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Fecal Bacteria and General Standard
Total Maximum Daily Load
Development for
Bluestone River

Prepared for:
Virginia Department of Environmental
Quality

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EXECUTIVE SUMMARY

Background and Applicable Standards

Bluestone River was placed on the Commonwealth of Virginia's 1996 Section 303(d) TMDL Priority List because of violations of the fecal coliform bacteria water quality standard, and the General Standard (benthic). The focus of this TMDL is on the fecal coliform and benthic impairments in Bluestone River. Based on exceedances of the standard recorded at Virginia Department of Environmental Quality (VADEQ) monitoring stations, the stream does not support primary contact recreation (*e.g.,* swimming, wading, and fishing). The new applicable state standard (Virginia Water Quality Standard 9 VAC 25-260-170) specifies that the number of fecal coliform bacteria shall not exceed a maximum allowable level of 400 colony-forming units (cfu) per 100 milliliters (ml). Alternatively, if data is available, the geometric mean of two or more observations taken in a calendar month should not exceed 200-cfu/100 ml. A review of available monitoring data for the watershed indicated that fecal coliform bacteria were consistently elevated above the 400-cfu/100 ml standard. EPA directed that the state develop a water quality standard for *E. coli* bacteria to eventually replace the fecal coliform standard. This new standard specifies that the number of *E. coli* bacteria shall not exceed a maximum allowable level of 235-cfu /100 ml (Virginia Water Quality Standard 9 VAC 25-260-170). During the development of this TMDL, 58% of samples analyzed for the presence *E. coli* exceeded the 235-cfu/100 ml standard. 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, Bluestone River 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: grazing livestock, land application of manure, land application of biosolids, urban/suburban runoff, failed and malfunctioning septic systems, uncontrolled discharges (straight pipes, dairy parlor waste, etc.), and wildlife. There are nine National Pollutant Discharge Elimination System (NPDES) permitted discharges in the Bluestone River watershed. Two municipal wastewater treatment plants are permitted for fecal coliform bacteria discharge.

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. Therefore, the first step in the development of a Benthic TMDL, known as a stressor identification, is to determine the cause 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 Bluestone River. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring data from ambient monitoring stations 9-BST023.05 and 9-BST029.57 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 Bluestone River 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 on the benthic community. VADEQ staff at the Southwest Regional Office noted that, upstream of the Town of Bluefield, the streambanks had very poor structure due to livestock access to the stream. In addition, Dill Spring has significant sediment deposits in the vicinity of Bluefield's raw water intake. Urban runoff, construction activity, and agricultural activity are the most likely sources. Based on the analyses, sediment was the target pollutant used to address the benthic impairment in the Bluestone River.

Sediment is delivered to the Bluestone River 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 (*e.g.,* along stream edge, uncontrolled access to streams, etc.), forest harvesting, construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events.

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks, which leads to greater potential for channel erosion. 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, 1990; 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 two permits for wastewater/sewage treatment plants, two industrial stormwater discharge permits, and five industrial wastewater discharge permits located within the watershed.

Water Quality Modeling

Fecal Coliform

The U.S. 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. Mean daily discharge at USGS Gaging Station #03177710 (Bluestone River at Falls Mills, Virginia) and precipitation at Wytheville station #449301 were available from October 1980 to April 1997. The modeling period was selected to include the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Bluestone River segment on the 1996 Section 303 (d) list.

The time periods covered by calibration and validation represent a broad range of hydrologic and climatic conditions and are representative of the long-term precipitation and discharge record. For purposes of modeling watershed inputs to in-stream water quality, the Bluestone River drainage area was divided into nine subwatersheds. The model was calibrated for water quality predictions using data collected at VADEQ monitoring stations over the period October 1981 through September 1985 and validated using data collected between October 1986 and September 1990. The hydrologic model performed well when compared to the observed flow, with a percent difference (or error) between observed and modeled data for total in-stream flows, -2.9%, upper 10% flows, -9.3%, and lower 50% flows, 2.2%. The water quality calibration was conducted using monitored data from October 1993 through September 1998. 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 in-stream criteria for sediment in Virginia; therefore, a reference watershed approach was used to define allowable TMDL loading rates in the Bluestone River watershed. This approach pairs two watersheds: one that is supportive of its designated use(s) and one whose streams are impaired. The Dry River watershed was selected as the TMDL reference for Bluestone River. The TMDL sediment load was defined as the modeled sediment load for existing conditions from the non-impaired Dry River watershed, area-adjusted to the Bluestone River watershed. The Generalized Watershed Loading Function (GWLF) model (Haith et al., 1992) was used for comparative modeling for both Bluestone River and Dry River. The model for Bluestone River was calibrated using the mean daily flow from USGS Station #03177700 for the period January 1972 through December 1979, and daily precipitation and temperature data from Wytheville 1S, station #449301. The model was initially parameterized with recommended model parameters for the landuses and conditions in the Bluestone River watershed. The reference watershed (Dry River) did not have an observed streamflow station located within the watershed boundary. The model for Dry River was calibrated using streamflow data from nearby downstream USGS Station #01622000 for the period

January 1994 through March 2000, and precipitation and temperature data from the Dale Enterprise Station #442208. Model calibrations were considered good to excellent for total runoff volume. Monthly fluctuations were variable, but were still considered reasonably good considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.,* Tetra Tech, 2001 and BSE, 2003).

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 Bluestone River watershed were all 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 (*e.g.,* straight pipes), direct deposition by livestock, and direct deposition by wildlife.

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 to September 1991. Under 2003 existing conditions, 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 Bluestone River was developed using sediment as the primary stressor and the Dry River watershed as the reference watershed. Because the Dry River watershed is larger than the Bluestone watershed, landuse categories in the Dry River watershed were decreased by a multiple of 0.6404 to establish a common basis for comparing loads between the two watersheds. After area-adjustment, the Dry River watershed was equal in size to Bluestone River (19,911 ha). The average annual sediment load (metric tons per year) from the area-adjusted Dry River defined the TMDL sediment load for Bluestone River. The sediment loads for existing conditions were calculated using the period of January 1994 through March 2000 as representative of both wet and dry periods of precipitation. The target sediment TMDL load for existing conditions was 6,634 T/yr. The existing load from Bluestone River was 7,774 T/yr. The benthic TMDL for Bluestone River is composed of three components: waste load allocations (WLA) from point sources, load allocations (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 5,647 T/yr.

Since urban development is expected to occur in Bluestone River 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 of developed land increasing from 4.7% to 7.7%. The sediment load including future development was 8,000 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 in loading from existing conditions are given in Table ES.1.

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	98.3	31.8
2	0	0	0	0	0	100	95.0	31.7
3	0	0	90	50	50	100	68.3	21.6
4	0	0	100	60	60	100	51.7	19.3
5	0	0	100	99	99	100	1.67	5.37
6	0	50	100	99	99	100	0.0	1.59
7	0	74	100	99	99	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), transitional land, disturbed forest, and the stream channel.

Table ES.2 Required reductions for the Bluestone River Watershed.

Load Summary	Bluestone River (T/yr)	Reductions Required (T/yr)	Reductions Required (% of existing load)
Projected Future Loads	8,081	2,434	31.0
Existing Load	7,855	2,208	28.1
TMDL	6,364		
Target Modeling Load	5,647		

Two alternatives are presented in Table ES.3. Alternative 1 requires a sediment reduction of 40% from four of the source areas: pastureland, stream edge – principally livestock, disturbed forest, and transitional lands. A 20% reduction is required from channel erosion and a 23.2 % reduction is required from cropland. The reductions are expected to be achieved through adding riparian buffers, streambank stabilization, livestock exclusion, stabilizing transitional areas or conversion to urban, stormwater management, reclaiming disturbed forest areas, and improving pasture management and reducing tillage operations. Sediment reductions through livestock streambank exclusion would also result in reducing direct deposition of waste into the stream. Alternative 2 requires a more aggressive approach to achieving reductions through the near elimination of erosion from livestock stream access or overgrazing within 10 feet of the stream edge. Alternative 2 reductions also require 60% transitional lands, 50% reduction from disturbed forestlands and channel erosion, 20% from cropland and 23.5% from pastureland.

Table ES.3 TMDL sediment allocation scenarios for Bluestone River impairment at Bluefield.

Sediment Source Categories	Future Conditions (T/yr)	Allocations			
		Alternative 1		Alternative 2	
		(% Reduction)	(T/yr)	(% Reduction)	(T/yr)
LDR-PER	23.035		23.035		23.035
HDR-PER	2.001		2.001		2.001
COM-PER	9.086		9.086		9.086
Transitional	**430.626**	**40.0**	**258.376**	**60**	**172.250**
Forest	203.523		203.523		
Disturbed Forest	**795.782**	**40.0**	**477.469**	**50**	**397.891**
Urban Grass	1.994		1.994		1.994
Hay	5.173		5.173		5.173
Pastureland	**2,956.866**	**40.0**	**1,774.120**	**23.5**	**2,262.002**
Stream Edge-Access	**41.881**	**40.0**	**25.129**	**95**	**2.094**
Cropland	**2,661.568**	**23.2**	**2,044.084**	**20**	**2, 129.254**
LDR-IMP	107.28		107.28		107.28
HDR-IMP	26.042		26.042		26.042
COM-IMP	96.639		96.639		96.639
Water	0.000		0.000		0.000
NPS Load	7,361.495		5,053.951		5,234.738
Channel Erosion	**638.365**	**20.0**	**510.692**	**50**	**319.183**
WLA	81.363		81.363		81.363
Total	**8,081.223**		**5,646.006**		**5,635.284**
Target Allocation Load (TMDL-MOS-WLA)			**5647.000**		**5647.000**

Tables ES.4 and ES.5 show the approximate reductions required from both the Virginia and West Virginia components of the Bluestone River impairment to meet the overall reductions identified (Table ES.2) and allocation scenarios (ES.3). The sediment loads given in Table ES.6 represent modeled sediment contributions from each area (*i.e.,* Virginia and West Virginia) with the exception that streambank erosion was modeled as a watershed entity. The distribution between the Virginia component of the watershed and the West Virginia component of the watershed was based on the ratio of the continuous stream lengths. From this relationship, 20% of the streambank erosion was attributed to West Virginia streams and 80% was attributed to Virginia streams. The allocations for load reductions to achieve the TMDL target established by reference watershed Dry River were approximated for each section of the watershed, *i.e.,* the Virginia and West Virginia sections, based on the ratio of respective modeled loads (Table ES.6). For example, the total load reduction for pastureland (allocation scenario 1- Table ES.4) was 40%. The distribution for each section of the watershed was 77% in Virginia [*i.e.,* 2,287.223 - 0.77x(2,956.866 – 1,774.120)] and 23% in West Virginia [*i.e.,* 669.643 - 0.23x(2,956.866 – 1,774.120)].

Table ES.4 TMDL allocation scenario 1 by state for the Bluestone River impairment at Bluefield.

Sediment Source Categories	Future Conditions			Allocation Scenario 1			
					Stream Sediment Load		
	Total (T/yr)	VA (T/yr)	WVA (T/yr)	Load Reduction (%)	Total (T/yr)	VA (T/yr)	WVA (T/yr)
LDR-PER	23.035	13.097	9.938		23.035	13.097	9.938
HDR-PER	2.001	0.000	2.001		2.001	0.000	2.001
COM-PER	9.086	5.260	3.826		9.086	5.260	3.826
Transitional	**430.626**	**265.728**	**164.898**	**40 (62,38)**	**258.376**	**158.933**	**99.443**
Forest	203.523	161.459	42.064		203.523	161.459	42.064
Disturbed Forest	**795.782**	**627.988**	**167.794**	**40 (79,21)**	**477.469**	**376.521**	**100.948**
Urban Grass	1.994	1.994	0.000		1.994	1.994	0.000
Hay	5.173	3.697	1.476		5.173	3.697	1.476
Pastureland	**2,956.866**	**2,287.223**	**669.643**	**40 (77,23)**	**1,774.120**	**1,376.509**	**397.611**
Stream Edge-Access	**41.881**	**35.501**	**6.380**	**40 (85,15)**	**25.129**	**21.262**	**3.867**
Cropland	**2,661.568**	**1,608.747**	**1,052.821**	**23.2 (60,40)**	**2,044.084**	**1,238.257**	**805.827**
LDR-IMP	107.28	33.225	74.055		107.28	33.225	74.055
HDR-IMP	26.042	0.000	26.042		26.042	0.000	26.042
COM-IMP	96.639	68.939	27.700		96.639	68.939	27.700
Water	0.000	0.000	0.000		0.000	0.000	0.000
NPS Load	7,361.495	5,112.857	2,248.638		5,053.951	3,459.153	1,594.798
Channel Erosion	**638.365**	**510.692**	**127.673**	**40 (80,20)**	**510.692**	**408.554**	**102.138**
WLA	81.363	81.363			81.363	81.363	
Total	**8,081.223**	**5,704.912**	**2,376.311**		**5,646.006**	**3,949.070**	**1,696.936**
	Target Allocation Load (TMDL-MOS-WLA)				**5647.000**	**3,949.765**	**1,697.235**

Table ES.5 TMDL allocation scenario 2 by state for the Bluestone River impairment at Bluefield.

Sediment Source Categories	**Future Conditions**			**Allocation Scenario 2**			
					Stream Sediment Load		
	Total (T/yr)	**VA (T/yr)**	**WVA (T/yr)**	**Load Reduction (%)**	**Total (T/yr)**	**VA (T/yr)**	**WVA (T/yr)**
LDR-PER	23.035	13.097	9.938		23.035	13.097	9.938
HDR-PER	2.001	0.000	2.001		2.001	0.000	2.001
COM-PER	9.086	5.260	3.826		9.086	5.260	3.826
Transitional	**430.626**	**265.728**	**164.898**	**60 (62,38)**	**172.250**	**105.535**	**66.715**
Forest	203.523	161.459	42.064			161.459	42.064
Disturbed Forest	**795.782**	**627.988**	**167.794**	**50 (79,21)**	**397.891**	**313.654**	**84.237**
Urban Grass	1.994	1.994	0.000		1.994	1.994	0.000
Hay	5.173	3.697	1.476		5.173	3.697	1.476
Pastureland	**2,956.866**	**2,287.223**	**669.643**	**23.5 (77,23)**	**2,262.002**	**1,752.178**	**509.824**
Stream Edge-Access	**41.881**	**35.501**	**6.380**	**95 (85,15)**	**2.094**	**1.682**	**0.412**
Cropland	**2,661.568**	**1,608.747**	**1,052.821**	**20 (60,40)**	**2, 129.254**	**1,287.559**	**841.695**
LDR-IMP	107.28	33.225	74.055		107.28	33.225	74.055
HDR-IMP	26.042	0.000	26.042		26.042	0.000	26.042
COM-IMP	96.639	68.939	27.700		96.639	68.939	27.700
Water	0.000	0.000	0.000		0.000	0.000	0.000
NPS Load	7,361.495	5,112.857	2,248.638		5,234.738	3,748.279	1,486.459
Channel Erosion	**638.365**	**510.692**	**127.673**	**50 (80,20)**	**319.183**	**255.346**	**63.837**
WLA	81.363	81.363			81.363	81.363	
Total	**8,081.223**	**5,704.912**	**2,376.311**		**5,635.284**	**4,084.988**	**1,550.296**
		Target Allocation Load (TMDL-MOS-WLA)			**5647.000**	**3,949.765**	**1,697.235**

Table ES.6 Comparison of categorized sediment loads for Bluestone River and Reference Watershed Dry River.

Source Category	**Future Conditions Bluestone River**			**Reference Dry River**
	Virginia **(T/yr)**	West Virginia **(T/yr)**	Virginia + West Virginia **(T/yr)**	**(T/yr)**
Agriculture	3,935.168	1,730.32	5,665.490	3,818.780
Hay	3.697	1.476	5.175	62.487
Cropland	1,608.747	1,052.821	2,661.568	3,271.753
Pastureland	2,287.223	669.643	2,956.866	450.855
Stream Edge-Access	35.501	6.380	41.881	33.685
Urban	122.515	143.562	266.077	414.271
Transitional	265.728	164.898	430.626	8.318
Forestry	789.447	209.858	999.305	2,668.991
Disturbed Forest	627.988	167.794	795.782	666.305
Channel Erosion	510.692	127.673	638.365	214.027
Point Source	81.363		81.363	

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

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 previously mentioned Stage I scenario targeted controllable, anthropogenic bacteria and sediment sources.

Public Participation

During development of the TMDL for the Bluestone River watershed, public involvement was encouraged through four meetings. A basic description of the TMDL process and the agencies involved was presented at the kickoff meeting. Stakeholders, VADEQ and MapTech personnel met at New River Roundtable Agriculture subcommittee on August 9, 2003. The 1st public meeting was held to discuss the source assessment input, bacterial source tracking, and model calibration data. The final model simulations and the TMDL load allocations were presented during the final public meeting.

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

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PART I: BACKGROUND AND APPLICABLE STANDARDS

1. INTRODUCTION

1.1 Background

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

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

The Bluestone River watershed in Virginia's Tazewell County and West Virginia’s Mercer County is part of the New River basin (Figure 1.1). The Bluestone River flows into the New River, which drains into the Ohio River. The Ohio River flows into the Mississippi River, which finally drains to the Gulf of Mexico.

According to the 1996 303(d) TMDL Priority List, the Virginia Department of Environmental Quality (VADEQ) identified Bluestone River (waterbody ID # VAS-N36R) as impaired with regard to both fecal coliform and the General Standard (benthic). Bluestone River remained on the 1998 and 2002 303(d) lists.

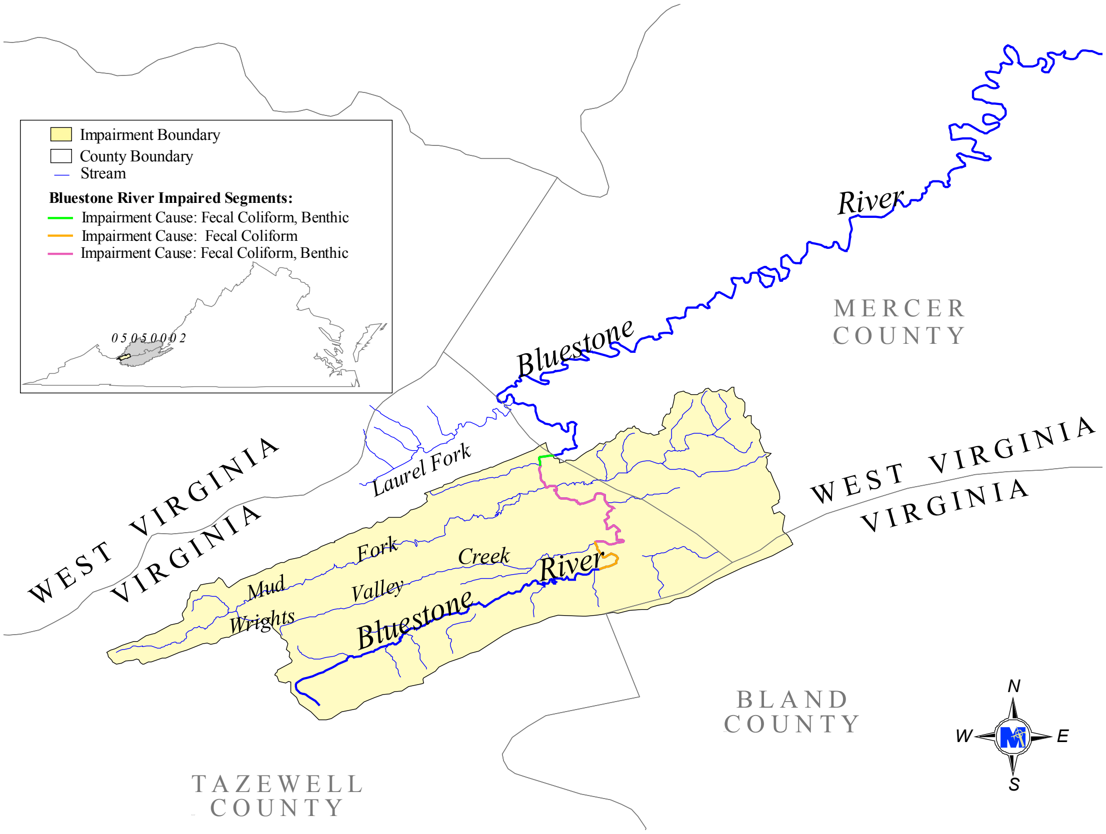

Figure 1.1 Location of the impaired segment in the Bluestone River Watershed.

During the 2002 assessment period, 9 of 51 samples taken at river mile 23.05 violated the fecal coliform standard and one benthic monitoring station (9BST022.27) had a rating of moderately impaired. The impairment of Bluestone River extends from the Wrights Valley confluence, near the western Bluefield city limit, to the Virginia/West Virginia state line.

The Bluestone River watershed (USGS Hydrologic Unit Code #05050002) is part of the New River basin. The land area of the affected watershed is approximately 49,000 acres, with forest/wetlands and pasture/hay as the primary landuses (Figure 1.2).

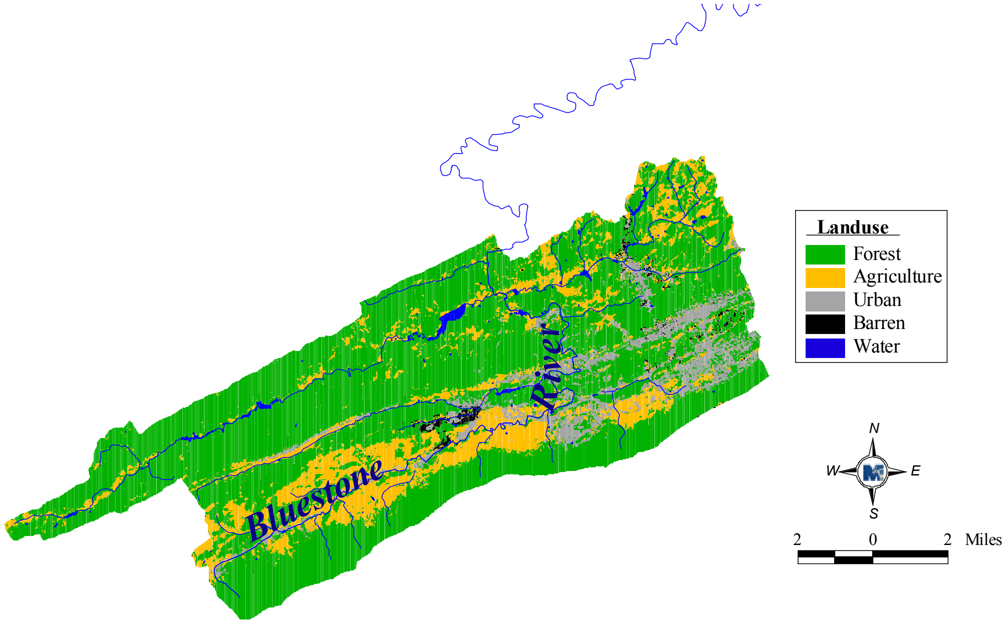

Figure 1.2 Landuses in the Bluestone River Watershed

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 the impaired segment are given in Table 1.1.

Table 1.1 Area affecting the impairment and contributing landuses.

Bluestone River	
Landuse	**Acreage**
Water	141
Residential/Recreational	2,020
Commercial & Services	1,394
Barren	426
Woodland/Wetland	35,611
Pasture/Hay	7,660
Livestock Access	460
Cropland	1,370

The estimated human population within the drainage area is 23,131 (USCB, 1990, 2000). Among Virginia counties, Tazewell County ranks 31st for the number of dairy cows, 25th for the number of all cattle and calves, 29th for beef cattle, 6th for the number of sheep and lambs, and 25th for production of corn silage (Virginia Agricultural Statistics 2001). Tazewell County is also home to 421 species of wildlife, including 53 types of mammals (*e.g.,* beaver, raccoon, and white - tailed deer) and 166 types of birds (*e.g.,* wood duck, wild turkey, Canada goose) (VDGIF,1999).

For the period from 1951 to 2000, the Bluestone River watershed received average annual precipitation of approximately 38.53 inches, with 52% of the precipitation occurring during the May – October growing season (SERCC, 2002). Average annual snowfall is 25.6 inches with the highest snowfall occurring during January (SERCC, 2002). Average annual daily temperature is 50.6 ºF. The highest average daily temperature of 81.9 ºF occurs in July, while the lowest average daily temperature of 21.7 ºF occurs in January (SERCC, 2002).

1.2 Applicable Water Quality Standards

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

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

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ◆
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*
>
> *G. The [State Water Control] board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*
>
> 1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
>
> 2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*
>
> ◆
>
> 6. *Controls more stringent than those required by §§301(b) and 306 of the Clean Water Act would result in substantial and widespread economic and social impact.*

Because this study addresses both fecal coliform and benthic impairments, two water quality criteria are applicable. 9 VAC 25-260-170 applies to the fecal coliform impairment, whereas the General Standard section (9 VAC25-260-20) 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 VAC25-260-20, 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 assessment of the benthic macroinvertebrate community. Streams in this study were assessed based on 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) that measure different aspects of the community's overall health. Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level.

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

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

Bluestone River was initially placed on the Virginia 1996 Section 303(d) TMDL Priority List based on monitoring performed (Table 2.1); it remained on the 303(d) listing for 2002. 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 Bluestone River 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 waterbody 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 Bluestone River 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 will help in identifying the actions that may have to be undertaken to meet water quality standards. Fecal coliform sources within the Bluestone River 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).

Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for the period January 1980 through March 2001.

Impairment	VADEQ Station	Count (#)	Minimum (cfu/100ml)	Maximum (cfu/100ml)	Mean (cfu/100ml)	Median (cfu/100ml)	Violations[1] %	Violations[2] %
Bluestone River	9-BST023.05	69	10	20,000	1,344	420	23	51
Bluestone River	9-BST029.57	40	20	6,000	730	220	20	43
Bluestone River	9-BST029.71	117	0	9,300	1,373	600	32	56

[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)

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 and Figure 2.2). That is, the analysis showed no obvious dominance of either nonpoint sources or point sources. High concentrations were recorded at both high and low flow conditions. Based on this analysis, a time period for calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5). The resulting period for calibration was October 1980 through September 1985. For validation, the time period selected was October 1986 through September 1991.

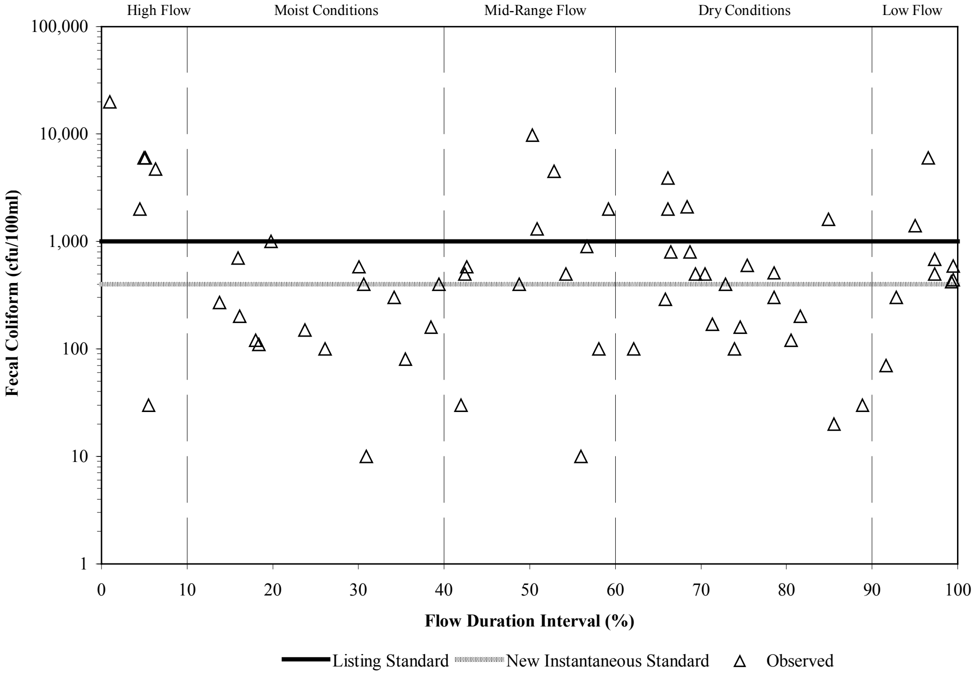

Figure 2.1 Relationship between fecal coliform concentrations (VADEQ Station 9BST023.05) and discharge in Bluestone River.

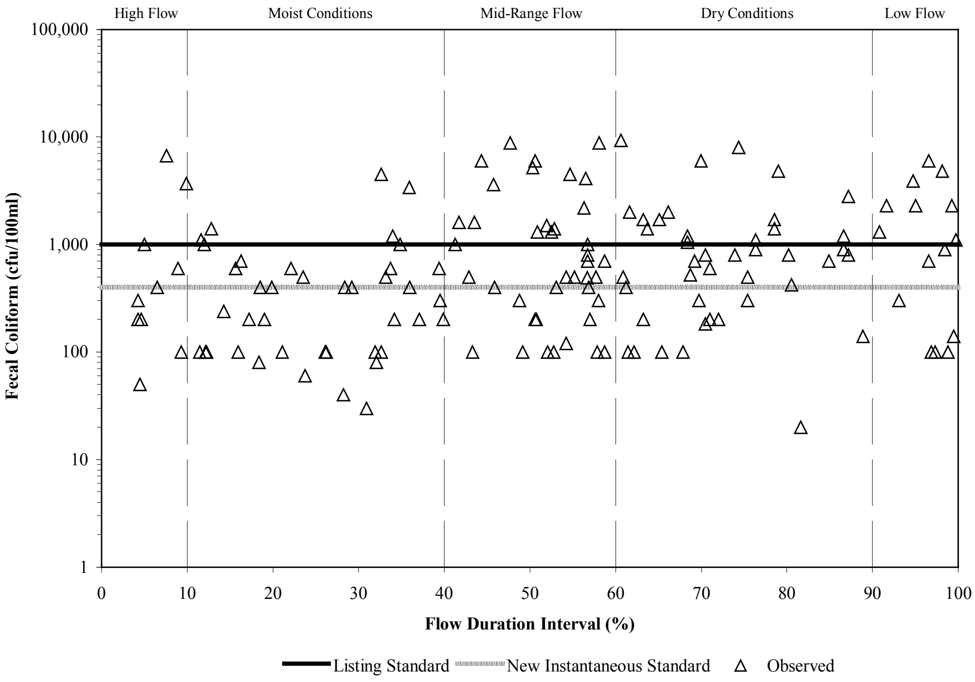

Figure 2.2 Relationship between fecal coliform concentrations (VADEQ Station 9BST029.57 and 9BST029.71) and discharge in Bluestone River.

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 Bluestone River 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 3 VADEQ in-stream monitoring stations used for TMDL assessment; 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 1980 through March 2001 (Figure 2.3) and are included in the analysis. Samples were taken for the expressed purpose of determining compliance with the state instantaneous standard limiting concentrations to less than 1,000 cfu/100 ml. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.1 summarizes the fecal coliform samples collected at the in-stream monitoring stations used for TMDL assessment.

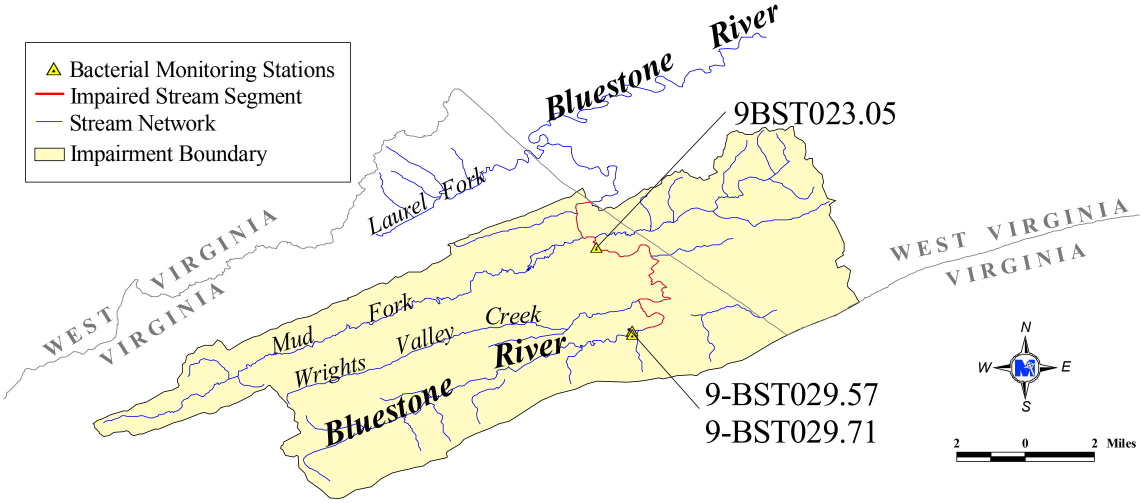

Figure 2.3 Location of VADEQ water quality monitoring stations used for TMDL assessment in the Bluestone River watershed.

2.2.1.2 Water Quality Monitoring Conducted During TMDL Development

Ambient water quality monitoring was performed from September 2002 through August 2003. Specifically, water quality samples were taken at two sites throughout the Bluestone River watershed (Figure 2.4). 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 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 is discussed in greater detail in Section 2.2.2.2.

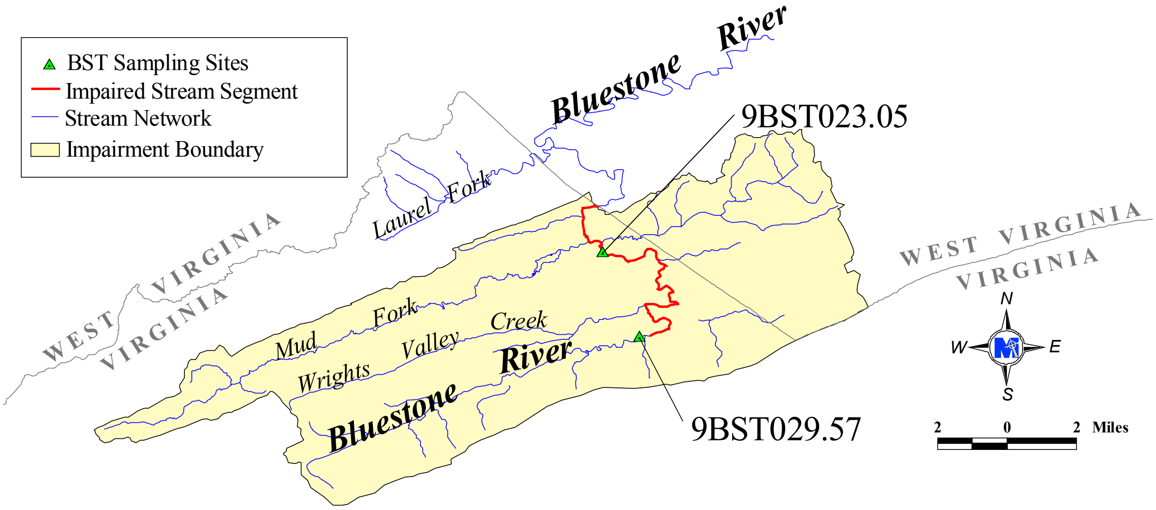

Figure 2.4 Location of BST water quality monitoring stations in the Bluestone River watershed.

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] (%)
Bluestone River	9BST023.05	12	80	12,000	3,141	845	42	67
Bluestone River	9BST029.57	12	90	14,000	3,198	725	33	67

[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] (%)
Bluestone River	9BST023.05	12	1	8,400	1,427	245	58
Bluestone River	9BST029.57	12	10	8,700	1,113	375	58

[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 at all flow levels, indicating 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 observed time period. Recent sampling indicates that violations continue.

2.2.2.2 Bacterial Source Tracking

MapTech, Inc. was contracted to do analyses 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 samples identified as originating from either human, pet, livestock, or wildlife sources.

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

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

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

Station	Date	Fecal Coliform (cfu/100 ml)	*E. coli* (cfu/100 ml)	Percent Isolates classified as:[1] Human	Pets	Livestock	Wildlife
9-BST023.05	9/5/02	4,000	310	**21**	**38**	**33**	8
	10/2/02	830	200	**25**	**13**	**25**	**37**
	11/21/02	8,600	5,800	**21**	**13**	**53**	**13**
	12/16/02	860	350	8	**25**	**17**	**50**
	1/27/03	100	48	4	**38**	**17**	**41**
	2/18/03	80	<1	--	**--**	**--**	--
	3/4/03	370	76	0	**25**	8	**67**
	4/21/03	390	44	**21**	**58**	**13**	8
	5/21/03	7,500	1,400	**17**	**21**	**25**	**37**
	6/9/03	2,400	250	8	**29**	**29**	**34**
	7/21/03	560	240	4	**21**	**71**	4
	8/5/03	12,000	8,400	**21**	**13**	**45**	**21**
9-BST029.57	9/5/02	14,000	790	**50**	0	**21**	**29**
	10/2/02	6,000	1,400	0	17	33	50
	11/21/02	800	700	**84**	4	8	4
	12/16/02	570	250	**38**	4	**45**	**13**
	1/27/03	300	230	0	**25**	**50**	**25**
	2/18/03	650	15	0	0	57	43
	3/4/03	210	80	**13**	8	**21**	**58**
	4/21/03	90	<10	--	**--**	**--**	**--**
	5/21/03	960	550	**13**	**29**	**17**	**41**
	6/9/03	400	130	**38**	**50**	4	8
	7/21/03	2,400	500	**25**	**21**	**46**	8
	8/5/03	12,000	8,700	8	**13**	**33**	**46**

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

2.2.2.4 Precipitation

Total monthly precipitation measured at station #449301 in Wythe County, was analyzed, and no overall, long-term trend or seasonality was found.

2.2.2.5 Discharge

Total monthly flow measured at USGS Station #03177710 (Bluestone River at Falls Mills, Virginia) in Tazewell County, Virginia from October 1980 to April 1997, was analyzed, and no significant trend in flow was found (Table 2.5). Differences in mean monthly flow at Station #03177710 (Bluestone River at Falls Mills, Virginia) are indicated in Table 2.6. Flows during months with the same median group letter are not significantly different from each other at the 95% significance level. For example, August, September, October, and November are all in median group "A" 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, August is in both median group "A" and "B" and is not significantly different than either group. In general, flow in the winter-spring months tends to be higher than flow in the fall-summer months.

Table 2.5 Summary of trend analysis on flow (cfs).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
USGS #03177710	62.66	47.71	310.33	8.64	48.82	199	No Trend

[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 the Mood Median Test on mean monthly flow at USGS Station 03177710 (p<0.001).

Month	Mean (cfs)	Minimum (cfs)	Maximum (cfs)	Median Groups			
January	84.16	8.64	210.16			C	D
February	109.31	41.69	168.14			C	D
March	118.91	21.03	228.13				D
April	93.06	30.53	310.33			C	D
May	84.04	31.00	155.90			C	D
June	59.96	12.99	145.63			C	
July	31.21	14.25	70.03		B		
August	29.05	10.88	75.97	A	B		
September	27.02	13.54	113.27	A			
October	27.65	12.48	110.55	A	B		
November	33.88	12.21	64.43	A	B	C	
December	57.61	21.19	102.42			C	

2.2.2.6 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 9BST029.71. The slope of this trend was estimated at –50 cfu/100 ml/yr. Remaining stations had no overall trend (Table 2.7). Differences in mean monthly fecal coliform concentration for station 9BST029.71 are indicated in Table 2.8. Fecal coliform concentrations during months with the same median group letter are not significantly different from each other at the 95% significance level. For example, January, February, April, May, June, July, August, September, October, and December are all in median group "B" and are not significantly different from each other. Fecal coliform concentrations during months with multiple groups are the result of the 95% confidence interval for that month, overlapping more than one median group. For example, April is in both median group "A" and "B" and is not significantly different than either group.

Table 2.7 Summary of trend analysis on fecal coliform (cfu/100 ml).

Station	Mean	Median	Max	Min	SD[1]	N[2]	Significant Trend[3]
9BST023.05	1,152.90	420	8,000	100	1,873.90	69	No Trend
9BST029.57	738	220	6,000	100	1,258.97	40	--
9BST029.71	1,351.99	600	8,000	100	1,922.04	117	-50.00

[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 2.8 Summary of Mood Median Test on mean monthly fecal coliform at Station BST029.71 (p<0.001).

Month	Mean (cfu/100 ml)	Minimum (cfu/100 ml)	Maximum (cfu/100ml)	Median Groups	
January	462.50	100	1,400	A	B
February	470.00	100	1,600	A	B
March	272.73	100	700	A	
April	483.33	100	1,100	A	B
May	1,950.00	100	6,000	A	B
June	2,036.36	200	8,000		B
July	2,450.00	200	8,000		B
August	3,300.00	200	8,000		B
September	2,133.33	100	6,000	A	B
October	1,750.00	100	6,700		B
November	390.00	100	1,200	A	
December	864.78	100	3,700	A	B

3. FECAL COLIFORM SOURCE ASSESSMENT

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

3.1 Assessment of Point Sources

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

Table 3.1 Permitted Point Sources in the Bluestone River Watershed.

Facility	VPDES #	Design Discharge (MGD)	Permitted For Fecal Control	Data Availability
Bluefield Westside WWTP	VA0025054	5.3	Yes	1999 – 2004
Tazewell County PSA/Falls Mills-Hales Bottom STP	VA0062561	0.108	Yes	1999 – 2003
Boxley Materials Company-Bluefield Ready Mix	VAG110001	-----------NO DISCHARGE-----------		
Fast Stop	VAG750008	.001	No	1999 - 2003
Mike's Soft Cloth	VAG750032	.001	No	2000 – 2003
MASH Car Wash	VAG750067	.001	No	2002 - 2003
Pounding Mill Quarry Corporation/Bluefield Plant	VAG840021	.001	No	1999 – 2003
Floyd Asphalt Paving Company Inc	VAR0510047	Stormwater	No	Not Applicable
Thistle Foundry and Machine Company	VAR0510098	Stormwater	No	Not Applicable

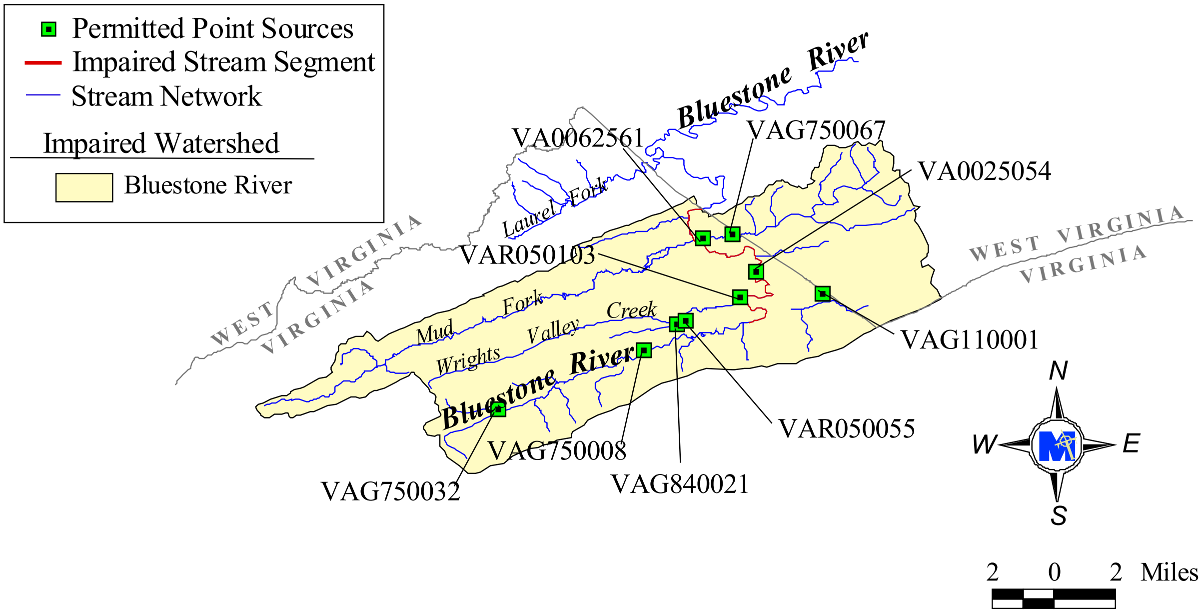

Figure 3.1 Location of VPDES permitted point sources in the Bluestone River watershed.

3.2 Assessment of Nonpoint Sources

In the Bluestone River 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 livestock waste, and direct and land-based deposits by 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 pipes 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 by 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 Bluestone River watershed.[1]

Impaired Segment	Population	Housing Units	Sanitary Sewer	Septic Systems	Other [2]
Bluestone River	23,131	11,592	9,018	2,447	127

[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 type of livestock in the Bluestone River watershed is beef cattle, although all types of livestock identified were considered in modeling the watershed. Animal populations were based on communication with Virginia Cooperative Extension Service (VCE), Natural Resources Conservation Service (NRCS), Tazewell Soil and Water Conservation District (TSWCD), watershed visits, verbal communication with farmers, and review of all publicly available information on animal type and approximate numbers known to exist within Tazewell and Mercer Counties and the TMDL project areas. Table 3.3 gives estimates of livestock populations in the Bluestone River watershed. Fecal coliform density values 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 Bluestone River watershed.

Watershed	Beef Cattle	Horse	Sheep	Goat
Bluestone River, VA	1,400	100	40	0
Bluestone River, WV	110	10	0	50

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

Type	Waste Load (lb/d/an)	FC Density (cfu/g)
Beef (800 lb)	46.4	101,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000

[1] American Society of Agricultural Engineers.

Fecal coliform bacteria 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. In the case of the Bluestone River watershed, no confined animal facilities were identified, so only 2 of these pathways were considered.

All grazing livestock were expected to deposit some portion of waste on pasture land areas. The percentage of time spent on pasture for beef cattle was reported by SWCD, NRCS, VADCR, and VCE personnel (Table 3.5). Horses, sheep, beef cattle and goats were assumed to be in pasture 100% of the time. The average amount of time spent by beef cattle in stream access areas (*i.e.,* within 100 feet of the stream) for each month is given in Table 3.5.

Table 3.5 Estimated average time beef cows spend in different areas per day.

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 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 3.6 (Bidrowski, 2003;

Costanzo, 2003; Farrar, 2003; Knox, 2003; Norman and Lafon, 2002; and Rose and Cranford, 1987). The numbers of animals estimated to be in the Bluestone River watershed are reported in Table 3.7 (Tazewell County estimates were used to represent the entire watershed). 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 3.8 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife waste 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 3.9.

Table 3.6 Wildlife population density.

Wildlife	Tazewell County Density	Density Unit
Raccoon	0.0703	an/ac of habitat
Muskrat	2.7512	an/ac of habitat
Beaver	4.8	an/mi of stream
Deer	0.0344	an/ac of habitat
Turkey	0.0091	an/ac of forest
Goose	0.0032	an/ac
Duck	0.0190	an/ac

Table 3.7 Estimated wildlife populations in the Bluestone River watershed.

Watershed	Deer	Turkey	Goose	Duck	Muskrat	Raccoon	Beaver
Bluestone River	1,622	395	18	106	3,524	3,215	311

Table 3.8 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 3.9 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

3.2.5 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 3.10. Table 3.11 lists the domestic animal populations for the watershed.

Table 3.10 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 3.11 Estimated domestic animal populations in the Bluestone River watershed.

Watershed	Dog	Cat
Bluestone River	6,190	6,932

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

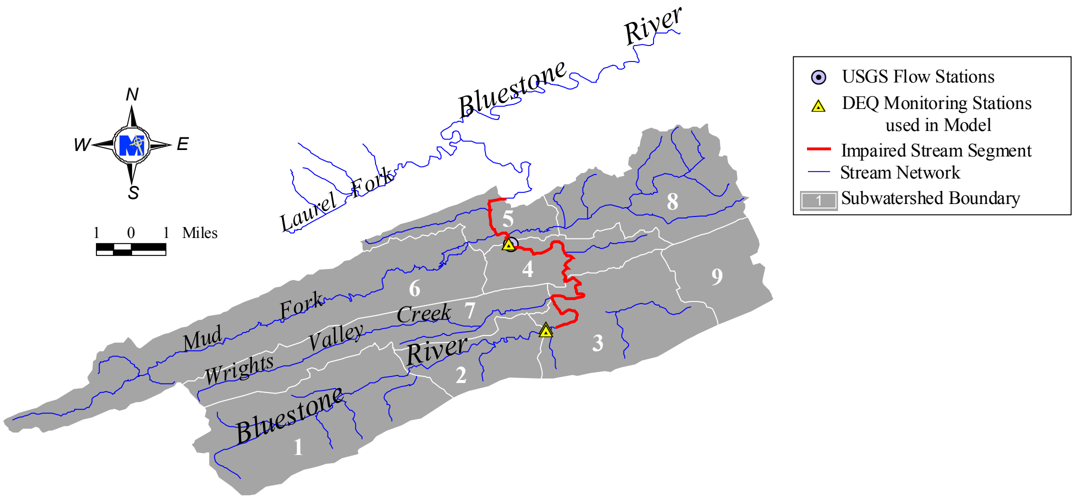


Figure 4.1 **Subwatersheds delineated for modeling and location of VADEQ water quality monitoring stations and USGS Gaging Station in the Bluestone River watershed.**

Table 4.1 **VADEQ monitoring stations and corresponding reaches in the Bluestone River watershed.**

Station Number	Reach Number
9-BST029.57	2
9-BST029.71	2
9-BST023.05	4

Using aerial photographs, MRLC identified up to 21 possible landuse types in the watershed. The landuse types were consolidated into eight 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. The percentages of pervious and impervious areas were calculated from data provided in VADCR's online 2002 NPS assessment database (VADCR, 2002). 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 two IMPLND types, while there are eight PERLND types, each with parameters describing a particular landuse (Table 4.2). Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

Table 4.2 Consolidation of MRLC landuse categories for the Bluestone River watershed.

