creek watershed and 49% of the Crab Creek watershed.

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

Landuse Categories	Landuse	Crab Creek		Upper Tinker Creek	
		acres	%	acres	%
Agricultural	Barren	55	0.45	23	0.31
	Cropland/Row Crops	500	4.04	78	1
	Livestock Access	207	1.67	276	3.7
	Pasture	5,279	42.65	3,793	50.8
Total Agricultural		**6,041**	**48.81**	**4,170**	**55.8**
Urban	Commercial	639	5.16	4	0.05
	Residential	1,591	12.85	91	1.2
Total Urban		**2,230**	**18.01**	**95**	**1.3**
Natural	Forest and Wetlands	4,096	33.09	3,173	42.5
Other	Water	11	0.09	30	0.41
Total		**12,378**	**100.00**	**7,468**	**100**

The soil hydrologic groups in both watersheds were examined. The soils series present in both the Upper Tinker Creek and Crab 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 12).

Table 4.12 Soil distribution in Tinker Creek and Crab Creek.

Statsco ID	Hydrologic Soil Group	Percent of Watershed	
		Tinker Creek	Crab Creek
VA001	B	0%	3%
VA002	B/C	50%	1%
VA003	B/C	40%	95%
VA005	B/C	10%	0%
VA017	C	0%	1%

Additional watershed characteristics of Tinker Creek and Crab 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 Crab Creek Watershed Characteristics.

Watershed	Drainage Area (acre)	Main Channel Slope	Main Channel Length (ft)	Drainage Density (ft/acre)
Tinker Creek	7482	0.08	2,162	14
Crab Creek	12455	0.02	14,3769	31

Based on the landuse distribution, soil types, and watershed physical characteristics, the Upper Tinker Creek watershed is hydrologically similar to the Crab 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 Upper Tinker Creek watershed were used as base input parameters for Crab Creek when calibrating Crab Creek with the nine base flow values from USGS station #03171170 (Crab Creek at STP near Christiansburg, VA). Parameters that were adjusted during the hydrologic calibration represented the amount of evapotranspiration from the root zone (MON-LZETP), 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 EPA as to typically encountered values. Final calibrated parameters did not go outside of typical values, except in the case of LZETP, which ranged just outside the high value of 0.9, with a peak value of 1.035 for the forest land-use during the summer months, which coincided with periods of lower than expected flows in the observed record.

The model was calibrated for hydrologic accuracy using instantaneous flow data from USGS Station #03171170 (Crab Creek at STP near Christiansburg, VA). The distribution of flow volume between surface runoff, interflow, and groundwater was 17%, 28%, and 55%, respectively. The results of calibration for Crab Creek are presented in Figure 4.12. While there were no peak flow values in the observed record to verify output during storm events, and only 14 observations in total, the model predicted base flow conditions well, with an R^2 value of 0.66 during modeled base flow events.

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

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	0.0	0.0
LZSN	in	2.0 – 15.0	2.0 – 3.0	2.0
INFILT	in/hr	0.001 – 0.50	0.006 – 0.296	0. 0683 – 0. 232
LSUR	ft	100 – 700	100 – 700	100 – 800
SLSUR	---	0.001 – 0.30	0.001 – 0.155	0.001 – 0.15
KVARY	1/in	0.0 – 5.0	0.05 – 0.12	0.12
AGWRC	1/day	0.85 – 0.999	0.989 – 0.994	0.980
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	0.15
BASETP	---	0.0 – 0.20	0.0315 – 0.0325	0.0487
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	1.0	1.25
IRC	1/day	0.30 – 0.85	0.3 – 0.85	0.3
MON-INT	in	0.01 - 0.40	0.01 – 0.4	0.01 – 0.40
MON-UZS	in	0.05 – 2.0	0.05 – 2.0	0.261 – 2.0
MON-LZE	---	0.1 – 0.9	0.1 – 0.9	0.115 – 1.035
MON-MAN		0.10 – 0.50	0.1 – 0.48	0.1 – 0.42
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

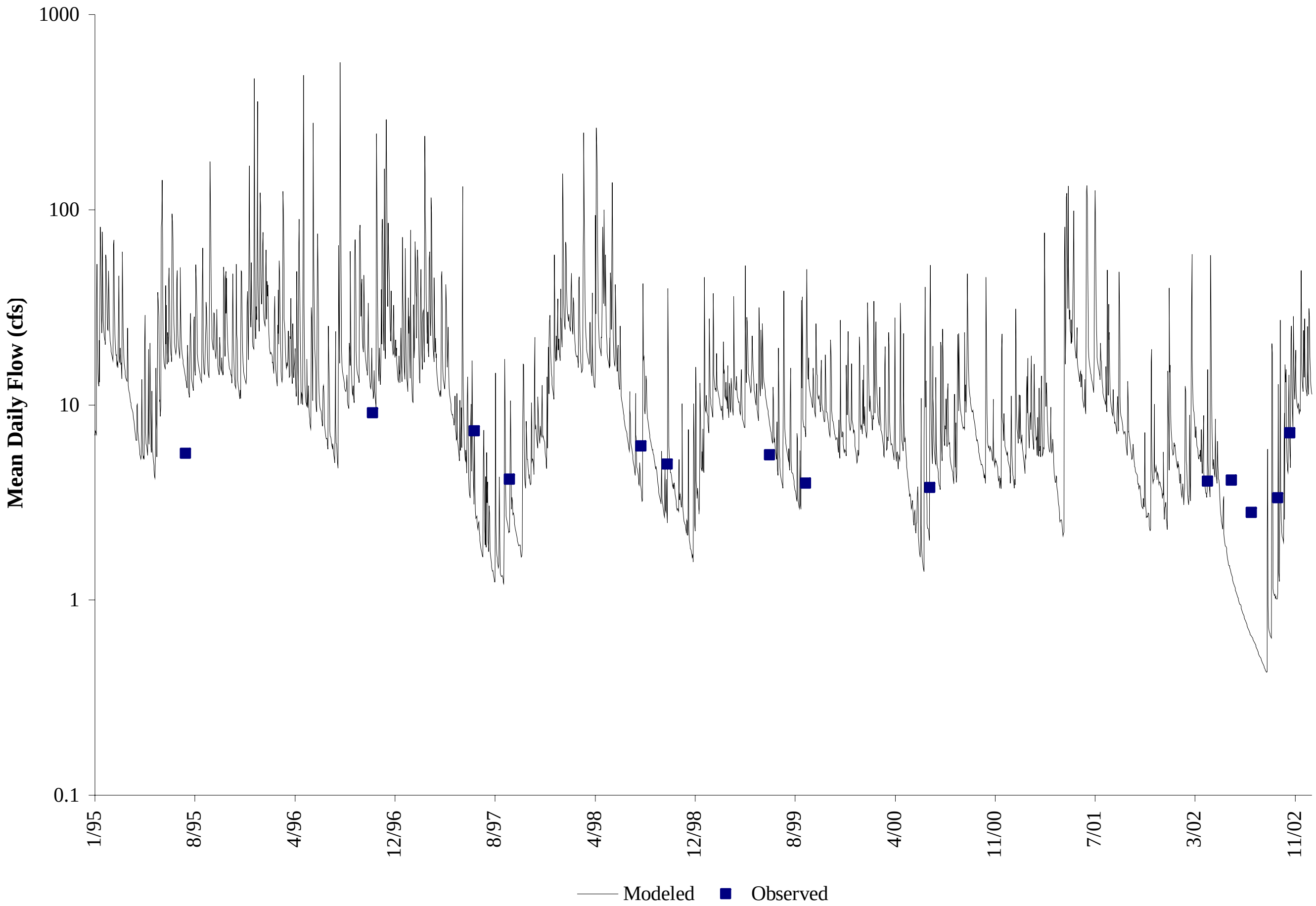


Figure 4.12 Calibration results for subwatershed 3 of Crab Creek for the period 1/1/1995 through 12/31/2002.

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 (maximum values were at times censored at 8,000 and, at other times, 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). Figures 4.13 and 4.14 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 – 7.0E+10	0.0E+00 – 7.0E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0E+00 – 3.6E+11	0.0E+00 – 2.0E+12
WSQOP	in/hr	0.05 – 3.00	0-1.8	0.01- 0.27
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	1.00
THFST	---	1.0 – 2.0	1.07	1.07

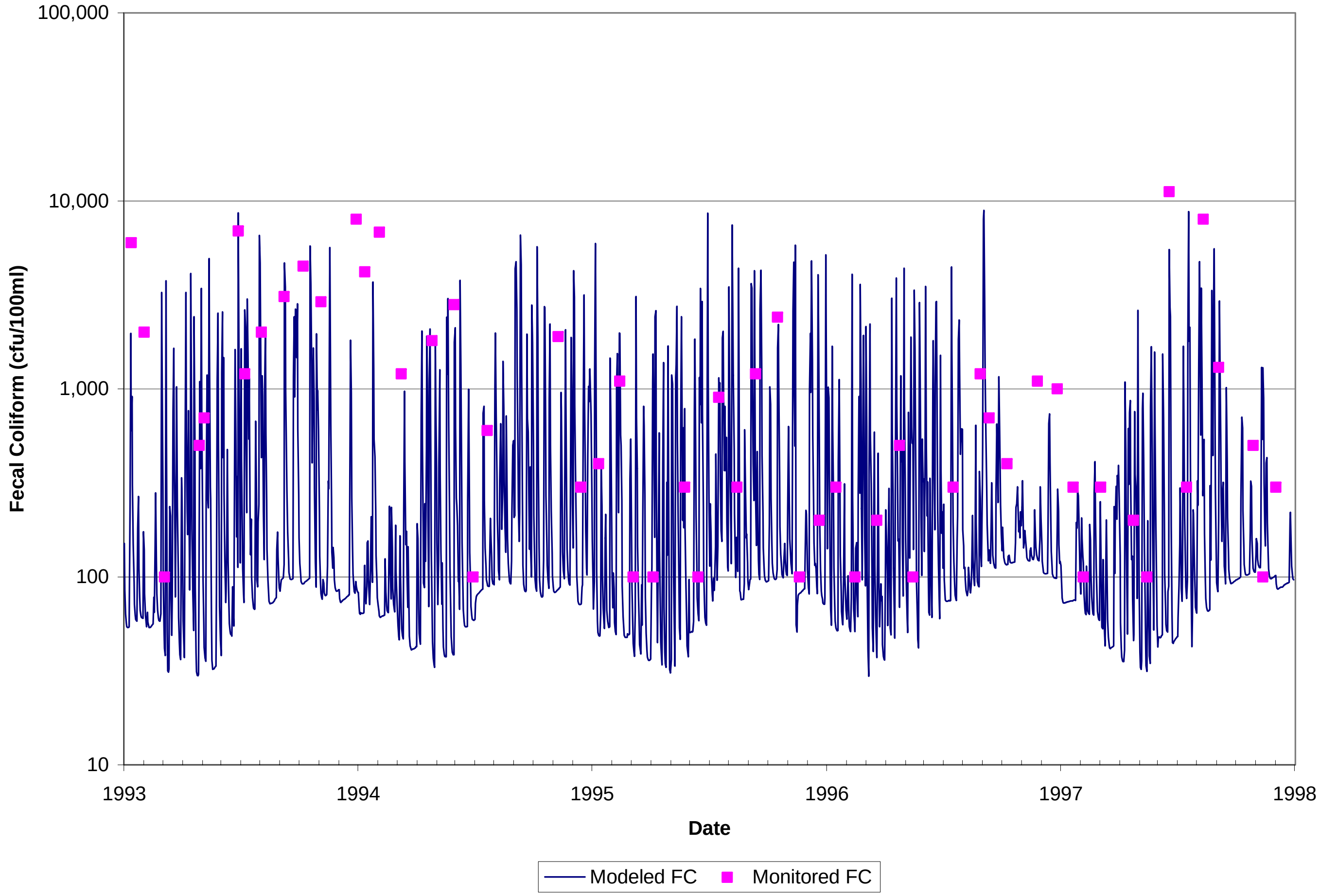


Figure 4.13 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Crab Creek impairment, during the calibration period.

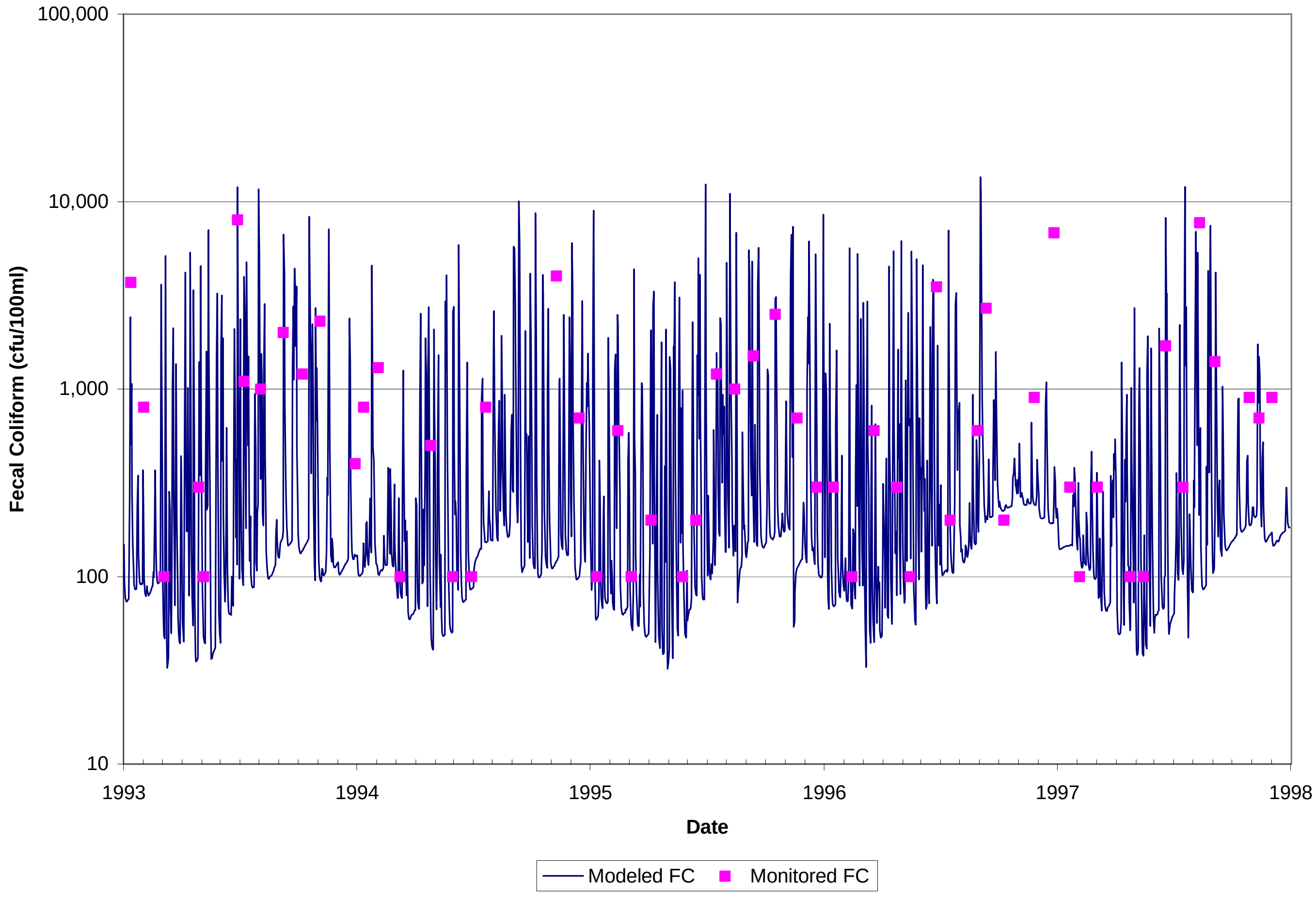


Figure 4.14 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 3 in the Crab Creek impairment, during the calibration period.

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:

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

where

$$\begin{aligned} observed &= \text{an observed value of fecal coliform} \\ modeled_i &= \text{a modeled value in the 2-day window surrounding the observation} \\ n &= \text{the number of modeled observations in the 2-day window} \end{aligned}$$

This 2-day window is considered to be a reasonable time frame to take into account the temporal variability in direct loadings from wildlife and livestock, the spatial and temporal variability inherent in the use of point measurements of precipitation, and in the use of daily precipitation data. 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-CBC004.38	100	58,852
9-CBC006.35	93.4	48,671

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 4.15 through 4.18. 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.

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-CBC001.00	20	49,821
9-CBC004.38	93	39,964
9-CBC006.35	115	29,293
9-CBC009.81	125	15,029

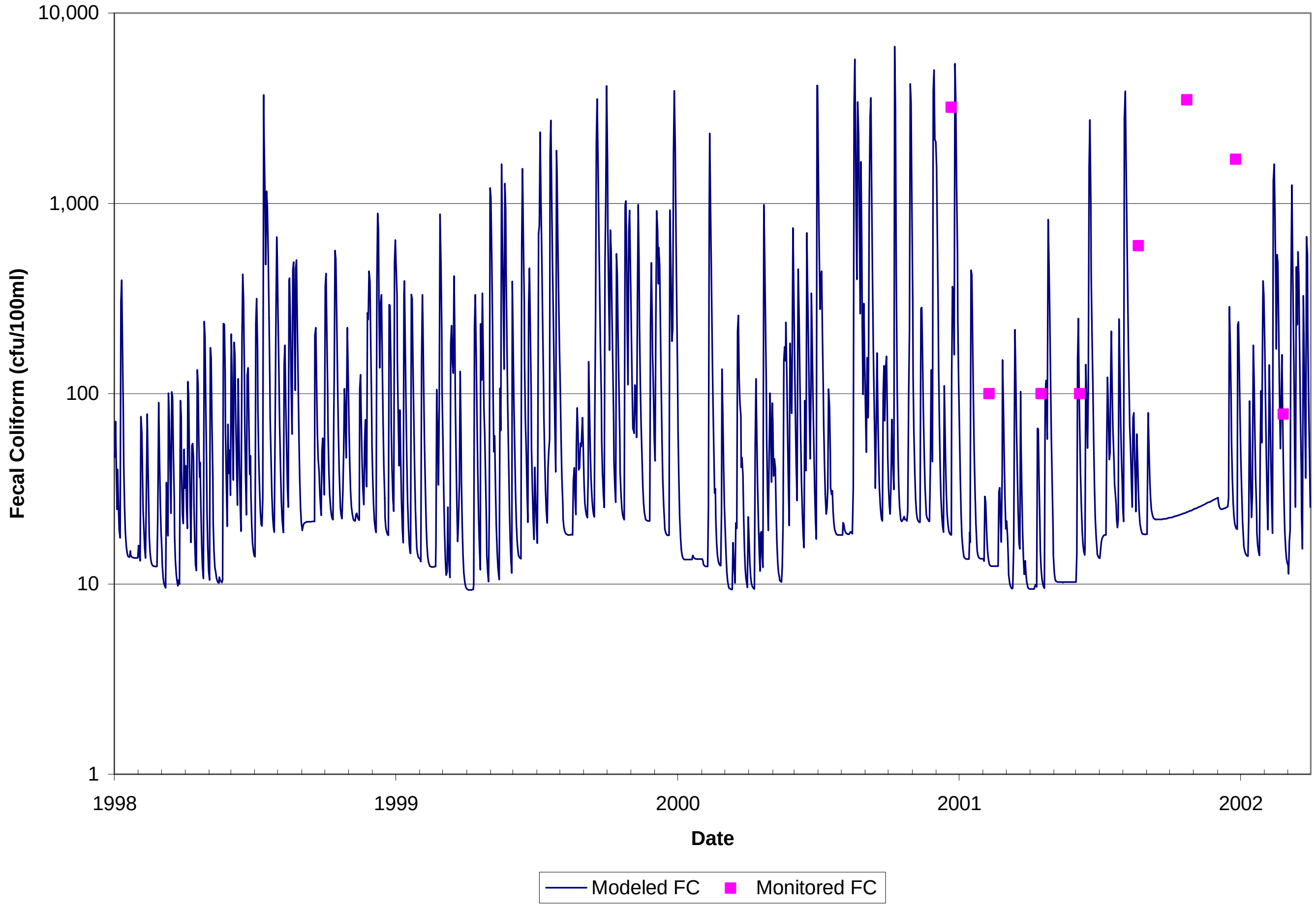


Figure 4.15 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 1 in the Crab Creek impairment, during the validation period.

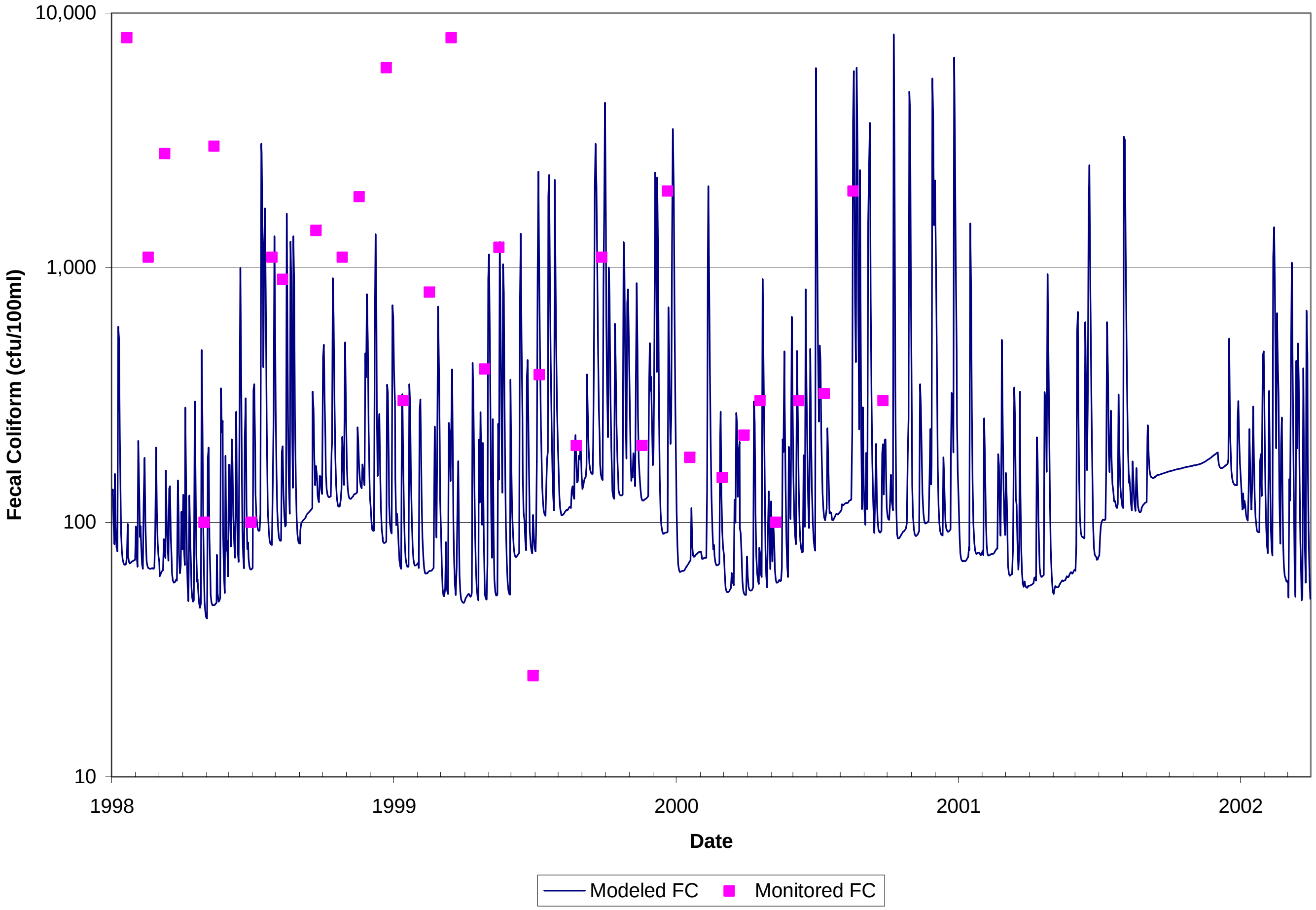


Figure 4.16 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Crab Creek impairment, during the validation period.

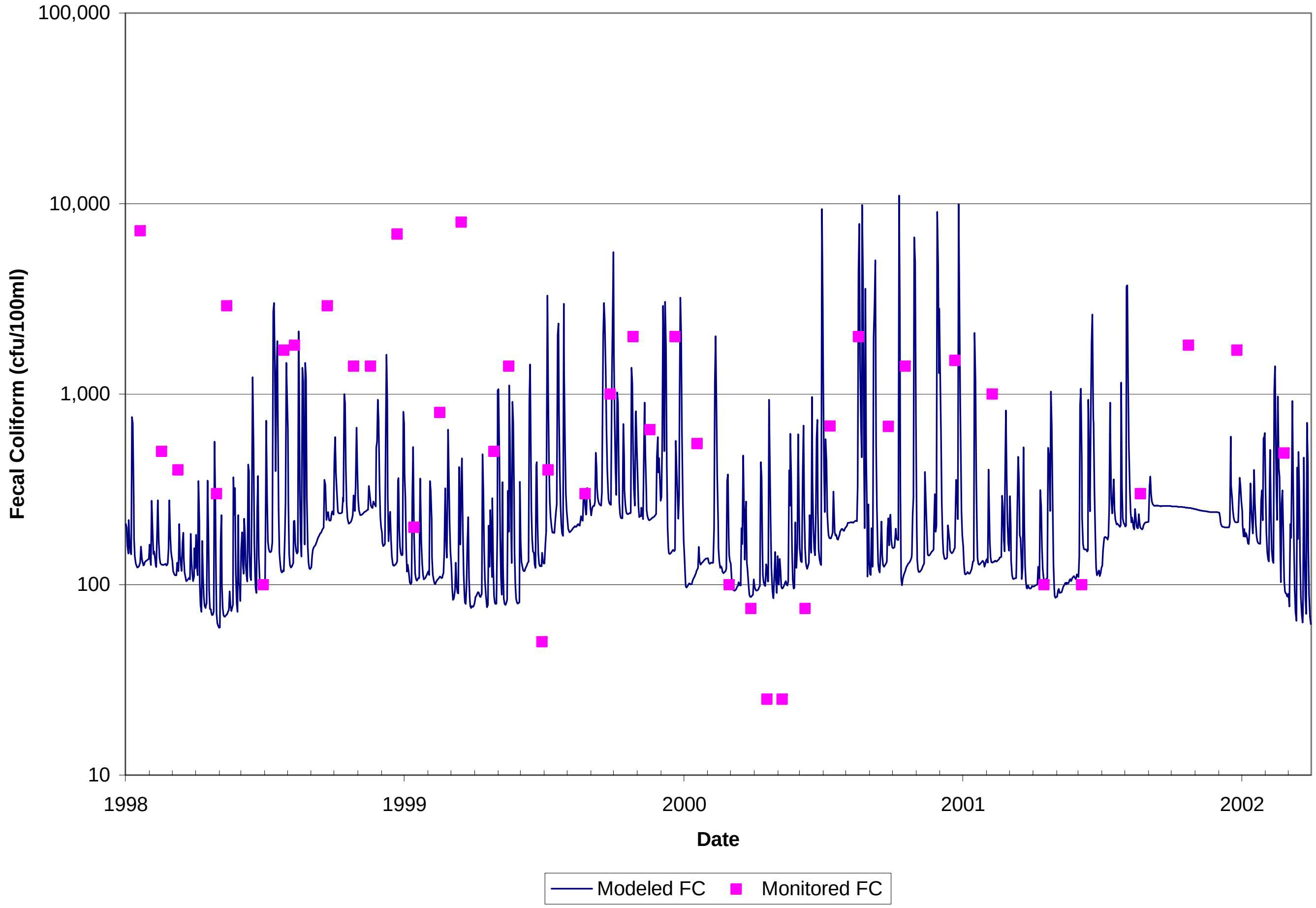


Figure 4.17 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 3 in the Crab Creek impairment, during the validation period.

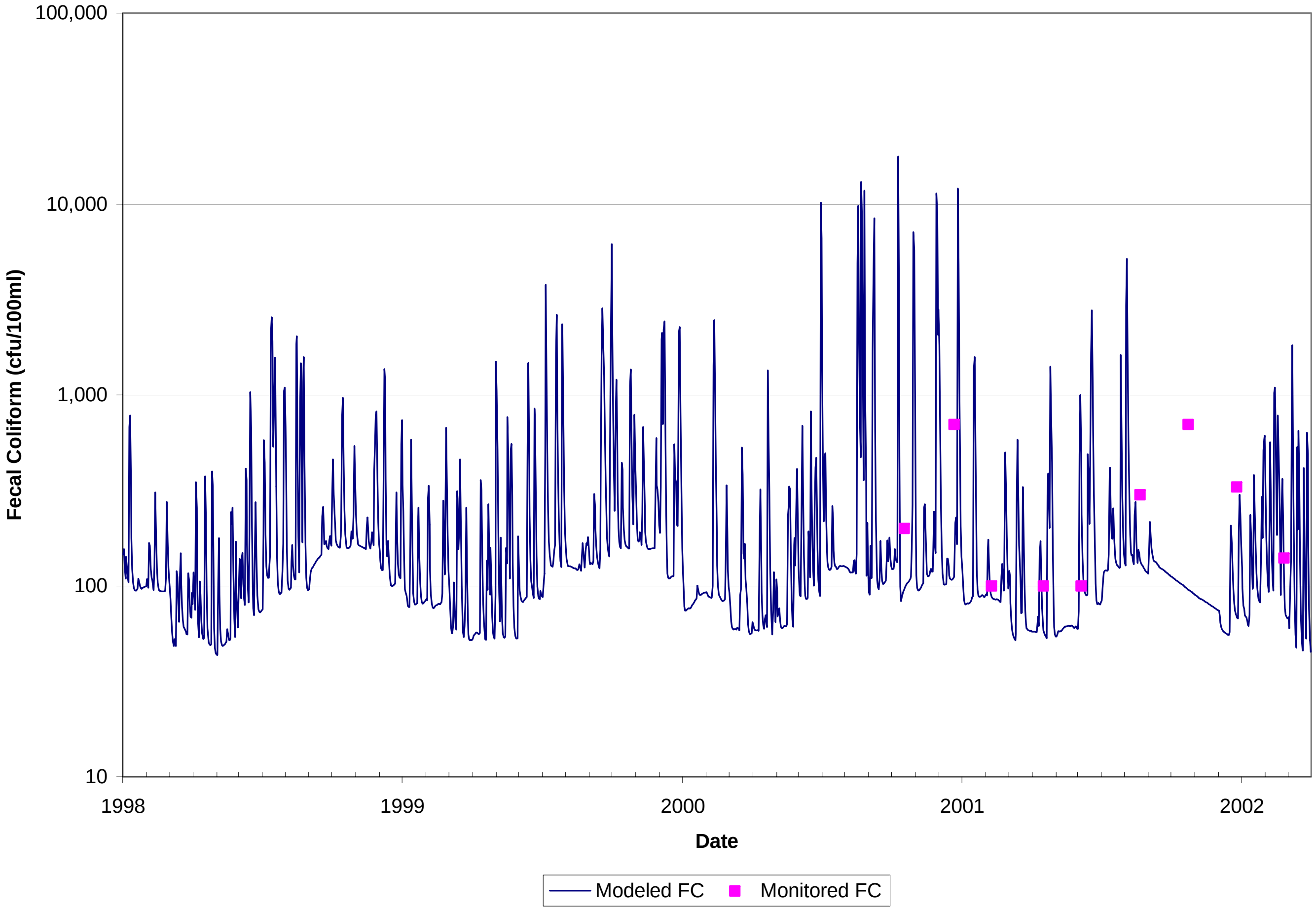


Figure 4.18 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 4 in the Crab Creek impairment, during the validation period.

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 4.19 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126 cfu/100 ml standard at the outlet of Crab Creek. Figure 4.20 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.

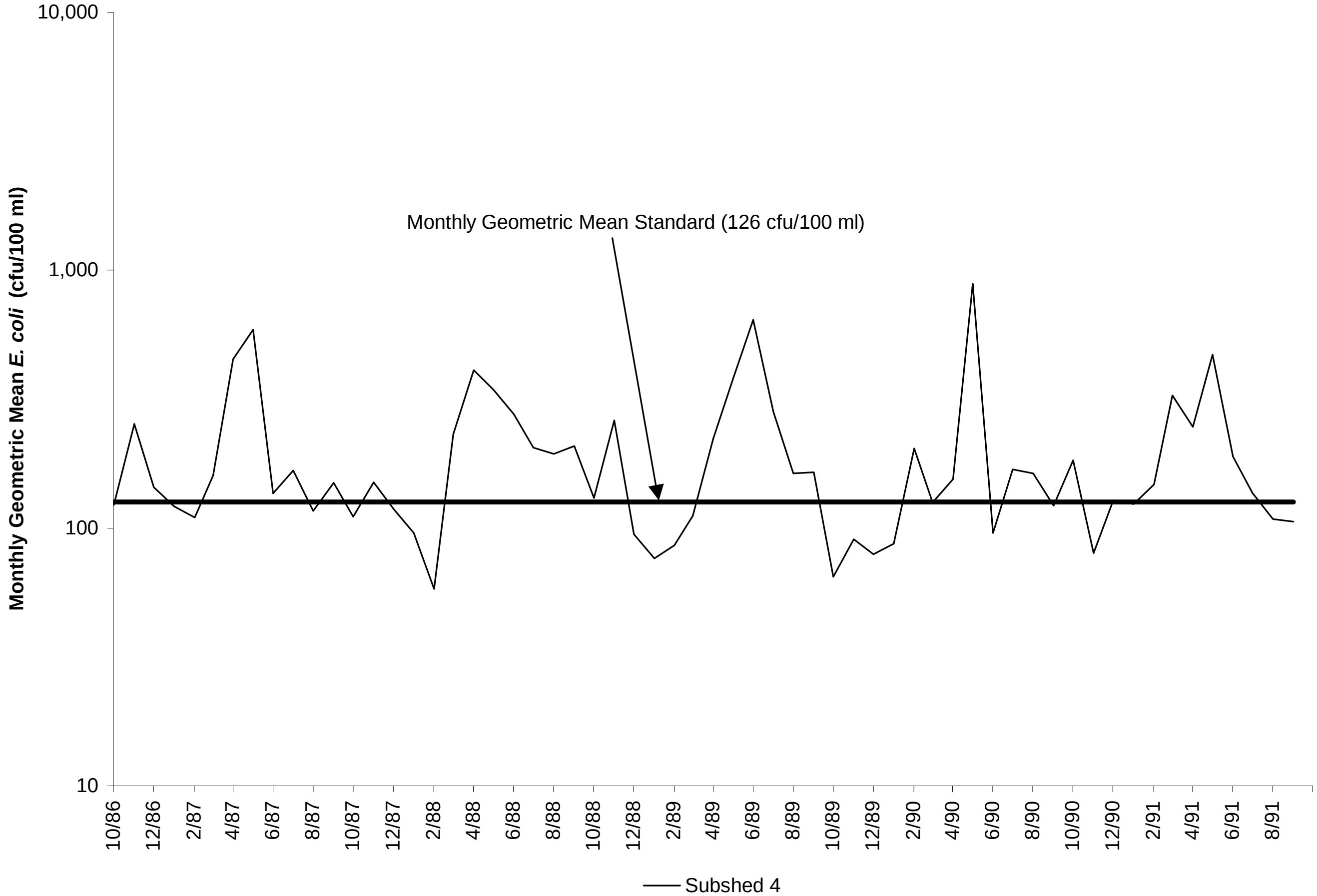


Figure 4.19 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Crab Creek impairment.

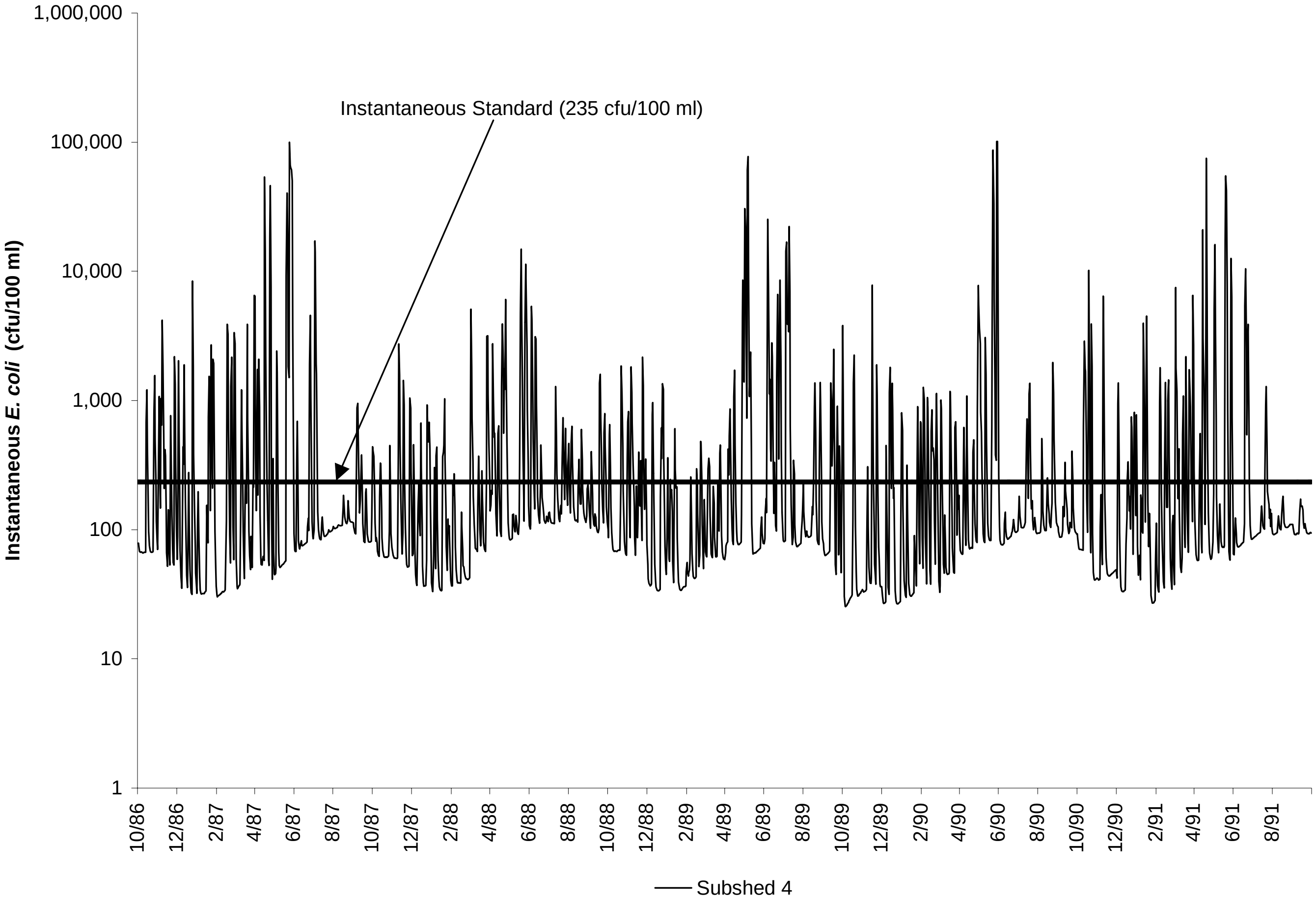


Figure 4.20 Existing conditions (*i.e.*, mean daily) of *E. coli* concentrations at the outlet of the Crab Creek impairment.

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,
- selecting a modeling period that represented the critical hydrologic conditions in the watershed, and

- 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 Crab Creek watershed were 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 the 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 5.1 and 5.2). 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.

