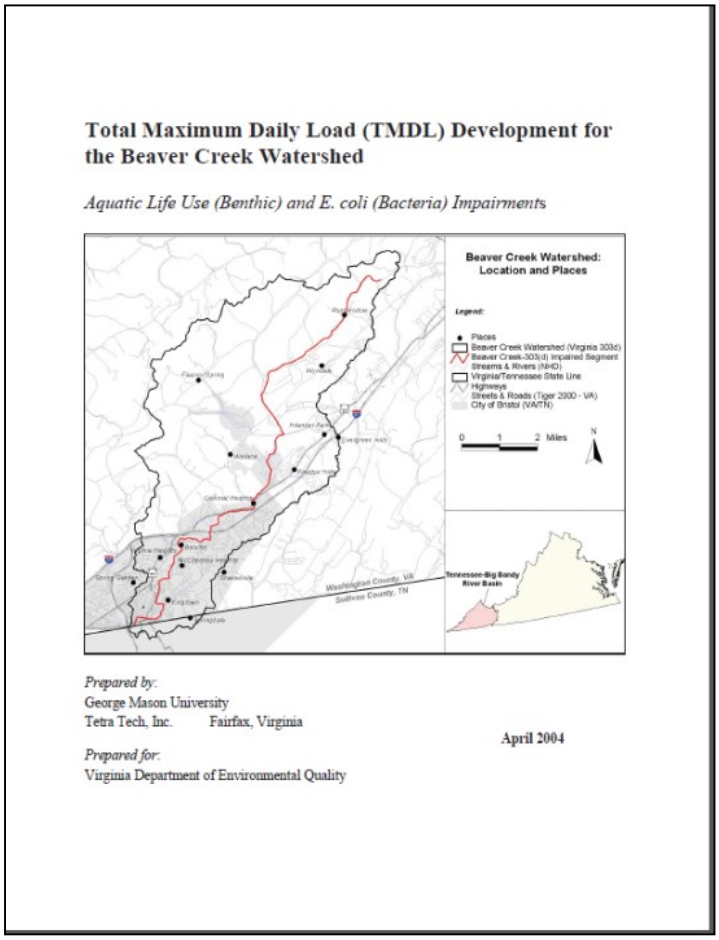
Bacteria and Benthic Total Maximum Daily Load (TMDL) Revision for the Beaver Creek Watershed located in Bristol City and Washington County, Virginia



Total Maximum Daily Load (TMDL) Development for the Beaver Creek Watershed

Aquatic Life Use (Benthic) and E. coli (Bacteria) Impairments

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EXECUTIVE SUMMARY

Background and Applicable Standards

Virginia's Department of Environmental Quality (VADEQ) initiated the TMDL development process for an impaired segment of Beaver Creek approximately 14.7 miles in length and extending from the Route 611 Bridge, near the headwaters of Beaver Creek, to the Virginia/Tennessee state line (**Table ES. 1**). A map of the TMDL watershed study area is provided in **Figure ES. 1**

Table ES. 1 Impairments within the Beaver Creek watershed included in this study.

Stream Name Impairment ID	**Impairments Contracted**	**Initial Listing Year**	**Impairment Length**	**Impairment Location Description**
Beaver Creek VAS-O07R_BEV02A94	Benthic *E. coli*	2002	7.57	From RT. 611 bridge in headwaters to Beaver Creek Dam
Beaver Creek VAS-O07R_BEV01A94	Benthic *E. coli*	2002	7.13	From Beaver Creek Dam to the Virginia/ Tennessee state line

The resulting TMDL document was submitted to VADEQ in April 2004, and was titled *Total Maximum Daily Load (TMDL) Development for the Beaver Creek Watershed*. In progressing toward implementation planning for the impaired waters, three issues were identified that required attention – the bacteria standard used for setting allocations in the original TMDL had been changed, plans for the addition of a new permitted discharge in the watershed for a new waste water treatment facility, and changes in watershed land use distribution. The changes in land use are significant enough to warrant reconfiguring the model and updating the original source assessment estimates.

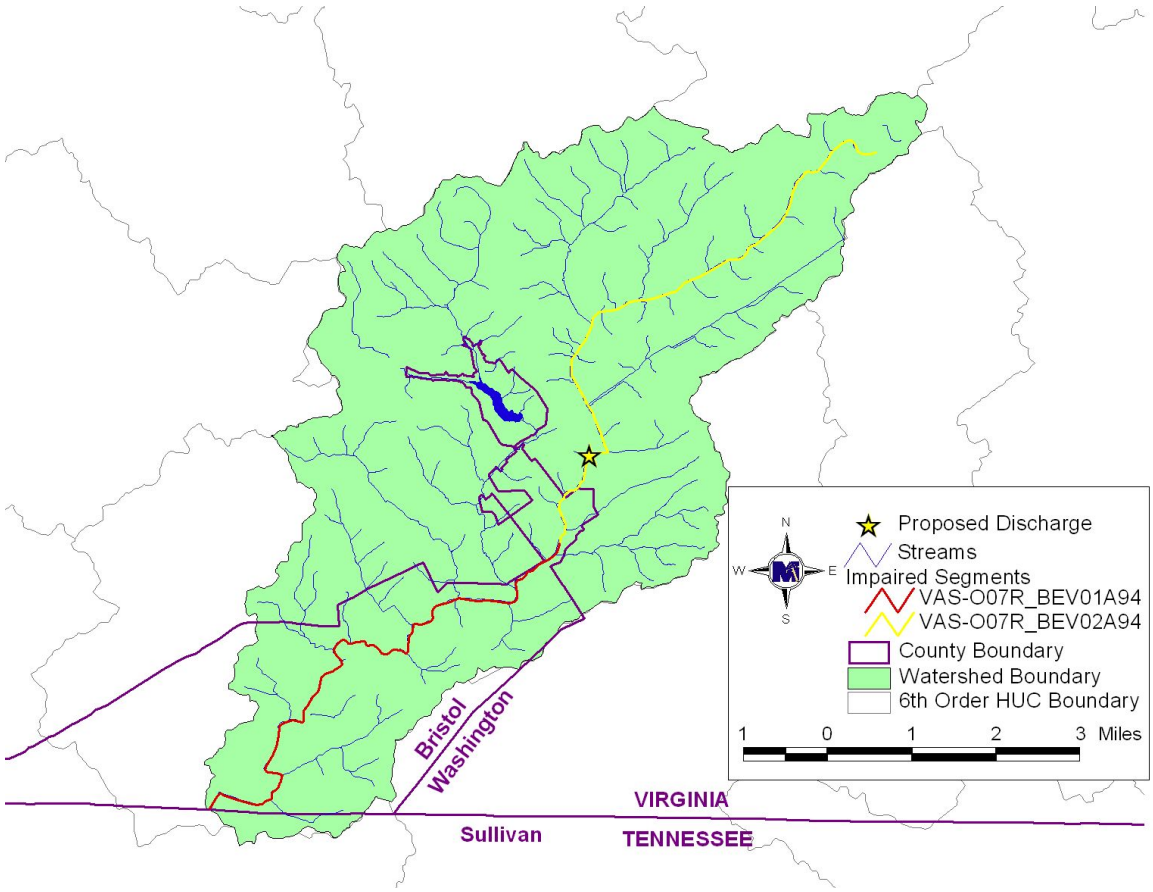


Figure ES. 1 Beaver Creek watershed study area.

In Virginia, once a waterbody violates a given standard, a Total Maximum Daily Load (TMDL) must be developed. The TMDL is a pollution budget that determines the amount of pollutant the waterbody can receive in a given period of time and still meet the intended standard.

For the General Standard violations (benthic macroinvertebrate), a process called a stressor analysis is conducted to determine the likely cause of the impairment. The results of this process for Beaver Creek determined excess sediment was the most probable stressor, which is consistent with what was found in the original TMDL.

The Primary Contact Use (recreational/swimming) *E. coli* standard was updated in 2009. The new standard states that *E. coli* bacteria shall not exceed a monthly geometric mean

of 126 cfu/100mL. If there are less than four weekly samples in any calendar month, the standard states that no more than 10% of the total samples in the assessment period shall exceed 235 cfu/100mL *E. coli*.

TMDL Endpoint and Water Quality Assessment

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL modification, the in-stream *E. coli* target was both a geometric mean not exceeding 126 cfu/100mL, and a single sample not exceeding 235 cfu/100 ml more than 10% of the time. A translator developed by VADEQ was used to convert modeled fecal coliform values to *E. coli* values.

The General Standard states that waters should be free of substances that are harmful to aquatic life. The stressor determined to be impacting the aquatic life in Beaver Creek is sediment. The sediment endpoint was calculated from an unimpaired reference watershed.

Source Assessment

Sources of bacteria were updated and quantified in the Beaver Creek watershed for this modification. Sources included point sources as well as non-point sources. The quantification of sources is important to determine the baseline of current conditions that is causing the impairment. Sources of bacteria included human, livestock, wildlife, pets, as well as permitted point sources. Sediment sources are from various activities such as agricultural activities and development, as well as streambank erosion.

Modeling Procedures for Bacteria

Computer modeling is used to relate the sources on the ground to the water quality in the streams and rivers. This is important since not every colony of bacteria in the Beaver Creek watershed ends up in the streams and rivers. The computer models help quantify the portion of bacteria within the Beaver Creek watershed that ends up in the stream.

The computer modeling process consists of several steps. First, the characteristics of the drainage area including land use, slopes, stream network, soil properties, are entered into

the model. The quantities of bacteria are also entered into the model. A process known as calibration is then conducted by comparing model simulations with monitored field data. Model parameters are adjusted during calibration to minimize the error between simulated and monitored values. This process is conducted for hydrology (flow) as well as water quality. Once the model is calibrated, it is then used to determine the existing water quality conditions in the study area and may be used to determine the reductions necessary to meet the water quality standard or endpoint.

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform loads. For purposes of re-modeling the Beaver Creek watershed, inputs to streamflow, and in-stream fecal bacteria, the drainage area was divided into fifteen (15) subwatersheds.

Hydrology calibration and validation modeling time periods were selected to include critical conditions, or the combination of environmental factors (e.g., rainfall, temperature, etc.) that yield high and low flows of an acceptably low frequency of occurrence. The inclusion of critical conditions ensures that the water quality is protected during times when it is most vulnerable. For additional information on model calibration, validation, and the selection of critical time periods refer to **APPENDIX B**.

Bacteria

Wildlife populations, the rate of failure of septic systems, domestic pet populations, and numbers of livestock are examples of land-based nonpoint sources used to calculate fecal coliform loads. Also represented in the model were direct sources of uncontrolled discharges, direct deposition by wildlife, and direct deposition by livestock. Contributions from all of these sources were updated to current conditions to establish existing conditions for the watershed.

Modeling Procedures for Sediment

A similar overall modeling procedure was used in modeling the sediment loads to the Beaver Creek watershed as was used for bacteria. The model used in this study was the *Visual Basic*™ version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The target TMDL load for Beaver Creek is the average annual load in metric tons per year (t/yr) from the area-adjusted Walker Creek watershed under existing conditions. The reference watershed was chosen based on meeting the General Standard and having similar characteristics as the impaired watershed. To reach the TMDL target goal, different load allocation scenarios were run with GWLF.

Load Allocation Scenarios

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 or endpoints. Bacterial load reduction scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. A final scenario was chosen, and the reductions needed are presented in **Table ES. 2**. The final TMDL information is shown in **Table ES. 3**.

The reductions called for in **Table ES. 2** apply to the entire drainage area of the Beaver Creek study area. This however does not mean that each subwatershed will experience the same amount of reduction as all other subwatersheds because reductions will be based on actual, on-the-ground sources. For example, while the TMDL calls for eliminating 98% of direct deposition from livestock from the entire drainage area, if one of the subwatersheds does not have any livestock with access to streams, no reductions will take place in that subwatershed for the livestock direct deposition category.

The final bacterial TMDL for the Beaver Creek watershed includes 100% reductions in straight pipes. During model calibration, an unidentified source of bacteria was identified in the downstream end of the watershed. This unknown source was included in the

model as a constant point source of bacteria, and will need to be identified and removed during implementation.

Table ES. 2 Percent reductions to existing fecal bacteria loads needed to meet the water quality standard.

Source	Necessary Reduction (%)
Unidentified Source	100
Straight Pipes	100
Direct Livestock Deposition to Stream	98
Load from Developed and Commercial Lands	85
Load from Agricultural Lands	50

Table ES. 3 Average annual in-stream E. coli bacterial loads (cfu/yr) modeled after TMDL allocation at the outlet of the Beaver Creek watershed.

Impairment	WLA[1]	LA	MOS	TMDL
Beaver Creek	4.38E+12	4.17E+13	*Implicit*	4.61E+13
VAG400012	1.74E+09			
VAG400209	1.74E+09			
VAG400210	1.74E+09			
VPG210001	0.00E+00			
City of Bristol MS4 (VAR040048)	1.30E+12			
Proposed Permit	2.61E+12			
Future Load	4.61E+11			

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

Multiple sediment load reduction scenarios were also evaluated for the Beaver Creek watershed. The final reductions associated with the final chosen scenario are presented in **Table ES. 4**. As with the bacterial load reductions, all reductions called for in **Table ES. 4** apply to the entire drainage area of the Beaver Creek study area. The final TMDL information is shown in **Table ES. 5**.

Table ES. 4 Percent reductions to existing sediment loads needed to meet the TMDL endpoint.

Source	Necessary Reduction (%)
Load from Cropland	16.7
Load from Pasture	16.7
Load from Barren Land	16.7
Channel Erosion	16.7
Load from Developed and Commercial Lands	16.7

Table ES. 5 Final annual sediment TMDL for the Beaver Creek watershed.