TMDL Landuse Categories	Pervious / Impervious (Percentage)	MRLC Landuse Classifications (Class No.)
Water	Pervious (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 Bluestone River drainage area.

Landuse	Bluestone River Acreage
Water	141
Residential/Recreational	2,020
Commercial & Services	1,394
Barren	426
Woodland/Wetland	35,611
Pasture/Hay	7,660
Livestock Access	460
Cropland	1,370

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 accumulated 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 (1993-2002). 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

Design flow capacities were used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu/100 ml for discharges 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 Bluestone River watershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watershed to enumerate the septic systems. Households were then distributed among residential landuse types. Each landuse area was assigned a number of septic systems based on census data. A total of 2,240 septic systems were estimated in the Bluestone River watershed in 1995. During allocation runs, the number of households was projected to 2003, based on current Tazewell County growth rates (USCB, 2000) resulting in 2,447 septic systems (Table 4.4). The number of septic systems was projected to increase to 2,576 by 2008.

Table 4.4 Estimated failing septic systems (2003).

Impaired Segment	Total Septic Systems	Failing Septic Systems	Straight Pipes
Bluestone River	2,447	641	21

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 Bluestone River 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 December 2002, there were 39 reported sewer overflows, leading to a significant input of fecal bacteria into the watershed. All 39 reported overflows were included in the model during the calibration/validation period. 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 modeled as reported. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative.

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 TSWCD, VCE and NRCS, as well as taking into account growth rates in Tazewell 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 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.

4.3.3.2 Direct Deposition to Streams

Beef cattle are the primary sources of direct deposition by livestock in the Bluestone River 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 no biosolids applications have occurred within the Bluestone River watershed. For model calibration, biosolids were not modeled. 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.

4.3.5 Wildlife

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

Seasonal distribution of waste was determined using seasonal food preferences for deer and turkey. Goose and duck populations were varied based on migration patterns, but the load available for delivery to the stream was never reduced below 40% of the maximum to account for the resident population of birds. For each species, a portion of the total waste load was considered to be land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.9). 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.

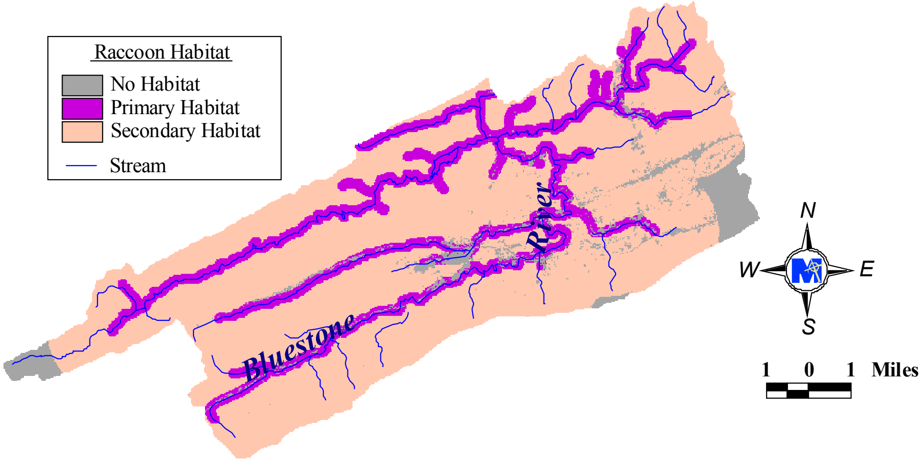


Figure 4.2 Example of raccoon habitat layer developed by MapTech in the Bluestone River watershed.

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 location of households was 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.

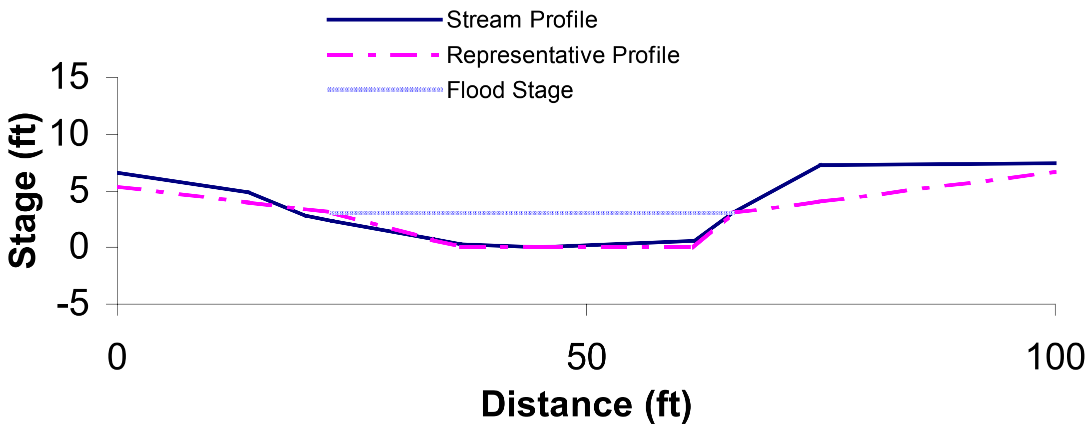


Figure 4.3 Stream profile representation in HSPF.

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, 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, and photographs were taken of the stream sections. 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 reported 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 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 represents the surface area of the flow in acres. The volume corresponds to the total volume of the flow in the reach, and is reported in acre-feet. The outflow is simply the stream discharge, in cubic feet per second.

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

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

4.5 Selection of Representative Modeling Period

Selection of the calibration/validation periods was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Mean daily discharge at USGS Gaging Station #03177710 (Bluestone River at Falls Mills, Virginia) and precipitation at Wytheville station #449301 were available from October 1980 to April 1997. The modeling period was selected to include the VADEQ assessment period from July 1992 through June 1997 that led to the inclusion of the Bluestone River segment on the 1996 Section 303 (d) list. In addition, the fecal concentration data from this period were evaluated for use during calibration and validation of the model.

The mean daily flow and precipitation for each season were calculated for the period October 1980 through September 1996. This resulted in 16 observations of mean flow and 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 initial period was chosen based on the availability of discharge data closest to the fecal coliform assessment period. The representative period was chosen such that the mean and variance of each season in the modeled period was not significantly different from the historical data (Table 4.6, Figure 4.4 and Figure 4.5).

Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The resulting period for hydrologic calibration/validation was:

- Calibration: 1981-1985 (Comparison to 30 minute flow data)
- Validation: 1986-1990 (Comparison to 30 minute flow data)

Table 4.6 Comparison of modeled period to historical records.

	Mean Flow (cfs)				**Precipitation (in/day)**			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Historical Record (1981-1996)							
Mean	36.52	104.02	78.08	29.11	0.0910	0.0996	0.1137	0.1099
Variance	219.79	1,402.94	758.06	186.97	0.0008	0.0009	0.0005	0.0011
	Calibration & Validation Period (10/80 – 09/85, 10/85 – 09/89)							
Mean	32.22	85.62	80.75	31.39	0.0931	0.0894	0.1103	0.1134
Variance	207.92	1,309.73	1,230.06	322.02	0.0011	0.0010	0.0006	0.0014
	p-Values							
Mean	0.2426	0.1203	0.4229	0.3718	0.4381	0.2143	0.3650	0.4109
Variance	0.4905	0.4822	0.1995	0.1734	0.2742	0.4092	0.4063	0.3305

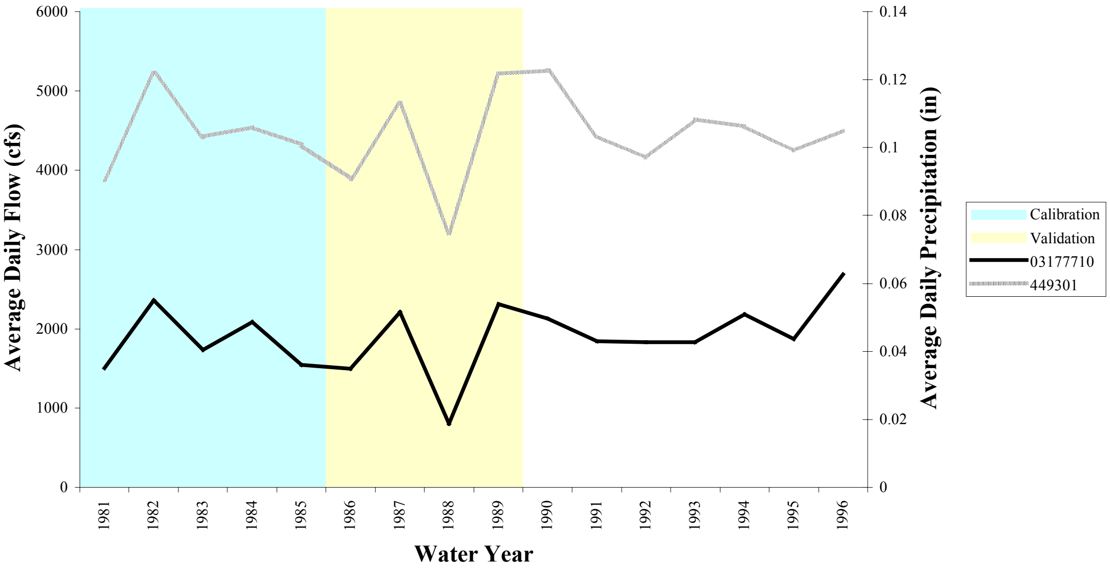


Figure 4.4 Hydrologic calibration and validation periods compared to annual flow (USGS 03177710) and precipitation (USGS 449301) records.

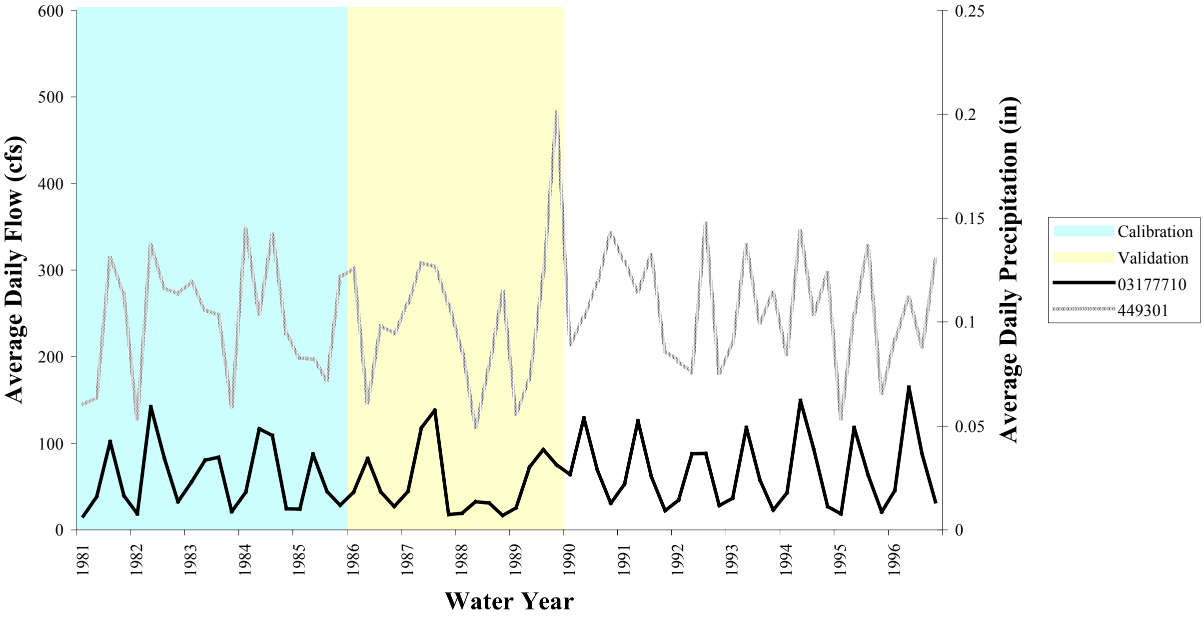


Figure 4.5 **Hydrologic calibration and validation periods compared to seasonal flow (USGS 03177710) and precipitation (USGS 449301) records.**

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 1980 through 1985. 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), which governs surface transport, and MON-LZETP (Monthly Lower Zone Evapotranspiration), which affects soil moisture. To a lesser extent peak flows were sensitive to changes in LZSN (Lower Zone Storage) and UZSN (Upper Zone Storage). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the *Low Flows* and *Summer Flow Volume* statistics) were AGWRC (Groundwater Recession Rate), INFILT, DEEPFR (Losses to Deep Aquifers), INTERCEP (interception) and, to a lesser extent, BASETP (Evapotranspiration from Base Flow). The response of pertinent hydrologic outputs was recorded, and is 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	0.98
BASETP	Base Flow Evapotranspiration	---	0.02
CEPSC	Interception Storage Capacity	in	0.1
DEEPFR	Fraction of Deep Groundwater	---	0.1
INFILT	Soil Infiltration Capacity	in/hr	0.16
INTFW	Interflow Inflow	---	0.75
KVARY	Groundwater Recession Coefficient	1/day	0.0
LZSN	Lower Zone Nominal Storage	in	4-6.5
MON-LZETPARM	Monthly Lower Zone Evapotranspiration	---	0.2-0.4
NSUR	Manning's *n* for Overland Flow	---	0.75
UZSN	Upper Zone Storage Capacity	in	1.92-2.068

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	3.27%	33.13%	-64.35%	5.87%	-2.56%	-7.90%	21.49%	27.88%
AGWRC	-10	1.17%	10.38%	-32.42%	6.45%	-3.67%	-13.48%	16.15%	21.93%
AGWRC[1]	1	0.28%	-2.43%	15.49%	-6.18%	-1.17%	8.21%	6.90%	-17.13%
BASETP	-50	0.55%	-0.89%	2.75%	-0.37%	1.13%	2.13%	-0.47%	-0.38%
BASETP	-10	0.11%	-0.18%	0.56%	-0.08%	0.23%	0.43%	-0.10%	-0.11%
BASETP	10	-0.11%	0.18%	-0.56%	0.08%	-0.22%	-0.42%	0.10%	0.08%
BASETP	50	-0.53%	0.93%	-2.80%	0.38%	-1.12%	-2.10%	0.53%	0.09%
DEEPFR[2]	0.1	-7.26%	-2.53%	-12.71%	-6.04%	-6.44%	-9.45%	-8.75%	-5.09%
DEEPFR[2]	0.5	-35.47%	-13.69%	-58.74%	-30.26%	-32.00%	-45.15%	-41.41%	-27.03%
INFILT	-50	-1.16%	24.40%	-29.45%	3.71%	-1.33%	-10.09%	-0.45%	9.91%
INFILT	-10	-0.26%	3.86%	-4.73%	0.66%	-0.18%	-1.94%	-0.34%	1.63%
INFILT	10	0.26%	-3.47%	4.30%	-0.61%	0.17%	1.86%	0.40%	-1.46%
INFILT	50	1.27%	-14.64%	18.04%	-2.78%	0.68%	8.44%	2.34%	-6.77%
INTFW	-50	0.25%	2.83%	1.49%	0.27%	0.13%	0.86%	-0.23%	-0.67%
INTFW	-10	0.05%	0.29%	0.23%	0.07%	0.03%	0.11%	-0.02%	-0.06%
INTFW	10	-0.04%	-0.21%	-0.20%	-0.05%	-0.01%	-0.10%	0.01%	0.05%
INTFW	50	-0.15%	-0.70%	-0.76%	-0.20%	-0.08%	-0.41%	0.09%	0.13%
LZSN	-50	0.83%	7.54%	-7.59%	6.81%	0.61%	-8.43%	-0.19%	5.30%
LZSN	-10	0.15%	1.01%	-0.89%	0.94%	0.25%	-0.99%	-0.36%	0.56%
LZSN	10	-0.14%	-0.88%	0.76%	-0.81%	-0.26%	0.80%	0.38%	-0.57%
LZSN	50	-0.66%	-3.53%	2.65%	-3.23%	-1.36%	2.78%	1.85%	-2.12%
MON-INTERCEP	-50	1.84%	-1.15%	6.61%	0.44%	1.29%	3.77%	3.44%	-0.10%
MON-INTERCEP	-10	0.29%	-0.16%	1.00%	0.03%	0.20%	0.65%	0.60%	0.12%
MON-INTERCEP	10	-0.32%	0.14%	-1.03%	-0.04%	-0.25%	-0.70%	-0.56%	-0.11%
MON-INTERCEP	50	-1.28%	0.73%	-4.43%	-0.11%	-0.77%	-3.18%	-2.40%	-0.17%
MON-LZETP	-50	8.02%	13.20%	3.11%	6.47%	3.69%	7.22%	20.00%	9.05%
MON-LZETP	-10	1.04%	1.31%	1.08%	0.78%	0.47%	0.87%	2.77%	0.97%
MON-LZETP	10	-0.88%	-1.03%	-1.04%	-0.68%	-0.31%	-0.82%	-2.40%	-0.70%
MON-LZETP	50	-3.64%	-4.20%	-4.45%	-2.81%	-1.28%	-3.90%	-9.38%	-2.96%
MON-MANNING	-50	0.21%	1.90%	-0.97%	0.35%	0.21%	-0.04%	0.24%	0.60%
MON-MANNING	-10	0.04%	0.34%	-0.17%	0.06%	0.04%	-0.02%	0.03%	0.10%
MON-MANNING	10	-0.03%	-0.30%	0.16%	-0.05%	-0.04%	0.02%	-0.02%	-0.09%
MON-MANNING	50	-0.13%	-1.36%	0.71%	-0.25%	-0.18%	0.11%	-0.07%	-0.38%
MON-UZSN*	-50	2.31%	9.80%	-4.91%	0.11%	2.73%	4.60%	3.32%	5.40%
MON-UZSN*	-10	0.30%	1.52%	-0.77%	-0.03%	0.33%	0.68%	0.48%	0.77%
MON-UZSN	10	-0.26%	-1.38%	0.70%	0.05%	-0.29%	-0.60%	-0.43%	-0.66%
MON-UZSN	50	-1.01%	-5.77%	2.95%	0.32%	-1.06%	-2.54%	-1.86%	-2.82%

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

[2] Numbers represent actual values used for variable, as values represented in .UCI are 0.00

*Where minimum value falls below allowable minimum, variable is assigned minimum 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.

Since the water quality standard for *E. coli* bacteria is based on concentrations rather than loadings, it was considered necessary to analyze the effect of source changes on the monthly geometric-mean *E. coli* 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 4.9 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

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	24.92	24.98	27.49	28.62	26.89	26.84	29.04	30.06	29.51	28.34	27.83	26.53
FSTDEC	-10	4.07	3.98	4.38	4.58	4.40	4.50	4.89	5.00	4.90	4.75	4.68	4.41
FSTDEC	10	-3.76	-3.66	-4.02	-4.21	-4.07	-4.19	-4.53	-4.62	-4.53	-4.39	-4.33	-4.09
FSTDEC	50	-16.43	-15.96	-17.49	-18.30	-17.77	-18.40	-19.70	-19.98	-19.58	-19.05	-18.83	-17.85
SQOLIM	-50	-12.66	-9.03	-16.05	-14.00	-15.07	-11.72	-8.84	-9.20	-8.29	-5.59	-6.69	-11.94
SQOLIM	-25	-5.15	-3.83	-6.76	-6.02	-6.62	-5.16	-4.06	-4.22	-3.76	-2.49	-2.82	-4.86
SQOLIM	50	10.10	7.05	11.48	9.22	10.88	8.40	7.07	7.28	6.51	4.81	5.90	9.99
SQOLIM	100	17.40	11.84	19.22	15.85	19.57	15.15	12.94	13.38	11.55	8.67	10.67	17.73
WSQOP	-50	16.93	12.17	17.42	17.59	19.54	15.88	12.49	11.84	10.18	8.20	10.33	16.97
WSQOP	-10	2.28	1.66	2.52	2.46	2.66	2.13	1.64	1.60	1.38	1.06	1.31	2.21
WSQOP	10	-1.98	-1.45	-2.23	-2.16	-2.32	-1.85	-1.41	-1.39	-1.20	-0.90	-1.11	-1.89
WSQOP	50	-7.86	-5.80	-9.17	-8.74	-9.28	-7.34	-5.57	-5.55	-4.81	-3.51	-4.32	-7.45

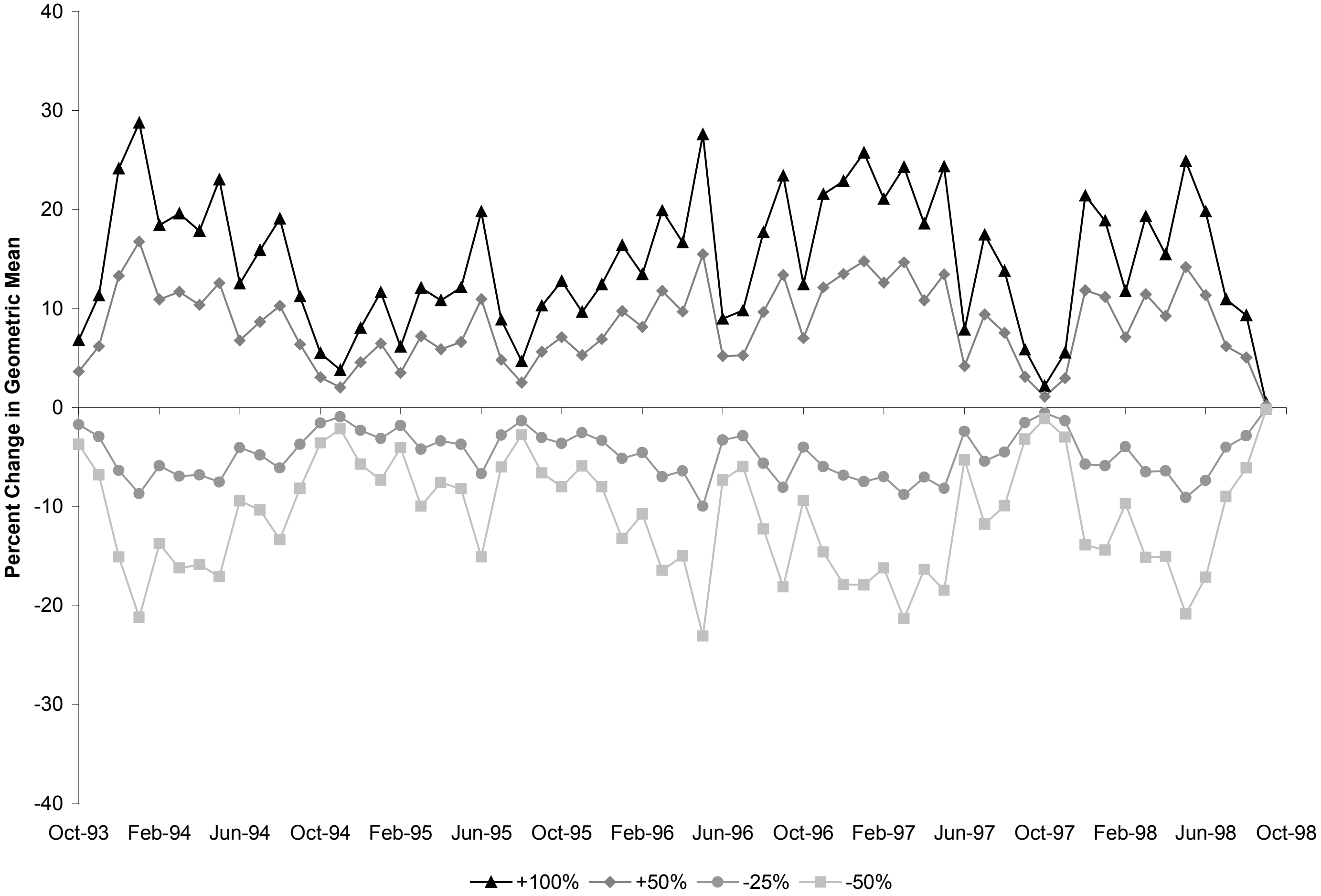


Figure 4.6 Results of sensitivity analysis on monthly geometric-mean concentrations in the Bluestone River watershed, as affected by changes in maximum FC accumulation on land (MON-SQOLIM).

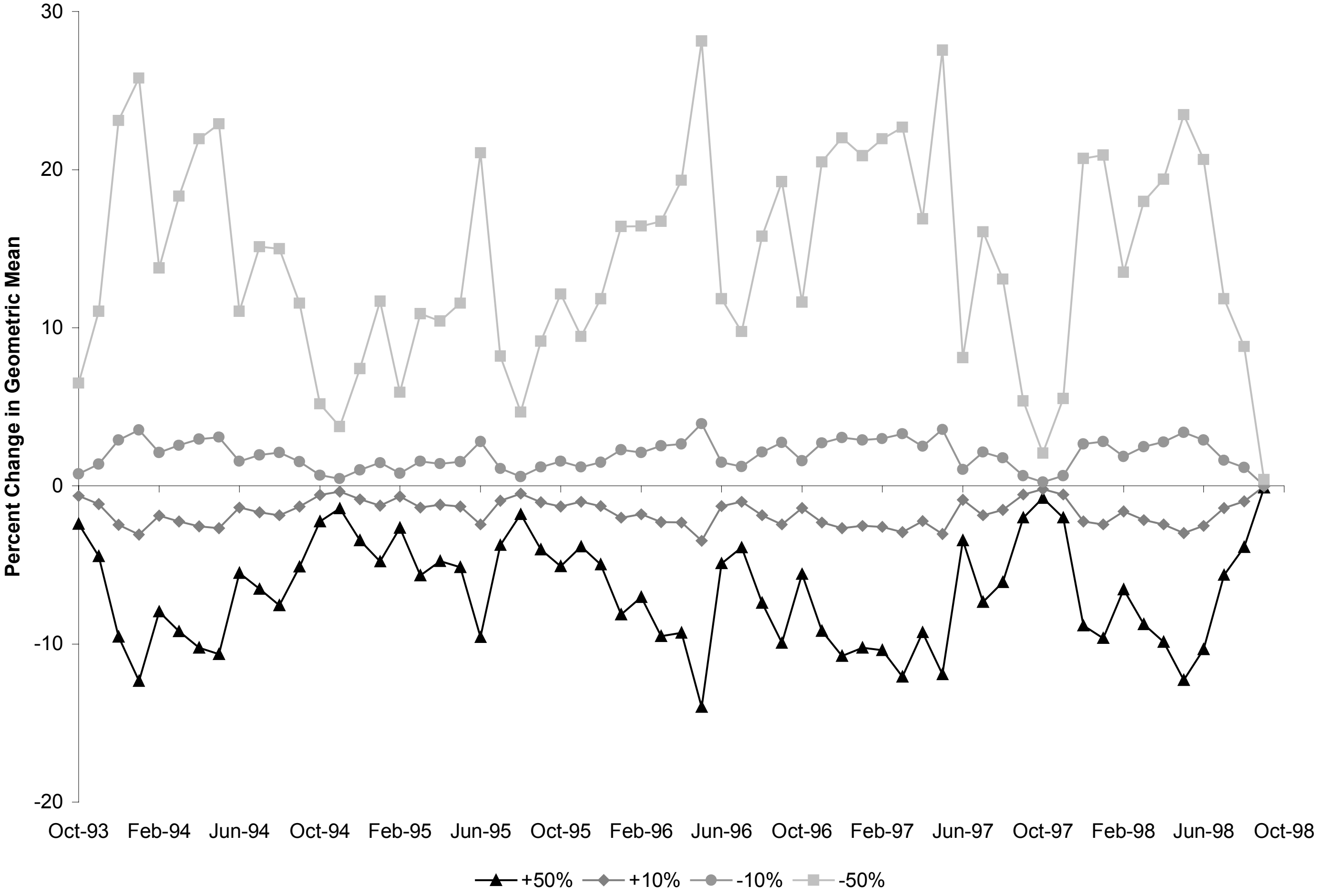


Figure 4.7 Results of sensitivity analysis on monthly geometric-mean concentrations in the Bluestone River watershed, as affected by changes in the wash-off rate for FC fecal coliform on land surfaces (WSQOP).

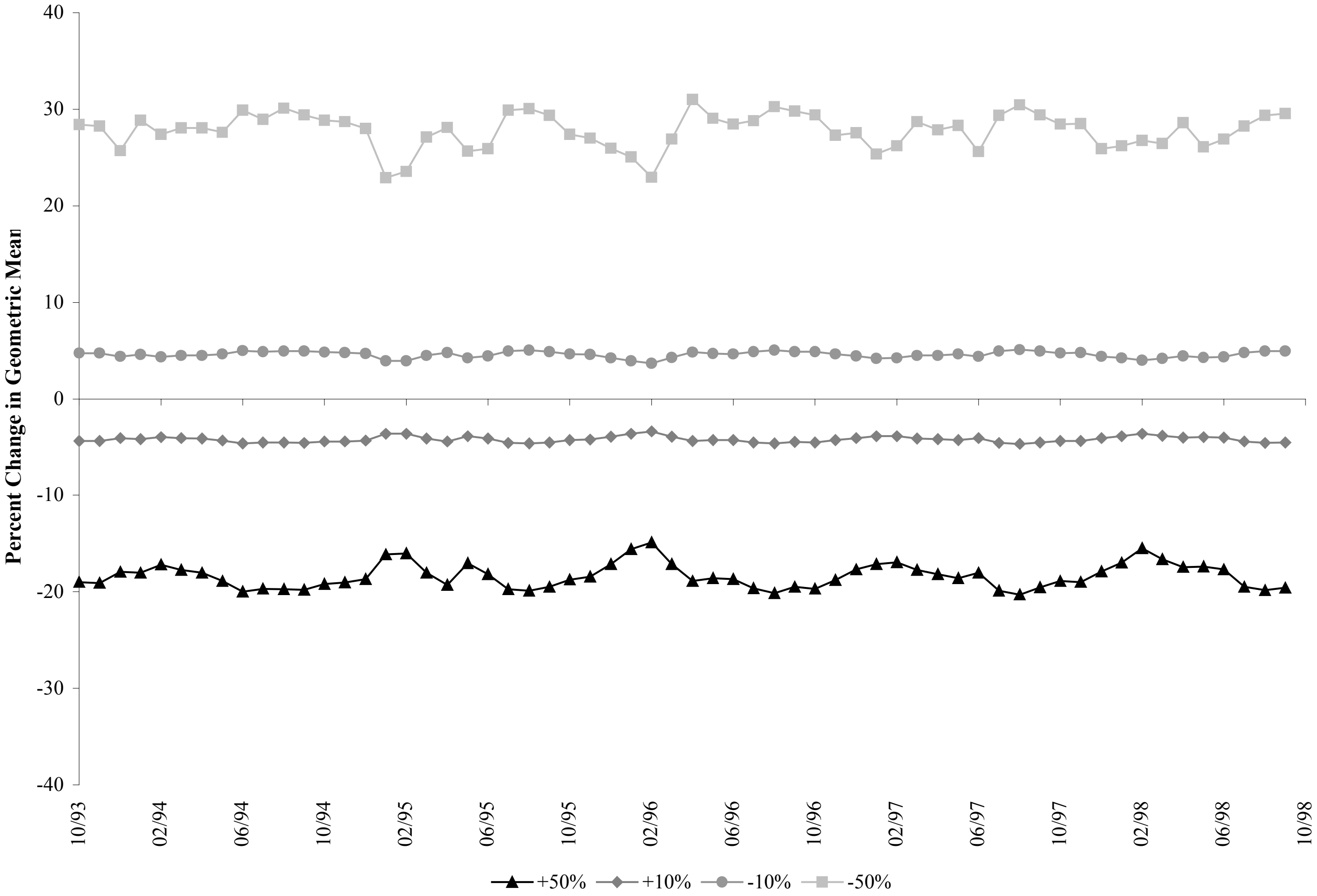


Figure 4.8 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Bluestone River watershed, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

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, 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 shows that direct loads had the greatest impact, with land-applied loads having a lesser, but measurable impact.

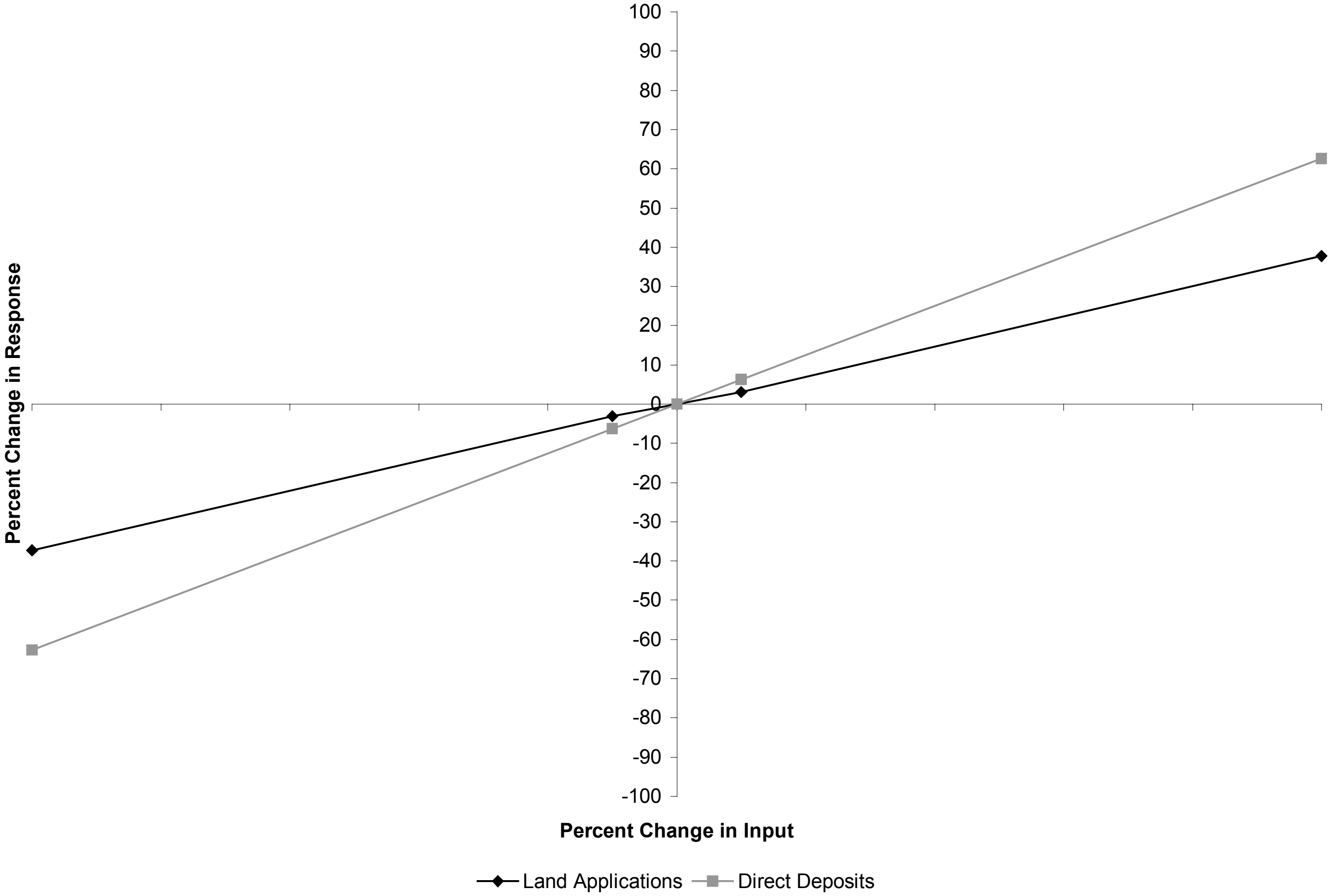


Figure 4.9 Total loading sensitivity to changes in direct and land-based loads for the Bluestone River watershed.

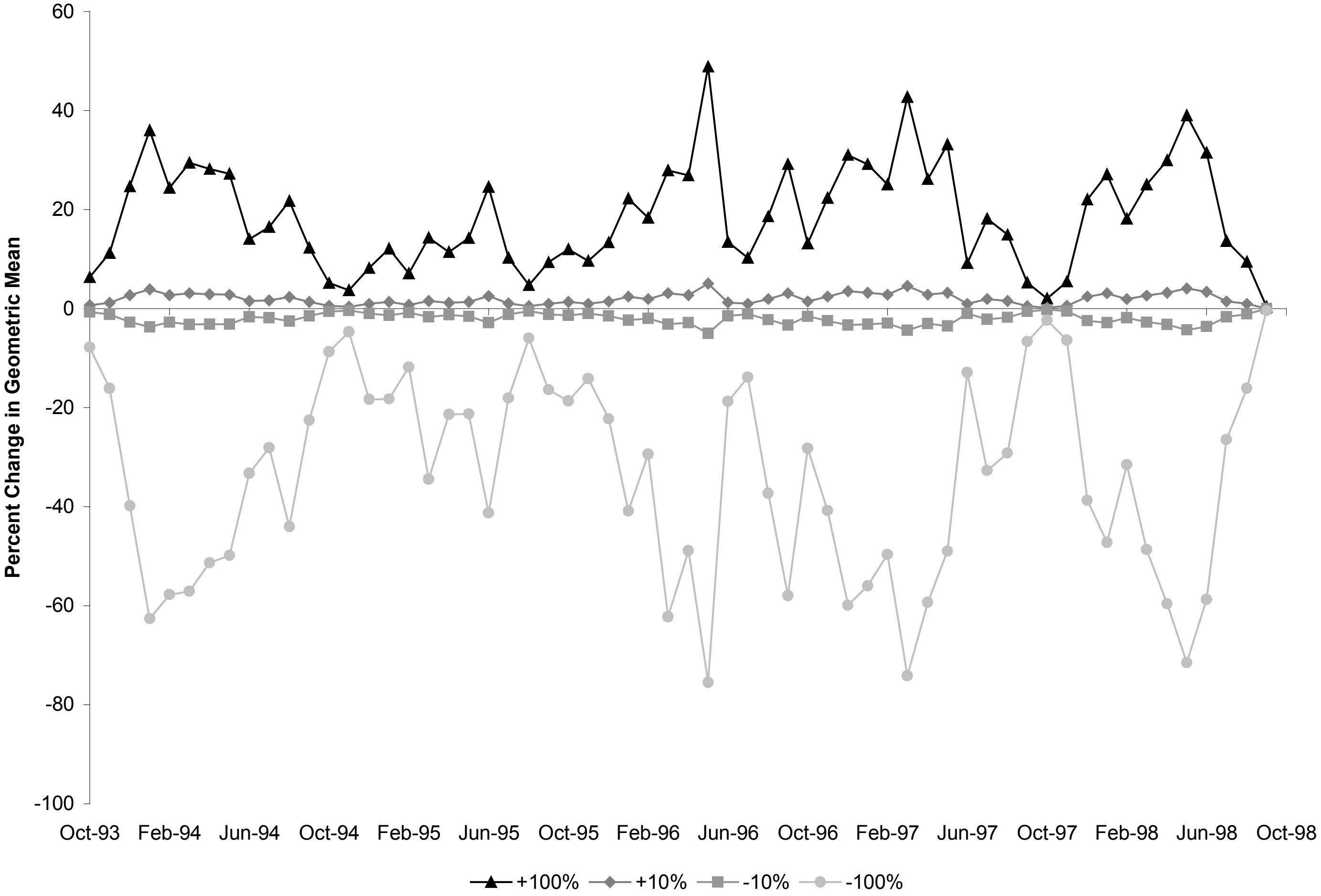


Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations in the Bluestone River watershed, as affected by changes in land-based loadings.

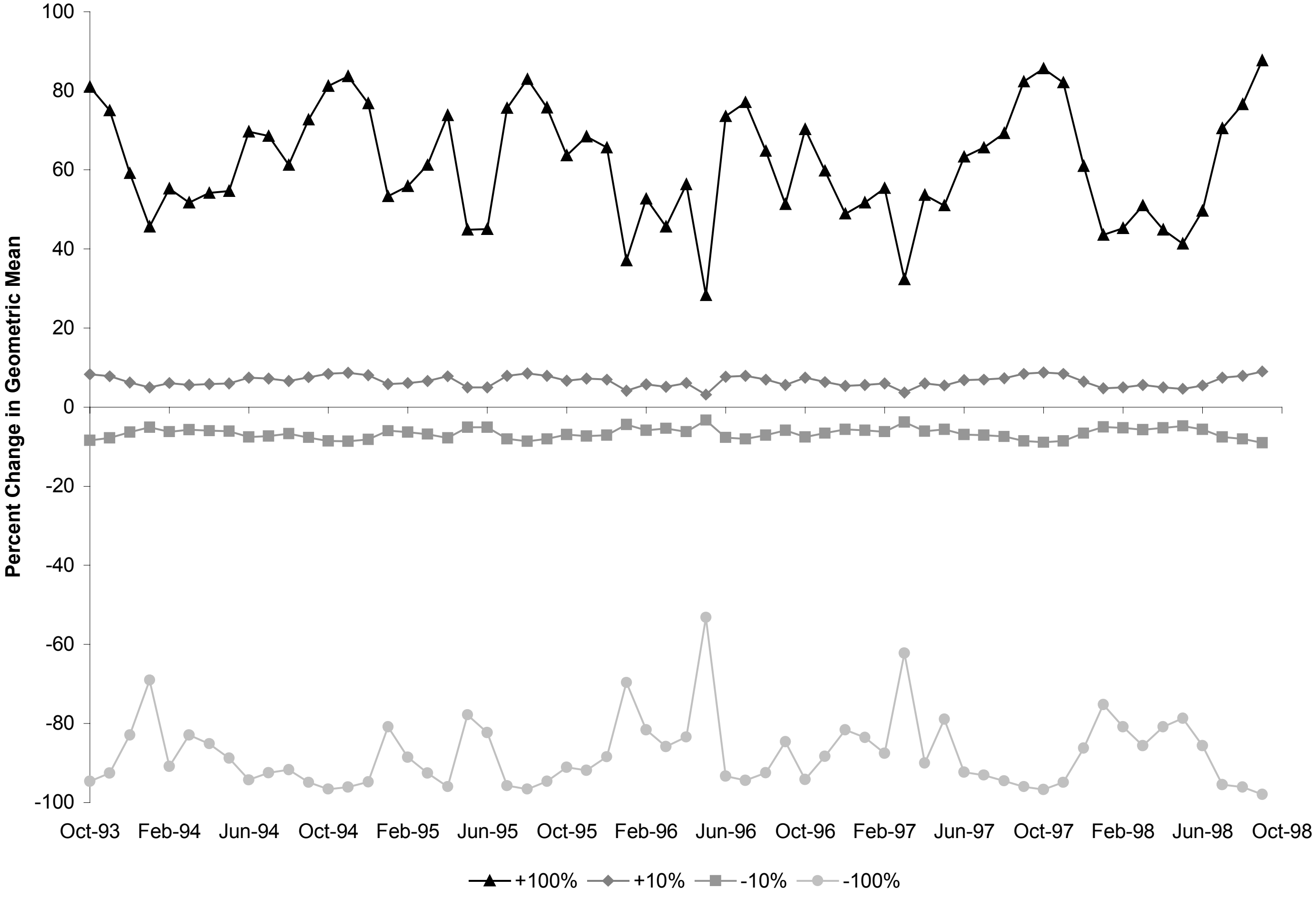


Figure 4.11 **Results of sensitivity analysis on monthly geometric-mean concentrations in the Bluestone River watershed, as affected by changes in loadings from direct nonpoint sources.**

4.7 Model Calibration and Validation Processes

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

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

4.7.1 Hydrologic Calibration and Validation

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 4.11 contains the typical range for the above parameters along with the initial estimate and final calibrated value. Although HSPF is not a physically based model, and thus parameters are adjusted during calibration in order to match observed data, guidelines are provided by E.P.A as to typically encountered values. Final calibrated parameters did not go outside of typical values, except in the case of MON-UZS, which ranged outside the high value of 2.0, with a peak value of 4.78 during November. This parameter can account for many surface storage factors in the watershed, and its effects are felt most in its impact on low flows and on storm flows. This was considered necessary to match the trends in observed data.

Table 4.11 Model parameters utilized for hydrologic calibration.

Parameter	Units	Typical Range of Parameter Value	Initial Parameter Estimate	Calibrated Parameter Value
FOREST	---	0.0 – 0.95	0.0	1.0
LZSN	in	2.0 – 15.0	4 – 6.5	4.8
INFILT	in/hr	0.001 – 0.50	0.16	0.005 – 0.085
LSUR	ft	100 – 700	1-500	100 – 800
SLSUR	---	0.001 – 0.30	0.001 –0.1755	0.01 – 0.1755
KVARY	1/in	0.0 – 5.0	0.0	0.0
AGWRC	1/day	0.85 – 0.999	0.98	0.99
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	0.1	0.0
BASETP	---	0.0 – 0.20	0.02	0.03
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	0.75	1 - 4
IRC	1/day	0.30 – 0.85	0.5	0.85
MON-INT	in	0.01 - 0.40	0.1	0.03 - 0.11
MON-UZS	in	0.05 – 2.0	1.92 – 2.068	0.9-4.78
MON-LZE	---	0.1 – 0.9	0.2 – 0.4	0.1 - 0.7
MON-MAN		0.10 – 0.50	0.75	1 - 4
RETSC	in	0.0 – 1.0	0.1	0.1
KS	---	0.0 – 0.9	0.5	0.5

The model was calibrated/validated for hydrologic accuracy using 30-minute flow data from USGS Station #03177710 (Bluestone River at Falls Mills). The results of calibration and validation for Bluestone River are presented in Tables 4.12 and 4.13 and Figures 4.12 through 4.19. The distribution of flow volume between surface runoff, interflow, and groundwater was 20%, 41%, and 39%, respectively, for Bluestone River. Table 4.12 shows the percent difference (or error) between observed and modeled data for total in-stream flows, -2.9%, upper 10% flows, -9.3%, and lower 50% flows, 2.2% during model calibration. These values represent a close agreement with the observed data, indicating a well-calibrated model.