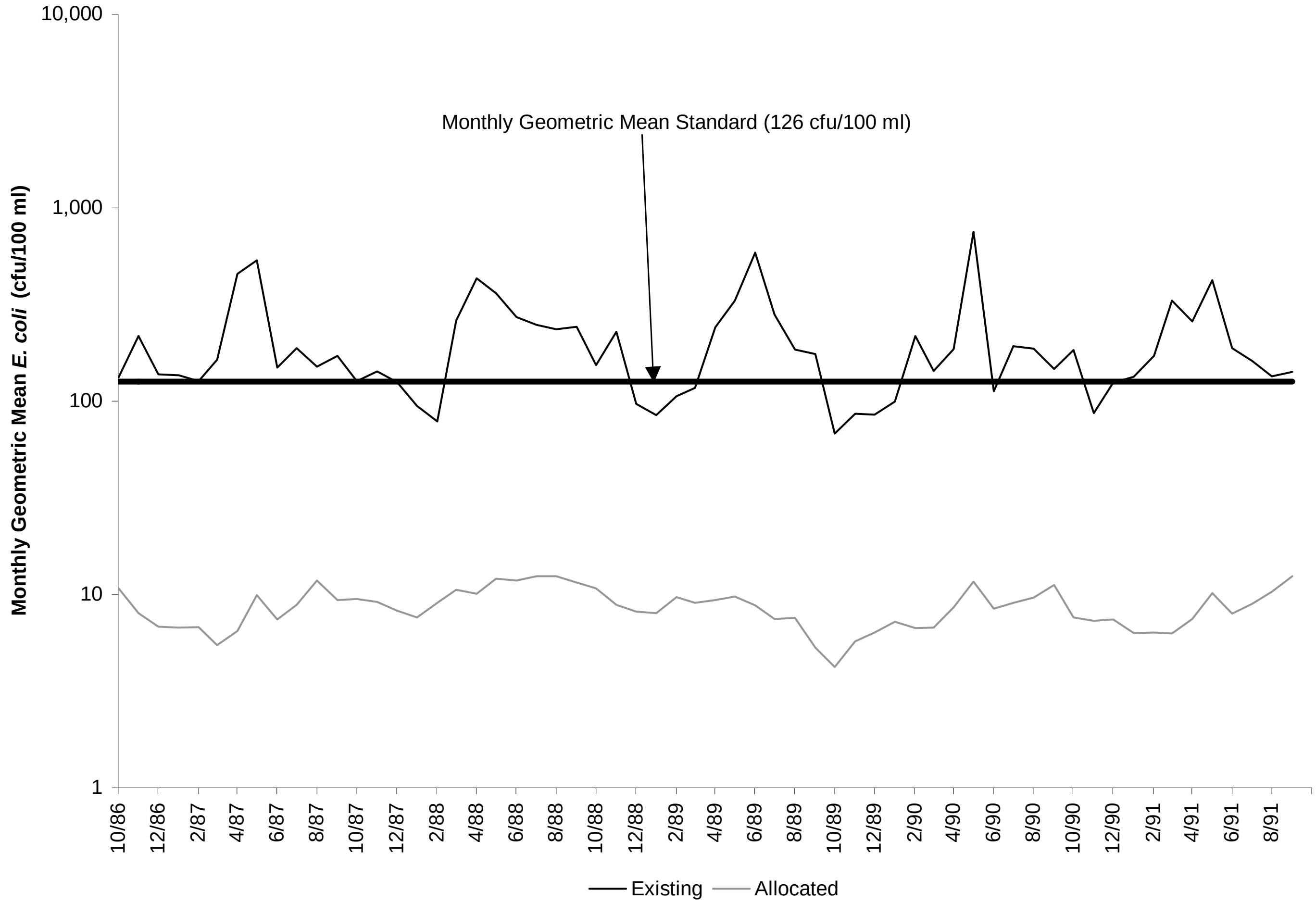


Figure 5.1 Monthly geometric mean *E. coli* concentrations for the Crab Creek impairment, under existing and allocated conditions.

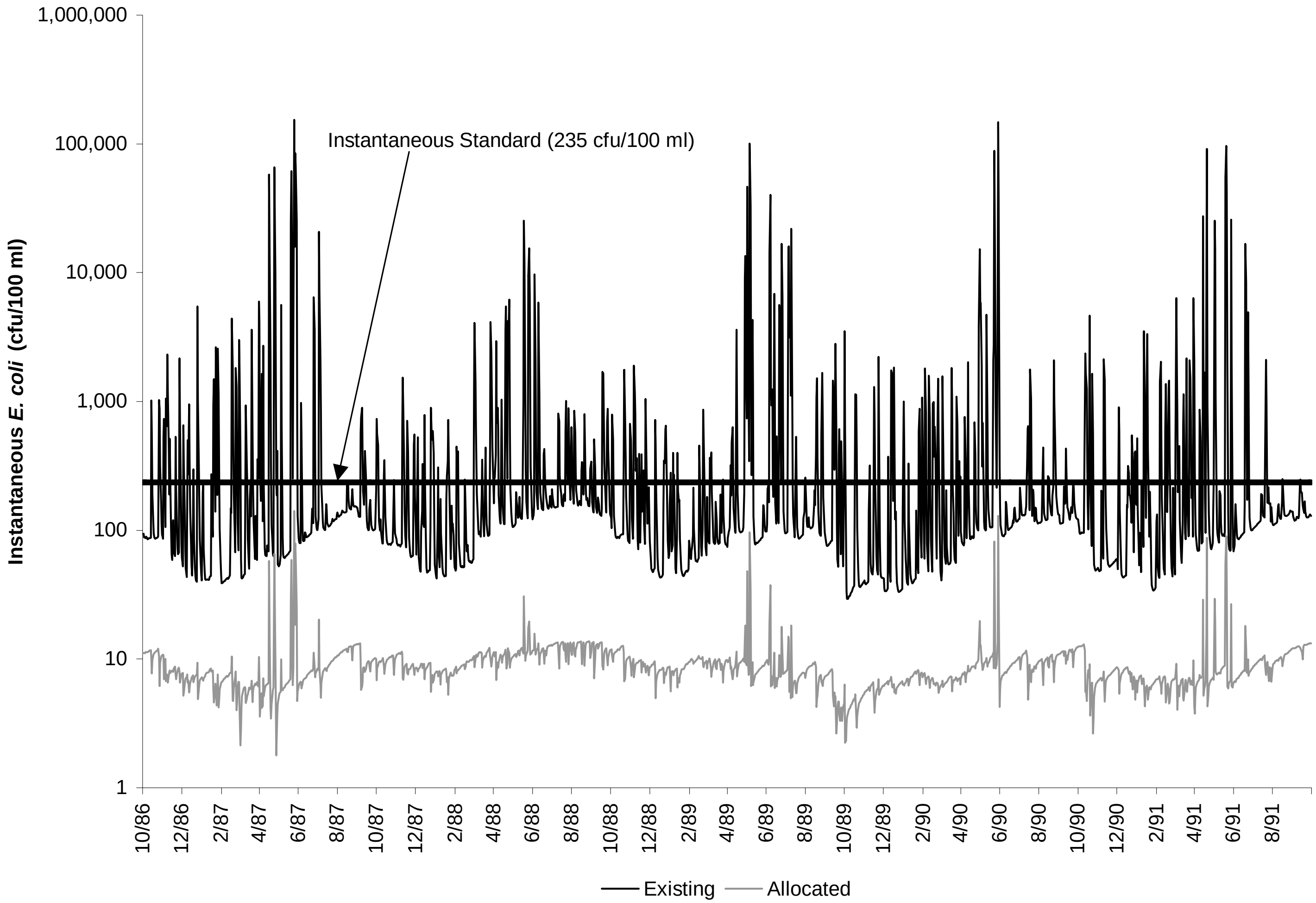


Figure 5.2 Instantaneous *E. coli* concentrations for the Crab Creek impairment, under existing and allocated conditions.

5.2.1 Wasteload Allocations

There are seventeen point sources currently permitted to discharge in the Crab Creek watershed (Figure 3.1 and Table 3.1). None of these sources are currently permitted for fecal control in the impairment area. The only discharges with potential for significant fecal contribution are the MS4 permits. The combined MS4 permit area was identified as the impervious areas within the watershed. For allocation runs, NPS loads from the MS4 permit area were modeled and allocated based on the associated land uses.

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 the most significant impact during high-flow conditions, while direct deposition NPS had the 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 Crab 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 Chapter 2.

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Crab 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	76.7	27.8
2	0	0	0	0	0	100	73.3	27.8
3	0	0	90	50	50	100	11.7	17.6
4	0	0	100	60	60	100	3.33	16.1
5	0	0	100	99	99	100	0.0	1.92
6	0	99	100	99	99	100	0.0	1.53
7	99	99	100	99	99	100	0.0	1.53
8	0	99	100	99.95	99.95	100	0.0	0.0

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 2 contains 100% reductions in sewer overflows and uncontrolled residential discharges (*i.e.*, straight pipes). Land-based loads were not addressed in this scenario, nor were direct loads from wildlife. This scenario improved conditions in the stream, but failed to eliminate exceedances.

With scenario 3, attention continued with reductions to anthropogenic sources with a reduction of 50% to land loads from urban and agricultural lands and 90% reduction from livestock stream access. As noted in Table 5.1, the number of exceedances is reduced but violations persist.

With scenario 4, the reductions of land-based loads were increased from 50% to 60% and livestock stream access was reduced 100%. This scenario still does not meet either water quality standard. With land-based load reductions increased to 99%, scenario 5 in Table 5.1, the geometric mean standard is met without reductions to wildlife. The instantaneous standard cannot be met without reductions in wildlife loads. Reducing the direct wildlife load did not have an effect on the percent instantaneous exceedance (Table 5.1, scenarios 6 and 7). Additional scenarios were made by further reducing anthropogenic land-based loads until a reduction scenario was found that resulted in zero exceedances of the standard (scenario 8, Table 5.1).

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 contains the existing and allocated loads for the Crab Creek impairment reported as total annual coliforms for *E. coli* from both direct and land-based sources. The percent reduction needed to meet water quality is given in the final column of this table. Table 5.3 is known as the TMDL table, which gives the number of coliforms of *E. coli* that can reach the stream in a given year, and still meet existing water quality standards. This figure is broken up into Waste Load Allocation (the portion of *E. coli* coliforms that may come from permitted discharge sources, including NPS sources under an MS4 permit) and Load Allocation (the portion of these coliforms that may come from the non-permitted non-point sources existing in the watershed).

Table 5.2 Land-based and Direct nonpoint source load reductions in the Crab 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	4.11E+14	2.06E+11	99.95
Commercial	1.15E+13	5.75E+09	99.95
Barren	6.72E+11	3.36E+08	99.95
Cropland	7.42E+14	3.71E+11	99.95
Livestock Access	9.18E+13	4.59E+10	99.95
Pasture	1.54E+15	7.70E+11	99.95
Forest	1.36E+14	1.36E+12	99
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	9.30E+14	0.00E+00	100
Wildlife	2.62E+12	2.62E+12	0
Straight Pipes and Sewer Overflows	1.52E+15	0.00E+00	100

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

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Crab Creek (FC)	3.40E+08	1.27E+12	*Implicit*	1.27E+12
MS4 Permits[1]	*3.40E+08*			

[1] MS4 permits include Christiansburg (VAR040025) and VDOT (VAR040016).

To determine if the allocation scenario presented (Table 5.1, scenario 8) 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.

PART III: GENERAL WATER QUALITY (BENTHIC) TMDLS

6. WATER QUALITY ASSESSMENT

6.1 Benthic Assessment

Crab 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 Crab Creek stations 9-CBC006.35, 9-CBC004.38, 9-CBC001.00.

Table 6.1 The RBPII biological assessment for the last 5 years for Crab Creek at station 9-CBC001.00.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998	4.35	Severely Impaired	36.36	Severely imp. (BPJ)
1999	4.17	Severely Impaired	21.74	Moderately Impaired
2000	30.43	Moderately Impaired	43.48	Moderately Impaired
2001		(not sampled)		(not sampled)
2002	73.91	Slightly Impaired	63.64	Slightly Impaired
Seasonal 5-yr average	28.22		41.31	
Seasonal last 2-yr average	NA		NA	
Final 5-yr average	34.76			
Final 2-yr average	NA			

Table 6.2 The RBPII biological assessment for the last 5 years for Crab Creek at station 9-CBC004.38.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998		(not sampled)	22.73	Severely imp. (BPJ)
1999	37.50	Moderately Impaired	47.83	Moderately Impaired
2000	39.13	Moderately Impaired	34.78	Moderately Impaired
2001		(not sampled)		(not sampled)
2002	65.22	Slightly Impaired	59.09	Slightly Impaired
Seasonal 5-yr average	47.28		41.12	
Seasonal last 2-yr average	NA		NA	
Final 5-yr average			43.75	
Final 2-yr average			NA	

Table 6.3 The RBPII biological assessment for the last 5 years for Crab Creek at station 9-CBC006.35.

Year	Spring score	Spring assessment	Fall score	Fall assessment
1998	30.43	Moderately Impaired	22.73	Moderately Impaired
1999	50.00	Moderately Impaired	52.17	Slightly imp.
2000	47.83	Slightly imp. (BPJ)	34.78	Moderately Impaired
2001		(not sampled)		(not sampled)
2002	52.17	Moderately Impaired	59.09	Slightly Impaired
Seasonal 5-yr average	45.11		42.19	
Seasonal last 2-yr average	NA		NA	
Final 5-yr average			43.65	
Final 2-yr average			NA	

Data from benthic surveys completed on Crab Creek are summarized in Tables 6.4 through 6.6. With over a dozen surveys completed at three stations, the condition of the benthic community has been well established on Crab Creek. Results from all three stations consistently indicate impaired conditions. 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 CBC001.00.

Date	Taxa	EPT	%Ephem	%PT-H	%Scraper	%Chiron	%2Dom	%MFBI	SCI
10/06/94	50.0	45.5	43.5	2.3	18.8	0.0	51.7	75.4	35.9
04/20/95	27.3	9.1	0.0	0.0	1.1	49.7	4.7	59.0	18.9
10/19/95	40.9	18.2	16.6	0.0	8.2	99.2	28.1	65.8	34.6
04/30/96	31.8	9.1	0.0	0.0	9.5	26.5	32.5	55.7	20.6
09/26/96	31.8	18.2	6.7	0.0.	21.6	87.6	53.6	64.1	35.5
04/30/97	31.8	27.3	12.4	0.0	1.1	41.4	24.9	35.8	21.8
10/06/97	40.9	27.3	24.8	0.0	12.3	93.5	36.1	66.7	37.7
04/28/98	13.6	9.1	0.0	0.0	0.0	11.0	7.2	57.4	12.3
10/21/98	36.4	36.4	3.4	3.0	8.5	0.0	12.2	61.8	20.2
03/11/99	31.8	27.3	5.0	0.0	0.8	20.0	16.3	20.6	15.2
10/26/99	50.0	45.5	27.4	0.0	7.7	92.0	57.7	73.6	44.2
05/01/00	59.1	72.7	21.1	34.4	11.0	51.0	46.1	64.5	45.0
10/13/00	63.6	63.6	90.0	0.0	15.4	94.6	54.7	81.1	57.9
04/05/02	86.4	54.5	15.4	0.0	49.0	73.0	78.0	68.5	53.1
Mean	39.2	31.5	19.3	3.1	8.9	51.3	32.8	60.1	30.8
Median	36.4	27.3	12.4	0.0	8.5	49.7	32.5	64.1	34.6

Table 6.5 Summary of biological monitoring data for Station CBC004.38.

Date	Taxa	EPT	%Ephem	%PT-H	%Scraper	%Chiron	%2Dom	%MFBI	SCI
10/06/94	36.4	36.4	18.5	0.0	18.3	91.5	39.5	67.0	38.4
04/20/95	22.7	9.1	0.0	0.0	2.7	69.5	7.3	59.7	21.4
10/19/95	31.8	18.2	7.2	0.0	12.8	92.0	35.8	65.1	32.9
04/30/96	36.4	18.2	1.6	0.0	3.2	15.0	13.0	60.0	18.4
09/26/96	22.7	9.1	0.0	0.0	10.7	94.2	20.3	61.9	27.4
04/30/97	40.9	27.3	3.0	0.0	3.0	65.7	53.4	43.7	29.6
10/06/97	40.9	18.2	16.9	0.0	9.7	93.1	41.1	63.0	35.4
10/21/98	22.7	9.1	0.0	0.0	0.0	90.9	10.5	60.2	24.2
03/11/99	40.9	36.4	45.8	0.0	28.3	69.3	65.8	75.1	45.2
10/26/99	31.8	27.3	20.0	0.0	4.6	90.6	31.3	66.2	34.0
05/01/00	45.5	45.5	30.3	0.0	13.0	71.0	52.4	69.0	40.8
10/13/00	59.1	45.5	58.5	1.2	13.6	95.6	51.1	72.7	49.7
04/05/02	68.2	36.4	8.5	0.0	62.8	81.2	59.0	73.5	48.7
Mean	38.5	25.9	16.2	0.1	14.1	78.4	37.0	64.4	34.3
Median	36.4	27.3	8.5	0.0	10.7	90.6	39.5	65.1	34.0

Table 6.6 Summary of biological monitoring data for Station CBC006.35.

Date	Taxa	EPT	%Ephem	%PT-H	%Scraper	%Chiron	%2Dom	%MFBI	SCI
10/06/94	45.5	45.5	35.6	5.1	11.7	99.1	36.7	69.5	43.6
04/20/95	59.1	63.6	25.0	5.6	2.2	92.7	37.5	66.6	44.0
10/19/95	40.9	36.4	39.7	5.1	61.0	97.3	55.9	78.2	51.8
04/30/96	40.9	36.4	19.6	5.2	29.9	58.3	60.1	70.7	40.1
09/26/96	22.7	18.2	16.3	0.0	64.5	0.0	41.7	75.5	29.9
04/30/97	63.6	54.5	48.9	2.2	38.5	82.3	93.2	75.3	57.3
10/06/97	40.9	18.2	6.8	0.0	21.8	97.9	30.1	63.3	34.9
04/28/98	40.9	27.3	12.7	0.0	17.2	68.9	43.4	67.0	34.7
10/21/98	45.5	45.5	11.4	2.5	22.6	94.7	29.1	65.3	39.6
03/11/99	59.1	54.5	45.5	0.0	13.2	74.8	66.8	73.3	48.4
10/26/99	45.5	54.5	64.8	21.9	33.2	97.9	68.6	82.2	58.6
05/01/00	45.5	54.5	64.4	0.0	20.7	89.9	64.9	75.0	51.9
10/13/00	63.6	54.5	46.6	2.4	14.0	97.0	29.4	70.4	47.2
04/05/02	50.0	36.4	5.4	0.0	32.3	83.3	47.1	70.1	40.6
Mean	46.2	42.0	30.5	3.7	28.4	79.8	51.9	71.7	44.3
Median	45.5	45.5	25.0	2.2	22.6	89.9	47.1	70.7	43.6

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.

Although Plots of the Stream Condition Index (SCI) scores, displayed in Figure 6.1 were prepared for Crab Creek 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 Crab Creek displays seasonality with SCI scores generally higher in the fall than in the spring. Until December of 1998, the Christiansburg sewage treatment plant discharged to Crab Creek just upstream from monitoring station CBC004.38. The resulting improvement in SCI scores at Station CBC001.00 and Station CBC004.38 can be seen in Figure 6.1. Beginning in 2000, seasonality is less pronounced and there is a decline in SCI scores at all three stations. These two trends are attributed to the drought of 2000-2003.

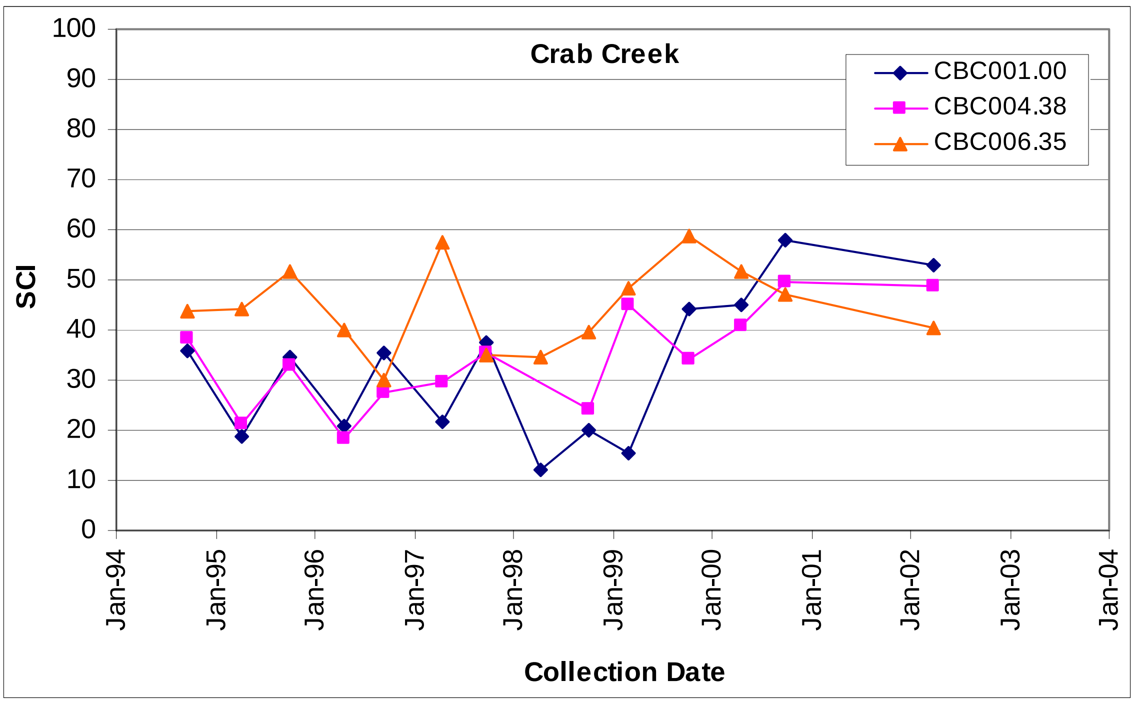


Figure 6.1 Biological assessment scores over time for Crab Creek.

Valuable insight into the stressor(s) causing a particular benthic impairment can often be gained by examining individual metric scores and these are displayed in Figures 6.3 through 6.6. There is data from 14 benthic samples at two stations and 13 benthic samples at the third. The data is 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.

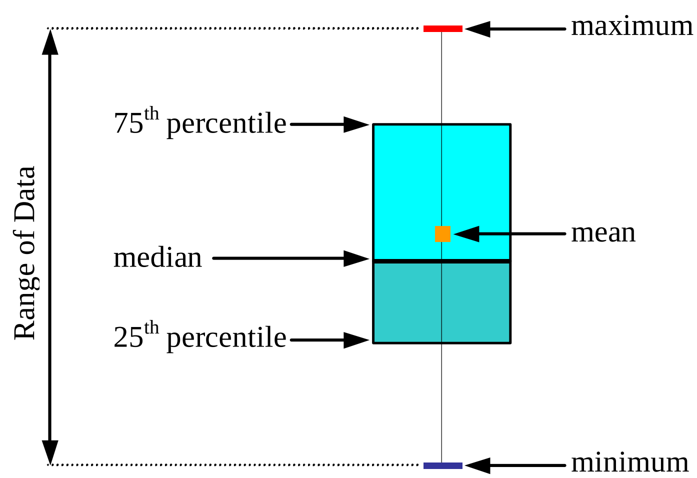


Figure 6.2 Interpretation of Box and Whisker plots.

The figures display the same general pattern; an increase in metric score from %2Dom to %Chiron, followed by a large drop in score for the next four metrics (%Ephem, %PT-H, %Scraper, %EPT) and then increased scores for Taxa Richness and %MFBI. The last metric displayed is the SCI score, obtained by averaging the eight individual metric scores. In Crab Creek, the SCI score is lowered by the small number of individuals belonging to the sensitive invertebrate families found in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT). The only family well represented from these orders is Hydropsychidae, a family with facultative species that often become abundant in streams subjected to moderate levels of pollution from fine particulates high in organic matter and nutrients (Voshell, 2002).

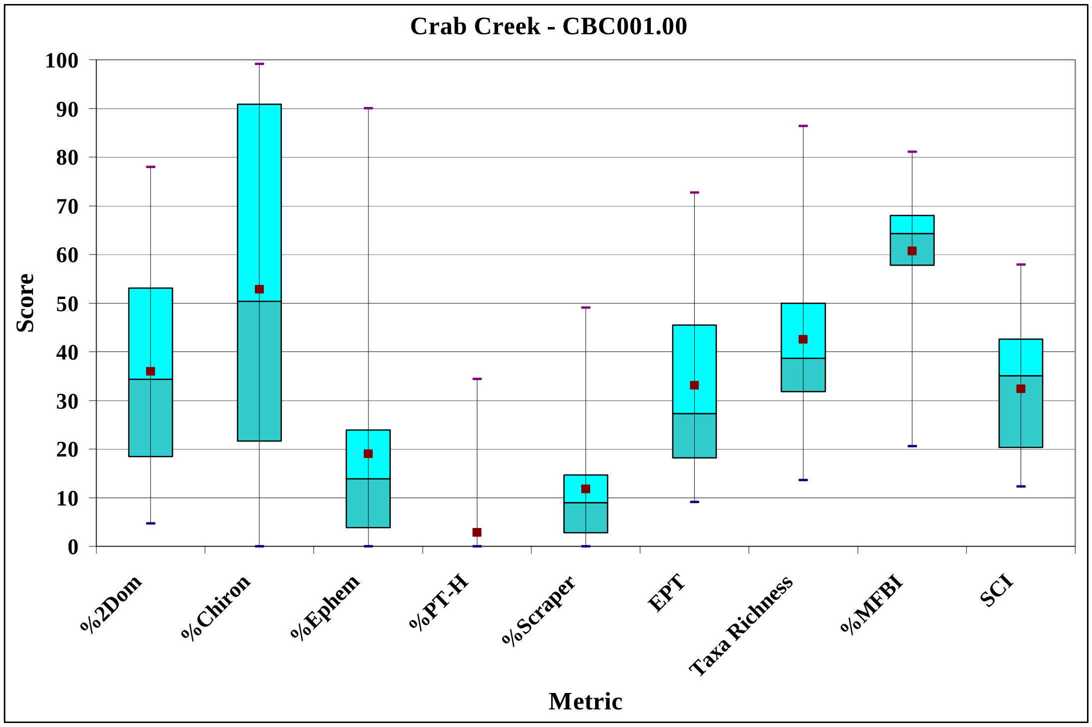


Figure 6.3 SCI metric scores for Crab Creek at Station CBC001.00.

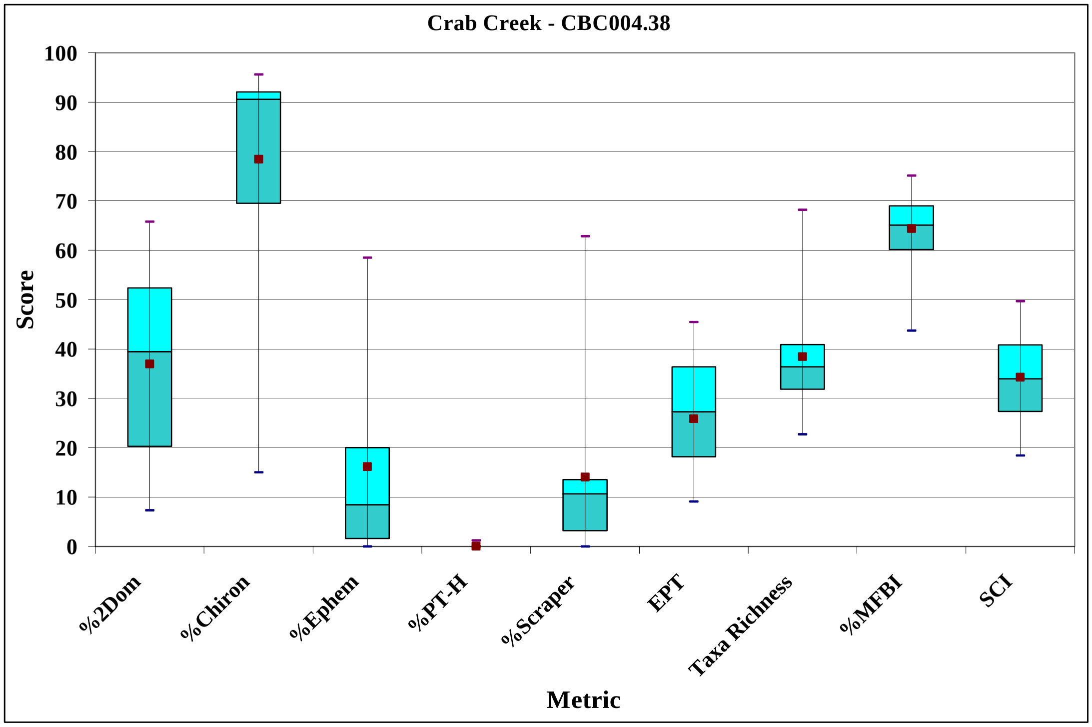


Figure 6.4 SCI metric scores for Crab Creek at Station CBC004.38.

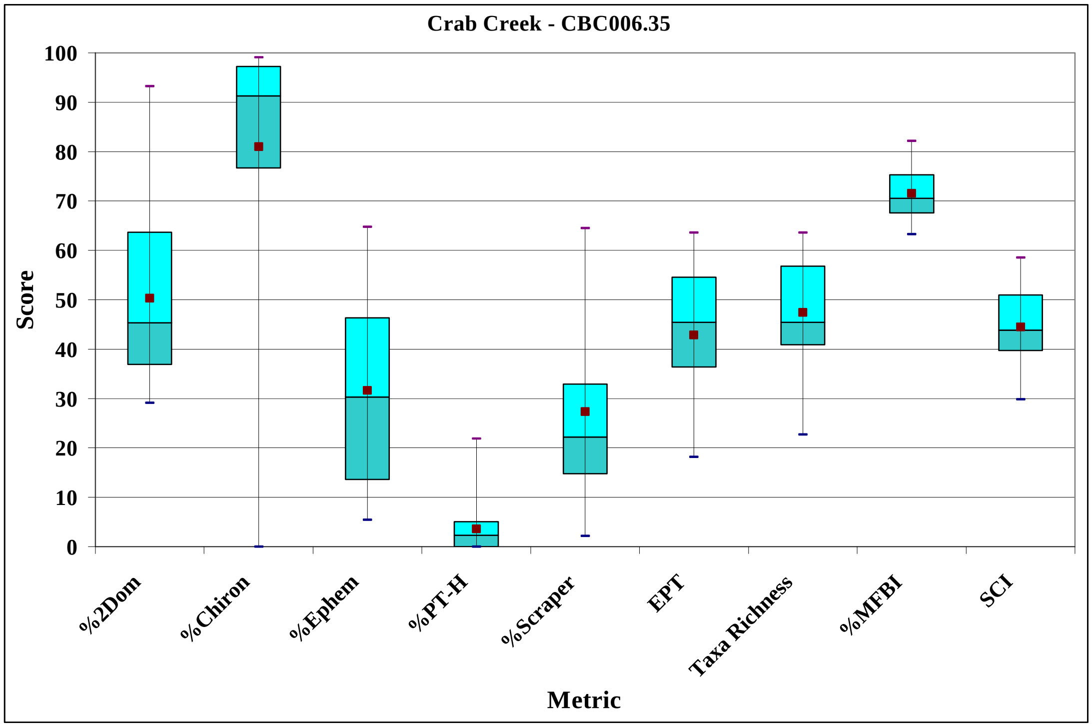


Figure 6.5 SCI metric scores for Crab Creek at Station CBC006.35.

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 by channel modification. Habitat can be altered indirectly by changes in the riparian corridor leading to conditions such as streambank destabilization or by landuse changes in the watershed such as increasing the area of impervious surfaces. Habitat assessment for the Crab Creek watershed will include an analysis of habitat scores recorded by VADEQ biologists.

6.2.1 Habitat assessment at biological monitoring stations

Habitat assessments are typically carried out as part of benthic sampling. The overall habitat score being the sum of nine individual metrics, each metric ranging from 0 to 20.

The classification schemes for both the habitat metrics and the overall habitat score for a stream 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	Sub-optimal
6-10	51-100	Marginal
0-5	0-50	Poor

Habitat assessments on Crab Creek are displayed in Figures 6.6 through Figure 6.8 and indicate sub-optimal conditions. Stream flow and riffles are in the optimal range at all three stations but riparian vegetation is marginal at the upper station and poor at the middle and lower stations. The other habitat metrics are all in the sub-optimal range at all three stations with the exception of marginal scores for sediment at the middle and upper stations. The primary problem with habitat is the lack of riparian vegetation. Loss of the vegetative buffer strip leaves the stream more vulnerable to sedimentation and nutrient that, in turn, leads to increased embeddedness and loss of habitat for the EPT families.

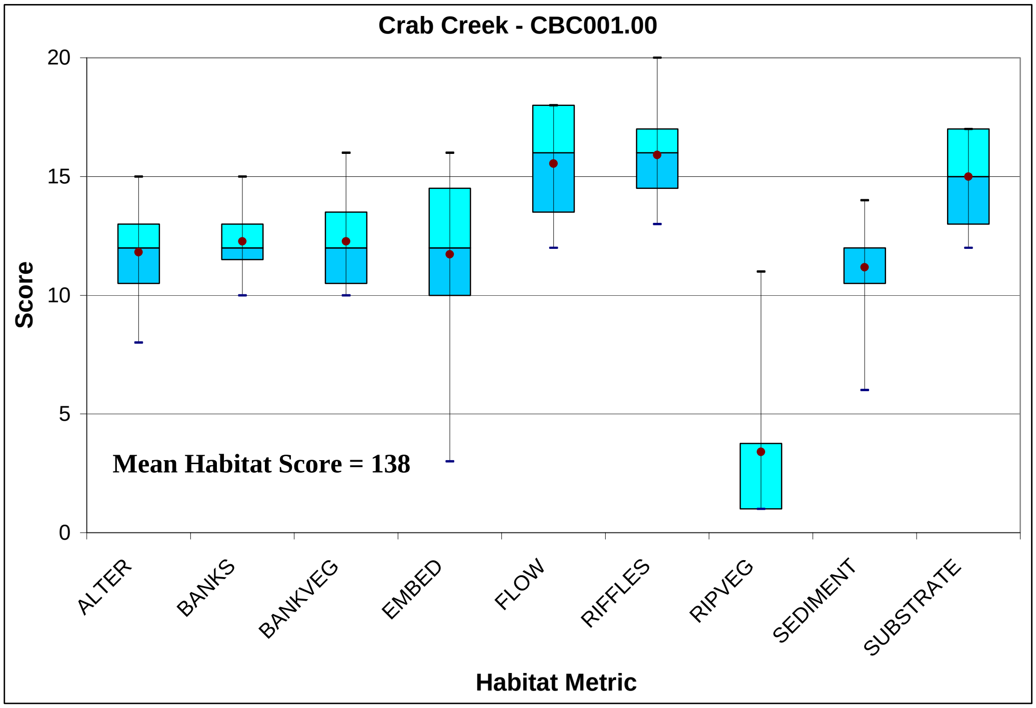


Figure 6.6 Habitat scores for Crab Creek at Station CBC001.00.

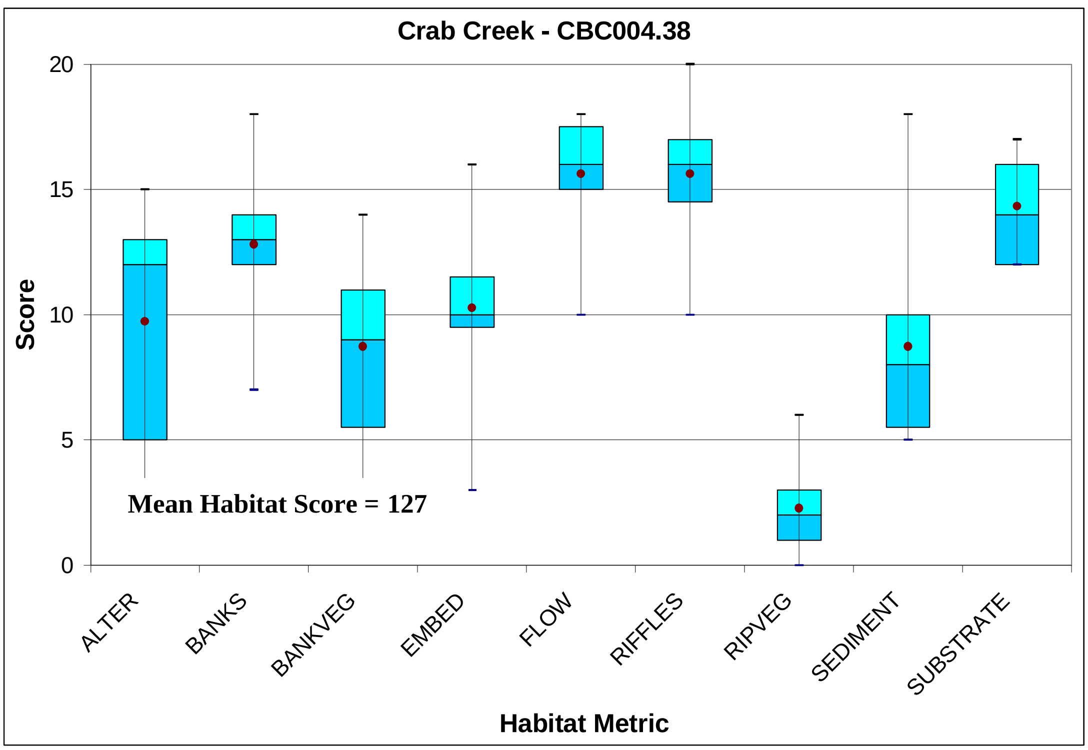


Figure 6.7 Habitat scores for Crab Creek at Station CBC004.38.

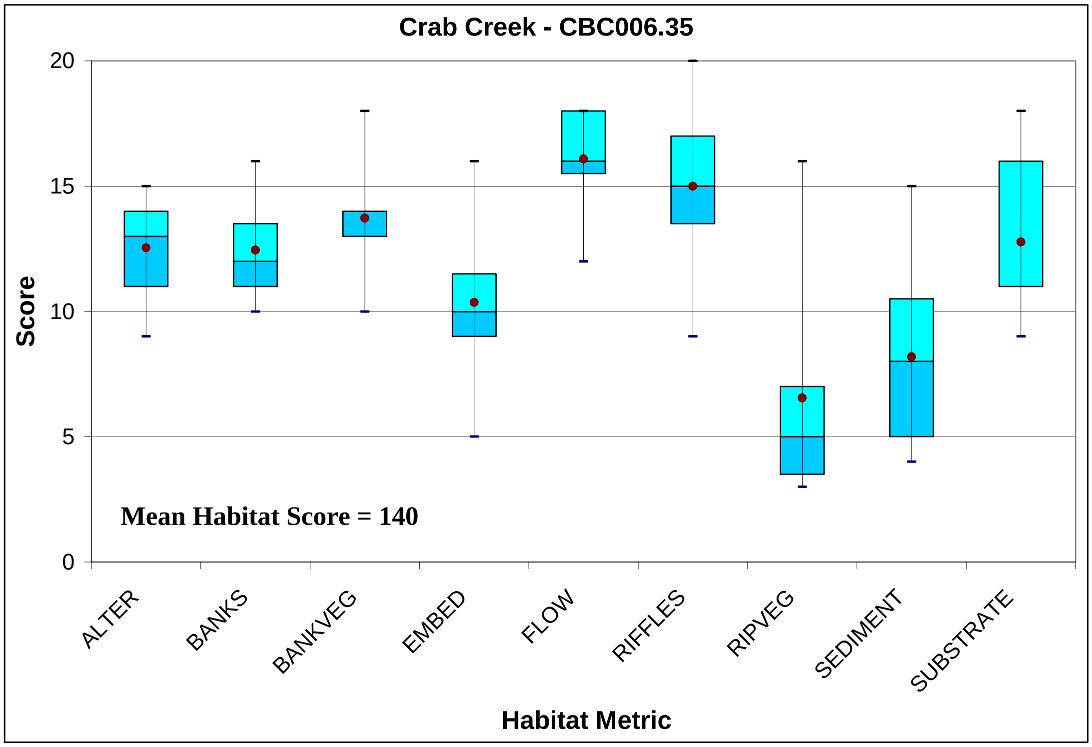


Figure 6.8 Habitat scores for Crab Creek at Station CBC006.35.

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION AND WATERSHED SELECTION

7.1 Background

Crab Creek begins in Montgomery County approximately 0.7 miles east of interstate 81. It flows northwest through the Town of Christiansburg before its confluence with the New River near Radford. It is a second order stream underlain by limestone and dolomite. The dominant landuse is pasture and hay but the headwaters are urban/suburban. There are currently 17 VPDES permitted discharges to Crab Creek. In addition, until December of 1998 the Christiansburg sewage treatment plant discharged to Crab Creek just upstream from monitoring station 9-CBC004.38. Table 7.1 summarizes the discharges permitted under VADEQ's general permit program. Table 7.2 shows Virginia Department of Environmental Quality (VDEQ) monitoring stations on Crab Creek with recent ambient data.

Table 7.1 DEQ general permits in the Crab Creek watershed.

Facility	VPDES #	Type
VDOT - Salem District - Rte 81 0081-060-119 C501	VAR100229	Construction Stormwater
VDOT - Christiansburg (4541)	VAR101126	Construction Stormwater
Depot Street School Residence	VAR102138	Construction Stormwater
Oaktree Townhomes Phase VI	VAR102140	Construction Stormwater
Holy Spirit Catholic Church	VAR102148	Construction Stormwater
New River Medical Assoc. Medical Office Park	VAR102164	Construction Stormwater
Edgemont of Diamond Hill	VAR102279	Construction Stormwater
Lions Gate	VAR102308	Construction Stormwater
Hunters Ridge Phase III	VAR103014	Construction Stormwater
Oak Tree Professional Park	VAR103064	Construction Stormwater
Hans Meadow Drainage Improvements	VAR103090	Construction Stormwater
Oak Tree Townhouses	VAR103349	Construction Stormwater
Marshall Concrete Products Inc - Christiansburg	VAG110015	Concrete
Town of Christiansburg	VAR051370	Industrial Stormwater
Federal Express Corp - WALA Station	VAR520312	Industrial Stormwater
MS4 – Town of Christiansburg	VAR040025	Stormwater
MS4 – VDOT	VAR040016	Stormwater

Table 7.2 VADEQ ambient water quality monitoring stations on Crab Creek.