Impairment	WLA	LA	MOS	TMDL
	t/yr	t/yr	t/yr	t/yr
Beaver Creek	310.91	1985.74	255.24	2551.90
VAG400012	0.041			
VAG400209	0.041			
VAG400210	0.041			
VPG210001	0			
City of Bristol MS4 (VAR040048)	159.97			
VAR050028	8.65			
VAR050043	12.99			
VAR050053	7.04			
VAR050080	3.41			
VAR050081	2.55			
VAR050084	11.26			
VAR050468	6.49			
VAR051522	1.29			
VAR051907	2.93			
Construction Permits	6.48			
Proposed Permit	62.22			
Future Load	25.52			

Accounting for Natural Background Pollutant Contributions

TMDLs consist of waste load allocations (WLAs) and load allocations (LAs). The load allocation (LA) is the portion of a receiving waters loading capacity attributed either to existing or future nonpoint sources of pollution, or to natural background sources. LA

estimates depend on the availability of data and appropriate techniques for predicting the loading. Wherever possible, natural and nonpoint source loads should be distinguished.

For bacteria, water quality monitoring represents existing conditions which are the sum of anthropogenic and natural background pollutants. Water quality modeling mimics the sum condition. Nevertheless, because wildlife represents the major source of natural background bacteria pollution, it was quantified and a separate load assigned. In the final TMDL equation, the natural background contributions are included in the LA component.

Sources of sediment include stream channel erosion and nonpoint loading from the different land covers. A reference watershed in which there was no aquatic life use impairment was used to estimate natural background loads expected in the Beaver Creek TMDL watershed.

Accounting for Critical Conditions and Seasonal Variations

To ensure that the water quality of the Beaver Creek watershed study area is protected during times when it is most vulnerable, modeling periods for calibration, validation, and allocation were selected to account for critical conditions associated with all potential sources within the watershed. 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.

The bacterial water quality model simulated stream flow, overland runoff and was used to perform TMDL allocations in the watershed. 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 spatial subdivision of the watersheds allowed for a more refined representation of pollutant sources and a more realistic description of hydrologic factors in the watersheds. The bacteria model was run at a 1-hour time step and so simulated the fine scale of temporal conditions.

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

Implementation

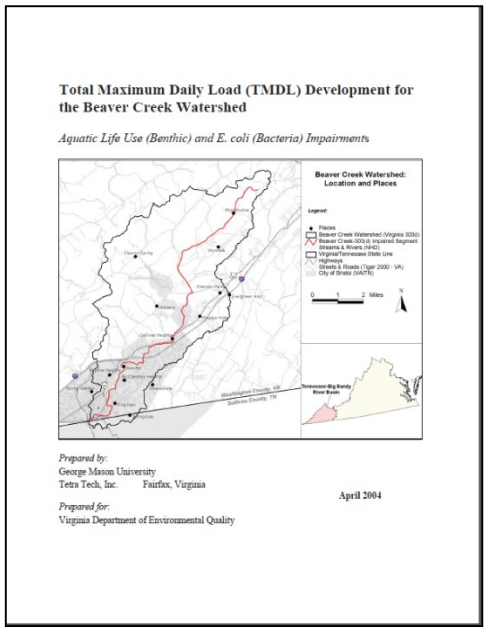
The goal of the TMDL program is to establish a path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents a revision of that effort for the impairments in the Beaver Creek watershed. The next step is the development of a TMDL implementation plan (IP), required by Virginia's 1997 Water Quality Monitoring, Information, and Restoration Act (WQMIRA). A TMDL IP was developed in 2007 for the Beaver Creek watershed based on the original 2004 TMDL. The final step is to implement the TMDL IP and to monitor water quality to determine if water quality standards are being attained.

Public Participation

For the TMDL revision, the first technical advisory committee meeting was held on 05/23/2013. A second technical advisory committee meeting was held on 11/13/2013. A public meeting for the TMDL revision was held on XX/XX/XXXX. An introduction of the agencies involved, an overview of the TMDL process, details of the pollutant sources, and the specific approach to developing the Beaver Creek watershed TMDL modification was presented at the public meeting. Public understanding of, and involvement in, the TMDL process was encouraged. The model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period after the public meeting. Written comments were addressed in the final document.

1. INTRODUCTION

In addressing provisions of the Clean Water Act and agreements with the United States Environmental Protection Agency (EPA), Virginia's Department of Environmental Quality (VADEQ) initiated the TMDL development process for an impaired segment of Beaver Creek approximately 14.7 miles in length and extending from the Route 611 Bridge, near the headwaters of Beaver Creek, to the Virginia/Tennessee state line.


Total Maximum Daily Load (TMDL) Development for the Beaver Creek Watershed

Aquatic Life Use (Benthic) and E. coli (Bacteria) Impairments

Beaver Creek Watershed: Location and Places

Legend:

Prepared by:
George Mason University
Tetra Tech, Inc. Fairfax, Virginia

Prepared for:
Virginia Department of Environmental Quality

April 2004

The resulting TMDL document was submitted to VADEQ in April 2004, and was titled *Total Maximum Daily Load (TMDL) Development for the Beaver Creek Watershed*. A TMDL implementation plan (IP) was developed in 2007 for the Beaver Creek watershed based on the original 2004 TMDL. In progressing toward implementation of the IP for the impaired waters, three issues were identified that required attention – specifically, the bacteria standard used for setting allocations in the original TMDL, plans for the addition of a new permitted discharge in the watershed for a new waste water treatment facility, and changes in watershed conditions. With regard to the bacteria standard used for setting allocations, the proper standard was applied at the time of TMDL development; however, the standard has since been changed. While the original TMDL is protective of the new standard, the loading reduction scenarios need to be revisited in light of the new standard. Regarding the new permitted discharge, the original TMDL allocations did not take into account growth in the bacteria loadings of this magnitude, and thus the allocations need to be revisited. Furthermore, since the development of the original TMDL model, more recent and more accurate land cover data has become available. The changes in land use are significant enough to warrant reconfiguring the model, as shown in, **Figure 1-2**, and **Figure 1-3**. This modification seeks to address these three issues and the portions of the original document that have changed.

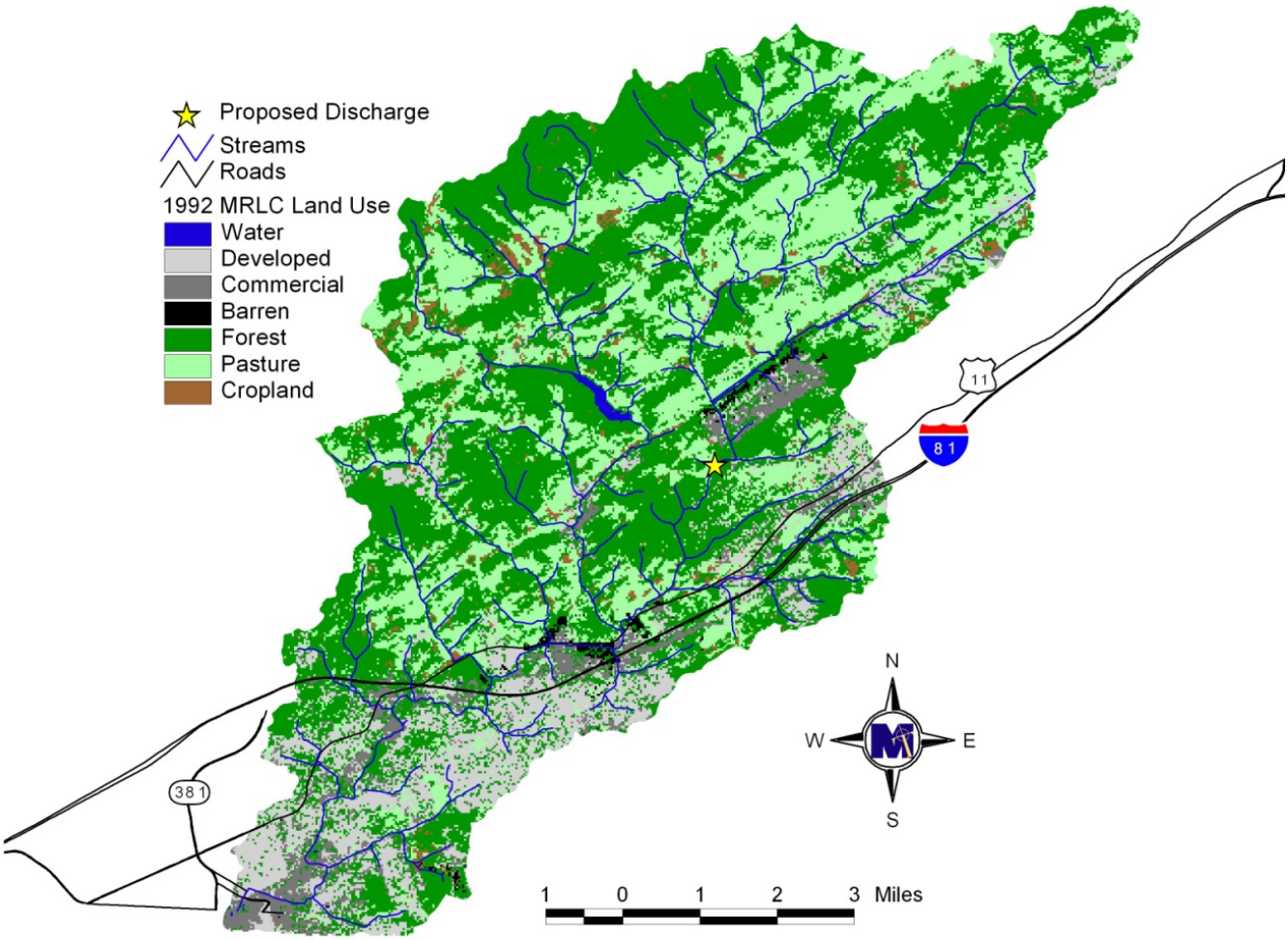


Figure 1-1. 1992 MRLC/NLDC land use data used in original TMDL watershed modeling of the Beaver Creek watershed study area.

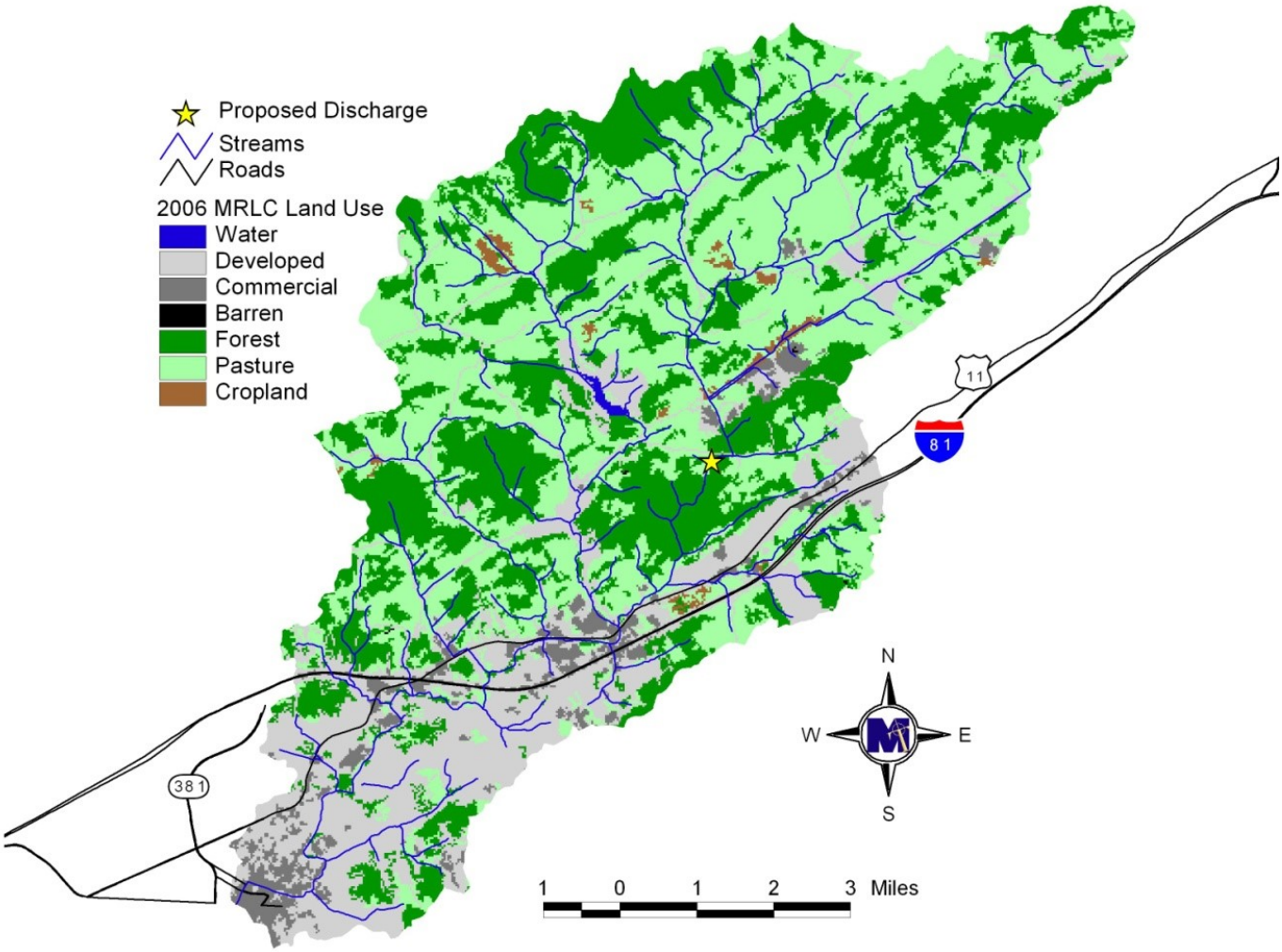


Figure 1-2. 2006 MRLC/NLCD land use data used in updated model of the Beaver Creek watershed study area.