Table 4.12 Hydrology calibration criteria and model performance for Bluestone River for the period 10/01/80 through 9/30/85.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	52.37	50.86	-2.89%
Upper 10% Flow Values:	19.84	18.00	-9.26%
Lower 50% Flow Values:	8.77	8.97	2.22%
Winter Flow Volume	20.33	21.88	7.64%
Spring Flow Volume	18.53	15.14	-18.30%
Summer Flow Volume	6.50	5.75	-11.61%
Fall Flow Volume	7.01	8.09	15.43%
Total Storm Volume	43.58	43.43	-0.32%
Winter Storm Volume	18.18	20.04	10.27%
Spring Storm Volume	16.33	13.29	-18.64%
Summer Storm Volume	4.28	3.89	-9.13%
Fall Storm Volume	4.79	6.21	29.82%

Table 4.13 Hydrology validation criteria and model performance for Bluestone River for the period 10/01/85 through 9/30/90.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	51.59	48.54	-5.91%
Upper 10% Flow Values:	20.14	17.74	-11.95%
Lower 50% Flow Values:	8.74	8.14	-6.83%
Winter Flow Volume	18.92	20.38	7.76%
Spring Flow Volume	16.50	15.06	-8.76%
Summer Flow Volume	7.42	5.19	-30.10%
Fall Flow Volume	8.75	7.91	-9.60%
Total Storm Volume	42.91	42.55	-0.83%
Winter Storm Volume	16.77	18.90	12.73%
Spring Storm Volume	14.34	13.56	-5.44%
Summer Storm Volume	5.25	3.68	-29.94%
Fall Storm Volume	6.55	6.41	-2.13%

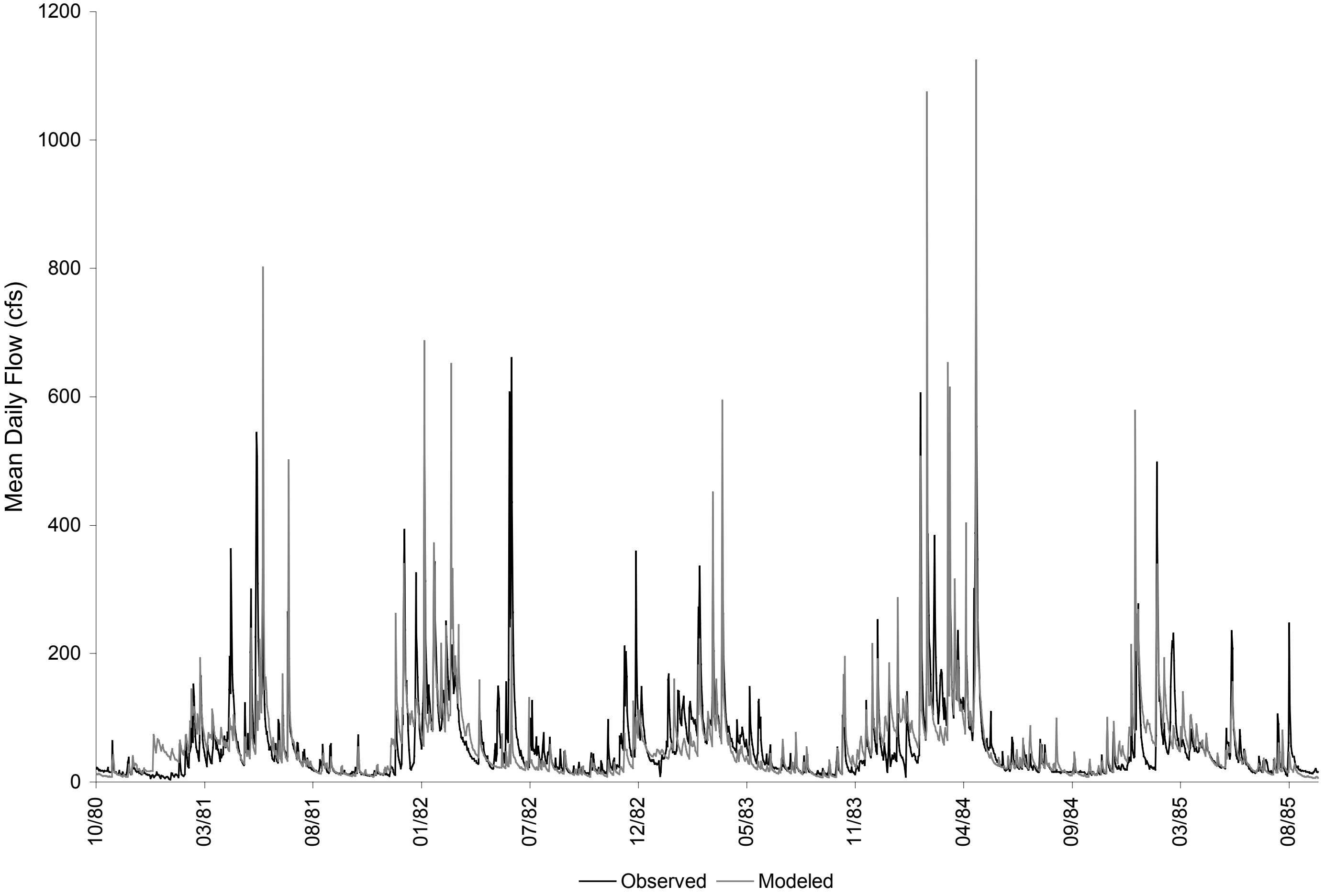


Figure 4.12 **Calibration results for Bluestone River for the period 10/01/80 through 9/30/85.**

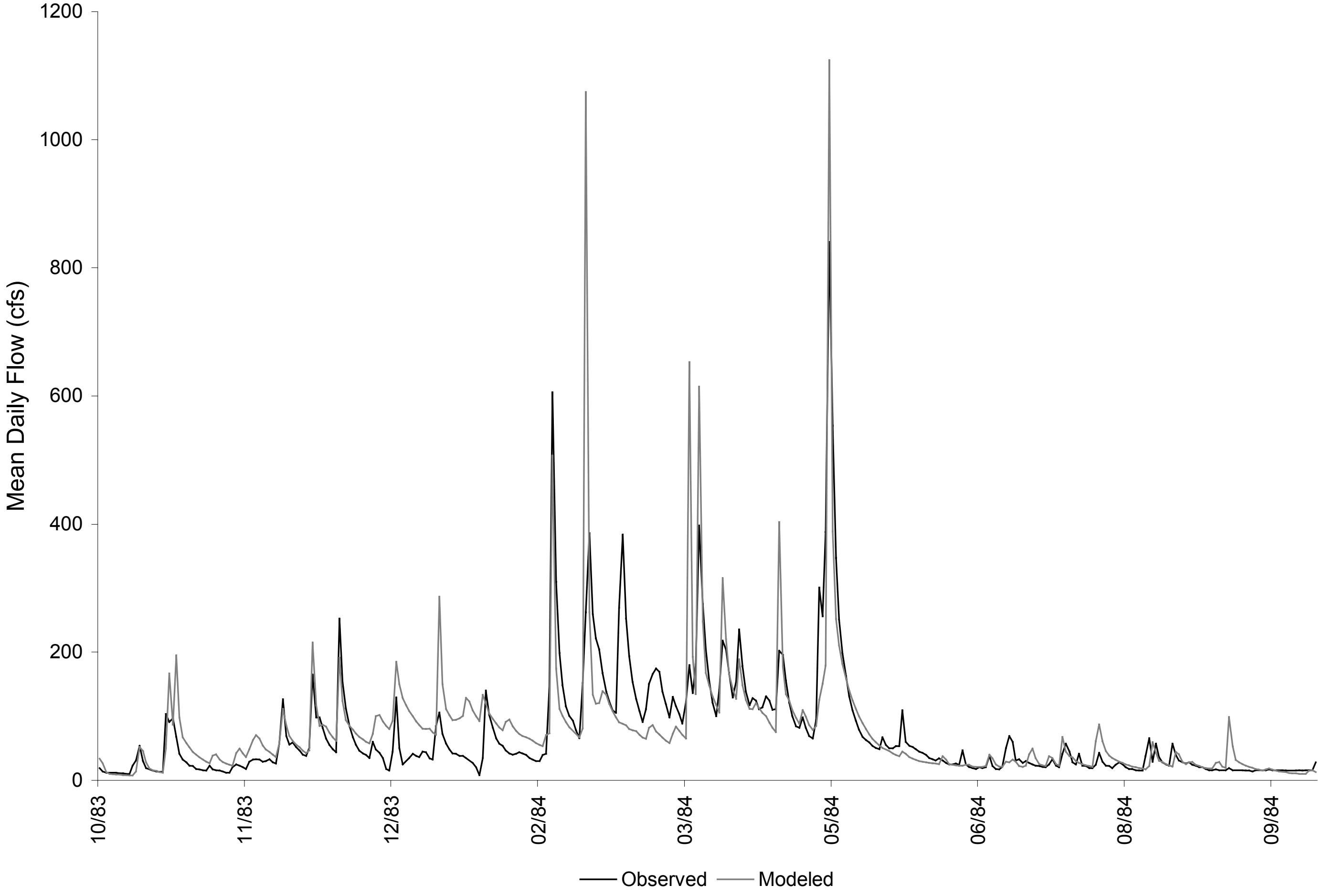


Figure 4.13 Calibration results for Bluestone River for the period 10/01/83 through 9/30/84.

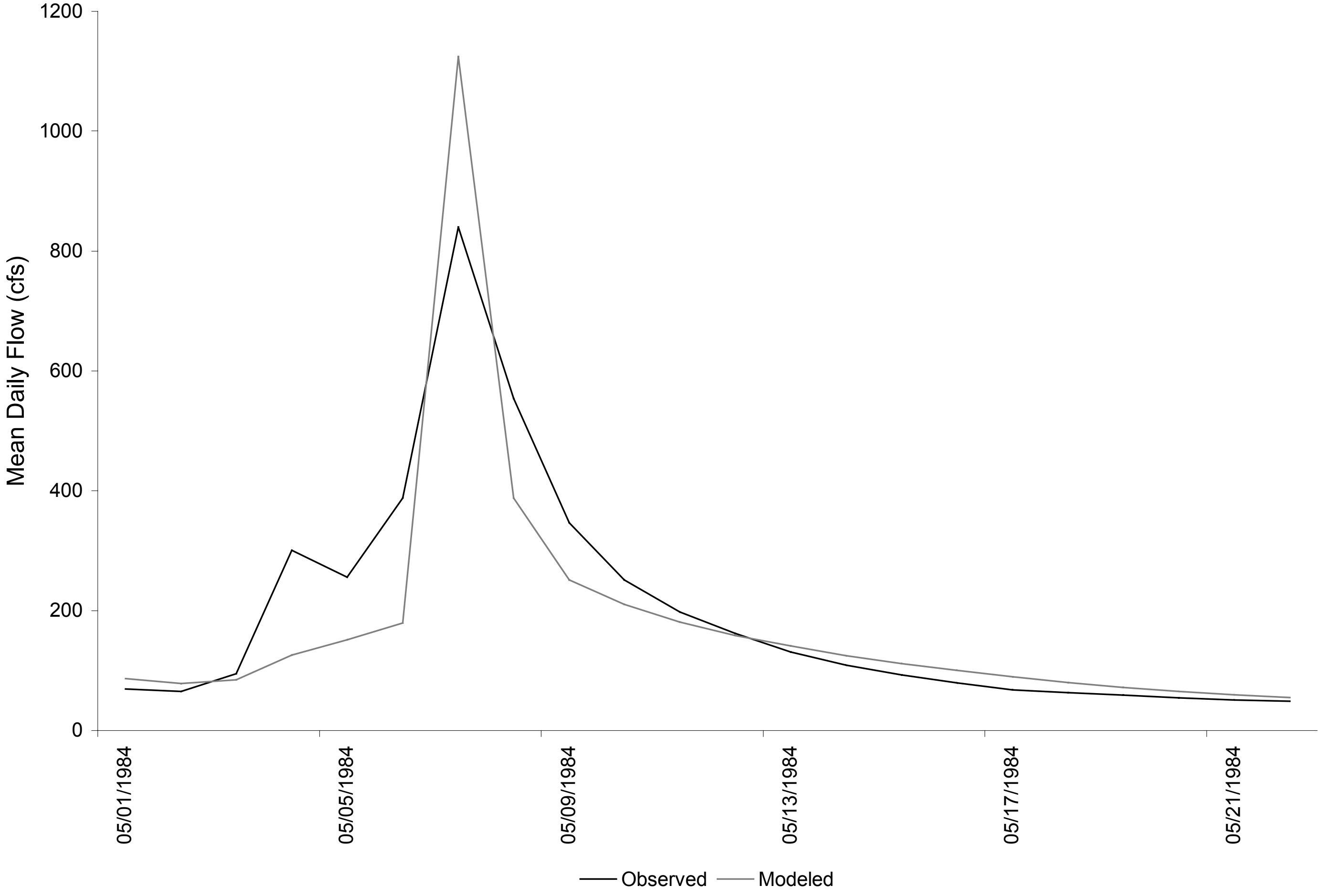


Figure 4.14 Calibration results for a single storm for Bluestone River.

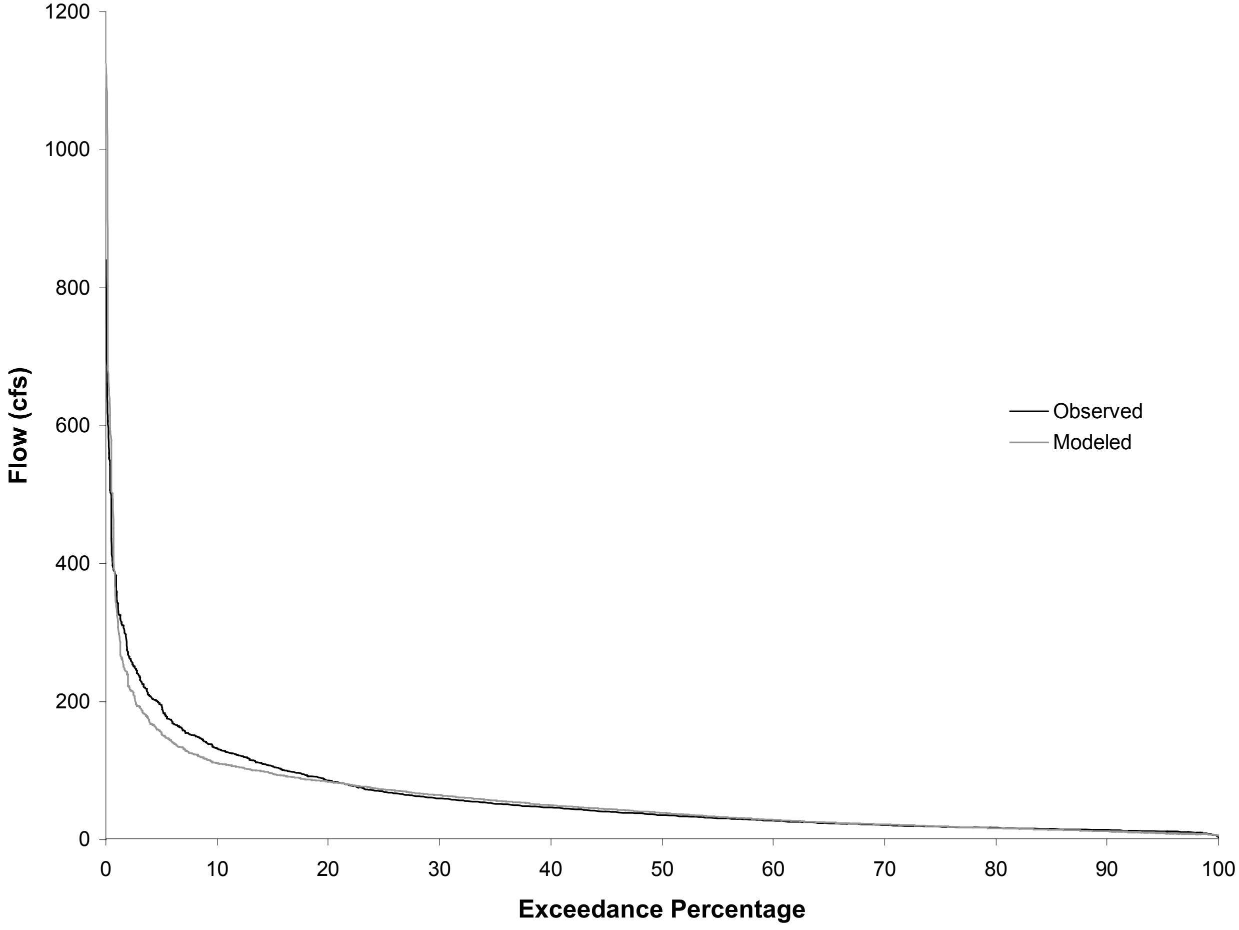


Figure 4.15 Bluestone River flow duration for calibration period (October 1, 1980 – September 30, 1985).

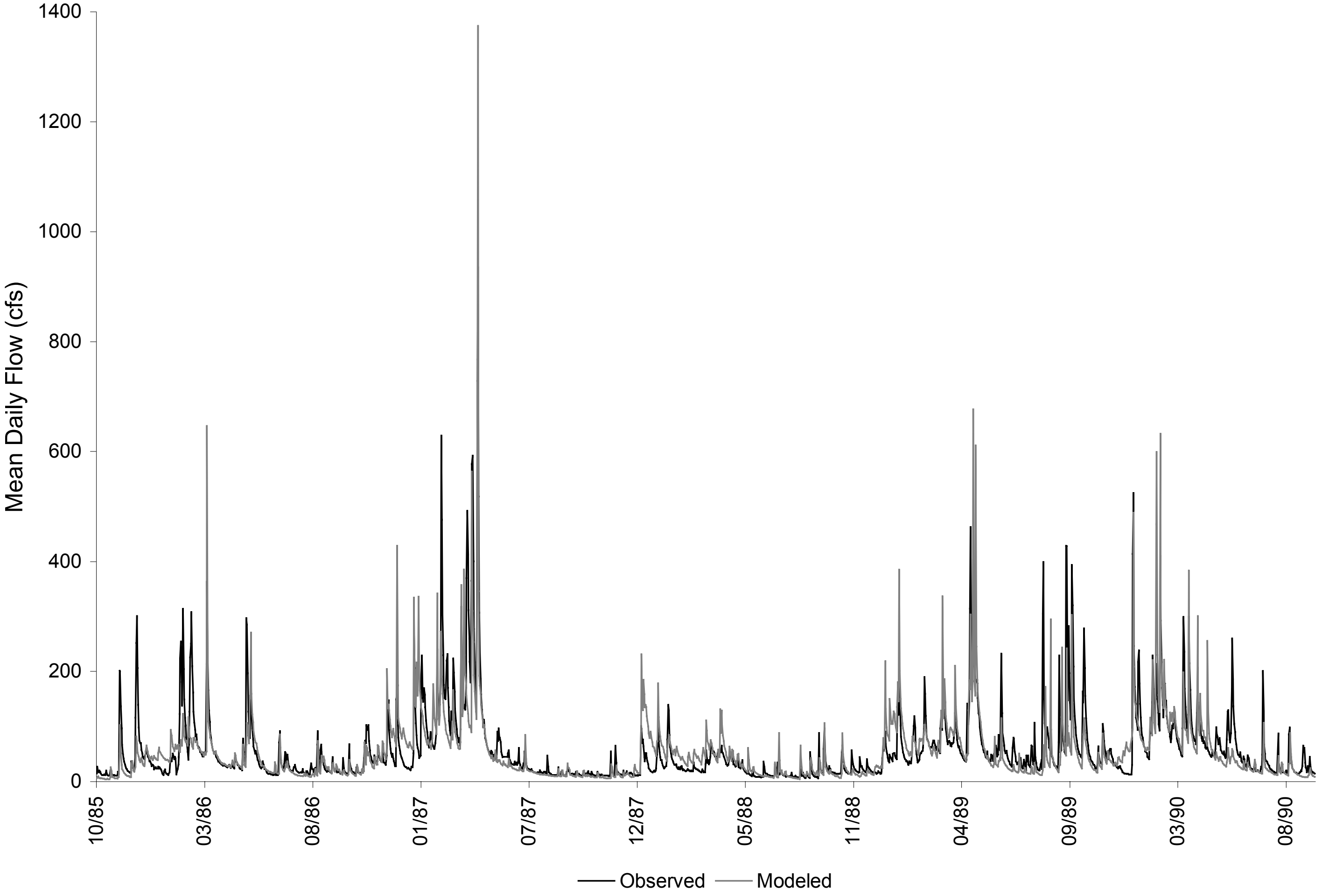


Figure 4.16 Validation results for Bluestone River for the period 10/1/85 through 9/30/90.

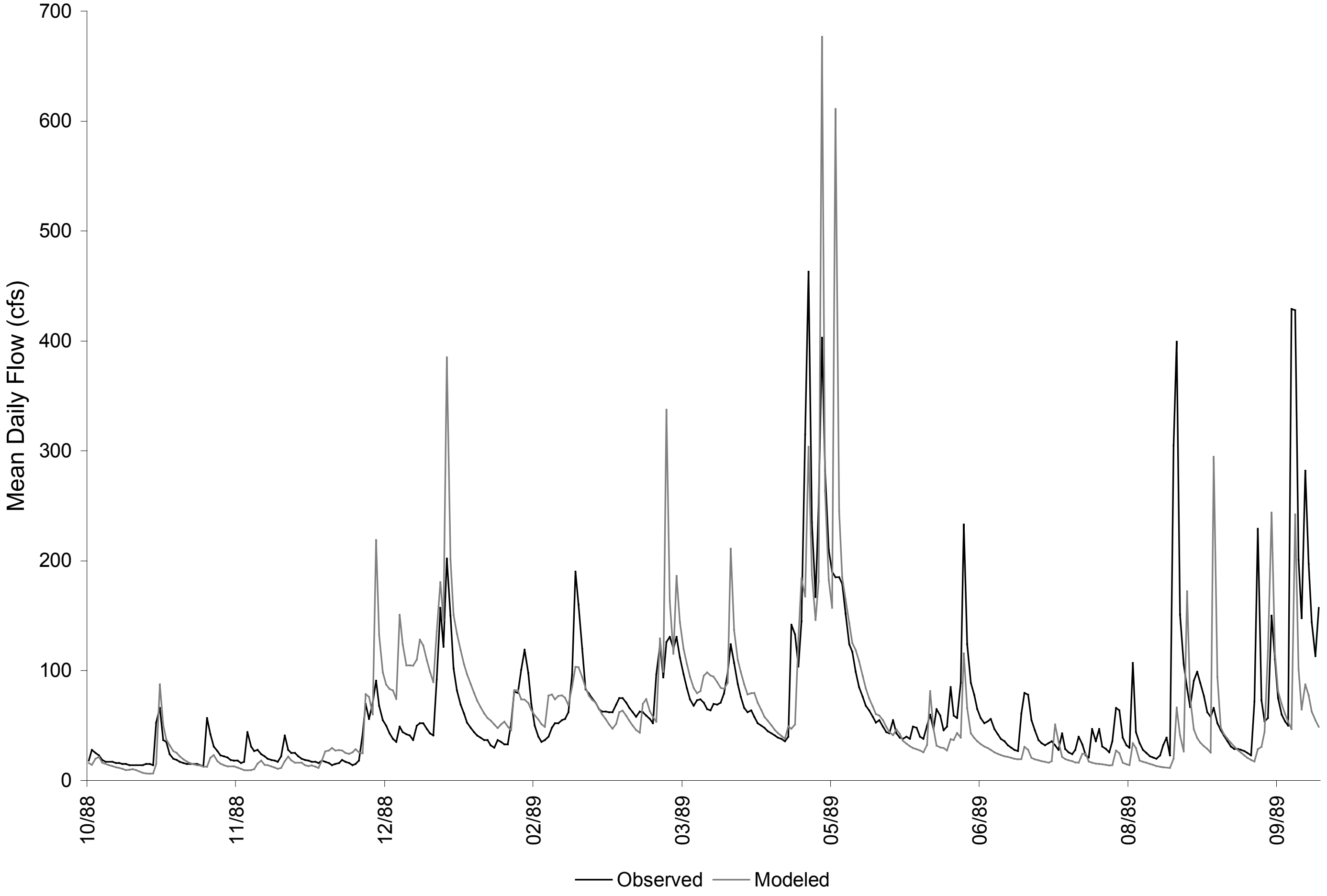


Figure 4.17 Validation results for Bluestone River for the period 10/1/88 through 9/30/89.

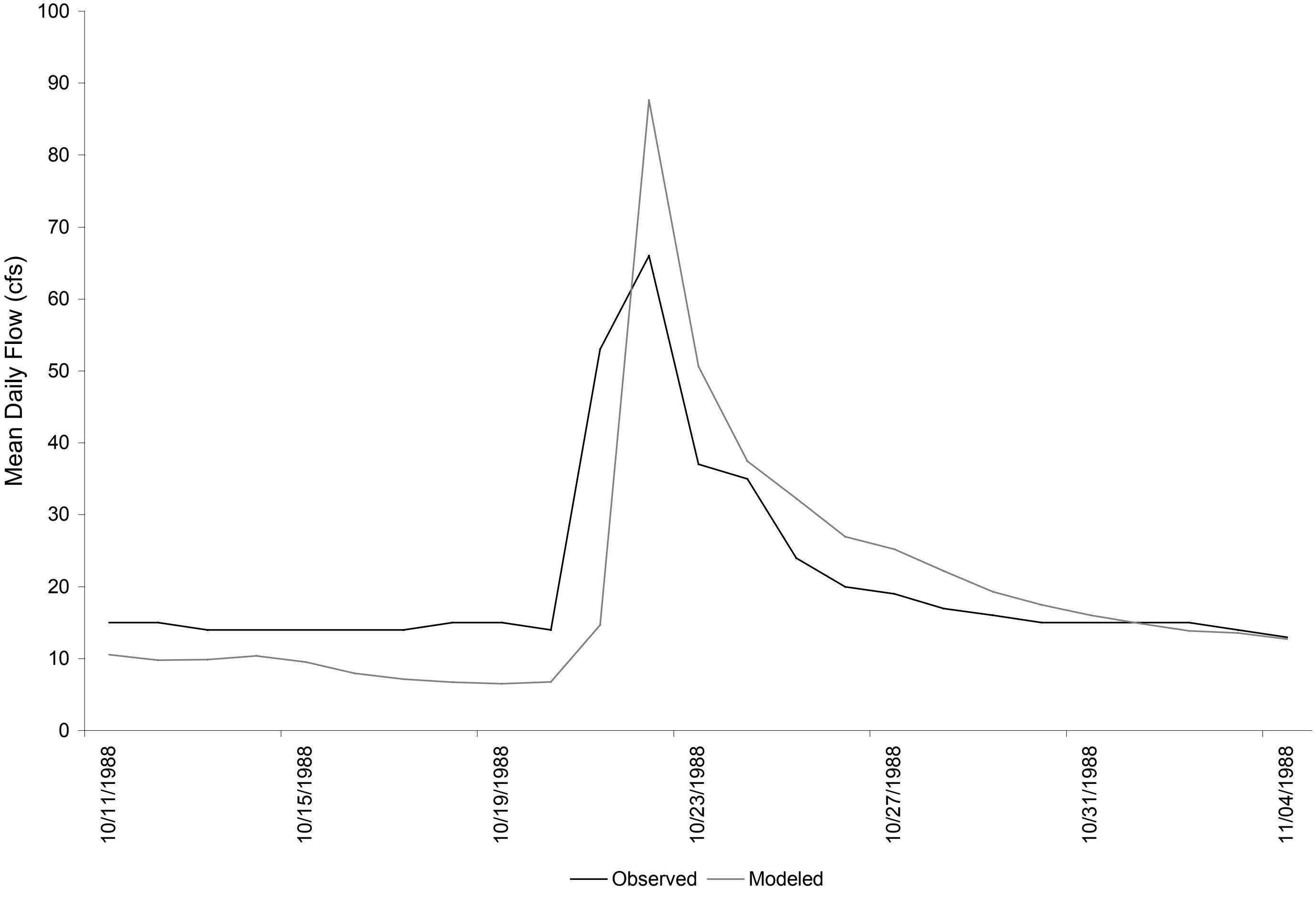


Figure 4.18 Validation results for a single storm for Bluestone River.

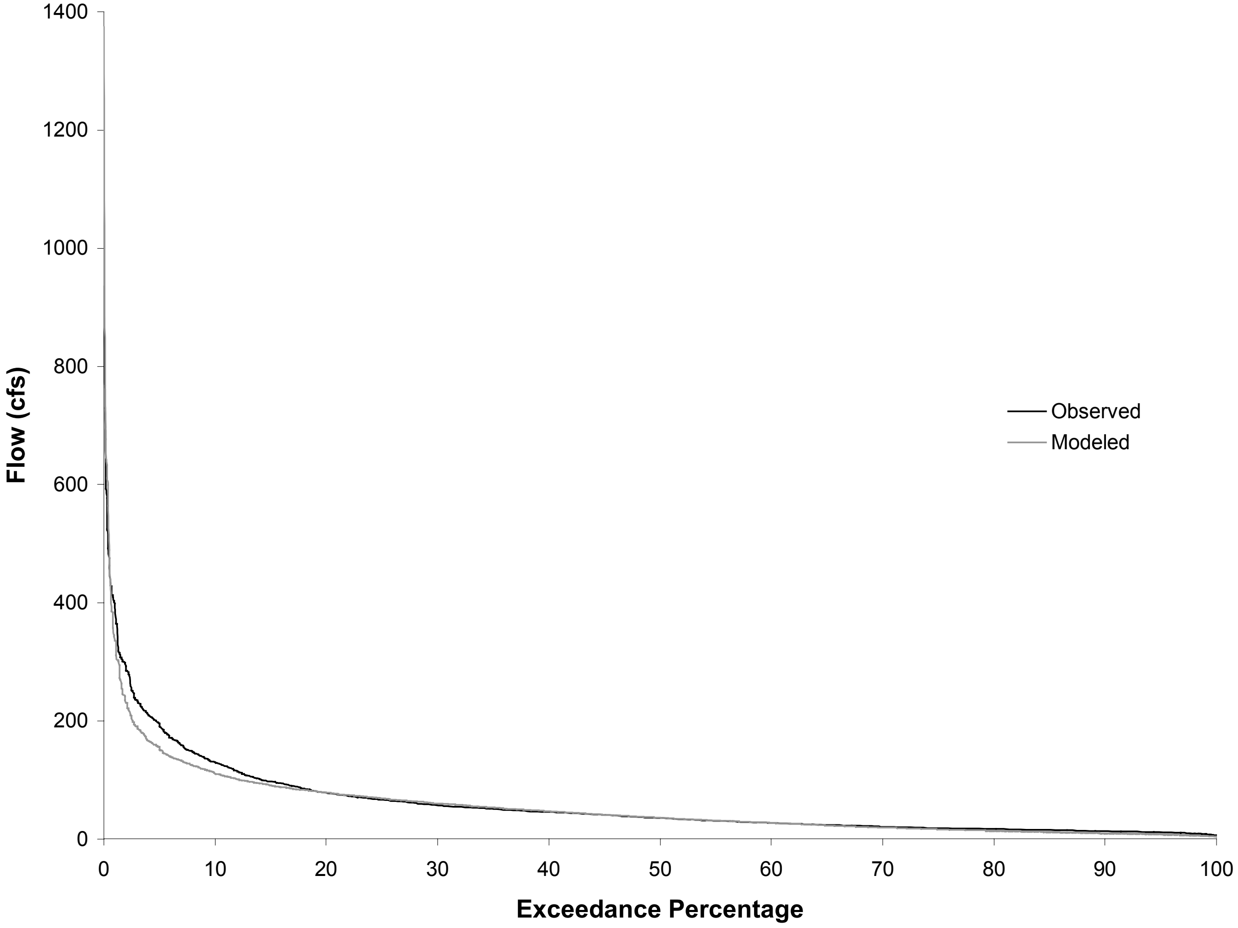


Figure 4.19 Bluestone River flow duration for validation period (October 1, 1985 – September 30, 1990)

4.7.2 Water Quality Calibration and Validation

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

The water quality calibration was conducted using monitored data from 10/1/93 through 9/30/98. Three parameters were utilized for model adjustment; in-stream first-order decay rate (FSTDEC), maximum accumulation on land (SQOLIM), and rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.14). Figures 4.20 and 4.21 show the results of calibration. Short-period fluctuations in the modeled data denotes the effective modeling of the variability within daily concentrations that was achieved through distributing direct depositions from wildlife, livestock, and uncontrolled discharges across each day (Section 4.3). Modeled coliform levels successfully predicted both high and low coliform values during a variety of flow condition that were consistent with trends in the observed data.

Table 4.14 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 – 8.0E+10	0.0E+00 – 8.0E+10
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0E+00 – 3.6E+11	0.0E+00 – 4.0E+12
WSQOP	in/hr	0.05 – 3.00	0-1.8	0.01- 3.06
IOQC	FC/ft^3	0.0E+00 – 1.0E+06	0	0
AOQC	FC/ft^3	0 – 10	0	0
DQAL	FC/100ml	0 – 1,000	200	200
FSTDEC	1/day	0.01 – 10.00	1.15	0.01
THFST	---	1.0 – 2.0	1.07	1.07

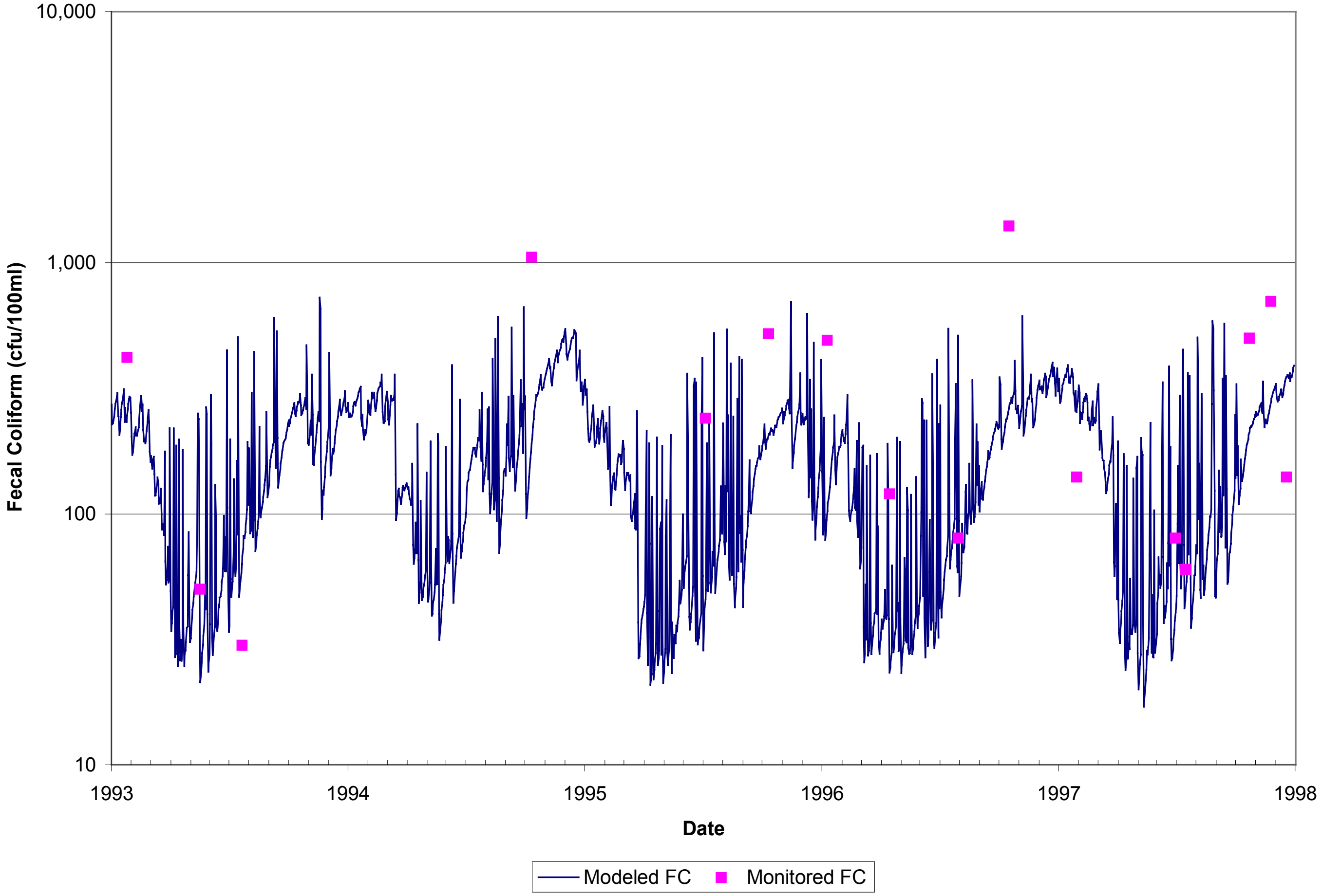


Figure 4.20 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Bluestone River impairment, during the calibration period.

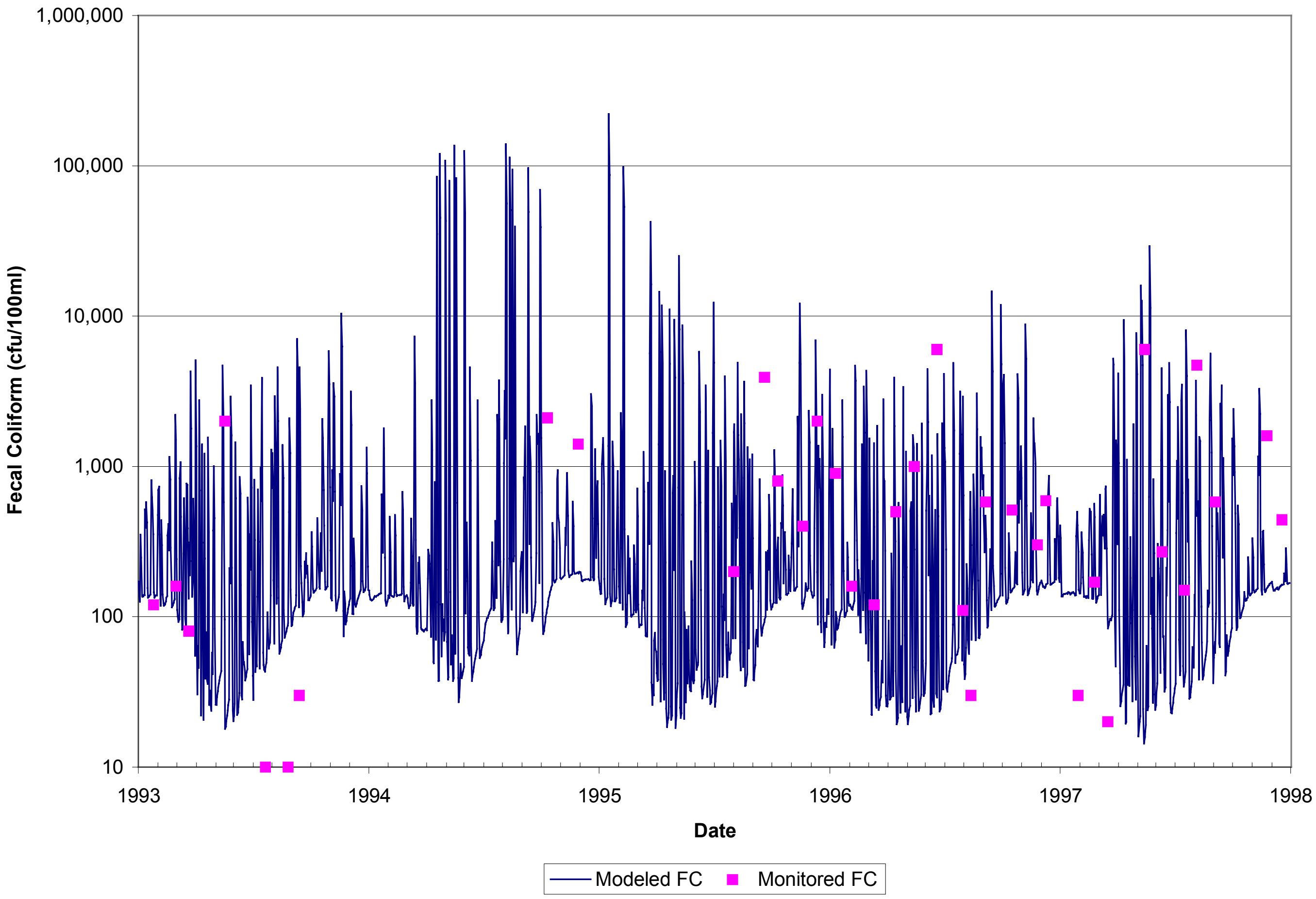


Figure 4.21 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 4 in the Bluestone River impairment, during the calibration period.

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

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

where

$observed$ = an observed value of fecal coliform

$modeled_i$ = a modeled value in the 2 - day window surrounding the observation

n = the number of modeled observations in the 2 - day window

This 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, and 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 4.15).

Table 4.15 Results of analyses on calibration runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-BST023.05	152	487,830
9-BST029.57-71	71	1,584

The water quality validation was conducted using data for the time period from 10/1/98 to 12/31/02. The relationship between observed values and modeled values is shown in Figures 4.22 and 4.23. The results of standard error and maximum value analyses are reported in Table 4.16. Standard errors calculated from validation runs were comparable to standard errors calculated from calibration runs. Maximum simulated values were comparable to observed values in the area (Section 2).

Table 4.16 Results of analyses on validation runs.

WQ Monitoring Station	Mean Standard Error (cfu/100 ml)	Maximum Simulated Value (cfu/100 ml)
9-BST023.05	121	296,110
9-BST029.57-71	49	1,572

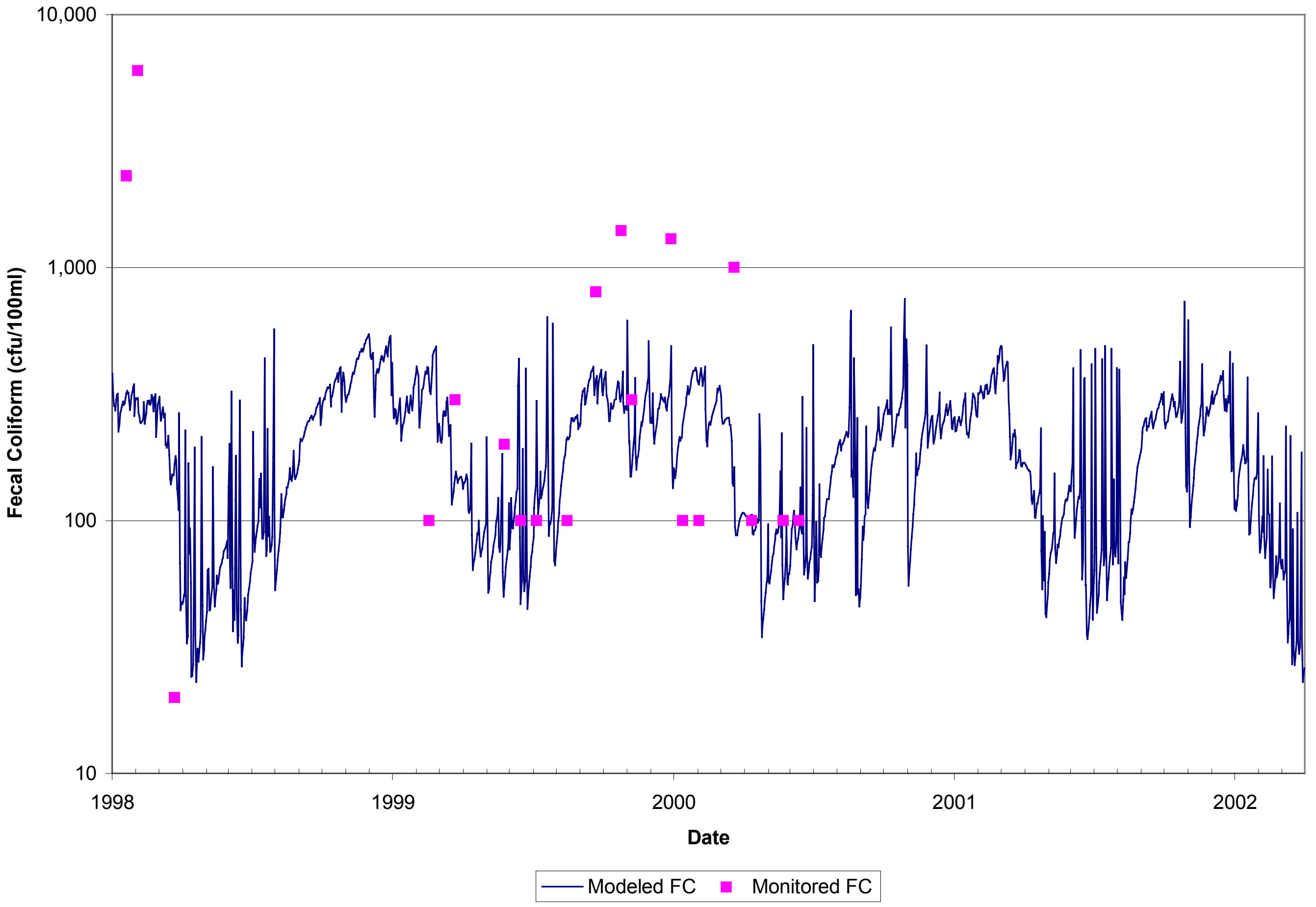


Figure 4.22 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 2 in the Bluestone River impairment, during the validation period.

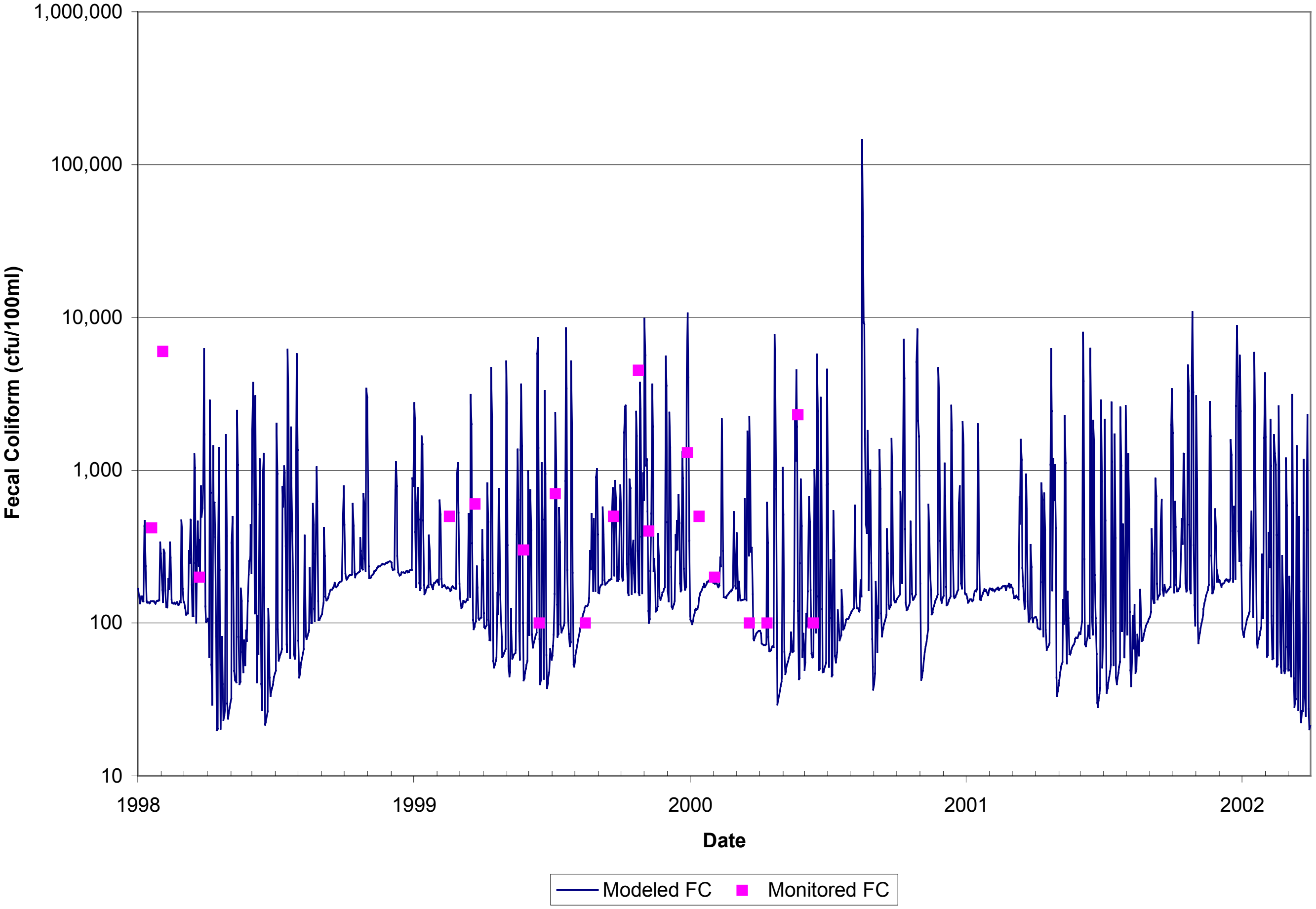


Figure 4.23 Mean daily modeled fecal coliform concentrations compared to instantaneous observed fecal coliform concentrations for subwatershed 4 in the Bluestone River impairment, during the validation period.

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 a representative period used for hydrologic calibration (10/1/80 through 9/30/85). Figure 4.18 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126 cfu/100 ml standard. Figure 4.19 show 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.

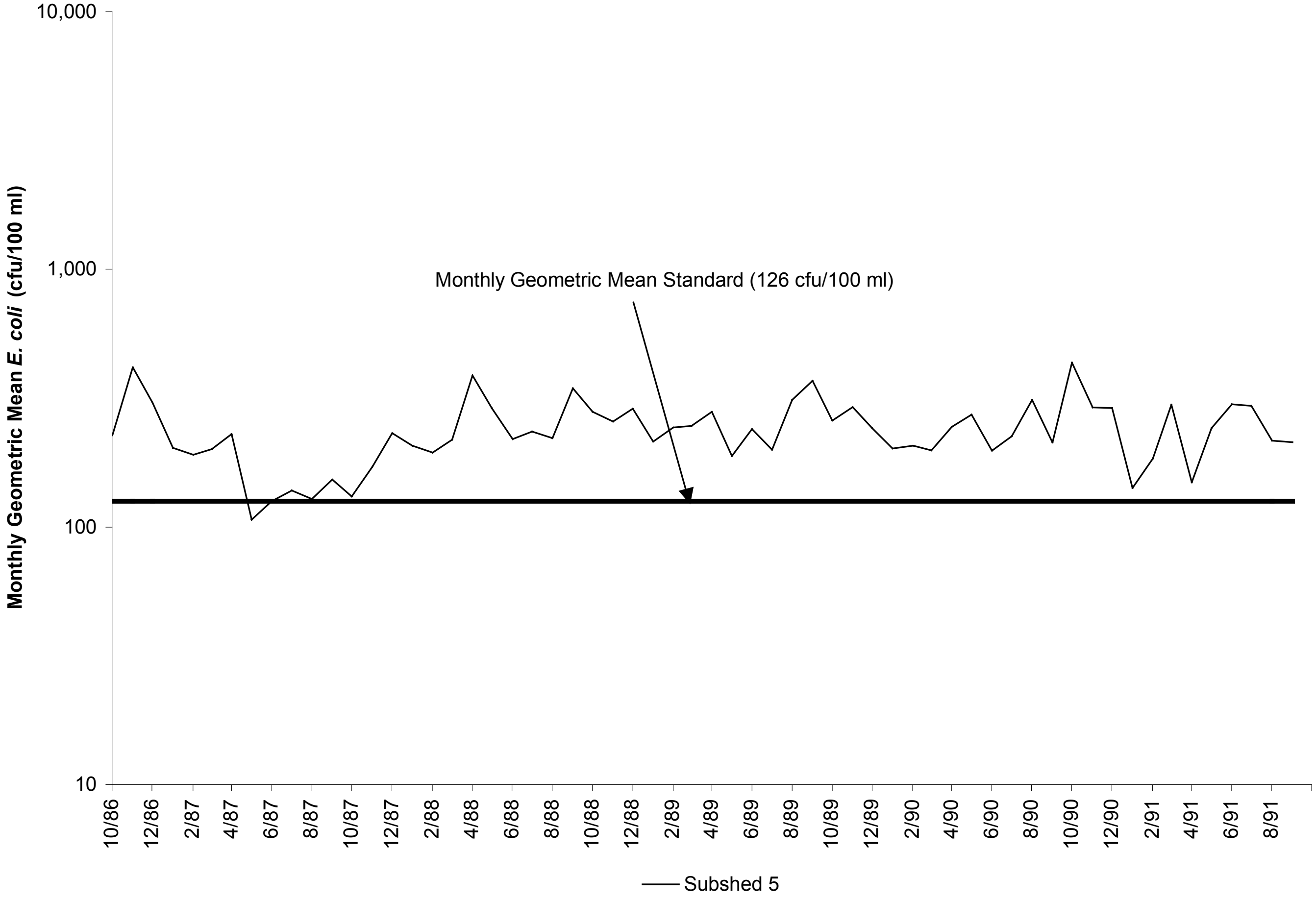


Figure 4.24 Existing conditions (*i.e.*, monthly geometric-mean) of *E. coli* concentrations at the outlet of the Bluestone River impairment.