Station	Description	Type	Period of Record
9-CBC001.00	Rt. 663	Ambient/Biological	1989-2003
9-CBC004.38	Rt. 660	Ambient/Biological	1988-2003
9-CBC006.35	Rt. 661	Ambient/Biological/Fish Tissue	1988-2001
9-CBC009.81	Rt. 111	Ambient	2001-2003

Ambient monitoring data from stations 9-CBC001.00, 9-CBC004.38, 9-CBC006.35 and 9-CBC009.81 were used in the analysis. In cases where the results were similar among all three monitoring stations only data from 9-CBC004.38 were used in the graphs. Ambient monitoring data from all the Crab Creek stations are included in Appendix D.

There were a total of 15 benthic surveys for 9-CBC001.00 and 9-CBC006.35 between October of 1994 and December of 2002. Fourteen benthic surveys were performed at 9-CBC004.38 during the same time period. The four different reference stations used over the eight-year sampling period are identified in Table 7.3. 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 do not 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 Crab 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 potential stressors are: sediment, toxics, low dissolved oxygen, nutrients, pH, metals, conductivity, temperature and organic matter.

Table 7.3 Reference stations used in benthic assessments on Crab Creek.

Station	Stream	River Basin	Order
9-PKC011.11	Peak Creek	New River	3
9-SNK012.06	Sinking Creek	New River	4
9-CBC006.35	Crab Creek	New River	2

9-TOM012.78	Toms Creek	New River	2

The results of the stressor analysis for Crab Creek are 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).

7.1.1 Non-Stressors

7.1.1.1 Temperature

The maximum temperature recorded in Crab Creek at station, 9-CBC001.00 was 26 ^{o}C, which is below the specific state standard for the New River Basin of 29^{o}C. Temperature measurements were consistent among all the Crab Creek monitoring stations (Figure 7.1). Therefore temperature was eliminated as a potential stressor.

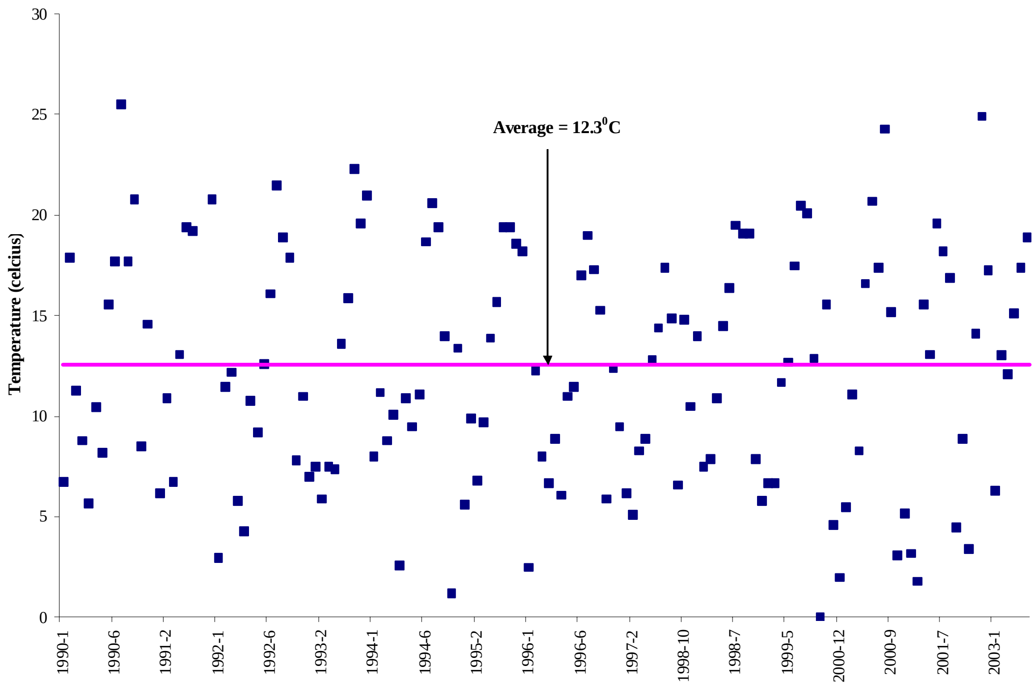


Figure 7.1 Temperature data for station 9-CBC004.38.

7.1.1.2 pH

A summary of pH data for Crab Creek is displayed in Figure 7.2. The maximum and minimum pH values were within the state standard range (6 ≤ pH ≤ 9) at all Crab Creek monitoring stations at a rate of 99% between 1/1990 and 5/2003. The exceptions were above the upper standard of 9.0 and the maximum value recorded was 9.2. This is reasonable because the geology of the drainage area is limestone. Occasional values at this level do not adversely impact benthic communities. Median pH values at the three monitoring stations were around 8.2. Alkalinity concentrations, shown in Figure 7.3, are within the expected normal range of 30-500 mg/L for this ecoregion. Therefore pH was eliminated as a possible stressor.

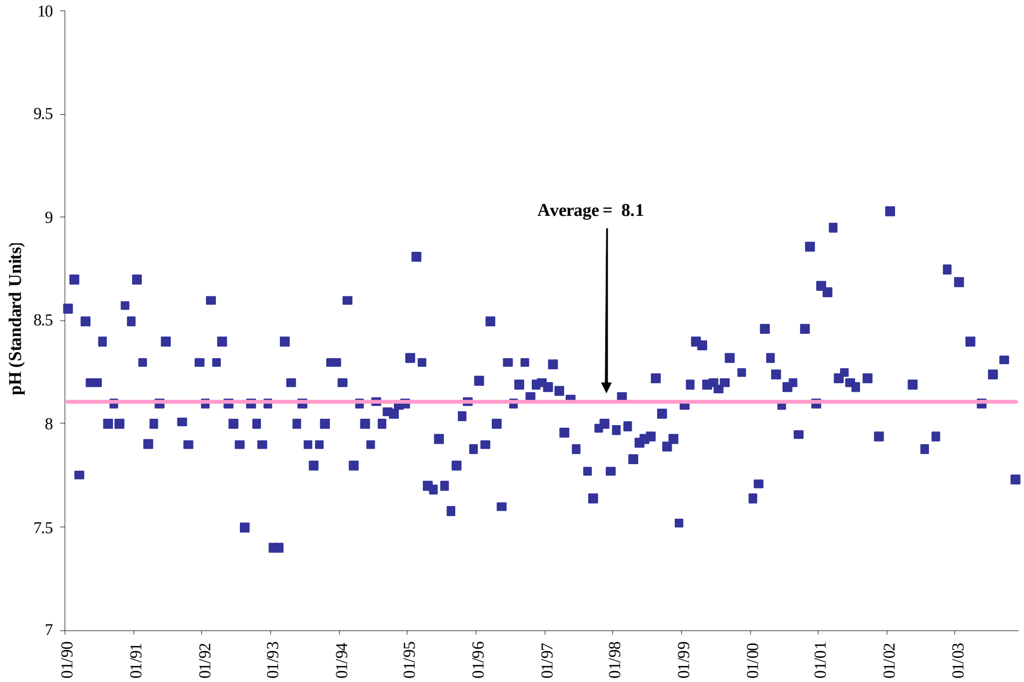


Figure 7.2 Field pH data at station 9-CBC004.38.

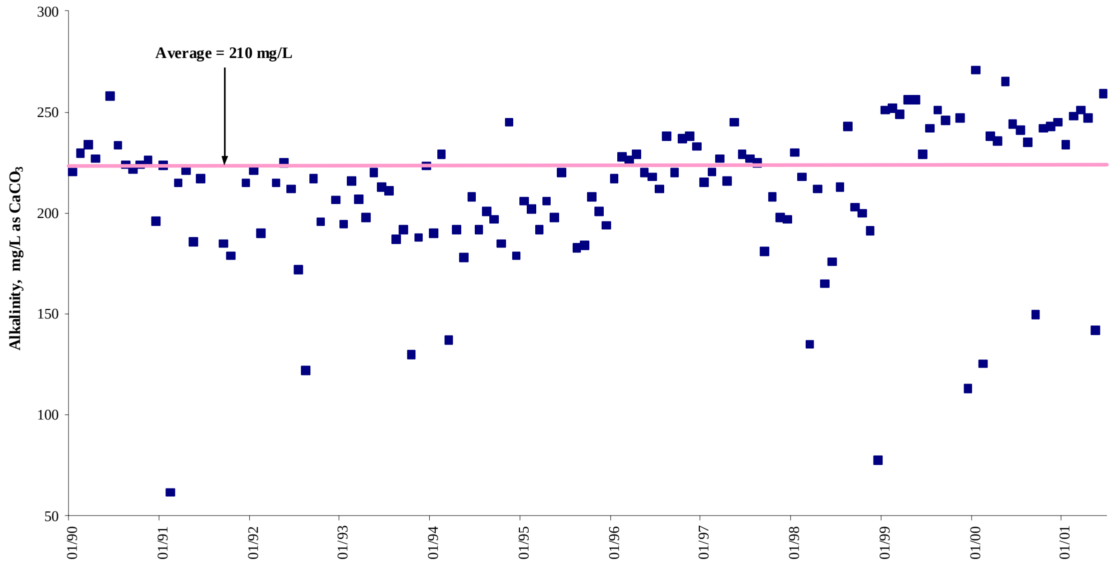


Figure 7.3 Alkalinity concentration at station 9-CBC004.38.

7.1.1.3 Low Dissolved Oxygen

Dissolved oxygen concentrations, shown in Figure 7.4, remained well above the water quality standard at all Crab Creek monitoring stations. Station 9-CBC004.38 was representative of the stream as a whole. The wider swings in concentrations near the end of the sampling period are believed to be due to the drought. Low dissolved oxygen was eliminated as a potential stressor.

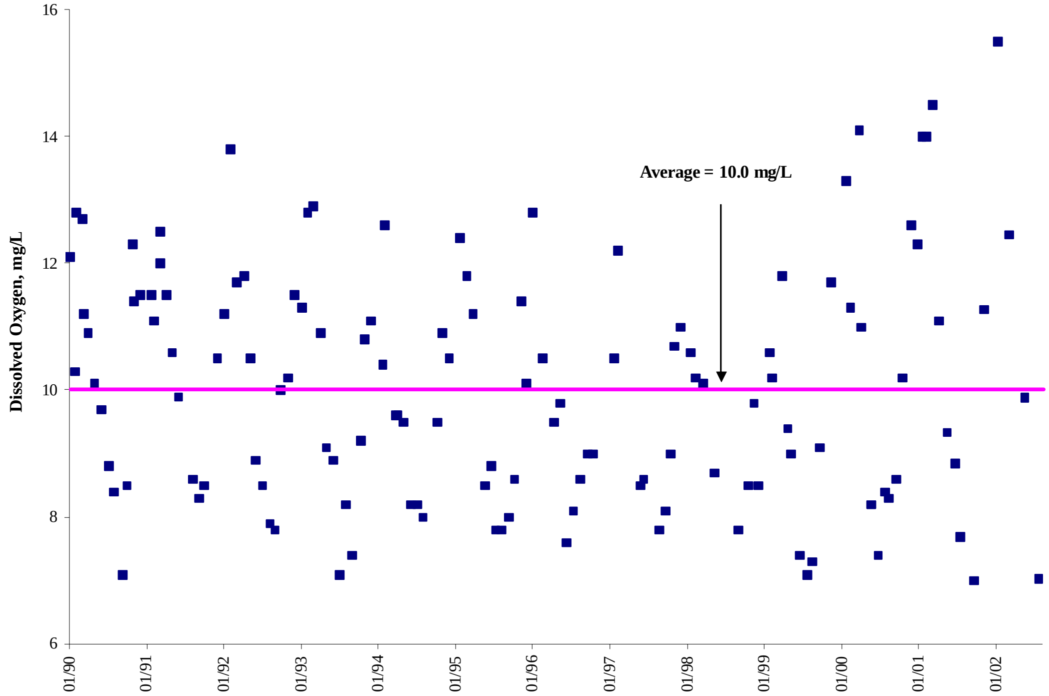


Figure 7.4 Dissolved oxygen concentration at station 9-CBC004.38.

7.1.1.4 Metals

The water column and sediment monitoring data indicated that metals are not likely stressors because values were below the appropriate water quality standard or the consensus based Probable Effect Concentration (PEC; MacDonald et al., 2000) screening value.

7.1.1.5 Toxics

The water column and sediment monitoring data indicated that toxics are not as likely stressors because values were below the appropriate water quality standard or PEC screening value (ammonia is discussed separately in the Possible Stressors section). Chloride concentrations were well below EPA's chronic criterion of 230 mg/l (Figure 7.5). Fish tissue and sediment sampling was performed at monitoring station 9-CBC006.35 on June 20, 2000. There were no elevated levels of toxic parameters found in fish tissue and sediment toxic values were all below PEC screening values. Two underground storage tank releases were reported to VADEQ in August and September

2003 from sites at 925 Cambria Street in Christiansburg; both involved heating oil. This location is near to monitoring station 9-CBC009.81. One site is approximately 50 feet from Crab Creek and removal of approximately 32.32 tons of petroleum contaminated soil was necessary. The consultants for the project recommended that work on the site be closed. The second site is located approximately 200 feet from Crab Creek and 9.5 tons of petroleum contaminated soil was removed. Storm drain inlets that discharge to Crab Creek are in the vicinity of each release but no sheen or other evidence of petroleum product was reported in Crab Creek. The consultant recommended aggressive remediation actions be taken at the second site to protect Crab Creek from potential damage. They also recommended that a Site Characterization Report (SCR) be prepared to determine the vertical and horizontal extent of the release plume. The sediment sampling done at 9-CBC006.35 in June 2000 indicated that a number of benzene compounds had values that were 60 to 75% lower than the PEC value. It is likely that if a significant quantity of petroleum product was impacting the stream it would have been evident in the sediment sampling results. It is recommended that VADEQ follow the consultant’s recommendations so that any potential damage to the benthic community from the affected site can be prevented.

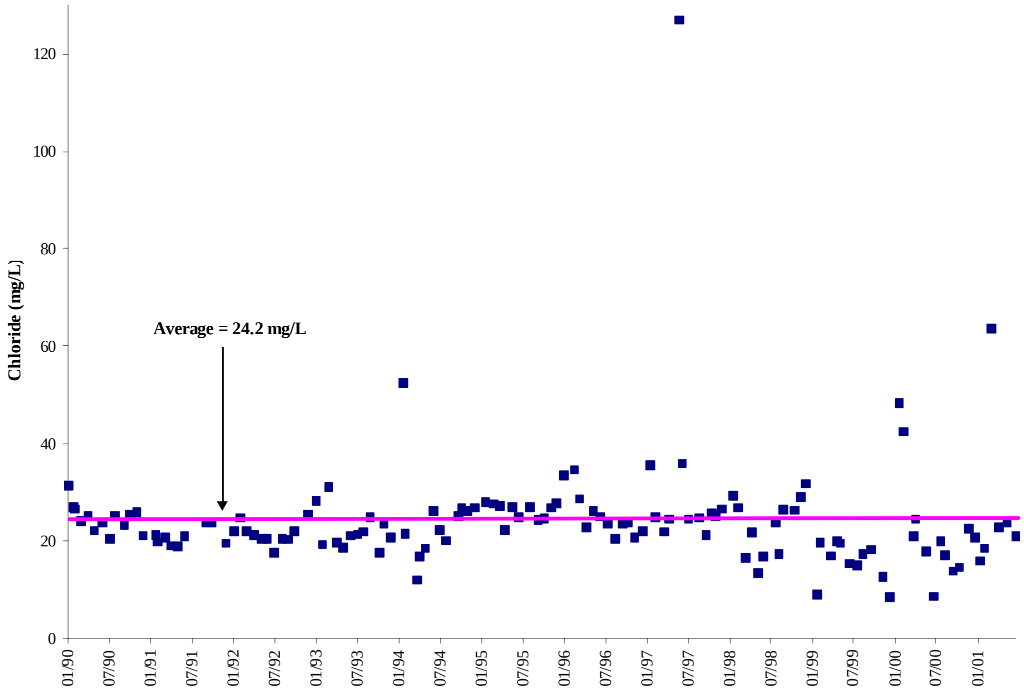


Figure 7.5 Chloride concentrations at station 9-CBC004.38.

7.1.1.6 Conductivity

Conductivity values, shown in Figure 7.6, were moderate, and median values ranging from 502 to 528 µmho/cm from all Crab Creek monitoring stations with recent data. Station 9-CBC009.81 did record an extreme value of 2,420 µmho/cm on January 29, 2003. Downstream values on that date were 528 µmho/cm (9-CBC004.38) and 545 µmho/cm (9-CBC001.00). Extremely high or wide swings in conductivity can contribute to environmental stress for benthic macroinvertebrates. For example, values higher than 1,000 µmho/cm can be stressful to pollution sensitive benthic organisms (Moeykens, 2002). Conductivity was eliminated as a potential stressor.

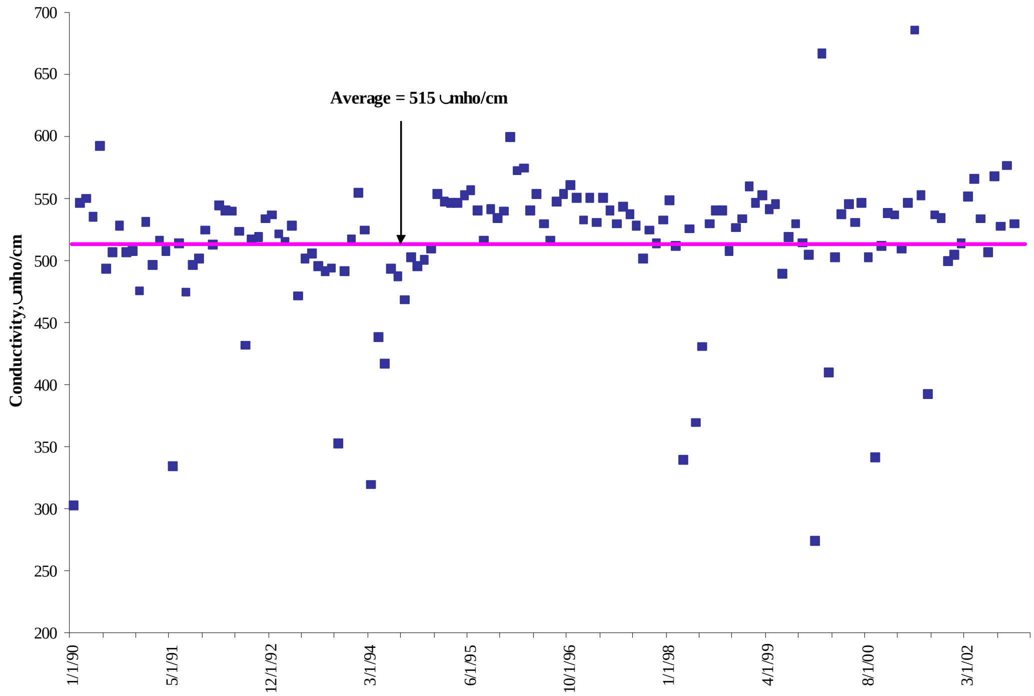


Figure 7.6 Conductivity at station 9-CBC004.38.

7.1.2 Possible Stressors

7.1.2.1 Ammonia

Ammonia data for Crab Creek is displayed in Figure 7.7. The median concentration for Station 9-CBC004.38 is 0.12 mg/L, slightly above the freshwater background level of 0.1 mg/L suggested by the USGS. However, there were many spikes throughout the data record. Twice concentrations exceeded 3.0 mg/L and another eight concentrations exceeded 1.0 mg/L. Concentrations approached the acute freshwater ammonia water quality standard in the early 1990s but, never exceeded it (Figure 7.8). The 30-day average chronic water quality standard was exceeded six times between January 1990 and February 1994. The samples violating the chronic standard are shown in Figure 7.9. Exceeding the chronic standard does not represent a water quality standard violation because monitored values are collected monthly and therefore are not 30-day averages but, it is further evidence of high ammonia levels. Ammonia concentrations have not exceeded 1.0 mg/L since 1998. The likely reason for the improvement is the removal of the Christiansburg STP discharge. The outfall pipe was moved from Crab Creek to the New River in December of 1998. Figure 7.7 shows the decrease in ammonia concentrations to levels closer to the upstream monitoring station 9-CBC006.35. It is logical to presume that if ammonia was a stressor there would have been dramatic improvement in the benthic community at Station 9-CBC004.38. The benthic scores at all three Crab Creek monitoring stations were evaluated against the new proposed biocriteria, the Stream Condition Index (SCI) for Virginia. The difference between the SCI values at 9-CBC004.38 from October 1994 to October 1998 and the values from March 1999 to December 2002 were statistically significant ($p = 0.001$), however, differences during the same time periods at the other two stations were not significant. Therefore, high ammonia levels in the discharge from the Christiansburg STP may have harmed the benthic community at 9-CBC004.38. Ammonia is toxic and concentrations are higher than typical background levels, so it is considered a possible stressor.

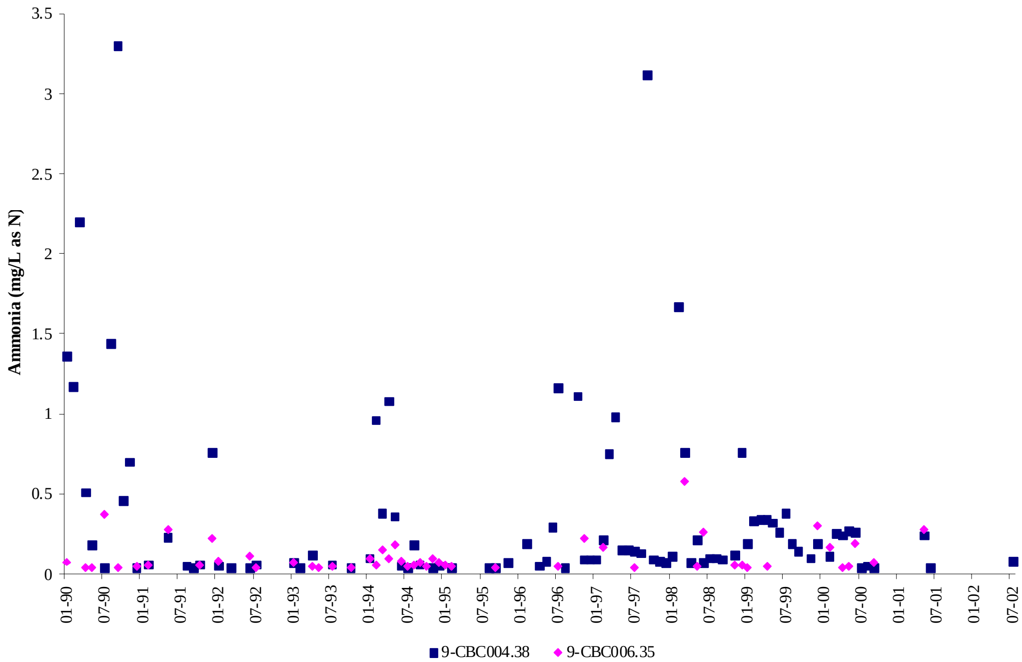


Figure 7.7 Ammonia concentrations at stations 9-CBC004.38 and 9-CBC006.35.

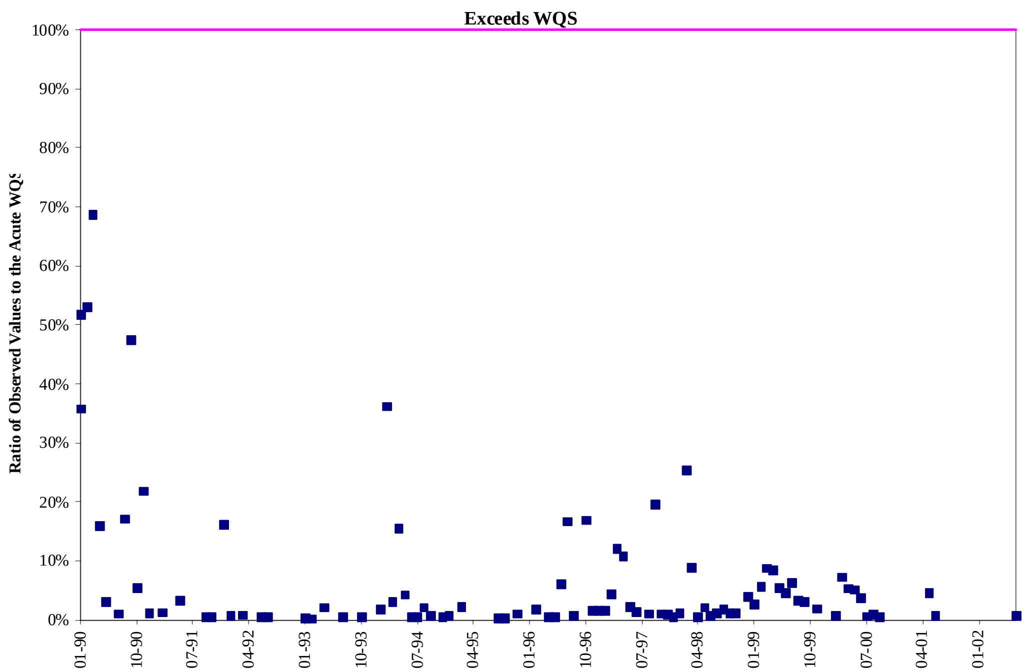


Figure 7.8 Ammonia concentrations and the acute water quality standard at station 9-CBC004.38.

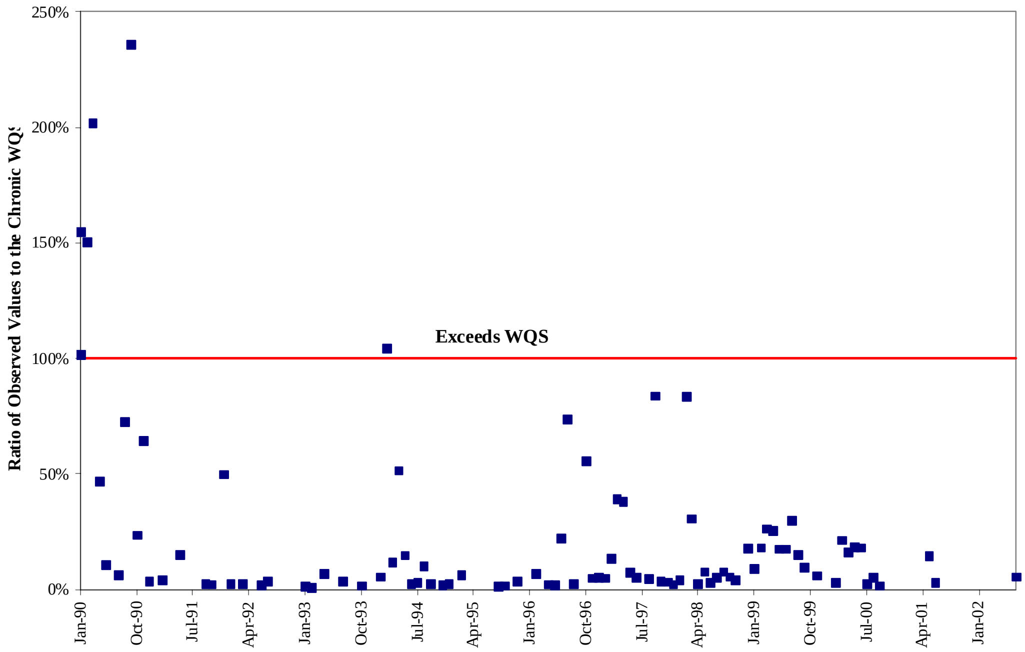


Figure 7.9 Ammonia concentrations and the chronic water quality standard at station 9-CBC004.38.

7.1.2.2 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 the amount of dissolved organic matter. Total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS) provide an indication of the amount of particulate organic matter in a stream. BOD_5 concentrations at Station 9-CBC004.38 (Figure 7.10) were within acceptable levels, however, two values reached 12 mg/L prior to January 1999. This suggests that dissolved organic matter may not be a significant stressor. COD (Figure 7.11) and TOC (Figure 7.12) concentrations were within normal ranges. Volatile solids concentrations were elevated in Crab Creek (Figure 7.13). Median VS concentrations were more than double those in Sinking Creek, the reference station (Figure 7.14). Hydropsychidae, a family of caddisflies, are netspinners that thrive on particulate organic matter. They were a dominant family at all three Crab Creek monitoring stations. The benthic metric MFBI can be indicator of excessive organic solids. Average scores at CBC001.00, CBC004.38 and CBC006.35 were 5.81, 5.57 and 5.41, respectively. MFBI scores range from 0 to 10 and increasing values were correlated with increasing organic matter. Although low dissolved oxygen concentrations are often associated with high organic matter, this does not always apply for high gradient streams with adequate re-aeration potential. Based on this information organic matter was considered a possible stressor.

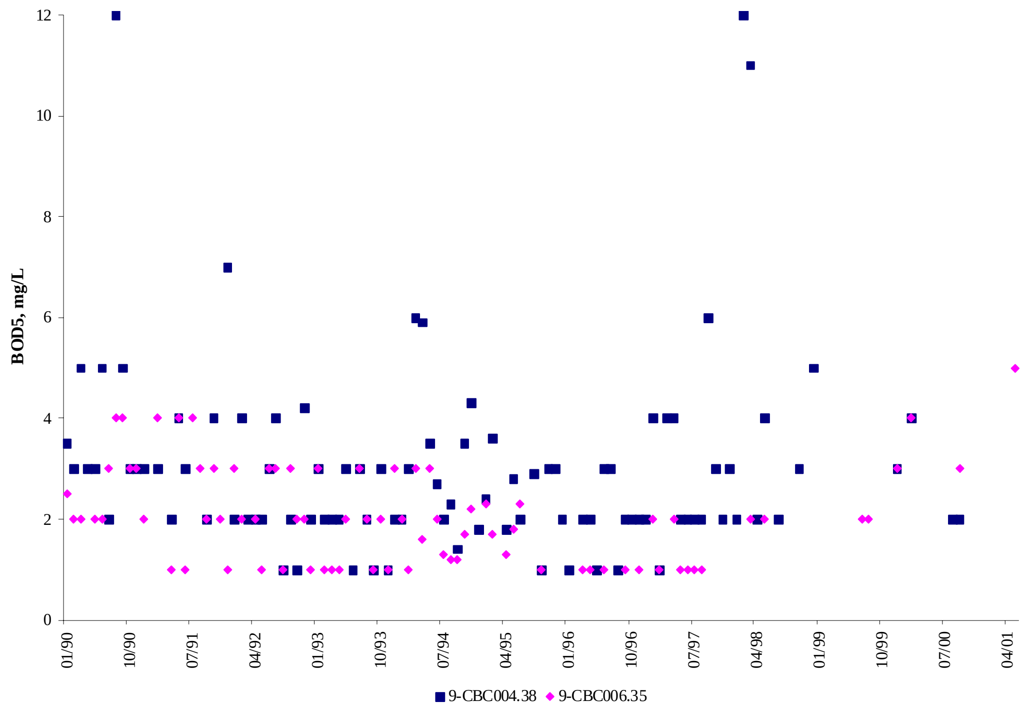


Figure 7.10 BOD_5 concentrations at stations 9-CBC004.38 and 9-CBC006.35.

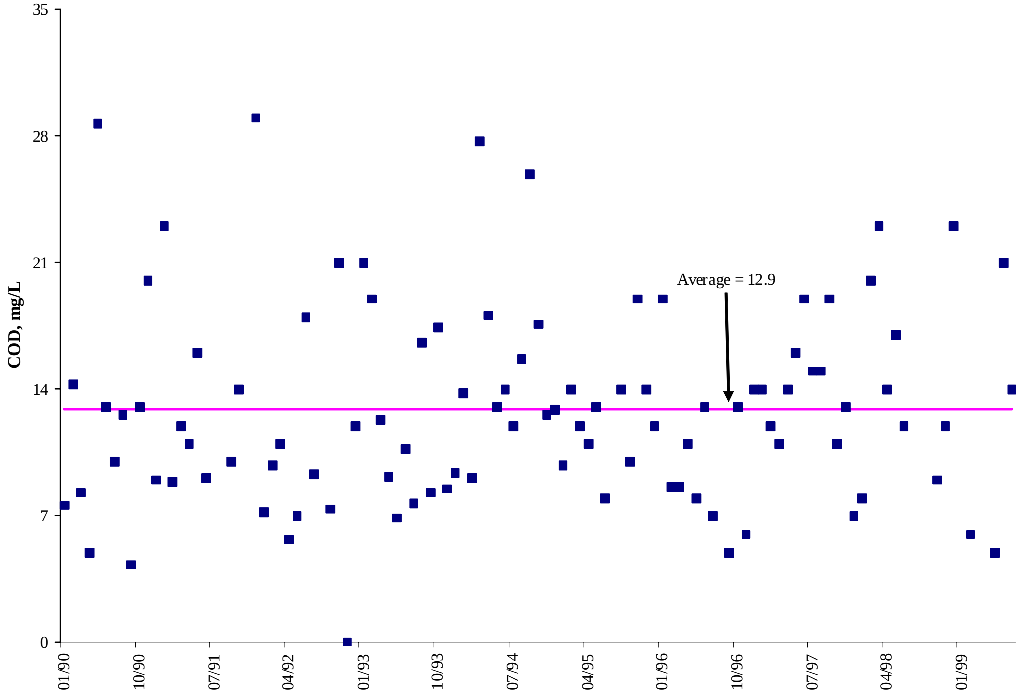


Figure 7.11 COD concentrations at station 9-CBC004.38.

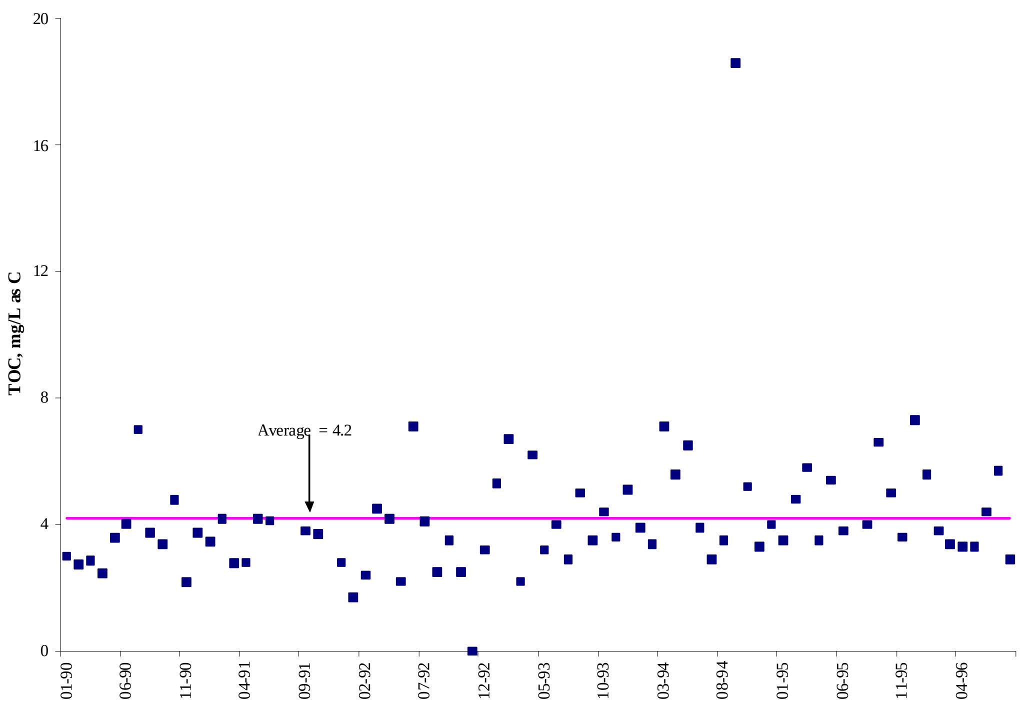


Figure 7.12 TOC concentrations at station 9-CBC004.38.

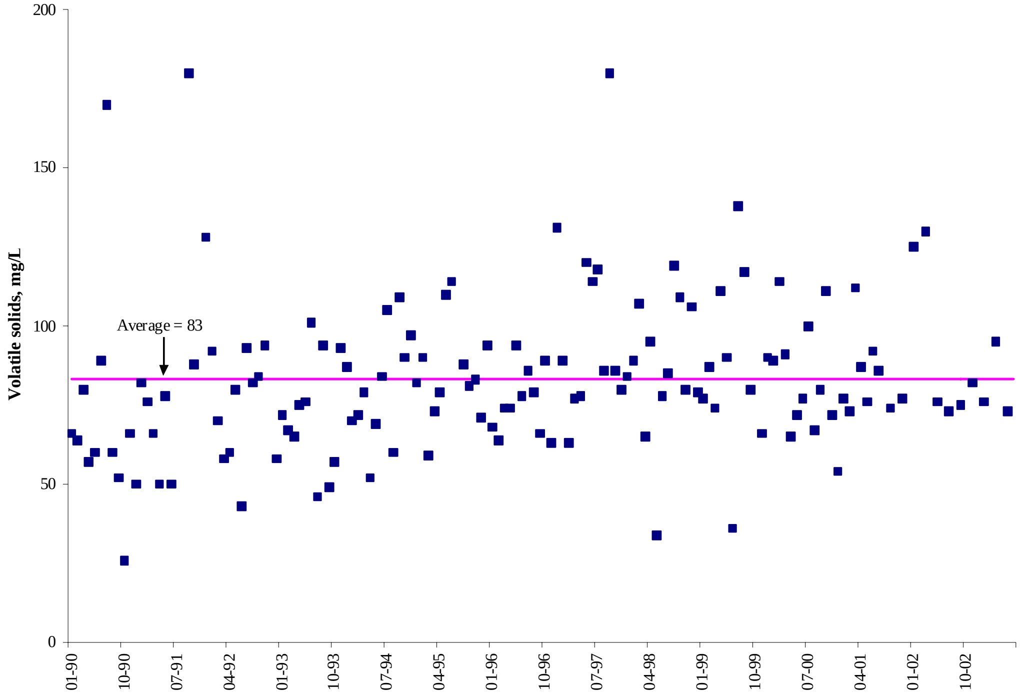


Figure 7.13 Volatile solids concentrations at station 9-CBC004.38.

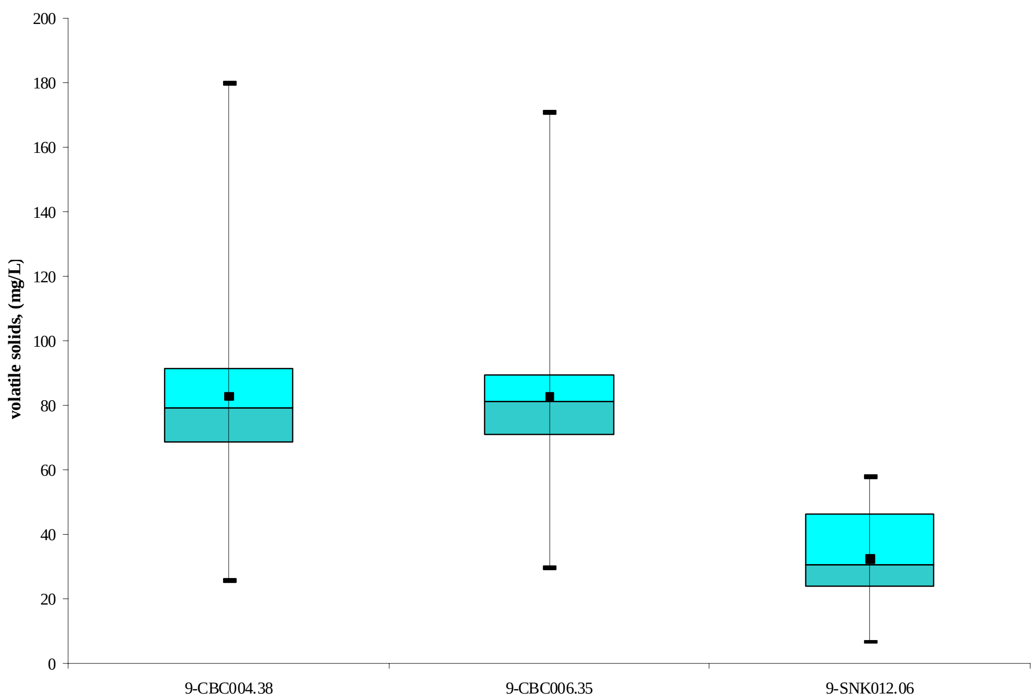


Figure 7.14 Box and whisker plot of volatile solids concentrations at stations 9-CBC004.38, 9-CBC006.35 and 9-SNK012.06.