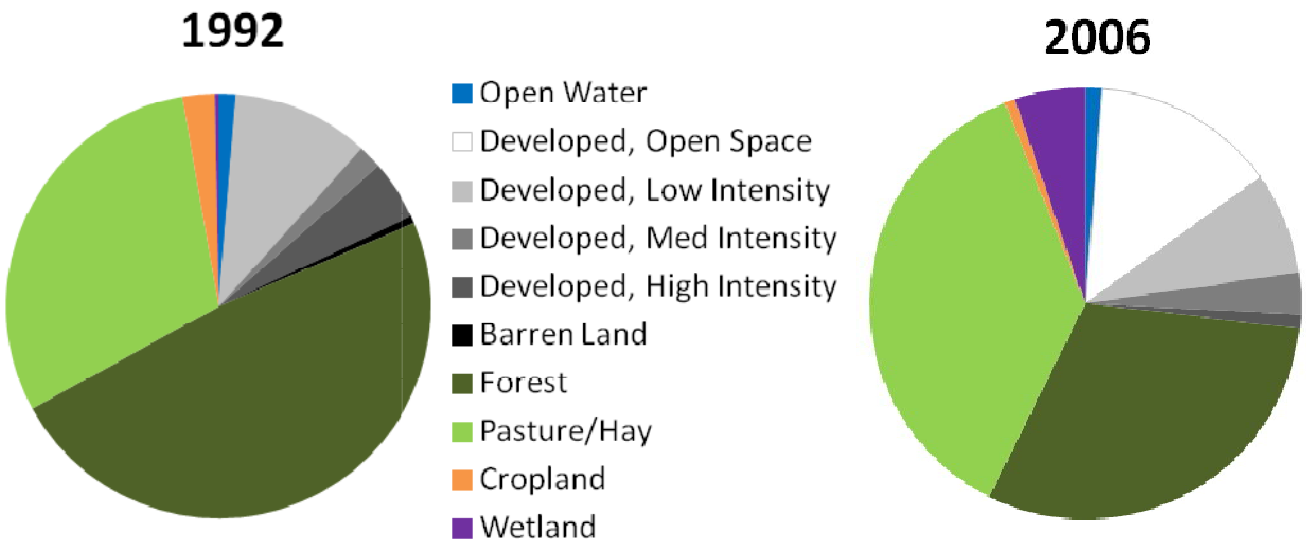


Figure 1-3. Comparison of MRLC/NLCD land use data used in original TMDL model (1992 data) to that used in updated model (2006 data) for the Beaver Creek watershed study area.

Two technical advisory committee (TAC) meetings were held during the development of this TMDL revision. At the first TAC meeting on May 23, 2013, the issues leading to the need for this TMDL revision were laid out and input on the revised source assessment was requested. The second TAC meeting was held on November 13, 2013 and was used to outline the results of the TMDL revision and obtain input on the revised TMDL. A public meeting was held on DATE to present the results of the TMDL revision. There was a 30-day public comment period following the public meeting. Written comments received during this time are addressed in APPENDIX.

2. BACTERIAL TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

As noted earlier, the water quality standards have been changed since the original TMDL was developed. The updated standards are included here, as well as a discussion of the most recent monitoring data available.

2.1 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.

2.2 Applicable Criteria for Fecal Bacteria Impairments

Virginia adopted its current *E. coli* and *enterococci* standard in January 2003, and it was updated in 2009. The criteria which were used in developing the bacteria TMDLs in this study are outlined in Section 9 VC 25-260-170 (Bacteria; other recreational waters) and read as follows:

A. The following bacteria criteria (colony forming units (cfu)/100mL) shall apply to protect primary contact recreational uses in surface waters, except waters identified in subsection B of this section:

E. coli bacteria shall not exceed a monthly geometric mean of 126 cfu/100mL in freshwater.

Enterococci bacteria shall not exceed a monthly geometric mean of 35 cfu/100mL in transition and saltwater.

1. See 9VAC25-260-140C for boundary delineations for freshwater, transition, and saltwater.

2. Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples.

3. If there are insufficient data to calculate monthly geometric means in freshwater, no more than 10% of the total samples in the assessment period shall exceed 235 E. coli cfu/100mL.

4. If there are insufficient data to calculate monthly geometric means in transition and saltwater, no more than 10% of the total samples in the assessment period shall exceed enterococci 104 cfu/100mL.

5. For beach advisories or closures, a single sample maximum of 235 E. coli cfu/100mL in freshwater and a single sample maximum of 104 enterococci cfu/100mL in saltwater and transition zones shall apply.

2.3 Selection of a Bacteria TMDL Endpoint

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 bacteria impairments in this study, the applicable endpoints and associated target values can be determined directly from the Virginia water quality regulations. 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.

For the purpose of this TMDL, VADEQ interprets the bacteria standard as requiring compliance with both the geometric-mean and the single-sample maximum criteria. Since the water bodies in question are fresh water, the in-stream *E. coli* targets for the TMDLs in this study were both monthly geometric means not exceeding 126 cfu/100 ml and no more than 10% exceedance of the 235 cfu/100 mL single-sample criterion.

2.4 Discussion of In-Stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal bacteria monitoring data in the Beaver Creek watershed, including data taken since the completion of the original TMDL. An examination of data from water quality stations used in the 303(d) assessment was performed. Sources of data and pertinent results are discussed.

2.4.1 Inventory of Water Quality Monitoring Data

The primary sources of available fecal bacteria information are bacterial enumerations from 10 VADEQ in-stream water quality monitoring stations which date from January 2001 to February 2013.

2.4.1.1 VADEQ Water Quality Monitoring for TMDL Assessment

Data from in-stream water samples, collected at VADEQ monitoring stations from January 2001 to February 2013 (**Figure 2-1**) were analyzed for fecal coliform (**Table 2.1**) and *E. coli* (**Table 2.2**). Samples were taken for the express purpose of determining compliance with the state single sample maximum standards, limiting fecal coliform concentrations to 400 cfu/100mL and *E. coli* concentrations to 235 cfu/100mL. As a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100mL or in excess of a specified cap (e.g. 8,000 or 16,000 cfu/100mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported values of 100 cfu/100mL most likely represent concentrations below 100 cfu/100mL, and reported concentrations of 8,000 or 16,000 cfu/100mL most likely represent concentrations in excess of those values. *E. coli* concentrations have minimum and maximum laboratory detection concentrations of 25 and 2,000 cfu/100 mL, respectively.

Frequency analyses of the *E. coli* data collected within the watershed is presented in **APPENDIX A: Frequency Analysis of Bacteria Data**.

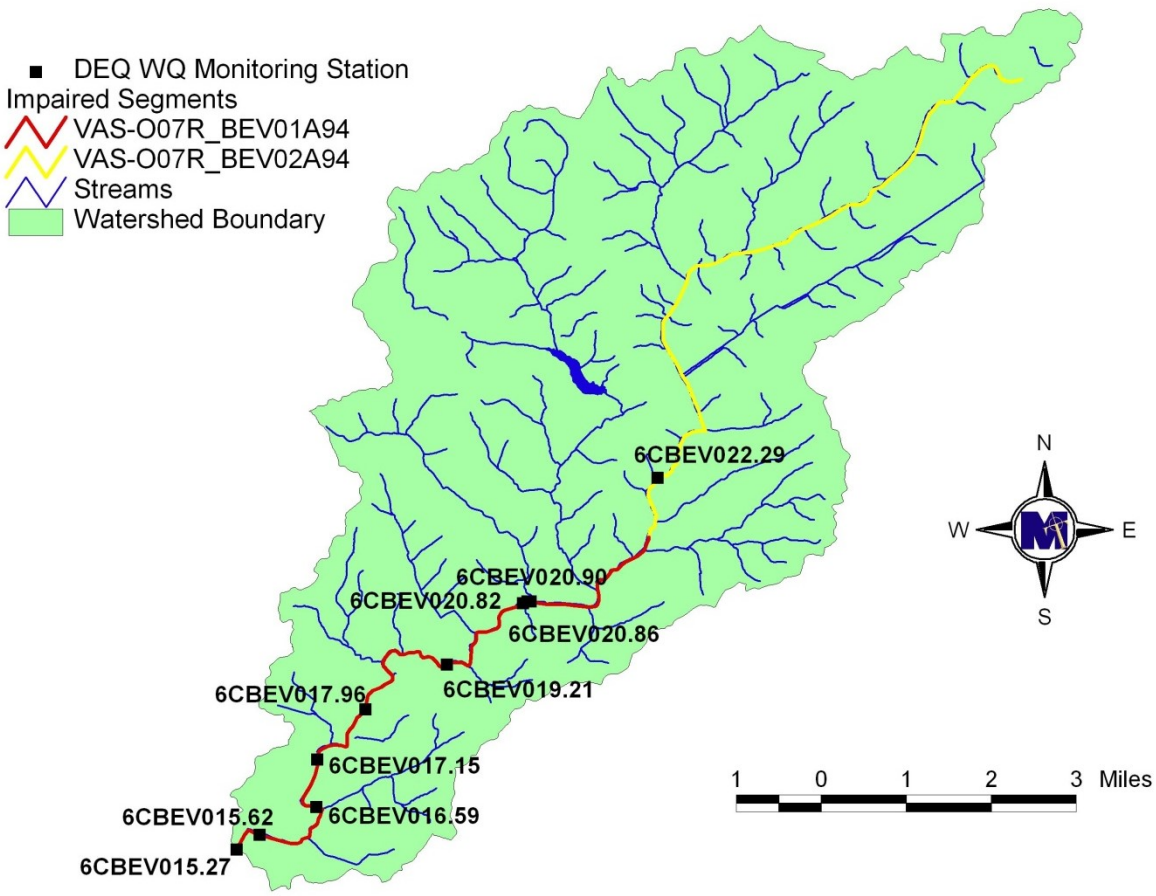


Figure 2-1. Location of VADEQ water quality (WQ) monitoring stations in the Beaver Creek watershed study area.

Table 2.1. Summary of fecal coliform (cfu/100mL) data collected by VADEQ from January 2001 to February 2013.

Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	% Violation*
6CBEV015.27	1/01 - 10/02	10	350	5,000	2,073	1,250	1,761	90.0
6CBEV015.62	8/01 - 6/03	12	200	6,000	1,625	800	1,776	91.7
6CBEV016.59	8/01 - 6/03	12	100	3,300	592	300	893	41.7
6CBEV017.15	8/01 - 6/03	12	100	1,700	625	600	505	58.3
6CBEV017.96	8/01 - 6/03	12	100	900	383	300	295	33.3
6CBEV019.21	8/01 - 6/03	12	100	1,500	483	350	449	50.0
6CBEV020.82	10/01 - 6/03	20	50	2,000	418	238	514	30.0
6CBEV020.86	2/01 - 1/02	8	100	8,000	1,213	200	2,750	25.0
6CBEV020.90	10/01 - 1/02	4	200	400	300	300	115	0.0
6CBEV022.29	8/01 - 6/03	12	100	6,000	917	450	1,650	50.0

*Based on an single sample maximum fecal coliform standard of 400 cfu/100mL.

Table 2.2. Summary of E. coli (cfu/100mL) data collected by VADEQ from January 2001 to February 2013.

Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	% Violation*
6CBEV015.27	1/01 - 2/13	32	25	2,000	986	850	737	84.4
6CBEV020.82	7/02 - 6/03	11	20	800	319	230	282	36.4
6CBEV020.86	9/12 - 2/13	6	25	600	225	63	282	33.3
6CBEV022.29	9/12 - 2/13	5	50	2,000	580	325	812	60.0

*Based on the current single sample maximum *E. coli* standard of 235 cfu/100mL. A 10% violation rate is acceptable.

3. BACTERIA SOURCE ASSESSMENT

The TMDL revision described in this report includes an updated examination of all potential sources of fecal bacteria in the Beaver Creek watershed study area. The source assessment was used as the basis of model development and ultimate analysis of revised TMDL allocation options. In evaluation of the sources, loads were characterized by the best available information, landowner input, literature values, and local management agencies. This chapter is organized into point and nonpoint sections and documents the available information and interpretation for the analysis. The representation of the following sources in the model is discussed at greater length in **APPENDIX B**.

3.1 Assessment of Permitted Sources

There are several existing point sources permitted to discharge to surface water bodies in the Beaver Creek watershed study area through the Virginia Pollutant Discharge Elimination System (VPDES) permit program, as well as one proposed permitted facility that can be expected to have fecal bacteria in their waste water. The proposed waste water treatment plant (WWTP) will discharge treated effluent to Beaver Creek (**Table 3.1**). Permitted point discharges, such as this proposed WWTP, that may contain pathogens associated with fecal matter are required to maintain an *E. coli* concentration below 126 cfu/100mL, the geometric mean standard.

Table 3.1. Proposed VPDES permit.

Facility	Receiving Stream	Permitted Discharge Amount
Proposed WWTP	Beaver Creek	1.5 MGD

Table 3.2 shows the three single family home permits within the Beaver Creek watershed study area. The use of "UT" in this table refers to unnamed tributaries. These permits allow treated residential waste water to be discharged to surface waters. All of these housing units discharge water and bacteria to the streams.

Table 3.2. Single family home permits in the Beaver Creek watershed study area.

Permit	Receiving Stream	Facility Type
VAG400012	Beaver Creek	Domestic
VAG400209	Beaver Creek, UT	Domestic
VAG400210	Beaver Creek, UT	Domestic

There is one VPDES permitted Confined Animal Feeding Operation (CAFO) in the study area (**Table 3.3**).

Table 3.3. Confined animal feeding operation (CAFO) permits in the Beaver Creek watershed study area.

Permit	Receiving Stream	Facility Name	Animal Type	Maximum Number
VPG210001	Beaver Creek	Green Valley Poultry Farm	Chicken	1,200,000

Table 3.4 shows the Municipal Separate Storm Sewer System (MS4) permits. These are areas of land with stormwater runoff collection that discharge to surface waters. The land area within these permit boundaries has bacteria from land-based sources (pet, human, wildlife) which can be present in the runoff.

Table 3.4. Permits for MS4 in the Beaver Creek watershed study area.