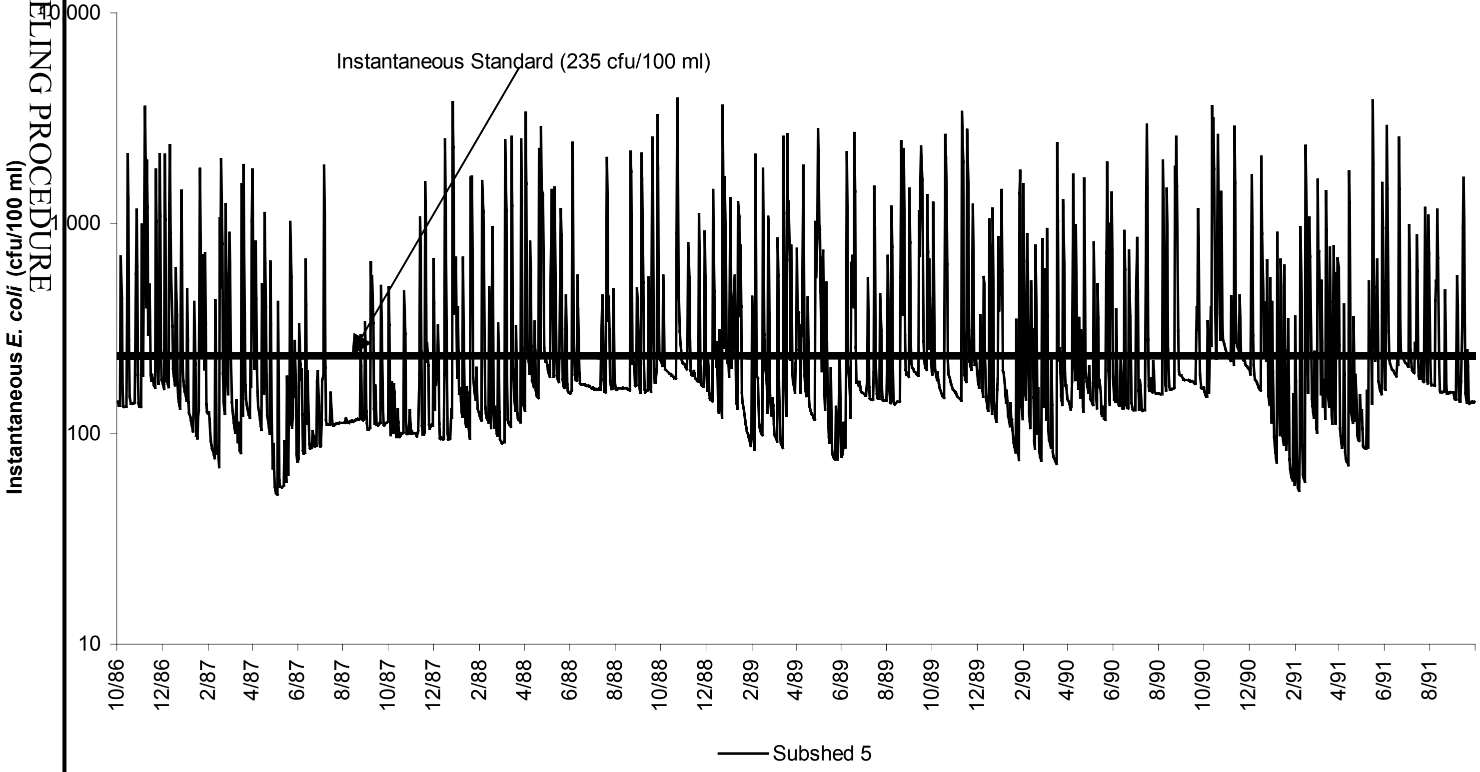


Figure 4.25 Existing conditions (*i.e.*, instantaneous) of *E. coli* concentrations at the outlet of the Bluestone River impairment.

5. ALLOCATION

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

$$TMDL = WLAs + LAs + MOS$$

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

5.1 Incorporation of a Margin of Safety

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

- Allocating permitted point sources at the maximum allowable fecal coliform concentration
- The selection of a modeling period that represented the critical hydrologic conditions in the watershed
- Modeling biosolids applications at the maximum allowable rate and fecal coliform concentration in all permitted fields

5.2 Scenario Development

Allocation scenarios were modeled using HSPF. Existing conditions were adjusted until the water quality standards were attained. The TMDL developed for the Bluestone River 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.

Although West Virginia's fecal bacteria standard is based on fecal coliform, the resulting water quality endpoints are nearly identical to those of Virginia, based on the equation described above. For development of this TMDL, it was assumed that waters crossing the WV-VA border were meeting the WV standard. All allocations described here apply solely to Virginia lands and waters. West Virginia is moving ahead with its own TMDL process for the Bluestone River watershed. Specifics of the load reductions for the West Virginia portion of the study area will be determined through this process (Section 10.2).

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

5.2.1 Wasteload Allocations

There are nine point sources currently permitted to discharge in the Bluestone River watershed (Figure 3.1 and Table 3.1). Of these sources, only two are permitted for fecal control in the impairment area. For allocation runs, sources without fecal control permits were modeled as discharging the average recorded value of water, with no *E. coli* bacteria. The allocation for these sources is zero cfu/100 ml. The allocation for the sources permitted for fecal control is equivalent to their current permit levels (*i.e.,* design flow and 126 cfu/100 ml).

5.2.2 Load Allocations

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

Allocation scenarios for Bluestone River are shown in Table 5.5. 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.

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 livestock or wildlife. This scenario improved conditions in the stream, but failed to eliminate exceedances.

Scenario 3 continued with reductions to anthropogenic sources of 50% to land loads from urban and agricultural lands and a 90% reduction to direct loads from livestock. As noted in Table 5.5, the number of exceedances is reduced but violations persist. With scenario 4, the reduction of land-based loads was increased from 50% to 60% and reductions to direct livestock loads increased to 100% in addition to the reductions in Scenario 2. Scenario 4 still does not meet either water quality standards. With land-based reductions increased to 99%, Scenario 5 in Table 5.5, neither water quality standard is met. The geometric mean and instantaneous standard cannot be met without reductions to wildlife. Additional scenarios were made by first exhausting options related to anthropogenic sources then iteratively making reductions in wildlife until a reduction scenario was found that resulted in zero exceedances of the standards (Scenario 7, Table 5.5).

Table 5.1 Allocation scenarios for bacterial concentration with current loading estimates in the Bluestone River impairment.

	Percent Reduction in Loading from Existing Condition						Percent Violations	
Scenario Number	Direct Wildlife	NPS Wildlife	Direct Livestock	NPS Pasture / Livestock	Res./ Urban	Straight Pipe/ Sewer Overflow	GM > 126 cfu/ 100ml	Single Sample Exceeds 235 cfu/ 100ml
1	0	0	0	0	0	0	98.3	31.8
2	0	0	0	0	0	100	95.0	31.7
3	0	0	90	50	50	100	68.3	21.6
4	0	0	100	60	60	100	51.7	19.3
5	0	0	100	99	99	100	1.67	5.37
6	0	50	100	99	99	100	0.0	1.59
7	0	74	100	99	99	100	0.0	0.0

Figures 5.7 and 5.8 show graphically the existing and allocated conditions for the geometric-mean concentrations and instantaneous concentrations, respectively. Table 5.2 indicates the land-based and direct load reductions resulting from the final allocation. Table 5.3 shows the final TMDL loads for the impairment.

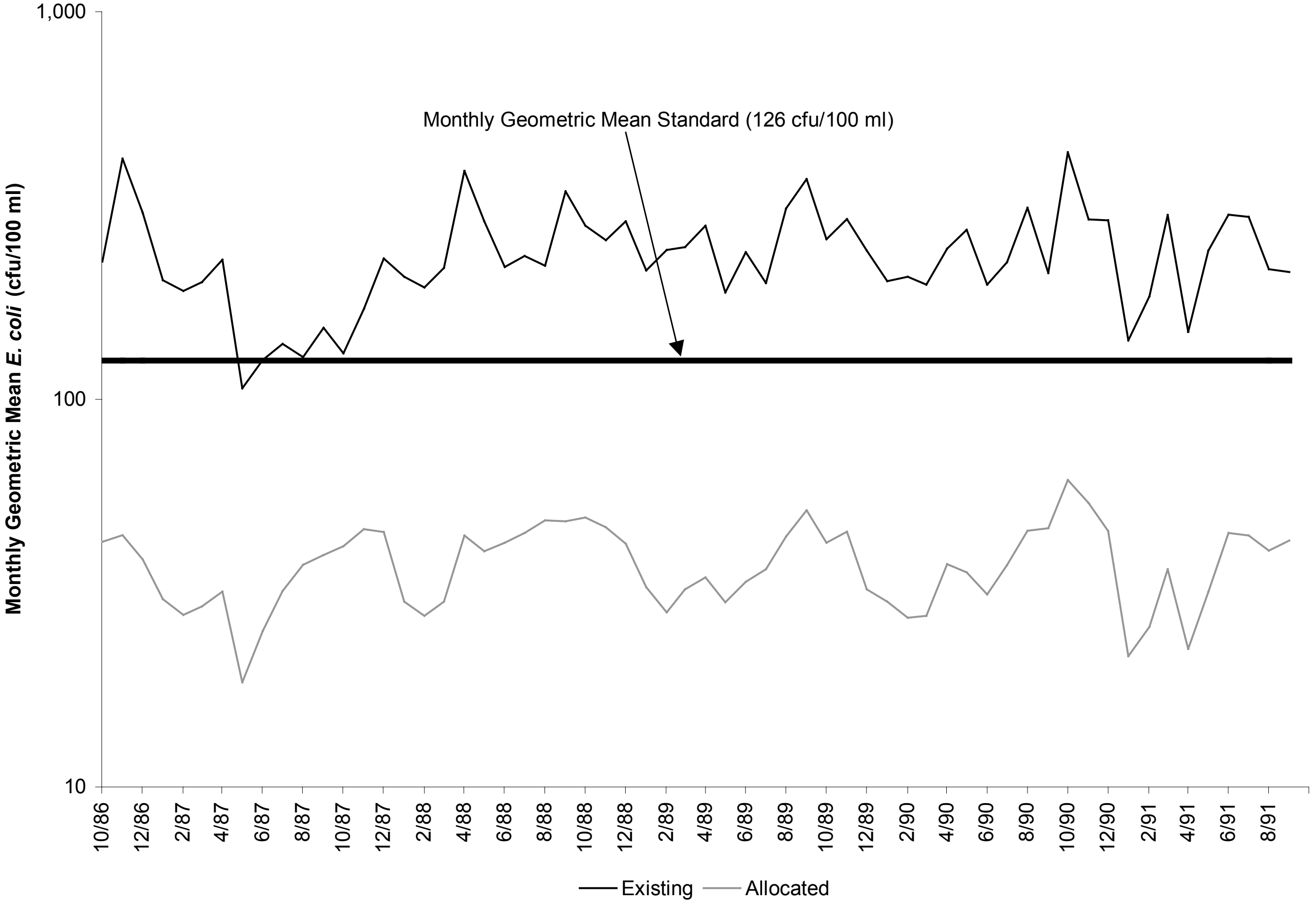


Figure 5.1 Monthly geometric mean *E. coli* concentrations for the Bluestone River impairment, under existing and allocated conditions.

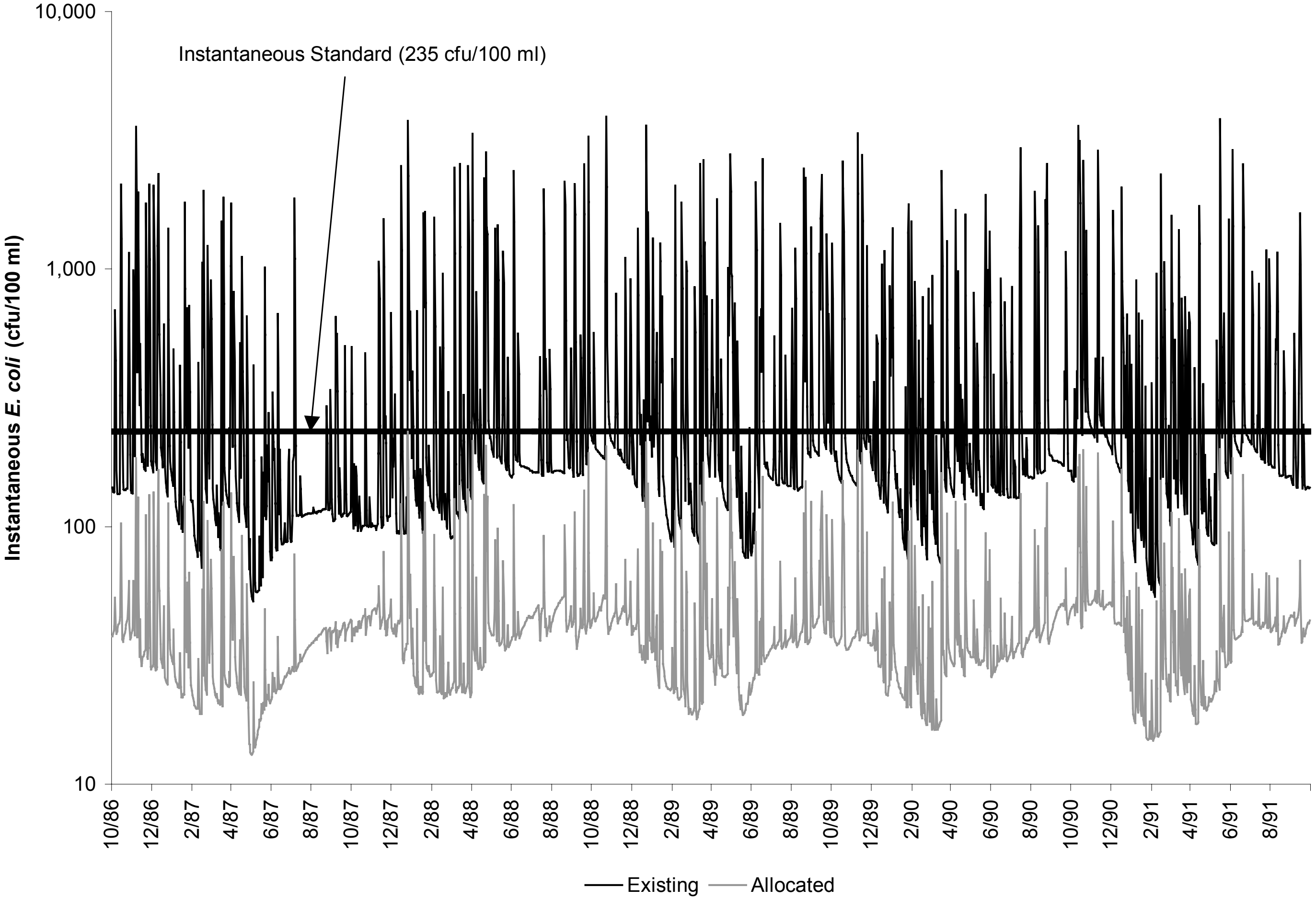


Figure 5.2 Instantaneous *E. coli* concentrations for the Bluestone River impairment, under existing and allocated conditions.

Table 5.2 Land-based and Direct nonpoint source load reductions in the Bluestone River 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	6.42E+14	6.42E+12	99
Commercial	2.608E+13	2.61E+11	99
Barren	6.105E+12	6.10E+10	99
Cropland	5.93E+13	5.93E+11	99
Livestock Access	3.32E+14	3.32E+12	99
Pasture	1.50E+15	1.50E+13	99
Forest	8.87E+14	2.31E+14	74
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	2.42E+13	0.00E+00	100
Wildlife	3.05E+12	3.05E+12	0
Straight Pipes and Sewer Overflows	2.40E+11	0.00E+00	100

Table 5.3 Average annual *E. coli* loads (cfu/year) modeled after TMDL allocation in the Bluestone River impairment.

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Bluestone River (FC)	9.41E+12	3.42E+13	Implicit	4.36E+13
VA0025054[1]	*9.23E+12*			
VA0062561[2]	*1.88E+11*			

1 Bluefield Westside WWTP
2 Falls Mills STP

To determine if the allocation scenario presented (Table 5.5, scenario 7) 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) TMDL

6. WATER QUALITY ASSESSMENT

6.1 Benthic Assessment

Bluestone River was listed as violating the General Standard, as well as the Fecal Coliform and Fish Tissue standards. The General Standard is evaluated by VADEQ through application of the Rapid Bioassessment Protocol II (RBP II). Bluestone River was assessed as being moderately impaired based on the RBP II method from a single benthic survey carried out on the Bluestone River at Station 9-BST022.27 on June 25, 1997.

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. Based on the June 25, 1997 benthic survey at Station 9-BST022.27, the SCI score was 27.9, indicating impaired conditions. In Virginia, streams with an SCI of less than 61.3 are approaching conditions unlike references sites. Although SCI scores in the New River watershed have varied by a factor of three between spring and fall samples, the VADEQ biologist has a high level of confidence that the single sample was sufficient to clearly establish the existence of a benthic impairment on the Bluestone River.

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 Figure 6.1. The SCI score is low because the EPT families are not well represented in the benthic community and there were no individuals from the Ephemeroptera order. The last metric displayed is the SCI score, obtained by averaging the eight individual metric scores. Chironomids and Hydropsychids, both families that are adapted to highly sedimented streams, dominate the benthic community.

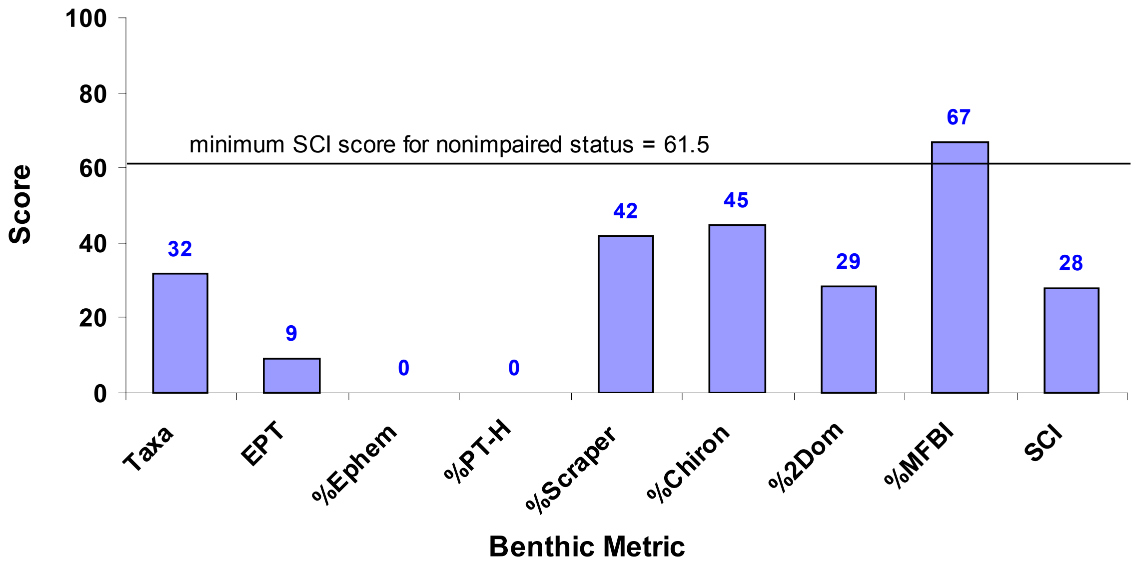


Figure 6.1 SCI metric scores for Bluestone River at Station 9-BST022.27.

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.

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 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 6.1.

Table 6.1 Classification of habitat metrics based on score.

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

Habitat scores for the Bluestone River are displayed in Figure 6.2 and the assessment indicates problems that could easily lead to an impaired benthic community. Riffles and riparian vegetation are on the dividing line between suboptimal and marginal, substrate is marginal, and the score for embeddedness is poor. The metrics in question are related and indicate loss of the particular habitat preferred by the EPT families, *i.e.,* loss of proper substrate caused by sedimentation in riffles leading to embeddedness. The habitat assessment is consistent with findings from the benthic assessment that found the community dominated by Chironomids and Hydropsychidae, both families that are adapted to highly sedimented streams. The consistency in results from the benthic assessment and habitat assessment provides a clear indication of the impaired condition of the stream.

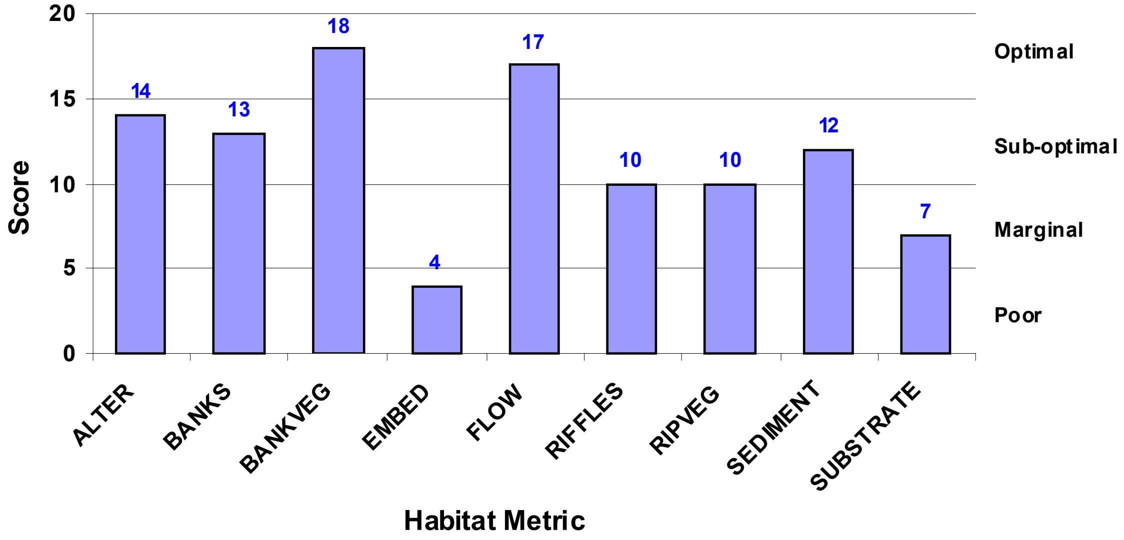


Figure 6.2 Habitat scores for Bluestone River at Station 9-BST022.27.

7. TMDL ENDPOINT: STRESSOR IDENTIFICATION AND REFERENCE WATERSHED SELECTION

7.1 Background

The Bluestone River begins in Tazewell County and flows North-North West into West Virginia (river mile 20.94) before its confluence with the New River. In Virginia it is a third order stream underlain by limestone and dolomite and is influenced by large springs. While the headwaters are mostly rural the Bluestone River flows through an urban area, Town of Bluefield, before entering the State of West Virginia. Bluefield is served by a major municipal point source discharge and the Tazewell County Public Service Authority has a minor municipal discharge located closer to the state line (Table 7.1).

Table 7.1 VPDES discharges in the Bluestone River watershed.

Permit #	Facility	Permitted Flow, MGD
VA0025054	Bluefield Westside WWTP	5.3
VA0062561	Tazewell County PSA/Falls Mills-Hales Bottom	0.108

An industrial park is just upstream of Bluefield and Bluefield's raw water intake is on the Bluestone River. The Tazewell County landfill is on the drainage divide between the Bluestone and Clinch Rivers. The active portion of the landfill and monitoring wells are in the Clinch River drainage. The Tazewell County Landfill is active and therefore required to submit annual groundwater monitoring data reports. The 2002 data was reviewed even though it was collected in another watershed.

The U.S. Geological Survey had a flow measuring gage on the Bluestone River from 10/1/1980 – 4/27/1997 at the Rt. 717 bridge (river mile 23.05). There was no chemical data associated with it. There was a single sampling event on a very limited number of parameters in 2000 from two USGS wells in the watershed.

Only one benthic survey on the Bluestone River (6/97) is available for this stressor analysis. The survey site is located downstream of the Rt 717 bridge at river mile 22.27

and is approximately two miles downstream of the major municipal discharge from the Westside Bluefield WWTP. The Bluestone River is a third order stream at the survey site. This site is also where a VADEQ ambient monitoring station is located and a USGS flow gaging station was located there until 1997. Martin Creek a fourth order stream in the Clinch River Basin was the reference station used for the Bluestone River benthic survey.

No recent chemical data is available for Martin Creek so a comparison with the Bluestone River is not possible. The upper Peak Creek in Pulaski County was used since it is a third order non-impaired reference station for other streams in the New River Basin and it has similar geology.

Table 7.2 lists the VADEQ ambient monitoring stations in the Bluestone River. Ambient monitoring data from all the Bluestone River stations are included in Appendix D.

Table 7.2 VADEQ ambient water quality monitoring stations on the Bluestone River.

Station	Description	Type	Period of Record
9-BST021.26	Rt. 643 Bridge	Special, Study, Fish Tissue	7/90, 8/17/00
9-BST023.05	Rt. 717 at gage	Ambient	5/26/92-Present
9-BST029.57	Private Bridge-Richwood	Ambient	7/16/92-Present
9-BST029.71	Rt. 650 Bridge above WTP	Ambient, Fish Tissue	9/67-10/91, 8/17/00

Limited information is available for seven small discharges permitted under VADEQ's general permit program (Table 7.3).

Table 7.3 VADEQ general permits in the Bluestone River watershed.

Permit #	Facility	Stream
VAG400041	Cassell Titus Residence SFH STP	Bluestone River
VAG400048	Coal Fillers Incorporated	Wrights Valley Creek
VAG400093	Harrys STP	Bluestone River
VAG400164	Ron's Kwik Stop #1 STP	Bluestone River, X-Trib
VAG750006	Mickel's Car Wash	Bluestone River
VAG750039	Mike's Soft Cloth	Bluestone River
VAG840021	Pounding Mill Quarry Corporation/Bluefield PI	Wright's Valley Creek

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 EPA's Stressor Identification Guidance Document (EPA, 2000) was used to separately identify the most probable stressor(s) for the Bluestone River. 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, ammonia, and organic matter.

The results of the stressor analysis for the Bluestone River 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 data 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 the Bluestone River at monitoring station 9-BST023.05 was 23.4 ^{o}C, which is well below the special state standard for the New River Basin of 27 ^{o}C (Figure 7.1). Temperature readings as high as 28 ^{o}C were measured upstream of the benthic impaired segment. Therefore, temperature can be eliminated as a potential stressor.

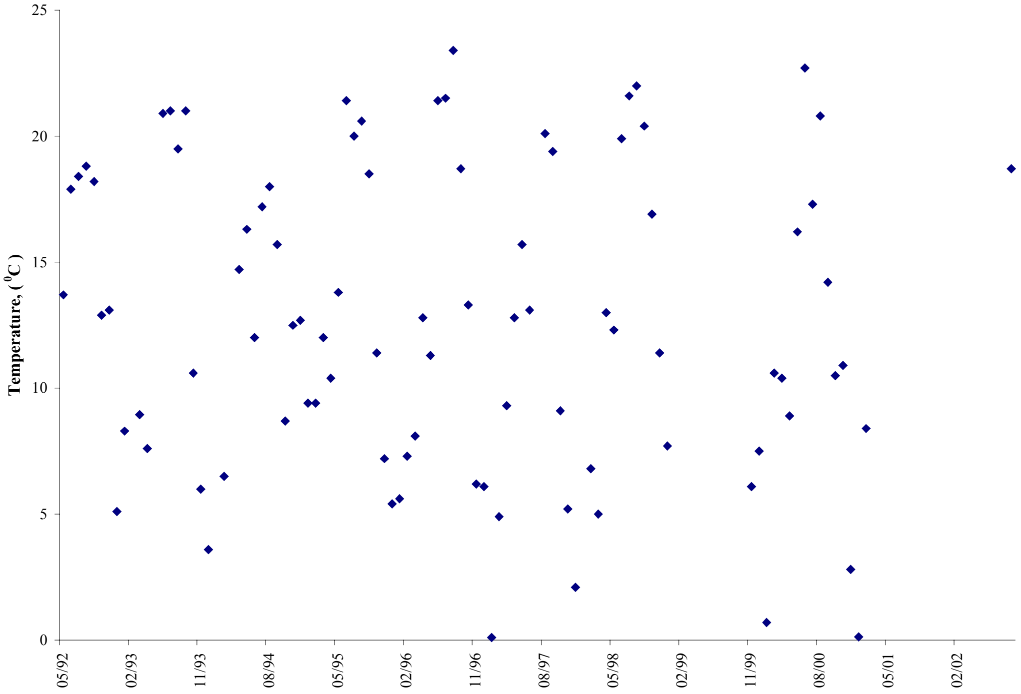


Figure 7.1 Water temperature at 9-BST023.05.

7.1.1.2 pH

The maximum and minimum pH values were within the state standards range of 6-9 at the 9-BST023.05 monitoring station (Figure 7.2). Alkalinity concentrations are also constant and within the expected normal range of 30 – 500 mg/l for this ecoregion (Figure 7.3). Therefore, pH was eliminated as a possible stressor.

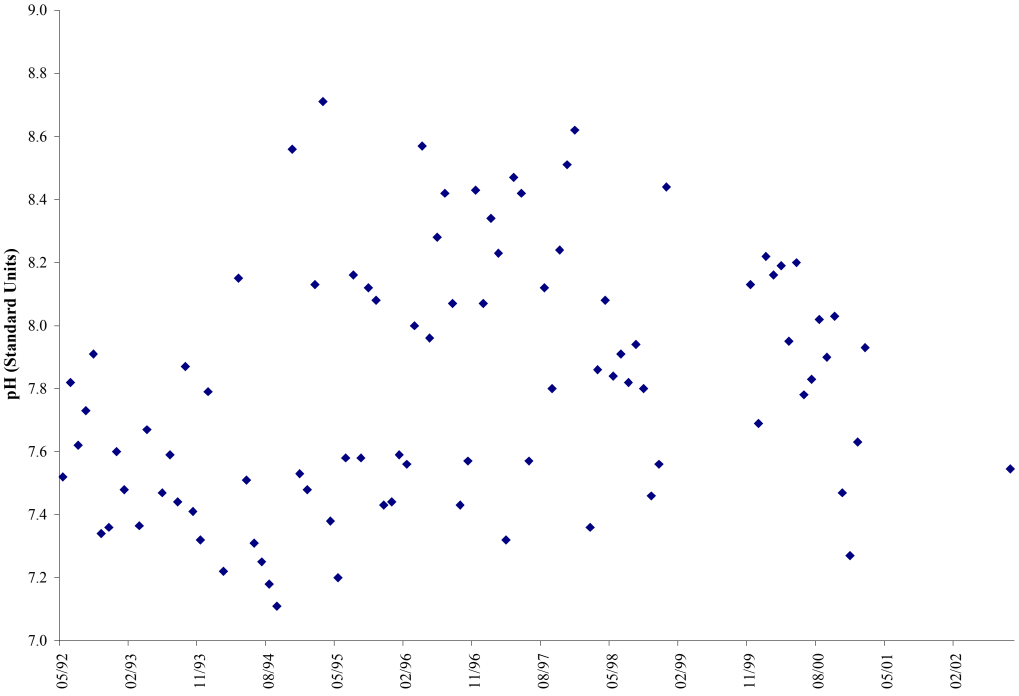


Figure 7.2 **Field pH data at 9-BST023.05.**

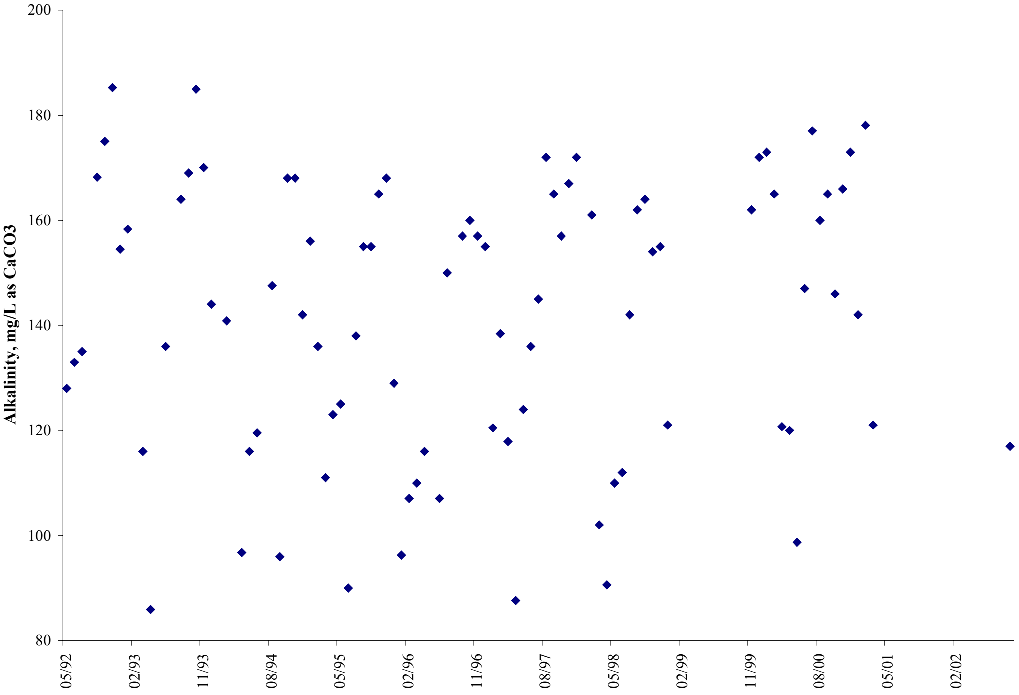


Figure 7.3 **Alkalinity concentrations at 9-BST023.05.**

7.1.1.3 Low Dissolved Oxygen

From October 1992 to September 1994, dissolved oxygen levels were very low; three samples collected during June – August 1993 were below the state's instantaneous minimum standard of 4.0 mg/l (Figure 7.4). According to the VADEQ Southwest Regional Office, the Bluefield Westside WWTP discharged very poor quality effluent in the early 1990s before it was completely upgraded. Since the upgrade, it has been in compliance with its VPDES permit limits. This information corresponds with the normal DO values recorded from the mid 1990s to the present. Low dissolved oxygen was eliminated as a potential stressor.

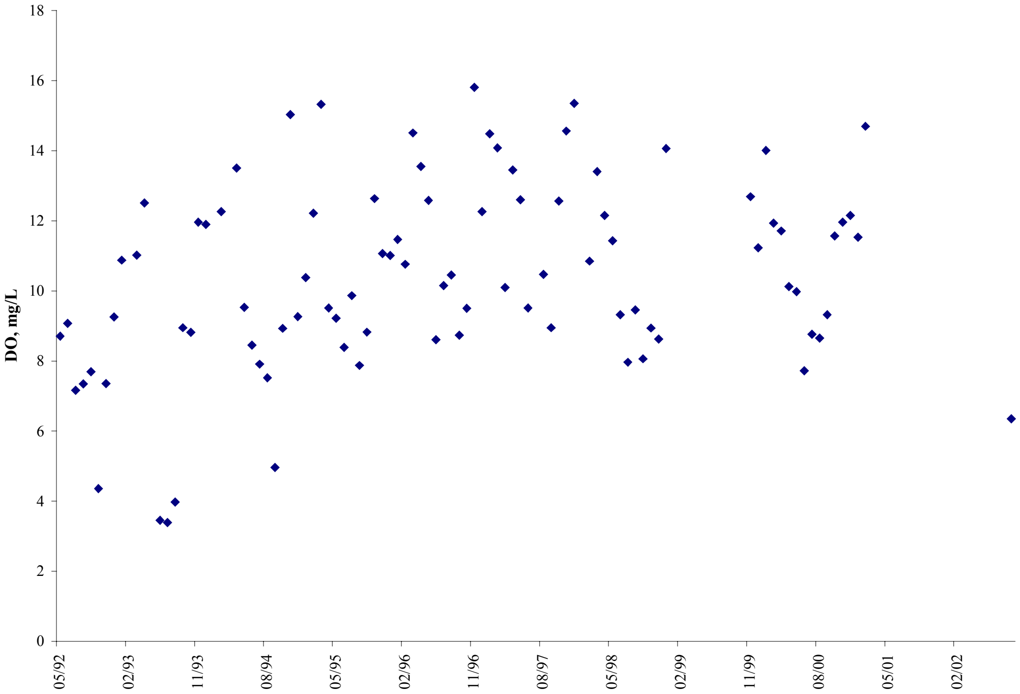


Figure 7.4 Dissolved oxygen concentrations at 9-BST023.05.

7.1.1.4 Metals

Both the water column and sediment monitoring data indicated that metals should not be considered as a likely stressor(s) because values were below the appropriate water quality standard or the consensus based Probable Effect Concentration (PEC; MacDonald et al.,

2000) screening value. The majority of the values were below the minimum detection level.

7.1.1.5 Toxics

Both the water column and sediment monitoring data indicated that toxics should not be considered as likely stressors because values were below the appropriate water quality standard or the PEC screening value (ammonia is discussed separately in the Possible Stressors section). Nearly all of the sample values were below the minimum level of detection. Chloride concentrations were well below the EPA's chronic water quality criterion of 230 mg/l (Figure 7.5). In a letter dated October 21, 2003, the EPA Region III Freshwater Biology Team notified VADEQ that chronic toxicity testing at two sites on the Bluestone River showed no effects on Ceriodaphnia or Fathead Minnows. However, there were some anomalies. PCBs were found in fish tissue samples of carp collected on August 17, 2000 at levels high enough for the Virginia Department of Health to issue a fish consumption advisory for carp. In addition, PCB levels in a white sucker collected at the same time exceeded VADEQ's water quality standard of 54 ppb. VADEQ's Southwest Regional Office is planning additional sediment sampling to try and isolate a potential source(s). It is theoretically possible that the fish could have come from West Virginia. A search of the EPA STORET database of stations monitored by West Virginia on the Bluestone River did not reveal any PCB data. A USGS monitoring site located near Spanishburg, West Virginia did not indicate any elevated levels of PCBs or other toxics. With the limited amount of data available on PCBs, and the chronic toxicity study showing no chronic toxicity impacts, toxic pollutants were eliminated as a potential stressor.

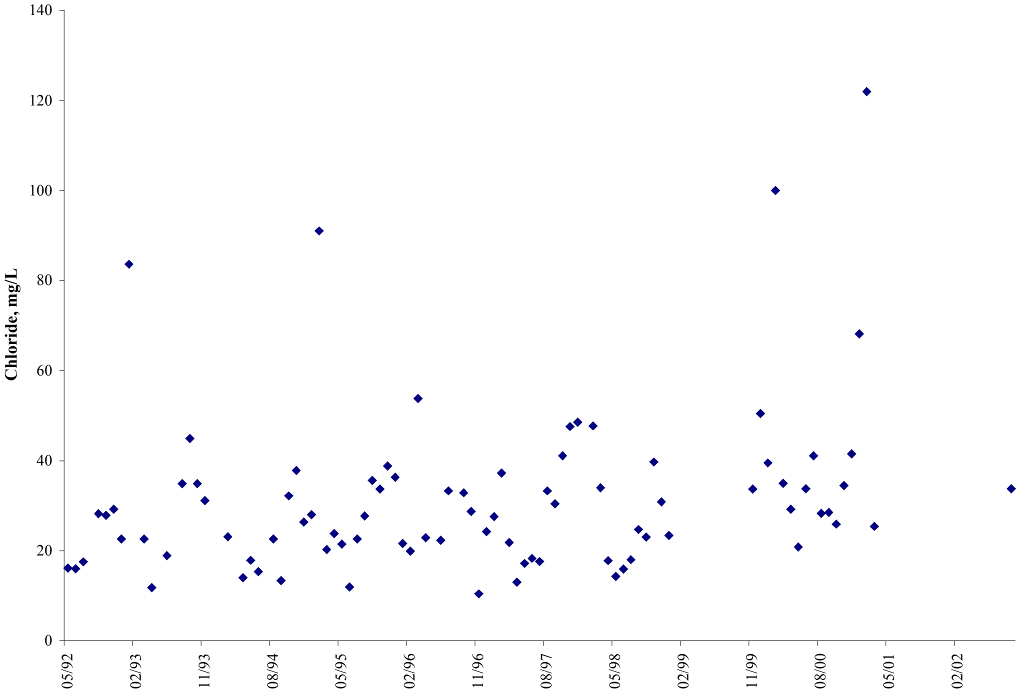


Figure 7.5 Chloride concentrations at 9-BST023.05.

7.1.1.6 Conductivity

Conductivity values varied considerably at 9-BST023.05. They did not reach levels of 1,000 µmho/cm or higher, but in January of 2001 there was a spike of 790 µmho/cm (Figure 7.6). Extremely high or wide swings in values of conductivity can cause environmental stress on benthic macroinvertebrates. Without further supporting data conductivity was eliminated as a potential stressor.

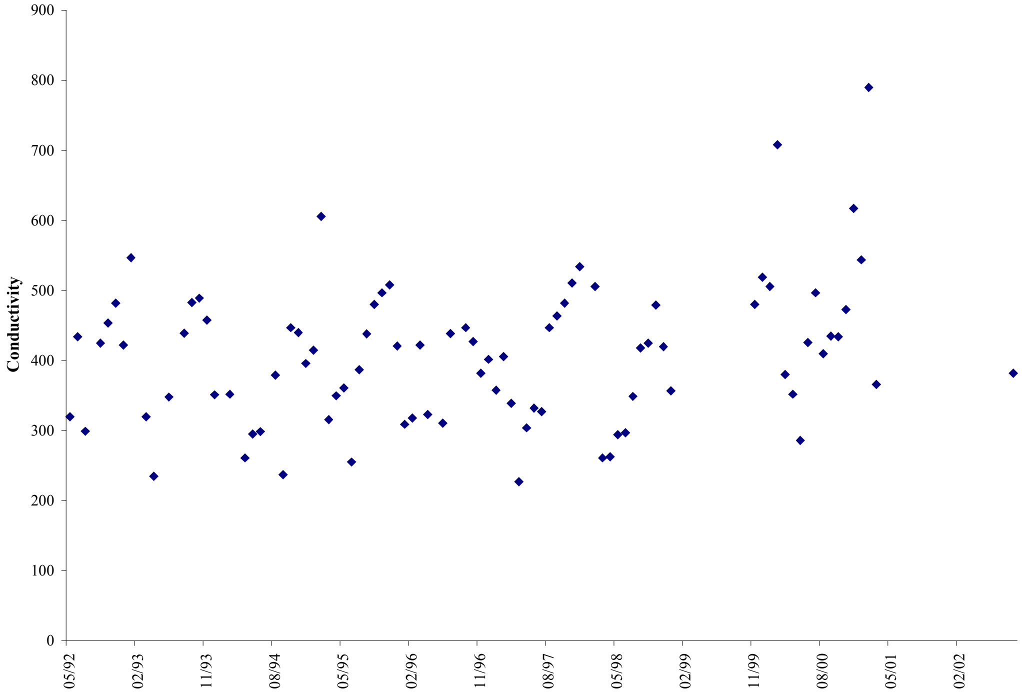


Figure 7.6 Conductivity at 9-BST023.05.

7.1.2 Possible Stressors

7.1.2.1 Nutrients

Median Total Phosphorus (TP) concentrations were well below the VADEQ assessment screening value of 0.2 mg/l. However, there was a high degree of variability in the data at 9-BST023.05, which is typical of monitoring stations downstream of urban areas and large wastewater treatment plant discharges (Figure 7.7). 13 out of 101 samples collected exceeded the screening value for TP concentration during the sampling period. Median TP concentrations at 9-BST023.05 were seven times greater than those at the non-impaired upper Peak Creek reference station (9-PCK011.11) and three times higher than concentrations upstream of Bluefield and the wastewater treatment plant at 9-BST029.57 (Figure 7.8). Median Nitrate Nitrogen (NO_3-N) values were above 1.0 mg/l at 9-BST023.05 (which the USGS considers to be an acceptable background level) and, at times, reached levels of nearly 4.0 mg/l (Figure 7.9). A more thorough examination of nutrients was performed to determine the potential for eutrophication from the existing data. 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. Station 9-BST023.05 had TP concentrations above the Problem Likely to Exist (PLE) threshold during the algal growing season 20% of the time. Therefore if other conditions are present TP concentrations are high enough to cause eutrophication on an infrequent basis. All of the TN values exceeded the PLE threshold. The situation was different upstream at monitoring station 9-BST029.57 where no TP values exceeded the PLE threshold. Total nitrogen values exceeded the PLE threshold 79% of the time. Total nitrogen is still a matter of concern because minor increases in TP concentrations could result in favorable conditions for eutrophication the majority of the time if other conditions are favorable. The benthic survey was dominated by Chironomidae, Elmidae and Simuliidae. When Chironomidae are dominant it is indicative of an environment that is enriched by nutrients and/or organic matter (Voshell 2003). Based on the available chemical and biological data, nutrients are considered a possible stressor.

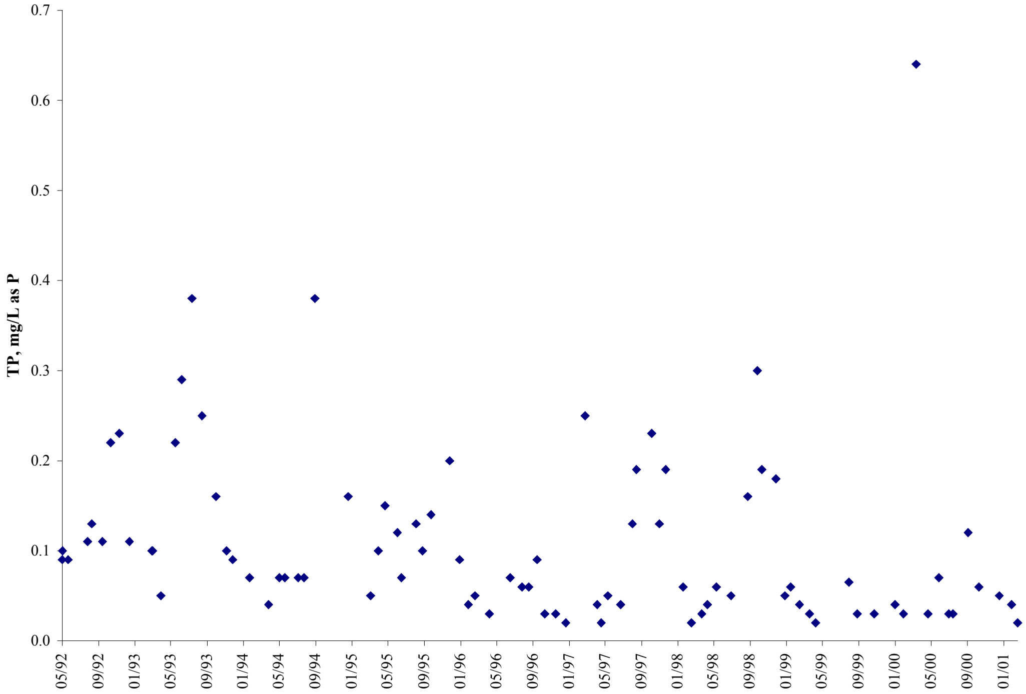


Figure 7.7 **Total Phosphorus concentrations at 9-BST023.05.**

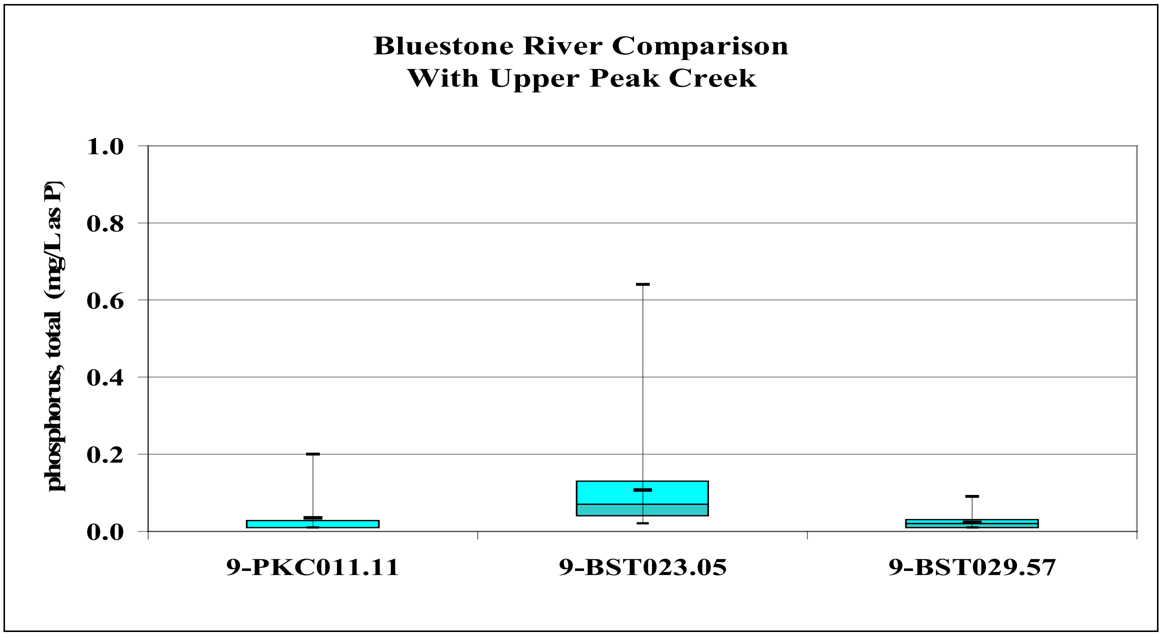


Figure 7.8 **Box & Whisker Plot of Total Phosphorus in the Bluestone River and Upper Peak Creek.**

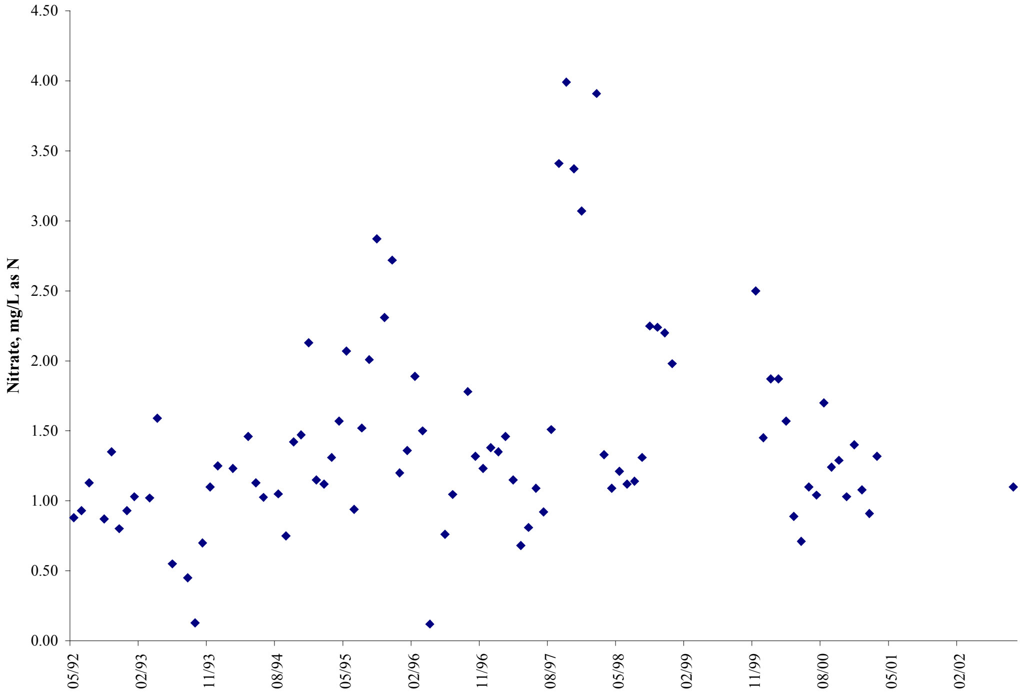


Figure 7.9 Nitrate Nitrogen concentrations at 9-BST023.05.