7.1.2.3 Nutrients

Median Total Phosphorus (TP) concentrations at monitoring station 9-CBC004.38 were considerably higher than the VADEQ assessment screening value of 0.2 mg/L (0.7 mg/L) until January 1999 (Figure 7.15). Median TP levels dropped to what is considered a normal background level, 0.1 mg/L, following the elimination of the Christiansburg Sewage Treatment Plant (STP) discharge. The values were consistent with the upstream station, 9-CBC006.35. Nitrate nitrogen (NO_3-N) values showed the same pattern as the TP values (Figure 7.16). Prior to December 1998, the median NO_3-N concentration was 3.91 mg/L and the extreme maximum concentration of 8.04 mg/L was recorded in August 1995. Since January 1999, the median concentration was 1.23 mg/L. The median concentration at 9-CBC006.35 was 1.64 mg/L. Therefore, NO_3-N concentrations at both monitoring stations were higher than 1.0 mg/L, which is considered a typical background concentration by the USGS. A more thorough examination of nutrients to determine the potential for eutrophication from the existing data was performed. The criteria used can be found in; Water Quality Assessment: A Screening Procedure For Toxic and Conventional Pollutants by W.B.Mils, J.D. Dean and D.B. Porcella et al, 1985. The results indicated that TP was the most limiting nutrient in nearly every case. Table 7.3 summarizes the percent of time that TP concentrations were above the Problem Likely to Exist (PLE) threshold during the algal growing season.

Table 7.4 Percent of time that TP concentrations exceeded the PLE.

Station	Data Period	Problem Likely to Exist
9-CBC001.00	9/01-5/03	0%
9-CBC004.38*	1/99-5/03	26%
9-CBC006.35	1/90-5/01	18%
9-CBC009.81	9/01-5/03	0%

*Only data after the sewage treatment plant went offline was used

The data shows that the high TP concentrations have the potential to cause eutrophication. This is a matter of concern because total nitrogen (TN) exceeded the PLE 100% of the time at all four monitoring stations. Minor increases in TP concentrations could result in favorable conditions for eutrophication more frequently. Dissolved oxygen levels were in the normal range indicating that eutrophication may not be a current problem, however, nutrients should be considered a possible stressor.

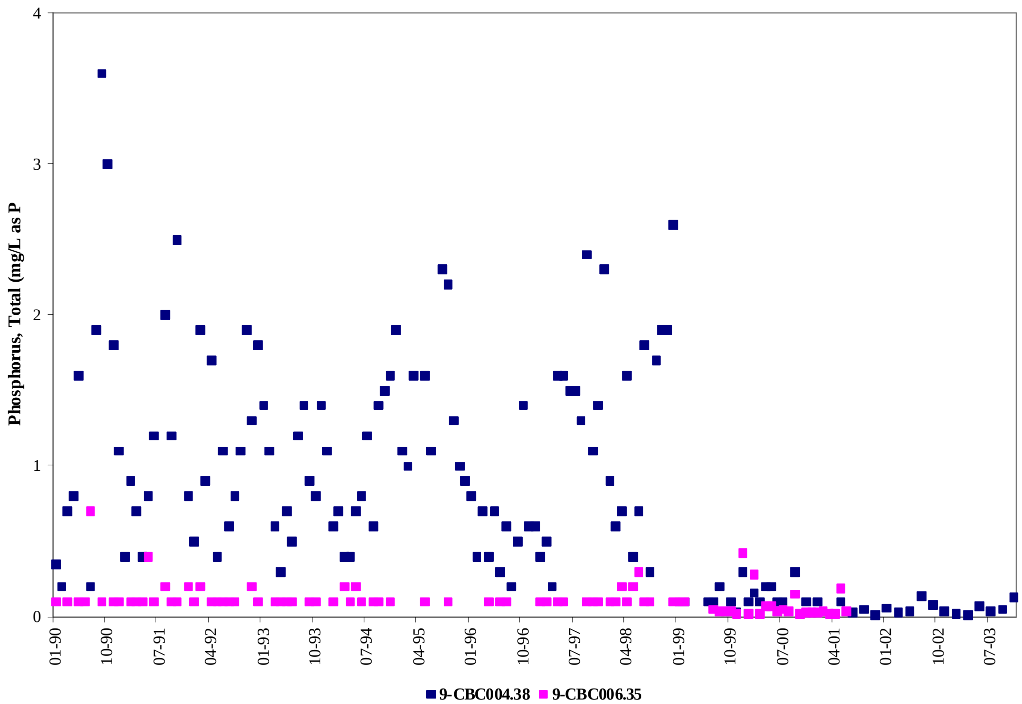


Figure 7.15 Total phosphorus concentrations at stations 9-CBC004.38 and 9-CBC006.35.

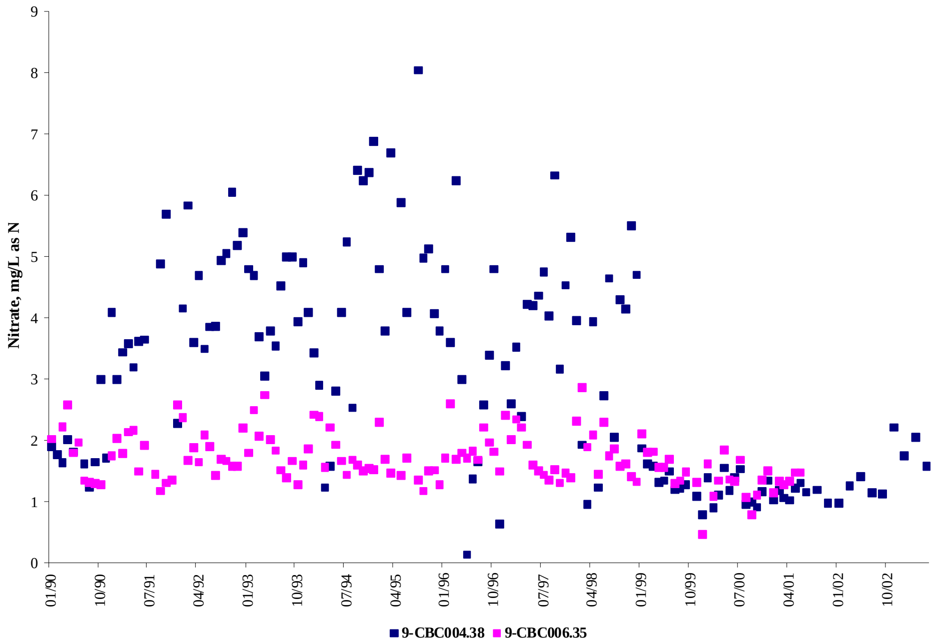


Figure 7.16 Nitrate nitrogen concentrations at stations 9-CBC004.38 and 9-CBC006.35.

Data from a diurnal DO study of Crab Creek (August 18-19, 2003) further indicated that nutrients do not threaten stream health (Figure 7.17). Although a well-defined diurnal pattern indicated significant primary production in Crab Creek, the minimum DO levels remained well above the DO standard of 4 mg/L and the diurnal swing was not sufficient to stress the benthic community.

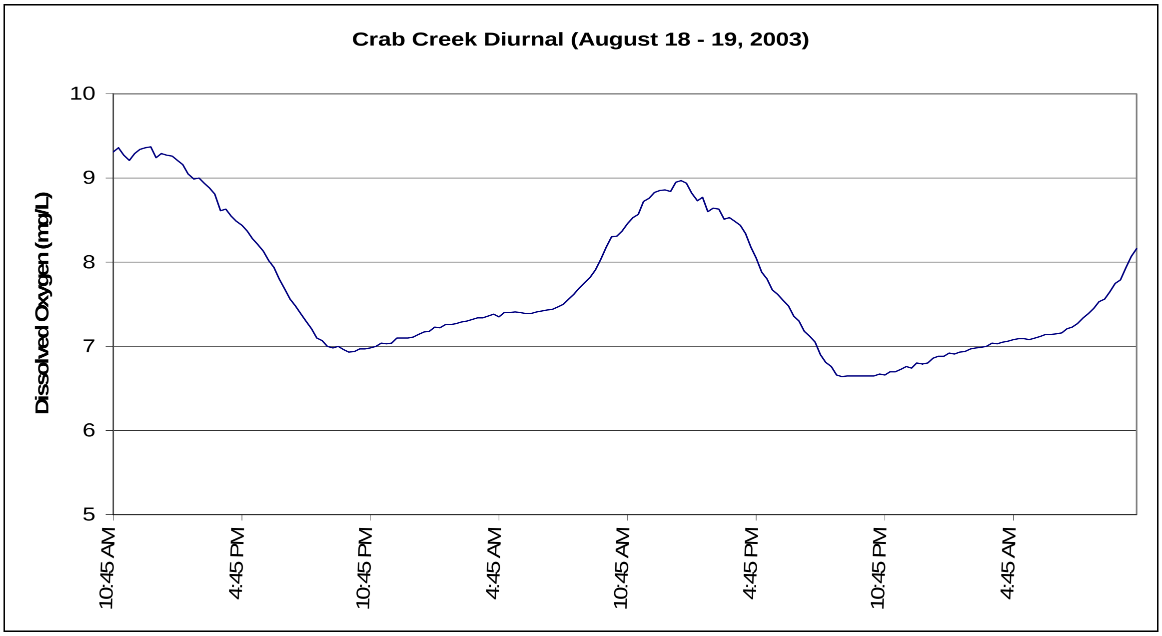


Figure 7.17 Diurnal DO study on Crab Creek.

7.1.3 Most Probable Stressor

7.1.3.1 Sediment

Values for habitat and benthic metrics show that sediment is the most probable stressor. Table 7.5 shows several average habitat scores that indicate problems for the three benthic stations on Crab Creek from 1994 through 2002.

Table 7.5 Habitat scores for the three benthic stations on Crab Creek.

Habitat Parameter	9-CBC001.00	9-CBC004.38	9-CBC006.35
Sediment Deposition	11	9	8
Embeddedness	11	10	10
Riparian Vegetation	4	3	7

The average sediment deposition scores at two of the three benthic monitoring stations (9-CBC004.38 and 9-CBC006.35) were marginal, indicating moderate deposits of fine sediment (30 to 50%) on the pool bottom. High levels of sediment are indicative of unstable and continually changing environments that are unsuitable for sensitive organisms. Embeddedness is a measure of fine sediment deposits in the riffle area and its average score was marginal for the same two benthic stations. This means that 50 to 75%

of the suitable habitat in the riffle area is surrounded by fine sediment. Riparian vegetation scores were poor at 9-CBC001.00 and 9-CBC004.38 and marginal at 9-CBC006.35. Riparian vegetation is an important buffer between the land and the stream, which filters out contaminants and prevents erosion. A poor score indicates that the vegetative zone width along the streambanks is less than 20 feet.

The benthic surveys at the three Crab Creek benthic monitoring stations were dominated by facultative or moderately pollution tolerant organisms, Chironomidae (midges) and Hydropsychidae (netspinning caddisflies). These two families made up 60% of the assemblages at all three monitoring stations over the eight-year sampling period. In contrast, the reference station on Sinking Creek was dominated by Mayflies (57%). Further, total suspended solids (TSS) data shows extreme variability at the two stations closest to Christiansburg (9-CBC004.38 & 9-CBC006.35). In fact station 9-CBC006.35 had a maximum TSS concentration of 1,304 (mg/L). Figure 7.18 compares TSS concentrations at the three Crab Creek monitoring stations to a reference monitoring station on Sinking Creek.

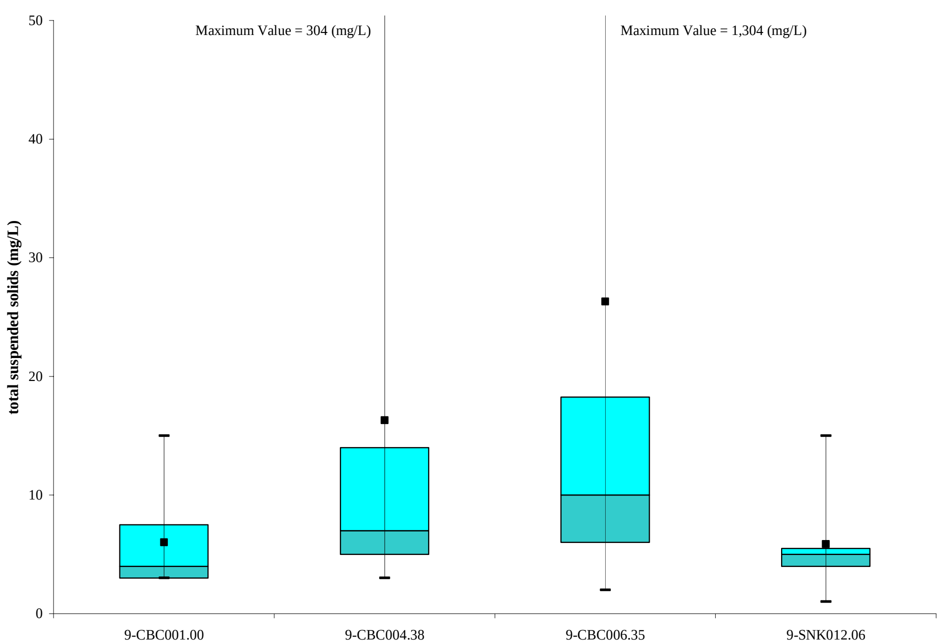


Figure 7.18 Box & Whisker Plot of TSS concentrations.

Sediment was used as the target pollutant to address the benthic impairments in Crab Creek.

In summary, sediment was the best and most practical pollutant with which to develop the TMDL due to its interconnection with other possible stressors, *i.e.* organic matter, nutrients and lack of vegetative cover in the stream corridor. TP is typically bound to soil particles and enters the aquatic environment by the transport of sediment from the land. Reducing livestock access to streams allows streambank vegetation to recover, and reduces inputs of organic matter (manure) and nutrients. Stream buffers can reduce overland flow velocities and decrease the amount of sediment and sediment bound nutrients that reach the stream.

7.2 Reference Watershed Selection

A reference watershed approach was used to estimate the necessary load reductions needed to restore a healthy aquatic community and allow the streams in the Crab Creek watershed to achieve their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar landuse, soils, and stream characteristics (*e.g.*, stream order, corridor, slope), and area (not to exceed or be less than double or half the impaired watershed). The modeling process uses load rates in the non-impaired watershed as a target for load reductions in the impaired watershed. The impaired watershed is modeled to determine the current load rates and determine what reductions are necessary to meet the load rates of the non-impaired watershed.

A total of 29 potential reference watersheds were selected from the Central Appalachian Ridges and Valleys eco-region for analysis that would lead to the selection of a reference watershed for Crab Creek (Figure 7.19). The potential reference watersheds were ranked based on quantitative and qualitative comparisons of watershed attributes (*e.g.*, landuse, soils, slope, stream order, watershed size, etc.). Based on these comparisons and after conferring with state and regional VADEQ personnel, Toms Creek watershed in Montgomery County was selected as the reference watershed for Crab Creek.

Figure 7.20 shows the location of Crab Creek and Toms Creek within the eco-region. Figure 7.21 compares the landuse distributions between the two watersheds. The biggest weakness is the urban component for Toms Creek. Figure 7.22 compares the land slope distributions between the two watersheds, a key parameter in erosion estimates. Figure 7.23 compares runoff potential between the two watersheds as indexed by the soil hydrologic group code. Figure 7.24 compares the soil erosive potential between the two watersheds as indexed by the soil erodibility index. Figure 7.25 compares the available soil moisture storage capacity in the solum between the two watersheds. Finally, Table 7.6 compares drainage characteristics between the two watersheds. The results of these analyses support the use of Toms Creek as a reference watershed for sediment load allocations.

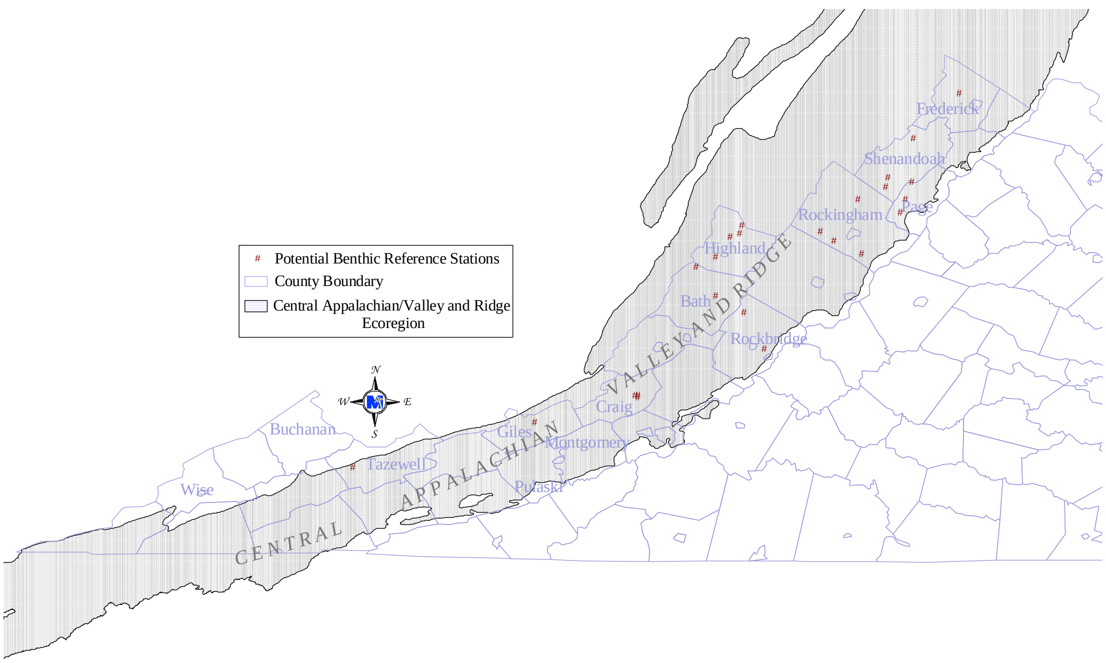


Figure 7.19 Location of potential reference watersheds.

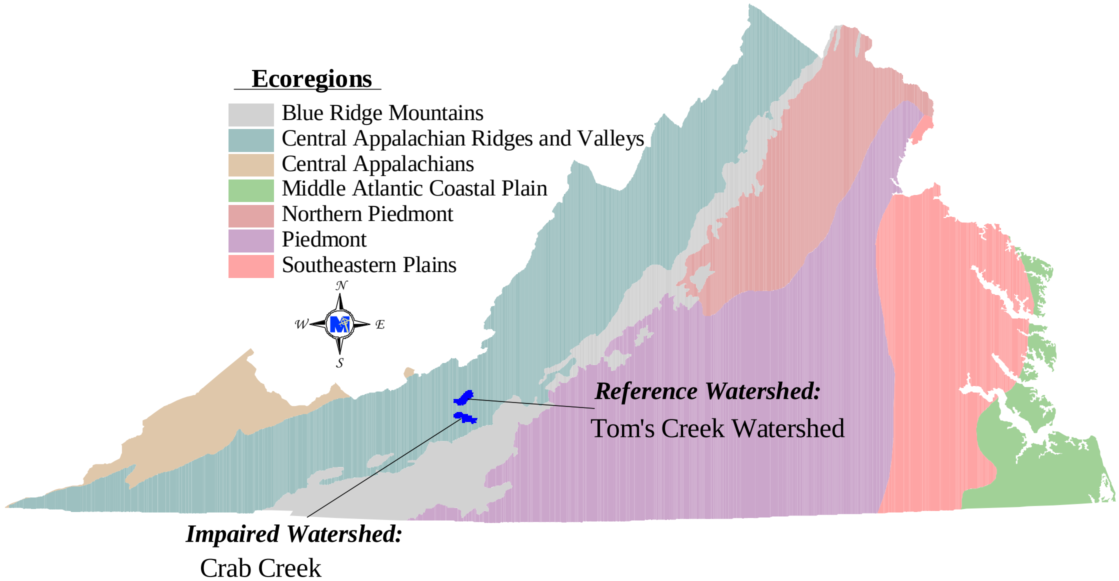


Figure 7.20 Location of impaired and reference watershed within eco-region.

Impaired Watershed **Reference Watershed**

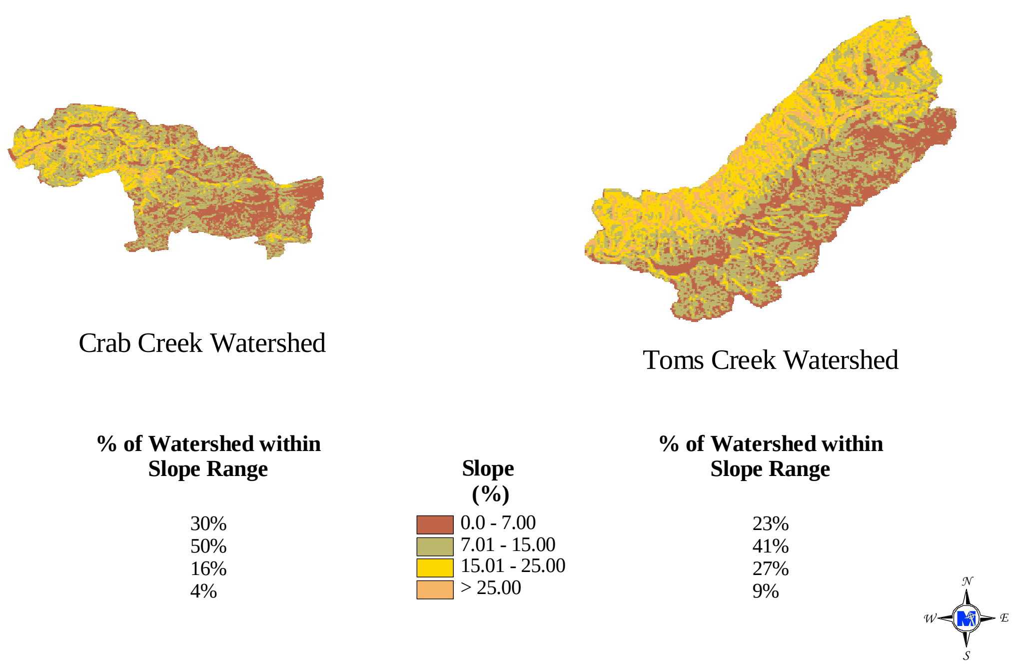
Crab Creek Watershed

Tom's Creek Watershed

% Landuse in Watershed (Crab Creek)	Landuse	% Landuse in Watershed (Tom's Creek)
18.04%	Urban	3.50%
33.02%	Forest	58.77%
48.38%	Agriculture	36.98%
0.45%	Transition	0.53%
0.02%	Wetlands	0.15%
0.09%	Water	0.07%

Figure 7.21 Crab Creek and Toms Creek landuse comparison.

Impaired Watershed **Reference Watershed**



Crab Creek Watershed

Toms Creek Watershed

% of Watershed within Slope Range (Crab Creek)	Slope (%)	% of Watershed within Slope Range (Toms Creek)
30%	0.0 - 7.00	23%
50%	7.01 - 15.00	41%
16%	15.01 - 25.00	27%
4%	> 25.00	9%

Figure 7.22 Crab Creek and Toms Creek slope comparison.

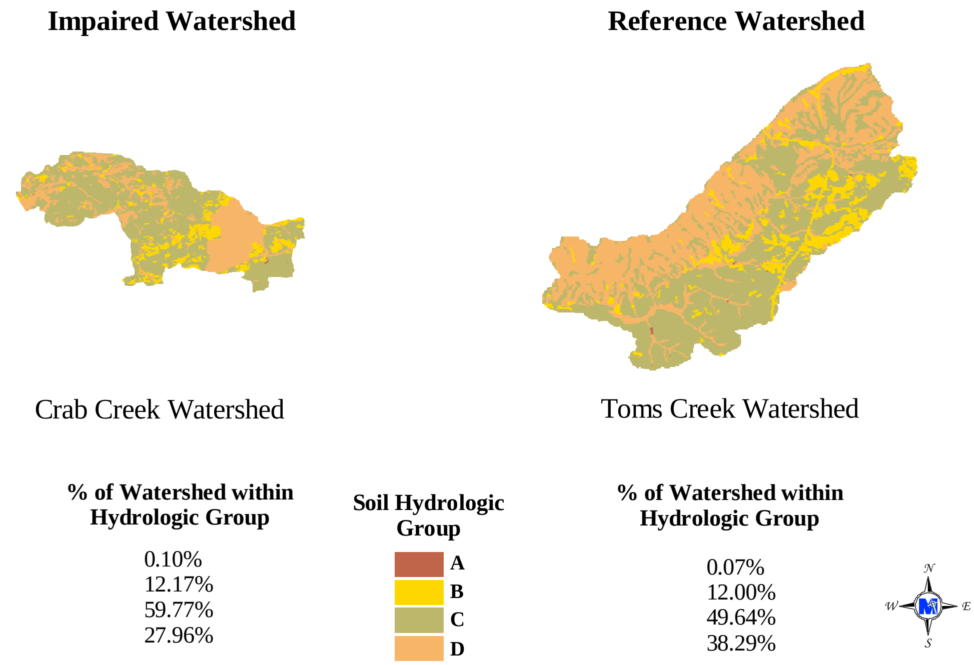


Figure 7.23 Crab Creek and Toms Creek soil hydrologic group code comparison.

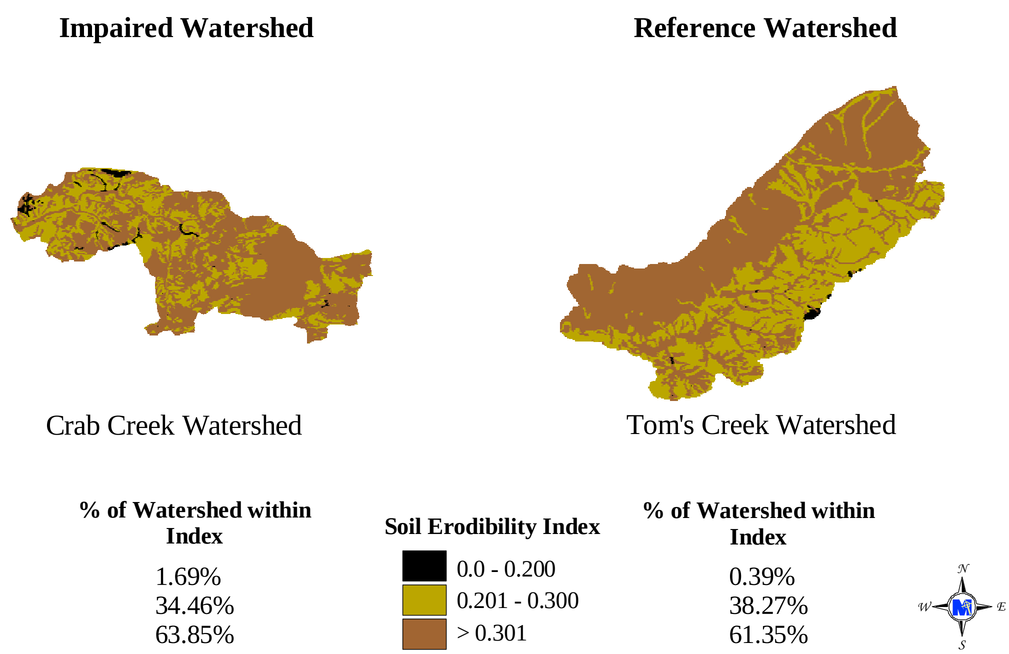


Figure 7.24 Crab Creek and Toms Creek soil erodibility index comparison.

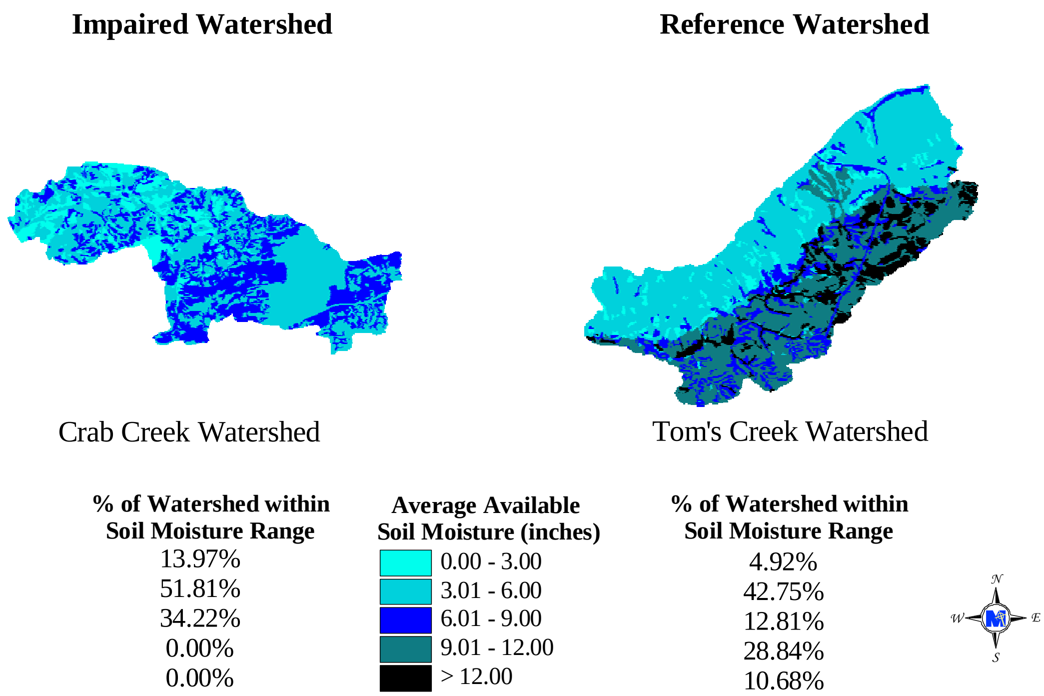


Figure 7.25 Crab Creek and Toms Creek soil available moisture storage comparison.

Table 7.6 Crab Creek and Toms Creek drainage characteristics comparison.

Watershed	Stream Length (% Total)		Approx. Length-Width Ratio
	Intermittent	Continuous	
Crab Creek	77.9	22.1	3.73
Toms Creek	80.5	19.5	3.10

8. MODELING PROCEDURE

A reference watershed approach was used in this study to develop benthic TMDLs for sediment for the Crab Creek watershed. As noted in Section 7.1.3.1, sediment was identified as the primary stressor for the Crab Creek watershed. A watershed model was used to simulate sediment loads from potential sources in both the impaired and reference watersheds. The model used in this study was the Visual *Basic™* 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. Numeric endpoints were based on unit-area loading rates calculated for respective reference watersheds. The TMDLs were then developed for the impaired watersheds based on these endpoints and the results from load allocation scenarios.

8.1 Model Framework Selection

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. It operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from a 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 of pollution. The model considers flow input from both surface and groundwater. Landuse classes are used as the basic unit for representing variable source areas. The calculation of nutrient loads from septic systems, streambank erosion from livestock access, and the inclusion of sediment and nutrient loads from point sources are also supported. 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 for 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 April 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 Model Setup

Watershed data needed to run GWLF used in this study were generated using GIS spatial coverage, 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 segment impaired. The reference watershed outlet was located approximately five kilometers upstream of biological monitoring station 9-TOM0002.19. The outlet is located immediately upstream of the confluence where the drainage becomes third order. For TMDL development, the total area for reference watershed Toms Creek was equated with the area of Crab Creek impairment. To accomplish this, the area of landuse categories in reference watershed Toms Creek was proportionately reduced based on the percentage landuse distribution. After adjustment, the distribution of landuse remained the same as pre-adjustment values.

8.3 Source Assessment

Three source areas were identified as the primary contributors to sediment loading in the impaired watershed that are the focus of this study – Surface runoff, Point sources, and Streambank erosion. The sediment process is a continual process but is often accelerated by human activity. An objective of the TMDL process is to minimize the acceleration of the sediment process. This section describes predominant sediment source areas, model parameters, and input data needed to simulate sediment loads.

8.3.1 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.) in runoff. Rainfall energy, soil cover, soil characteristics, topography, and land management affect the magnitude of sediment loading. Agricultural management activities such as overgrazing (particularly on steep slopes), high tillage operations, livestock concentrations (along stream edge, uncontrolled access to streams etc.), forest harvesting, and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic accumulates on impervious areas and is transported to streams during runoff events. Street sweeping and/or other street maintenance operations can reduce sediment deposited from vehicular traffic. The magnitude of sediment loading from this source is affected by other factors such as the level of wind erosion from which deposition will occur.

8.3.2 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 the 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). The impairment has significant livestock production.

8.3.3 Point Sources TSS Load and MS4 NPS loads

Fine sediments are included in total suspended solids (TSS) loads that are permitted for various facilities with industrial and construction VPDES permits within the Crab Creek watershed. There are 12 construction permit dischargers and 3 industrial stormwater dischargers permitted within the watershed. One MS4 permit has been issued to the Town of Christiansburg, which covers nearly 43% of the watershed and one permit is held by the Virginia Department of Transportation (VDOT).

"Small municipal separate storm sewer systems owners/operators must reduce pollutants in their stormwater discharges to the maximum extent practicable to protect water quality. Small municipal separate storm sewer systems permits require the owner/operator to develop a stormwater management program designed to prevent harmful pollutants from being washed by stormwater runoff into the municipal separate storm sewer systems (or from being dumped directly into the municipal separate storm sewer systems) and then discharged from the municipal separate storm sewer systems into local waterbodies" (http://www.deq.state.va.us/water/bmps.html).

Unlike point source discharges, all sediment from MS4s is essentially from nonpoint sources. Sediment loads from industrial and construction permitted sites and stormwater from MS4 are included in the waste load allocation (WLA) component of the TMDL, in compliance with 40 CFRξ130.2(h).

8.4 Source Representation – Input Requirements

As described in Section 8.1, the GWLF model 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 affect 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.

8.4.1 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.*

Running the model for a 3-month period prior to the chosen period during which loads were calculated initialized the following parameters:

- *<u>Initial unsaturated storage (cm):</u> Initial depth of water stored in the unsaturated (surface) zone.*
- *<u>Initial saturated storage (cm):</u> Initial depth of water stored in the saturated zone.*
- *<u>Initial snow (cm):</u> 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 files.*

Month Related Parameter Descriptions

- *Month: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that 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.*

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

- *Hours per Day: mean number of daylight hours.*

- *Erosion Coefficient: 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)

- *<u>% Developed Land:</u> Percentage of the watershed with urban-related landuses- defined as all land in MDR, HDR, and COM landuses, as well as the impervious portions of LDR.*
- *<u>Animal density:</u> Calculated as the number of beef and dairy 1000-lb equivalent animal units (AU) divided by watershed area in acres.*
- *<u>Stream length:</u> Calculated as the total stream length of natural stream channel, in meters. Excludes the non-erosive hardened and piped sections of the stream.*
- *<u>Stream length with livestock access:</u> calculated as the total stream length in the watershed where livestock have unrestricted access to streams, resulting in streambank trampling in meters.*

8.4.2 Streamflow and Weather data

No stream flow data existed within or nearby Crab Creek that were appropriate for calibrating the GWLF model. Precipitation and temperature data were obtained from a web site created by BSE, 2002 to facilitate the use of the GWLF model. Rainfall from a group of nearby stations was Theissen weighted to provide a single record. Access to the database is through the Virginia Hydrologic Units code.

Table 8.1 Weather stations used in GWLF models for Crab Creek and Toms Creek.

Watersheds	Weather Stations (station_id, location, Thiessen weights)	Data Type	Data Period
Crab Creek	**Station id:** 440766 **Location:** Blacksburg, 3 SE **Thiessen weight:** 1	Daily Precipitation & Temperature	1/1/1994–3/30/2000
Toms Creek	**Station id:** 440766 **Location:** Blacksburg, 3 SE **Thiessen weight:** 1	Daily Precipitation & Temperature	1/1/1994–3/30/2000

8.4.3 Landuse/landcover classes

Landuse classes were used as the basic response unit for performing runoff and erosion calculations and summarizing sediment transport. Landuse coverage was obtained from Multi-Resolution Land Characteristics (MRLC) data (EPA, 1992) for Crab Creek and reference watershed Toms Creek. The landuse categories were consolidated from MRLC classifications as given in Table 8.2. Urban landuse categories- 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- hay, overgrazed pasture, unimproved pasture, improved pasture, and stream edge. The percentage of the pasture/hay acreage that was assigned to each category was obtained from Gall, 2004 and VADCR's online 2002 NPS Assessment Database. Cropland was also sub-divided 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) and Gall, 2004. Landuse distributions for Crab Creek and Toms Creek are given in Table 8.3. Landuse acreage for Toms Creek was adjusted down by the ratio of impaired watershed to reference watershed maintaining the original landuse distribution.

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.

8.4.4 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 the Crab Creek reference watershed was obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004), Montgomery County and the Montgomery County soil survey report (SCS, 1985a). 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 calculate the unsaturated soil moisture capacity. Soils data for the Toms Creek reference watershed also was obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004), Montgomery County and the Montgomery County soil survey report (SCS, 1985a). The area-weighted USLE parameters, K and LS, for Toms Creek were calculated following the procedures outlined for the Crab Creek impairment.

8.4.5 Pervious and Impervious Surfaces

Four TMDL categories define urban landuse/landcover (Table 8.3). Each urban area was sub-divided into pervious areas (USLE sediment algorithm applies) and impervious areas where an exponential buildup-washoff algorithm applies. The average percentage of pervious and impervious area was calculated from data obtained from VADCR's 2002 NPS Assessment Landuse/Landcover Database (VADCR, 2002). These values were used to determine the percentage of pervious and impervious for LDR, HDR, and COM urban categories.

Table 8.2 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)

Table 8.3 Landuse distributions for impaired and reference watersheds.

Landuse Category	Crab Creek (ha)	Toms Creek (Adjusted) (ha)
Low Density Residential (LDR-PER)	504.458	84.556
High density Residential (HDR-PER)	1.549	0.202
Commercial (COM-PER)	98.899	14.972
Transitional	22.611	26.542
Forest		
Disturbed-FOR	49.950	88.965
Forest-FOR	1,615.130	2,876.532
Urban Grass	0.000	0.000
Pasture/Hay		
Hay	268.408	145.307
Overgrazed	687.615	304.037
Unimproved	491.154	304.037
Improved	85.846	912.110
Stream Edge	3.713	12.417
Cropland		
High Tillage	61.049	57.694
Low Tillage	142.447	134.618
Low Density Residential (impervious)	142.283	51.825
High density Residential (impervious)	1.122	0.165
Commercial (impervious)	161.362	24.427
Water	4.484	3.673

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.

8.4.6 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).

8.4.7 SCS Runoff Curve Number

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 then were adjusted based on the numerical area-weighted soil HG codes.

8.4.8 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, percent of developed land, mean stream depth, and watershed area. The animal density was calculated by dividing the number of livestock (beef and dairy) by watershed area in acres. The number of animal units (1000 pound per animal) was obtained from Soil and Water Conservation District personnel. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The length of hardened channel was estimated as equal to the distance of streams flowing through urban areas. The mean stream depth was estimated as a function of watershed area.

8.4.9 Evapotranspiration Cover Coefficients

Evapotranspiration (ET) cover coefficients were entered by month. Monthly ET cover coefficients were assigned each landuse/land cover condition (from MRLC classification) following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each sediment source class.

8.5 Point Source TSS Loads and MS4 Permits

Seventeen point sources were identified in the Crab Creek watershed with locations given in Figure 3.1 and discharge specifics listed in Table 8.4. Permitted loads were calculated as the maximum annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/l. The modeled runoff for industrial stormwater dischargers was calculated for both pervious and impervious commercial sediment source areas. The calculations involved calculating a weighted maximum runoff value for commercial areas by multiplying the maximum annual modeled runoff depth from pervious commercial times the percentage of commercial area that is pervious and adding to the maximum annual modeled runoff depth from commercial impervious areas multiplied by the percentage of impervious commercial areas. The weighted maximum runoff (cm) from commercial areas is multiplied by the permit area (ha) times permitted concentration (TSS/mg/L) times 0.00010001 to get permit load in T/yr. For construction permit dischargers, the modeled runoff was taken as the maximum annual runoff depth (cm) for transitional landuses. Future loads for MS4 permits were calculated as the urban impervious area load for Crab Creek (2,140.6 ha). The calculated future load was reduced based on the assumption that the baseline load plus any additional load from increases in impervious area would be reduced by 50%. A baseline load for MS4 permits was calculated as the load from urban areas under existing conditions and assumed equal to the sediment load from impervious urban areas. These areas were defined separately in modeling existing conditions and future growth scenarios. There were no single-family residence wastewater permits in Crab Creek.

Table 8.4 VPDES point source facilities and permitted TSS load.