Permit	Facility Name	Bacteria Contribution
VAR040048	City of Bristol MS4	Yes

3.2 Assessment of Nonpoint Sources

In the Beaver Creek watershed study area, both residential and agricultural nonpoint sources of fecal coliform bacteria were considered. Sources include land application of waste (livestock), residential sewage disposal systems, livestock, wildlife, and pets. Sources were identified and enumerated. MapTech previously collected samples of fecal coliform sources (i.e. wildlife, livestock, pet, and human waste) and enumerated the density of fecal coliform bacteria. This analysis was used to support the modeling process for the current project and expand the database of known fecal coliform sources

for purposes of bacterial source tracking. Where appropriate, the spatial distribution of sources was also determined. Significant changes in land use and population since the original TMDL was developed prompted the calculation of updated estimates for human sources as well as wildlife, livestock, and domestic pet populations. These values are laid out in the following sections.

3.2.1 Private Residential Sewage Treatment

Population, housing units, and type of sewage treatment from the U.S. Census Bureau were calculated using GIS (**Table 3.5**). In the U.S. Census questionnaire, housing occupants were asked which type of sewage disposal existed for the housing unit. Houses can be connected to a public sanitary sewer, a septic tank or a cesspool, or the sewage is disposed of in some other way. The Census category "Other Means" includes houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage via a straight pipe (direct stream outfall).

Table 3.5. Human population and residential sewage treatment information for 2012 in the Beaver Creek watershed study area.

Population	Housing Units	Housing Units with Sewer	Housing Units with Septic Systems	Housing Units with Straight Pipes
17,126	8,277	6,503	1,697	77

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 are 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, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal bacteria is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to

naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal bacteria to surface waters.

A septic failure occurs when a drain field has inadequate drainage or a "break" occurs, such that effluent flows directly to the soil surface, bypassing 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 survey of septic pump-out contractors, previously performed by MapTech, showed that failures were more likely to occur in the winter-spring months than in the summer-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 in the yard.

MapTech previously sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 mL (MapTech, 1999). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

3.2.2 Biosolids

Biosolids have not been applied in the Beaver Creek watershed study area.

3.2.3 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Beaver Creek watershed study area 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 previously measured by MapTech. Fecal coliform density for dogs and cats was previously measured from samples collected by MapTech. A summary of the data collected is given in **Table 3.6**. **Table 3.7** lists the domestic animal populations in the Beaver Creek watershed study area.

Table 3.6. Domestic animal population density, waste load, and fecal coliform density of waste.

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 3.7. Estimated domestic animal populations for 2012 in the Beaver Creek watershed study area.

Dogs	Cats
4,084	4,573

3.2.4 Livestock

The predominant type of livestock in the Beaver Creek watershed study area is beef cattle, although other types of livestock identified were considered in modeling the watershed. **Table 3.8** gives a summary of livestock populations in the Beaver Creek watershed study area. Animal populations were based on data from the National Agricultural Statistics Service, communication with VADEQ, Soil and Water Conservation Districts (SWCD), watershed visits, and verbal communication with citizens at the first public meeting.

Table 3.8. Estimated livestock populations for 2012 in the Beaver Creek watershed study area.

Dairy Milker	Dairy Replacement Heifer	Dairy Calf	Beef Cattle	Beef Calf	Sheep	Horse
245	123	123	5,055	1,472	713	322

Values of fecal coliform density of livestock sources were based on sampling previously performed by MapTech (MapTech, 1999). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in **Table 3.9**.

Table 3.9. Average fecal coliform densities and waste loads associated with livestock types.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off Factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Dairy milker (1,400 lb)	120.4	271,329	0.5
Dairy heifer (850 lb)	70.0	271,329	0.25
Dairy calf (350 lb)	29.0	271,329	0.5
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA
Poultry (1 lb):			
Broiler	0.17	586,000	0.5
Layer	0.26	586,000	0.5

Fecal 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 may have drainage systems that divert wash-water and waste directly to drainage ways or streams.

As noted earlier, some livestock were expected to deposit a portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was estimated based on projects in other areas of southwest Virginia. All livestock, with the exception of dairy cows, were assumed to be in pasture 100% of the time. Dairy cows are typically confined for portions of the day, and the waste they produce when confined was modeled as being collected and applied to cropland and pasture throughout the year. The time allocations and manure distributions for dairy cattle in the two dairy operations within the study area used were the same as determined in the original TMDL.

It was assumed that beef cattle with access to streams would make a significant contribution through direct deposition. For areas where direct deposition by cattle is assumed, the average amount of time that beef cattle, dry cows, and replacement heifers spend in stream access areas for each month used in the new model were the same as are provided in the original TMDL document.

3.2.5 Wildlife

The predominant wildlife species in the Beaver Creek watershed study area were determined through consultations with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, and source sampling. Population densities were calculated from data provided by VDGIF and FWS, and are listed in **Table 3.10** (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987). The numbers of animals estimated to be in the Beaver Creek watershed study area are reported in **Table 3.11**.

Table 3.10. Wildlife population densities for the Beaver Creek watershed study area.

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0279	0.0087	0.0189	0.0333	0.6115	0.0226	0.25

Table 3.11. Estimated wildlife populations for 2012 in the Beaver Creek watershed study area.

Deer	Turkey	Beaver	Raccoon	Muskrat	Duck	Goose
759	150	879	1,569	2,209	46	23

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 determined from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999). **Table 3.12** summarizes the habitat and waste production information that was obtained.

Table 3.12. Wildlife waste production rates and habitat.

Animal	Waste Load (g/an-day)	Habitat
Raccoon	450	**Primary** = region within 600 ft of perennial streams **Secondary** = region between 601 and 7,920 ft from perennial streams **Infrequent/Seldom** = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	100	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Beaver[1]	200	**Primary** = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) **Infrequent/Seldom** = rest of the watershed area
Deer	772	**Primary** = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land **Secondary** = low density residential, medium density residential **Infrequent/Seldom** = remaining land use areas
Turkey[2]	320	**Primary** = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land **Secondary** = cropland, pasture **Infrequent/Seldom** = remaining land use areas
Goose[3]	225	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Mallard (Duck)	150	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area

[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 (2003)

Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in **Table 3.13**. Where available, fecal coliform densities were based on MapTech sampling of wildlife scat. The only value that was not obtained from MapTech sampling in the watershed was for beaver.

Table 3.13. Average fecal coliform densities in waste and portion of day spent in stream access areas for wildlife species.

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

3.3 Unidentified Bacteria Source

During the water quality calibration process (**APPENDIX B: Bacteria Modeling Procedure**), an unidentified source of bacteria loading in the Bristol area near the state line was detected. While the model could be adequately calibrated in the upper parts of the watershed, identified sources in the watershed could not account for the historically high levels of bacteria reported in the two most downstream monitoring stations (6CBEV015.27 and 6CBEV015.62). The load does not appear to be associated with storm events (**APPENDIX E: Unidentified Source Investigation**). For purposes of this project, the unidentified source was modeled as a constant point load of fecal coliform at a rate of 4.11E11 cfu/day.

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4. BACTERIA MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Computer modeling was used in this study as a tool that allows simulation of the interaction between the land surface and subsurface along with the quantities of various bacteria sources by location. The model used in the analysis was the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model. 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. The model allows the climatological factors, and in particular precipitation, to drive this interaction. By modeling the watershed conditions and bacteria sources, the model allows quantifying the relationship between sources as they exist throughout the watershed to bacteria concentrations within the watershed. A brief summary of the modeling procedure is presented in this section. A complete description of the bacteria modeling approach is presented in **APPENDIX B**.

To adequately represent the spatial variation in the watershed parameters and pollutant quantification, the Beaver Creek watershed drainage area was divided into fifteen (15) subwatersheds (**Figure B. 1**). Hydrologic parameters collected for the watershed were used to calibrate and validate the simulated flow. Flow was calibrated by comparing model output to observed flow within Beaver Creek and making the proper adjustments to obtain the best match between simulated and observed flow. Once the hydrologic model was calibrated, a separate time period was simulated and compared to observed data to validate the model, ensuring that is performs well for multiple time periods. Once the flow component was built, quantified bacteria sources were entered into the model and simulated bacteria concentration was generated. The simulated bacteria concentration was calibrated by comparing model simulations of bacteria to observed bacteria values collected by VADEQ at multiple locations. Finally, the bacteria concentration was validated using a different time period from the calibration period.

Existing conditions of bacteria were then entered into the model to simulate the baseline conditions. This stage gives an indication of the current predicted violation rates of the

geometric mean standard. At this point, the model was used in the allocation process where reductions were simulated for various sources until the bacteria geometric mean standard was met. A sensitivity analysis was run on the model to determine the impacts of changing certain parameters on the resulting pollutant loads. The results of these analyses can be used in planning and prioritizing implementation strategies.

Critical conditions were considered directly during model development. Critical conditions for waters impacted by land-based nonpoint sources of bacteria 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, include non-point sources that are not precipitation-driven (e.g. fecal coliform deposition directly to steams).

Graphical analyses of fecal bacteria concentrations and flow duration intervals (FIGURES) showed that water quality standard violations occurred at nearly every flow interval at all VADEQ monitoring stations in the Beaver Creek watershed study area. Therefore, time periods for calibration, validation, and allocation of the model were chosen based on the overall distribution of wet and dry seasons in order to capture a wide range of hydrologic circumstances for all impaired streams in the study area.

Throughout the modeling process, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. For example, modeling periods extended across high and low flow seasons over a period of several years. The use of HSPF allowed consideration of seasonal aspects of precipitation and stream flow patterns within the watershed. It was also used to simulate the change in land-based nonpoint sources based on land use type and season (e.g. the seasonal changes in livestock grazing habits) and the seasonal distribution of septic failure loads. Finally, the bacteria models were run at a 1-hour timestep, capturing a fine scale of temporal and seasonal conditions.

5. BACTERIAL ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, non-permitted 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 waterbody and still achieve water quality standards. For the recreational use impairment in Beaver Creek, the TMDL is expressed in terms of colony forming units (or resulting concentration).

Water quality monitoring represents existing conditions which are the sum of anthropogenic and natural background pollutants. Water quality modeling mimics this sum condition. Nevertheless, because wildlife represents the major source of natural background bacteria pollution, it was quantified and a separate load assigned. In the final TMDL equation, the natural background contributions are included in the LA component.

Allocation scenarios were modeled using the HSPF model. Scenarios were created by simulating reducing direct and land-based bacteria until the water quality standards were attained. The TMDLs developed for the impairments in the Beaver Creek watershed study area were based on the *E. coli* riverine Virginia State standards. As detailed in Section 2.2, the VADEQ requires that the TMDL addresses both the calendar-month geometric-mean criterion (not to exceed 126 cfu/100 mL) and the single-sample maximum criterion (no more than 10% exceedance of 235 cfu/100 mL).

According to the guidelines put forth by VADEQ (VADEQ, 2003) for modeling bacteria 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 data set containing 493 paired data points):

$$log_2(C_{EC}) = -0.0172 + 0.91905 * log_2(C_{FC})$$

where C_{EC} is the concentration of *E. coli* in cfu/100 mL and C_{FC} is the concentration of fecal coliform in cfu/100 mL.

Pollutant concentrations were modeled over a representative period and pollutant loads were adjusted until the standards were met. The development of the allocation scenarios was an iterative process that required numerous runs, each followed by an assessment of source reduction against the applicable water quality standards.

5.1 Margin of Safety (MOS)

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. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

A MOS 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 an MOS in the development of a bacterial TMDL is to ensure that the modeled loads do not underestimate the actual loadings that exist in the watershed. An implicit MOS was used in the development of these TMDLs. An implicit MOS ensures that the recommended reductions will in fact succeed in meeting the water quality standard. Examples of the implicit MOS used in the development of these TMDLs are:

- Allocating permitted point sources at the maximum allowable fecal coliform concentration,
- Selecting a modeling period that represented the critical hydrologic conditions in the watershed, and

- Ensuring that each subwatershed in a given watershed unit meets the water quality standards, with the reductions for an entire grouping being determined by the most limiting subwatershed, and
- Using the daily average of modeled hourly data to perform assessment – when taking the daily average of a log-normally distributed data set (e.g. bacteria concentrations), the violation rate and long-term geometric mean are skewed upward

5.2 Waste Load Allocations (WLAs)

As detailed in **Section 3.1**, there are several point sources currently permitted to discharge bacteria into the Beaver Creek watershed study area, and one proposed permit which is also included here. The allocation for the sources permitted for *E. coli* control is their permit maximum (design discharge with an *E. coli* concentration of 126 cfu/100mL). Permits for CAFO operations are included in the WLA listings, but with a permitted load of 0 cfu/yr. While CAFOs are permitted operations, they do not have a permit to discharge directly to the stream. However, there is a potential load from CAFOs in runoff from the land surface, thus any load from CAFOs are actually included in the Load Allocation section of the TMDL (described below). Future growth in each watershed was accounted for by setting aside 1% of the TMDL for future growth in permitted discharges or the creation of new ones.

5.3 Load Allocations (LAs)

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (livestock, wildlife, straight pipes, and sewer overflows). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads most significantly impact bacteria concentrations during high-flow conditions, while direct deposition NPS loads most significantly impact low flow bacteria concentrations. Nonpoint source load reductions were performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by land use. **APPENDIX D: Current Conditions Fecal Coliform Loads** contains tables of the annual fecal coliform load by land use for each subwatershed. The wildlife species included in **APPENDIX D**:

Current Conditions Fecal Coliform Loads (deer, raccoon, goose, etc.) represent the natural background conditions considered in the development of the fecal bacteria TMDL in the Beaver Creek watershed.

5.4 Final Total Maximum Daily Loads (TMDLs)

Allocation scenarios were run for the entire watershed. All subwatersheds falling within the impairment were allocated to meet the applicable standards. **Table 5.1** shows scenarios developed to determine the TMDLs. The table references subwatersheds that are shown in **APPENDIX B** (**Figure B. 1**).

The existing condition, Scenario 1, shows violations of the standard at all impaired subwatershed outlets. Eliminating the unidentified source in Scenario 2 decreased the single-sample violation rate by 8% in the most limiting subwatershed (on which **Table 5.1** is based). Scenario 3, which eliminated illicit residential discharges and/or straight pipes, showed dramatic improvement. Reduction of livestock direct deposition in streams and land-based loads from agricultural, developed, and commercial areas further improved water quality. The final scenario, 12, shows that after eliminating the unidentified source and illicit residential discharges and straight pipes, a 98% reduction in livestock direct deposition, 85% reduction in land-based loads from developed and commercial areas, and 50% reduction in land-based loads from agricultural areas would benefit water quality and allow Beaver Creek to meet the recreational use standard.