7.1.2.2 Ammonia

Concentrations of ammonia were considerably higher at the ambient monitoring station 9-BST023.05 than are typically observed in streams in this ecoregion, ranging from 0.04 – 2.32 mg/l with a median of 0.32 mg/l (Figure 7.10). The USGS considers 0.1 mg/l to be a typical freshwater background level for ammonia. Concentrations at an upstream monitoring station (9-BST029.57) ranged from 0.08 – 0.13 mg/l with a median of 0.105 mg/l (Figure 7.11). Very high concentrations at 9- BST023.05 were observed during two time periods (October 1992 to February 1995 and December 1999 to February 2001) and were often associated with low flows. The ammonia concentrations at 9-BST023.05 were lower than the acute freshwater water quality standards in Virginia (Figure 7.12). The 30-day average chronic water quality standard was exceeded once during the September 1993 sampling period (Figure 7.13). This does not represent a water quality standard violation because these concentrations are not 30-day averages; however, it demonstrates that ammonia levels are very high. There is not enough evidence at this point to suggest that ammonia toxicity is a critical stressor in the Bluestone River. With concentrations occasionally exceeding the 30 day average chronic water quality standard, it could become a stressor in the future.

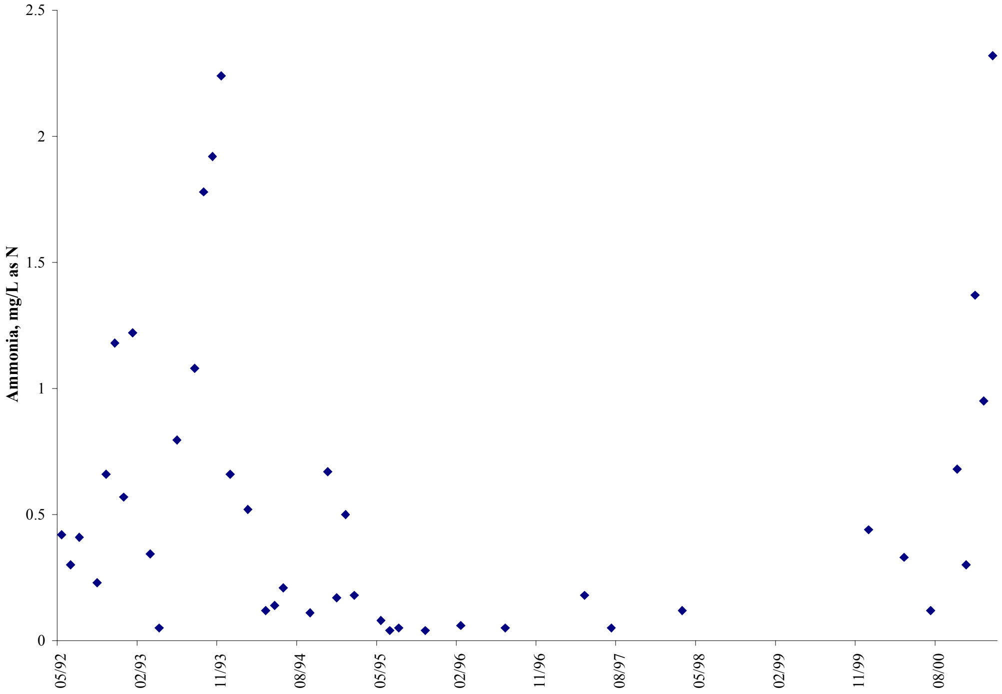


Figure 7.10 Ammonia concentrations at 9-BST023.05.

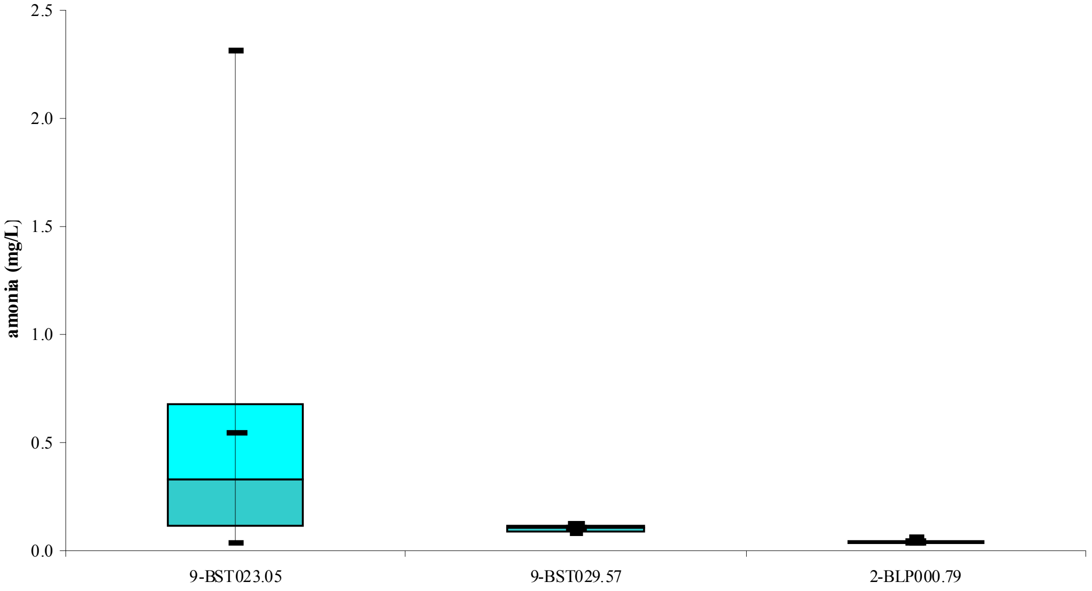


Figure 7.11 Box &Whisker Plot of ammonia in the Bluestone River and Upper Peak Creek.

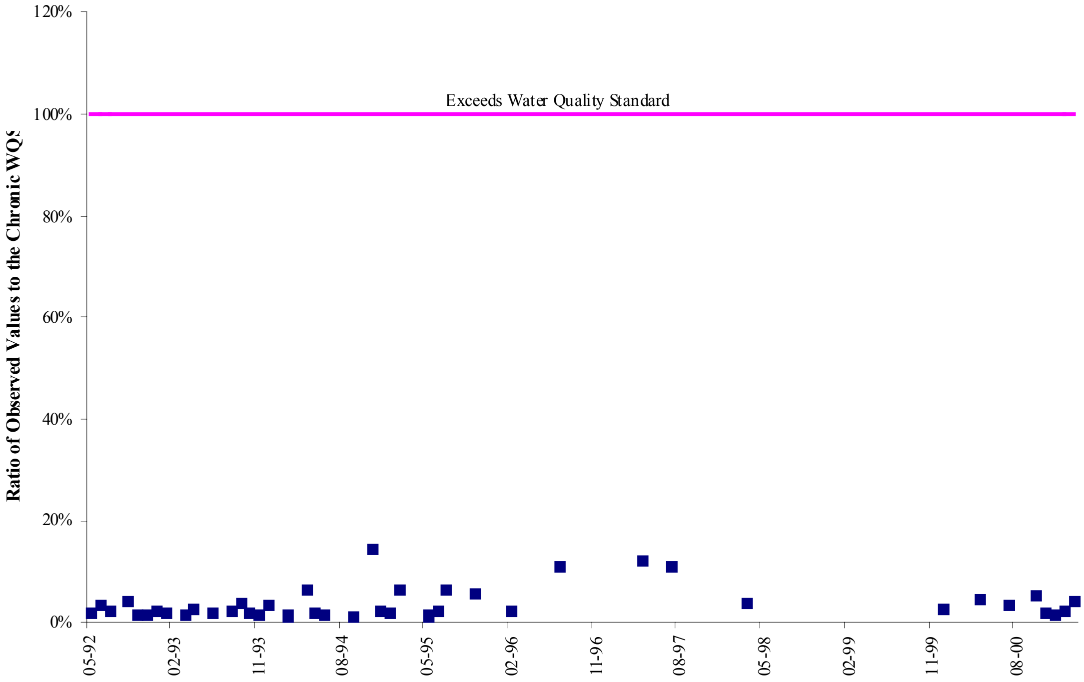


Figure 7.12 Ammonia concentrations at 9-BST023.05 and the acute water quality standard.

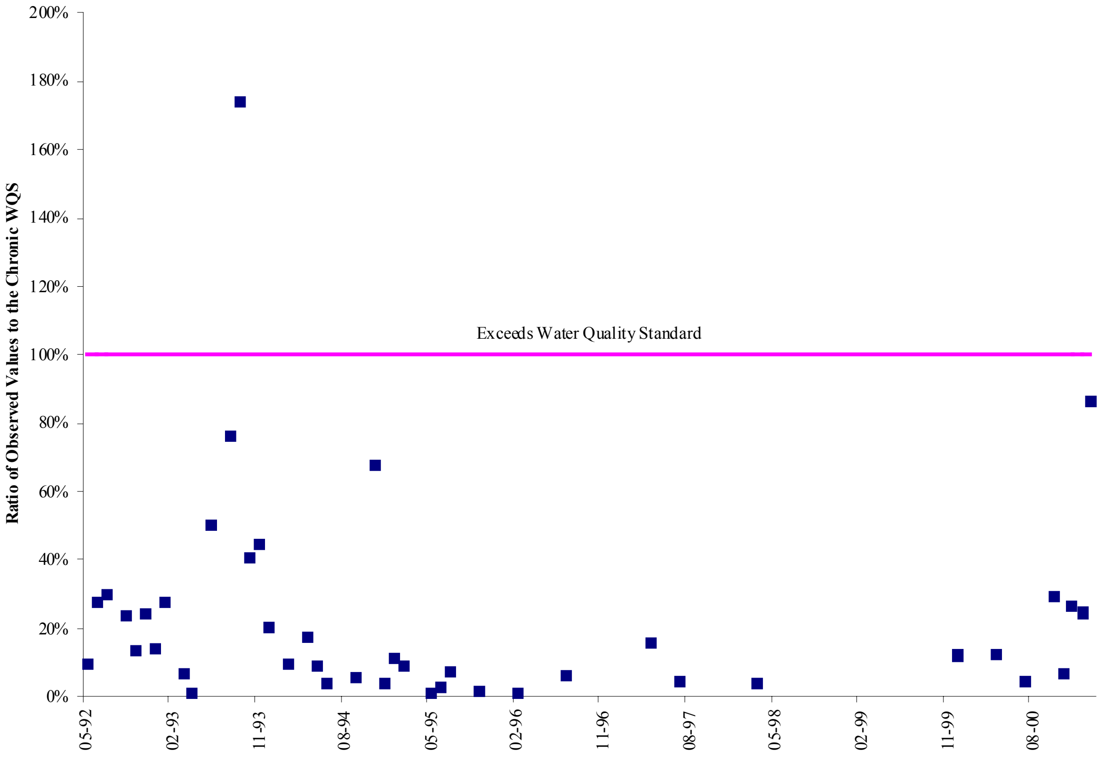


Figure 7.13 Ammonia concentrations at 9-BST023.05 and the chronic water quality standard.

7.1.2.3 Organic Matter

Several different parameters can be used to determine if organic matter in a stream is at a level high enough to impact the benthic macroinvertebrate community. Biochemical oxygen demand (BOD_5) can provide an indication of how much dissolved organic matter is present. Total organic carbon (TOC), chemical oxygen demand (COD), and volatile solids (VS) can be used as indicators of particulate organic matter. BOD_5 concentrations were slightly elevated at 9-BST023.05; however, they were lower toward the end of the sampling period than they were in the early 1990s (Figure 7.14). This is consistent with the dissolved oxygen concentrations discussed earlier. In the early 1990s there were several violations of the minimum instantaneous dissolved oxygen standard of 4.0 mg/l, but oxygen levels were much higher in the mid to late 1990s. This indicates that dissolved organic matter may not be a significant stressor. COD (Figure 7.15) and TOC (Figure 7.16) were within normal expected ranges. Both parameters were higher in the early 1990s. One of the benthic metrics (MFBI) indicates that organic matter in the stream is slightly elevated. Simuliidae were a dominant organism in the benthic survey and they thrive on organic matter (Voshell 2002) further demonstrating the potential for organic enrichment. Based on this information, particulate organic matter is a possible stressor.

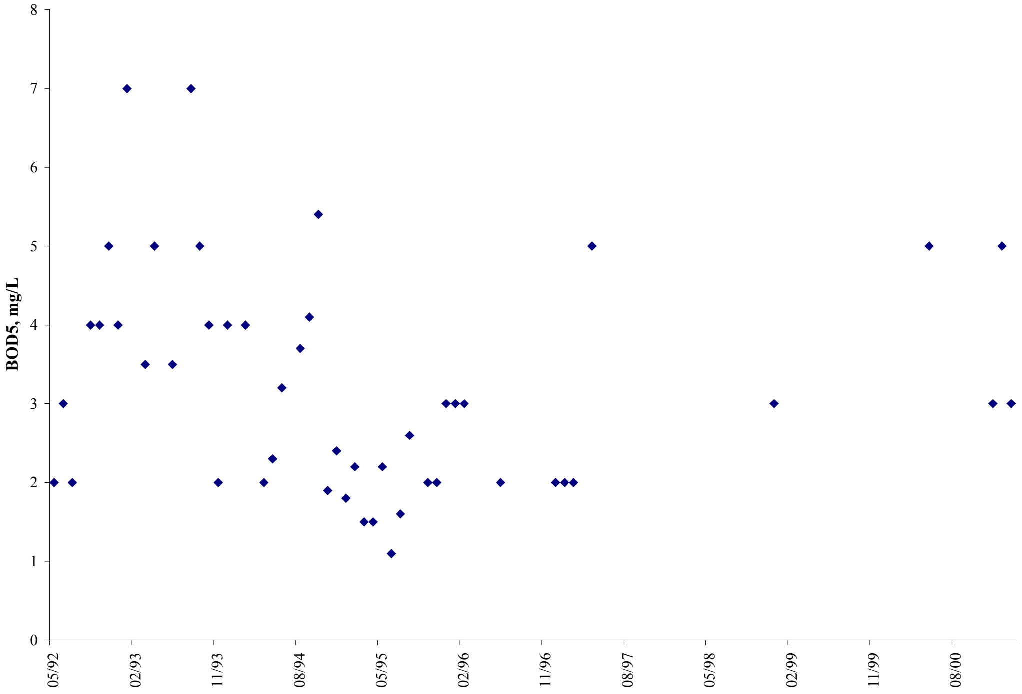


Figure 7.14 BOD$_5$ concentrations at 9-BST023.05.

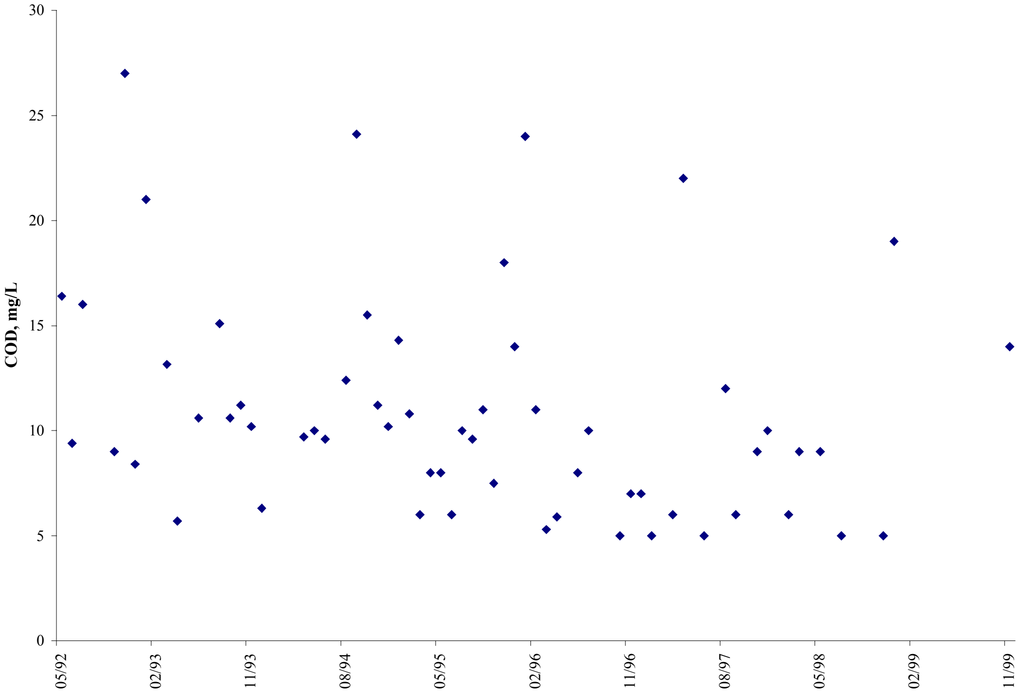


Figure 7.15 COD concentrations at 9-BST023.05.

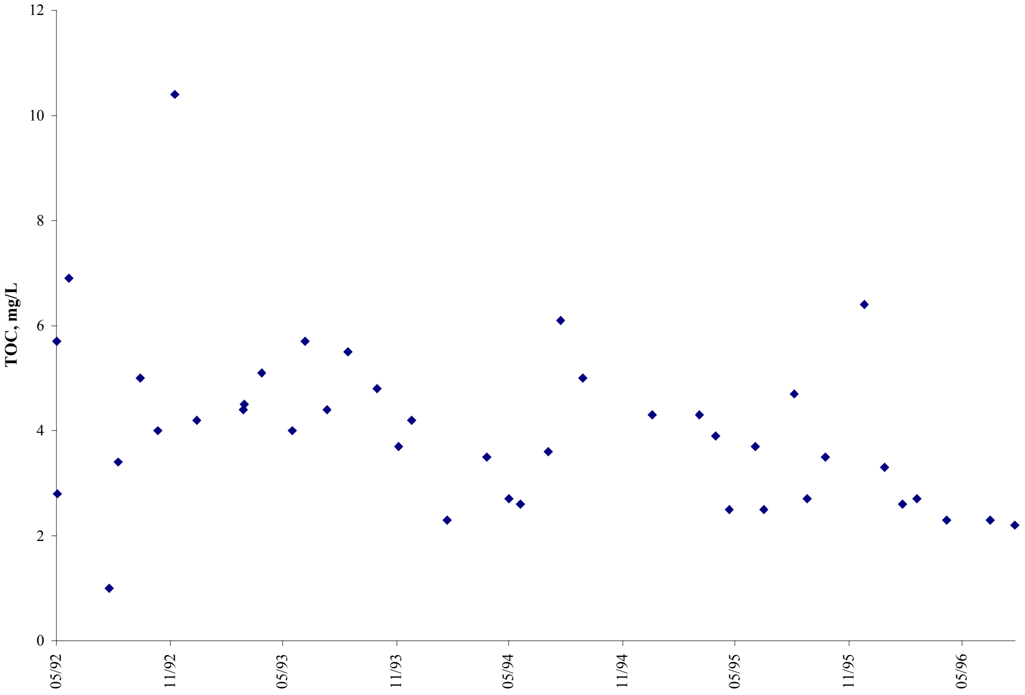


Figure 7.16 TOC concentrations at 9-BST023.05.

7.1.3 Most Probable Stressor

7.1.3.1 Sediment

The case for sediment being the most probable stressor was determined by examining the habitat and benthic metrics. The embeddedness and substrate scores on the habitat evaluation were both in the poor category. Embeddedness is an indication of significant fine sediment accumulation in the riffle area of a stream. The low substrate score indicates that there is limited coarse, clean habitat. Another benthic assessment index used in support of the RBP II method for streams in this ecoregion is the Macroinvertebrate Aggregated Index for Streams (MAIS). One of the MAIS benthic metrics provided an indication of how much coarse, clean substrate is available for clingers and crawlers, "% Haptobenthos". The score for Bluestone River was very low and confirms the habitat assessment score for embeddedness. The Bluestone River benthic survey was dominated by Chironomidae (a), Elmidae and Simuliidae. These families are moderately pollution tolerant (six on a scale from zero to 10). An important finding from the benthic survey results was the total absence of stoneflies and mayflies and low occurrence of caddisflies. This can be linked to toxic conditions; however, in this case it is most likely the result of sediment smothering these more sensitive organisms and eliminating much of their habitat. There was also an absence of predators. Sediment reduces visibility, lowering the success rate of predatory macroinvertebrates in capturing prey.

All of this evidence points to sediment as the most probable stressor on the benthic community. VADEQ staff at the Southwest Regional Office noted that, upstream of the Town of Bluefield, the streambanks had poor structure due to livestock access to the streams. In addition, Dill Spring has significant sediment deposits in the vicinity of Bluefield's raw water intake. Urban runoff, construction activity and agricultural activity are, therefore, the most likely sources. Sediment will be used as the target pollutant to address the benthic impairment in the Bluestone River.

7.2 Reference Watershed Selection

A reference watershed approach was used to estimate the load reductions necessary in order to restore a healthy aquatic community, and allow the streams in the Bluestone River watershed to attain their designated uses. The reference watershed approach is based on selecting a non-impaired watershed that has similar landuse, soils, stream characteristics, and area. (The area must not exceed double, or be less than half, the size of 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 and Central Appalachian Valley and Ridge ecoregions for analysis that would lead to the selection of a reference watershed for Bluestone River (Figure 7.17). 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 VADEQ personnel, the Dry River watershed in Rockingham County was selected as the reference watershed for Bluestone River.

Figure 7.18 shows the location of Bluestone River and Dry River in the ecoregions. Figure 7.19 compares the landuse distributions between the two watersheds. Figure 7.20 compares the land slope distributions between the two watersheds, a key parameter in erosion estimates. Figure 7.21 compares runoff potential between the two watersheds as indexed by the soil hydrologic group code. Figure 7.22 compares the soil erosive potential between the two watersheds as indexed by the soil erodibility index. Figure 7.23 compares the available soil moisture storage capacity in the solum between the two watersheds. Finally, Table 7.4 compares drainage characteristics between the two watersheds. The results of these analyses support the use of Dry River as a reference watershed for sediment load allocations.

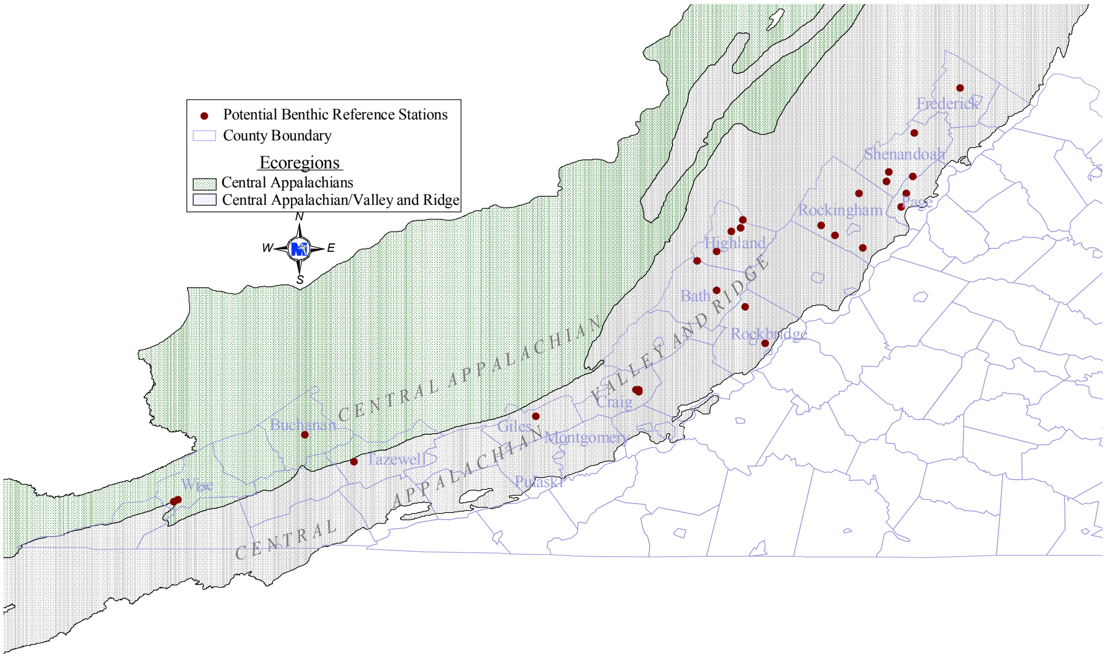


Figure 7.17 Location of potential reference watersheds.

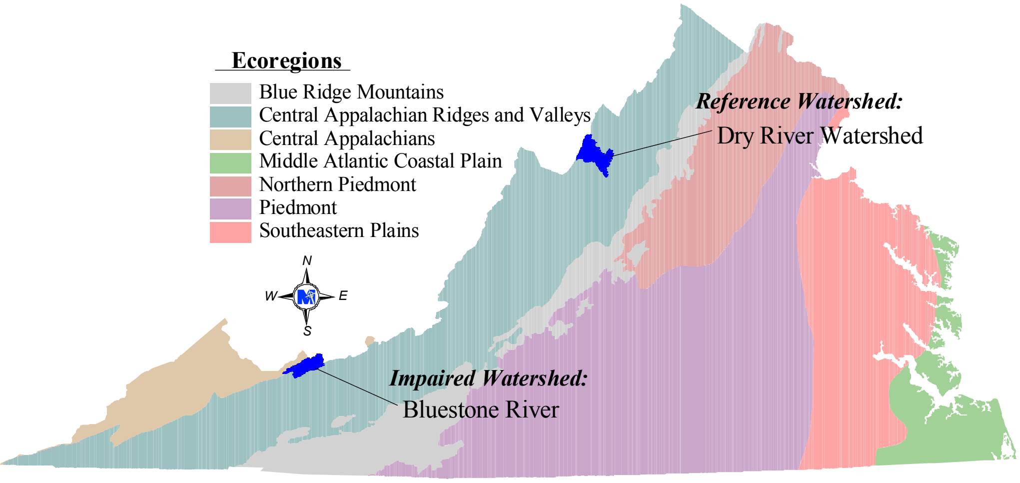


Figure 7.18 Location of impaired and reference watershed within ecoregions.

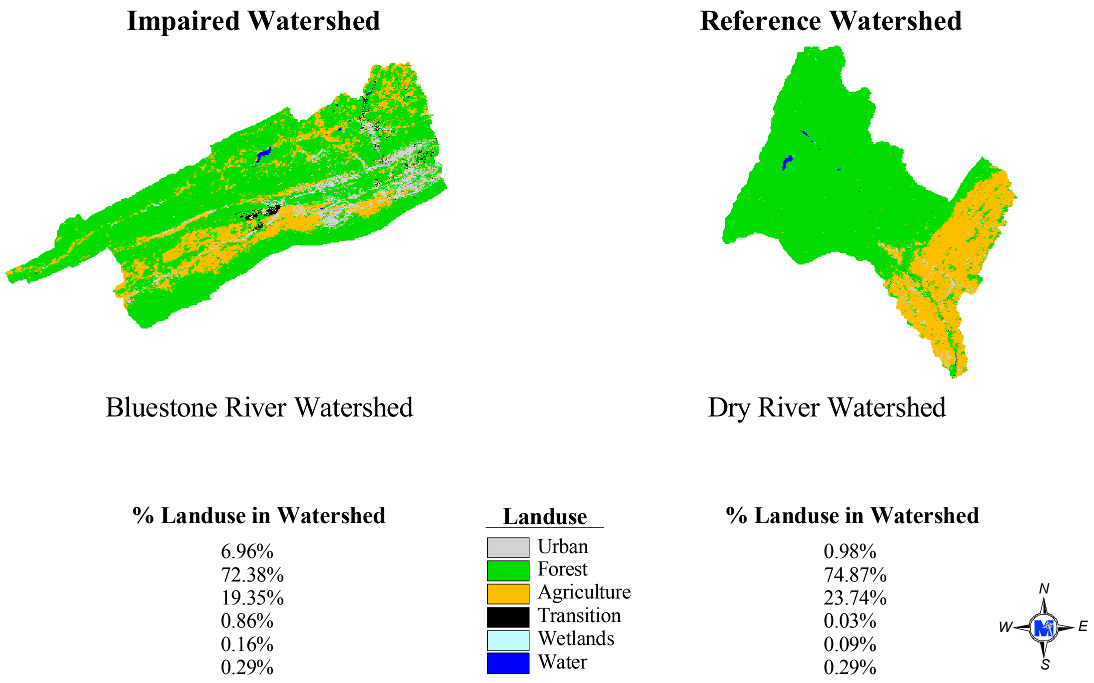
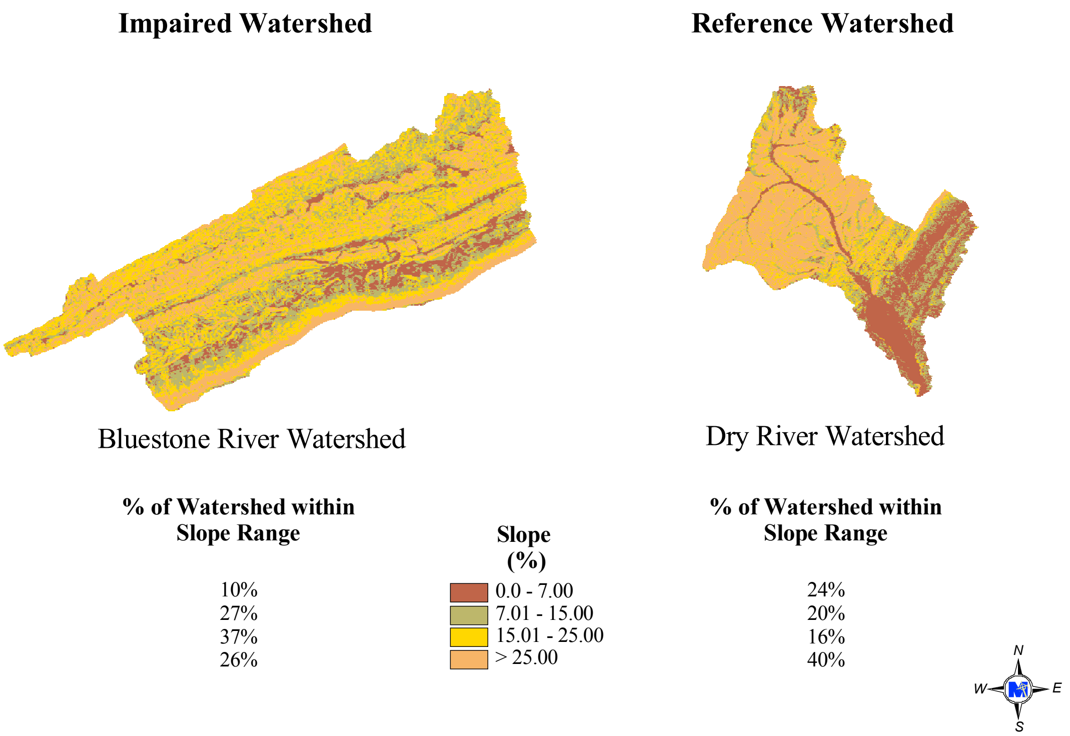


Figure 7.19 Bluestone River and Dry River landuse comparison.



% of Watershed within Slope Range (Bluestone River Watershed)	Slope (%)	% of Watershed within Slope Range (Dry River Watershed)
10%	0.0 - 7.00	24%
27%	7.01 - 15.00	20%
37%	15.01 - 25.00	16%
26%	> 25.00	40%

Figure 7.20 Bluestone River and Dry River slope comparison.

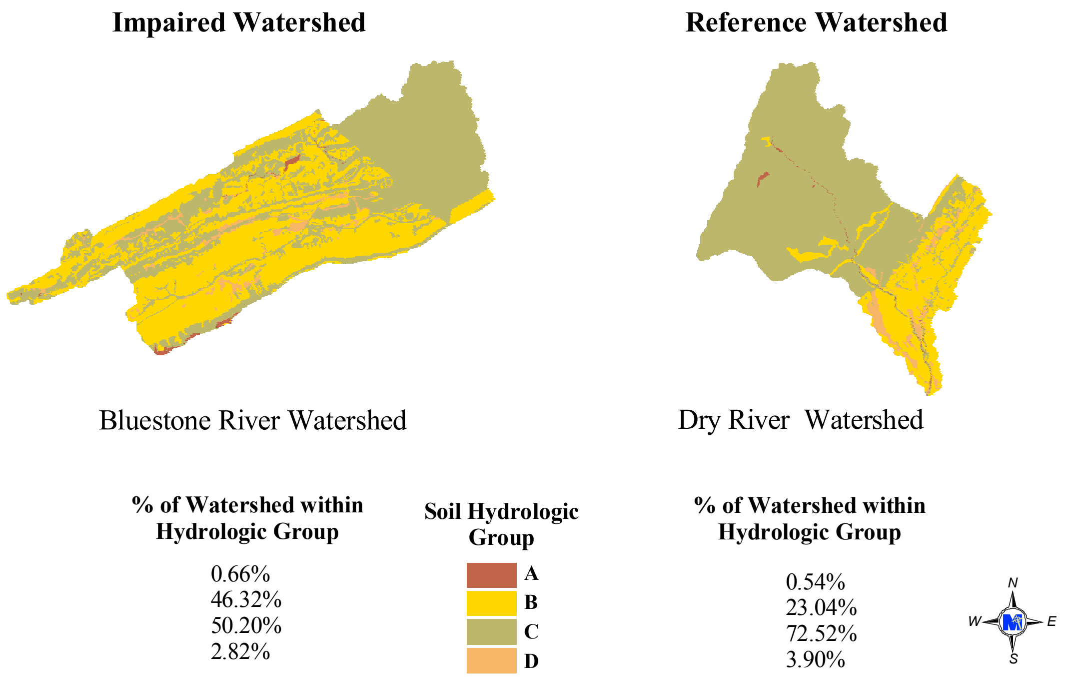


Figure 7.21 Bluestone River and Dry River soil hydrologic group code comparison.

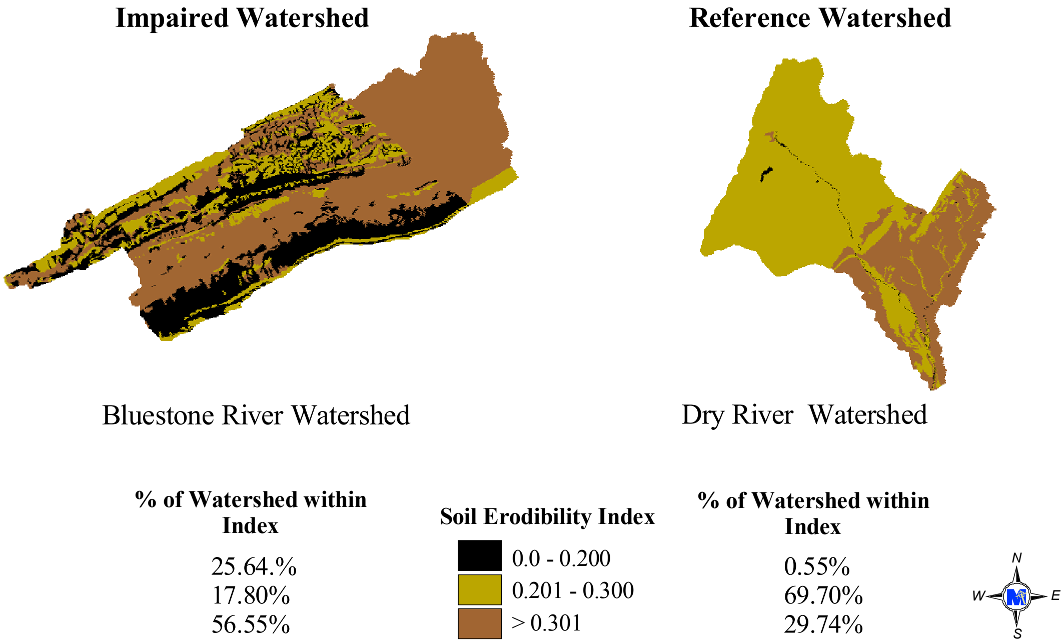


Figure 7.22 Bluestone River and Dry River soil erodibility index comparison.

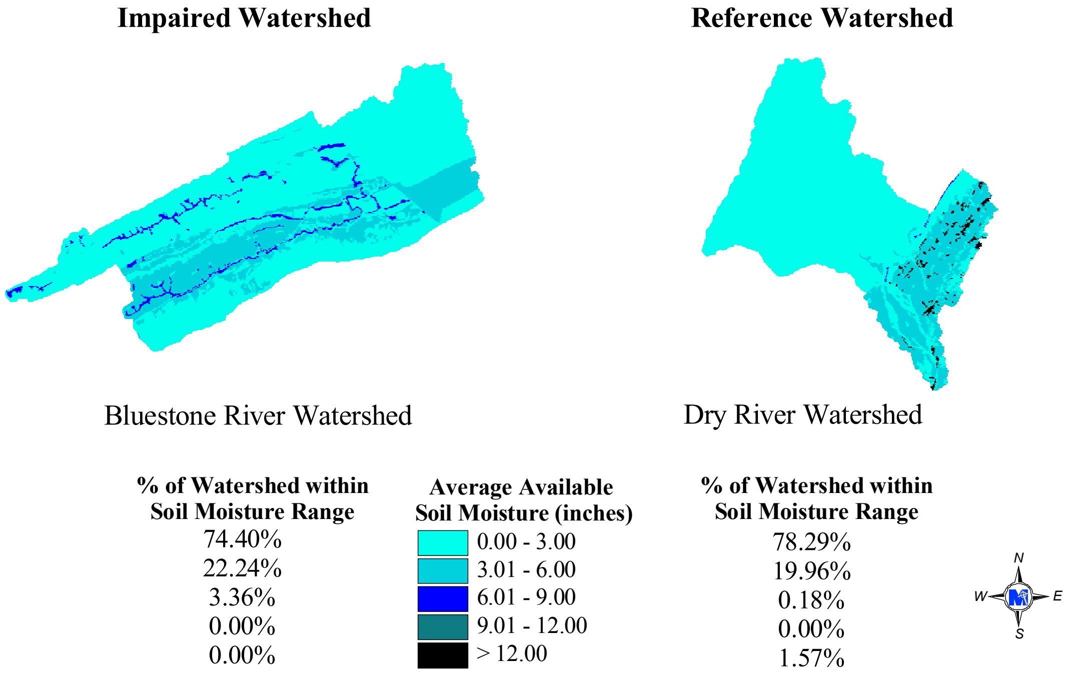


Figure 7.23 **Bluestone River and Dry River soil available moisture storage comparison.**

Table 7.4 **Bluestone River and Dry River drainage characteristics comparison.**

Watershed	**Stream Length (% Total)**		**Approx. Length-Width Ratio**
	Intermittent	Continuous	
Bluestone River	62.2	37.8	2.85
Dry River	58.7	41.3	2.66

8. MODELING PROCEDURE

A reference watershed approach was used in this study to develop benthic TMDLs for sediment for the Bluestone River watershed. As noted in Section 7.0, sediment was identified as the primary stressor for the Bluestone River. A watershed model was used to simulate sediment loads from potential sources in Bluestone River and the Dry River reference watershed. The model used in this study was the Visual *Basic*^{TM} version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The model also included modifications made by Yagow et al., 2002 and BSE, 2003. Numeric endpoints were based on unit-area loading rates calculated for the respective reference watershed. The TMDLs were then developed for the impaired watershed 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 that operates on a daily time step for water balance calculations and monthly calculations for sediment and nutrients from daily water balance. In addition to runoff and sediment, the model simulates dissolved and attached nitrogen and phosphorus loads delivered to streams from watersheds with both point and nonpoint sources 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, stream-bank 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 impaired stream segment and the selected reference watershed were delineated from USGS 7.5 minute digital topographic maps using GIS techniques. The Bluestone River watershed was delineated from the downstream extent of the impaired segment. The reference watershed outlet for Dry River was located at biological monitoring station 1BDUR000.11 just upstream of the confluence with North River. For TMDL development, the total area for reference watershed Dry River was equated with the area of Bluestone River impairment. To accomplish this, the area of landuse categories in reference watershed Dry River was proportionately reduced based on the percentage landuse distribution. As a result, the watershed area for Dry River was reduced to be equal to the watershed area for the Bluestone River impairment. After adjustment, the distribution of landuse remained the same as pre-adjustment values.

8.3 Source Assessment

Three source areas identified as the primary contributors to sediment loading in the Bluestone River watershed include 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 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.). 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 (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, and construction (roads, buildings, etc.) all tend to accelerate erosion at varying degrees. During dry periods, sediment from air or traffic builds up on impervious areas and is transported to streams during runoff events. The magnitude of sediment loading from this source is affected by various factors, *e.g.,* the deposition from wind erosion and vehicular traffic. Sediment loading is also affected by sediment deposited from vehicular traffic. Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peaks which leads to greater channel erosion potential. It has been well documented that livestock with access to streams can significantly alter physical dimensions of streams through trampling and shearing (Armour et al., 1991; Clary and Webster, 1990; Kaufman and Kruger, 1984). Increasing the bank full width decreases stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998). The Bluestone River watershed has significant livestock production.

8.3.2 Point Sources TSS Loads

Fine sediments are included in total suspended solids (TSS) loads that are permitted for various facilities with wastewater and industrial stormwater VPDES permits within the Bluestone River watershed. There are 7 permitted wastewater and 2 industrial stormwater dischargers permitted within the watershed. There were no construction stormwater permits or MS4 permits located in the watershed. Sediment loads from permitted wastewater and industrial stormwater dischargers 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 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 to estimate runoff and sediment from different pervious areas (HUs) in the watershed (Li, 1972; England, 1970). 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

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

- *<u>Month</u>: Months were ordered, starting with April and ending with March – in keeping with the design of the GWLF model and its assumption that stored sediment is flushed from the system at the end of each Apr-Mar cycle. Model output was modified in order to summarize loads on a calendar year basis.*
- *<u>ET CV:</u> Composite evap-transpiration cover coefficient, calculated as an area-weighted average from landuses within each watershed.*
- *<u>Hours per Day:</u> mean number of daylight hours.*
- *<u>Erosion Coefficient:</u> This a regional coefficient used in Richard's equation for calculating daily erosivity. Each region is assigned separate coefficients for the months October-March, and for April-September.*

Sediment Parameters

Watershed-Related Parameter Descriptions

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

Landuse-Related Parameter Descriptions

- *USLE K-factor: The soil erodibility factor was calculated as an area weighted average of all component soil types.*
- *USLE LS-factor: This factor is calculated from slope and slope length.*
- *USLE C-factor: The vegetative cover factor for each landuse was evaluated following GWLF manual guidance and Wischmeier and Smith (1978).*
- *Daily sediment build-up rate on impervious surfaces: The daily amount of dry deposition deposited from the air on impervious surfaces on days without rainfall, assigned using GWLF manual guidance.*

Streambank Erosion Parameter Descriptions (Evans, 2002)

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

8.4.2 Streamflow and Weather data

Daily streamflow data obtained from USGS gaging stations were used to calibrate hydrologic parameters in the GWLF model are given in Table 8.1. 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 is Theissen weighted to provide a single record. Access to the database is through the Virginia Hydrologic Units code.

Table 8.1 USGS gaging stations used in GWLF model for Bluestone River and Dry River.

Watersheds	USGS station site number	USGS gage location	Data Period
Bluestone River	USGS03177700	Bluestone River at Bluefield, Virginia	1/1/1972–12/31/1979
Dry River	USGS01622000	Lost River near Burketown, Virginia	1/1/1994–03/30/2000

Table 8.2 Weather stations used in GWLF models for Bluestone River and Dry River.

Watersheds	Weather Stations (station_id, location, Thiessen weights)	Data Type	Data Period
Bluestone River	**Station id**: 449301 **Location:** Wytheville 1S **Thiessen weight:** 1.	Daily Precipitation & Temperature	1/1/1972–12/31/1979
Bluestone River (Existing Conditions)	Station id: **441209** Location: **Burke Garden** **Thiessen weight:** 1.	Daily Precipitation & Temperature	1/1/1994-03/30/2000
Dry River	Station id: **442208** Location: **Dale Enterprise** Thiessen weight**:** 1**.**	Daily Precipitation & Temperature	1/1/1994–03/30/2000

8.4.3 Landuse/landcover classes

Landuse classes are 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 all impaired and reference watersheds. The landuse categories were consolidated from MRLC classifications as given in Table 8.3. 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 local sources and VADCR's online 2002 NPS Assessment. 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), Boring, 2004, and local information. Landuse distributions for Bluestone River and Dry River are given in Table 8.4. Landuse acreage for Dry River was adjusted down by the ratio of impaired watershed to reference watershed maintaining the original landuse distribution.

Table 8.3 Landuse Categories for TMDL Analysis.

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

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

Table 8.4 Landuse distributions for impaired and reference watersheds.

Landuse Category	Bluestone River			Dry River (Adjusted) (ha)
	Va (ha)	WVa (ha)	Va+WVa (ha)	
Low Density Residential (LDR-PER)	246.294	357.496	603.79	152.989
High density Residential (HDR-PER)	0.000	5.552	5.552	0.128
Commercial (COM-PER)	159.757	77.574	237.331	12.709
Transitional	83.478	88.630	172.108	5.255
Forest				
Disturbed-FOR	337.657	95.654	433.311	447.549
Forest-FOR	10,917.573	3,092.827	14,010.4	14,470.749
Urban Grass	56.288	0.000	56.288	0.000
Pasture/Hay				
Hay	75.989	22.934	98.923	2075.611
Overgrazed	1,223.600	369.816	1,593.416	518.903
Unimproved	367.090	110.945	478.035	207.561
Improved	856.548	258.870	1,115.418	290.585
Stream Edge	9.696	1.904	11.600	20.756
Cropland				
High Tillage	91.921	46.772	138.693	404.646
Low Tillage	275.764	140.315	416.079	1213.938
Low Density Residential (impervious)	61.573	89.374	150.947	16.999
High density Residential (impervious)	0.000	3.702	3.702	0.055
Commercial (impervious)	220.617	107.127	327.744	12.709
Water	40.833	16.409	57.242	58.597

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 Bluestone River watershed was obtained from the Soil Survey Geographic (SSURGO) database for Virginia, the State Soil Geographic (STATSGO) database for Mercer County, West Virginia, and the Tazewell County soil survey manual (SCS, 1977). 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 length-of-slope values were developed in cooperation with local SCS Office personnel for much of Virginia during the VirGIS program. 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 by GIS techniques. Soils data for the Dry River reference watershed was obtained from the Soil Survey Geographic (SSURGO) database for Virginia (SCS, 2004), Rockingham County. The area-weighted USLE parameters, K and LS, for Dry River were calculated following the procedures outlined for the Bluestone River 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 percentage of pervious and impervious area was calculated from data obtained from VADCR's 2002 NPS Assessment Landuse/Landcover Database (VADCR, 2002).

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

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

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 developed land, mean stream depth, and watershed area. The number of dairy and beef cattle in the Bluestone watershed was obtained from information provided by the Soil and Water Conservation District. The number of livestock in Rockingham County was estimated from Virginia Agricultural Statistical data (VASA, 2001), which listed 110,000 beef and dairy animals in the county. The data were converted to animal units (1,000 pound base) with the following assumptions. The animal break-down included 25,000 dairy with average weight of 1,300 pounds; 25,000 beef with average weight of 1,000 pounds; 25,000 dairy replacement heifers/dry cows with an average weight of 800 pounds; 22,500 calves with an average weight of 500 pounds; and 12,500 stockers with an average weight of 800 pounds. This placed the number of animal units for the county at 98,750. The number of animals in the Dry River watershed were determine from the ratio of watershed pasture area to the county area times the county total. The animal density was calculated by dividing the animal units of livestock (beef and dairy) by watershed area in acres. The total length of the natural stream channel was estimated from USGS NHD hydrography coverage using GIS techniques. The length of harden channel was estimated as the length of stream flowing through commercial areas using GIS techniques. The mean stream depth was estimated as a function of watershed area.

8.5 Point Source TSS Loads

Nine point sources were identified in the Bluestone River watershed with location shown in Figure 3.1 and discharge specifics listed in Table 8.5. Permitted loads were calculated as the maximum annual modeled runoff times the area governed by the permit times a maximum TSS concentration. The modeled runoff for industrial stormwater dischargers was calculated for both pervious and impervious commercial sediment source areas. A weighted maximum runoff value was calculated for commercial areas by multiplying the maximum annual modeled runoff depth from pervious commercial by the percentage of commercial area that is pervious, and adding that figure 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 times the permit area (ha) times permitted concentration (TSS/mg/L) times 0.00010001 to get permit load in T/yr.

Table 8.5 VPDES point source facilities and permitted TSS load.