Crab Creek Point Sources		Existing Conditions				Future Conditions
VPDES ID	**Name**	**Runoff (cm)**	**Area (ha)**	**Conc. (mg/L)**	**TSS (T/yr)**	**TSS (T/yr)**
Construction Stormwater Discharge Permits						
VAR100229	VDOT-Salem District	29.90	8.50	100	2.54	2.54
VAR101126	VDOT – Christiansburg (4541)	29.90	2.99	100	0.90	0.90
VAR102138	Depot Street School Residence	29.90	0.917	100	0.27	0.27
VAR102140	Oaktree Townhouses Phase VI	29.90	2.83	100	0.85	0.85
VAR102148	Holy Spirit Catholic Church	29.90	1.00	100	0.30	0.30
VAR102164	New River Medical Assoc. Medical Office Park	29.90	2.02	100	0.61	0.61
VAR102279	Edgemont of Diamond Hill	29.90	19.02	100	5.69	5.69
VAR102308	Lions Gate	29.90	5.38	100	1.61	1.61
VAR 103014	Hunters Ridge Phase III	29.90	1.09	100	0.33	0.33
VAR103064	Oak Tree Professional Park	29.90	3.24	100	0.97	0.97
VAR103090	Hans Meadow Drainage Improvements	29.90	0.809	100	0.24	0.24
VAR103349	Oak Tree Townhouses	29.90	12.38	100	3.70	3.70
Industrial Stormwater Discharge Permits						
VAR051370	Town of Christiansburg	60.60	13.63	30	2.479	2.479
VAG110015	Marshall Concrete	60.60	3.24	30	0.589	0.589
VAR520312	Federal Express Corp-WALA Station	60.60	0.809	30	0.147	0.147
Total Point Source Loads					**21.23**	**21.23**
MS4 Permits						
VAR040025	Town of Christiansburg				55.14	27.57
VAR040016	VDOT (load included in Town of CHBG					
Total MS4 Source loads					**55.14**	**27.57**
Total Point Source Loads + MS4 Source Loads					**76.38**	**48.76**

8.6 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.

8.7 Selection of a Representative Modeling Period

The selection of the modeling period was based on two factors; availability of streamflow and corresponding weather data and the need to represent critical hydrological conditions and seasonal variability. A discussion of analysis conducted to select a representative period is given in Section 4.0.

8.8 Hydrologic Model Calibration Process

Hydrologic calibration was not performed for Crab Creek or Toms Creek, as no suitable stream flow data existed within or nearby either watershed. The GWLF model was originally developed for use in ungaged watersheds and this was considered an acceptable alternative since both the impaired and reference watershed are located nearby 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.

8.9 Existing Conditions

A listing of parameters from the GWLF Transport input files that were finalized for existing conditions are given in Table 8.5 through 8.10. Watershed parameters for the Crab Creek and reference watershed Toms Creek are given in Table 8.5.

Table 8.5 Crab Creek and Reference Watershed Toms Creek GWLF Watershed parameters for existing conditions.

GWLF Watershed Parameter	Units	Crab Creek	Toms Creek
Recession Coefficient	Day^{-1}	0.0325	0.0325
Seepage Coefficient	Day^{-1}	0.0002	0.0002
Sediment Delivery Ratio		0.14	0.14
Unsaturated Water Capacity	(cm)	12.95	18.18
Erosivity Coefficient (April-Sept.)		0.25	0.25
Erosivity Coefficient (Oct.-Mar)		0.06	0.06
% Developed land	(%)	8.0	1.6
Livestock density	(AU/ac)	0.1870	0.1076
Area-weighted soil erodibility		0.33	0.322
Area weighted runoff curve number		74.01	70.98
Total Stream Length	(m)	12821	21176
Mean channel depth	(m)	2.3	1.3

Monthly evaporation cover coefficients are listed in Table 8.6.

Table 8.6 Crab Creek and Reference Watershed Toms Creek GWLF monthly evaporation cover coefficients for existing conditions

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Crab Creek	0.67	0.85	0.81	0.80	0.81	0.85	0.84	0.59	0.52	0.69	0.72	0.71
Toms Creek	0.60	0.95	0.92	0.91	0.91	0.95	0.94	0.53	0.48	0.62	0.64	0.63

The area-weighted USLE erosion parameter and runoff curve number are listed by landuse (erosion source areas) in Table 8.7 for Crab Creek and reference watershed Toms Creek.

Table 8.7 Crab Creek and Reference Watershed Toms Creek GWLF landuse parameters for existing conditions.

Landuse	Crab Creek		Toms Creek	
Categories	**CN**	**KLSCP**	**CN**	**KLSCP**
LDR-PER	72.76	0.001048	69.18	0.000698
HDR-PER	66.94	0.001502	70.62	0.000328
COM-PER	72.76	0.000970	67.71	0.000917
Transitional	86.37	0.029102	85.34	0.034843
Forest	75.94	0.093775	76.12	0.154224
Disturbed Forest	68.56	0.001172	68.80	0.001928
Urban Grass	75.94	0.010159	68.80	0.000000
Hay	68.63	0.004834	67.46	0.003159
Pasture 1	84.73	0.072512	84.10	0.047385
Pasture 2	77.18	0.034322	76.28	0.022429
Pasture 3	71.63	0.006284	70.46	0.004107
Stream Edge	87.27	0.145024	86.91	0.094770
High-tillage	81.81	0.264019	83.21	0.202833
Low-tillage	79.33	0.072148	79.89	0.055428
LDR-IMP	98.00	0.001048	98.00	0.000000
HDR-IMP	98.00	0.001502	98.00	0.000328
COM-IMP	98.00	0.000970	98.00	0.000917

The area adjustment for Crab Creek reference watershed is listed in Table 8.8.

Table 8.8 Area adjustment for Crab Creek TMDL Reference Watershed Toms Creek.

Landuse Categories	Impaired Crab Creek	Reference Original Toms Creek	Reference (Area-adjusted) Toms Creek (x 0.962644)
LDR-PER	504.458	87.838	84.556
HDR-PER	1.549	0.210	0.202
COM-PER	98.899	15.553	14.972
Transitional	22.611	27.572	26.542
Disturbed Forest	49.952	92.417	88.965
Forest	1,615.126	2,988.164	2,876.532
Urban Grass	0.000	0.000	0.000
Hay	268.408	150.946	145.307
Pasture 1	687.615	315.836	304.037
Pasture 2	491.154	315.836	304.037
Pasture 3	785.846	947.507	912.110
Stream Edge	3.713	12.898	12.417
High-tillage	61.049	59.933	57.694
Low-tillage	142.447	139.843	134.618
LDR-IMP	142.283	53.836	51.825
HDR-IMP	1.122	0.172	0.165
Com-IMP	161.362	25.375	24.427

The existing sediment loads were modeled for Crab Creek and Toms Creek and adjusted for agricultural BMPs applied to both watersheds as identified in the Virginia Agricultural BMP database (SCS, 2004). The agricultural BMP database provides the type of BMP, acres benefited, sheet and rill erosion and gully erosion reduction. The total sediment reduction due to BMPs was calculated by multiplying the total erosion times the delivery ratio for the respective watersheds. An efficiency factor was then calculated based on the existing sediment load from agricultural land and agricultural category adjusted for BMPs.

Existing MS4 loads were assumed to represent loads generated in areas covered by the MS4 permits prior to implementation of Phase II MS4 regulations. The base value for MS4 loads was estimated as the load from impervious areas within the Town of Christiansburg, Virginia. The area covered and associated sediment load are listed in Table 8.9. Acreage and loads were adjusted in Table 8.9 to reflect the non-MS4 permit areas.

Table 8.9 Existing sediment loads for Crab Creek and reference watershed Toms Creek.

Sediment Sources	Crab Creek			Toms Creek (Area adjusted)	
	Area (ha)	Sediment (T/yr)	Sediment (T/ha)	Sediment (T/yr)	Sediment (T/ha)
LDR-PER	504.458	12.475	0.025	1.135	0.013
HDR-PER	1.549	0.041	0.026	0.001	0.004
COM-PER	98.899	2.263	0.023	0.251	0.017
Transitional	22.611	20.998	0.929	28.861	1.087
Forest	1,615.126	36.117	0.022	350.266	3.934
Disturb. Forest	49.952	120.342	2.408	105.183	0.037
Hay	268.408	24.753	0.092	8.014	0.055
Pasture 1	117.288	1,549.718	2.254	441.597	1.451
Pasture 2	1,055.195	458.947	0.934	175.278	0.576
Pasture 3	792.133	114.645	0.146	77.772	0.085
Stream-Edge-Past	3.713	17.406	4.688	37.470	3.016
High Tillage	12.881	474.530	7.773	358.697	6.212
Low Tillage	190.615	285.906	2.007	211.341	1.569
LDR-IMP	13.297	2.686	0.202	10.461	0.202
HDR-IMP	0.080	0.016	0.202	0.033	0.202
COM-IMP	18.396	3.716	0.202	4.931	0.202
Water	4.484	0.000	0.000	0.000	0.000
MS4	**272.99**	**55.14**	**0.202**	**0.0**	
Active Ag. BMPs		-281.960		-83.50	
NPS Load		3,179.699		1,811.291	
Channel Erosion		3,408.641	0.266	822.907	0.039
Point Source – Loads		21.23			
Watershed Totals	**5,042**	**6,306.699**		**2,551**	

9. ALLOCATION

TMDLs consist of WLAs, and LAs including natural background levels. Additionally, the TMDL must include a MOS that either implicitly or explicitly accounts for uncertainties in the process (*e.g.*, landuses cover factors). 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 sediment, the TMDL is expressed in terms of metric tons or metric tons per hectare.

This section describes the development of benthic TMDLs for sediment for Crab Creek using a reference watershed approach. The model was run for existing conditions over the period January 1994 to March 2000. The average annual sediment load from reference watershed Toms Creek (area adjusted) was used to define the TMDL load for the Crab Creek watershed. A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

9.1 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 crop cover conditions, runoff curve number, etc.). Sensitivity analyses were run on the watershed parameters listed in Table 9.1. For a given simulation, the model parameters in Table 9.1 were set at the base value except for the parameter being evaluated. Each parameter was evaluated through 10 and 50 percentage changes from the base value. The results show that the model is extremely sensitive to parameter changes resulting in major changes in either runoff or sediment (Table 9.2). For example, decreases in the runoff curve number (65) resulted in little change in channel erosion; however, the channel erosion output changed greatly with increases in the curve number. The results tend to reiterate the importance of carefully evaluating conditions in the watershed and following systematic protocol in establishing values for model parameters.

Table 9.1 Base watershed parameter values used to determine hydrologic and sediment response.

GWLF Watershed Parameter	Units	Base Value
Recession Coefficient	Day^{-1}	0.384
Seepage Coefficient	Day^{-1}	0.02
Unsaturated Water Capacity	(Cm)	10
Erosivity Coefficient (April – September)		0.26
Erosivity Coefficient (October - March)		0.06
% Developed land	(%)	10%
Livestock density	(AU/ac)	0.1785
Area weighted soil erodibility (K-factor)		0.28
Area weighted runoff curve number		65
Total Stream Length	(m)	684,590
Mean Channel Depth	(m)	1.5

Table 9.2 Sensitivity of model response to change in selected parameters.

Model Parameter	Parameter Change	% Change in Runoff	% Change in Sediment Load	% Change in Channel Sediment Load
Recession Coefficient	-50	-50	-4.76	-11.4
Recession Coefficient	-10	-3	-0.06	-1.71
Recession Coefficient	10	3	9.6	1.92
Recession Coefficient	50	50	19	4.57
Seepage Coefficient	-50	17.1	0.06	0.002
Seepage Coefficient	-10	2.94	0.08	0.001
Seepage Coefficient	10	-2.74	-0.08	-0.001
Seepage Coefficient	50	-12.1	-0.35	-0.002
Unsaturated Water Capacity	-50	7.89	0.298	0.002
Unsaturated Water Capacity	-10	1	2.6	0.001
Unsaturated Water Capacity	10	-1	-2.5	-0.001
Unsaturated Water Capacity	50	4.2	-0.1	-0.002
Erosivity Coefficient (April – September)	-50	Insensitive	-39.7	-49
Erosivity Coefficient (April – September)	-10	Insensitive	-9.5	-11.9
Erosivity Coefficient (April – September)	10	Insensitive	9.58	11.2
Erosivity Coefficient (April – September)	50	Insensitive	48	51.6
% Developed land	-50	Insensitive	insensitive	Insensitive
% Developed land	-10	Insensitive	Insensitive	Insensitive
% Developed land	10	Insensitive	Insensitive	Insensitive
% Developed land	50	Insensitive	Insensitive	Insensitive
No. of livestock	-50	Insensitive	Insensitive	Insensitive
No. of livestock	-10	Insensitive	Insensitive	Insensitive
No. of livestock	10	Insensitive	Insensitive	Insensitive
No. of livestock	50	Insensitive	Insensitive	Insensitive
Area weighted soil erodibility	-50	Insensitive	-50	Insensitive
Area weighted soil erodibility	-10	Insensitive	-10	Insensitive
Area weighted soil erodibility	10	Insensitive	10	Insensitive
Area weighted soil erodibility	50	Insensitive	10	55000
Area weighted runoff curve number	-50	-4.02	-1.20	Insensitive
Area weighted runoff curve number	-10	-1.5	-3.70	Insensitive
Area weighted runoff curve number	10	1.5	3.87	10700
Area weighted runoff curve number	50	4.02	1.23	143200
Total Stream Length	-50	Insensitive	Insensitive	-49
Total Stream Length	-10	Insensitive	Insensitive	-11.9
Total Stream Length	10	Insensitive	Insensitive	11.2
Total Stream Length	50	Insensitive	Insensitive	51.6
Mean Channel Depth	-50	Insensitive	Insensitive	-49
Mean Channel Depth	-10	Insensitive	Insensitive	-8.9
Mean Channel Depth	10	Insensitive	Insensitive	11.2
Mean Channel Depth	50	Insensitive	Insensitive	51.6

9.2 Crab Creek Benthic TMDL

The Crab Creek benthic TMDL was developed for sediment, with Toms Creek as the reference watershed. The area of Toms Creek was decreased by the ratio of the impaired watershed area to the reference watershed area (0.96264). After adjustment, the Toms Creek reference watershed area equaled the Crab Creek watershed area (5,042.09 ha). Landuse acreage for Toms Creek was reduced while maintaining the original landuse distribution.

The target TMDL load for Crab Creek is the average annual load from the area-adjusted Toms Creek watershed under existing conditions (Table 9.3). The benthic TMDL for Crab Creek includes three components – WLA, LA, and MOS. The margin of safety was explicitly set to 10% to account for uncertainty in developing benthic TMDLs. The WLA was calculated as the sum of various point source loads and 50% of the MS4 load (Table 8.5). It was assumed that the implementation of stormwater BMPs would reduce the load by a maximum of 50%. The LA was calculated as the TMDL minus the WLA minus the MOS.

Table 9.3 Sediment TMDL Targets for Crab Creek Watershed.

Impairment	WLA (T/year)	LA (T/year)	MOS	TMDL (T/year)
Crab Creek	77.0	2,219	255	2,551
VAR100229	*2.54*			
VAR101126	*0.90*			
VAR102138	*0.27*			
VAR102140	*0.85*			
VAR102148	*0.30*			
VAR102164	*0.61*			
VAR102279	*5.69*			
VAR102308	*1.61*			
VAR103014	*0.33*			
VAR103064	*0.97*			
VAR103090	*0.24*			
VAR103349	*3.70*			
VAR051370	*2.48*			
VAR110015	*0.59*			
VAR520312	*0.15*			
VAR015370[1]	*55.15*			

[1] MS4 permit for Christiansburg.

9.2.1 Future Development

Active development is expected to continue near Christiansburg including commercial and housing over the next 25 years. A scenario including single-family homes built on 5-acre lots was run to assess possible impact on the TMDL. The following assumptions were used to arrive at the expected landuse change listed in Table 9.4. It was assumed that 2.5% of pastureland (56 ha) in and near Christiansburg, Virginia would convert to some form of commercial development. A total of 0.5% of pasture (11ha) would be in transitional state. A total of 5% of pastureland and forestland would be single-family housing units on 0.81 (2 acre) to 2.02 (5 acre) hectare lots. The future growth scenario resulted in the developed land increasing from 8.0% to 11.3%. The sediment load would be expected to increase by 868 T/yr due to expected growth (Table 9.5).

Table 9.4 Summary of landuse scenario for 25-year projected growth.

Landuse	Existing	Projected	% Change
Forest	1,665.07	1,582.07	-5
Pasture	2,236.75	2,057.75	-8
Transitional	22.62	32.62	+48.6
LDR	646.74	841.74	+30.2
COM	260.26	316.26	+21.5

Future projected loads are presented in Table 9.5

Table 9.5 Future projected sediment loads for Crab Creek Watershed.

Sediment Sources	Area (ha)	Crab Creek Sediment (T/yr)	Sediment (T/ha)
LDR-PER	591.818	14.662	0.025
HDR-PER	1.549	0.041	0.026
COM-PER	151.719	3.477	0.023
Transitional	33.611	31.272	0.930
Forest	1,534.616	34.375	0.022
Disturb. Forest	47.462	114.548	2.413
Hay	246.928	22.810	0.092
Pasture 1	107.901	1,428.315	2.258
Pasture 2	970.750	422.960	0.936
Pasture 3	728.740	106.673	0.146
Stream-Edge-Past	3.416	16.043	4.697
High Tillage	12.881	475.407	7.787
Low Tillage	190.615	286.401	2.011
LDR-IMP	13.297	2.686	0.202
HDR-IMP	0.080	0.016	0.202
COM-IMP	18.396	3.716	0.202
Water	4.484	0.000	0.000
MS4-Existing	272.994	55.145	0.202
MS4-Future	110.653	22.351	0.202
Active Ag. BMPs		-281.960	
NPS Load		3,040.898	
Channel Erosion		4,416.561	0.344
Point Source – Loads		21.230	
Watershed Totals	**5,042**	**7,196.729**	

The required reductions for both existing and projected future loads are shown in Table 9.6. Since the projected future loads exceed the sediment load boundary defined by existing conditions, the TMDL allocation scenarios were developed for the projected future sediment load (Table 9.5). To aid the development of TMDL allocation scenarios, nonpoint source areas were grouped into agriculture, urban and forestry categories. Sub-categories for agriculture and forestry were also included to provide better definition of allocation within the broader groupings (Table 9.7). The predominant sediment loads are from agriculture (cropland and pasture) and the stream channel. It is assumed that stormwater BMPs will be implemented with maximum effectiveness reducing the NPS loads from Phase II MS4 permit areas by 50%.

Table 9.6 Required reductions for Crab Creek Watershed.

Load Summary	Crab Creek	Reductions Required (T/yr)	Reductions Required (% of existing load)
Projected Future Load	7,197	4,978	78.9
Existing Load	6,307	4,088	64.8
TMDL	2,551		
Target Modeling Load	2,219		

Table 9.7 Comparison of grouped sediment loads for future conditions Crab Creek with reference watershed Toms Creek.

Source Category	Future Conditions Crab Creek (T/yr)	Reference Toms Creek (T/yr)
Agriculture	2,757.608	1,310.169
Hay	22.810	8.014
Cropland	761.808	570.038
Pastureland	1,956.948	694.647
Stream-Edge (access)	16.043	37.470
Urban – non MS4	49,578	45.673
Forestry	156.459	455.450
Disturbed Forest	120.342	350.026
Channel Erosion	4,416.561	822.907
Point Source Loads	21.23	0
MS4 Loads	77.496	0

Two sediment reduction alternatives are presented in Table 9.8. Alternative 1 requires sediment reductions from pastureland (72%), channel erosion (79.1%), and MS4 permitted areas (50%). The reductions could be achieved through riparian buffers, livestock exclusion from streams, storm water management and improved pasture management. Alternative 2 requires a 41% reduction from cropland, a 51% reduction from pastureland, an 82% reduction of channel erosion, and 50% reductions in MS4 permitted areas. Significant reductions appear feasible through the implementation of aggressive measures to minimize streambank erosion through improved stormwater control in urban areas, installation of riparian buffers, and livestock exclusion from streams.

Table 9.8 TMDL sediment allocation scenarios for Crab Creek impairment.

Sediment Source Categories	Existing Condition	Allocations			
		Alternative 1		Alternative 2	
	(T/yr)	(%)	(T/yr)	(%)	(T/yr)
LDR-PER	14.662	0	14.662	0	14.662
HDR-PER	0.041	0	0.041	0	0.041
COM-PER	3.477	0	3.477	0	3.477
Transitional	31.272	0	31.272	0	31.272
Forest	34.375	0	34.375	0	34.375
Disturbed Forest	114.548	0	114.548	0	114.548
Pastureland	**1,996.801**	**72**	**547.801**	**51**	**978.432**
Cropland	**761.808**	0	761.808	**41**	**449.467**
LDR-IMP	2.686	0	2.686	0	2.686
HDR-IMP	0.016	0	0.016	0	0.016
COM-IMP	3.716	0	3.716	0	3.716
Water	0.000	0	0.000	0	0.000
MS4-Existing	**55.145**	**50**	**27.573**	**50**	**27.573**
MS4-Future	**22.351**	**50**	**11.176**	**50**	**11.176**
NPS Load	3,040.942		1.553.151		1,671.441
Active Ag. BMPs	-281.960		-281.960		-281.960
Channel Erosion	**4,416.561**	**79.1**	**923.061**	**82**	**794.981**
Point Source Loads	21.230		21.230		21.230
Total	**7,196.773**		**2,215.482**		**2.205.692**
Target Allocation Load (TMDL-MOS-MS4s-Point Sources)			**2,219.000**		**2219.000**

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 benthic impairments on Crab 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 direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion. Improved pasture management including less intensive grazing, minimize animal concentrations by frequent movement of winter feeding areas, improving pasture forages, etc, can significantly reduce soil loss from pasture areas. Reducing tillage operations, farming on the contour, strip cropping, maintaining a winter cover crop, etc., have been demonstrated as effective measure to reduce erosion from cropland agriculture.

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. Implementable BMPs appropriate for controlling urban wash-off from parking lots and roads 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, a scenario was devised assuming reductions of 100% in all anthropogenic land-based loads, 100% reduction in sewer overflows and uncontrolled residential discharges, 100% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. The model predicted violations of the water quality standards for this scenario.

The Stage I water quality goal is to reduce the number of violations of the instantaneous standard to less than 10%. However, if the allocation scenario required to achieve this goal requires reductions in loads greater than 60% in land-based loads from urban and agricultural sources and any reductions in wildlife loads, then the Stage I allocation is defined as a 100% reduction in loads from sewer overflows and uncontrolled residential discharges (straight pipes), a 100% reduction in direct in-stream loads from livestock, a 60% reduction in land-based loads from urban and agricultural sources and a 0% reduction in all wildlife loads. This is the case in Crab Creek (Table 10.1, scenario 4).

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	76.7	27.8
2	0	0	0	0	0	100	73.3	27.8
3	0	0	90	50	50	100	11.7	17.6
4	0	0	100	60	60	100	3.33	16.1
5	0	0	100	99	99	100	0.0	1.92
6	0	99	100	99	99	100	0.0	1.53
7	99	99	100	99	99	100	0.0	1.53
8	0	99	100	99.95	99.95	100	0.0	0.0

Table 10.2 details the load reductions required for meeting the Stage I Implementation described in Table 10.1.

Table 10.2 Nonpoint source allocations in the Crab 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	4.11E+14	1.65E+14	60
Commercial	1.15E+13	4.60E+12	60
Barren	6.72E+11	2.69E+11	60
Cropland	7.42E+14	2.97E+14	60
Livestock Access	9.18E+13	3.67E+13	60
Pasture	1.54E+15	6.16E+14	60
Forest	1.36E+14	1.36E+14	0
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	9.30E+14	0.00E+00	100
Wildlife	2.62E+12	2.62E+12	0
Straight Pipes and Sewer Overflows	1.52E+15	0.00E+00	100

Stage I scenarios – Sediment

The Stage I goal was to reduce sediment loads in Crab Creek to within 40% of target reductions. The target reduction goal during Stage I for Crab Creek is 4,210 T/yr. The proposed management scenarios to achieve the Stage I water quality goal are summarized in Table 10. 3.

Table 10.3 Management scenarios to achieve 60% of required sediment reductions for Crab Creek impairment.

Sediment Source Categories	Management Scenarios	Area/Len. Affected (ha) : (m)	Existing Condition (T/yr)	Benefit (t/ha) : (T/m)	Implem. Condition (T/yr)
LDR-PER			14.662		14.662
HDR-PER			0.041		0.041
COM-PER			3.477		3.477
Transitional			31.272		31.272
Forest			34.375		34.375
Forest Disturbed			114.548		114.548
Pastureland	Pasture Improvement (rotational grazing, improved grasses, lower animal densities on steep slopes, reduce overgrazing by 90%)	**475**	**1,996.801**	**2.122**	**988.851**
Cropland	High Tillage to Low Tillage (*e.g.*, no-tillage), strip cropping, rotations)	**61**	**761.808**	**5.776**	**409.472**
LDR-IMP			2.686		2.686
HDR-IMP			0.016		0.016
COM-IMP			3.716		3.716
Water			0.000		0.000
MS4-Existing		**136.497**	**55.145**	**0.202**	**27.573**
MS4-Future		**55.327**	**22.351**	**0.202**	**11.176**
NPS Load			3,040.942		1,603.116
Active Ag. BMPs			-281.960		1,321.156
Channel Erosion	Improve riparian buffer, livestock exclusion, urban storm water management	**4,530**	**4,416.561**	**0.344**	**2,858.241**
Point Sources			21.230	0	21.230
Total			**7,196.773**		**4,200.627**
	Stage I Implementation Target (60% reduction)				4,209.933
	Target Allocation Load (TMDL-MOS-MS4s-Point Sources)				2,219.000

The development of the implementation plan is expected to be an iterative process, with monitoring data refining its final design. Subsequent refinements will be made as the progress toward meeting milestones and the expressed TMDL goals is assessed. As practices are implemented, periodic analyses of water quality conditions will be conducted to evaluate the progress toward meeting end goals.

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 Crab 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.

The Town of Christiansburg is covered by existing VPDES permits for Phase II municipal separate storm sewer systems (MS4s), which covers over 40% of the headwaters of Crab Creek. Recent MS4 permits have included language that recognizes that *"it is the intention of the Commonwealth that the TMDL will be implemented using existing regulations and programs, and utilizing 40 CFR ξ122,44(k)"* which states that NPDES permit conditions may consist of *"Best management practices to control or abate the discharge of pollutants when:… (2) Numeric effluent limitations are infeasible…"*

10.3 Reasonable Assurance for Implementation

10.3.1 Follow-up Monitoring

VADEQ will continue monitoring the Crab 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 stations on Crab Creek will continue to be monitored on a bi-monthly basis. Watershed monitoring stations are designed to provide complete 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…*".

There currently MS4 permits in the Crab Creek watershed held by the Town of Christiansburg (VAR015370) and the Virginia Department of Transportation (VDOT-VAR100229 and VAR101126).

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 6.4.5 below). At some future time, it may therefore become necessary to investigate the stream's use designation and adjust the water quality criteria through a Use Attainability Analysis. Any changes to the TMDL resulting from water quality standards change on Crab Creek would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

Additional information on Virginia's Stormwater 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 Crab 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 re-assess 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 Crab 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 farmers), VADEQ, and MapTech personnel met at the New River Roundtable Agricultural subcommittee on August 9, 2003.

The first public meeting took place on October 14, 2003 at the Montgomery County Government Center in Christiansburg, Virginia; 15 people (2 citizens, 8 government agents, 5 consultants) attended. The meeting was publicized 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 nine participants, including five citizens from the Back Creek area, three government agents, and one MapTech representative. Participants were shown examples of aquatic life from a nearby reference stream, then looked at two sites on Back Creek to contrast the differences and discuss potential implementation strategies. Field Day was announced at the first public meeting. People 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 25 attendees, including 8 citizens, 5 government agents, 7 MapTech representatives, and 5 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 Crab Creek watershed.

Date	Location	Attendance[1]	Type	Format
5/29/03	Dublin Library 300 Giles Avenue Dublin, Virginia	24	Kickoff[2]	Open to public at large
10/14/03	Montgomery County Government Center 755 Roanoke St. Christiansburg, Virginia	15	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	25	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 arganization 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 25^{th}, 50^{th}, and 75^{th} 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 50^{th} quartile is also known as the median. The 25^{th} and 75^{th} 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 qualitative 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 stormwater 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 $E(y) = B_0 + B_1 x_1$ are fit and the “best” x_1 is selected based on the *t*-test for B_1. Next, two-variable models of the form $E(y) = B_0 + B_1 x_1 + B_2 x_i$ 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. *Stormwater 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 FECAL COLIFORM

Figure A.1 Frequency analysis of fecal coliform concentrations at station 9-CBC001.00 in the Crab Creek impairment for period September 1989 to November 2003.

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

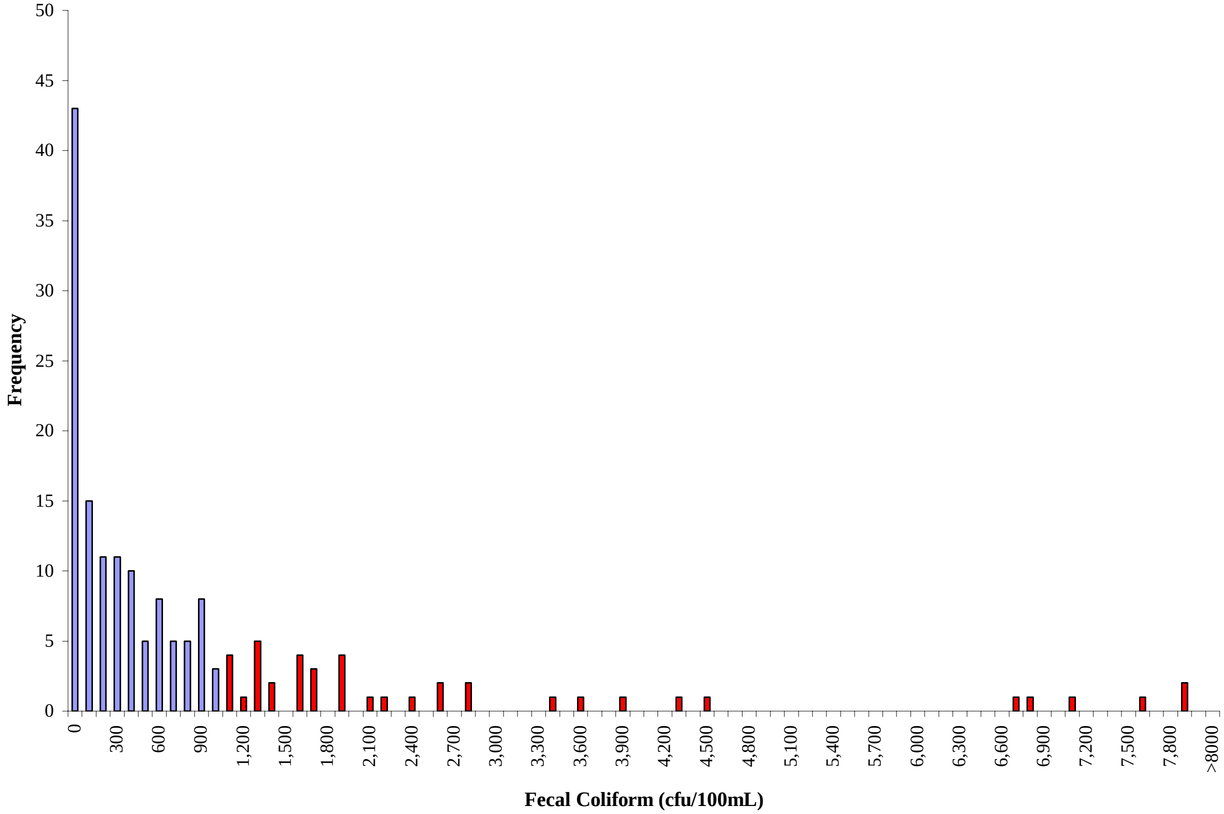

Figure A.2 Frequency analysis of fecal coliform concentrations at station 9-CBC004.38 in the Crab Creek impairment for period July 1988 to November 2003.

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

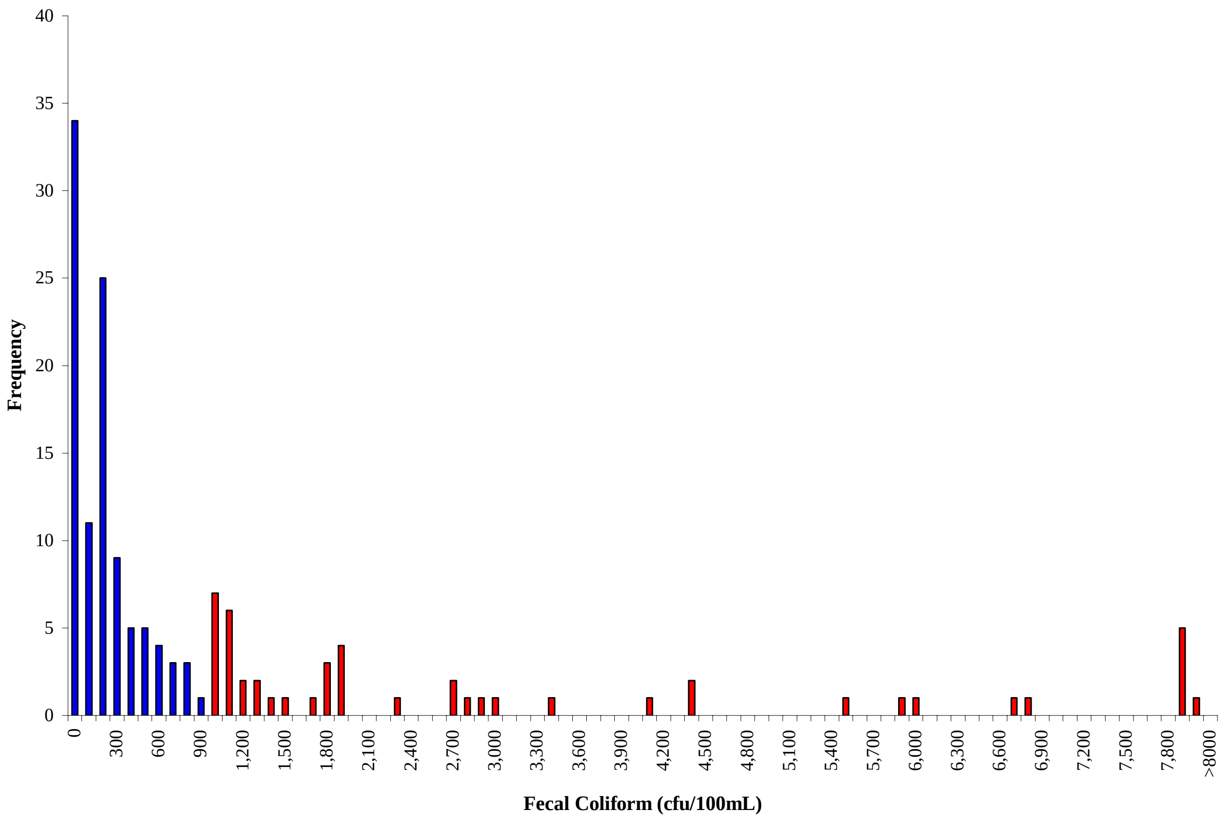

Figure A.3 Frequency analysis of fecal coliform concentrations at station 9-CBC006.35 in the Crab Creek impairment for period July 1998 to June 2001.

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

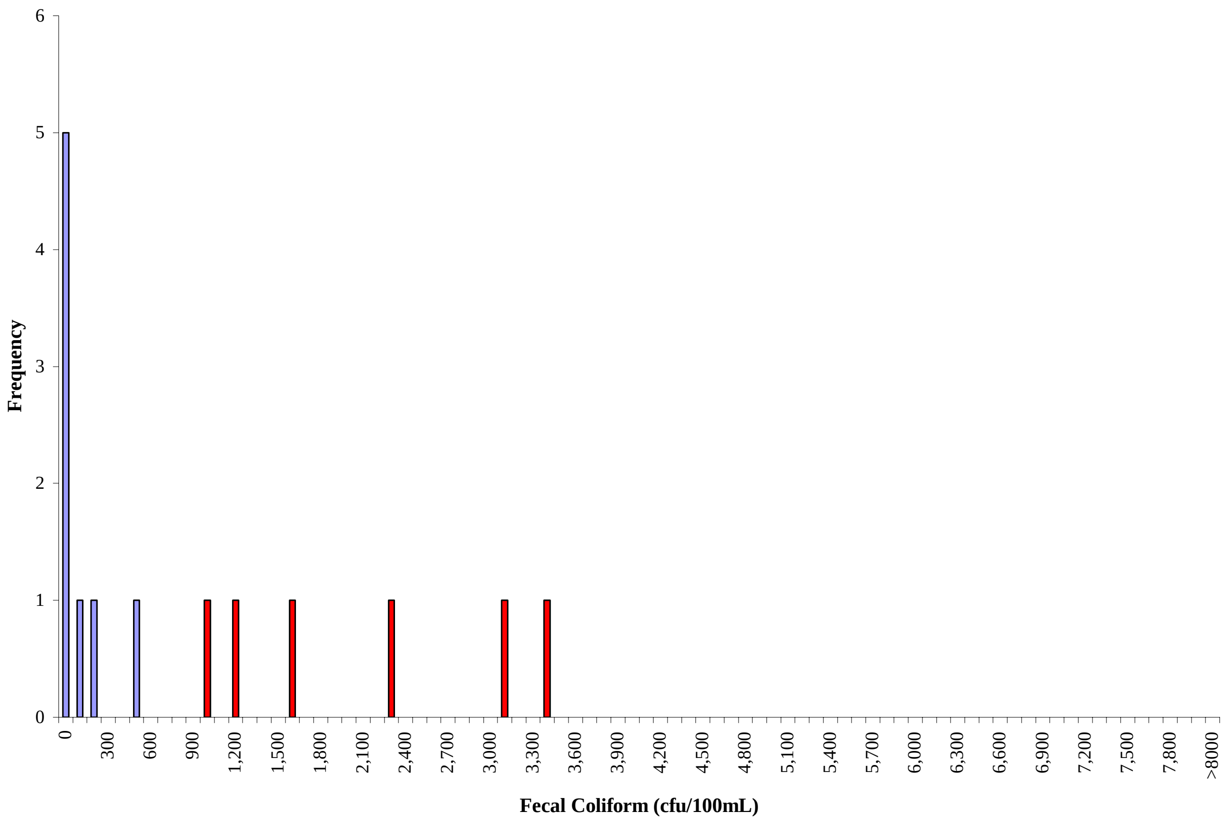

Figure A.4 Frequency analysis of fecal coliform concentrations at station 9-CBC009.81 in the Crab Creek impairment for period September 2001 to November 2003.

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

APPENDIX B

FECAL COLIFORM LOADS IN EXISTING CONDITIONS

Table B.1 Current conditions (2003) of land applied fecal coliform load for Crab Creek impairment (Subsheds 24-28).

	Barren (cfu/ac*day)	Commercial (cfu/ac*day)	Forest (cfu/ac*day)	Pasture (cfu/ac*day)
January	4.92E+09	1.18E+10	1.28E+10	1.66E+10
February	4.45E+09	1.07E+10	1.15E+10	1.59E+10
March	4.92E+09	1.18E+10	1.28E+10	1.70E+10
April	4.76E+09	1.14E+10	1.24E+10	1.66E+10
May	4.92E+09	1.18E+10	1.28E+10	8.38E+12
June	4.76E+09	1.14E+10	1.24E+10	1.72E+10
July	4.92E+09	1.18E+10	1.28E+10	1.76E+10
August	4.92E+09	1.18E+10	1.28E+10	1.76E+10
September	4.76E+09	1.14E+10	1.24E+10	1.67E+10
October	4.92E+09	1.18E+10	1.28E+10	1.71E+10
November	4.76E+09	1.14E+10	1.24E+10	1.63E+10
December	4.92E+09	1.18E+10	1.28E+10	1.67E+10

Table B.1 Current conditions (2003) of land applied fecal coliform load for Crab Creek impairment (Subsheds 24-28).

	Livestock Access (cfu/ac*day)	Residential (cfu/ac*day)	Row Crops (cfu/ac*day)	Water (cfu/ac*day)
January	5.54E+10	1.56E+10	1.69E+10	0.00E+00
February	5.05E+10	1.46E+10	1.70E+10	0.00E+00
March	5.71E+10	1.53E+10	8.23E+10	0.00E+00
April	5.72E+10	1.49E+10	8.20E+10	0.00E+00
May	5.89E+10	1.51E+10	8.23E+10	0.00E+00
June	5.87E+10	1.47E+10	1.03E+10	0.00E+00
July	6.04E+10	1.49E+10	1.06E+10	0.00E+00
August	6.04E+10	1.49E+10	1.06E+10	0.00E+00
September	5.72E+10	1.46E+10	3.14E+10	0.00E+00
October	5.71E+10	1.48E+10	8.23E+10	0.00E+00
November	5.50E+10	1.46E+10	8.20E+10	0.00E+00
December	5.54E+10	1.52E+10	1.69E+10	0.00E+00

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Crab Creek impairment (Subsheds 24-28).