Table 5.1. Allocation scenarios for reducing current bacteria loads in the Beaver Creek watershed.

Scenario	Percent Reductions to Existing Bacterial Loads								Percent Violations of VADEQ Standards*	
	Unidentified Source	Wildlife Direct	Wildlife Land Based	Livestock Direct	Livestock Land Based	Agricultural Land Based	Human Direct	Human Land Based	Monthly Geometric Mean	Single Sample Maximum
			Barren, Forest, Wetland		Pasture, LAX**	Cropland		Developed, Commercial	126 cfu/100mL *E. coli*	235 cfu/100mL *E. coli*
1	0	0	0	0	0	0	0	0	100.00	93.89
2	100	0	0	0	0	0	0	0	100.00	85.68
3	100	0	0	0	0	0	100	0	58.33	34.49
4	100	0	0	50	50	50	100	0	36.11	21.26
5	100	0	0	50	50	50	100	50	33.33	18.16
6	100	0	0	75	75	75	100	50	16.67	13.96
7	100	0	0	90	75	75	100	50	8.33	13.23
8	100	0	0	90	85	85	100	50	8.33	12.41
9	100	0	0	90	85	85	100	75	5.56	6.93
10	100	0	0	98	85	85	100	75	2.78	6.66
11	100	0	0	98	85	85	100	85	0.00	4.65
12	**100**	**0**	**0**	**98**	**50**	**50**	**100**	**85**	**0.00**	**8.85**

*Violation rate of the most limiting subwatershed in the study area. A 10% violation rate of the Single Sample Maximum is acceptable.
**LAX = Livestock Access

Figure 5-1 shows the existing and allocated monthly geometric mean *E. coli* concentrations, respectively, from the Beaver Creek outlet. **Figure 5-2** shows the same information for the most limiting subwatershed in the study area, subwatershed 13. The graphs show existing conditions in black, with allocated conditions overlaid in blue.

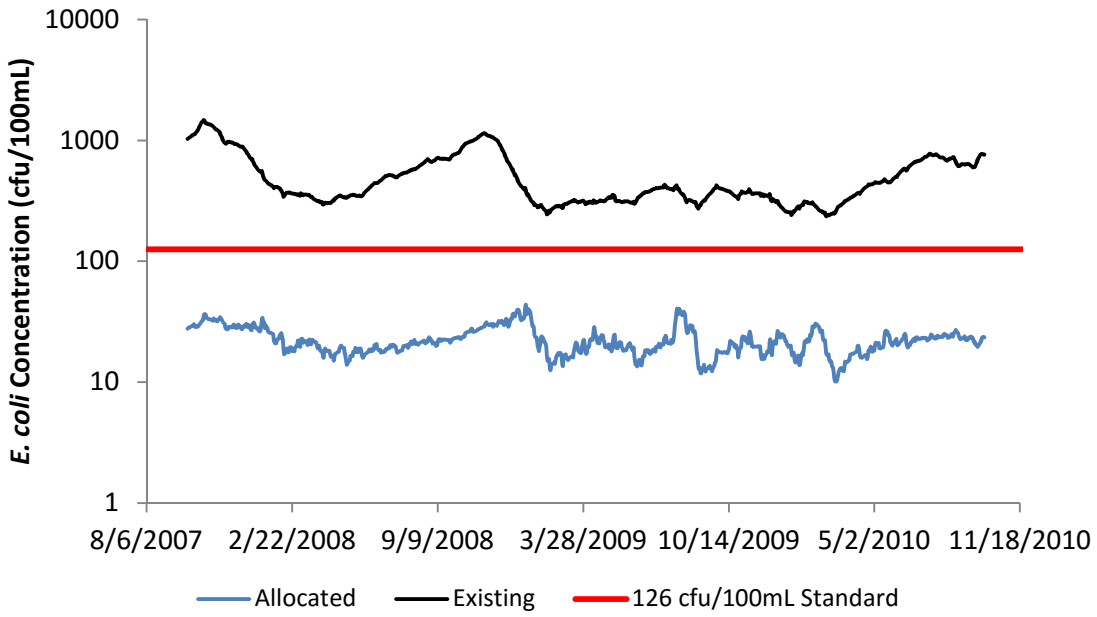

Figure 5-1. Existing and allocated monthly geometric mean in-stream *E. coli* concentrations at outlet of Beaver Creek watershed study area.

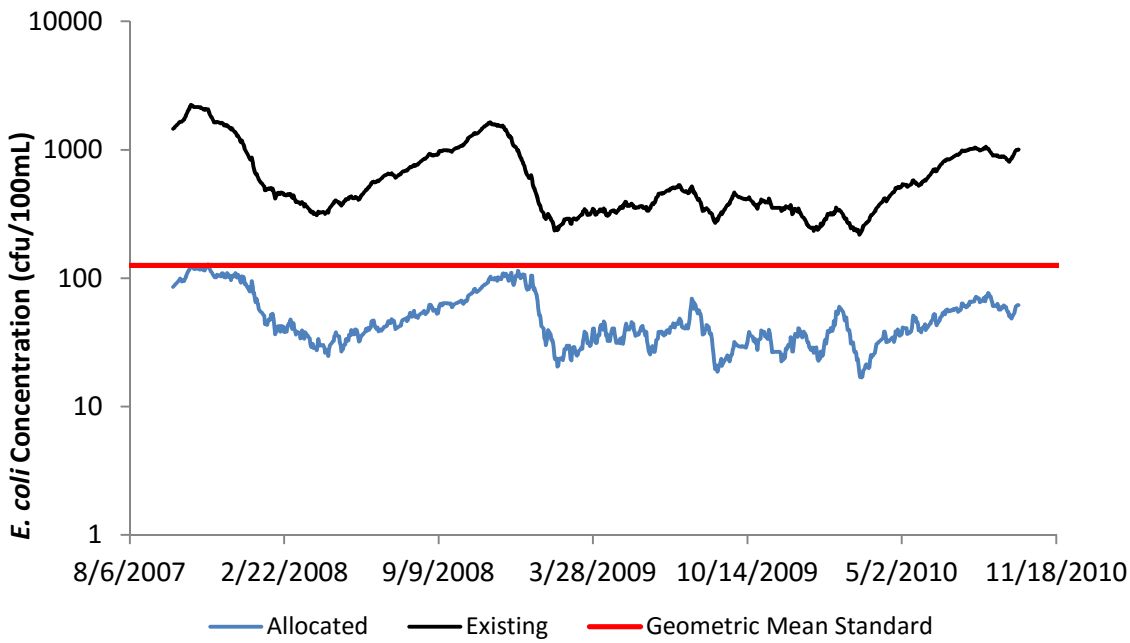

Figure 5-2. Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 13.

Table 5.2 contains estimates of existing and allocated in-stream *E. coli* loads at the Beaver Creek watershed outlet reported as average annual cfu per year. The estimates in **Table 5.2** are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The percent reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column.

Table 5.2. Estimated existing and allocated *E. coli* in-stream loads at the outlet of the Beaver Creek watershed study area.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction (%)
Land Based			
Developed	2.75E+12	4.13E+11	85
Commercial	5.26E+12	7.89E+11	85
Barren	5.18E+12	5.18E+12	0
Forest	3.07E+12	3.07E+12	0
Pasture	5.18E+13	2.60E+13	50
Cropland	4.33E+12	2.17E+12	50
LAX*	3.21E+12	1.61E+12	50
Direct			
Human	3.42E+13	0.00E+00	100
Livestock	6.45E+12	1.29E+11	98
Wildlife	2.37E+12	2.37E+12	0
Unidentified Source	7.66E+13	0.00E+00	100
Permitted Sources	5.23E+09	5.23E+09	0
Proposed Permit	n/a	2.61E+12	n/a
MS4	1.30E+12	1.30E+12	0
Future Growth	n/a	4.61E+11	n/a
Total Loads	**1.97E+14**	**4.61E+13**	**77**

*Livestock Stream Access

APPENDIX A: Frequency Analysis of Bacteria Data includes the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

Table 5.3 shows the average annual TMDL, which gives the average amount of bacteria that may be present in the stream in a given year and still meet the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.3. Average annual in-stream *E. coli* bacterial loads (cfu/yr) modeled after TMDL allocation at the outlet of the Beaver Creek watershed.

Impairment	WLA[1]	LA[2]	MOS	TMDL
Beaver Creek	4.38E+12	4.17E+13	*Implicit*	4.61E+13
VAG400012	1.74E+09			
VAG400209	1.74E+09			
VAG400210	1.74E+09			
VPG210001	0.00E+00			
City of Bristol MS4 (VAR040048)	1.30E+12			
Proposed Permit	2.61E+12			
Future Load	4.61E+11			

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

[2] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value is different from the table providing nonpoint source load (Table 5.2) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily maximum in-stream loads for Beaver Creek are shown in **Table 5.4**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100mL. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.4. Maximum daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation at the outlet of the Beaver Creek watershed.

Impairment	WLA	LA	MOS	TMDL
Beaver Creek	2.68E+10	1.58E+12	*Implicit*	1.61E+12
VAG400012	4.77E+06			
VAG400209	4.77E+06			
VAG400210	4.77E+06			
VPG210001	0.00E+00			
City of Bristol MS4 (VAR040048)	3.56E+09			
Proposed Permit	7.15E+09			
Future Load	1.61E+10			

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

[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100mL *E. coli*. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess the progress toward TMDL goals

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6. BENTHIC MACROINVERTEBRATE COMMUNITY WATER QUALITY ASSESSMENT

Since the development of the original TMDL, there has been significant monitoring effort in the Beaver Creek watershed. This section outlines the newest data used in the revision.

6.1 Applicable Criterion for Benthic Impairment

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

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

The General Standard use was implemented by VADEQ through application of the modified Rapid Bioassessment Protocol II (RBP II) (Barbour et al, 1999). However, in January 2008 VADEQ moved to a multimetric index approach called the Virginia Stream Condition Index (VASCI) (Burton and Gerritsen, 2003). The health of the benthic macroinvertebrate community is assessed through measurement of eight biometrics statistically derived from numerous reference sites in the non-coastal regions of Virginia (**Table 6.1**). Surveys of the benthic macroinvertebrate community performed by VADEQ are assessed at the family taxonomic level. VADEQ's not impaired benchmark with VASCI is a total score of 60 (10th percentile of the reference sites).

Table 6.1. Components of the Virginia Stream Condition Index (VASCI).

Biometric	Benthic Health [1]
Total Taxa Score	↑
% Plecoptera plus Trichoptera less Hydopschyidae Score	↑
% Ephemeroptera Score	↑
%Scraper Score	↑
EPT Taxa Score	↑
% Two Dominant Families Score	↓
% Chironomidae Score	↓
Modified Family Biotic Index (MFBI) Score	↓

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

6.2 Benthic Assessment

Beaver Creek was initially listed on the 1998 303(d) TMDL Priority List as not supporting aquatic life. The VADEQ 2010 integrated 305(b)/303(d) list reported that there was one impaired benthic monitoring station on Beaver Creek: 6CBEV023.99. Four benthic surveys were performed by VADEQ from April 2002 to September 2007 at 6CBEV023.99, and two additional surveys were performed in May and November of 2012 at monitoring station 6CBEV022.29 (**Figure 6-1**). The VASCI scores of all six surveys are presented in **Table 6.2** and **Figure 6-2**. All surveys found impaired benthic conditions, except for the November 2012 survey.

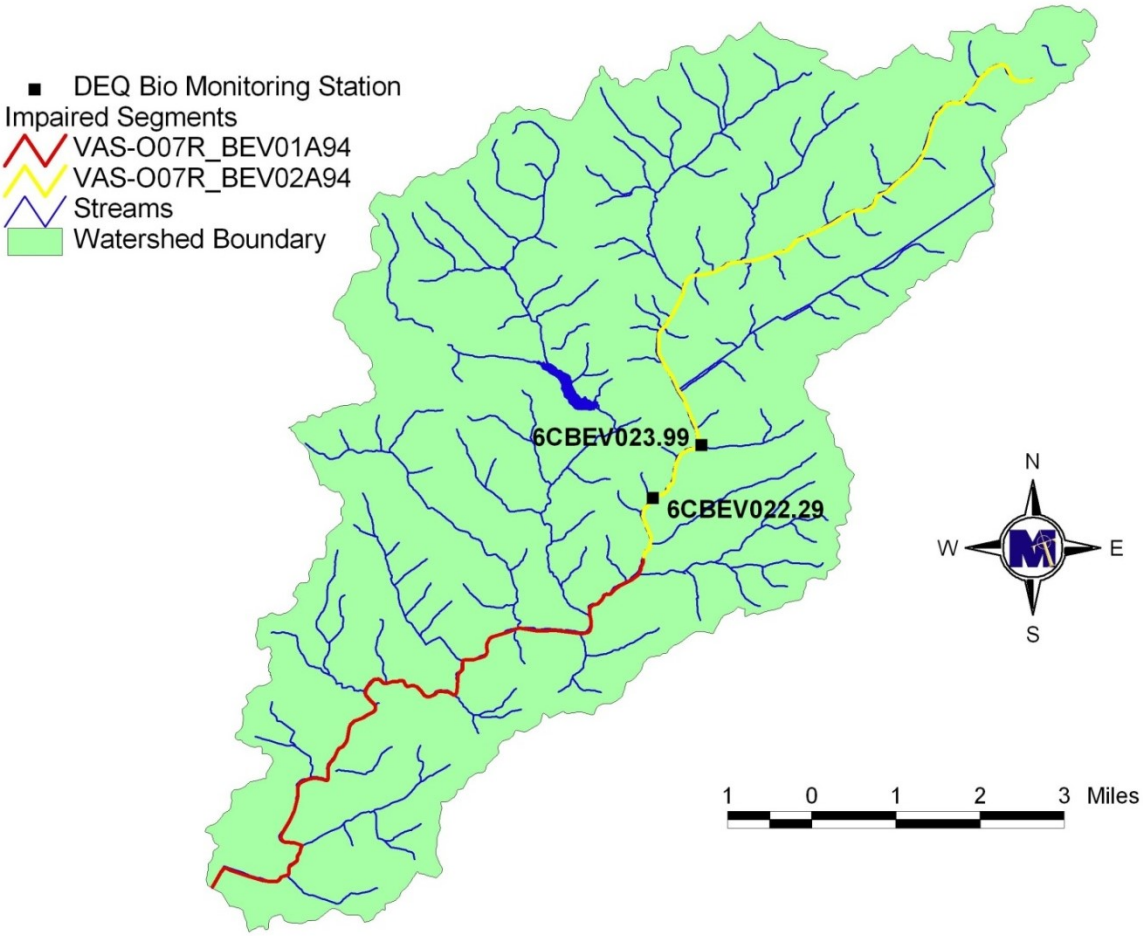

Figure 6-1. Biological monitoring stations in the Beaver Creek watershed study area.