Bluestone River Point Sources		Existing Conditions					Future Conditions
VPDES ID	**Name**	**Permit Discharge (MGD)**	**Runoff (cm)**	**Area (ha)**	**Conc. (mg/L)**	**TSS (T/yr)**	**TSS (T/yr)**
Industrial Stormwater Discharge Permits							
VAR051098	Thistle Foundry & Machine Co.	-	65.44	1.4569	100	0.953	0.953
VAR051047	Floyd Asphalt Paving Co., Inc.	-	65.44	1.0174	100	0.666	0.666
Wastewater Discharge Permits							
VA0025054	Bluefield Westside WWTP						
	6/1-11/30	5.3	-	-	7		
	12/1 – 5/31	5.3	-	-	13		
	Average/yr	5.3	-	-	99.99178	73.170	110.445*
VA0062561	Falls Mills STP	0.108	-	-	30	4.477	4.477
VAG110001	Bluefield Ready Mix	0.009	-	-	60	0.746	0.746
VAG750008	Fast Stop	0.0133	-	-	60	1.103	1.103
VAG750032	Mike Soft Cloth	0.0012	-	-	60	0.099	0.099
VAG750067	Mash Car Wash	0.0008	-	-	60	0.066	0.066
VAG840021	Pounding Mill Quarry	0.001	-	-	60	0.083	0.083
Total Point Source Loads						**81.363**	**118.638**

* TSS Load projected for 8 MGD discharge from Bluefield Westside WWTP

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 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

Although the GWLF model was originally developed for use in ungaged watersheds, calibration was performed to ensure that hydrology was being simulated accurately. This process was necessary to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soils, landuse, and topographic data. Parameters that were adjusted during calibration included the recession constant, the evapotranspiration cover coefficients, the unsaturated soil moisture storage, and the seepage coefficient.

The model for Bluestone River was calibrated using the mean daily flow from USGS Station #03177700 for the period January 1972 through December 1979. Precipitation and temperature data were obtained from a website maintained by the Virginia Tech Biological Systems Engineering Department for automated creation of weather data for GWLF in the State of Virginia. The hydrologic unit code is used to access the data (Table 8.2). The final calibration results for Bluestone River are given in Figures 8.1 and 8.2 with goodness of fit statistics given in Table 8.6. The final calibration results for Dry River are displayed in Figures 8.3 and Figure 8.4 for the calibration period with statistics showing the goodness of fit given in Table 8.6. Reference watershed Dry River did not have an observed streamflow station located within the watershed boundary. The model for Dry River was calibrated using nearby downstream USGS Station #01622000 for the period January 1, 1994 through March 31, 2000. Precipitation and temperature data stations are given in Table 8.2.

Model calibrations were considered good to excellent for total runoff volume. Monthly fluctuations were variable but were still reasonably good considering the general simplicity of GWLF. Results were also consistent with other applications of GWLF in Virginia (*e.g.,* Tetra Tech, 2001 and BSE, 2003).

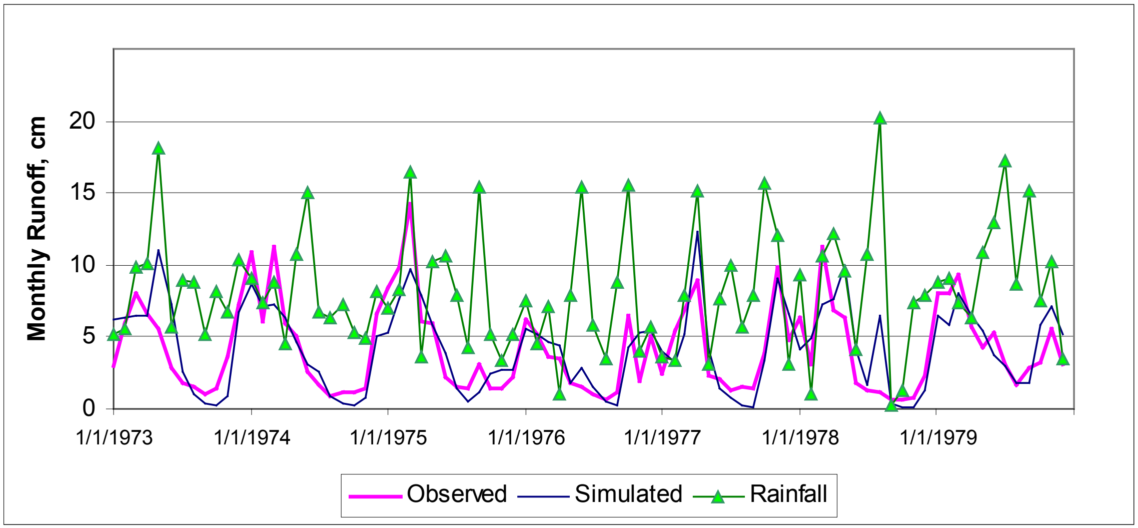


Figure 8.1 Comparison of monthly simulated and observed flow for the Bluestone River Watershed.

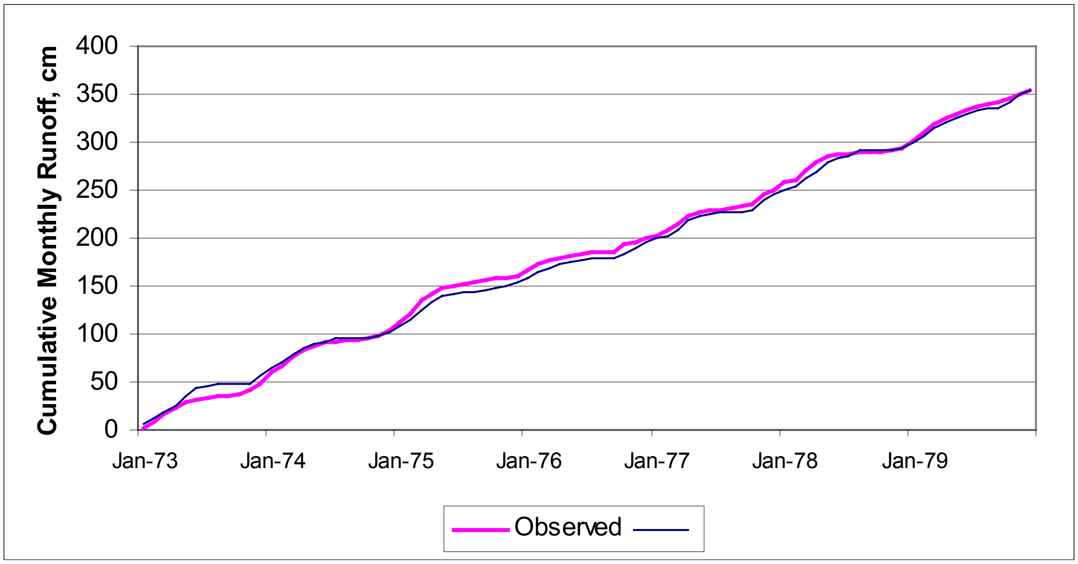


Figure 8.2 **Comparison of cumulative monthly simulated and observed flow for Bluestone River.**

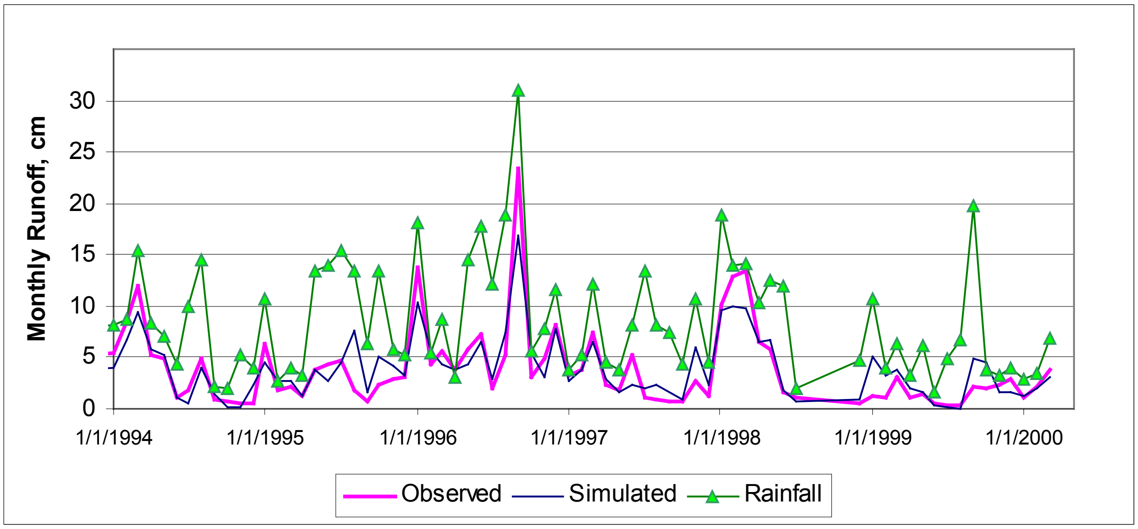


Figure 8.3 **Comparison of monthly simulated and observed flow for the Dry River Watershed.**

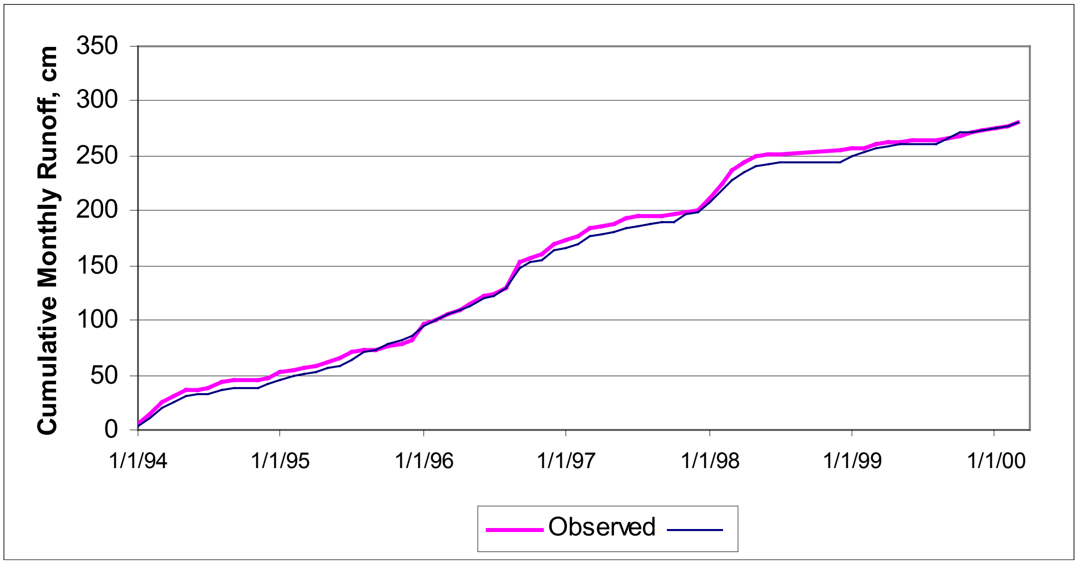


Figure 8.4 **Comparison of cumulative monthly simulated and observed for Dry River.**

Table 8.6 GWLF flow calibration statistics.

Watersheds	Simulation Period	R^2 (R^2 Correlation value)	Total Volume Error (Sim-Obs)
Bluestone River	1/1/72 –12/31/79	0.796	0.002
Dry River	1/1/94/ –3/30/2000	0.859	-0.001

8.9 Existing Conditions

A listing of parameters from the GWLF Transport input files that were finalized during hydrologic calibration for existing conditions are given in Tables 8.7 – 8.10. Watershed parameters for the Bluestone River and reference watershed Dry River are given in Table 8.7.

Table 8.7 Bluestone River and Reference Watershed Dry River GWLF Watershed parameters for existing conditions.

GWLF Watershed Parameter	Units	Bluestone River	Dry River
Recession Coefficient	Day^{-1}	0.0325	0.0384
Seepage Coefficient	Day^{-1}	0.0022	0.02
Sediment Delivery Ratio		0.093	0.093
Unsaturated Water Capacity	(cm)	9.575	3.292
Erosivity Coefficient (April-Sept.)		0.25	0.25
Erosivity Coefficient (Oct.-Mar)		0.06	0.06
% developed land	(%)	4.5	2.6
Livestock density	(AU/ac)	0.024	0.25
Area-weighted soil erodibility		0.279	0.27
Area weighted runoff curve number		65.06	68.18
Total Stream Length	(m)	81,888	150,710
Mean channel depth	(m)	5.14	5.17

Monthly evaporation cover coefficients are listed in Table 8.8.

Table 8.8 Bluestone River and Reference Watershed Dry River GWLF monthly evaporation cover coefficients for existing conditions

Watershed	Apr	May	Jun	Jul*	Aug	Sep	Oct	Nov	Dec	Jan*	Feb	Mar
Bluestone River	0.30	0.60	0.80	0.80	0.80	0.65	0.65	0.50	0.50	0.50	0.40	0.40
Dry River	0.45	0.50	1.20	1.20	1.20	0.47	0.44	0.27	0.25	0.23	0.20	0.26

The area-weighted USLE erosion parameter and runoff curve number are listed by landuse erosion source areas in Table 8.9 for Bluestone River and the reference watershed Dry River. The area adjustment for the reference watershed is listed in Table 8.10.

Table 8.9 Bluestone River and reference Watershed Dry River GWLF landuse parameters for existing conditions.

Landuse Category	Virginia		West Virginia		Dry River	
	CN	KLSCP	CN	KLSCP	CN	KLSCP
LDR-PER	67.57	0.00176	69.83	0.001757	65.06	0.0007
HDR-PER	67.57	0.00083	67.44	0.000835	69.84	0.0003
COM-PER	70.11	0.00183	68.25	0.001826	64.20	0.0005
Transitional	87.58	0.13528	72.45	0.135282	85.58	0.0606
Forest	67.57	0.15298	63.79	0.152983	75.68	0.2169
Disturbed Forest	70.11	0.00191	61.00	0.001912	68.20	0.0027
Urban Grass	87.58	0.00438	66.32	0.004378	61.00	0.0026
Hay	70.27	0.00628	83.48	0.006284	61.69	0.0021
Pasture 1	60.82	0.09426	75.40	0.094264	80.99	0.0313
Pasture 2	61.00	0.04462	69.32	0.044618	71.84	0.0148
Pasture 3	62.23	0.00817	86.56	0.008170	64.69	0.0027
Stream Edge	81.28	0.18853	81.43	0.188528	85.14	0.0626
High-tillage	72.25	0.57999	78.80	0.579988	79.15	0.2747
Low-tillage	65.23	0.15849	69.83	0.158492	75.61	0.0302
LDR-IMP	98.00	0.00083	98.00	0.001757	98.00	0.0003
HDR-IMP	98.00	0.00183	98.00	0.000835	98.00	0.0005
COM-IMP	98	0.00083	98	0.001826	98	0.0318

The existing sediment loads were modeled for Bluestone River and the reference watershed Dry River (Table 8.11). The existing sediment loads were adjusted for active agricultural BMPs using data from the digital Virginia Agricultural BMP database (VADCR, 2004), which provides the type of BMP, acres benefited, sheet and rill erosion, gully erosion reduction and shape file of locations. For active BMPs located within each watershed, the total erosion was determined from the database information and total sediment reduction was calculated by multiplying the total erosion by the delivery ratio for the respective watersheds. No BMPs were included in the VADCR 2002 database for Bluestone River. Since the Bluestone headwaters are in Mercer County, West Virginia, the summary of existing conditions includes sediment loads for Virginia and West Virginia and a combined sediment load for the watershed (*i.e.,* Virginia plus West Virginia components). The existing condition for the Bluestone watershed is the combined sediment load, which compares to the target TMDL load under existing conditions for the area-adjusted reference watershed Dry River. The target sediment TMDL load for Bluestone River is the average annual load from the area-adjusted Dry River watershed under existing conditions, which is 6,364 T/y (Table 8.11). The load for allocation is equal to the TMDL (6,364) minus a margin of safety (10% or 636) since the waste load (point sources) cannot be allocated.

Table 8.10 Area adjustments for Bluestone River TMDL reference watershed Dry River.

Landuse Categories	Impaired Bluestone River			Reference Original Dry River	Reference (area-adjusted) Dry River (x 0.640485)
	Va (ha)	WVa (ha)	Va+WVa (ha)	(ha)	(ha)
LDR-PER	246.294	357.496	603.79	238.867	152.989
HDR-PER	0.000	5.552	5.552	0.200	0.128
COM-PER	159.757	77.574	237.331	19.844	12.709
Transitional	83.478	88.630	172.108	8.205	5.255
Disturbed Forest	337.657	95.654	433.311	698.777	447.549
Forest	10,917.573	3,092.827	14,010.4	22,593.774	14,470.749
Urban Grass	56.288	0.0	56.288	0.000	0.000
Hay	75.989	22.934	98.923	3,240.736	2,075.611
Pasture 1	1,223.600	369.816	1,593.416	810.184	518.903
Pasture 2	367.090	110.945	478.035	324.074	207.561
Pasture 3	856.548	258.87	1,115.418	453.703	290.585
Stream Edge	9.696	1.9035	11.600	32.407	20.756
High-tillage	91.921	46.772	138.693	631.791	404.646
Low-tillage	275.764	140.315	416.079	1,895.372	1,213.938
LDR-IMP	61.573	89.374	150.947	26.541	16.999
HDR-IMP	0.000	3.702	3.702	0.086	0.055
Com-IMP	220.617	107.127	327.744	19.844	12.709
Water	40.833	16.409	57.242	91.488	58.597

Table 8.11 Existing sediment loads for Bluestone River and reference watershed Dry River.

Sediment Source	Bluestone River Existing Conditions						Reference	
	Virginia		West Virginia		Virginia + West Virginia		Dry River (Area Adjusted)	
	T/yr	T/ha	T/yr	T/ha	T/yr	T/ha	T/yr	T/ha
LDR-PER	5.340	0.022	7.501	0.021	12.842	0.021	1.769	0.012
HDR-PER	0.000	0.000	0.058	0.011	0.058	0.010	0.000	0.004
COM-PER	3.702	0.023	1.748	0.023	5.449	0.023	0.090	0.007
Transitional	237.139	2.840	147.940	1.669	385.053	2.237	8.316	1.583
Forest	168.636	0.015	51.099	0.017	219.731	0.016	2,002.146	4.474
Disturb. Forest	655.780	1.942	203.905	2.132	859.673	1.984	666.305	0.046
Urban Grass	1.991	0.035	0.000	0.000	1.991	0.035	0.000	0.000
Hay	3.876	0.051	1.720	0.075	5.596	0.057	62.474	0.030
Pasture 1	2,095.475	1.713	679.531	1.837	2,775.006	1.742	381.169	0.735
Pasture 2	222.687	0.607	73.300	0.679	295.987	0.619	57.119	0.275
Pasture 3	80.571	0.094	26.849	0.104	107.420	0.096	12.471	0.043
Stream-Edge-Pasture	37.240	3.841	7.447	3.912	44.687	3.853	33.678	1.623
High Tillage	918.531	9.993	793.891	16.491	1,712.422	12.347	2,514.315	6.214
Low Tillage	688.863	2.498	372.829	2.657	1,061.692	2.551	756.769	0.623
LDR-IMP	13.569	0.220	74.055	0.829	87.624	0.580	79.861	4.698
HDR-IMP	0.000	0.000	19.695	5.321	19.695	5.320	0.000	0.000
COM-IMP	48.618	0.220	0.815	0.008	49.433	0.151	0.092	0.007
Water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Active Ag. BMPs					0.000		-426.907	
NPS Loads	**5,182.019**		**2,464.383**		**7,646.402**		**6,149.667**	
Channel Erosion	101.936	0.007	25.484	0.005	127.420	0.006	214.027	0.011
Point Source Loads	81.363		-		81.363		0.000	
Watershed Totals	**5,365.318**		**2,489.867**		**7,855.185**		**6,363.694**	

9. ALLOCATION

The benthic Total Maximum Daily Loads (TMDL) for Bluestone River includes three components – waste load allocations (WLA) from point sources, the load allocation (LA) from nonpoint sources, and a margin of safety (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 all permitted point source discharges. The LA is calculated as the target TMDL load minus the WLA load and the MOS. 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 the Bluestone River using a reference watershed approach. As discussed in Chapter 8, the model was calibrated for hydrology and run for existing conditions over the period April 1994 through March 2000. A sensitivity analysis was performed to determine the impact of uncertainties in input parameters.

9.1 Sensitivity Analysis

Sensitivity analysis 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 change, from the base value. Results are listed in Table 9.2. The results show that the model is extremely sensitive to some parameters resulting in major changes in either runoff or sediment. For example, decreases in the runoff curve number (65) resulted in little change in channel erosion; however, the channel erosion output was changed dramatically with increases in the curve number. The results tend to reiterate the need to carefully evaluate conditions in the watershed and follow a 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)	684590
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 Bluestone River Benthic TMDL

The Bluestone River benthic TMDL was developed for sediment, with Dry River as the reference watershed. The area of the Dry River watershed was reduced by the ratio of the impaired watershed area to the reference watershed area (0.640485). After adjustment, the Dry River reference watershed area equaled the Bluestone River watershed area (19,911ha). Landuse acreage for Dry River was reduced while maintaining the original landuse distribution for Dry River.

The target TMDL load for Bluestone River is the average annual load from the area-adjusted Dry River watershed under existing conditions (Table 9.3). The margin of safety was explicitly set to 10% to account for uncertainty in developing benthic TMDLs. The TMDL targets for the Bluestone River watershed are listed in Table 9.3.

Table 9.3 TMDL Targets for Bluestone River Watershed

Impairment	WLA (T/year)	LA (T/year)	MOS	TMDL (T/year)
Bluestone River	81.4	5,647	636	6,364
VAR051098	*0.95*			
VAR051047	*0.67*			
VA0025054[1]	*73.17*			
VA0062561	*4.48*			
VAG110001	*0.75*			
VAG750008	*1.10*			
VAG750032	*0.099*			
VAG750067	*0.066*			
VAG840021	*0.083*			

[1] Bluefield Westside WWTP

9.2.1 Future Development

Expected future growth over the next 20-25 years was modeled to evaluate the potential impact on allocations based only on existing conditions. Modeled sediment loads in excess of existing conditions suggest a need for further allocations to maintain the target identified by the TMDL. A summary of the future growth landuse scenario is given in Table 9.4. Commercial development is expected to continue around existing hubs that have the capacity to provide infrastructure support (*e.g.,* the Bluefield area). For the most part, future development will result in the conversion of agricultural and forestry landuses to low and high-density residential housing, and to some form of commercial (includes commercial, industrial, transportation) development. The future growth scenario resulted in a percentage developed land increase from 4.5% to 7.7%. Modeled future sediment loads based on the scenario summarized in Table 9.4 are listed in Table 9.5. Based on model results, the sediment load for future conditions in the Bluestone River increased by 226 T/yr over the existing conditions (Table 8.11).

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

Virginia			West Virginia		
Existing	Projected Change		Existing	Projected Change	
From Landuse	Area (ha)	To Landuse	From Landuse	Area (ha)	To Landuse
Forest	331	LDR	Forest	144	LDR
Forest	159	COM	Forest	200	HDR
Pasture	115	LDR	Pasture	105	HDR
Forest	5	Trans	Forest	219	COM
Pasture	5	Trans	Forest	5	Trans
			Pasture	5	Trans

The required reductions for both existing and projected loads are compared in Table 9.6. Since future growth is expected in the Bluestone watershed, the reductions required to meet the TMDL will be based on the future growth conditions given in Table 9.5. To aid the development of TMDL allocation scenarios, nonpoint source areas were grouped into three main categories: agriculture, urban and forestry. Additional sub-categories for agriculture and forestry have also been added to provide better definition of allocation within the broader groupings (Table 9.7). Predominant sediment loads available for reductions are from the agriculture, transitional, disturbed forest and stream channel categories.

Table 9.5 Projected future sediment loads for Bluestone River impairment at Bluefield.

Sediment Source	Bluestone River Future Conditions Virginia		Bluestone River Future Conditions West Virginia		Bluestone River Future Conditions Virginia + West Virginia		Reference Dry River (Area Adjusted)	
	T/yr	T/ha	T/yr	T/ha	T/yr	T/ha	T/yr	T/ha
LDR-PER	13.097	0.022	9.938	0.021	23.035	0.038	1.769	0.012
HDR-PER	0.000	0.000	2.001	0.011	2.001	0.360	0.000	0.004
COM-PER	5.260	0.023	3.826	0.023	9.086	0.038	0.090	0.007
Transitional	265.728	2.843	164.898	1.672	430.626	2.502	8.316	1.583
Forest	161.459	0.015	42.064	0.017	203.523	0.015	2,002.146	4.474
Disturb. Forest	627.988	1.945	167.794	2.134	795.782	1.836	666.305	0.046
Urban Grass	1.994	0.035	0.000	0.000	1.994	0.035	0.000	0.000
Hay	3.697	0.051	1.476	0.075	5.173	0.052	62.474	0.030
Pasture 1	1,997.857	1.714	582.108	1.839	2,579.965	1.741	381.169	0.735
Pasture 2	212.477	0.608	64.511	0.679	276.988	0.623	57.119	0.275
Pasture 3	76.889	0.094	23.024	0.104	99.913	0.096	12.471	0.043
Stream-Edge-Pasture	35.501	3.844	6.380	3.915	41.881	3.854	33.678	1.623
High Tillage	919.476	10.003	679.654	14.531	1,599.130	11.530	2,514.315	6.214
Low Tillage	689.271	2.499	373.167	2.660	1,062.438	2.553	756.769	0.623
LDR-IMP	33.225	0.220	74.055	0.627	107.28	0.711	79.861	4.698
HDR-IMP	0.000	0.000	26.042	0.207	26.042	7.035	0.000	0.000
COM-IMP	68.939	0.220	27.700	0.118	96.639	0.295	0.092	0.007
Water	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Active BMPs							-426.907	
NPS Loads	**5,112.857**	**0.340**	**2,248.638**	**0.460**	**7,361.495**	**0.370**	**6,149.667**	**0.330**
Stream Channel Erosion	510.692		127.673		638.365	0.0078	214.027	0.0014
Point Source Loads	81.363				81.363		0.000	
Totals	**5,704.913**		**2,376.311**		**8,081.224**		**6,363.694**	

Table 9.6 Required reductions for Bluestone River impairment at Bluefield.

Load Summary	Bluestone River (T/yr)	Reductions Required (T/yr)	Reductions Required (% of existing load)
Projected Future Loads	8,081	2,434	30.1
Existing Load	7,855	2,208	28.1
TMDL	6,364		
Target Modeling Load	5,647		

Table 9.7 Comparison of categorized sediment loads for Bluestone River and Reference Watershed Dry River.

Source Category	Future Conditions Bluestone River Virginia (T/yr)	West Virginia (T/yr)	Virginia + West Virginia (T/yr)	Reference Dry River (T/yr)
Agriculture	3,935.168	1,730.32	5,665.490	3,818.780
Hay	3.697	1.476	5.175	62.487
Cropland	1,608.747	1,052.821	2,661.568	3,271.753
Pastureland	2,287.223	669.643	2,956.866	450.855
Stream Edge-Access	35.501	6.380	41.881	33.685
Urban	122.515	143.562	266.077	414.271
Transitional	265.728	164.898	430.626	8.318
Forestry	789.447	209.858	999.305	2,668.991
Disturbed Forest	627.988	167.794	795.782	666.305
Channel Erosion	510.692	127.673	638.365	214.027
Point Source	81.363		81.363	

Two alternatives are presented in Table 9.8. Alternative 1 requires a sediment reduction of 40% from four of the source areas: pastureland, stream edge – principally livestock, disturbed forest, and transitional lands. A 20% reduction is required from channel erosion and a 23.2 % reduction is required from cropland. The reductions are expected to be achieved through adding riparian buffers, streambank stabilization, livestock exclusion, stabilizing transitional areas or conversion to urban, stormwater management, reclaiming disturbed forest areas, and improving pasture management and reducing tillage operations. Sediment reductions through livestock streambank exclusion would also result in reducing direct deposition of waste into the stream. Alternative 2 requires a more aggressive approach to achieving reductions through the near elimination (95% reduction) of erosion from livestock stream access or overgrazing within 10 feet of the stream edge. Alternative 2 reductions also require 60% transitional lands, 50% reduction from disturbed forestlands and channel erosion, 20% from cropland and 30% from pastureland.

Table 9.8 TMDL sediment allocation scenarios for Bluestone River impairment at Bluefield.

Sediment Source Categories	Future Conditions (T/yr)	Allocations			
		Alternative 1		Alternative 2	
		(% Reduction)	(T/yr)	(% Reduction)	(T/yr)
LDR-PER	23.0		23.0		23
HDR-PER	2.0		2.0		2
COM-PER	9.1		9.1		9.1
Transitional	**430.6**	**40**	**258.4**	**60**	**172.2**
Forest	203.5		203.5		203.5
Disturbed Forest	**795.8**	**40**	**477.5**	**50**	**397.9**
Urban Grass	2.0		2.0		2
Hay	5.2		5.2		5.2
Pastureland	**2,956.9**	**40**	**1,774.1**	**30**	**2,069.80**
Stream Edge-Access	**41.9**	**40**	**25.1**	**95**	**2.1**
Cropland	**2,661.6**	**23.2**	**2,044.1**	**20**	**2, 129.3**
LDR-IMP	107.3		107.3		107.3
HDR-IMP	26.0		26.0		26
COM-IMP	96.6		96.6		96.6
Water	0.0		0.0		0
NPS Load	7,361.5		5,053.9		5,246.0
Channel Erosion	**638.4**	**20**	**510.7**	**50**	**319.2**
WLA	81.4		81.4		81.4
Total	**8,081.3**		**5,646.0**		**5,646.6**
Target Allocation Load (TMDL-MOS-WLA)			**5647.0**		**5647.0**

The approximate reductions required from both the Virginia and West Virginia components of the Bluestone River impairment to meet the overall reductions identified and allocation scenarios (Table 9.8) are listed in Tables 9.9 and 9.10. The sediment loads given in Table 9.7 represent modeled sediment contributions from each area (*i.e.,* Virginia and West Virginia) with the exception that streambank erosion was modeled as a watershed entity. The distribution between the Virginia component of the watershed and the West Virginia component of the watershed was based on the ratio of the continuous stream lengths. From this relationship, 20% of the streambank erosion was attributed to West Virginia streams and 80% was attributed to Virginia streams. The allocations for load reductions to achieve the TMDL target established by reference watershed Dry River were approximated for each section of the watershed (*i.e.,* the Virginia and West Virginia sections) based on the ratio of respective modeled loads (Table 9.7). The total allocated load from West Virginia, including point and nonpoint loads, is given for each scenario. West Virginia is moving ahead with its own TMDL process for the Bluestone

River watershed. Specifics of the load reductions for the West Virginia portion of the study area will be determined through this process (Section 10.2).

Table 9.9 TMDL allocation scenario 1 for the Bluestone River impairment at Bluefield, with West Virginia load indicated.

Sediment Source Categories	Future Conditions Stream Sediment Load (T/yr)	Load Reduction (%)	Allocation Scenario 1 Stream Sediment Load (T/yr)
LDR-PER	13.1		13.1
HDR-PER	0.0		0.0
COM-PER	5.3		5.3
Transitional	**265.7**	**40**	**159.4**
Forest	161.5		161.5
Disturbed Forest	**628.0**	**40**	**376.8**
Urban Grass	2.0		2.0
Hay	3.7		3.7
Pastureland	**2,287.2**	**40**	**1,372.3**
Stream Edge-Access	**35.5**	**40**	**21.3**
Cropland	**1,608.7**	**23.2**	**1,235.5**
LDR-IMP	33.2		33.2
HDR-IMP	0.0		0.0
COM-IMP	68.9		68.9
Water	0.0		0.0
Channel Erosion	**510.7**	**20**	**408.6**
WLA	81.4		81.4
VA Load – Including WLA	***5,704.9***	***31***	***3,943.0***
WV Load – Including WLA	***2,376.3***	***28***	***1,703.0***
Total	**8,081.2**		**5,646.0**

Table 9.10 TMDL allocation scenario 2 for the Bluestone River impairment at Bluefield, with West Virginia load indicated.

Sediment Source Categories	Future Conditions Stream Sediment Load (T/yr)	Load Reduction (%)	Allocation Scenario 2 Stream Sediment Load (T/yr)
LDR-PER	13.1		13.1
HDR-PER	0.0		0.0
COM-PER	5.3		5.3
Transitional	**265.7**	**60**	**106.3**
Forest	161.5		161.5
Disturbed Forest	**628.0**	**50**	**314.0**
Urban Grass	2.0		2.0
Hay	3.7		3.7
Pastureland	**2,287.2**	**30**	**1,601.0**
Stream Edge-Access	**35.5**	**95**	**1.8**
Cropland	**1,608.7**	**20**	**1,287.0**
LDR-IMP	33.2		33.2
HDR-IMP	0.0		0.0
COM-IMP	68.9		68.9
Water	0.0		0.0
Channel Erosion	**510.7**	**50**	**255.4**
WLA	81.4		81.4
VA Load – Including WLA	***5,704.9***	*31*	***3,934.6***
WV Load – Including WLA	*2,376.3*	*28*	***1,712.0***
Total	**8,081.2**		**5,646.6**

PART IV: IMPLEMENTATION AND PUBLIC PARTICIPATION

10. IMPLEMENTATION

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria and benthic impairments on Bluestone River. 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 hooves 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 septic system repair/replacement programs and the use of alternative waste treatment systems.

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

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

1. *It enables tracking of water quality improvements following BMP implementation through follow-up stream monitoring;*
2. *It provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;*
3. *It provides a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;*
4. *It helps ensure that the most cost effective practices are implemented first; and*
5. *It allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.*

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

Stage I scenarios - Bacteria

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

The Stage I water quality goal was to reduce the number of violations of the instantaneous standard in the main stem of Bluestone River to less than 10%. Table 10.1 contains a set of reductions in land-based and direct loads that are projected to achieve this goal, along with a projected percent of violation occurrence. As presented in Chapter 5, scenarios were devised assuming reductions of 60% 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 (Table 10.1, scenario 4). With this scenario, the model predicted 19.3% violations of the instantaneous water quality standard.

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	98.3	31.8
2	0	0	0	0	0	100	95.0	31.7
3	0	0	90	50	50	100	68.3	21.6
4	0	0	100	60	60	100	51.7	19.3
5	0	0	100	99	99	100	1.67	5.37
6	0	50	100	99	99	100	0.0	1.59
7	0	74	100	99	99	100	0.0	0.0

Table10.2 details the load reductions required for meeting the Stage I Implementation.

Table 10.2 Nonpoint source allocations in the Bluestone River 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	6.65E+14	2.66E+14	60
Commercial	2.94E+13	1.18E+13	60
Barren	6.30E+12	2.52E+12	60
Cropland	5.84E+13	2.34E+13	60
Livestock Access	1.43E+14	5.70E+13	60
Pasture	1.17E+15	4.67E+14	60
Forest	1.03E+15	1.03E+15	0
Water	0.00E+00	0.00E+00	0
Direct			
Livestock	3.70E+14	0.00E+00	100
Wildlife	1.38E+13	1.38E+13	0
Straight Pipes and Sewer Overflows	1.66E+15	0.00E+00	100

Stage I scenarios – Sediment

The Stage I goal was to reduce sediment loads in Bluestone River to within 40% of target reductions. The target reduction goal during Stage I for Bluestone River is 6,620.6 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 Bluestone River impairment at Bluefield.

Sediment Source Categories	Management Scenarios	Area/Len. Affected ha : (m)	Future Conditions T/yr	Benefit T/ha : (T/m)	Implem. Condition T/yr
LDR-PER			23.035		23.035
HDR-PER			2.001		2.001
COM-PER			9.086		9.086
Transitional	Transitional areas converted to urban, grass cover, stormwater management	**150**	**430.626**	**2.464**	**61.026**
Forest			203.523		203.523
Forest Disturbed			795.782		795.782
Urban Grass			1.994		1.994
Hay			5.173		5.173
Pastureland	Pasture Improvement (better forage species, rotational grazing, reduced animal units per acre, minimize feeding areas with concentration of animals, etc.)	**650**	**2,956.866**	**1.645**	**1,887.616**
Cropland			2,661.568		2,661.568
Stream Edge-Livestock Access			41.881		41.881
LDR-IMP			107.280		107.280
HDR-IMP			26.042		26.042
COM-IMP			96.639		96.639
Water			0.000		0.000
NPS Load			7,361.495		5,922.646
Channel Erosion	Riparian Buffer, Streambank stabilization, livestock exclusion, stormwater management	**(5,000)**	**638.365**	**(0.0078)**	**599.365**
WLA			81.363		81.363
Total			**8,081.223**		**6,603.374**
	Stage I Implementation Target (60% reduction)				**6,620.600**
	Target Allocation Load (TMDL-MOS-WLA)				**5647.000**

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 Bluestone River 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.

A one-year "pre-TMDL" monitoring effort in the West Virginia portion of the Bluestone River watershed will be implemented from July 1, 2004 to June 30, 2005. Necessary TMDLs will be completed by December 31, 2007. The Bluestone River in West Virginia is included as impaired relative to fecal coliform water quality criteria on the West Virginia 2004 Draft 303(d) list. Within the watershed, various segments and tributaries are also biologically impaired and/or impaired relative to fecal coliform, iron, aluminum, manganese and pH criteria.

The West Virginia watershed area and streams that contribute to the Virginia portion of the Bluestone will be evaluated in this effort. Although the subject waters are not presently identified as impaired, they will be carefully evaluated for the potential impairments associated with the Virginia TMDLs. Biological assessment, bacteria, sediment and nutrient monitoring will be performed at multiple locations in Brush Fork and Neil Hollow. Pollutant source investigation will be accomplished in the watersheds of those streams. At the conclusion of the monitoring period, WVDEP will possess recent data to assess bacteria and biological impairment, and to support TMDL development inclusive of biological stressors and causative sources. Where necessary, WVDEP will immediately direct contractual modeling and TMDL development.

Given the similarity of each State's bacteria criteria and biological assessment protocols, it is likely that WVDEP will reach impairment assessments consistent with the Virginia process. At that point, WVDEP could develop TMDLs that recognize the gross allocations of the Virginia TMDLs, and include detailed allocation directed by WVDEP and stakeholders. If the pre-TMDL monitoring contradicts the representations of the Virginia TMDLs, or if it is concluded that West Virginia water quality standards do not protect Virginia waters, then WVDEP stands ready to discuss/coordinate appropriate actions with Virginia and EPA.

10.3 Reasonable Assurance for Implementation

10.3.1 Follow-up Monitoring

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

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

Watershed stations are located at the outlet 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…"*.

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 Bluestone River would be reflected in the permittee's Stormwater Pollution Prevention Plan required by the MS4/VPDES permit.

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

10.3.4 Implementation Funding Sources

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

10.3.5 Addressing Wildlife Contributions

In some streams for which TMDLs have been developed, water quality modeling indicates that, even after removal of all bacteria sources other than wildlife, the stream will not attain standards under all flow regimes at all times. As is the case for Bluestone River, 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 Bluestone River TMDL greatly benefited from public involvement. Table 11.1 details the public participation throughout the project. The government kickoff meeting took place on May 28, 2003 at the Virginia Avenue United Methodist Church Fellowship Hall in Bluefield, Virginia with 25 people in attendance. The agencies represented at the meeting include: Tazewell County SWCD, Tazewell County PSA, VDH, VADCR, VADEQ, Cumberland Plateau PDC, Town of Bluefield, New River Highlands Resource Conservation and Development, USDA NRCS, Division of Mined Land Reclamation, West Virginia Department of Environmental Protection, and MapTech. The kickoff meeting was publicized through direct mailing to local government agencies. After the meeting, a letter was received from the Sanitary Board of Bluefield which provided information about the status of the WWTP and PCB locations and requested allocation of 8MGD to the system rather than that permitted. The New River Roundtable Agricultural subcommittee met on August 9, 2003.

The first public meeting was held at the Virginia Avenue United Methodist Church Fellowship Hall in Bluefield, Virginia on September 11, 2003 to discuss the process for TMDL development; 31 people (18 citizens, 5 consultants, and 8 government agents) 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.

The final public meeting for the Bluestone River watershed was held on March 18, 2004 at the Virginia Avenue United Methodist Church Fellowship Hall in Bluefield, Virginia. The meeting was publicized in the *Virginia Register* and in the *Bluefield Daily Telegraph* legal notices. Press releases were also sent to radio stations and the public access television station in Bluefield. The meeting was attended by 33 people, including 16 citizens, 9 government agents, 5 consultants, and 3 local officials. There was a 30 day-public comment period and no written comments were received.

Table 11.1 Public participation during TMDL development for the Bluestone River watershed.

Date	Location	Attendance[1]	Type	Format
5/28/03	Virginia Avenue United Methodist Church 1901 Virginia Avenue Bluefield, VA	25	Kickoff Meeting	Open to public at large
9/11/03	Virginia Avenue United Methodist Church 1901 Virginia Avenue Bluefield, VA	31	1st public	Open to public at large
3/18/04	Virginia Avenue United Methodist Church 1901 Virginia Avenue Bluefield, VA	33	Final public	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.

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

Raw sewage. *Untreated municipal sewage.*

Rapid Bioassessment Protocol (RBP). A suite of measurements based on a quantitative assessment benthic microinvertebrates and a qualititative assessment of their habitat.

RBP scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

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

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

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

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

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

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

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

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

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

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

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

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

Sewer. *A channel or conduit that carries wastewater and 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 WATER QUALITY SAMPLING DATA

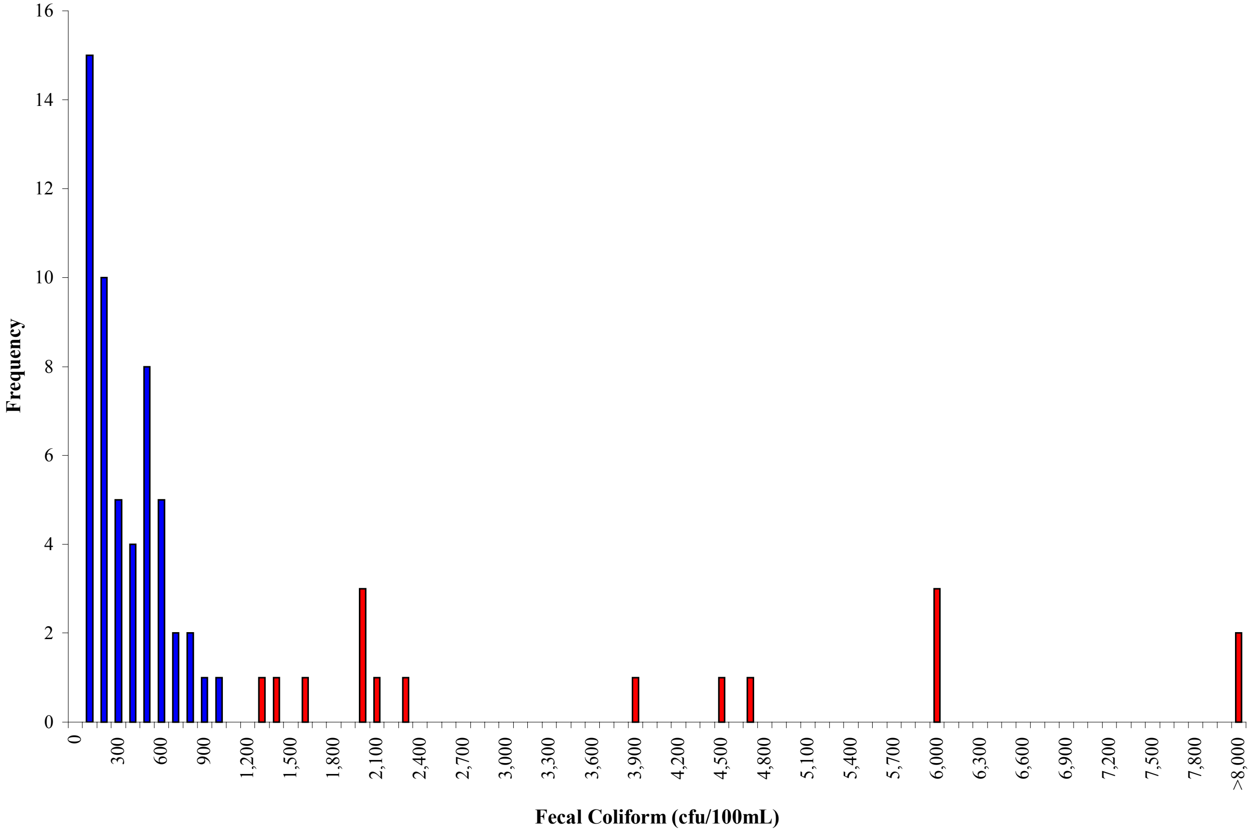

Figure A.1 **Frequency analysis of fecal coliform concentrations at station 9-BST023.05 in the Bluestone River impairment for period May 1992 to March 2001.**

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

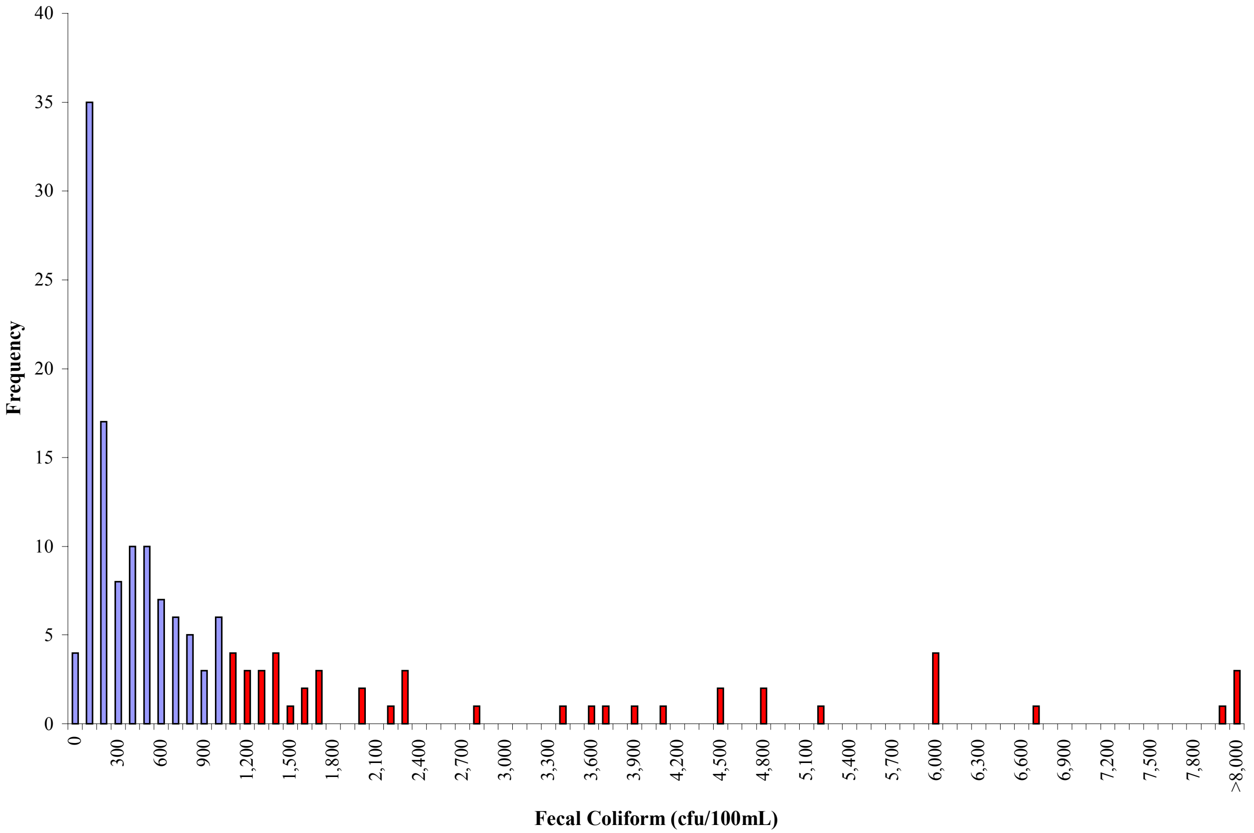

Figure A. 2 **Frequency analysis of fecal coliform concentrations at station 9-BST029.57 and 9-BST029.71 in the Bluestone River impairment for period January 1980 to March 2001.**

*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 Bluestone River impairment (Subsheds 1-9).

	Barren (cfu/ac*day)	Commercial (cfu/ac*day)	Forest (cfu/ac*day)	Pasture (cfu/ac*day)
January	4.83E+08	7.16E+08	7.07E+08	4.22E+09
February	4.83E+08	7.16E+08	7.07E+08	4.81E+09
March	4.83E+08	7.16E+08	7.07E+08	4.76E+09
April	4.83E+08	7.16E+08	7.07E+08	4.71E+09
May	4.83E+08	7.16E+08	7.07E+08	4.71E+09
June	4.83E+08	7.16E+08	7.07E+08	4.67E+09
July	4.83E+08	7.16E+08	7.07E+08	4.67E+09
August	4.83E+08	7.16E+08	7.07E+08	4.67E+09
September	4.83E+08	7.16E+08	7.07E+08	4.71E+09
October	4.83E+08	7.16E+08	7.07E+08	4.76E+09
November	4.83E+08	7.16E+08	7.07E+08	4.47E+09
December	4.83E+08	7.16E+08	7.07E+08	4.50E+09

Table B.1 Current conditions (2003) of land applied fecal coliform load for Bluestone River impairment (Subsheds 1-9). (continued).

	Livestock Access (cfu/ac*day)	Residential (cfu/ac*day)	Row Crops (cfu/ac*day)	Water (cfu/ac*day)
January	7.99E+09	7.60E+10	9.81E+08	0.00E+00
February	8.21E+09	7.45E+10	9.81E+08	0.00E+00
March	8.70E+09	7.15E+10	9.81E+08	0.00E+00
April	9.36E+09	7.00E+10	9.81E+08	0.00E+00
May	9.36E+09	6.85E+10	9.81E+08	0.00E+00
June	9.86E+09	6.69E+10	9.81E+08	0.00E+00
July	9.86E+09	6.39E+10	9.81E+08	0.00E+00
August	9.86E+09	6.39E+10	9.81E+08	0.00E+00
September	9.36E+09	6.39E+10	9.81E+08	0.00E+00
October	8.70E+09	6.24E+10	9.81E+08	0.00E+00
November	8.55E+09	6.39E+10	9.81E+08	0.00E+00
December	8.10E+09	7.00E+10	9.81E+08	0.00E+00

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Bluestone River impairment (Subsheds 1-9).