Reach	Source	Jan cfu/day	Feb cfu/day	Mar cfu/day	Apr cfu/day	May cfu/day	Jun cfu/day
24	Human	2.48E+08	2.48E+08	2.48E+08	2.48E+08	2.48E+08	2.48E+08
	Livestock	6.27E+09	7.03E+09	1.00E+10	1.41E+10	1.41E+10	1.71E+10
	Wildlife	1.66E+09	1.66E+09	1.66E+09	1.66E+09	1.66E+09	1.66E+09
25	Human	5.61E+07	5.61E+07	5.61E+07	5.61E+07	5.61E+07	5.61E+07
	Livestock	8.95E+09	1.00E+10	1.43E+10	2.00E+10	2.00E+10	2.43E+10
	Wildlife	2.45E+09	2.45E+09	2.45E+09	2.45E+09	2.45E+09	2.45E+09
26	Human	5.11E+08	5.11E+08	5.11E+08	5.11E+08	5.11E+08	5.11E+08
	Livestock	9.20E+09	1.03E+10	1.47E+10	2.06E+10	2.06E+10	2.50E+10
	Wildlife	1.84E+09	1.84E+09	1.84E+09	1.84E+09	1.84E+09	1.84E+09
27	Human	1.37E+06	1.37E+06	1.37E+06	1.37E+06	1.37E+06	1.37E+06
	Livestock	1.10E+10	1.18E+10	1.96E+10	2.82E+10	2.82E+10	3.60E+10
	Wildlife	1.18E+09	1.18E+09	1.18E+09	1.18E+09	1.18E+09	1.18E+09
28	Human	2.47E+07	2.47E+07	2.47E+07	2.47E+07	2.47E+07	2.47E+07
	Livestock	3.90E+09	4.36E+09	6.23E+09	8.73E+09	8.73E+09	1.06E+10
	Wildlife	4.16E+07	4.16E+07	4.16E+07	4.16E+07	4.16E+07	4.16E+07

Reach	Source	Jul cfu/day	Aug cfu/day	Sep cfu/day	Oct cfu/day	Nov cfu/day	Dec cfu/day
24	Human	2.48E+08	2.48E+08	2.48E+08	2.48E+08	2.48E+08	2.48E+08
	Livestock	1.71E+10	1.71E+10	1.41E+10	1.00E+10	8.96E+09	6.27E+09
	Wildlife	1.66E+09	1.66E+09	1.66E+09	1.66E+09	1.66E+09	1.66E+09
25	Human	5.61E+07	5.61E+07	5.61E+07	5.61E+07	5.61E+07	5.61E+07
	Livestock	2.43E+10	2.43E+10	2.00E+10	1.43E+10	1.28E+10	8.95E+09
	Wildlife	2.45E+09	2.45E+09	2.45E+09	2.45E+09	2.45E+09	2.45E+09
26	Human	5.11E+08	5.11E+08	5.11E+08	5.11E+08	5.11E+08	5.11E+08
	Livestock	2.50E+10	2.50E+10	2.06E+10	1.47E+10	1.31E+10	9.20E+09
	Wildlife	1.84E+09	1.84E+09	1.84E+09	1.84E+09	1.84E+09	1.84E+09
27	Human	1.37E+06	1.37E+06	1.37E+06	1.37E+06	1.37E+06	1.37E+06
	Livestock	3.60E+10	3.60E+10	2.82E+10	1.96E+10	1.85E+10	1.10E+10
	Wildlife	1.18E+09	1.18E+09	1.18E+09	1.18E+09	1.18E+09	1.18E+09
28	Human	2.47E+07	2.47E+07	2.47E+07	2.47E+07	2.47E+07	2.47E+07
	Livestock	1.06E+10	1.06E+10	8.73E+09	6.23E+09	5.57E+09	3.90E+09
	Wildlife	4.16E+07	4.16E+07	4.16E+07	4.16E+07	4.16E+07	4.16E+07

Table B.3 Existing annual loads from land-based sources for the Crab Creek impairment (Subsheds 24-28).

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	0.00E+00	0.00E+00	2.96E+14	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	7.65E+08	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	2.96E+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	7.40E+13	0.00E+00	0.00E+00
Livestock								
Dairy	0.00E+00	0.00E+00	0.00E+00	2.05E+14	1.20E+13	0.00E+00	7.29E+14	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	1.01E+15	5.37E+13	0.00E+00	0.00E+00	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	1.20E+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	1.62E+14	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	1.38E+15	6.58E+13	0.00E+00	7.29E+14	0.00E+00
Wildlife								
Raccoon	6.11E+11	8.16E+12	1.04E+14	1.06E+14	9.83E+12	3.42E+13	8.92E+12	0.00E+00
Muskrat	0.00E+00	2.29E+12	2.90E+12	1.88E+13	1.26E+13	1.82E+12	8.86E+11	0.00E+00
Deer	0.00E+00	0.00E+00	1.60E+13	2.10E+13	1.19E+12	1.55E+12	1.93E+12	0.00E+00
Turkey	2.69E+07	1.55E+08	7.00E+09	3.31E+09	3.02E+08	7.89E+08	2.52E+08	0.00E+00
Goose	2.29E+08	3.56E+09	1.78E+10	9.11E+09	7.94E+09	4.97E+09	8.88E+08	0.00E+00
Duck	9.21E+06	1.38E+08	6.97E+08	3.38E+08	2.28E+08	1.97E+08	2.71E+07	0.00E+00
Total	6.11E+11	1.05E+13	1.23E+14	1.52E+15	8.94E+13	4.08E+14	7.41E+14	0.00E+00

Table B.4 Existing annual loads from direct-deposition sources for the Crab Creek impairment (Subsheds 24-28).

Source	Fecal Coliform Load (cfu/yr)
Human	
Straight Pipes	3.07E+11
Total	3.07E+11
Livestock	
Dairy	4.05E+14
Beef	4.55E+14
Swine	0.00E+00
Sheep	5.13E+11
Goat	0.00E+00
Horse	6.94E+13
Poultry	0.00E+00
Total	9.30E+14
Wildlife	
Raccoon	6.82E+11
Muskrat	1.91E+12
Beaver	3.75E+05
Deer	2.08E+10
Turkey	5.93E+06
Goose	1.15E+09
Duck	6.42E+07
Total	2.62E+12

APPENDIX C

UCI FILE USED FOR MODELING

PERLND

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  ACTIVITY
*** <PLS >               Active Sections                               ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  508    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  508    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     Water                            1    1    0    0    0    0
  102     Resid./Recr                      1    1    0    0    0    0
  103     Comm./Ind./Tr                    1    1    0    0    0    0
  104     Barren                           1    1    0    0    0    0
  105     Forest/Wet                       1    1    0    0    0    0
  106     Row Crops                        1    1    0    0    0    0
  107     Pasture/Hay                      1    1    0    0    0    0
  108     Pot. Liv. Acc.                   1    1    0    0    0    0
  201     Water                            1    1    0    0    0    0
  202     Resid./Recr                      1    1    0    0    0    0
  203     Comm./Ind./Tr                    1    1    0    0    0    0
  204     Barren                           1    1    0    0    0    0
  205     Forest/Wet                       1    1    0    0    0    0
  206     Row Crops                        1    1    0    0    0    0
  207     Pasture/Hay                      1    1    0    0    0    0
  208     Pot. Liv. Acc.                   1    1    0    0    0    0
  301     Water                            1    1    0    0    0    0
  302     Resid./Recr                      1    1    0    0    0    0
  303     Comm./Ind./Tr                    1    1    0    0    0    0
  305     Forest/Wet                       1    1    0    0    0    0
  306     Row Crops                        1    1    0    0    0    0
  307     Pasture/Hay                      1    1    0    0    0    0
  308     Pot. Liv. Acc.                   1    1    0    0    0    0
  401     Water                            1    1    0    0    0    0
  402     Resid./Recr                      1    1    0    0    0    0
  403     Comm./Ind./Tr                    1    1    0    0    0    0
  404     Barren                           1    1    0    0    0    0
  405     Forest/Wet                       1    1    0    0    0    0
  406     Row Crops                        1    1    0    0    0    0
  407     Pasture/Hay                      1    1    0    0    0    0
  408     Pot. Liv. Acc.                   1    1    0    0    0    0
  501     Water                            1    1    0    0    0    0
  502     Resid./Recr                      1    1    0    0    0    0
  505     Forest/Wet                       1    1    0    0    0    0
  506     Row Crops                        1    1    0    0    0    0
  507     Pasture/Hay                      1    1    0    0    0    0
  508     Pot. Liv. Acc.                   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  508    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             0.       2.0   0.23167       100     0.001      0.12     0.980
  102             1.       2.0   0.07408       711   0.04116      0.12     0.980
  103             1.       2.0   0.09331       737    0.0243      0.12     0.980
  104             0.       2.0   0.10852       800   0.02346      0.12     0.980
  105             1.       2.0   0.08846       655    0.0514      0.12     0.980
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  106             1.        2.0   0.11946       800   0.03497      0.12     0.980
  107             0.        2.0   0.09277       800   0.03655      0.12     0.980
  108             1.        2.0   0.06834       100     0.001      0.12     0.980
  201             0.        2.0   0.13031       100     0.001      0.12     0.980
  202             1.        2.0   0.12488       501   0.04908      0.12     0.980
  203             1.        2.0   0.13410       366   0.05003      0.12     0.980
  204             0.        2.0   0.13500       800    0.0232      0.12     0.980
  205             1.        2.0   0.15629       543   0.07254      0.12     0.980
  206             1.        2.0   0.15502       679    0.0643      0.12     0.980
  207             0.        2.0   0.13420       505    0.0665      0.12     0.980
  208             1.        2.0   0.09437       100     0.001      0.12     0.980
  301             0.        2.0   0.09863       100     0.001      0.12     0.980
  302             1.        2.0   0.14449       361   0.08103      0.12     0.980
  303             1.        2.0   0.11315       193   0.07918      0.12     0.980
  305             1.        2.0   0.15152       364   0.12804      0.12     0.980
  306             1.        2.0   0.14460       314   0.08316      0.12     0.980
  307             0.        2.0   0.14296       435   0.09301      0.12     0.980
  308             1.        2.0   0.11877       100     0.001      0.12     0.980
  401             0.        2.0   0.13500       100     0.001      0.12     0.980
  402             1.        2.0   0.15837       429   0.06467      0.12     0.980
  403             1.        2.0   0.12925       332   0.05857      0.12     0.980
  404             0.        2.0   0.22479       336   0.14998      0.12     0.980
  405             1.        2.0   0.16781       400   0.12357      0.12     0.980
  406             1.        2.0   0.17342       447   0.09627      0.12     0.980
  407             0.        2.0   0.15767       544   0.08015      0.12     0.980
  408             1.        2.0   0.12425       100     0.001      0.12     0.980
  501             0.        2.0   0.08177       100     0.001      0.12     0.980
  502             1.        2.0   0.12967       800   0.06149      0.12     0.980
  505             1.        2.0   0.15144       493   0.06394      0.12     0.980
  506             1.        2.0   0.10381       463   0.04656      0.12     0.980
  507             0.        2.0   0.13612       517   0.05083      0.12     0.980
  508             1.        2.0   0.08095       100     0.001      0.12     0.980
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101  508       40.       35.        2.        2.      0.15    0.0487        0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                       (1/day)
  101  508       0.1     1.128       0.2      1.25       0.3     0.115
  END PWAT-PARM4

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101  508      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     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  102     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  103     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  104     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  105     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  106     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  107     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  108     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  201     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  202     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  203     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  204     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  205     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  206     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  207     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  208     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
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  301     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  302     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  303     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  305     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  306     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  307     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  308     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  401     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  402     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  403     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  404     0.0120.0120.0120.0230.0230.0580.0480.0630.0630.0310.0280.010
  405     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  406     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  407     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  408     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  501     0.0100.0100.0100.4000.4000.0170.0100.0100.0100.0100.0100.010
  502     0.0160.0160.0170.0230.0230.0600.0490.0650.0650.0200.0200.015
  505     0.0930.0930.0930.1800.1800.4000.3590.4000.4000.2280.2070.047
  506     0.1080.1080.1080.2100.2100.4000.4000.4000.4000.2660.2420.054
  507     0.0850.0850.0850.1510.2020.3250.2880.2880.2880.1440.0550.043
  508     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     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3651.3651.365
  102     1.5801.5801.6332.0002.0002.0002.0002.0002.0000.8160.7930.793
  103     1.5551.5551.6072.0002.0002.0002.0002.0002.0000.8010.7770.777
  104     1.9871.9872.0002.0002.0002.0002.0002.0002.0001.0360.9960.996
  105     1.5351.5351.6052.0002.0002.0002.0002.0002.0000.8010.7680.768
  106     0.3500.3401.1532.0002.0002.0002.0002.0002.0001.5720.9380.261
  107     1.9231.9231.9972.0002.0002.0002.0002.0002.0000.9980.9610.961
  108     1.5031.5031.5592.0002.0002.0002.0002.0002.0000.7780.7520.752
  201     1.7851.7851.7852.0002.0002.0002.0002.0002.0001.0761.0761.076
  202     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3591.3201.320
  203     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4831.4391.439
  204     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.9861.9091.909
  205     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3381.2821.282
  206     0.4790.4661.5812.0002.0002.0002.0002.0002.0002.0001.2860.358
  207     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4881.4331.433
  208     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.2891.2451.245
  301     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.2891.2891.289
  302     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4531.4111.411
  303     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.2291.1921.192
  305     1.8101.8101.8932.0002.0002.0002.0002.0002.0000.9450.9050.905
  306     0.4300.4181.4182.0002.0002.0002.0002.0002.0001.9331.1530.321
  307     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4001.3481.348
  308     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3101.2651.265
  401     2.0002.0002.0002.0002.0002.0002.0002.0002.0002.0002.0002.000
  402     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.2511.2151.215
  403     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4351.3931.393
  404     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.0521.0121.012
  405     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.0731.0281.028
  406     0.3770.3671.2452.0002.0002.0002.0002.0002.0001.6971.0120.282
  407     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3011.2531.253
  408     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.3061.2611.261
  501     1.4281.4281.4282.0002.0002.0002.0002.0002.0000.8600.8600.860
  502     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.1511.1181.118
  505     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4031.3441.344
  506     0.3950.3841.3032.0002.0002.0002.0002.0002.0001.7751.0590.295
  507     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4871.4321.432
  508     2.0002.0002.0002.0002.0002.0002.0002.0002.0001.4951.4431.443
  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     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  102     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  103     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
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  104     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  105     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  106     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  107     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  108     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  201     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  202     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  203     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  204     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  205     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  206     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  207     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  208     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  301     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  302     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  303     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  305     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  306     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  307     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  308     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  401     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  402     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  403     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  404     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  405     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  406     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  407     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  408     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  501     0.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.1000.100
  502     0.1000.1000.1000.1000.1000.1440.1440.1440.1440.1000.1000.100
  505     0.1400.1400.2800.2800.2800.4200.4200.4200.4200.2800.2800.140
  506     0.1000.1000.1730.2590.2590.3450.3450.3450.2590.1730.1000.100
  507     0.1200.1200.2400.2400.2400.3600.3600.3600.3600.2400.2400.120
  508     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     0.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.115
  102     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  103     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  104     0.1150.1150.1150.1220.1430.1600.1150.1150.1150.1330.1150.115
  105     0.7360.7360.7460.9091.0351.0350.5010.5010.5011.0030.7360.736
  106     0.3300.3300.3750.4920.7061.0350.4370.4370.4360.7150.3300.330
  107     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  108     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  201     0.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.115
  202     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  203     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  204     0.1150.1150.1150.1220.1430.1600.1150.1150.1150.1330.1150.115
  205     0.7360.7360.7460.9091.0351.0350.5010.5010.5011.0030.7360.736
  206     0.3300.3300.3750.4920.7061.0350.4370.4370.4360.7150.3300.330
  207     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  208     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  301     0.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.115
  302     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  303     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  305     0.7360.7360.7460.9091.0351.0350.5010.5010.5011.0030.7360.736
  306     0.3300.3300.3750.4920.7061.0350.4370.4370.4360.7150.3300.330
  307     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  308     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  401     0.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.115
  402     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  403     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  404     0.1150.1150.1150.1220.1430.1600.1150.1150.1150.1330.1150.115
  405     0.7360.7360.7460.9091.0351.0350.5010.5010.5011.0030.7360.736
  406     0.3300.3300.3750.4920.7061.0350.4370.4370.4360.7150.3300.330
  407     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  408     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  501     0.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.1150.115
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  502     0.1150.1150.1150.1660.1660.2210.1150.1150.1150.1150.1150.115
  505     0.7360.7360.7460.9091.0351.0350.5010.5010.5011.0030.7360.736
  506     0.3300.3300.3750.4920.7061.0350.4370.4370.4360.7150.3300.330
  507     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  508     0.5610.5610.5830.7250.8640.9920.4190.4190.4190.5610.5610.561
  END MON-LZETPARM

  NQUALS
*** x -  xNQUAL
  101  508    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  508   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   0.000   00.00    0.00
  102          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  103          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  104          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  105          0.00    0.00    0.00    0.00    0.00   0.270   00.00    0.00
  106          0.00    0.00    0.00    0.00    0.00   0.150   00.00    0.00
  107          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  108          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  201          0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  202          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  203          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  204          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  205          0.00    0.00    0.00    0.00    0.00   0.270   00.00    0.00
  206          0.00    0.00    0.00    0.00    0.00   0.150   00.00    0.00
  207          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  208          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  301          0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  302          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  303          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  305          0.00    0.00    0.00    0.00    0.00   0.270   00.00    0.00
  306          0.00    0.00    0.00    0.00    0.00   0.150   00.00    0.00
  307          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  308          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  401          0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  402          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  403          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  404          0.00    0.00    0.00    0.00    0.00   0.060   00.00    0.00
  405          0.00    0.00    0.00    0.00    0.00   0.270   00.00    0.00
  406          0.00    0.00    0.00    0.00    0.00   0.150   00.00    0.00
  407          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  408          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  501          0.00    0.00    0.00    0.00    0.00   0.000   00.00    0.00
  502          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  505          0.00    0.00    0.00    0.00    0.00   0.270   00.00    0.00
  506          0.00    0.00    0.00    0.00    0.00   0.150   00.00    0.00
  507          0.00    0.00    0.00    0.00    0.00   0.075   00.00    0.00
  508          0.00    0.00    0.00    0.00    0.00   0.075   00.00    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     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  102     09E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E08
  103     45E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E06
  104     23E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E06
  105     88E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E0688E06
  106     69E0669E0669E0669E0669E0669E0669E0669E0669E0669E0669E0669E06
  107     09E0810E0810E0810E0810E0810E0810E0810E0810E0809E0809E0809E08
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  108     12E0813E0816E0820E0820E0823E0823E0823E0820E0816E0815E0812E08
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     08E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E08
  203     70E0670E0670E0670E0670E0670E0670E0670E0670E0670E0670E0670E06
  204     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  205     97E0697E0697E0697E0697E0697E0697E0697E0697E0697E0697E0697E06
  206     74E0674E0674E0674E0674E0674E0674E0674E0674E0674E0674E0674E06
  207     10E0810E0810E0810E0810E0810E0810E0810E0810E0810E0809E0810E08
  208     07E0807E0808E0810E0810E0812E0812E0812E0810E0808E0808E0807E08
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     13E0812E0812E0812E0812E0811E0811E0811E0811E0811E0811E0812E08
  303     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  305     87E0687E0687E0687E0687E0687E0687E0687E0687E0687E0687E0687E06
  306     85E0685E0685E0685E0685E0685E0685E0685E0685E0685E0685E0685E06
  307     09E0810E0810E0810E0811E0810E0810E0810E0810E0810E0809E0809E08
  308     06E0807E0808E0810E0810E0812E0812E0812E0810E0808E0808E0806E08
  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     26E0825E0824E0823E0823E0822E0821E0821E0821E0820E0821E0823E08
  403     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  404     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  405     95E0695E0695E0695E0695E0695E0695E0695E0695E0695E0695E0695E06
  406     64E0875E0807E1007E1007E1092E0692E0692E0602E1007E1007E1064E08
  407     13E0814E0814E0814E0814E0820E0820E0820E0815E0815E0814E0813E08
  408     13E0814E0820E0827E0827E0834E0834E0834E0827E0820E0819E0813E08
  501     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  502     22E0821E0821E0820E0820E0820E0819E0819E0819E0819E0819E0820E08
  505     44E0644E0644E0644E0644E0644E0644E0644E0644E0644E0644E0644E06
  506     22E0622E0622E0622E0622E0622E0622E0622E0622E0622E0622E0622E06
  507     09E0810E0809E0809E0809E0809E0809E0809E0809E0809E0809E0809E08
  508     05E0805E0807E0810E0810E0812E0812E0812E0810E0807E0806E0805E08
  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     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  102     85E0885E0801E1002E1002E1002E1002E1002E1002E1001E1081E0883E08
  103     05E0805E0807E0811E0811E0811E0811E0811E0811E0807E0805E0805E08
  104     02E0802E0803E0806E0806E0806E0806E0806E0806E0803E0802E0802E08
  105     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  106     07E0807E0810E0817E0817E0817E0817E0817E0817E0810E0807E0807E08
  107     92E0801E1001E1002E1002E1002E1002E1002E1002E1001E1091E0892E08
  108     01E1001E1002E1005E1005E1006E1006E1006E1005E1002E1001E1001E10
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     84E0883E0801E1002E1002E1002E1002E1002E1002E1001E1078E0881E08
  203     07E0807E0811E0818E0818E0818E0818E0818E0818E0811E0807E0807E08
  204     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  205     10E0810E0815E0824E0824E0824E0824E0824E0824E0815E0810E0810E08
  206     07E0807E0811E0819E0819E0819E0819E0819E0819E0811E0807E0807E08
  207     95E0801E1002E1003E1003E1003E1003E1003E1003E1002E1094E0895E08
  208     66E0870E0801E1003E1003E1003E1003E1003E1003E1001E1079E0866E08
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     01E1001E1002E1003E1003E1003E1003E1003E1003E1002E1001E1001E10
  303     21E0821E0831E0852E0852E0852E0852E0852E0852E0831E0821E0821E08
  305     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  306     08E0808E0813E0821E0821E0821E0821E0821E0821E0813E0808E0808E08
  307     94E0801E1002E1003E1003E1002E1002E1002E1003E1002E1093E0894E08
  308     64E0868E0801E1003E1003E1003E1003E1003E1003E1001E1077E0864E08
  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     03E1003E1004E1006E1006E1006E1005E1005E1005E1003E1002E1002E10
  403     20E0820E0831E0851E0851E0851E0851E0851E0851E0831E0820E0820E08
  404     14E0814E0820E0834E0834E0834E0834E0834E0834E0820E0814E0814E08
  405     10E0810E0814E0824E0824E0824E0824E0824E0824E0814E0810E0810E08
  406     06E1007E1001E1202E1202E1223E0823E0823E0853E1001E1272E1006E10
  407     01E1001E1002E1003E1004E1005E1005E1005E1004E1002E1001E1001E10
  408     01E1001E1003E1007E1007E1008E1008E1008E1007E1003E1002E1001E10
  501     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  502     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  505     04E0804E0807E0811E0811E0811E0811E0811E0811E0807E0804E0804E08
  506     02E0802E0803E0806E0806E0806E0806E0806E0806E0803E0802E0802E08
  507     87E0895E0801E1002E1002E1002E1002E1002E1002E1001E1086E0887E08
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IMPLND
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*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
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  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  501    6    6    6    6    6    6    1    9
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*** <ILS >                           t-series Engl Metr Engl Metr
*** x -  x                            in  out
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  102     Comm./Ind./Tr                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
  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
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*** <ILS >        Flags
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  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
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  102            737    0.0243      0.05       0.1
  201            501   0.04908      0.05       0.1
  202            366   0.05003      0.05       0.1
  301            361   0.08103      0.05       0.1
  302            193   0.07918      0.05       0.1
  401            429   0.06467      0.05       0.1
  402            332   0.05857      0.05       0.1
  501            800   0.06149      0.05       0.1
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  501       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  501      0.01      0.01
  END IWAT-STATE1

  NQUALS
*** x -  xNQUAL
  101  501    1
  END NQUALS

  QUAL-PROPS
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*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
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  QUAL-INPUT
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
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  102         0.00    0.00    0.00    0.00   0.100
  201         0.00    0.00    0.00    0.00   0.100
  202         0.00    0.00    0.00    0.00   0.100
  301         0.00    0.00    0.00    0.00   0.100
  302         0.00    0.00    0.00    0.00   0.100
  401         0.00    0.00    0.00    0.00   0.100
  402         0.00    0.00    0.00    0.00   0.100
  501         0.00    0.00    0.00    0.00   0.100
  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     35E0635E0634E0634E0634E0634E0633E0633E0633E0635E0635E0635E06
  102     02E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E06
  201     37E0637E0636E0636E0636E0635E0635E0635E0635E0637E0637E0637E06
  202     03E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E06
  301     56E0655E0653E0652E0651E0650E0648E0648E0648E0656E0656E0656E06
  302     09E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E06
  401     01E0801E0899E0697E0694E0692E0687E0687E0687E0601E0801E0801E08
  402     09E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E06
  501     96E0694E0692E0690E0689E0687E0685E0685E0685E0696E0696E0696E06
  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     04E0803E0805E0809E0808E0808E0808E0808E0808E0804E0804E0804E08
  102     20E0620E0630E0650E0650E0650E0650E0650E0650E0620E0620E0620E06
  201     04E0804E0805E0809E0809E0809E0809E0809E0809E0804E0804E0804E08
  202     29E0629E0643E0672E0672E0672E0672E0672E0672E0629E0629E0629E06
  301     06E0805E0808E0813E0813E0813E0812E0812E0812E0806E0806E0806E08
  302     93E0693E0601E0802E0802E0802E0802E0802E0802E0893E0693E0693E06
  401     11E0810E0815E0824E0824E0823E0822E0822E0822E0811E0811E0811E08
  402     91E0691E0601E0802E0802E0802E0802E0802E0802E0891E0691E0691E06
  501     10E0809E0814E0823E0822E0822E0821E0821E0821E0810E0810E0810E08
  END MON-SQOLIM

END IMPLND
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APPENDIX D

OBSERVED STRESSOR DATA

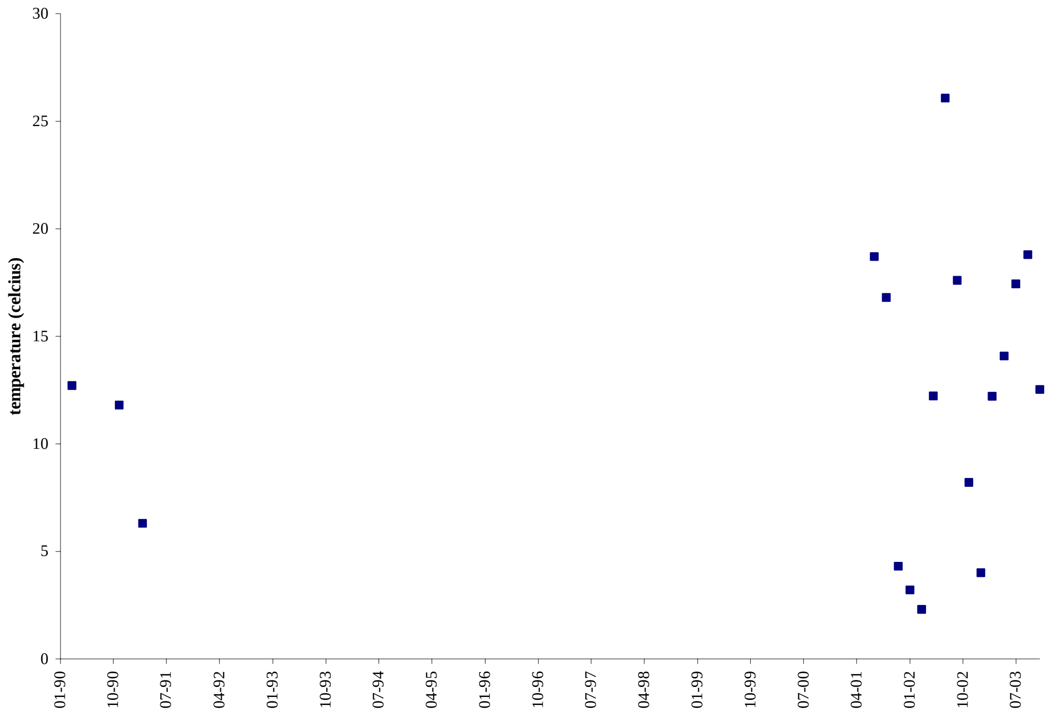

Figure D.1 Temperature measurements at 9-CBC001.00.

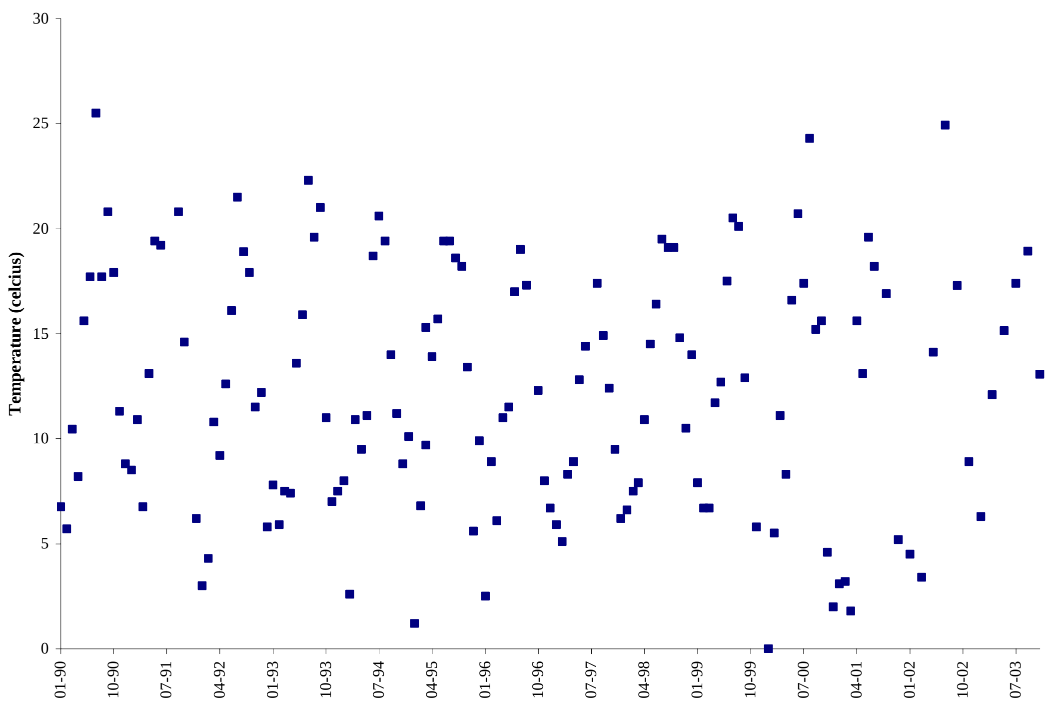

Figure D.2 Temperature measurements at 9-CBC004.38.

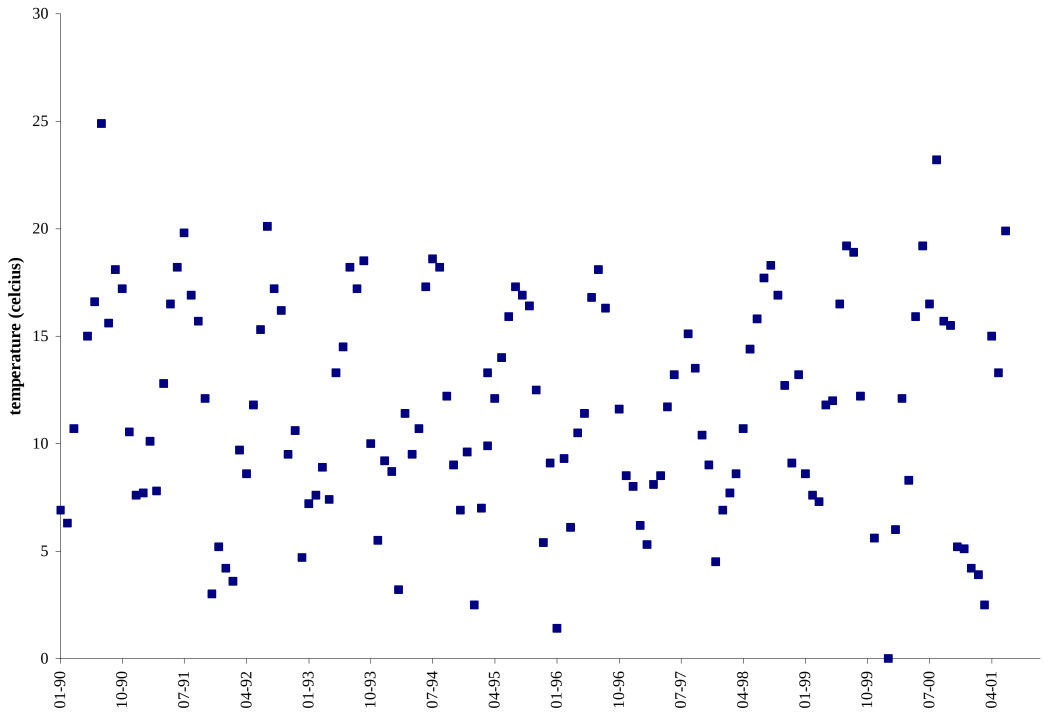

Figure D.3 Temperature measurements at 9-CBC006.35.

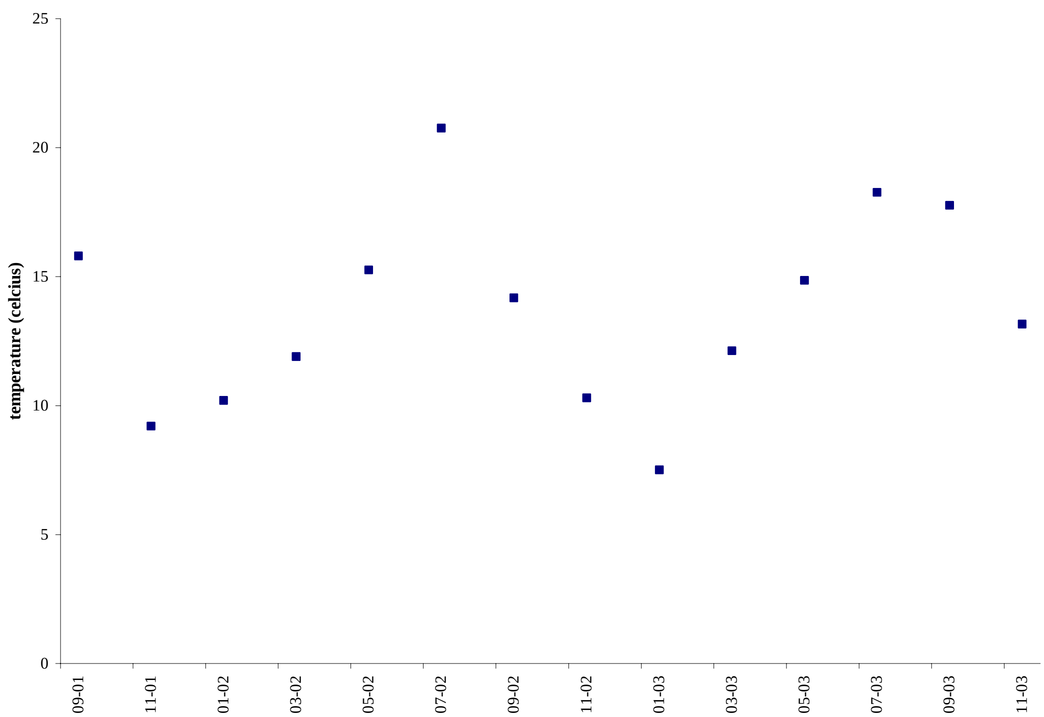

Figure D.4 Temperature measurements at 9-CBC009.81.

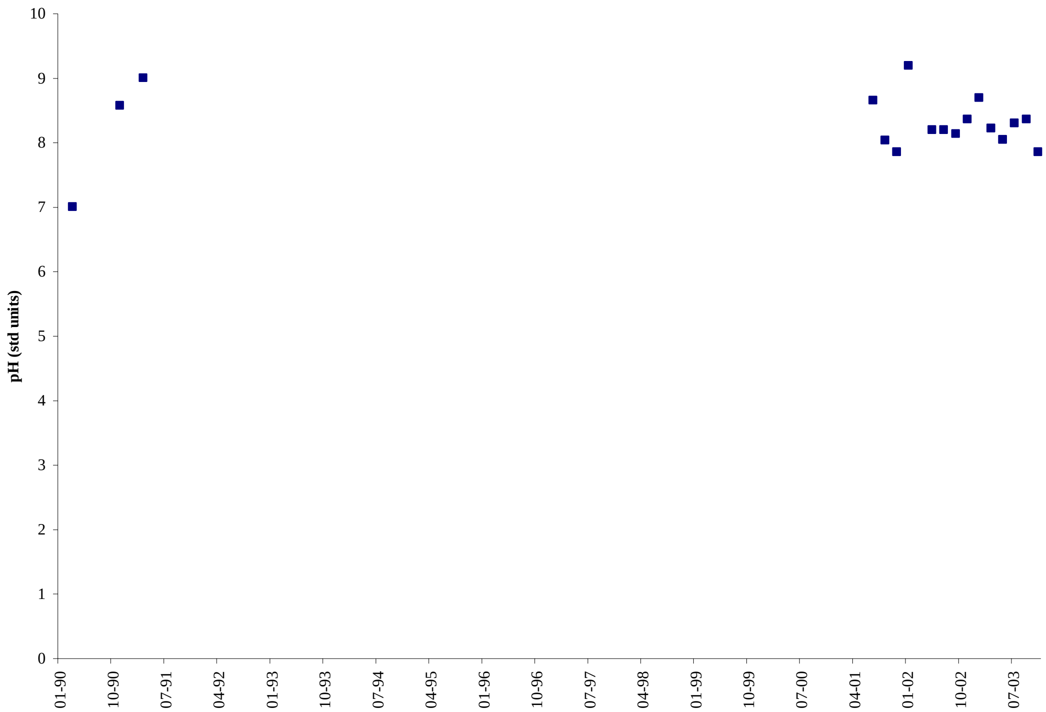

Figure D.5 pH measurements at 9-CBC001.00.

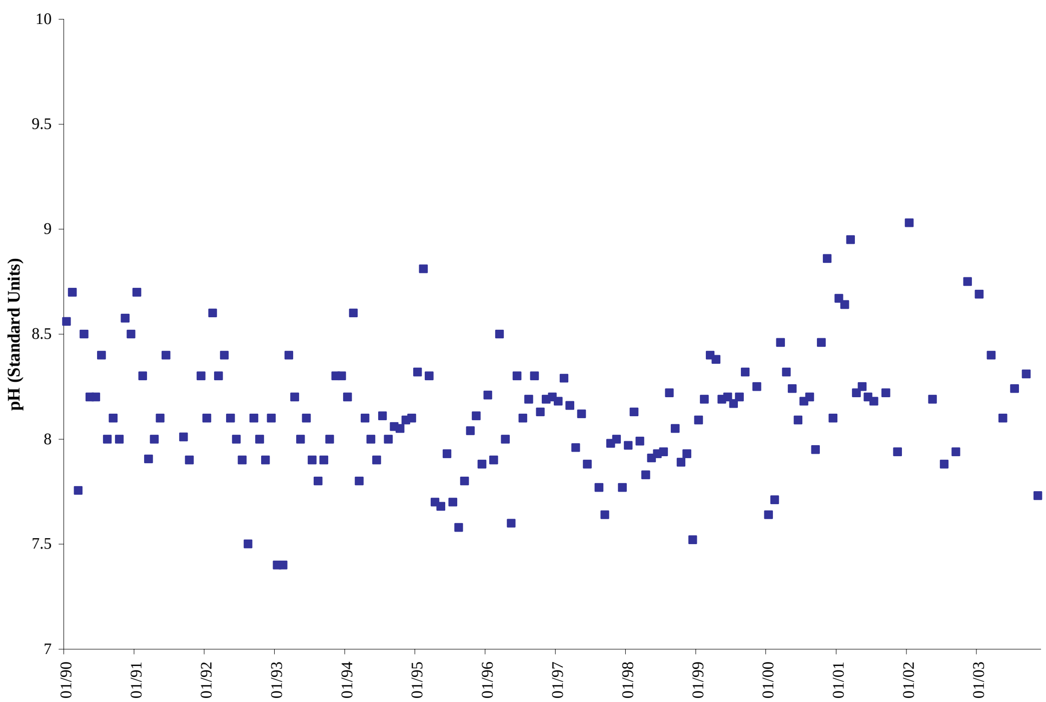

Figure D.6 pH measurements at 9-CBC004.38.