Table 6.2. VASCI biological monitoring station data for the Beaver Creek watershed study area.

Metric	6CBEV023.99				6CBEV022.29	
	4/30/2002	12/11/2002	5/21/2007	9/18/2007	5/1/2012	11/15/2012
Richness Score	45.45	45.45	54.55	45.45	54.55	59.09
EPT Score	36.36	27.27	45.45	27.27	27.27	54.55
%Ephem. Score	53.82	5.88	22.66	3.05	72.67	50.42
%PT-H Score	0.00	0.00	5.20	0.00	0.00	25.54
%Scraper Score	69.93	100.00	86.13	68.83	33.47	75.76
%Chironomidae Score	85.57	97.30	85.19	70.09	87.27	92.73
%2Dom Score	64.06	22.13	56.20	59.42	78.82	70.92
%MFBI Score	79.29	76.58	75.30	70.09	93.82	100.00
VASCI	**54.31**	**46.83**	**53.83**	**43.03**	**55.98**	**66.13**
Assessment	**Impaired**	**Impaired**	**Impaired**	**Impaired**	**Impaired**	**Not Impaired**

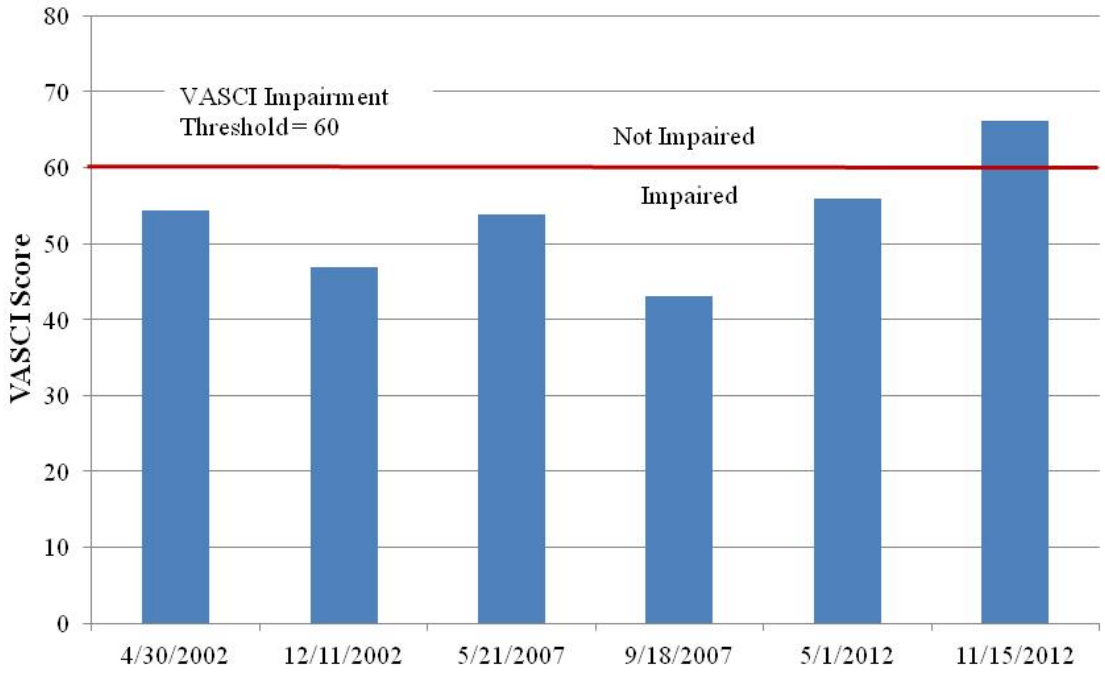

Figure 6-2. VASCI biological monitoring scores for VADEQ benthic monitoring station 6CBEV023.99 (2002-2007) and 6CBEV022.29 (2012).

6.3 Habitat Assessment

Benthic impairments have two general causes: input of pollutants to streams and alteration of habitat in either the stream or the watershed. Habitat can be altered directly (*e.g.,* by channel modification), indirectly (because of changes in the riparian corridor leading to conditions such as streambank destabilization), or even more indirectly (*e.g.,* due to land use changes in the watershed, such as clearing large areas).

Habitat assessments are normally carried out by VADEQ during benthic sampling. The overall habitat score is the sum of ten individual metrics, each metric ranging from 0 to 20. The classification schemes for the individual habitat metrics for a sampling site are shown in **Table 6.3.**

Table 6.3. Classification of habitat metrics based on score.

Habitat Metric	Optimal	Sub-optimal	Marginal	Poor
Embeddedness	16 - 20	11 – 15	6 - 10	0 - 5
Epifaunal Substrate	16 - 20	11 – 15	6 - 10	0 - 5
Pool Sediment	16 - 20	11 – 15	6 - 10	0 - 5
Flow	16 - 20	11 – 15	6 - 10	0 - 5
Channel Alteration	16 - 20	11 – 15	6 - 10	0 - 5
Riffles	16 - 20	11 – 15	6 - 10	0 - 5
Velocity	16 - 20	11 – 15	6 - 10	0 - 5
Bank Stability	18 - 20	12 – 16	6 - 10	0 - 4
Bank Vegetation	18 - 20	12 – 16	6 - 10	0 - 4
Riparian Vegetation	18 - 20	12 – 16	6 - 10	0 - 4

Habitat assessment for the Beaver Creek watershed study area includes an analysis of habitat scores recorded by VADEQ biologists at the benthic monitoring station 6CBEV023.99. The results of the VADEQ habitat assessments are displayed in **Table 6.4**. Two habitat assessments for VADEQ benthic monitoring station 6CBEV022.29, one in May and another in November 2012, are shown in **Table 6.5**.

Table 6.4. Habitat scores for VADEQ monitoring station 6CBEV023.99 on Beaver Creek.

Metric	04/30/02	12/11/02	05/21/07	09/18/07	Median
Channel Alteration	17	15	15	15	15
Bank Stability	11	**10**	13	**10**	11
Bank Vegetation	**9**	**10**	**10**	12	**10**
Embeddedness	**10**	**10**	15	13	12
Flow	17	19	17	12	17
Riffles	13	15	11	16	14
Riparian Vegetation	**8**	**10**	**10**	12	**10**
Pool Sediment	**8**	**8**	**9**	**10**	**9**
Epifaunal Substrate	**10**	15	13	15	14
Velocity	**10**	**10**	**10**	**10**	**10**

Bolded red values indicate marginal scores.

Table 6.5. Habitat scores for VADEQ monitoring station 6CBEV022.29 on Beaver Creek.

Metric	05/01/12	11/15/2012
Channel Alteration	19	19
Bank Stability	16	16
Bank Vegetation	13	13
Embeddedness	12	12
Flow	18	18
Riffles	15	15
Riparian Vegetation	15	15
Pool Sediment	**6**	**6**
Epifaunal Substrate	13	13
Velocity	**10**	**10**

Bolded red values indicate marginal scores.

Several habitat metrics had median scores within the marginal category. Bank stability is a measure of the erosion and potential for future erosion on the stream banks. A score in the marginal category indicates 30-60% of the bank length is unstable with obvious areas of erosion and high potential for further erosion during floods (Barbour et al, 1999). A

marginal score for bank vegetation indicates that only 50-70% of the streambank area is covered by vegetation and vegetation closely cropped by grazing is common, leaving the banks susceptible to increased erosion.

Embeddedness refers to the extent that rocks and snags are covered or sunken into fine sediment in the stream bed. As rocks become more embedded, there is less surface area available to macroinvertebrates and fish as habitat. Embeddedness results from large-scale sediment movement and deposition. A marginal score here indicates that rocks are 50-75% surrounded by fine sediments (Barbour et al, 1999). While the median score for embeddedness over the four samples was in the sub-optimal category, two of the four surveys resulted in marginal scores.

Pool Sediment scores were consistently in the marginal category indicating that 30-50% of the sediment bottom is affected by sediment deposits.

A marginal score for riparian vegetation means the riparian zone is only 6-12 m wide with a great deal of impact from human activities (Barbour et al, 1999). High levels of sediment deposition in pools are symptomatic of an unstable and continually changing environment, unsuitable for many organisms. A marginal score for velocity indicates a poor range of velocity/depth combinations. A variety of velocity and depth patterns are important for habitat diversity (Barbour et al, 1999).

6.4 In-stream Water Quality

Significant in-stream water quality data has been collected since the completion of the original TMDL at one of the water quality monitoring stations, 6CBEV015.27 (shown in **Figure 2-1**). This new data is outlined in **Table 6.6**. Only data that exceeded the minimum laboratory detection levels are shown.

Table 6.6. In-stream water quality data at 6CBEV015.27 on Beaver Creek.

Water Quality Constituent	Mean	SD[1]	Max	Min	Median	N[2]
Acid Neutralizing Capacity	245.0	NA	245.0	245.0	NA	1
Acidity (mg/L as CaCO3)	4.1	NA	4.1	4.1	NA	1
Alkalinity (mg/L as CaCO3)	243.0	NA	243.0	243.0	NA	1
Ammonia (mg/L as N)	0.1	0.0	0.1	0.1	0.1	8
Calcium (mg/L as Ca)	243.0	NA	243.0	243.0	NA	1
Chloride (mg/L)	11.0	0.1	11.0	10.9	11.0	2
Dissolved Oxygen (mg/L)	9.7	1.7	13.8	7.0	9.6	119
Field pH (standard units)	8.0	0.2	8.3	7.6	8.0	163
Magnesium (mg/L as Mg)	23.8	NA	23.8	23.8	NA	1
Nitrate Nitrogen (mg/L as N)	2.0	NA	2.0	2.0	NA	1
Nitrite plus Nitrate, Total (mg/L as N)	1.2	0.3	1.9	0.8	1.1	12
Nitrogen, Kjeldahl, Total (mg/L as N)	0.1	NA	0.1	0.1	NA	1
Nitrogen, Total (mg/L as N)	1.7	0.5	3.6	1.1	1.6	24
Phosphorus, Total (mg/L as P)	0.0	0.0	0.1	0.0	0.0	24
Sodium (mg/L as Na)	6.8	NA	6.8	6.8	NA	1
Sulfate, Total (mg/L as SO4)	15.9	0	15.9	15.9	15.9	2
Temperature (deg. Celsius)	13.4	6.4	22.6	3.7	14.7	163
Turbidity,Lab (ntu)	6.4	4.9	16.9	1.5	5.6	12
Magnesium (mg/L as Mg)	23.8	NA	23.8	23.8	NA	1
Nitrate Nitrogen (mg/L as N)	2.0	NA	2.0	2.0	NA	1
Nitrite plus Nitrate, Total (mg/L as N)	1.2	0.3	1.9	0.8	1.1	12
Nitrogen, Kjeldahl, Total (mg/L as N)	0.1	NA	0.1	0.1	NA	1
Nitrogen, Total (mg/L as N)	1.7	0.5	3.6	1.1	1.6	24

[1]SD: standard deviation, [2]N: number of sample measurements, NA not applicable.

7. BENTHIC MACROINVERTEBRATE COMMUNITY TMDL ENDPOINT: STRESSOR IDENTIFICATION

Analysis of additional water quality and biological monitoring data collected since the completion of the original TMDL was completed. It was determined that excessive sediment was still the most probable stressor for the benthic impairment on Beaver Creek.

7.1 Stressor Identification

Beaver Creek begins in Washington County and flows in a southerly direction through the City of Bristol before it reaches the Tennessee/Virginia state line. The impaired segment is 14.7 stream miles and begins at the headwaters near Ratcliff Knob and continues downstream to the Tennessee/Virginia state line (VADEQ segment identification numbers VAS-O07R_BEV01A94 and VAS-O07R_BEV02A94).

There are 10 water quality monitoring stations on Beaver Creek. This stressor analysis focused station 6CBEV022.29 because it was the closest ambient monitoring station to the benthic monitoring stations with most complete dataset. Conventional data results at the other nine stations were generally consistent with results from 6CBEV022.29. Graphs for parameters with more than one but less than nine data points are not shown in this chapter unless there are extreme values. The presence of nine values was selected as a cutoff in order to avoid using limited data not sampled during different seasons of the year or different flow regimes. However, all data were reviewed to ensure consistency with typical value ranges for a parameter in streams in Virginia.

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 when organisms are not classified beyond the family level. The process outlined in the Stressor Identification Guidance Document (USEPA, 2000b) was used to separately identify the most probable stressor(s) for Beaver Creek. A list of candidate causes was developed from published literature and VADEQ staff input. Chemical and physical monitoring

data provided evidence to support or eliminate potential stressors. Individual metrics for the biological and habitat evaluation were used to determine if there were links to a specific stressor(s). Land use 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, conductivity/total dissolved solids, temperature, and organic matter.

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

Non-Stressor(s): 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(s): Those stressors with data indicating possible links, but inconclusive data, were considered to be possible stressors.

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

7.2 Non-Stressors

Table 7.1 outlines the possible stressors in Beaver Creek and references the section within this document which discusses each parameter.