Reach	Source	Jan cfu/day	Feb cfu/day	Mar cfu/day	Apr cfu/day	May cfu/day	Jun cfu/day
1	Human	8.89E+08	8.89E+08	8.89E+08	8.89E+08	8.89E+08	8.89E+08
	Livestock	7.92E+09	8.62E+09	1.23E+10	1.72E+10	1.72E+10	2.09E+10
	Wildlife	6.33E+09	6.33E+09	6.33E+09	6.33E+09	6.33E+09	6.33E+09
2	Human	3.72E+07	3.72E+07	3.72E+07	3.72E+07	3.72E+07	3.72E+07
	Livestock	5.48E+09	6.00E+09	8.57E+09	1.20E+10	1.20E+10	1.46E+10
	Wildlife	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09
3	Human	2.87E+08	2.87E+08	2.87E+08	2.87E+08	2.87E+08	2.87E+08
	Livestock	1.86E+09	4.19E+09	5.99E+09	8.39E+09	8.39E+09	1.02E+10
	Wildlife	2.21E+09	2.21E+09	2.21E+09	2.21E+09	2.21E+09	2.21E+09
4	Human	5.82E+08	5.82E+08	5.82E+08	5.82E+08	5.82E+08	5.82E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.91E+09	1.91E+09	1.91E+09	1.91E+09	1.91E+09	1.91E+09
5	Human	5.35E+08	5.35E+08	5.35E+08	5.35E+08	5.35E+08	5.35E+08
	Livestock	5.83E+08	7.57E+08	1.08E+09	1.51E+09	1.51E+09	1.84E+09
	Wildlife	3.50E+09	3.50E+09	3.50E+09	3.50E+09	3.50E+09	3.50E+09
6	Human	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08
	Livestock	3.03E+09	3.38E+09	4.83E+09	6.76E+09	6.76E+09	8.21E+09
	Wildlife	1.09E+10	1.09E+10	1.09E+10	1.09E+10	1.09E+10	1.09E+10
7	Human	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+08
	Livestock	3.03E+09	3.38E+09	4.83E+09	6.76E+09	6.76E+09	8.21E+09
	Wildlife	5.21E+09	5.21E+09	5.21E+09	5.21E+09	5.21E+09	5.21E+09
8	Human	1.09E+09	1.09E+09	1.09E+09	1.09E+09	1.09E+09	1.09E+09
	Livestock	1.63E+09	1.84E+09	2.63E+09	3.68E+09	3.68E+09	4.47E+09
	Wildlife	7.14E+09	7.14E+09	7.14E+09	7.14E+09	7.14E+09	7.14E+09
9	Human	4.47E+07	4.47E+07	4.47E+07	4.47E+07	4.47E+07	4.47E+07
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.13E+08	2.13E+08	2.13E+08	2.13E+08	2.13E+08	2.13E+08

Table B.2 Monthly, directly deposited fecal coliform loads in each reach of the Bluestone River impairment (Subsheds 1-9) (continued).

Reach	Source	Jul cfu/day	Aug cfu/day	Sep cfu/day	Oct cfu/day	Nov cfu/day	Dec cfu/day
1	Human	8.89E+08	8.89E+08	8.89E+08	8.89E+08	8.89E+08	8.89E+08
	Livestock	2.09E+10	2.09E+10	1.72E+10	1.23E+10	1.13E+10	7.92E+09
	Wildlife	6.33E+09	6.33E+09	6.33E+09	6.33E+09	6.33E+09	6.33E+09
2	Human	3.72E+07	3.72E+07	3.72E+07	3.72E+07	3.72E+07	3.72E+07
	Livestock	1.46E+10	1.46E+10	1.20E+10	8.57E+09	7.82E+09	5.48E+09
	Wildlife	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09	4.22E+09
3	Human	2.87E+08	2.87E+08	2.87E+08	2.87E+08	2.87E+08	2.87E+08
	Livestock	1.02E+10	1.02E+10	8.39E+09	5.99E+09	5.99E+09	4.19E+09
	Wildlife	2.21E+09	2.21E+09	2.21E+09	2.21E+09	2.21E+09	2.21E+09
4	Human	5.82E+08	5.82E+08	5.82E+08	5.82E+08	5.82E+08	5.82E+08
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	1.91E+09	1.91E+09	1.91E+09	1.91E+09	1.91E+09	1.91E+09
5	Human	5.35E+08	5.35E+08	5.35E+08	5.35E+08	5.35E+08	5.35E+08
	Livestock	1.84E+09	1.84E+09	1.51E+09	1.08E+09	8.32E+08	5.83E+08
	Wildlife	3.50E+09	3.50E+09	3.50E+09	3.50E+09	3.50E+09	3.50E+09
6	Human	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08
	Livestock	8.21E+09	8.21E+09	6.76E+09	4.83E+09	4.33E+09	3.03E+09
	Wildlife	1.09E+10	1.09E+10	1.09E+10	1.09E+10	1.09E+10	1.09E+10
7	Human	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+08	1.70E+08
	Livestock	8.21E+09	8.21E+09	6.76E+09	4.83E+09	4.33E+09	3.03E+09
	Wildlife	5.21E+09	5.21E+09	5.21E+09	5.21E+09	5.21E+09	5.21E+09
8	Human	1.09E+09	1.09E+09	1.09E+09	1.09E+09	1.09E+09	1.09E+09
	Livestock	4.47E+09	4.47E+09	3.68E+09	2.63E+09	2.33E+09	1.63E+09
	Wildlife	7.14E+09	7.14E+09	7.14E+09	7.14E+09	7.14E+09	7.14E+09
9	Human	4.47E+07	4.47E+07	4.47E+07	4.47E+07	4.47E+07	4.47E+07
	Livestock	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
	Wildlife	2.13E+08	2.13E+08	2.13E+08	2.13E+08	2.13E+08	2.13E+08

Table B.3 Existing annual loads from land-based sources for the Bluestone River impairment (Subsheds 1-9).

Source	Barren	Commercial	Forest	Pasture	Livestock Access	Residential	Row Crop	Water
	(cfu/yr)	(cfu/yr)	(cfu/yr)	(cfu/yr)	(cfu/yr)	(cfu/yr)	(cfu/yr)	(cfu/yr)
Pets								
Dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.94E+14	0.00E+00	0.00E+00
Cats	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.28E+09	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.94E+14	0.00E+00	0.00E+00
Human								
Failed Septic	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.20E+14	0.00E+00	0.00E+00
Livestock								
Dairy	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef	0.00E+00	0.00E+00	0.00E+00	7.59E+14	4.05E+13	0.00E+00	0.00E+00	0.00E+00
Sheep	0.00E+00	0.00E+00	0.00E+00	4.79E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Goat	0.00E+00	0.00E+00	0.00E+00	5.15E+11	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	0.00E+00	6.14E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Total	0.00E+00	0.00E+00	0.00E+00	8.22E+14	4.05E+13	0.00E+00	0.00E+00	0.00E+00
Wildlife								
Raccoon	4.78E+12	1.91E+13	7.74E+14	2.03E+14	3.50E+13	4.14E+13	3.54E+13	0.00E+00
Muskrat	9.49E+11	7.62E+12	3.42E+13	8.34E+13	5.49E+13	2.85E+12	1.28E+13	0.00E+00
Deer	0.00E+00	0.00E+00	1.30E+14	2.80E+13	3.11E+12	1.80E+12	4.82E+12	0.00E+00
Turkey	1.34E+08	3.80E+08	4.72E+10	3.86E+09	7.30E+08	9.12E+08	7.44E+08	0.00E+00
Goose	5.48E+09	1.59E+10	1.23E+11	4.67E+10	4.41E+10	1.19E+10	9.68E+09	0.00E+00
Duck	2.03E+08	5.32E+08	5.11E+09	1.53E+09	1.30E+09	4.46E+08	2.86E+08	0.00E+00
Total	5.73E+12	2.67E+13	9.38E+14	1.14E+15	1.34E+14	6.60E+14	5.31E+13	0.00E+00

Table B.4 Existing annual loads from direct-deposition sources for the Bluestone River impairment (Subsheds 1-9).

Source	Fecal Coliform Load (cfu/yr)
Human	
Straight Pipes	1.54E+12
Total	1.54E+12
Livestock	
Dairy	0.00E+00
Beef	3.43E+14
Swine	0.00E+00
Sheep	2.05E+11
Goat	2.21E+11
Horse	2.63E+13
Poultry	0.00E+00
Total	3.70E+14
Wildlife	
Raccoon	2.81E+12
Muskrat	1.09E+13
Beaver	2.35E+06
Deer	8.37E+10
Turkey	2.70E+07
Goose	6.85E+09
Duck	3.83E+08
Total	1.38E+13

APPENDIX C

UCI FILE USED FOR MODELING

```
PERLND
  ACTIVITY
*** <PLS >               Active Sections                               ***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC ***
  101  908    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  908    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
  304     Barren                            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
  503     Comm./Ind./Tr                     1    1    0    0    0    0
  504     Barren                            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
  601     Water                             1    1    0    0    0    0
  602     Resid./Recr                       1    1    0    0    0    0
  603     Comm./Ind./Tr                     1    1    0    0    0    0
  605     Forest/Wet                        1    1    0    0    0    0
  606     Row Crops                         1    1    0    0    0    0
  607     Pasture/Hay                       1    1    0    0    0    0
  608     Pot. Liv. Acc.                    1    1    0    0    0    0
  701     Water                             1    1    0    0    0    0
  702     Resid./Recr                       1    1    0    0    0    0
  703     Comm./Ind./Tr                     1    1    0    0    0    0
  704     Barren                            1    1    0    0    0    0
  705     Forest/Wet                        1    1    0    0    0    0
  706     Row Crops                         1    1    0    0    0    0
  707     Pasture/Hay                       1    1    0    0    0    0
```

```
  708     Pot. Liv. Acc.                    1    1    0    0    0    0
  801     Water                             1    1    0    0    0    0
  802     Resid./Recr                       1    1    0    0    0    0
  803     Comm./Ind./Tr                     1    1    0    0    0    0
  804     Barren                            1    1    0    0    0    0
  805     Forest/Wet                        1    1    0    0    0    0
  806     Row Crops                         1    1    0    0    0    0
  807     Pasture/Hay                       1    1    0    0    0    0
  808     Pot. Liv. Acc.                    1    1    0    0    0    0
  901     Water                             1    1    0    0    0    0
  902     Resid./Recr                       1    1    0    0    0    0
  903     Comm./Ind./Tr                     1    1    0    0    0    0
  904     Barren                            1    1    0    0    0    0
  905     Forest/Wet                        1    1    0    0    0    0
  906     Row Crops                         1    1    0    0    0    0
  907     Pasture/Hay                       1    1    0    0    0    0
  908     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  908    0    1    1    1    1    0    0    0    1    1    0    0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY     AGWRC
*** x  - x                (in)   (in/hr)      (ft)              (1/in)   (1/day)
  101           1.00      4.80     0.021      1.00     0.010      0.00     0.990
  102           1.00      4.80     0.024    273.56     0.066      0.00     0.990
  103           1.00      4.80     0.024    172.31     0.079      0.00     0.990
  104           1.00      4.80     0.029    556.81     0.042      0.00     0.990
  105           1.00      4.80     0.024    555.60     0.133      0.00     0.990
  106           1.00      4.80     0.027    479.03     0.116      0.00     0.990
  107           1.00      4.80     0.025    377.05     0.094      0.00     0.990
  108           1.00      4.80     0.023      1.00     0.010      0.00     0.990
  201           1.00      4.80     0.030      1.00     0.010      0.00     0.990
  202           1.00      4.80     0.024    344.43     0.051      0.00     0.990
  203           1.00      4.80     0.025    352.28     0.054      0.00     0.990
  204           1.00      4.80     0.028    512.42     0.087      0.00     0.990
  205           1.00      4.80     0.024    507.32     0.106      0.00     0.990
  206           1.00      4.80     0.026    575.62     0.098      0.00     0.990
  207           1.00      4.80     0.025    429.63     0.064      0.00     0.990
  208           1.00      4.80     0.019      1.00     0.010      0.00     0.990
  301           1.00      4.80     0.016      1.00     0.010      0.00     0.990
  302           1.00      4.80     0.023    586.78     0.031      0.00     0.990
  303           1.00      4.80     0.022    582.25     0.038      0.00     0.990
  304           1.00      4.80     0.022    800.00     0.013      0.00     0.990
  305           1.00      4.80     0.021    754.78     0.092      0.00     0.990
  306           1.00      4.80     0.020    800.00     0.023      0.00     0.990
  307           1.00      4.80     0.026    446.76     0.043      0.00     0.990
  308           1.00      4.80     0.020      1.00     0.010      0.00     0.990
  401           1.00      4.80     0.018      1.00     0.010      0.00     0.990
  402           1.00      4.80     0.020    306.49     0.045      0.00     0.990
  403           1.00      4.80     0.020    326.89     0.052      0.00     0.990
  404           1.00      4.80     0.018    711.79     0.049      0.00     0.990
  405           1.00      4.80     0.020    444.37     0.124      0.00     0.990
  406           1.00      4.80     0.019    393.86     0.149      0.00     0.990
  407           1.00      4.80     0.019    333.26     0.060      0.00     0.990
  408           1.00      4.80     0.020      1.00     0.010      0.00     0.990
  501           1.00      4.80     0.030      1.00     0.010      0.00     0.990
  502           1.00      4.80     0.024    221.24     0.063      0.00     0.990
  503           1.00      4.80     0.017    138.18     0.022      0.00     0.990
  504           1.00      4.80     0.027    228.54     0.056      0.00     0.990
  505           1.00      4.80     0.020    579.37     0.151      0.00     0.990
  506           1.00      4.80     0.023    365.57     0.098      0.00     0.990
  507           1.00      4.80     0.022    416.99     0.067      0.00     0.990
  508           1.00      4.80     0.023      1.00     0.010      0.00     0.990
  601           1.00      4.80     0.085      1.00     0.010      0.00     0.990
  602           1.00      4.80     0.019    277.92     0.036      0.00     0.990
  603           1.00      4.80     0.005    800.00     0.176      0.00     0.990
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  605           1.00      4.80     0.020    584.57     0.156      0.00     0.990
  606           1.00      4.80     0.019    334.49     0.129      0.00     0.990
  607           1.00      4.80     0.019    322.61     0.096      0.00     0.990
  608           1.00      4.80     0.022      1.00     0.010      0.00     0.990
  701           1.00      4.80     0.026      1.00     0.010      0.00     0.990
  702           1.00      4.80     0.021    616.21     0.051      0.00     0.990
  703           1.00      4.80     0.019    341.88     0.090      0.00     0.990
  704           1.00      4.80     0.025    313.00     0.079      0.00     0.990
  705           1.00      4.80     0.020    744.14     0.137      0.00     0.990
  706           1.00      4.80     0.017    770.94     0.127      0.00     0.990
  707           1.00      4.80     0.020    440.32     0.079      0.00     0.990
  708           1.00      4.80     0.018      1.00     0.010      0.00     0.990
  801           1.00      4.80     0.018      1.00     0.010      0.00     0.990
  802           1.00      4.80     0.018    373.48     0.063      0.00     0.990
  803           1.00      4.80     0.018    506.05     0.080      0.00     0.990
  804           1.00      4.80     0.018    401.01     0.084      0.00     0.990
  805           1.00      4.80     0.018    465.27     0.133      0.00     0.990
  806           1.00      4.80     0.018    381.32     0.132      0.00     0.990
  807           1.00      4.80     0.018    407.22     0.109      0.00     0.990
  808           1.00      4.80     0.018      1.00     0.010      0.00     0.990
  901           1.00      4.80     0.022      1.00     0.010      0.00     0.990
  902           1.00      4.80     0.024    800.00     0.021      0.00     0.990
  903           1.00      4.80     0.021    800.00     0.016      0.00     0.990
  904           1.00      4.80     0.023    800.00     0.040      0.00     0.990
  905           1.00      4.80     0.023    800.00     0.040      0.00     0.990
  906           1.00      4.80     0.019    800.00     0.039      0.00     0.990
  907           1.00      4.80     0.024    800.00     0.030      0.00     0.990
  908           1.00      4.80     0.025      1.00     0.010      0.00     0.990
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP    AGWETP
*** x  - x   (deg F)   (deg F)
  101  908       40.       35.        2.        2.       0.0      0.03      0.00
  END PWAT-PARM3
  PWAT-PARM4
*** <PLS >     CEPSC      UZSN      NSUR     INTFW       IRC     LZETP
*** x -  x      (in)      (in)                         (1/day)
  101           0.01     2.000      0.01      1.00      0.85      0.01
  102           0.03     2.000      0.10      4.00      0.85      0.05
  103           0.03     2.000      0.10      4.00      0.85      0.05
  104           0.03     1.481      0.10      4.00      0.85      0.05
  105           0.13     2.000      0.40      4.00      0.85      0.35
  106           0.10     2.000      0.25      4.00      0.85      0.30
  107           0.05     2.000      0.30      4.00      0.85      0.25
  108           0.05     2.000      0.30      4.00      0.85      0.25
  201           0.01     2.000      0.01      1.00      0.85      0.01
  202           0.03     2.000      0.10      4.00      0.85      0.05
  203           0.03     2.000      0.10      4.00      0.85      0.05
  204           0.03     2.000      0.10      4.00      0.85      0.05
  205           0.13     1.995      0.40      4.00      0.85      0.35
  206           0.10     2.000      0.25      4.00      0.85      0.30
  207           0.05     2.000      0.30      4.00      0.85      0.25
  208           0.05     2.000      0.30      4.00      0.85      0.25
  301           0.01     2.000      0.01      1.00      0.85      0.01
  302           0.03     2.000      0.10      4.00      0.85      0.05
  303           0.03     1.992      0.10      4.00      0.85      0.05
  304           0.03     1.429      0.10      4.00      0.85      0.05
  305           0.13     1.697      0.40      4.00      0.85      0.35
  306           0.10     1.414      0.25      4.00      0.85      0.30
  307           0.05     2.000      0.30      4.00      0.85      0.25
  308           0.05     2.000      0.30      4.00      0.85      0.25
  401           0.01     1.456      0.01      1.00      0.85      0.01
  402           0.03     1.779      0.10      4.00      0.85      0.05
  403           0.03     2.000      0.10      4.00      0.85      0.05
  404           0.03     1.424      0.10      4.00      0.85      0.05
  405           0.13     1.479      0.40      4.00      0.85      0.35
  406           0.10     1.442      0.25      4.00      0.85      0.30
  407           0.05     1.799      0.30      4.00      0.85      0.25
  408           0.05     2.000      0.30      4.00      0.85      0.25
  501           0.01     1.250      0.01      1.00      0.85      0.01
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  502           0.03     1.352      0.10      4.00      0.85      0.05
  503           0.03     2.000      0.10      4.00      0.85      0.05
  504           0.03     1.211      0.10      4.00      0.85      0.05
  505           0.13     1.465      0.40      4.00      0.85      0.35
  506           0.10     1.586      0.25      4.00      0.85      0.30
  507           0.05     1.648      0.30      4.00      0.85      0.25
  508           0.05     2.000      0.30      4.00      0.85      0.25
  601           0.01     1.071      0.01      1.00      0.85      0.01
  602           0.03     1.571      0.10      4.00      0.85      0.05
  603           0.03     1.125      0.10      4.00      0.85      0.05
  605           0.13     1.580      0.40      4.00      0.85      0.35
  606           0.10     1.652      0.25      4.00      0.85      0.30
  607           0.05     1.791      0.30      4.00      0.85      0.25
  608           0.05     2.000      0.30      4.00      0.85      0.25
  701           0.01     2.000      0.01      1.00      0.85      0.01
  702           0.03     2.000      0.10      4.00      0.85      0.05
  703           0.03     2.000      0.10      4.00      0.85      0.05
  704           0.03     2.000      0.10      4.00      0.85      0.05
  705           0.13     1.975      0.40      4.00      0.85      0.35
  706           0.10     2.000      0.25      4.00      0.85      0.30
  707           0.05     2.000      0.30      4.00      0.85      0.25
  708           0.05     2.000      0.30      4.00      0.85      0.25
  801  808      0.05     1.424      0.20      4.00      0.85      0.15
  901           0.01     0.666      0.01      1.00      0.85      0.01
  902           0.03     1.442      0.10      4.00      0.85      0.05
  903           0.03     1.351      0.10      4.00      0.85      0.05
  904           0.03     1.431      0.10      4.00      0.85      0.05
  905           0.13     1.193      0.40      4.00      0.85      0.35
  906           0.10     1.321      0.25      4.00      0.85      0.30
  907           0.05     1.443      0.30      4.00      0.85      0.25
  908           0.05     1.445      0.30      4.00      0.85      0.25
  END PWAT-PARM4

  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x      CEPS      SURS       UZS      IFWS       LZS      AGWS      GWVS
  101           0.01      0.01     3.500      1.00      4.80       1.0       0.0
  102           0.05      0.01     4.052      1.00      4.80       1.0       0.0
  103           0.05      0.01     2.981      1.00      4.80       1.0       0.0
  104           0.05      0.01     1.481      1.00      4.80       1.0       0.0
  105           0.25      0.01     2.067      1.00      4.80       1.0       0.0
  106           0.20      0.01     3.892      1.00      4.80       1.0       0.0
  107           0.10      0.01     3.754      1.00      4.80       1.0       0.0
  108           0.10      0.01     3.105      1.00      4.80       1.0       0.0
  201           0.01      0.01     4.489      1.00      4.80       1.0       0.0
  202           0.05      0.01     3.727      1.00      4.80       1.0       0.0
  203           0.05      0.01     2.953      1.00      4.80       1.0       0.0
  204           0.05      0.01     3.374      1.00      4.80       1.0       0.0
  205           0.25      0.01     1.995      1.00      4.80       1.0       0.0
  206           0.20      0.01     4.625      1.00      4.80       1.0       0.0
  207           0.10      0.01     3.428      1.00      4.80       1.0       0.0
  208           0.10      0.01     3.582      1.00      4.80       1.0       0.0
  301           0.01      0.01     4.782      1.00      4.80       1.0       0.0
  302           0.05      0.01     2.486      1.00      4.80       1.0       0.0
  303           0.05      0.01     1.992      1.00      4.80       1.0       0.0
  304           0.05      0.01     1.429      1.00      4.80       1.0       0.0
  305           0.25      0.01     1.697      1.00      4.80       1.0       0.0
  306           0.20      0.01     1.414      1.00      4.80       1.0       0.0
  307           0.10      0.01     2.897      1.00      4.80       1.0       0.0
  308           0.10      0.01     3.327      1.00      4.80       1.0       0.0
  401           0.01      0.01     1.456      1.00      4.80       1.0       0.0
  402           0.05      0.01     1.779      1.00      4.80       1.0       0.0
  403           0.05      0.01     2.149      1.00      4.80       1.0       0.0
  404           0.05      0.01     1.424      1.00      4.80       1.0       0.0
  405           0.25      0.01     1.479      1.00      4.80       1.0       0.0
  406           0.20      0.01     1.442      1.00      4.80       1.0       0.0
  407           0.10      0.01     1.799      1.00      4.80       1.0       0.0
  408           0.10      0.01     2.100      1.00      4.80       1.0       0.0
  501           0.01      0.01     1.250      1.00      4.80       1.0       0.0
  502           0.05      0.01     1.352      1.00      4.80       1.0       0.0
  503           0.05      0.01     4.418      1.00      4.80       1.0       0.0
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  504           0.05      0.01     1.211      1.00      4.80       1.0       0.0
  505           0.25      0.01     1.465      1.00      4.80       1.0       0.0
  506           0.20      0.01     1.586      1.00      4.80       1.0       0.0
  507           0.10      0.01     1.648      1.00      4.80       1.0       0.0
  508           0.10      0.01     2.547      1.00      4.80       1.0       0.0
  601           0.01      0.01     1.071      1.00      4.80       1.0       0.0
  602           0.05      0.01     1.571      1.00      4.80       1.0       0.0
  603           0.05      0.01     1.125      1.00      4.80       1.0       0.0
  605           0.25      0.01     1.580      1.00      4.80       1.0       0.0
  606           0.20      0.01     1.652      1.00      4.80       1.0       0.0
  607           0.10      0.01     1.791      1.00      4.80       1.0       0.0
  608           0.10      0.01     2.186      1.00      4.80       1.0       0.0
  701           0.01      0.01     2.154      1.00      4.80       1.0       0.0
  702           0.05      0.01     3.367      1.00      4.80       1.0       0.0
  703           0.05      0.01     2.448      1.00      4.80       1.0       0.0
  704           0.05      0.01     2.215      1.00      4.80       1.0       0.0
  705           0.25      0.01     1.975      1.00      4.80       1.0       0.0
  706           0.20      0.01     2.093      1.00      4.80       1.0       0.0
  707           0.10      0.01     3.087      1.00      4.80       1.0       0.0
  708           0.10      0.01     3.181      1.00      4.80       1.0       0.0
  801  808      0.10      0.01     1.424      1.00      4.80       1.0       0.0
  901           0.01      0.01     0.666      1.00      4.80       1.0       0.0
  902           0.05      0.01     1.442      1.00      4.80       1.0       0.0
  903           0.05      0.01     1.351      1.00      4.80       1.0       0.0
  904           0.05      0.01     1.431      1.00      4.80       1.0       0.0
  905           0.25      0.01     1.193      1.00      4.80       1.0       0.0
  906           0.20      0.01     1.321      1.00      4.80       1.0       0.0
  907           0.10      0.01     1.443      1.00      4.80       1.0       0.0
  908           0.10      0.01     1.445      1.00      4.80       1.0       0.0
  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  908 0.03 0.03 0.03 0.04 0.04 0.05 0.08 0.08 0.08 0.11 0.11 0.10
  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  908 1.66 1.63 1.60 0.90 0.90 1.87 2.83 3.34 3.34 4.17 4.78 4.13
  END MON-UZSN

  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  908  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.7  0.7  0.7
  END MON-LZETPARM

  NQUALS
*** <PLS >
*** x -  xNQUAL
  101  908    1
  END NQUALS

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  908FECAL COLIFO       #    0    0    0    1    1    0    0    0    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            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     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
  102     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
  103     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.68000.00E+030.00E+00
  104     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.68000.00E+030.00E+00
  105     0.00E+000.00E+000.00E+001.00E+031.00E+00  3.06000.00E+030.00E+00
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106     0.00E+000.00E+000.00E+001.00E+031.00E+00  1.70000.00E+030.00E+00
107     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
108     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
201     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
202     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
203     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.68000.00E+030.00E+00
204     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.68000.00E+030.00E+00
205     0.00E+000.00E+000.00E+001.00E+031.00E+00  3.06000.00E+030.00E+00
206     0.00E+000.00E+000.00E+001.00E+031.00E+00  1.70000.00E+030.00E+00
207     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
208     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.85000.00E+030.00E+00
301     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
302     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
303     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
304     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
305     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
306     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
307     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
308     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
401     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
402     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
403     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
404     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
405     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
406     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
407     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
408     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
501     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
502     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
503     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
504     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
505     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
506     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
507     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
508     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
601     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
602     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
603     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
605     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
606     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
607     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
608     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
701     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
702     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
703     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
704     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
705     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
706     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
707     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
708     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
801     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
802     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
803     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
804     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
805     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
806     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
807     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
808     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
901     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.00000.00E+030.00E+00
902     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
903     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
904     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.10000.00E+030.00E+00
905     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.45000.00E+030.00E+00
906     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.25000.00E+030.00E+00
907     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
908     0.00E+000.00E+000.00E+001.00E+031.00E+00  0.12500.00E+030.00E+00
END QUAL-INPUT

*******************************************
*** MON-ACCUM HAS UPDATED ORDER NUMBERS ***
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  MON-ACCUM
*** <PLS >  Value at start of each month for accum rate of QUALOF (lb/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  102     36E0836E0834E0833E0832E0832E0830E0830E0830E0829E0830E0833E08
  103     03E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E08
  104     37E0637E0637E0637E0637E0637E0637E0637E0637E0637E0637E0637E06
  105     66E0666E0666E0666E0666E0666E0666E0666E0666E0666E0666E0666E06
  106     72E0672E0672E0672E0672E0672E0672E0672E0672E0672E0672E0672E06
  107     05E0805E0805E0805E0805E0805E0805E0805E0805E0805E0805E0805E08
  108     05E0805E0805E0806E0806E0806E0806E0806E0806E0805E0805E0805E08
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     13E0813E0813E0812E0812E0812E0811E0811E0811E0811E0811E0812E08
  203     96E0696E0696E0696E0696E0696E0696E0696E0696E0696E0696E0696E06
  204     53E0653E0653E0653E0653E0653E0653E0653E0653E0653E0653E0653E06
  205     69E0669E0669E0669E0669E0669E0669E0669E0669E0669E0669E0669E06
  206     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  207     07E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E08
  208     07E0807E0807E0809E0809E0809E0809E0809E0809E0807E0807E0807E08
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     08E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E0808E08
  303     56E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E06
  304     23E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E06
  305     71E0671E0671E0671E0671E0671E0671E0671E0671E0671E0671E0671E06
  306     56E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E0656E06
  307     04E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E08
  308     05E0806E0807E0808E0808E0809E0809E0809E0808E0807E0807E0806E08
  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     13E0813E0813E0813E0813E0813E0812E0812E0812E0812E0812E0813E08
  403     76E0676E0676E0676E0676E0676E0676E0676E0676E0676E0676E0676E06
  404     21E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E06
  405     86E0686E0686E0686E0686E0686E0686E0686E0686E0686E0686E0686E06
  406     80E0680E0680E0680E0680E0680E0680E0680E0680E0680E0680E0680E06
  407     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  408     07E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E0807E08
  501     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  502     02E1002E1001E1001E1001E1001E1001E1001E1001E1001E1001E1001E10
  503     03E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E08
  504     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  505     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  506     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  507     05E0806E0806E0806E0806E0806E0806E0806E0806E0806E0805E0805E08
  508     21E0822E0822E0823E0823E0824E0824E0824E0823E0822E0822E0821E08
  601     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  602     08E1008E1007E1007E1007E1007E1006E1006E1006E1006E1006E1007E10
  603     21E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E06
  605     83E0683E0683E0683E0683E0683E0683E0683E0683E0683E0683E0683E06
  606     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  607     10E0811E0811E0810E0810E0810E0810E0810E0810E0811E0810E0810E08
  608     13E0813E0814E0815E0815E0816E0816E0816E0815E0814E0813E0813E08
  701     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  702     21E0821E0820E0820E0820E0819E0818E0818E0818E0818E0818E0820E08
  703     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  704     18E0618E0618E0618E0618E0618E0618E0618E0618E0618E0618E0618E06
  705     82E0682E0682E0682E0682E0682E0682E0682E0682E0682E0682E0682E06
  706     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  707     07E0808E0808E0808E0808E0808E0808E0808E0808E0808E0807E0807E08
  708     13E0813E0814E0815E0815E0816E0816E0815E0815E0814E0814E0813E08
  801     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  802     19E0819E0818E0818E0818E0817E0817E0817E0817E0817E0817E0818E08
  803     44E0644E0644E0644E0644E0644E0644E0644E0644E0644E0644E0644E06
  804     84E0684E0684E0684E0684E0684E0684E0684E0684E0684E0684E0684E06
  805     87E0687E0687E0687E0687E0687E0687E0687E0687E0687E0687E0687E06
  806     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  807     03E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E0803E08
  808     09E0809E0810E0810E0810E0811E0811E0811E0810E0810E0810E0809E08
  901     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  902     11E0811E0811E0811E0811E0811E0811E0811E0811E0811E0811E0811E08
  903     16E0616E0616E0616E0616E0616E0616E0616E0616E0616E0616E0616E06
  904     21E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E0621E06
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  905     39E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E0639E06
  906     45E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E0645E06
  907     54E0654E0654E0654E0654E0654E0654E0654E0654E0654E0654E0654E06
  908     02E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08

  END MON-ACCUM

  *****************************************************
  *** PERLAND MAX-STORAGE HAS UPDATED ORDER NUMBERS ***
  *****************************************************

  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     40E0839E0856E0891E0889E0887E0882E0882E0882E0848E0833E0836E08
  103     03E0803E0804E0807E0807E0807E0807E0807E0807E0804E0803E0803E08
  104     41E0641E0661E0601E0801E0801E0801E0801E0801E0861E0641E0641E06
  105     73E0673E0601E0802E0802E0802E0802E0802E0802E0801E0873E0673E06
  106     79E0679E0601E0802E0802E0802E0802E0802E0802E0801E0879E0679E06
  107     06E0806E0809E0815E0815E0814E0814E0814E0815E0809E0806E0806E08
  108     05E0805E0809E0816E0816E0818E0818E0818E0816E0809E0806E0805E08
  201     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  202     14E0814E0821E0834E0833E0833E0832E0832E0832E0819E0813E0814E08
  203     01E0801E0802E0803E0803E0803E0803E0803E0803E0802E0801E0801E08
  204     59E0659E0688E0601E0801E0801E0801E0801E0801E0888E0659E0659E06
  205     75E0675E0601E0802E0802E0802E0802E0802E0802E0801E0875E0675E06
  206     02E0802E0802E0804E0804E0804E0804E0804E0804E0802E0802E0802E08
  207     08E0808E0812E0820E0820E0820E0820E0820E0820E0812E0808E0808E08
  208     07E0807E0812E0823E0823E0826E0826E0826E0823E0812E0808E0807E08
  301     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  302     02E1002E1002E1004E1004E1004E1004E1004E1004E1002E1002E1002E10
  303     11E0811E0817E0828E0828E0828E0828E0828E0828E0817E0811E0811E08
  304     05E0805E0807E0812E0812E0812E0812E0812E0812E0807E0805E0805E08
  305     14E0814E0821E0835E0835E0835E0835E0835E0835E0821E0814E0814E08
  306     11E0811E0817E0828E0828E0828E0828E0828E0828E0817E0811E0811E08
  307     78E0801E1002E1003E1003E1003E1003E1003E1003E1002E1001E1001E10
  308     96E0801E1002E1004E1004E1005E1005E1005E1004E1002E1001E1001E10
  401     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  402     03E1003E1004E1006E1006E1006E1006E1006E1006E1004E1002E1003E10
  403     15E0815E0823E0838E0838E0838E0838E0838E0838E0823E0815E0815E08
  404     04E0804E0806E0811E0811E0811E0811E0811E0811E0806E0804E0804E08
  405     17E0817E0826E0843E0843E0843E0843E0843E0843E0826E0817E0817E08
  406     16E0816E0824E0840E0840E0840E0840E0840E0840E0824E0816E0816E08
  407     41E0841E0862E0801E1001E1001E1001E1001E1001E1062E0841E0841E08
  408     01E1001E1002E1004E1004E1004E1004E1004E1004E1002E1001E1001E10
  501     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  502     31E1030E1044E1072E1070E1068E1065E1065E1065E1038E1026E1029E10
  503     63E0863E0895E0802E1002E1002E1002E1002E1002E1095E0863E0863E08
  504     45E0845E0868E0801E1001E1001E1001E1001E1001E1068E0845E0845E08
  505     25E0825E0837E0862E0862E0862E0862E0862E0862E0837E0825E0825E08
  506     42E0842E0863E0801E1001E1001E1001E1001E1001E1063E0842E0842E08
  507     01E1001E1002E1003E1003E1003E1003E1003E1003E1002E1099E0801E10
  508     04E1004E1007E1011E1011E1012E1012E1012E1011E1007E1004E1004E10
  601     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  602     02E1202E1202E1204E1203E1203E1203E1203E1203E1202E1201E1201E12
  603     04E0804E0806E0811E0811E0811E0811E0811E0811E0806E0804E0804E08
  605     17E0817E0825E0841E0841E0841E0841E0841E0841E0825E0817E0817E08
  606     30E0830E0846E0876E0876E0876E0876E0876E0876E0846E0830E0830E08
  607     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  608     03E1003E1004E1008E1008E1008E1008E1008E1008E1004E1003E1003E10
  701     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  702     04E1004E1006E1010E1010E1010E1009E1009E1009E1005E1004E1004E10
  703     24E0824E0836E0860E0860E0860E0860E0860E0860E0836E0824E0824E08
  704     04E0804E0806E0809E0809E0809E0809E0809E0809E0806E0804E0804E08
  705     16E0816E0825E0841E0841E0841E0841E0841E0841E0825E0816E0816E08
  706     23E0823E0835E0858E0858E0858E0858E0858E0858E0835E0823E0823E08
  707     01E1002E1002E1004E1004E1004E1004E1004E1004E1002E1001E1001E10
  708     03E1003E1004E1008E1008E1008E1008E1008E1008E1004E1003E1003E10
  801     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  802     04E1004E1005E1009E1009E1009E1008E1008E1008E1005E1003E1004E10
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  803     09E0809E0813E0822E0822E0822E0822E0822E0822E0813E0809E0809E08
  804     17E0817E0825E0842E0842E0842E0842E0842E0842E0825E0817E0817E08
  805     17E0817E0826E0844E0844E0844E0844E0844E0844E0826E0817E0817E08
  806     23E0823E0834E0857E0857E0857E0857E0857E0857E0834E0823E0823E08
  807     61E0865E0897E0802E1002E1002E1002E1002E1002E1097E0860E0861E08
  808     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  901     00E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E0000E00
  902     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  903     03E0803E0805E0808E0808E0808E0808E0808E0808E0805E0803E0803E08
  904     04E0804E0806E0810E0810E0810E0810E0810E0810E0806E0804E0804E08
  905     08E0808E0812E0819E0819E0819E0819E0819E0819E0812E0808E0808E08
  906     09E0809E0814E0823E0823E0823E0823E0823E0823E0814E0809E0809E08
  907     11E0811E0816E0827E0827E0827E0827E0827E0827E0816E0811E0811E08
  908     31E0831E0846E0877E0877E0877E0877E0877E0877E0846E0831E0831E08

  END MON-SQOLIM

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
  101  902    0    0    1    0    0    1
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
  101  902    4    4    4    4    4    4    1    9
  END PRINT-INFO

  GEN-INFO
***             Name             Unit-systems   Printer BinaryOut
*** <ILS >                           t-series Engl Metr Engl Metr
*** x -  x                            in  out
  101     Resid./Recr                 1    1    0    0    0    0
  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
  501     Resid./Recr                 1    1    0    0    0    0
  502     Comm./Ind./Tr               1    1    0    0    0    0
  601     Resid./Recr                 1    1    0    0    0    0
  602     Comm./Ind./Tr               1    1    0    0    0    0
  701     Resid./Recr                 1    1    0    0    0    0
  702     Comm./Ind./Tr               1    1    0    0    0    0
  801     Resid./Recr                 1    1    0    0    0    0
  802     Comm./Ind./Tr               1    1    0    0    0    0
  901     Resid./Recr                 1    1    0    0    0    0
  902     Comm./Ind./Tr               1    1    0    0    0    0
  END GEN-INFO

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
  101  902    0    1    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
  101         273.56  0.066025      0.05       0.1
  102         172.31  0.078782      0.05       0.1
  201         344.43  0.051265      0.05       0.1
  202         352.28  0.054268      0.05       0.1
  301         586.78   0.03108      0.05       0.1
  302         582.25  0.038005      0.05       0.1
```

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  401         306.49  0.045083      0.05       0.1
  402         326.89  0.052029      0.05       0.1
  501         221.24  0.063091      0.05       0.1
  502         138.18  0.022368      0.05       0.1
  601         277.92  0.035671      0.05       0.1
  602            800  0.175504      0.05       0.1
  701         616.21  0.050716      0.05       0.1
  702         341.88  0.090439      0.05       0.1
  801         373.48  0.063013      0.05       0.1
  802         506.05  0.079815      0.05       0.1
  901            800  0.021073      0.05       0.1
  902            800  0.015907      0.05       0.1
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
  101  902       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
  101  902      0.01      0.01
  END IWAT-STATE1

  NQUALS
*** <ILS >
*** x -  xNQUAL
  101  902    1
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW VAQC
  101  902   FECAL COLIFO    #    0    0    0    1    1    0    0    0    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                ac.day
  101     0.00E+000.00E+000.00E+000.00E+00   0.850
  102     0.00E+000.00E+000.00E+000.00E+00   0.680
  201     0.00E+000.00E+000.00E+000.00E+00   0.850
  202     0.00E+000.00E+000.00E+000.00E+00   0.680
  301     0.00E+000.00E+000.00E+000.00E+00   0.100
  302     0.00E+000.00E+000.00E+000.00E+00   0.100
  401     0.00E+000.00E+000.00E+000.00E+00   0.100
  402     0.00E+000.00E+000.00E+000.00E+00   0.100
  501     0.00E+000.00E+000.00E+000.00E+00   0.100
  502     0.00E+000.00E+000.00E+000.00E+00   0.100
  601     0.00E+000.00E+000.00E+000.00E+00   0.100
  602     0.00E+000.00E+000.00E+000.00E+00   0.100
  701     0.00E+000.00E+000.00E+000.00E+00   0.100
  702     0.00E+000.00E+000.00E+000.00E+00   0.100
  801     0.00E+000.00E+000.00E+000.00E+00   0.100
  802     0.00E+000.00E+000.00E+000.00E+00   0.100
  901     0.00E+000.00E+000.00E+000.00E+00   0.100
  902     0.00E+000.00E+000.00E+000.00E+00   0.100
  END QUAL-INPUT