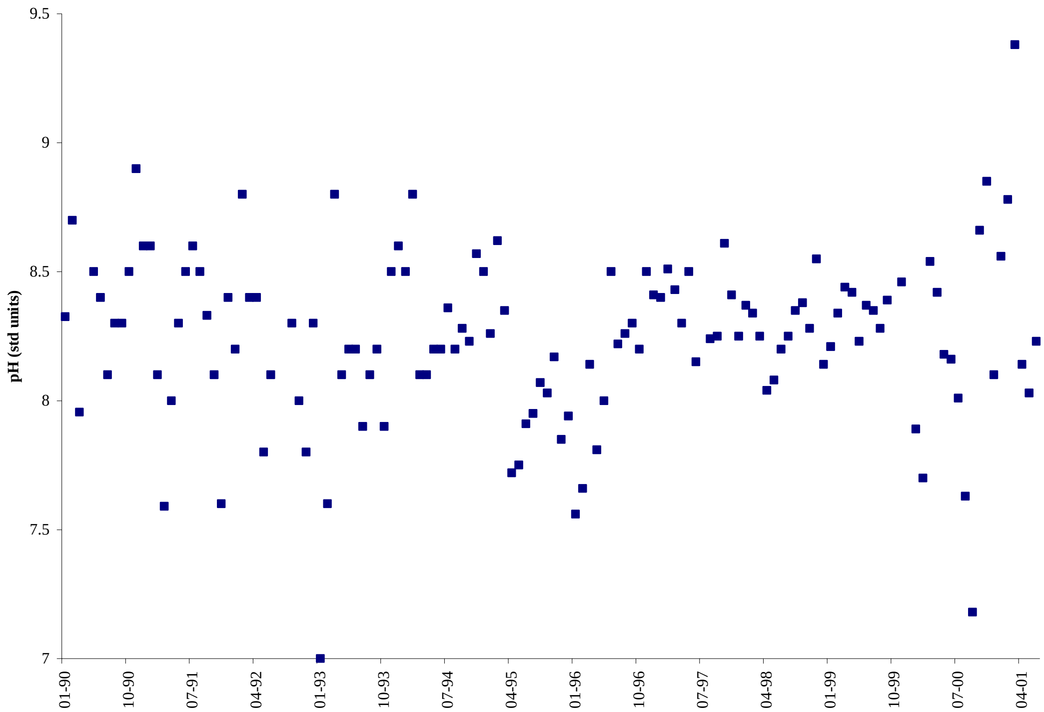

Figure D.7 pH measurements at 9-CBC006.35.

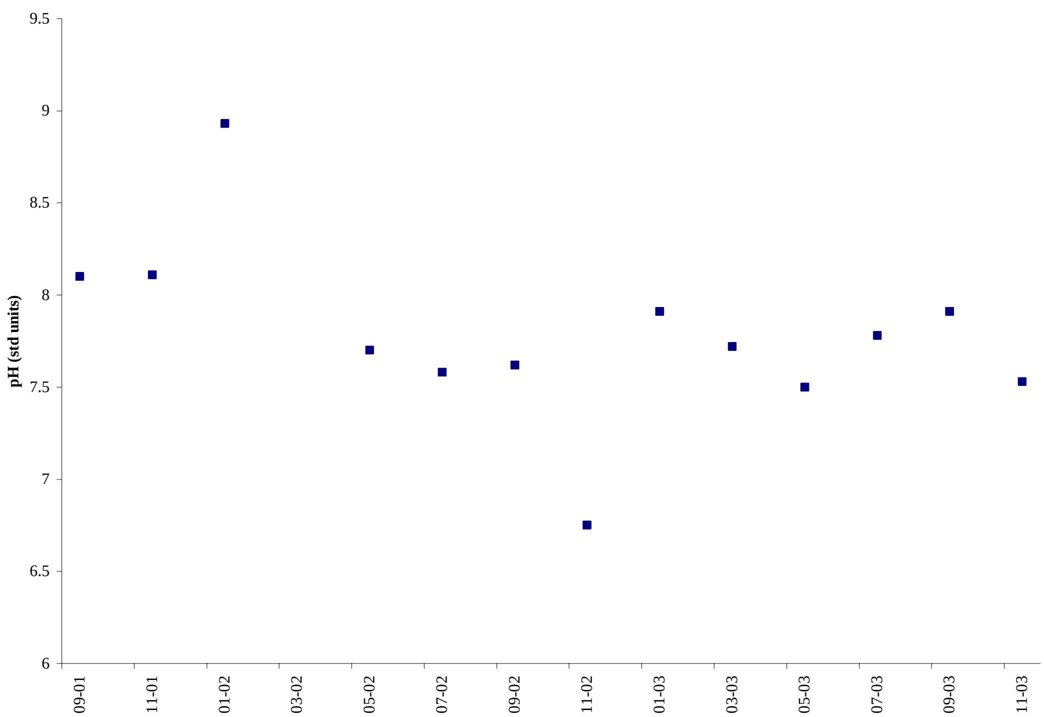

Figure D.8 pH measurements at 9-CBC009.81.

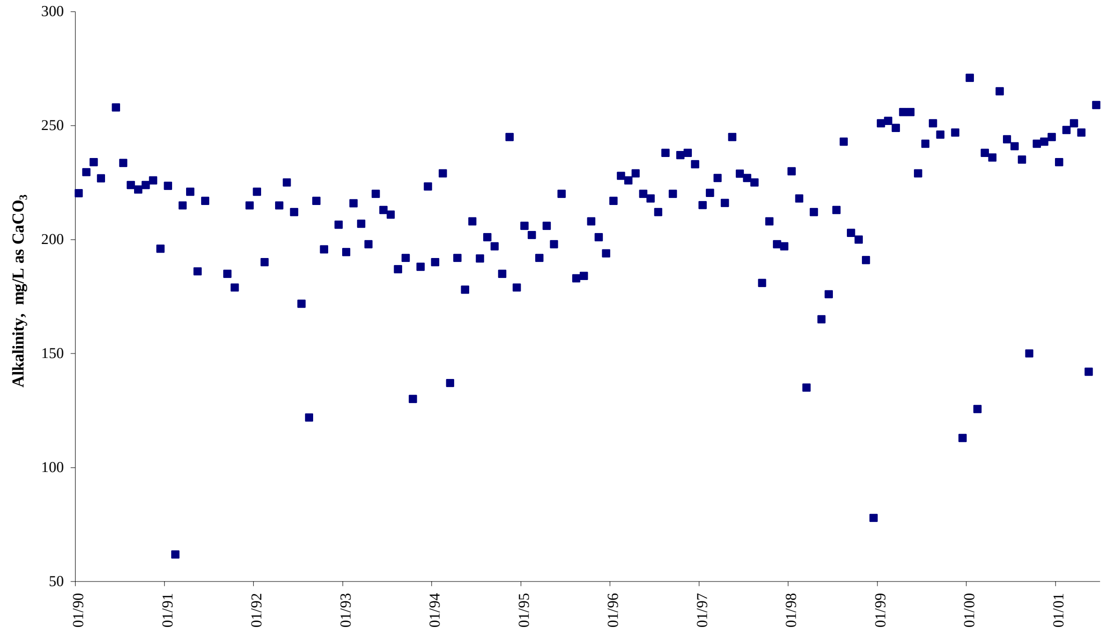

Figure D.9 Alkalinity concentrations at 9-CBC004.38.

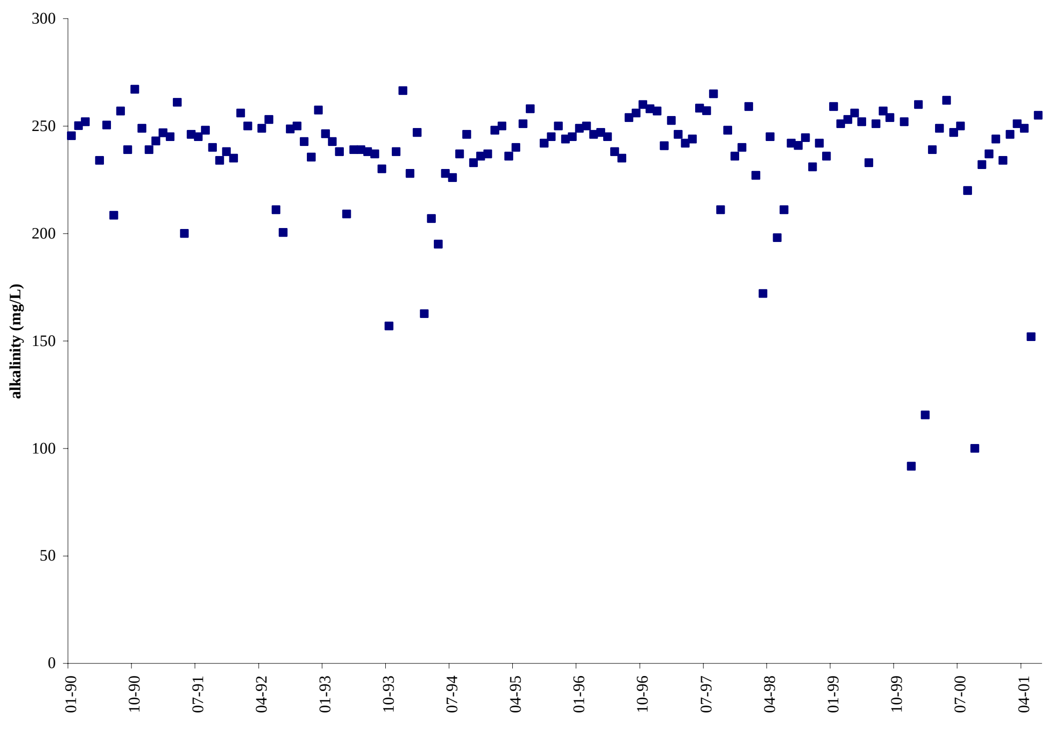

Figure D.10 Alkalinity concentrations at 9-CBC006.35.

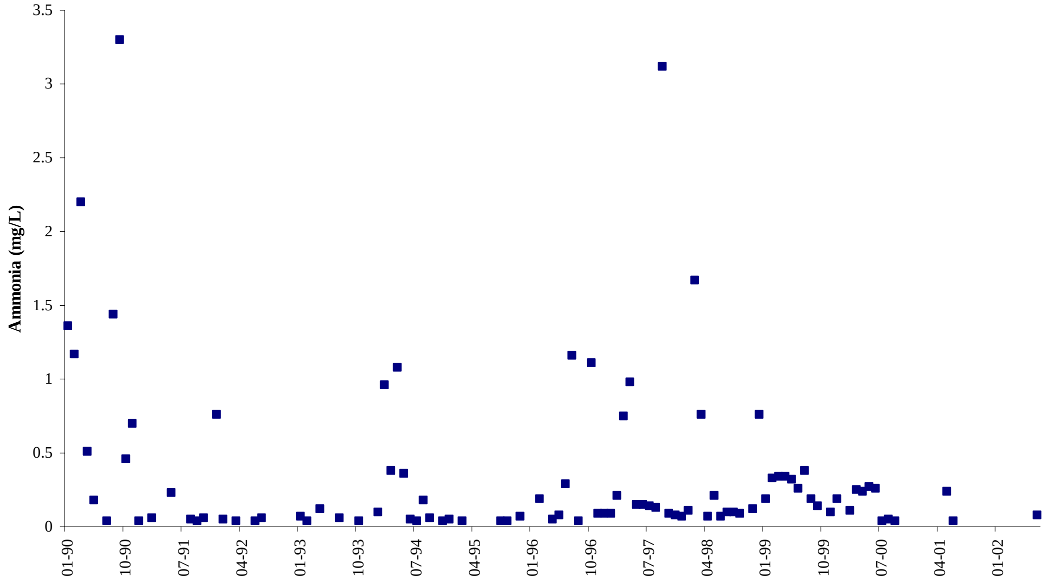

Figure D.11 Ammonia concentrations at 9-CBC004.38.

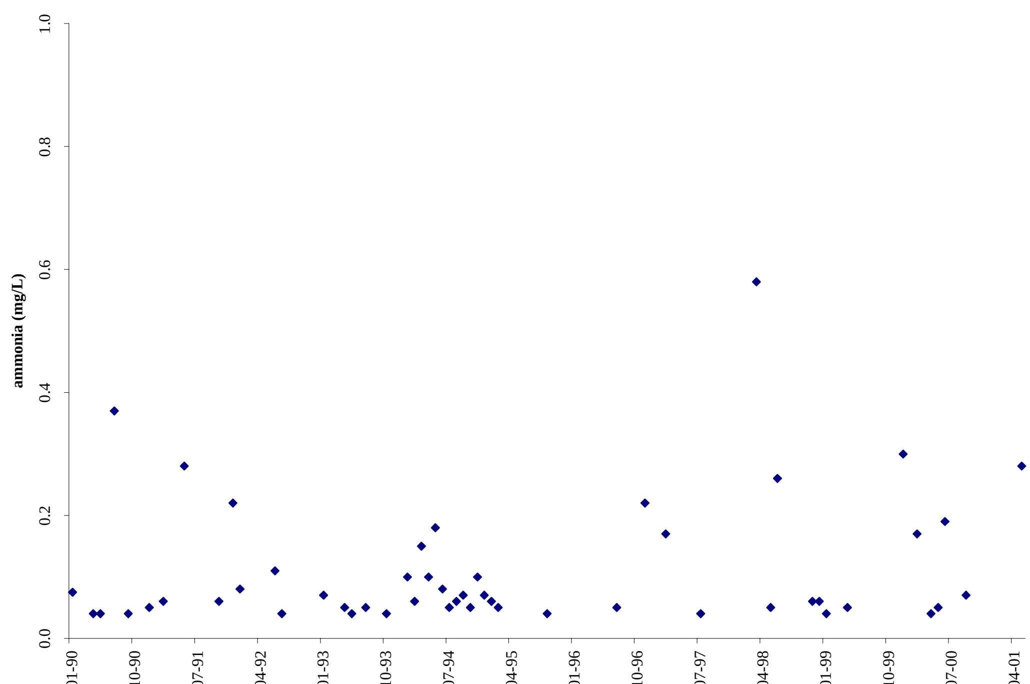

Figure D.12 Ammonia concentrations at 9-CBC006.35.

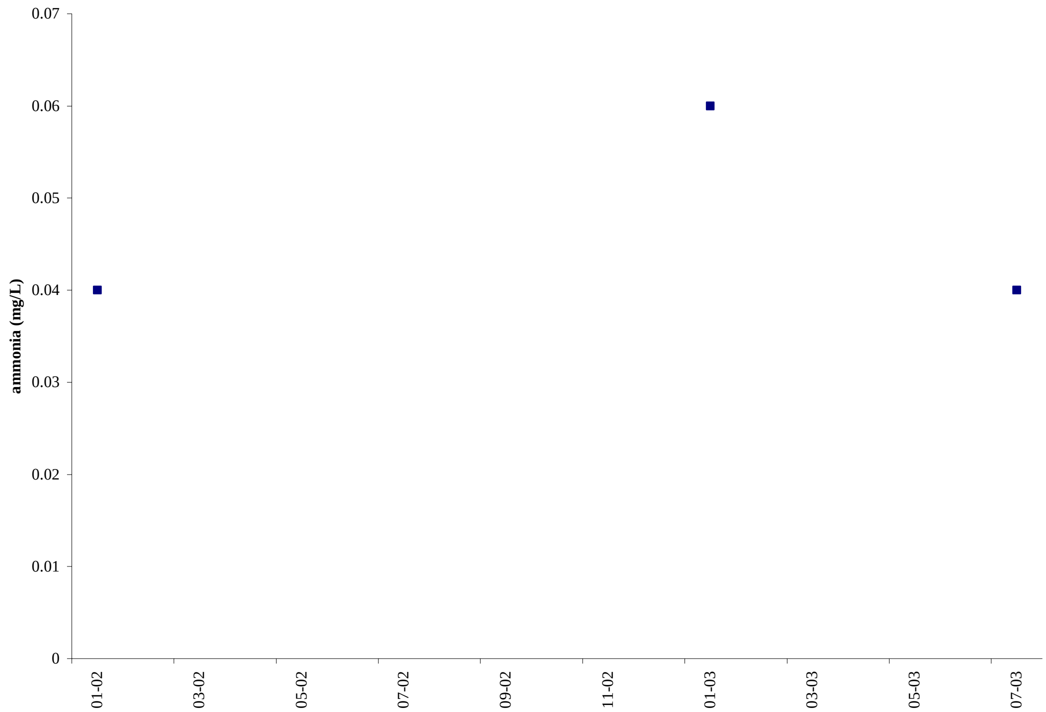

Figure D.13 Ammonia concentrations at 9-CBC009.81.

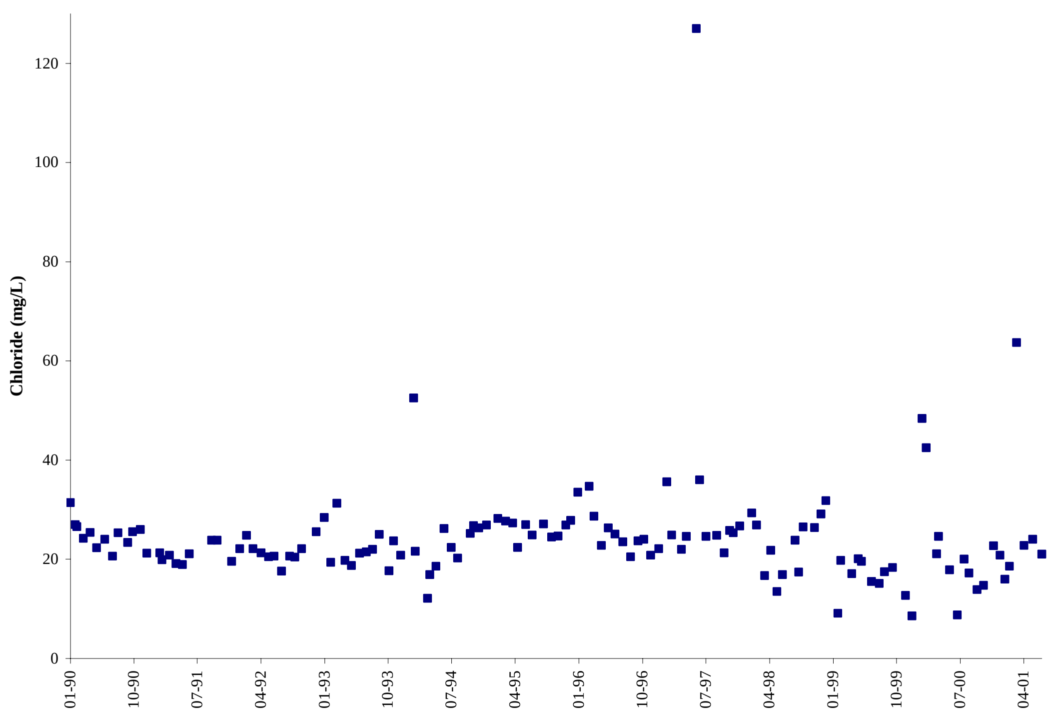

Figure D.14 Chloride concentrations at 9-CBC004.38.

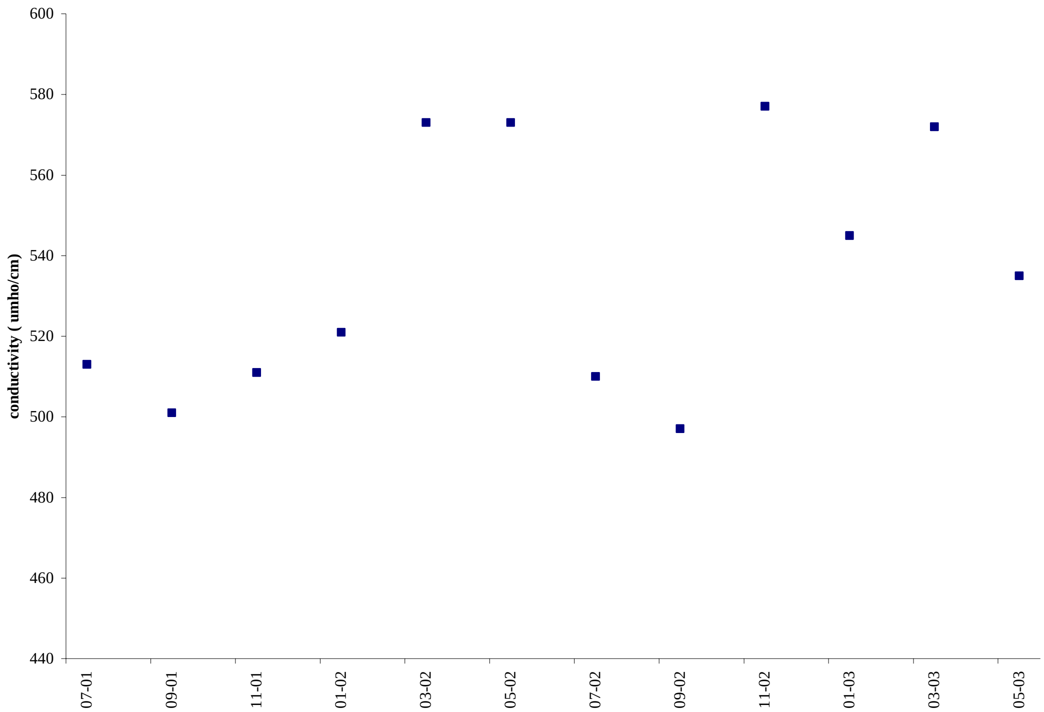

Figure D.15 Conductivity at 9-CBC001.00.

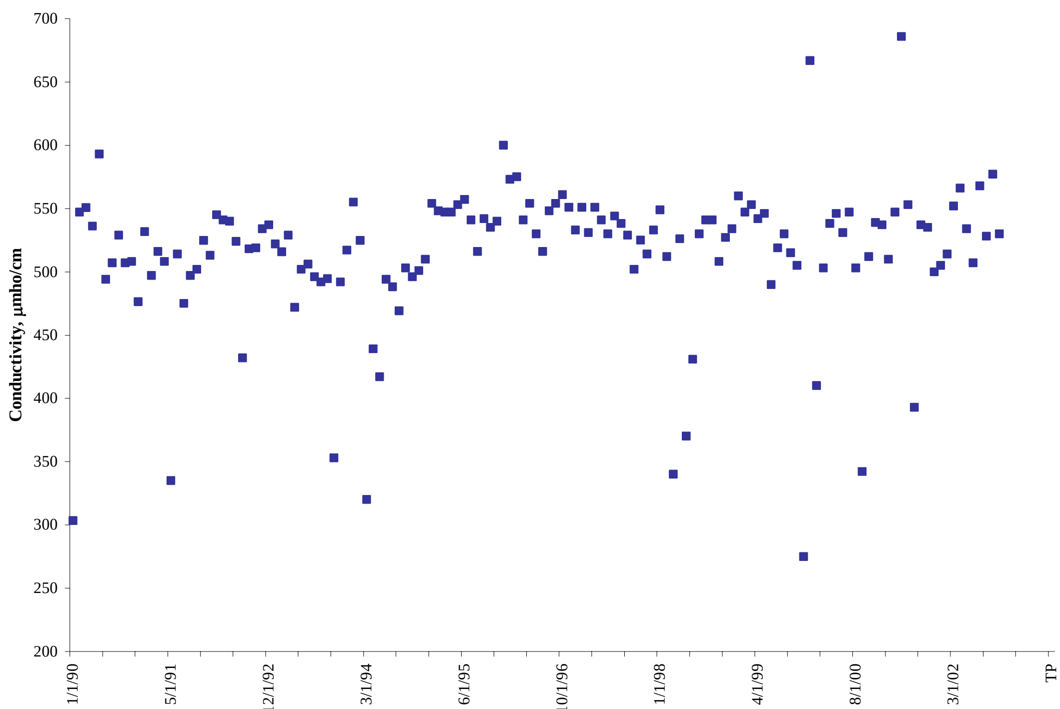

Figure D.16 Conductivity at 9-CBC004.38.

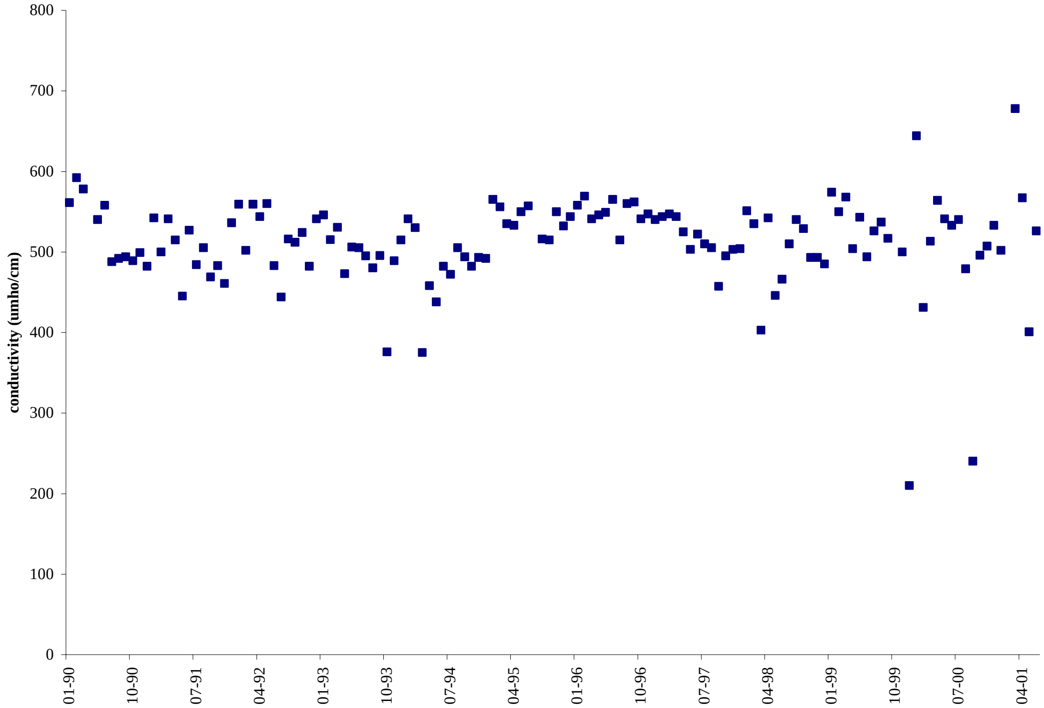

Figure D.17 Conductivity at 9-CBC006.35.

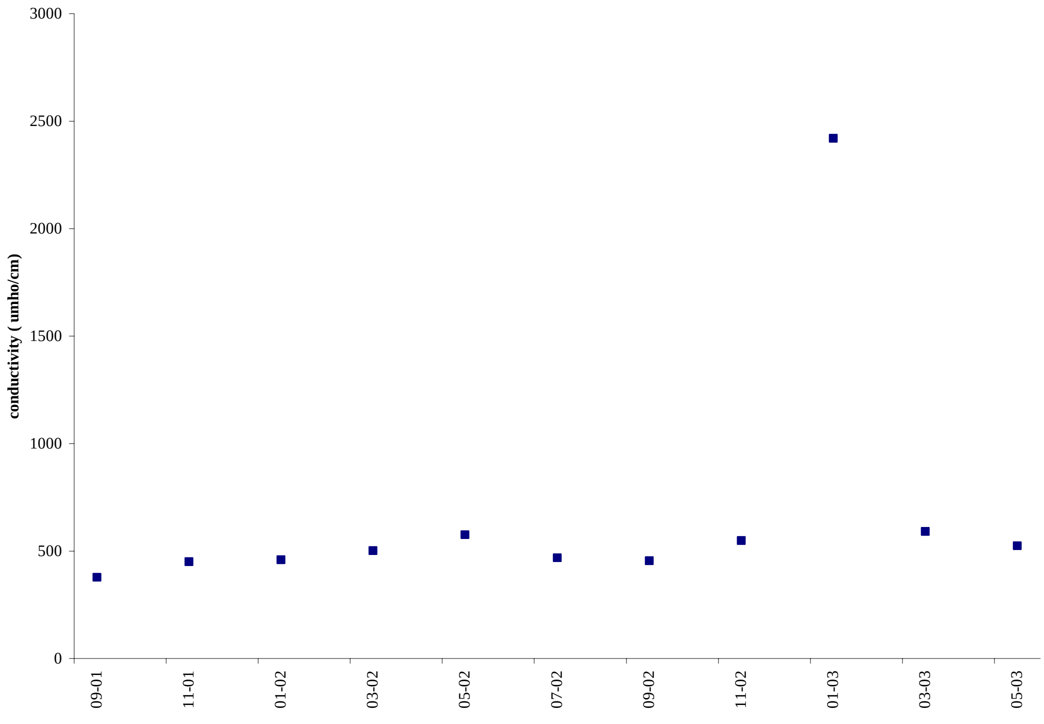

Figure D.18 Conductivity at 9-CBC009.81.

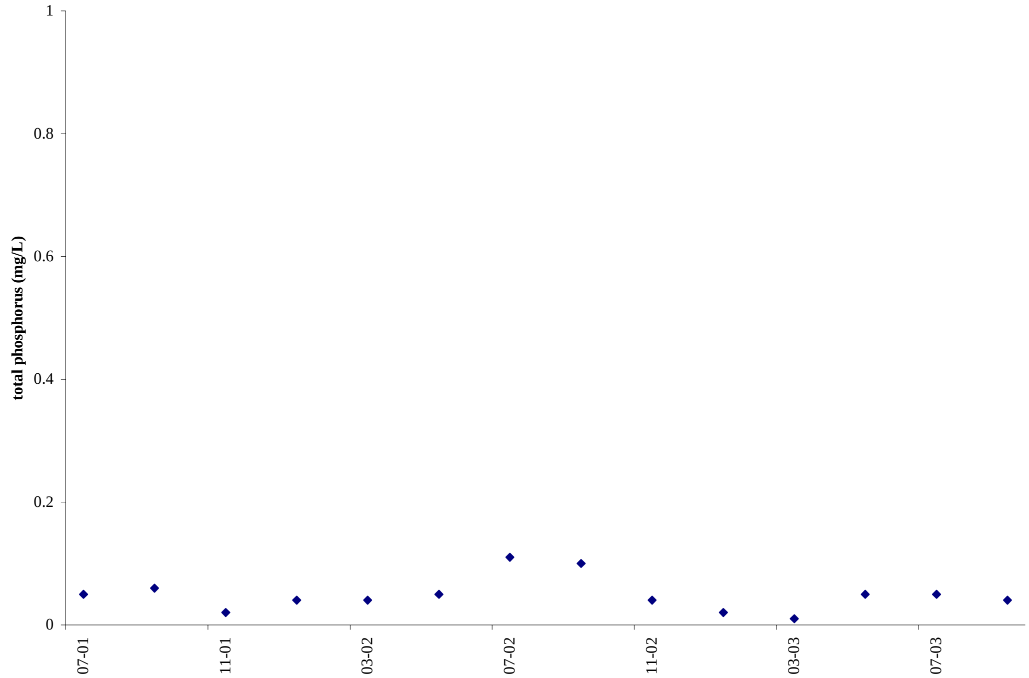

Figure D.19 Total phosphorus concentrations at 9-CBC001.00.

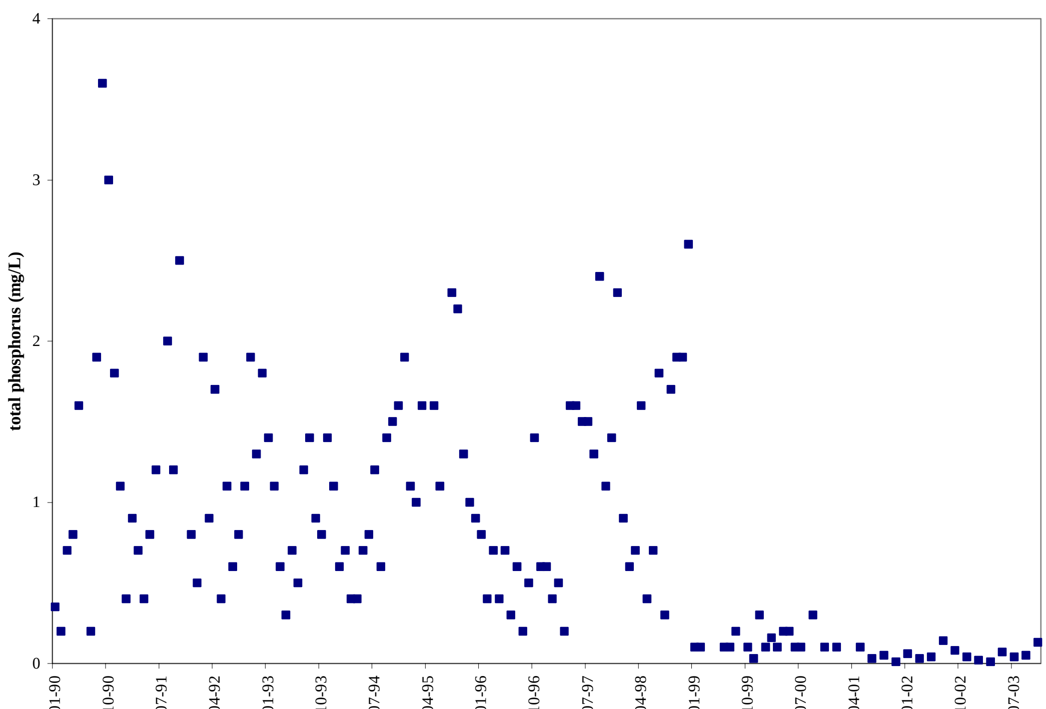

Figure D.20 Total phosphorus concentrations at 9-CBC004.38.

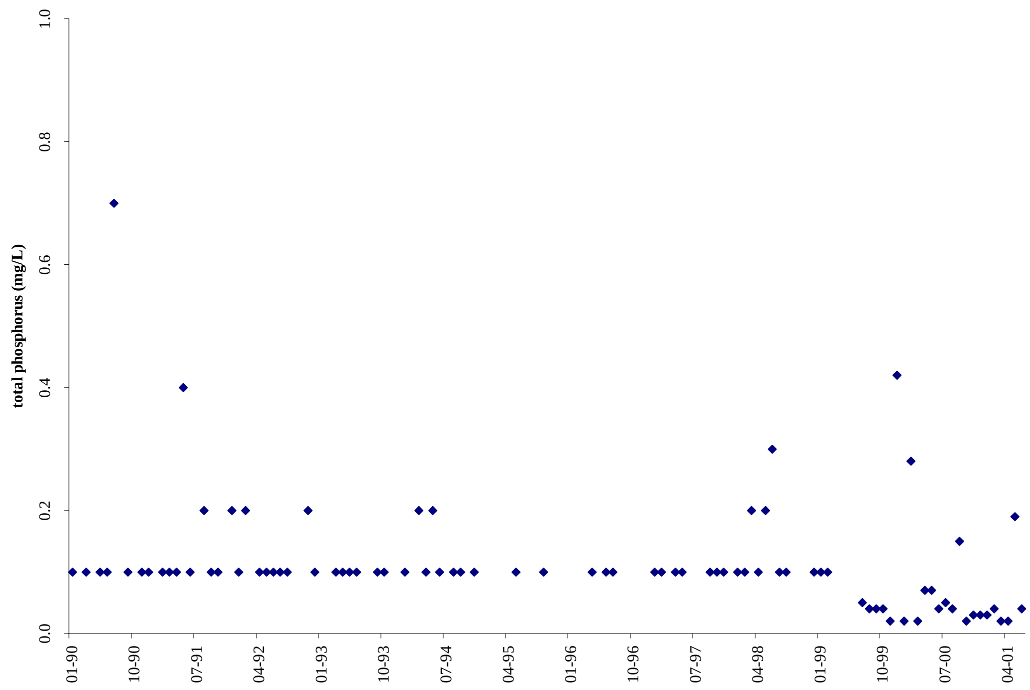

Figure D.21 Total phosphorus concentrations at 9-CBC006.35.

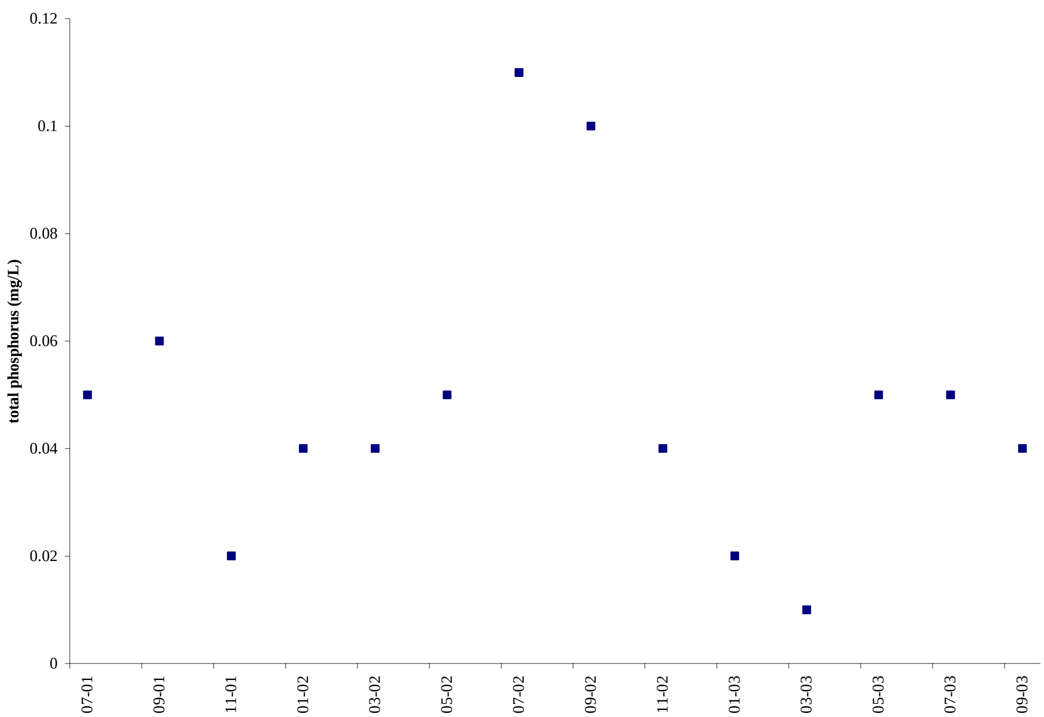

Figure D.22 Total phosphorus concentrations at 9-CBC009.81.

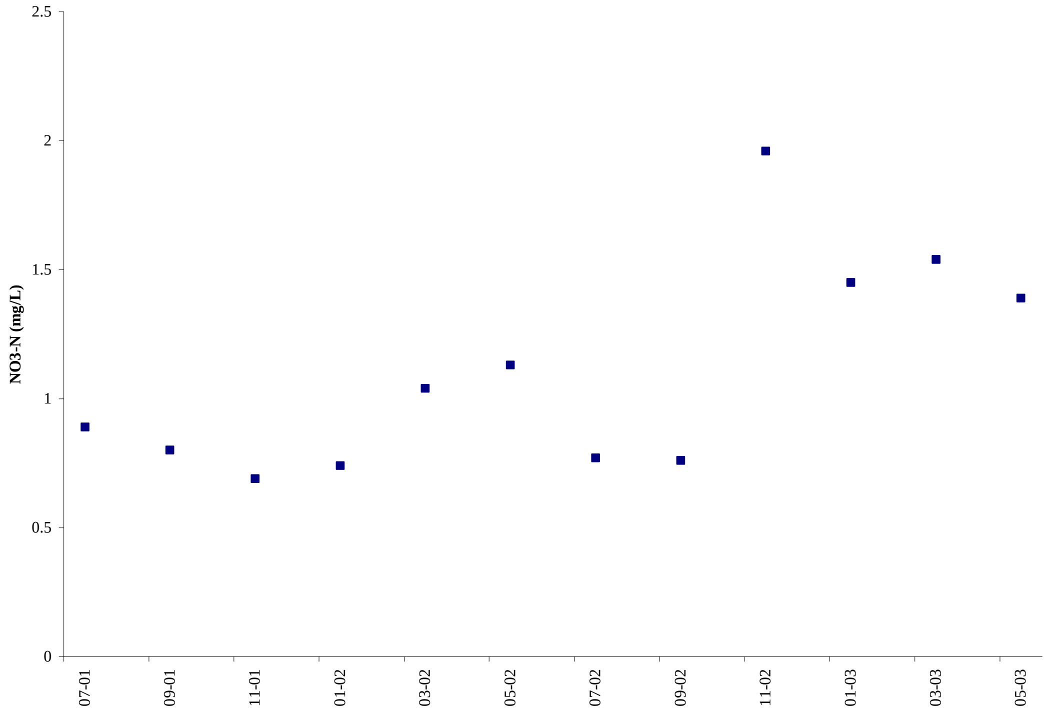

Figure D.23 Nitrate nitrogen concentrations at 9-CBC001.00.