Table 7.1. Non-stressors in Beaver Creek.

Parameter	Location in Document
Low dissolved oxygen	**Section 7.2.1**
Nutrients	**Section 7.2.2**
Toxics (ammonia, PAHs, PCBs and pesticides)	**Section 7.2.3**
Metals	**Section 7.2.4**
Temperature	**Section 7.2.5**
Field pH	**Section 7.2.6**
Organic matter	**Section 7.2.7**
Conductivity/Total Dissolved Solids	**Section 7.2.8**

There is always a possibility that conditions in the watershed, available data, and the understanding of the natural processes change more than anticipated by the TMDL. If additional monitoring shows that different most probable stressor(s) exist or water quality target(s) are protective of water quality standards (WQS), then the Commonwealth will make use of the option to refine the TMDLs for re-submittal to EPA for approval.

7.2.1 Low Dissolved Oxygen

Dissolved oxygen (DO) concentrations were well above the VADEQ minimum WQS of 4.0 mg/L at VADEQ monitoring station 6CBEV022.29 (**Figure 7-1**). Low dissolved oxygen is considered a non-stressor in Beaver Creek.

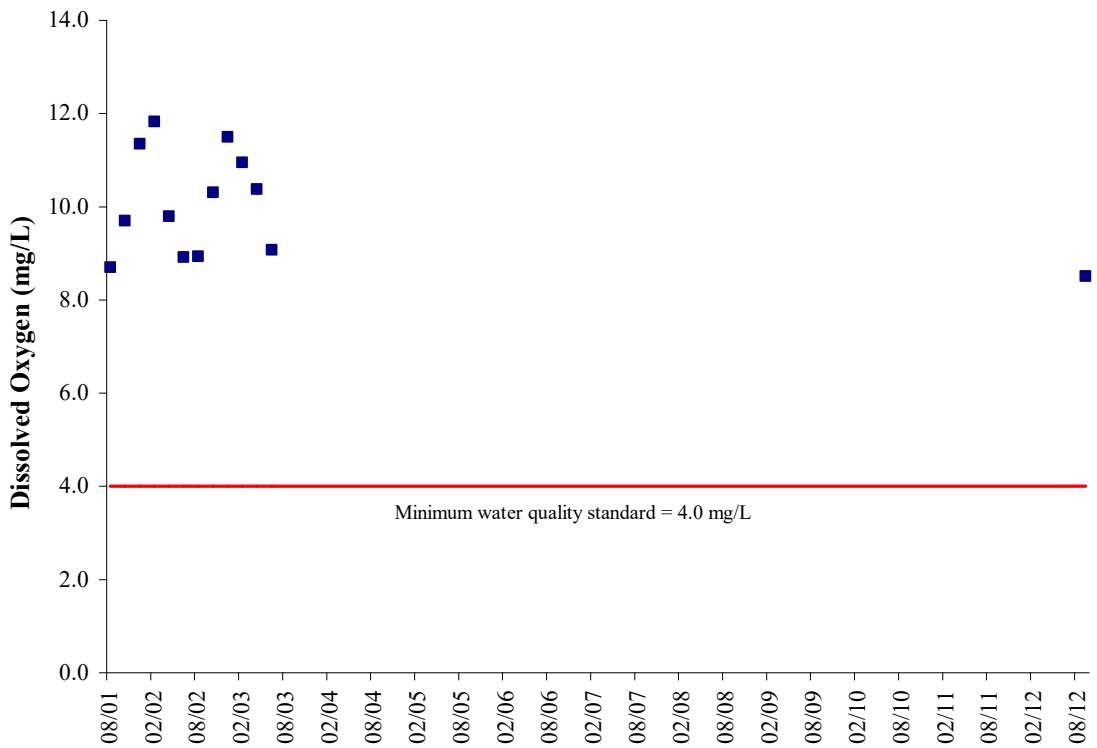

Figure 7-1. Dissolved oxygen concentrations at VADEQ monitoring station 6CBEV022.29.

7.2.2 Nutrients

Total phosphorus (TP) concentrations were very low at the VADEQ ambient monitoring station. All values were below VADEQ screening value of 0.2 mg/L with the exception of one value (**Figure 7-2**). Nitrate nitrogen concentrations were higher than the national USGS screening value of 0.6 (mg/L) (**Figure 7-3**). Total phosphorus is often the limiting nutrient in aquatic systems and dissolved oxygen concentrations don't show wide diurnal fluctuations, indicating that there is not a serious eutrophication problem in the stream. Therefore nutrients are considered non-stressors in Beaver Creek.

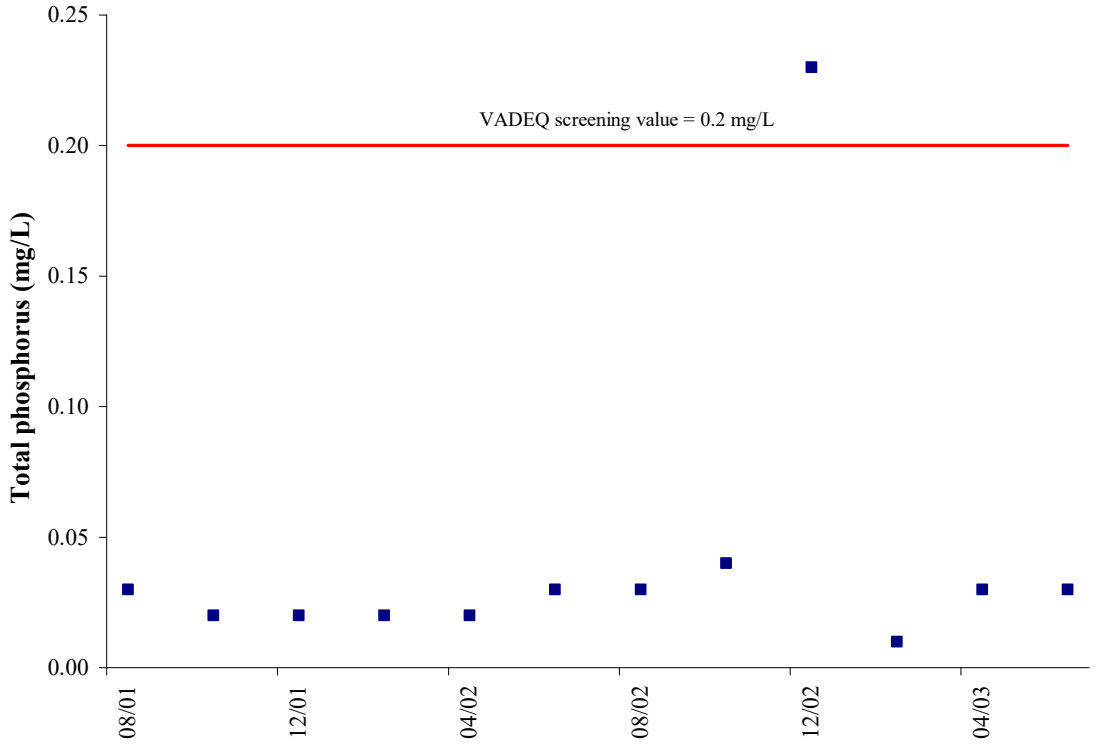

Figure 7-2. Total phosphorus concentrations at VADEQ station 6CBEV022.29.

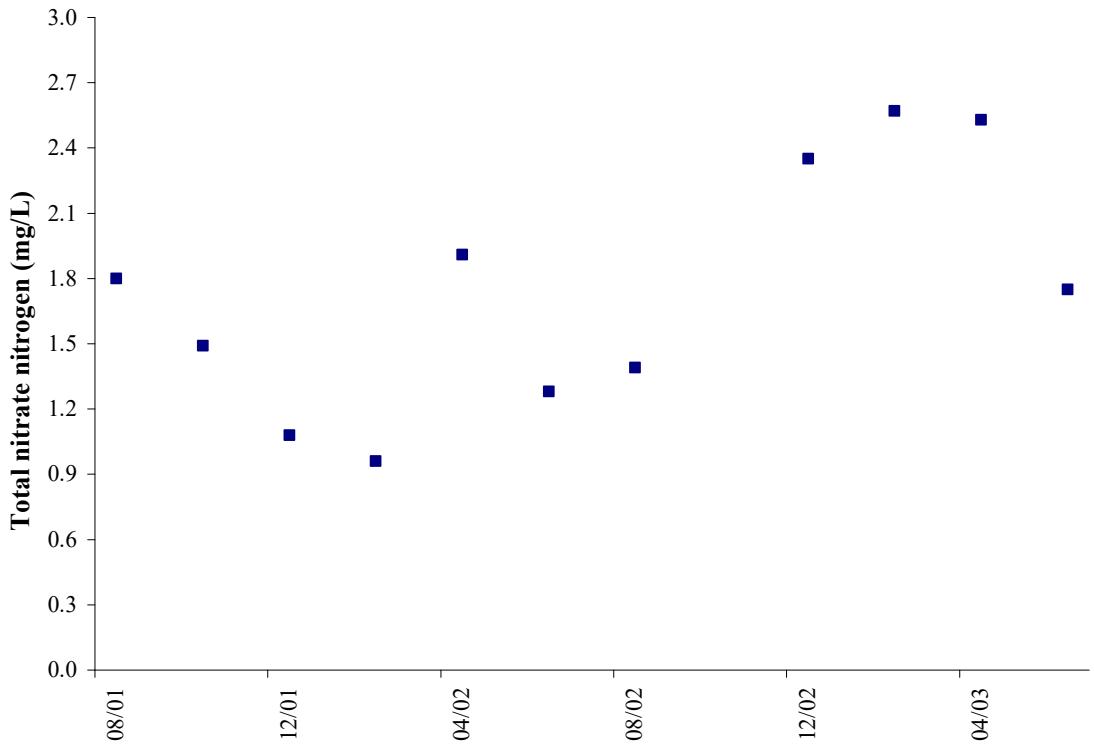

Figure 7-3. Nitrate-nitrogen concentrations at VADEQ station 6CBEV022.29.

7.2.3 Toxics (ammonia, PAHs, PCBs, and pesticides)

Ammonia (NH_3) concentrations were well below minimum laboratory detection levels with the exception of one value which did not exceed the chronic VADEQ water quality standard (WQS).

Sediment samples of polyaromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides were collected at a special study fish tissue and sediment monitoring station 6CBEV023.99 on 06/18/2002. All values were below the Probable Effect Concentration (PEC) screening values used by VADEQ to evaluate these parameters. Samples collected at station 6CBEV015.27 found total PCBs in fish tissue exceeding both VADEQ and VDH screening levels and Beaver Creek is listed on the 303(d) list as impaired for PCBs. Total PCBs in fish tissue collected at station 6CBEV022.29 were well within VADEQ and VDH screening levels. In addition, total

PCB concentrations in sediment samples at both monitoring stations were below the established PEC value. Therefore toxics are considered non-stressors in Beaver Creek.

7.2.4 Metals

Sediment metals were collected at special study fish tissue and sediment monitoring station (6CBEV023.99) on 06/18/2002 and all values were below the PEC value established for the metal. Metals are considered non-stressors in Beaver Creek.

7.2.5 Temperature

The maximum temperature WQS for Beaver Creek is 31.0°C. Temperature measurements were below the WQS (**Figure 7-4**). The maximum temperature recorded on Beaver Creek at 6CBEV022.29 was 18.5°C. Temperature is considered a non-stressor in Beaver Creek.

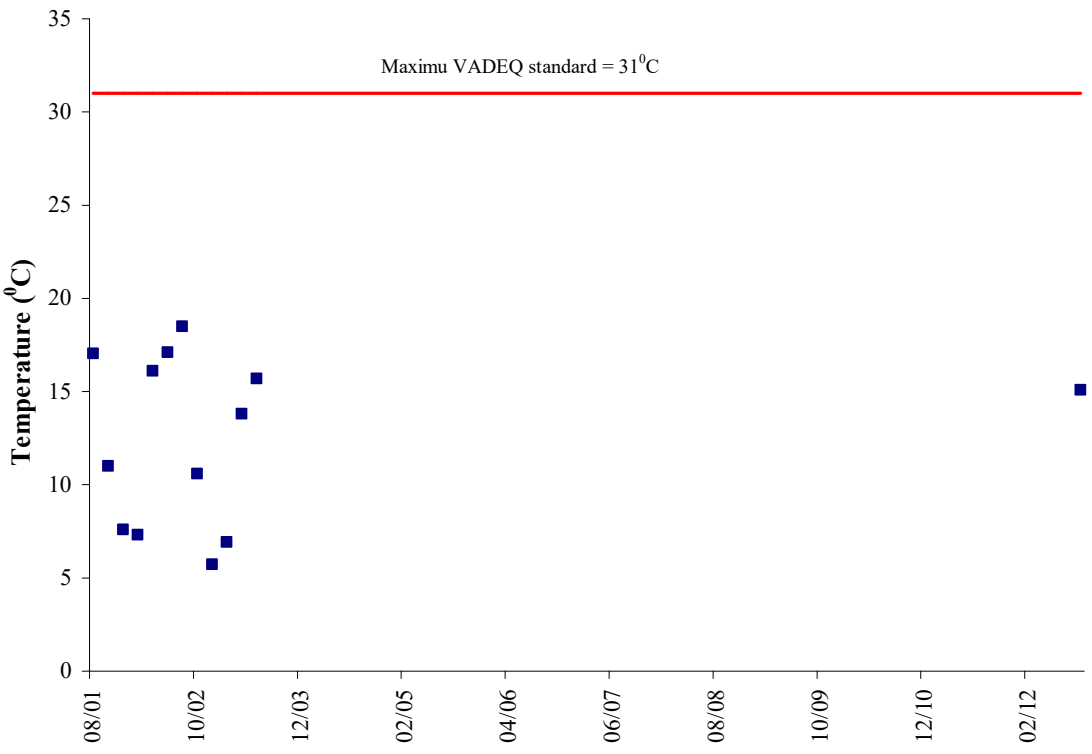

Figure 7-4. Temperature measurements at VADEQ station 6CBEV022.29.