  MON-ACCUM
*** <ILS >  Value at start of each month for accum rate of QUALOF (qty/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
  101     03E0803E0802E0802E0802E0802E0802E0802E0802E0802E0802E0802E08
  102     18E0618E0618E0618E0618E0618E0618E0618E0618E0618E0618E0618E06
  201     95E0693E0690E0689E0687E0686E0683E0683E0683E0681E0683E0689E06
  202     07E0607E0607E0607E0607E0607E0607E0607E0607E0607E0607E0607E06
  301     59E0659E0658E0658E0657E0657E0656E0656E0656E0656E0656E0658E06
```

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  302     04E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E0604E06
  401     97E0696E0694E0693E0691E0690E0688E0688E0688E0687E0688E0693E06
  402     05E0605E0605E0605E0605E0605E0605E0605E0605E0605E0605E0605E06
  501     11E0811E0811E0810E0810E0810E0809E0809E0809E0809E0809E0810E08
  502     23E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E0623E06
  601     57E0855E0853E0851E0850E0849E0846E0846E0846E0845E0846E0851E08
  602     02E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E0602E06
  701     02E0802E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  702     09E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E0609E06
  801     01E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E0801E08
  802     03E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E0603E06
  901     78E0678E0678E0678E0677E0677E0677E0677E0677E0677E0677E0678E06
  902     01E0601E0601E0601E0601E0601E0601E0601E0601E0601E0601E0601E06

  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF (#/ac)***
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC***
  101     03E0803E0804E0807E0807E0806E0806E0806E0806E0803E0802E0803E08
  102     20E0620E0630E0650E0650E0650E0650E0650E0650E0630E0620E0620E06
  201     01E0801E0801E0802E0802E0802E0802E0802E0802E0801E0891E0697E06
  202     08E0608E0611E0619E0619E0619E0619E0619E0619E0611E0608E0608E06
  301     12E0812E0817E0829E0829E0828E0828E0828E0828E0817E0811E0812E08
  302     80E0680E0601E0802E0802E0802E0802E0802E0802E0801E0880E0680E06
  401     19E0819E0828E0846E0847E0845E0844E0844E0844E0826E0818E0819E08
  402     01E0801E0802E0803E0803E0803E0803E0803E0803E0802E0801E0801E08
  501     02E1002E1003E1005E1005E1005E1005E1005E1005E1003E1002E1002E10
  502     05E0805E0807E0811E0811E0811E0811E0811E0811E0807E0805E0805E08
  601     11E1011E1016E1026E1026E1024E1023E1023E1023E1013E1009E1010E10
  602     31E0631E0646E0677E0677E0677E0677E0677E0677E0646E0631E0631E06
  701     31E0830E0844E0872E0873E0869E0867E0867E0867E0839E0827E0829E08
  702     02E0802E0803E0804E0804E0804E0804E0804E0804E0803E0802E0802E08
  801     27E0827E0839E0864E0865E0862E0861E0861E0861E0836E0824E0826E08
  802     64E0664E0696E0602E0802E0802E0802E0802E0802E0896E0664E0664E06
  901     16E0816E0823E0839E0839E0839E0838E0838E0838E0823E0815E0816E08
  902     23E0623E0635E0658E0658E0658E0658E0658E0658E0635E0623E0623E06

  END MON-SQOLIM
END IMPLND
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APPENDIX D

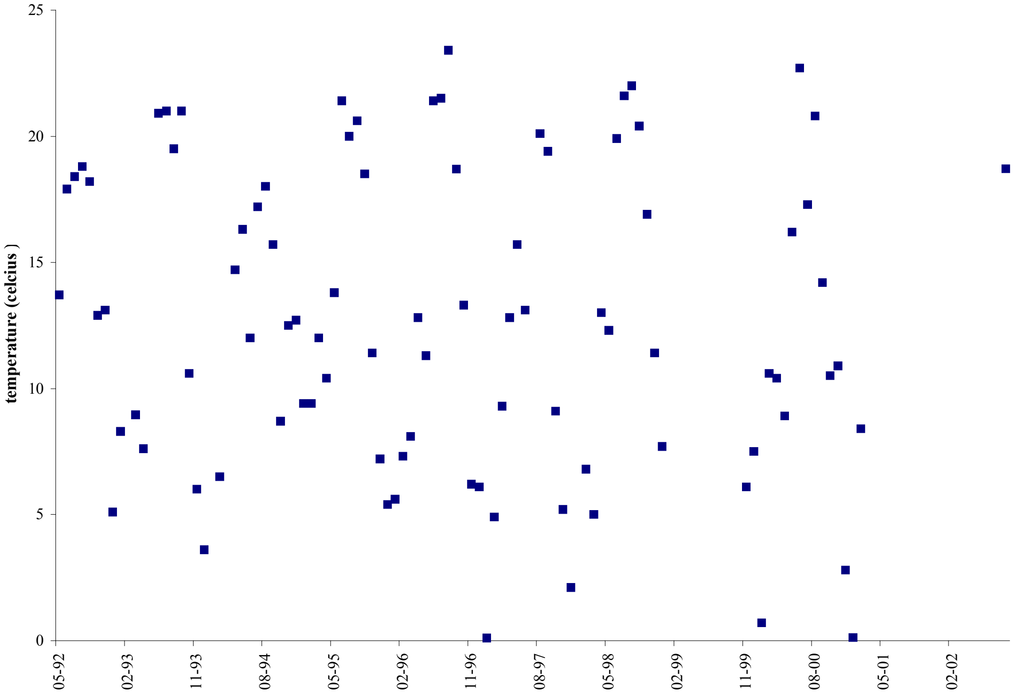

Figure D.1 Temperature measurements at 9-BST023.05.

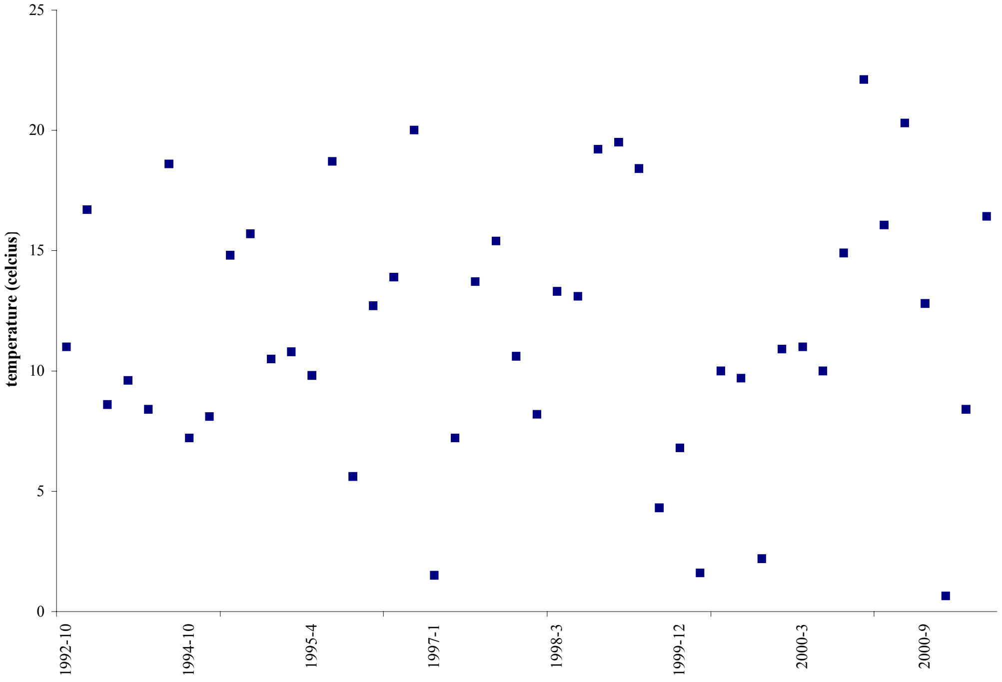

Figure D.2 Temperature measurements at 9-BST029.57.

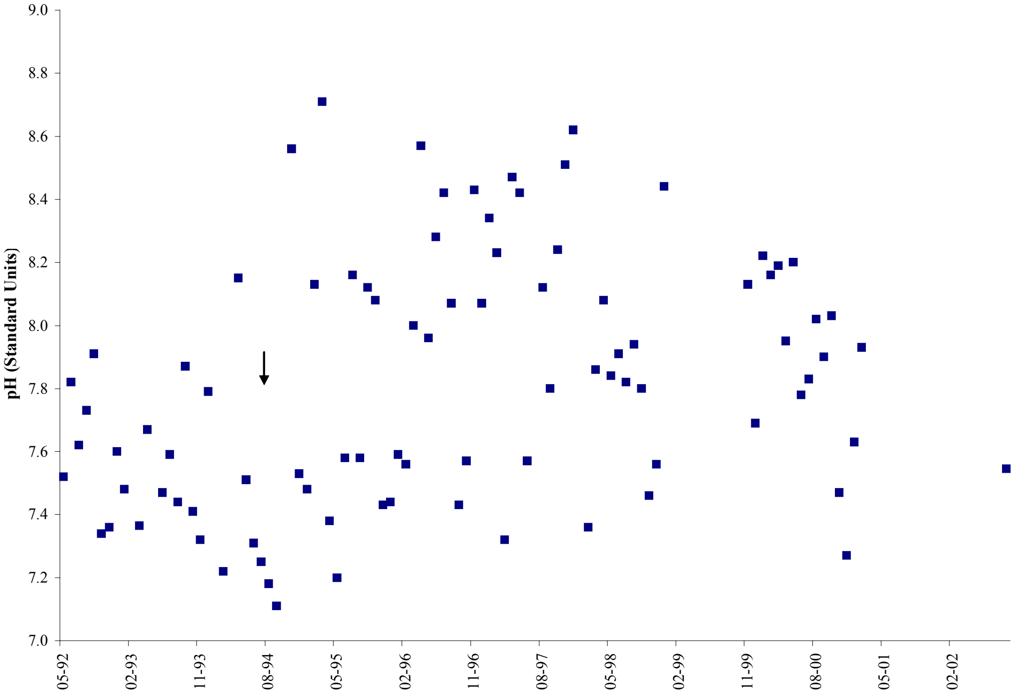

Figure D.3 pH measurements at 9-BST023.05.

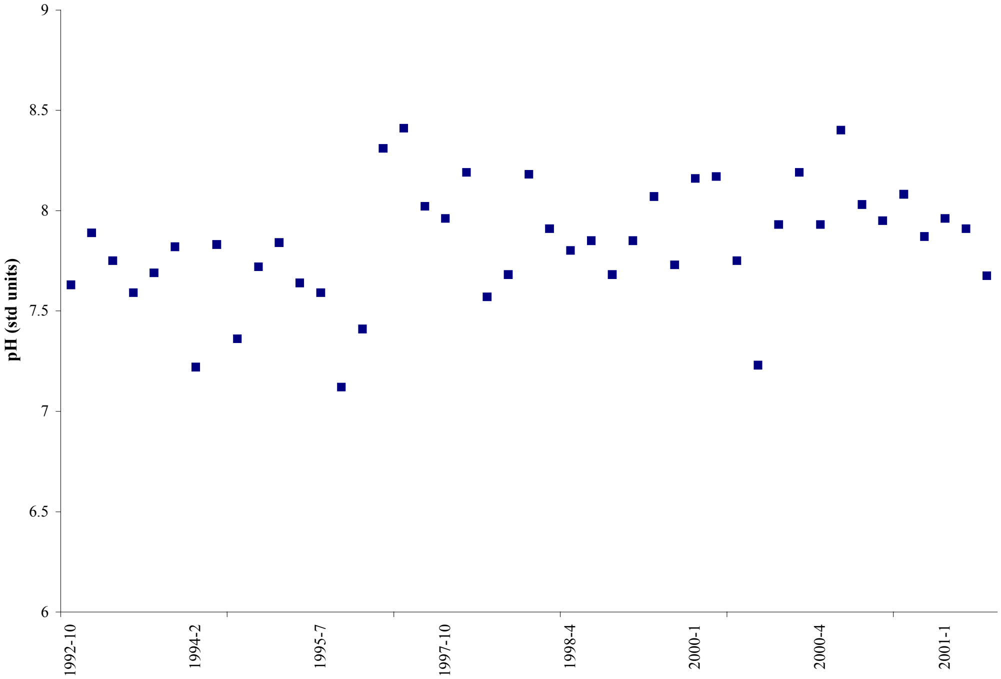

Figure D.4 pH measurements at 9-BST029.57.

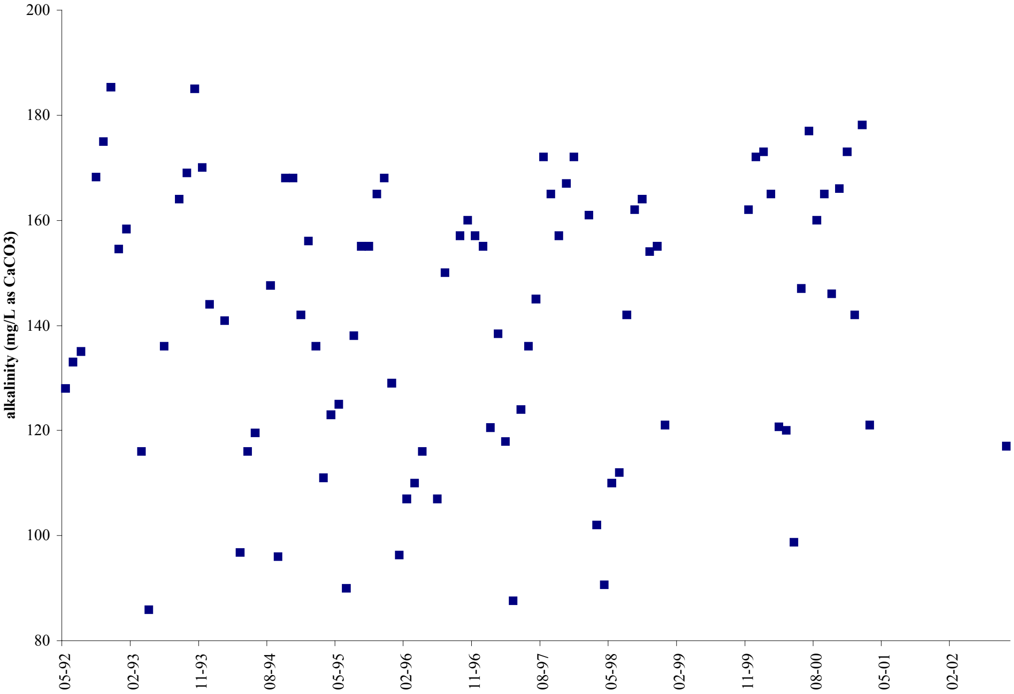

Figure D.5 Alkalinity concentrations at 9-BST023.05.

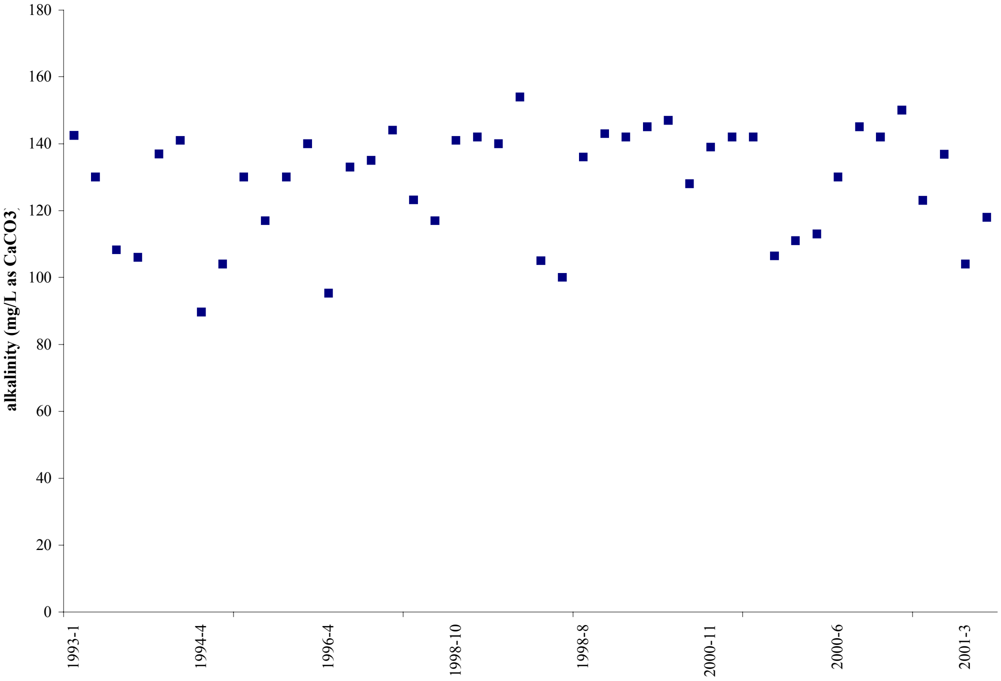

Figure D.6 Alkalinity concentrations at 9-BST029.57.

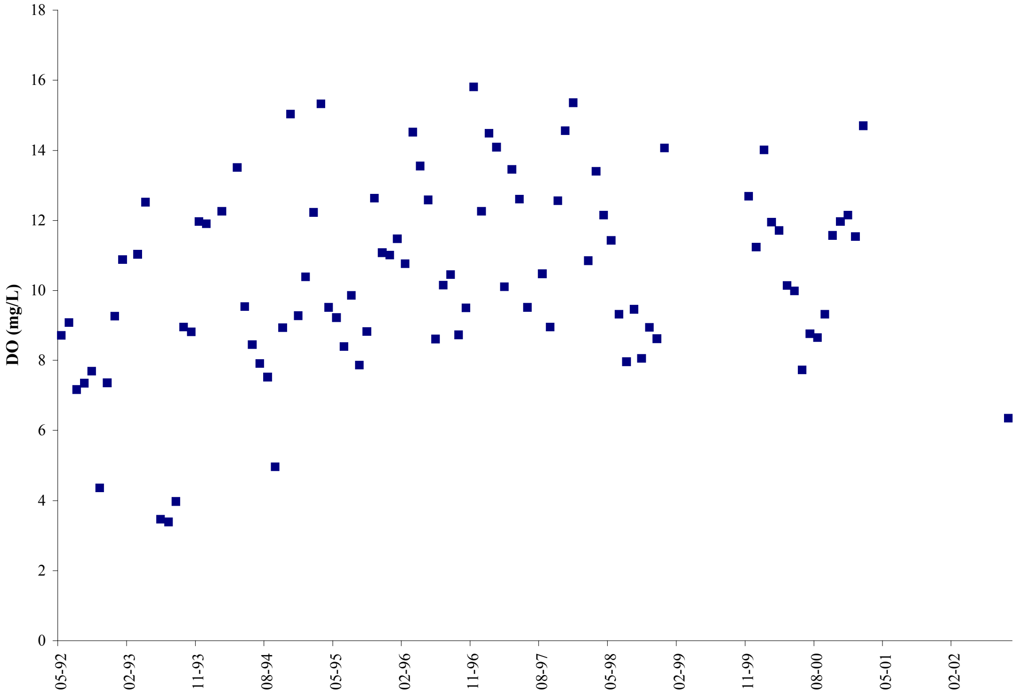

Figure D.7 Dissolved oxygen concentrations at 9-BST023.05.

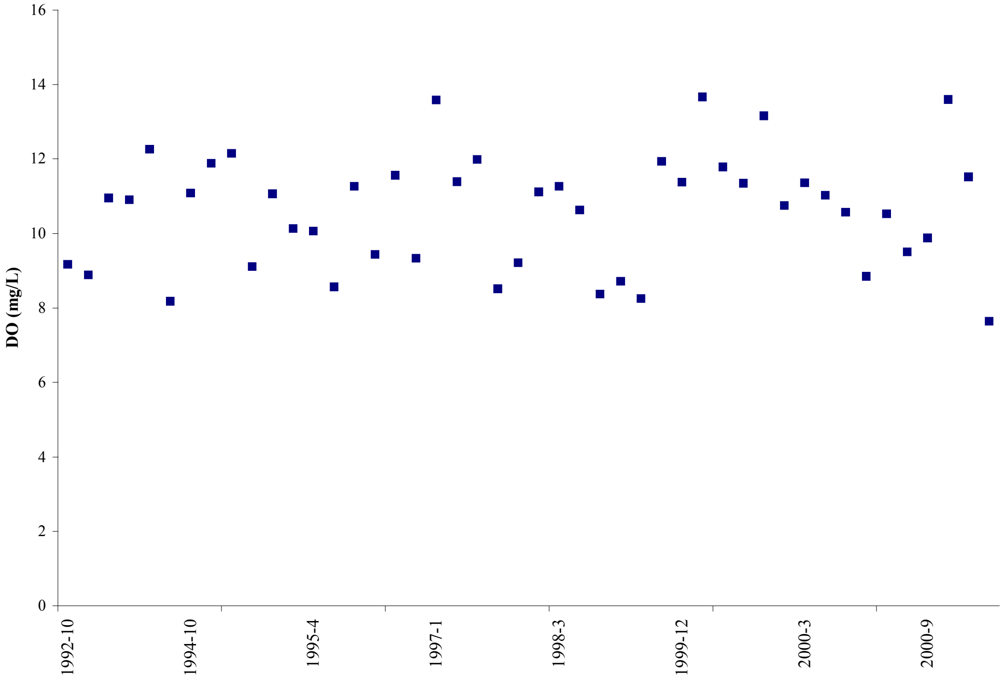

Figure D.8 Dissolved oxygen concentrations at 9-BST029.57.

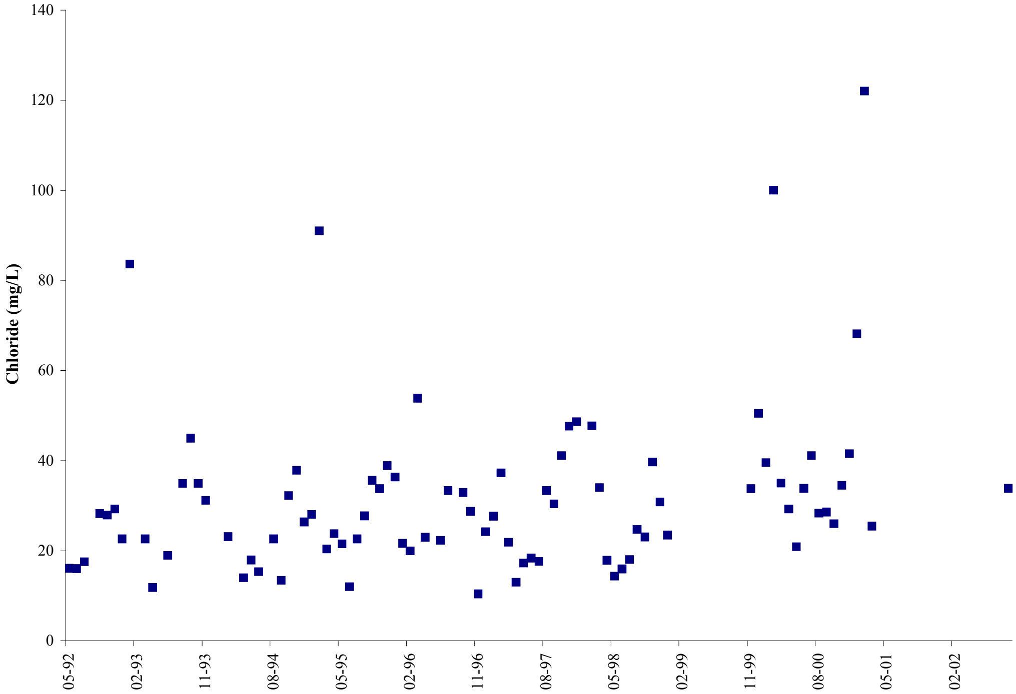

Figure D.9 Chloride concentrations at 9-BST023.05.

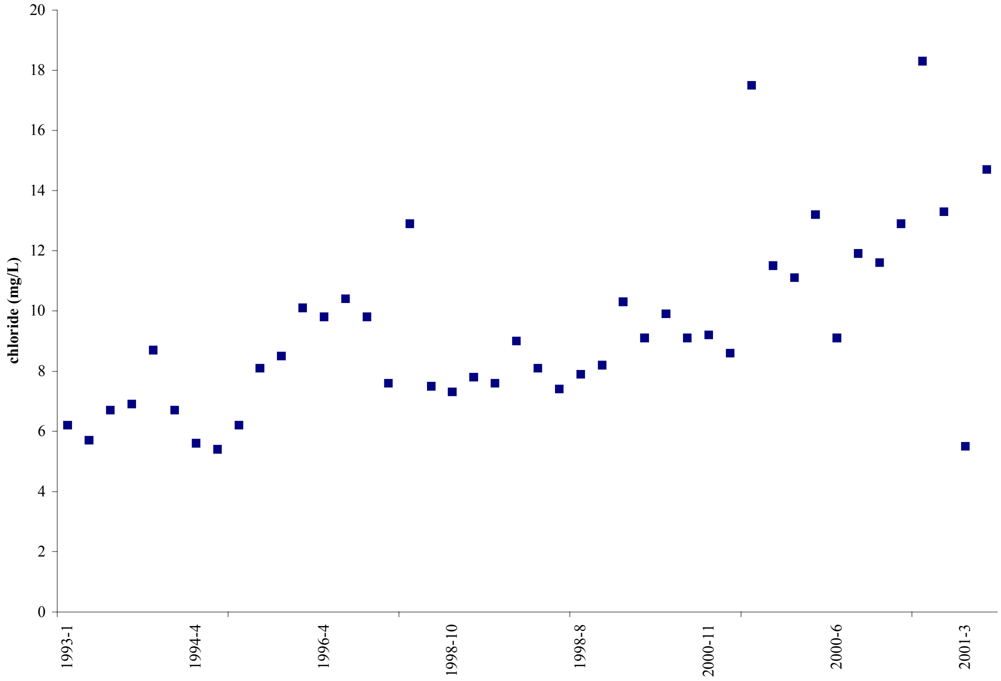

Figure D.10 Chloride concentrations at 9-BST029.57.

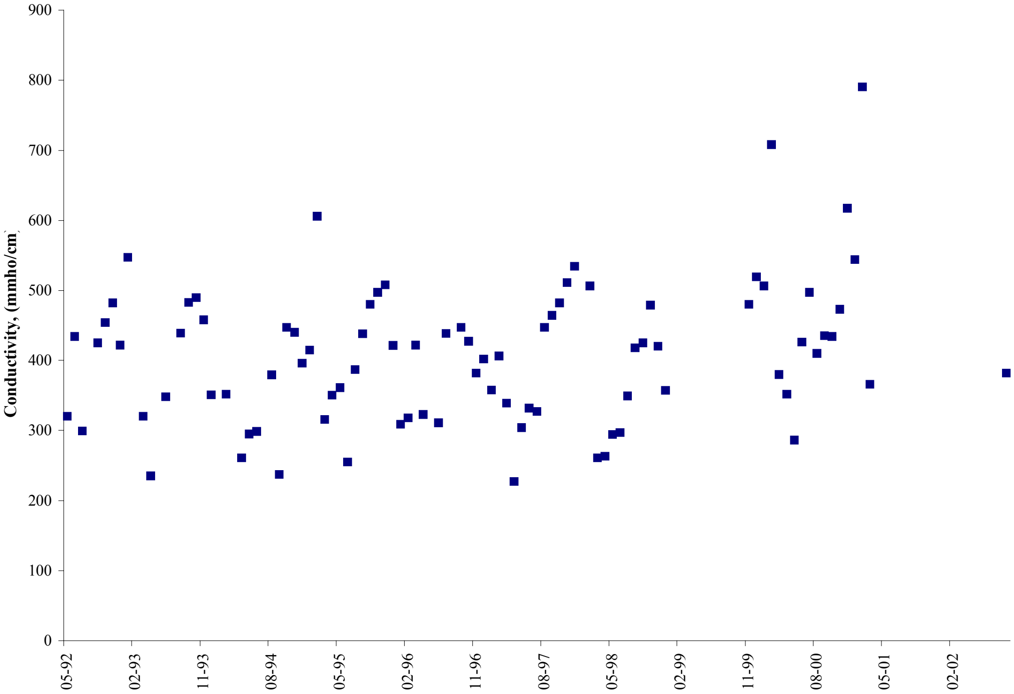

Figure D.11 Conductivity at 9-BST023.05.

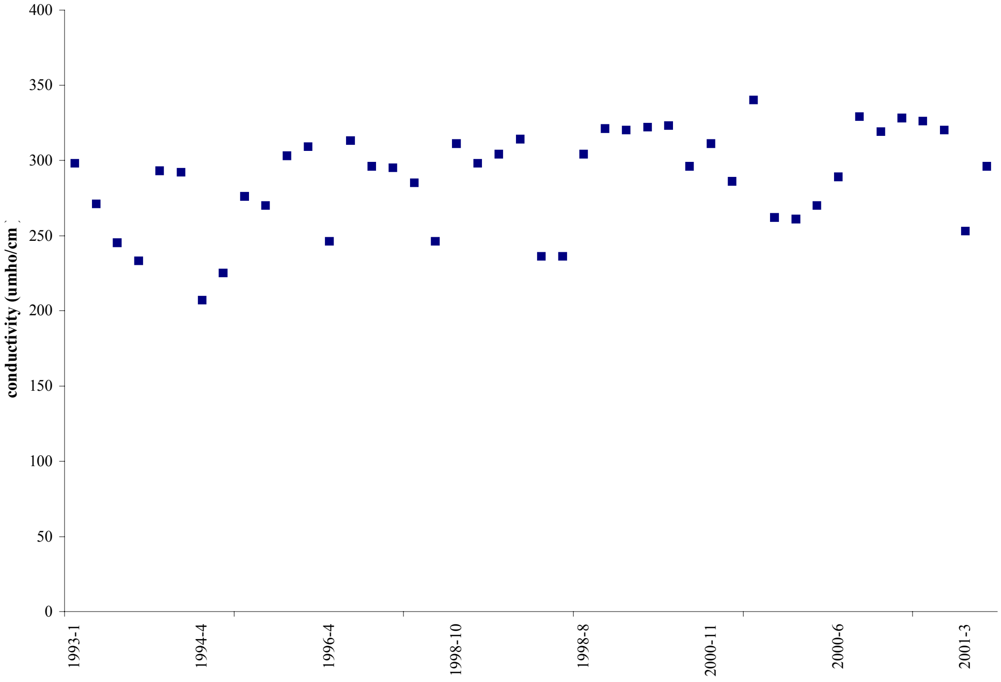

Figure D.12 Conductivity at 9-BST029.57.

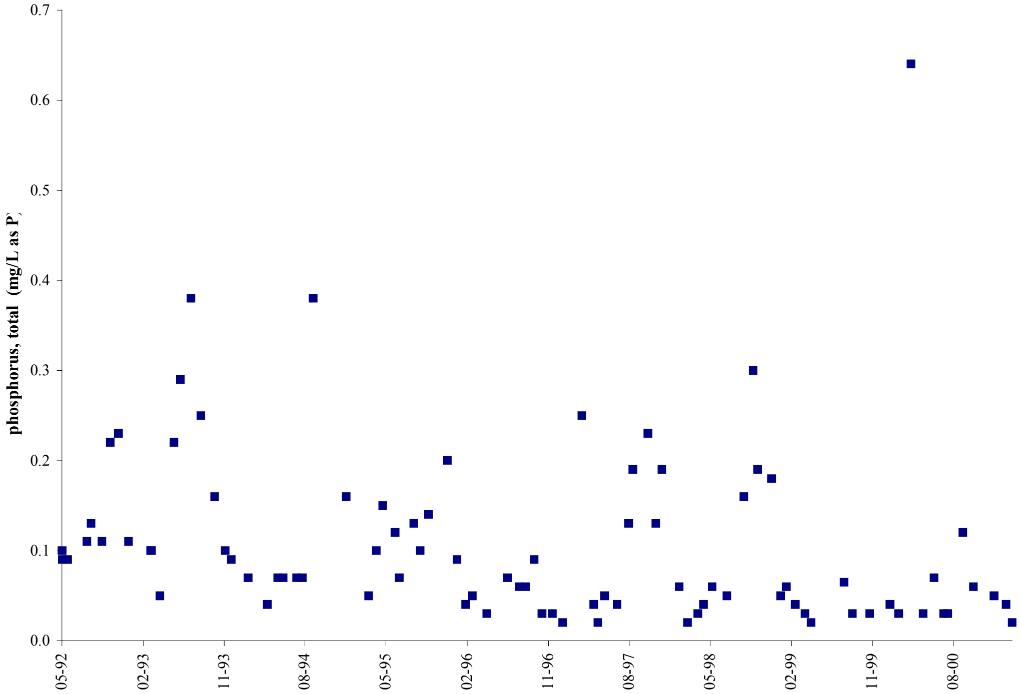

Figure D.13 Total phosphorus concentrations at 9-BST023.05.

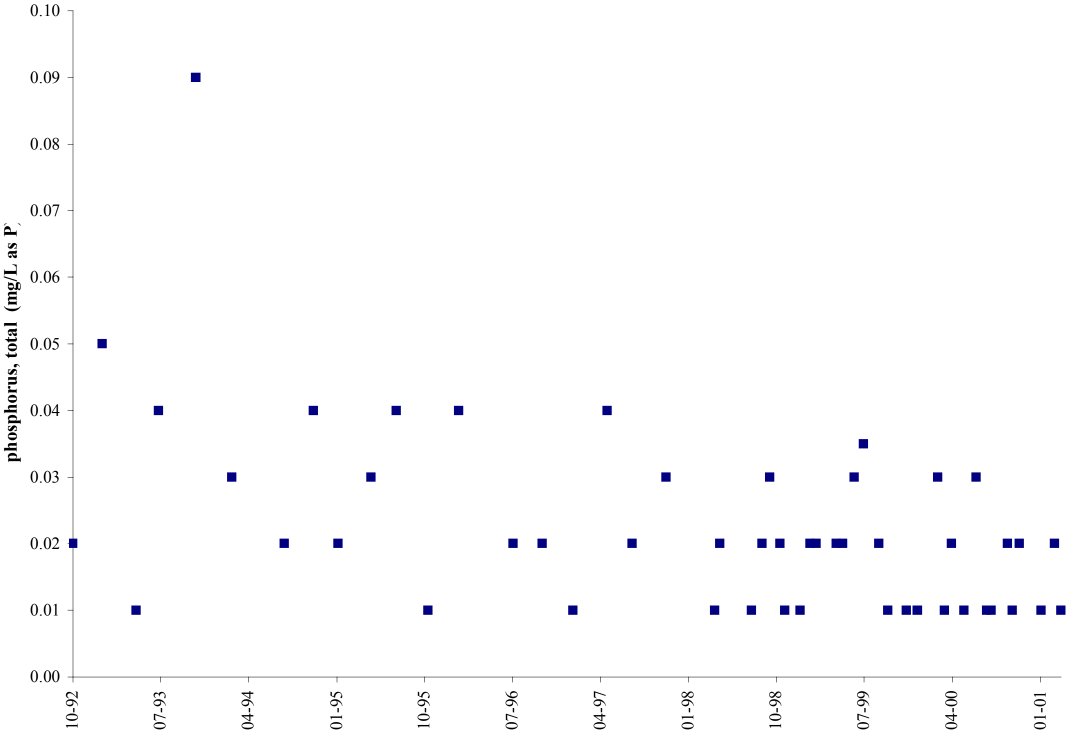

Figure D.14 Total phosphorus concentrations at 9-BST029.57.

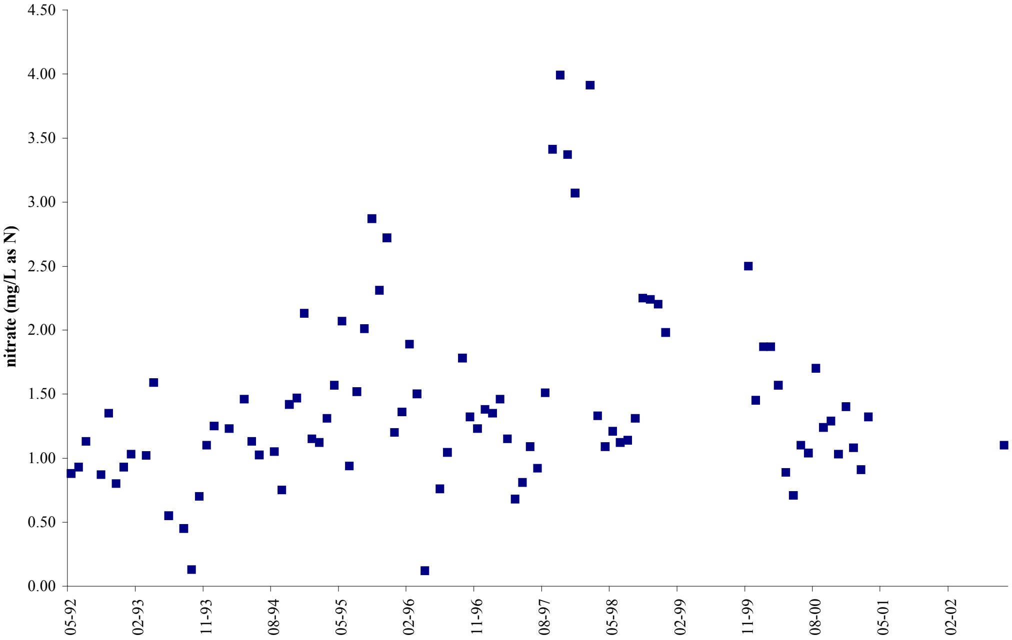

Figure D.15 Nitrate nitrogen concentrations at 9-BST023.05.

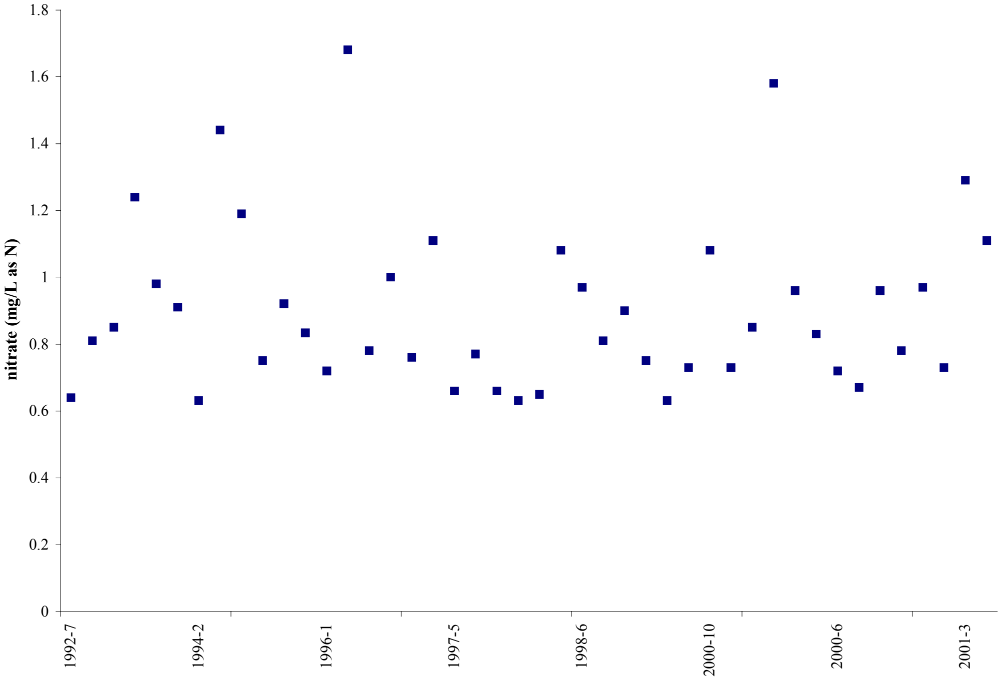

Figure D.16 Nitrate nitrogen concentrations at 9-BST029.57.

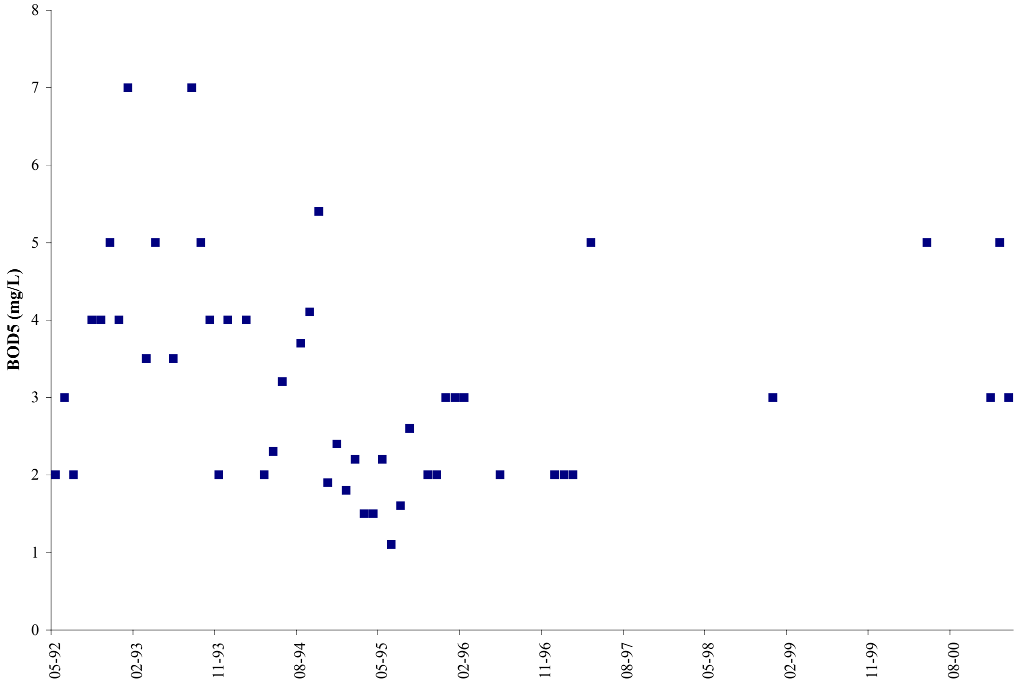

Figure D.17 BOD$_5$ concentrations at 9-BST023.05.

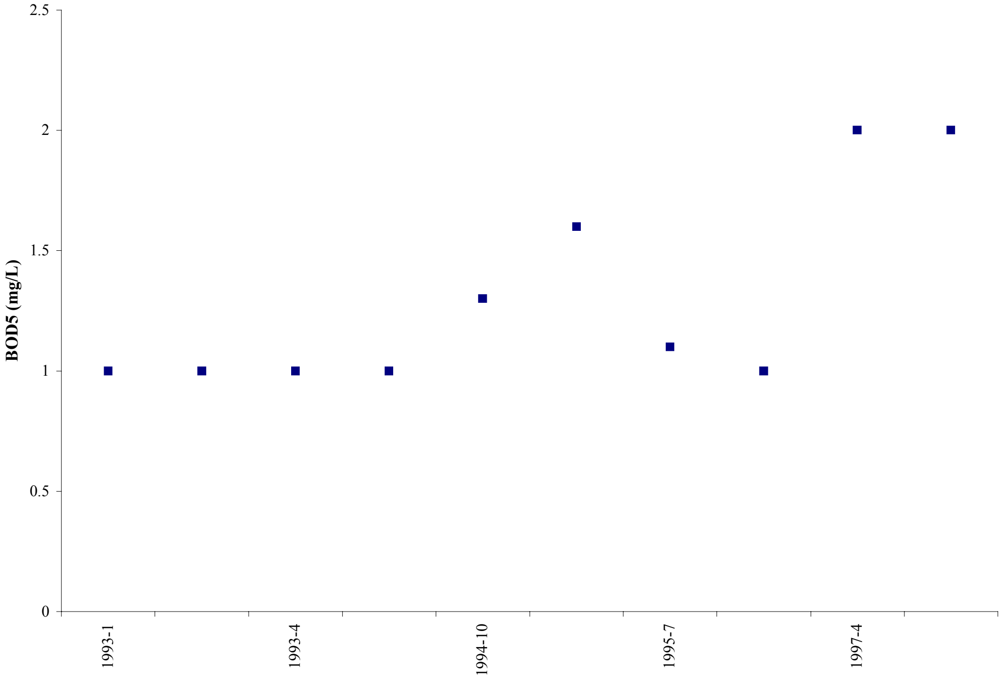

Figure D.18 BOD$_5$ concentrations at 9-BST029.57.

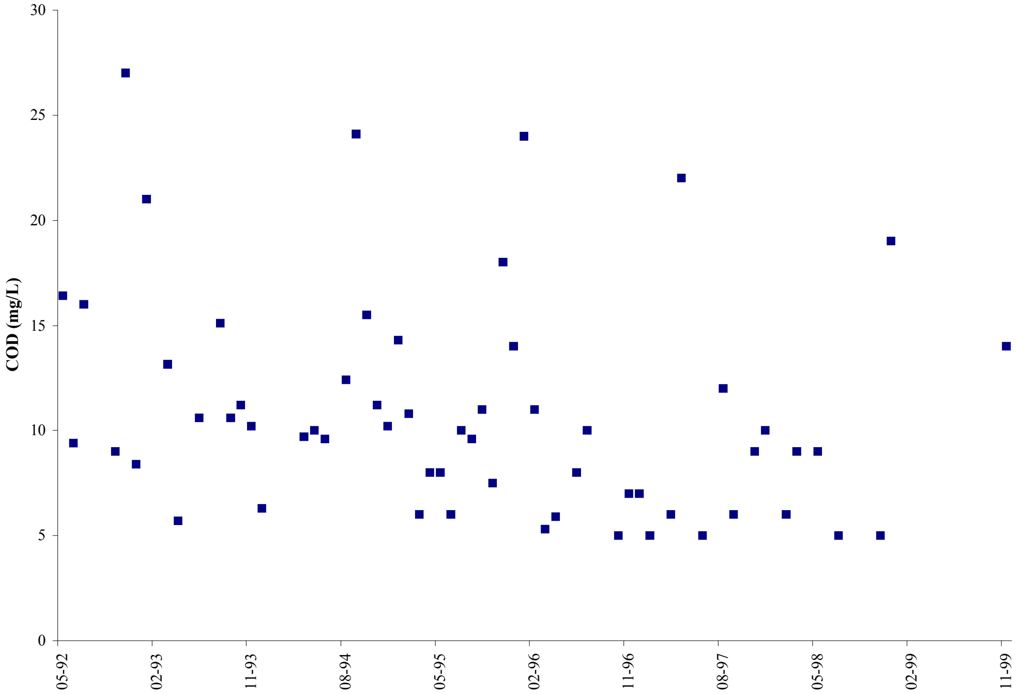

Figure D.19 COD concentrations at 9-BST023.05.

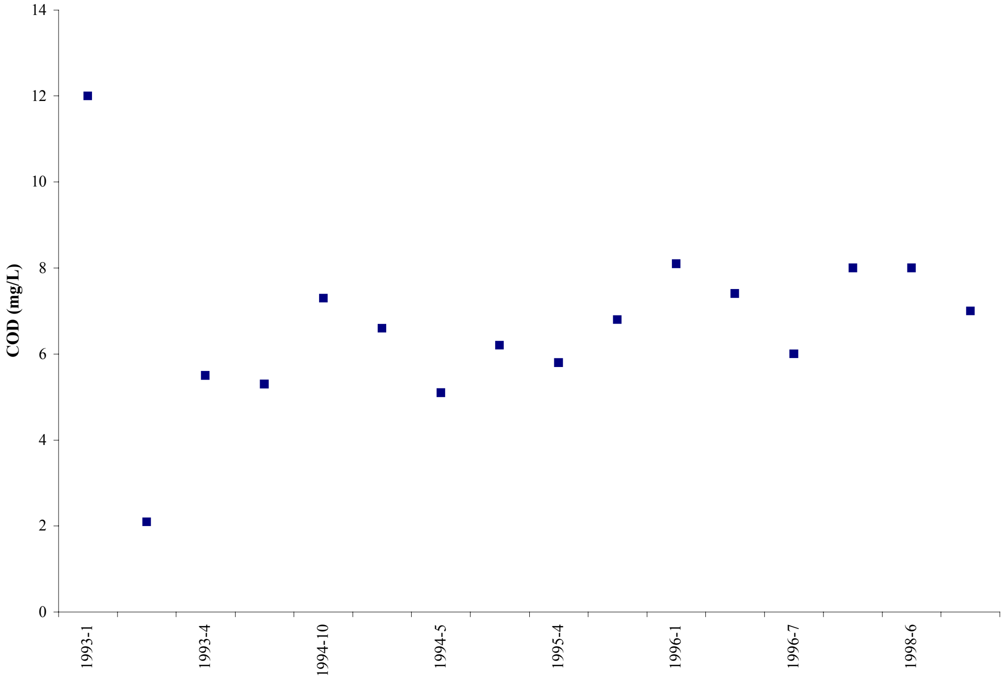

Figure D.20 COD concentrations at 9-BST029.57.

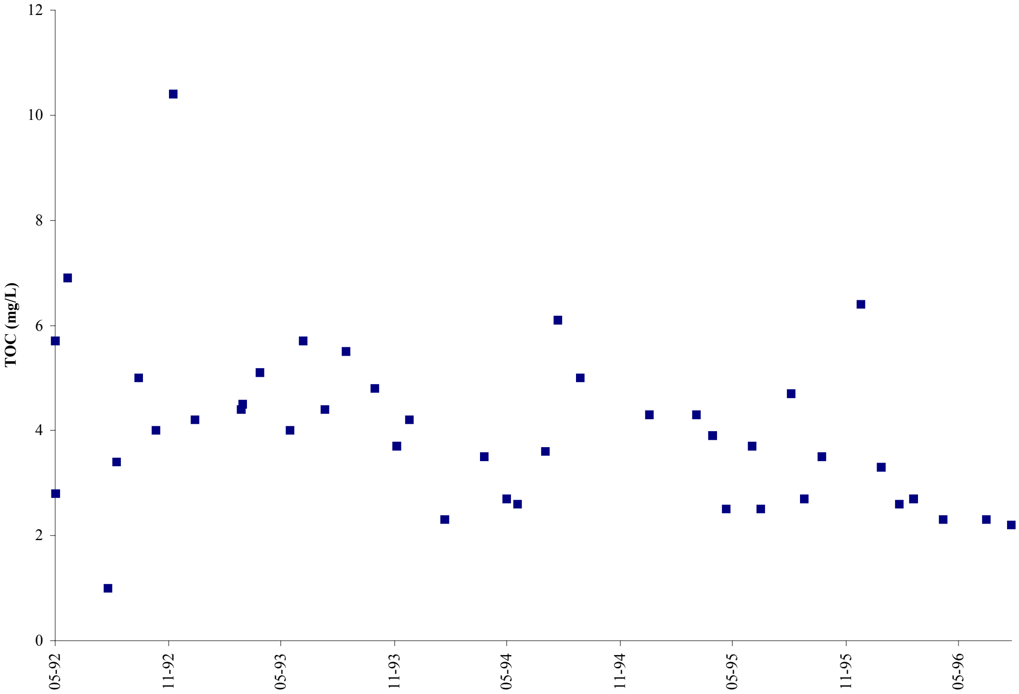

Figure D.21 TOC concentrations at 9-BST023.05.

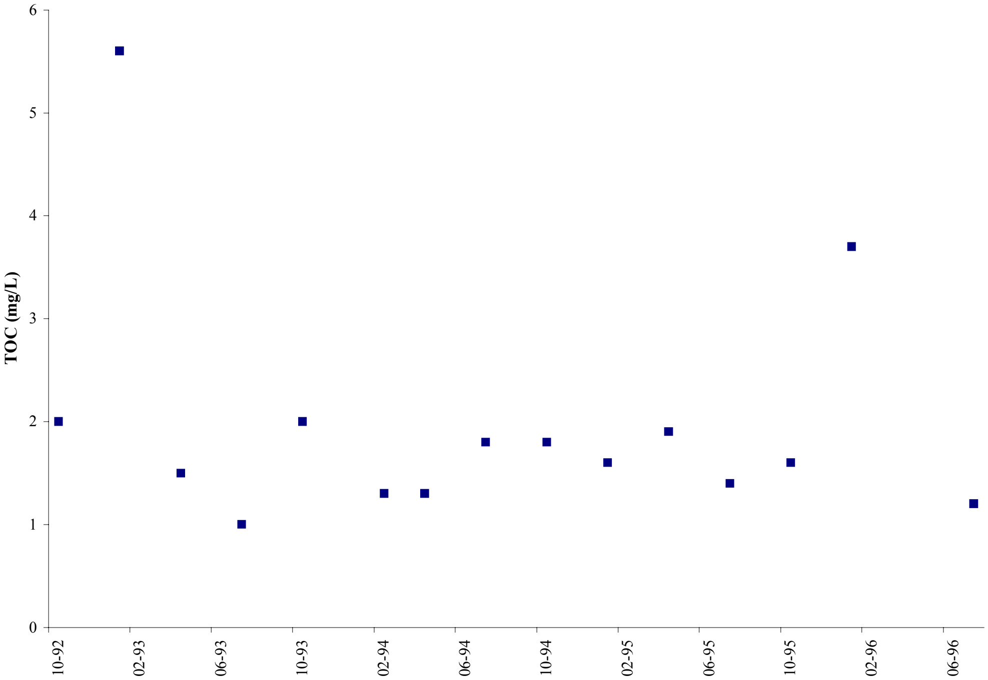

Figure D.22 TOC concentrations at 9-BST029.57.

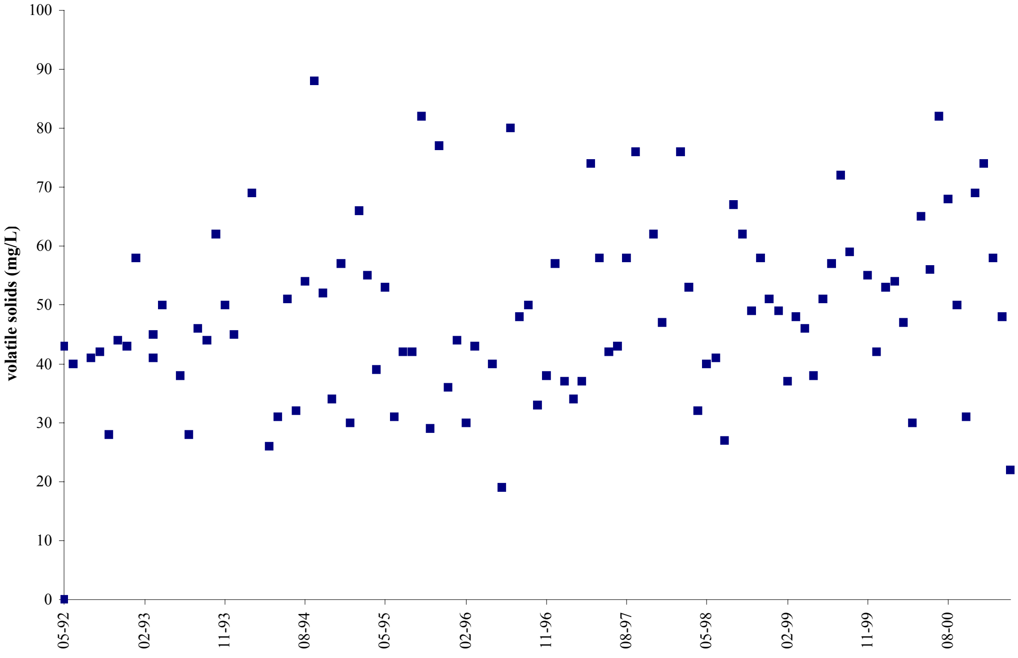

Figure D.23 Volatile solids concentrations at 9-BST023.05.

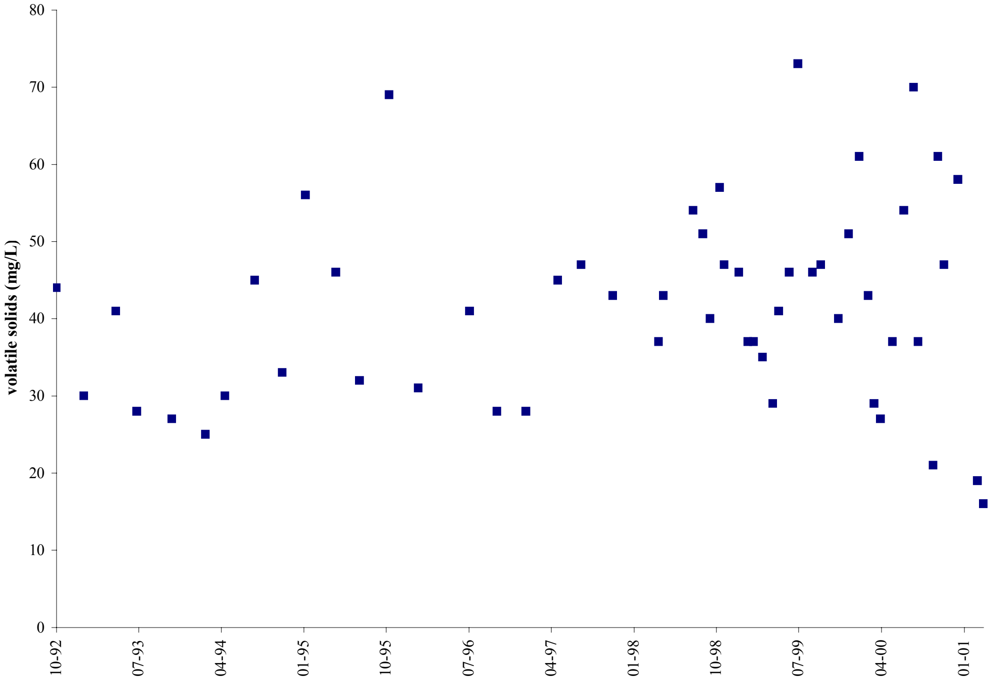

Figure D.24 Volatile solids concentrations at 9-BST029.57.

APPENDIX E

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

Impairment	WLA (cfu/year)	LA (cfu/year)	MOS	TMDL (cfu/year)
Bluestone River (FC)	4.71E+13	8.71E+12	*Implicit*	5.58E+13
VA0025054[1]	*4.62E+13*			
VA0062561[2]	*9.40E+11*			

[1] Bluefield Westside WWTP
[2] Falls Mills STP