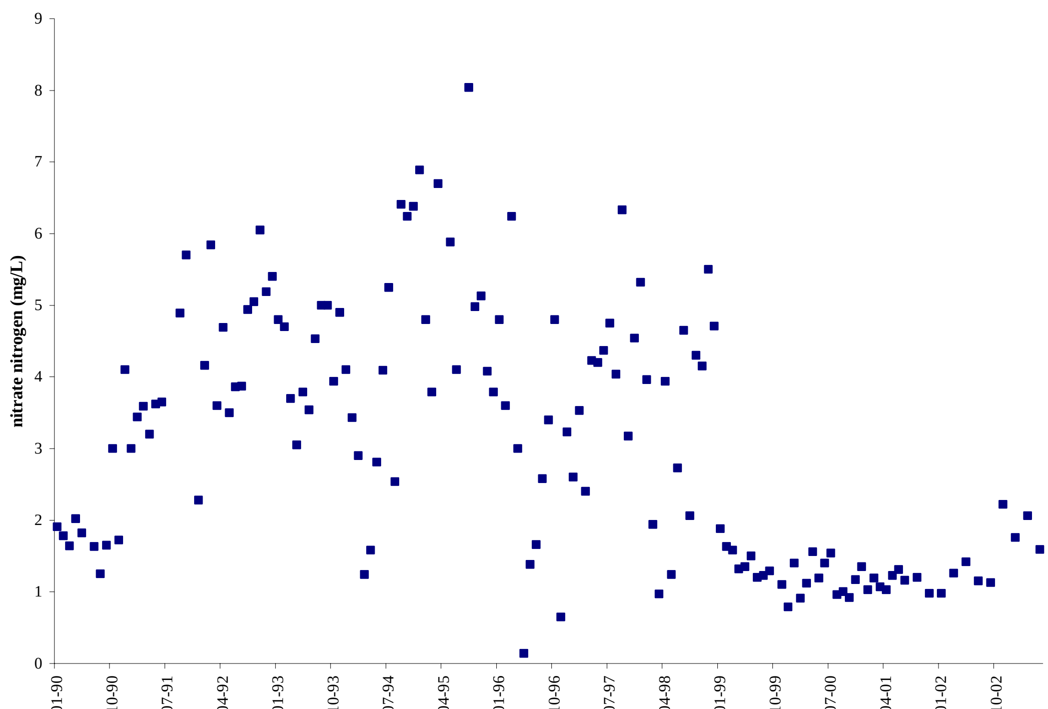

Figure D.24 Nitrate nitrogen concentrations at 9-CBC004.38.

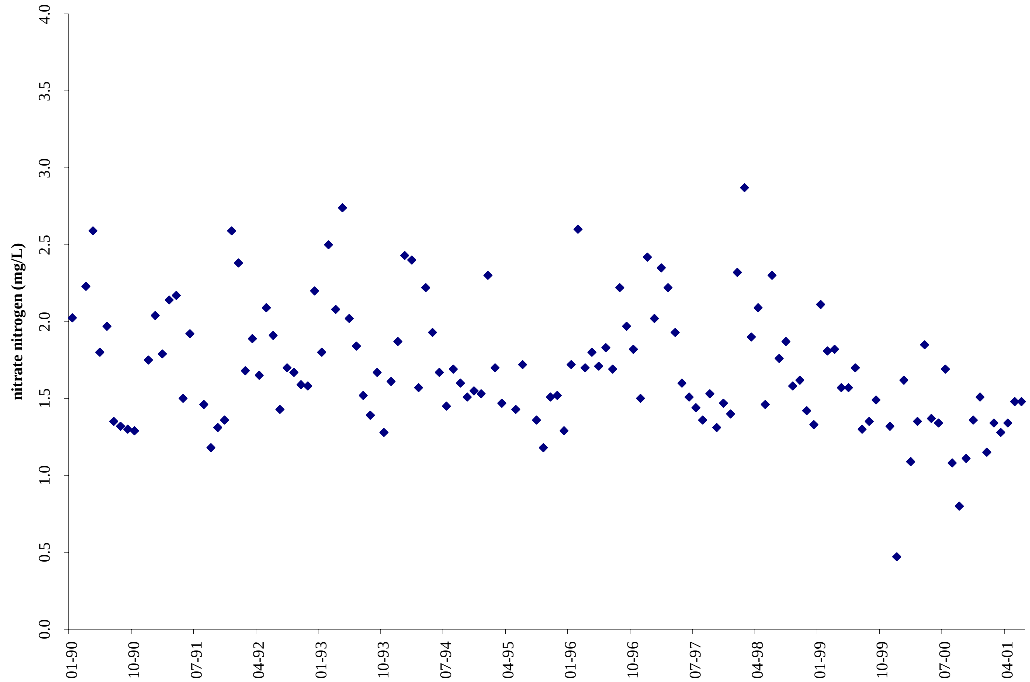

Figure D.25 Nitrate nitrogen concentrations at 9-CBC006.35.

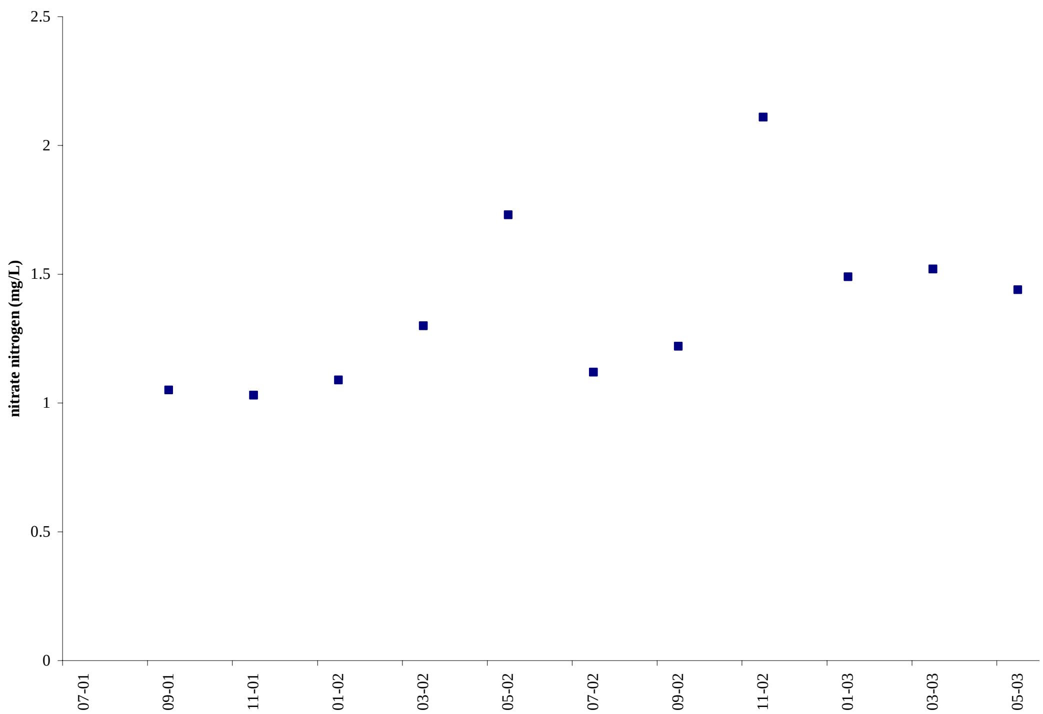

Figure D.26 Nitrate nitrogen concentrations at 9-CBC009.81.

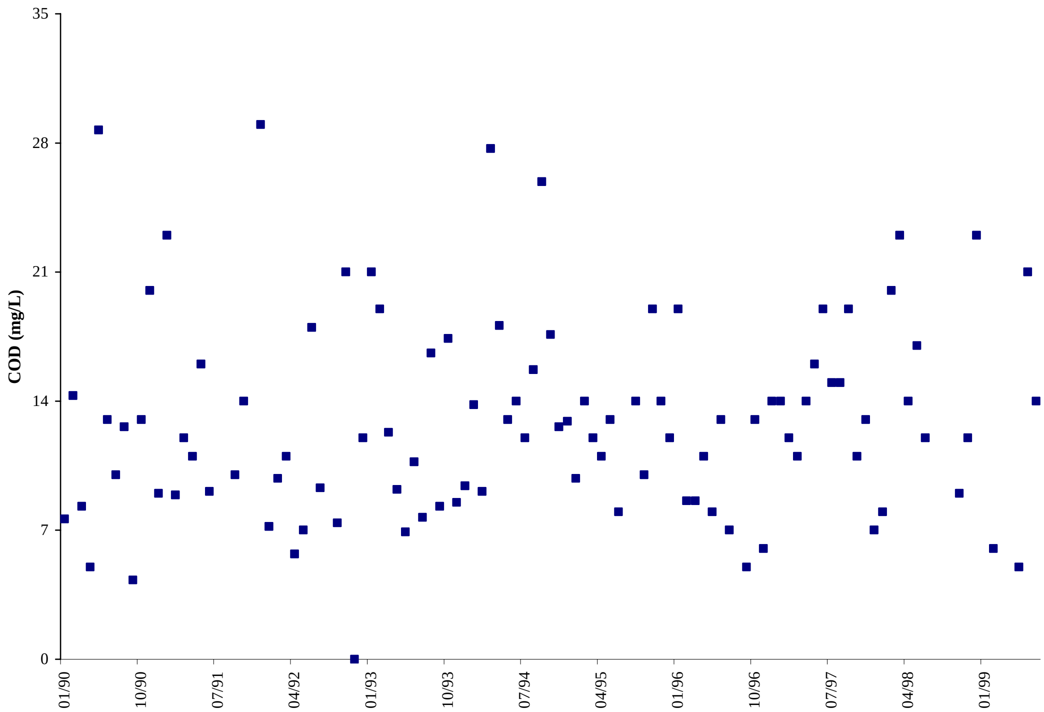

Figure D.27 Chemical oxygen demand concentrations at 9-CBC004.38.

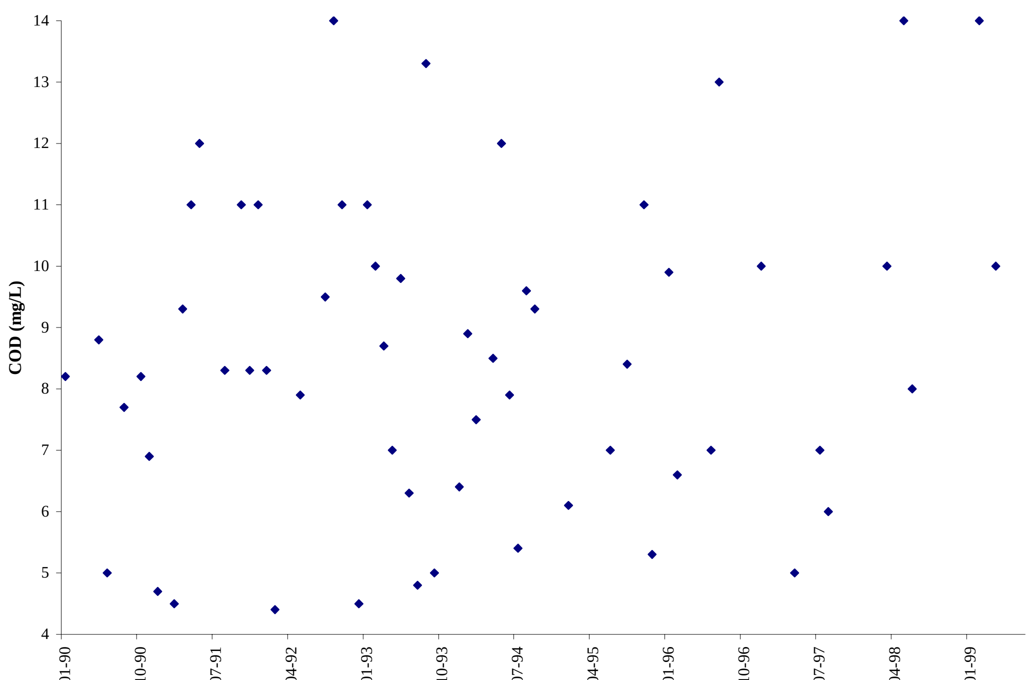

Figure D.28 Chemical oxygen demand concentrations at 9-CBC006.35.

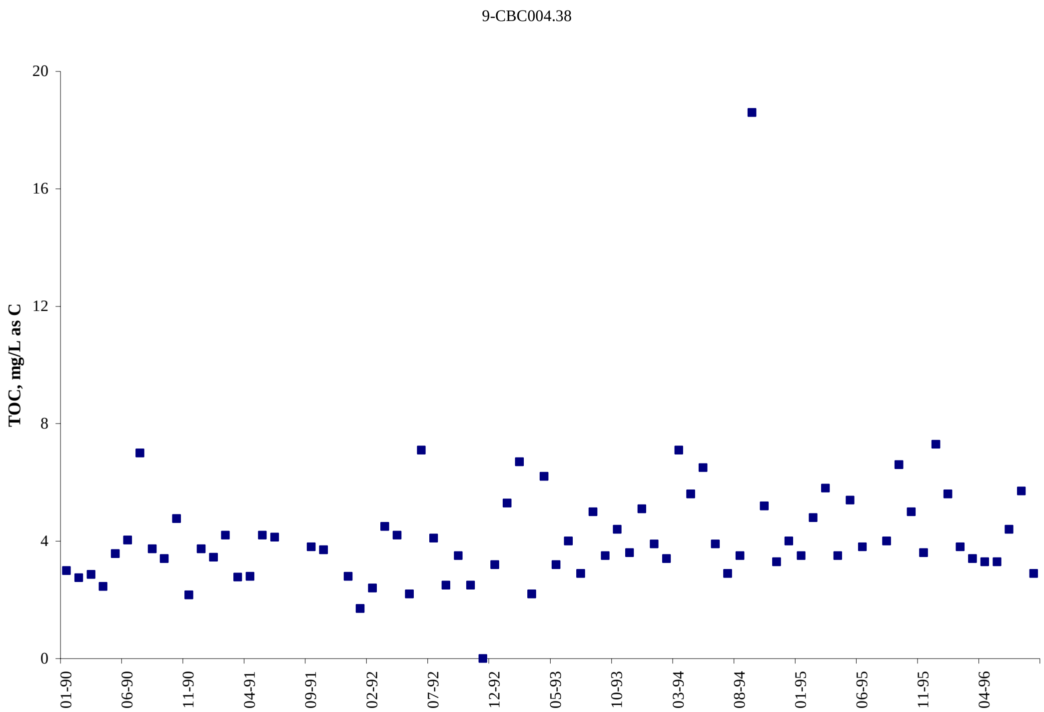

Figure D.29 Total organic carbon concentrations at 9-CBC004.38.

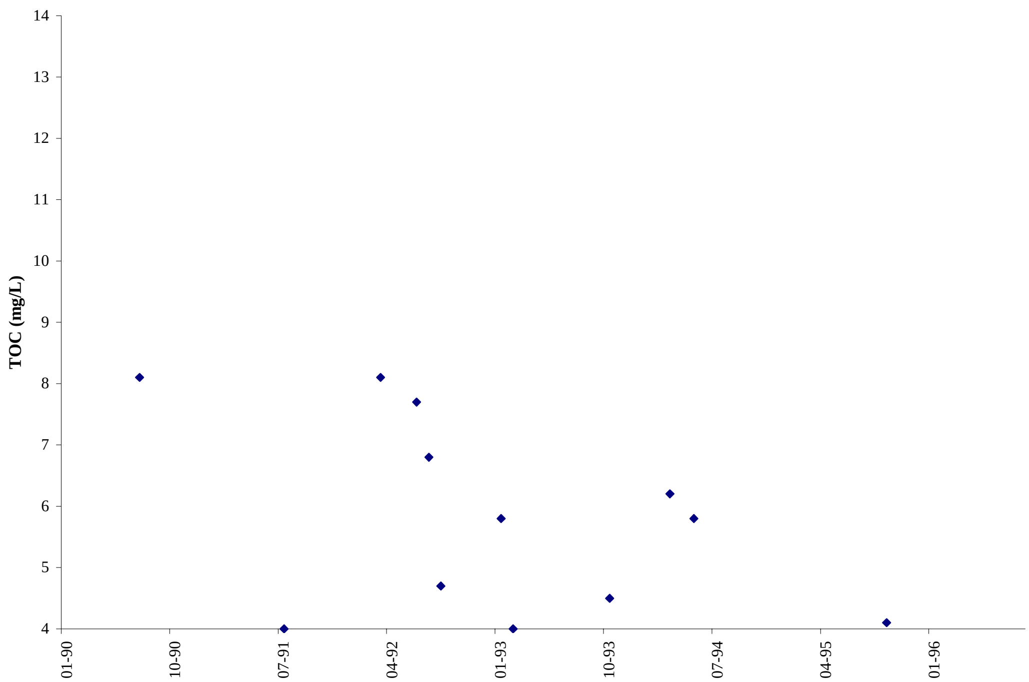

Figure D.30 Total organic carbon concentrations at 9-CBC006.35.

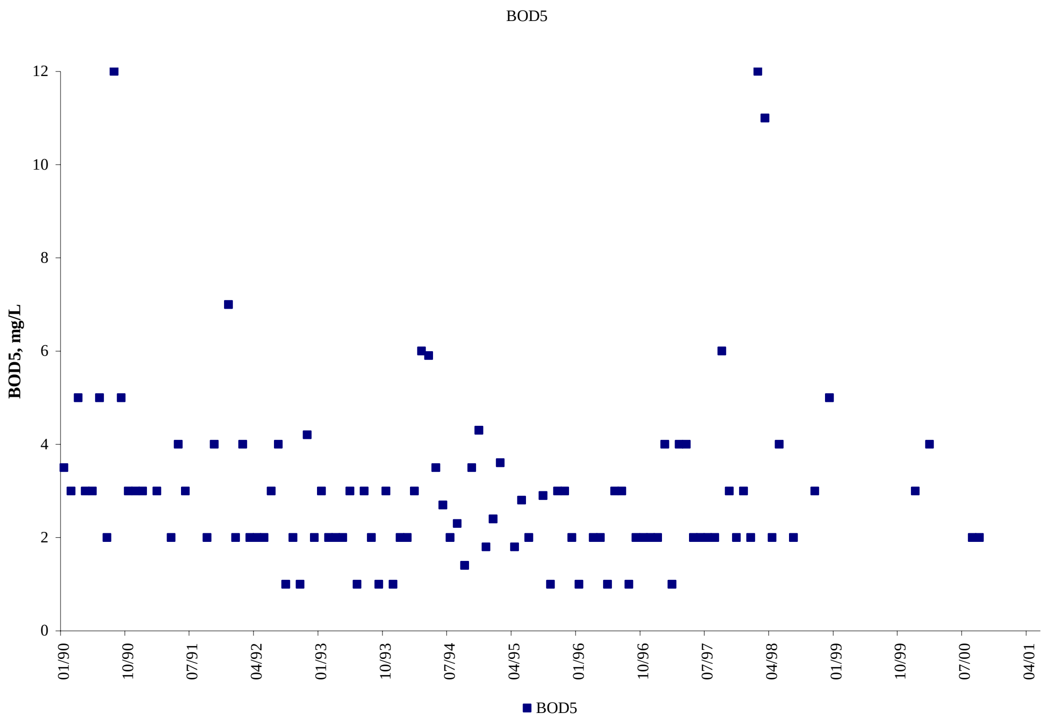

Figure D.31 Biochemical oxygen demand concentrations at 9-CBC004.38.

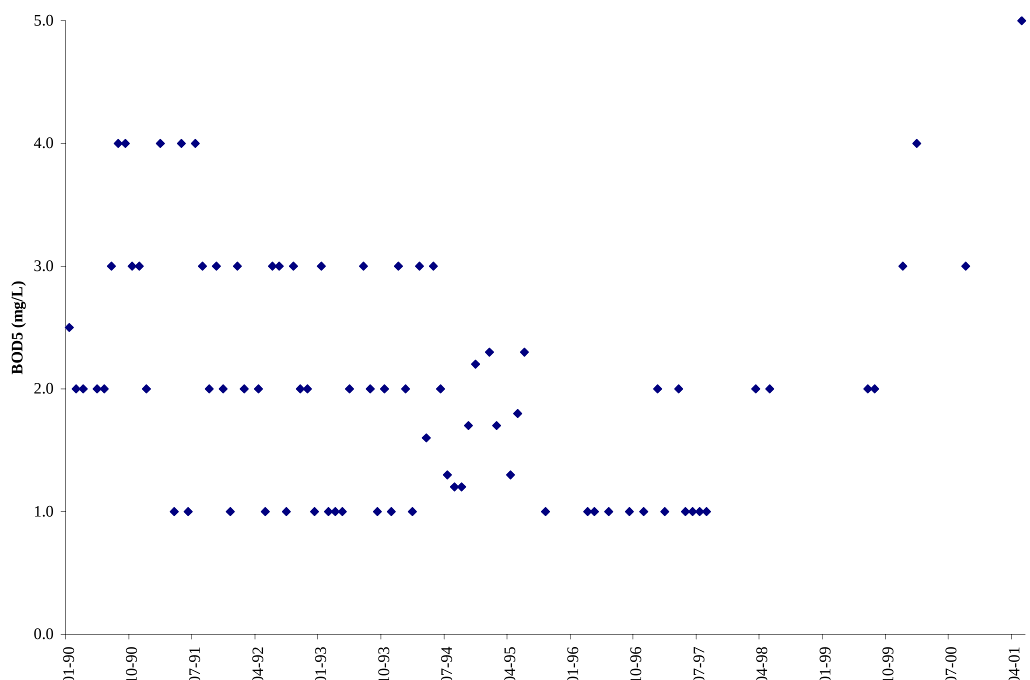

Figure D.32 Biochemical oxygen demand concentrations at 9-CBC006.35.

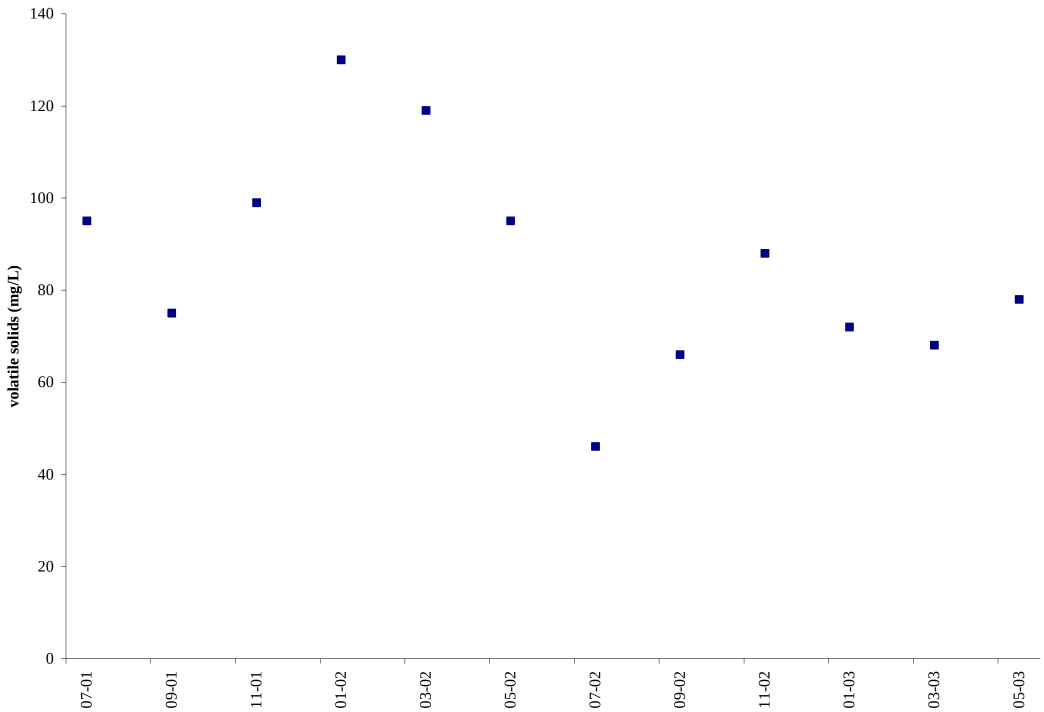

Figure D.33 Volatile solids concentrations at 9-CBC001.00.

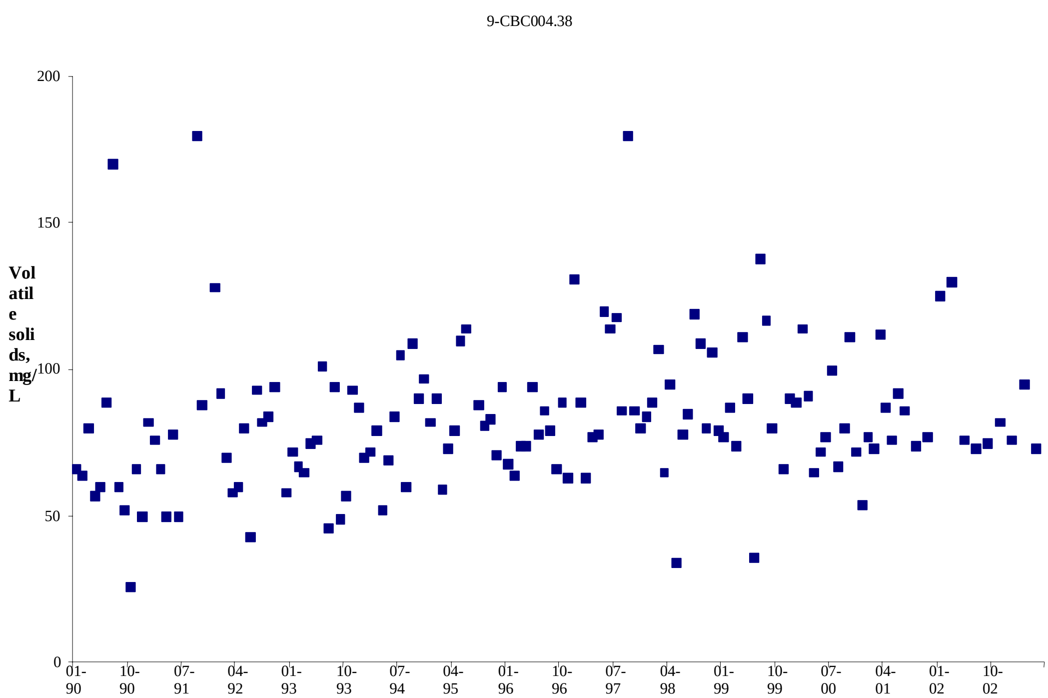

Figure D.34 Volatile solids concentrations at 9-CBC004.38.

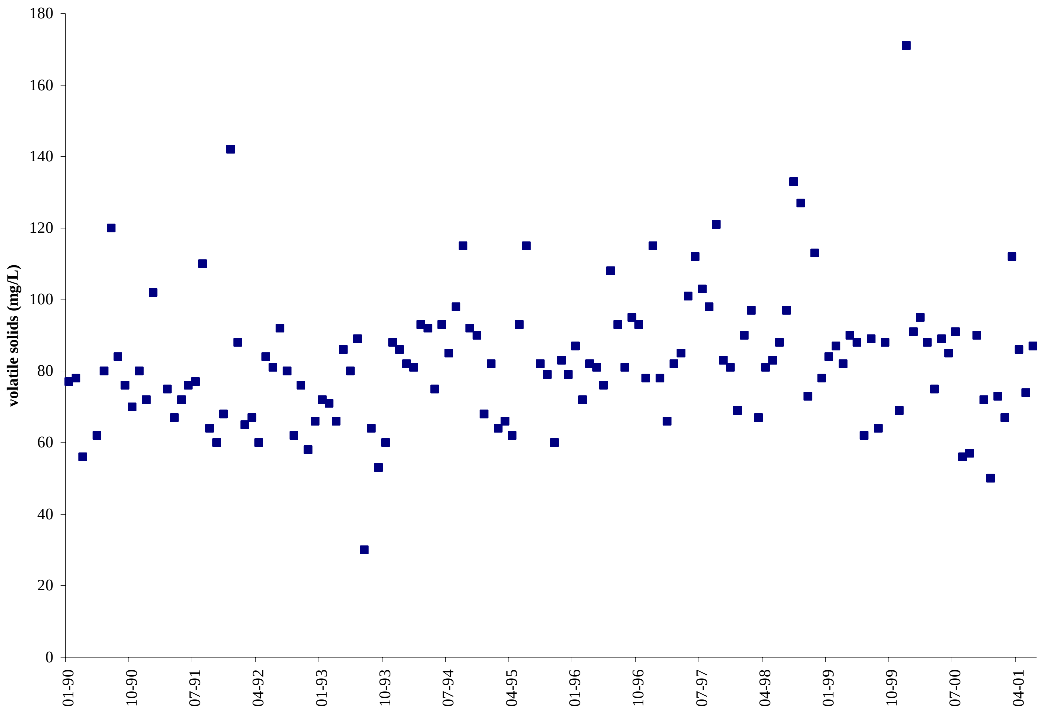

Figure D.35 Volatile solids concentrations at 9-CBC006.35.

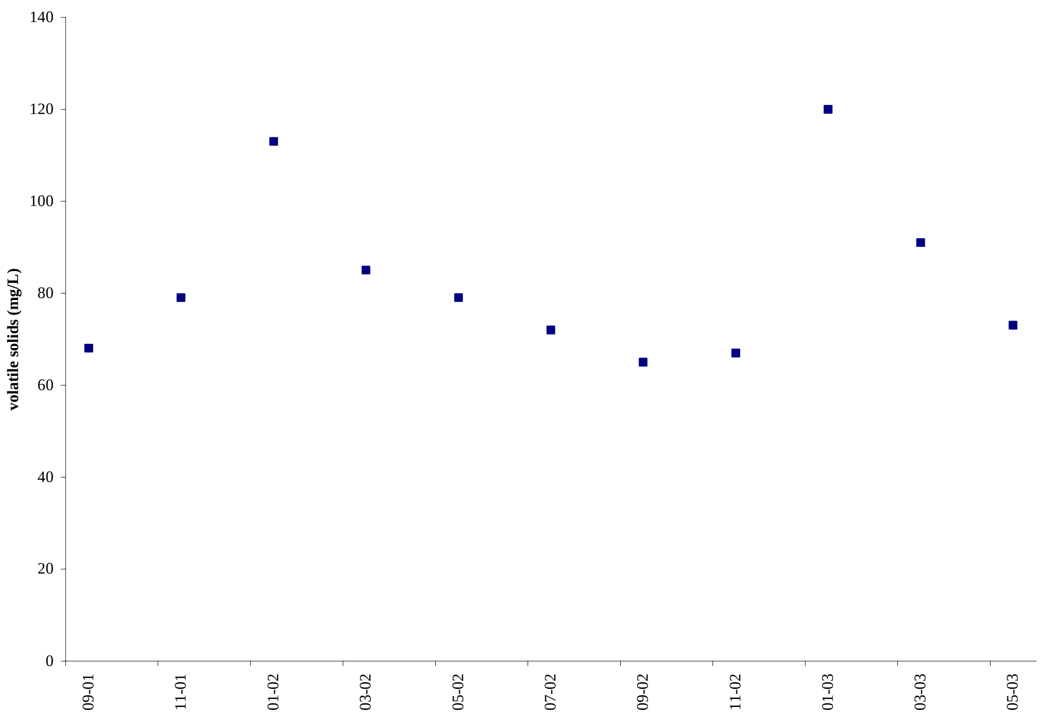

Figure D.36 Volatile solids concentrations at 9-CBC009.81.

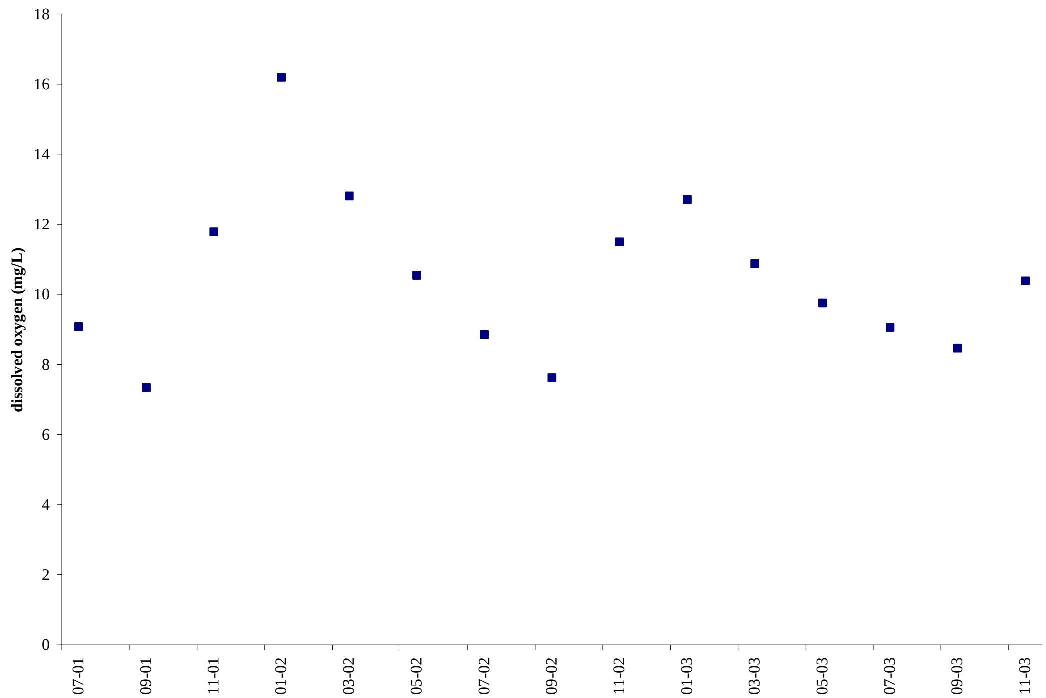

Figure D.37 Dissolved oxygen concentrations at 9-CBC001.00.

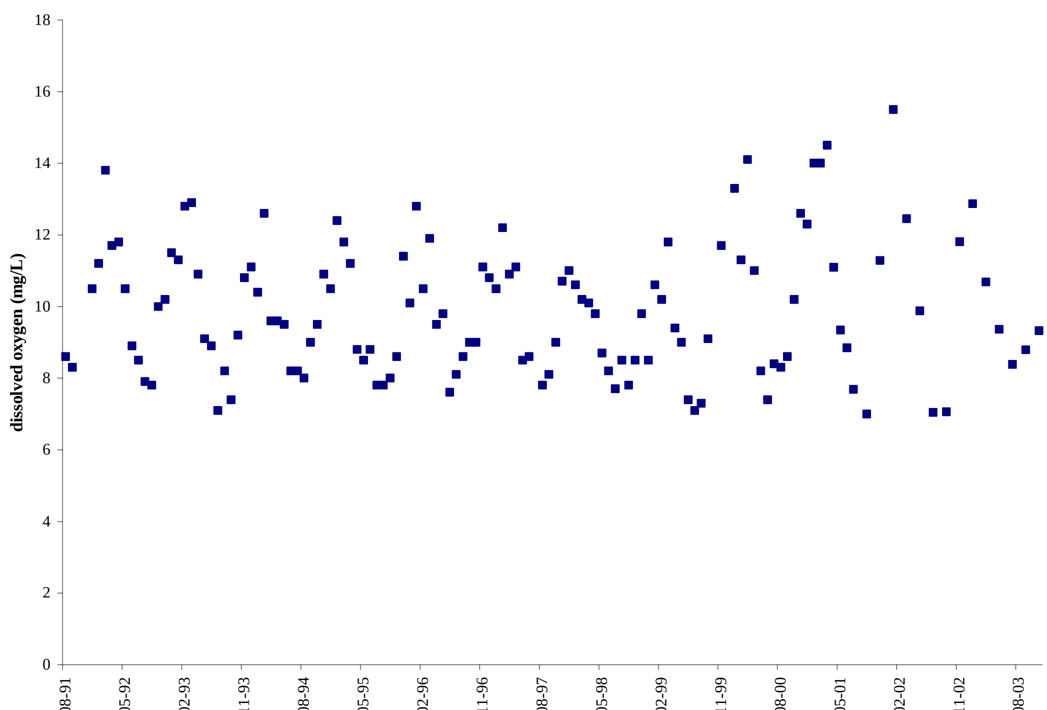

Figure D.38 Dissolved oxygen concentrations at 9-CBC004.38.

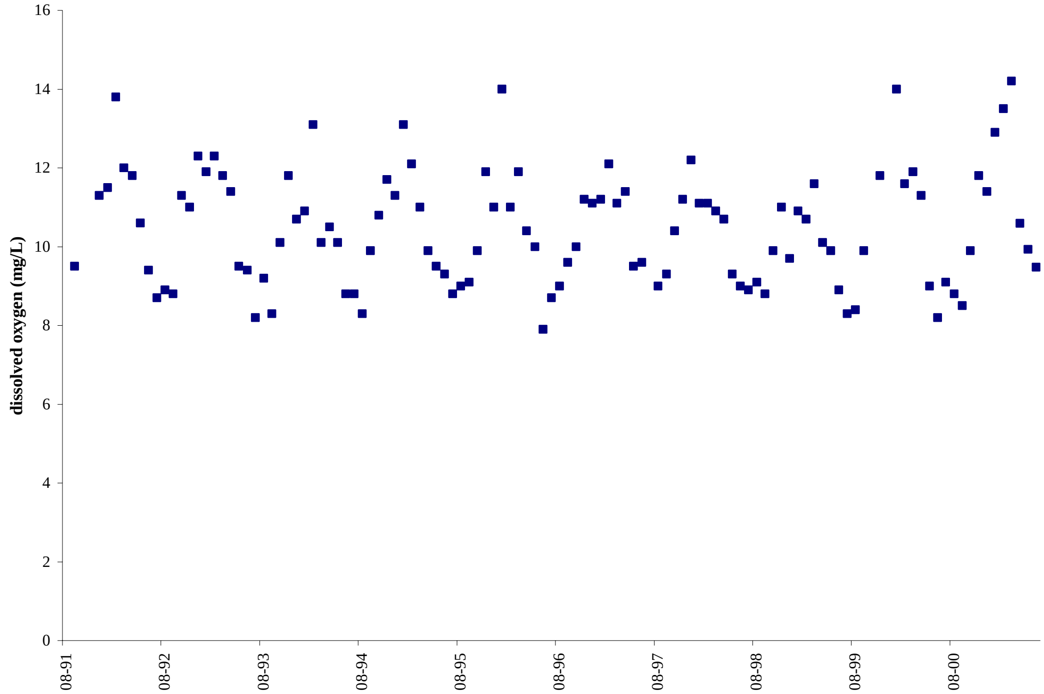

Figure D.39 Dissolved oxygen concentrations at 9-CBC006.35.

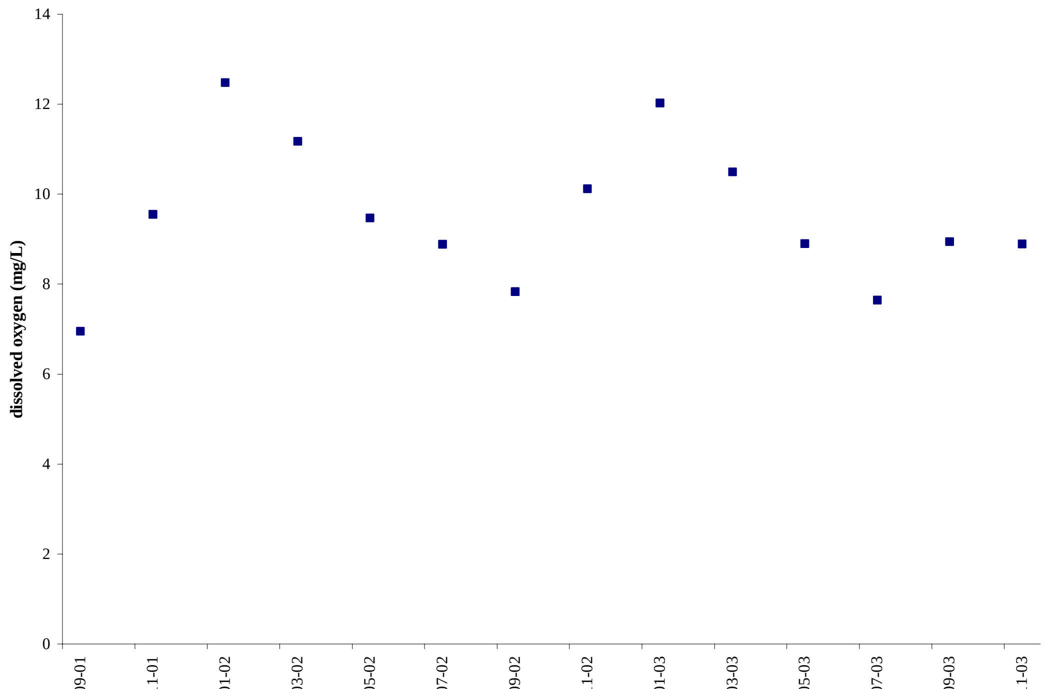

Figure D.40 Dissolved oxygen concentrations at 9-CBC009.81.

APPENDIX E

TMDL FOR EXPECTED POPULATION INCREASE

Table E.1 Average annual *E. coli* loads (cfu/year) modeled for the Crab 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)
Crab Creek (FC)	1.70E+09	1.74E+12	*Implicit*	1.74E+12
VAR015370[1]	*1.70E+09*			

[1] MS4 permit for Christiansburg