7.2.6 Field pH

Field pH values were within the minimum (6.0 std units) and maximum (9.0 std units) at 6CBEV022.29 (**Figure 7-5**). Therefore, field pH is considered a non-stressor in Beaver Creek.

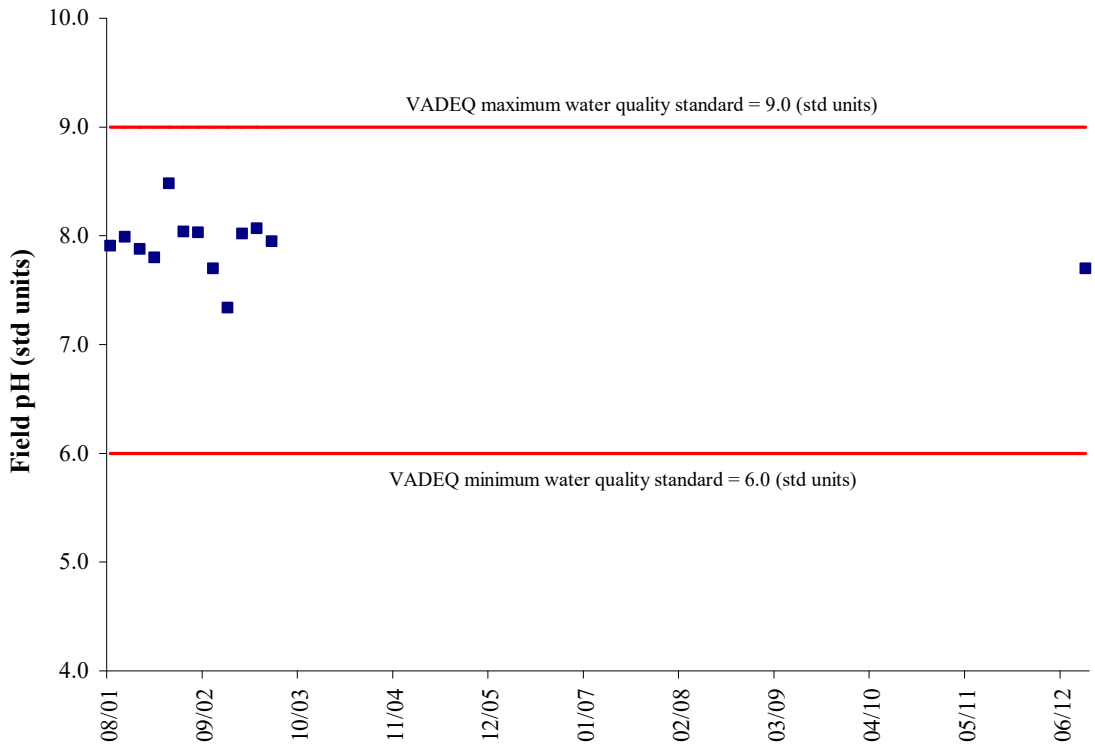

Figure 7-5. Field pH measurements at VADEQ station 6CBEV022.29.

7.2.7 Organic Matter

High amounts of organic matter in a stream can contribute to eutrophication problems. Two parameters that can be indicators of excessive amounts of organic matter are total Kjeldahl nitrogen (TKN) and total volatile solids (TVS). With the exception of an occasional spike neither parameter indicated that excessive organic matter was a chronic problem in Beaver Creek (**Figure 7-6** and **Figure 7-7**). As noted in **Section 7.2.2**, Beaver Creek does not appear to have a eutrophication problem. Therefore organic matter is considered a non-stressor in Beaver Creek.

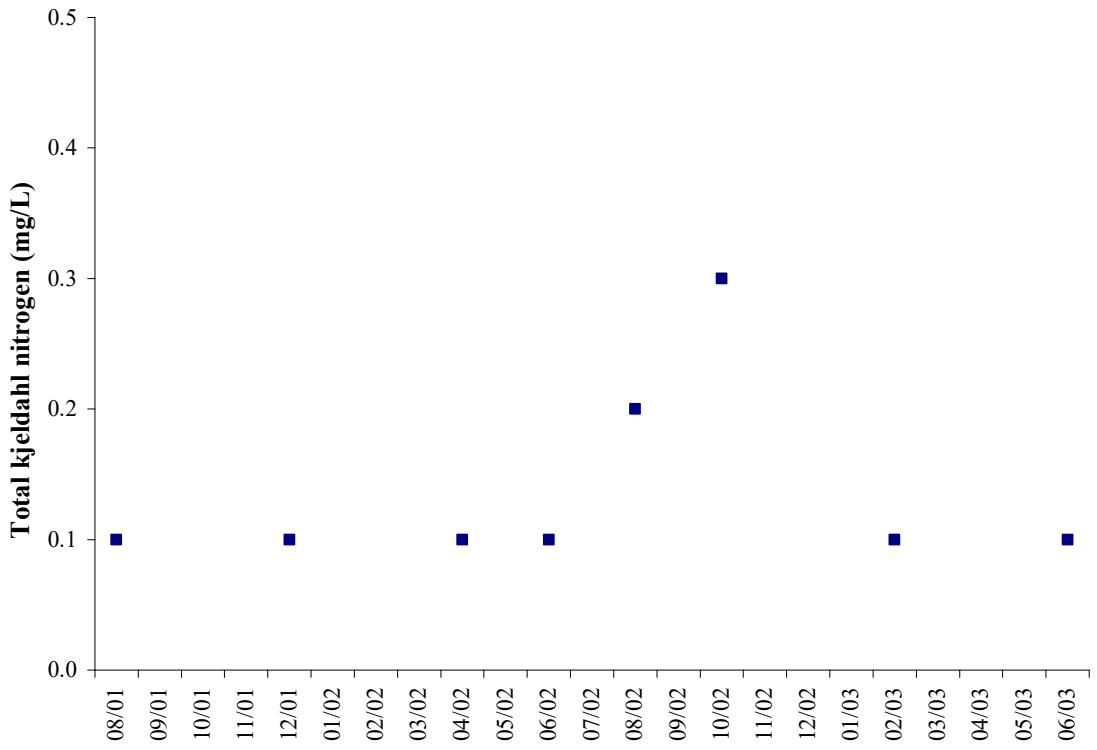

Figure 7-6. Total Kjeldahl nitrogen (TKN) concentrations at VADEQ station 6CBEV022.29.

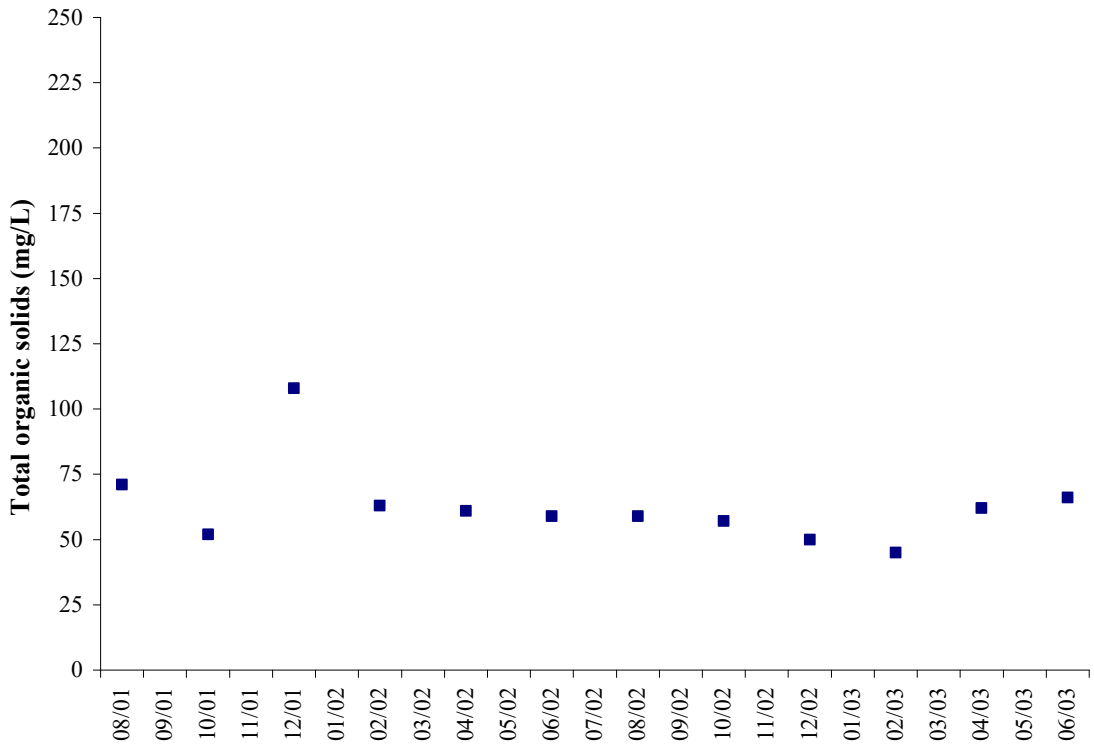

Figure 7-7. TVS concentrations at VADEQ station 6CBEV022.29.

7.2.8 Conductivity/Total Dissolved Solids (TDS)

Conductivity is a measure of the electrical potential in the water based on the ionic charges of the dissolved compounds that are present. TDS is a measure of the actual concentration of the dissolved ions, dissolved metals, minerals, and dissolved organic matter in water. Dissolved ions can include sulfate, calcium carbonate, chloride, etc. Therefore, even though they are two different measurements, there is a direct correlation between conductivity and TDS.

High conductivity values have been linked to poor benthic health (Merricks, 2003), and elevated conductivity is common with land disturbance and mine drainages. A recent report on the effects of surface mining on headwater stream biotic integrity in Eastern Kentucky noted that one of the most significant stressors in these watersheds was elevated TDS (Pond, 2004). Pond speculated that the increased salinity may irritate the

gill structures on mayflies and inhibit the absorption of oxygen, but research has not confirmed this.

In the development of both the Virginia and West Virginia Stream Condition Indices, the reference streams used had conductivity levels that did not exceed 500 µmhos/cm.

Both conductivity and TDS concentrations were within expected ranges on Beaver Creek. **Figure 7-8** shows conductivity measurements made at 6CBEV022.29; no measurement exceeded 500 µmho/cm. There were only two TDS samples analyzed and the maximum concentration was 254 mg/L. Conductivity/TDS are considered non-stressors in Beaver Creek.

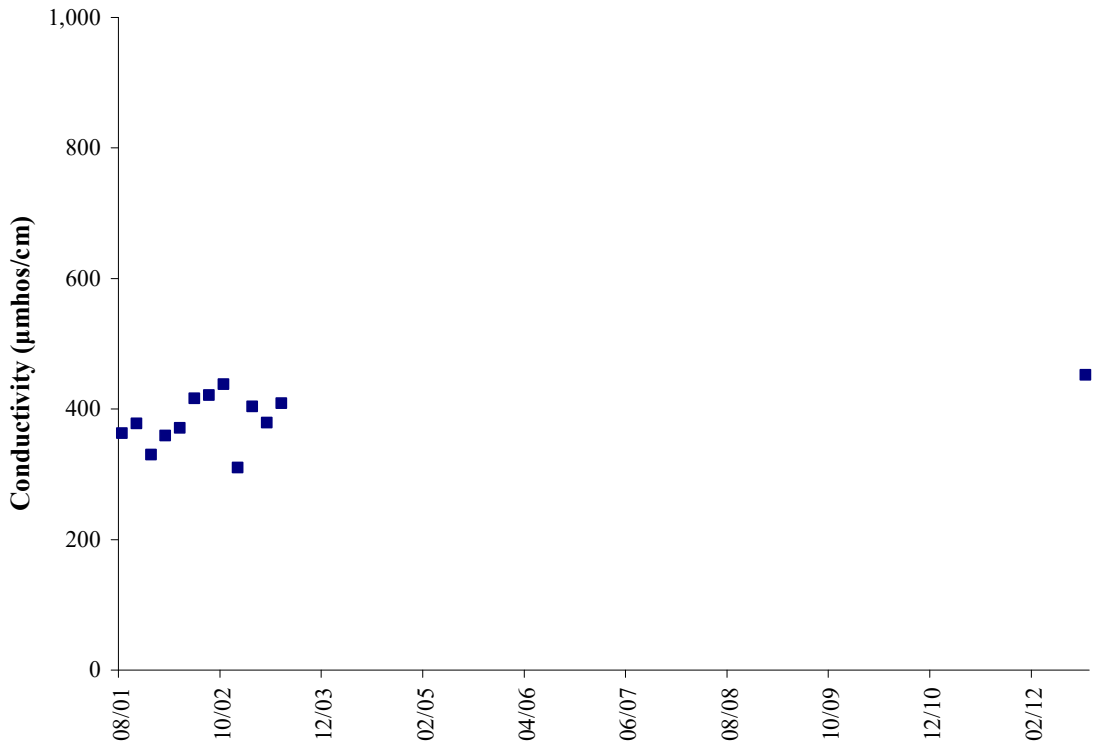

Figure 7-8. Conductivity measurements at 6CBEV022.29.

7.3 Possible Stressors

There are no stressors falling in the possible stressor category for Beaver Creek.

7.4 Most Probable Stressor

The most probable stressor of benthic life for Beaver Creek was identified as excessive sediment.

7.4.1 Sediment

Total suspended solids (TSS) concentrations were generally below 20 mg/L. However, a concentration of 95 (mg/L) was recorded on 12/5/2002 indicating that excessive suspended solids can be a periodic problem in Beaver Creek (**Figure 7-9**).

The habitat data supports this observation because marginal embeddedness and/or pool sediment scores were recorded at VADEQ benthic monitoring stations 6BBEV022.29 and 6CBEV023.99 on most of the sampling events. **Table 7.2** and **Table 7.3** summarize the low embeddedness and pool sediment scores at the Beaver Creek benthic monitoring stations. Based on the consistently low embeddedness and pool sediment scores and occasional high TSS concentrations, sediment is considered a most probable stressor in Beaver Creek.

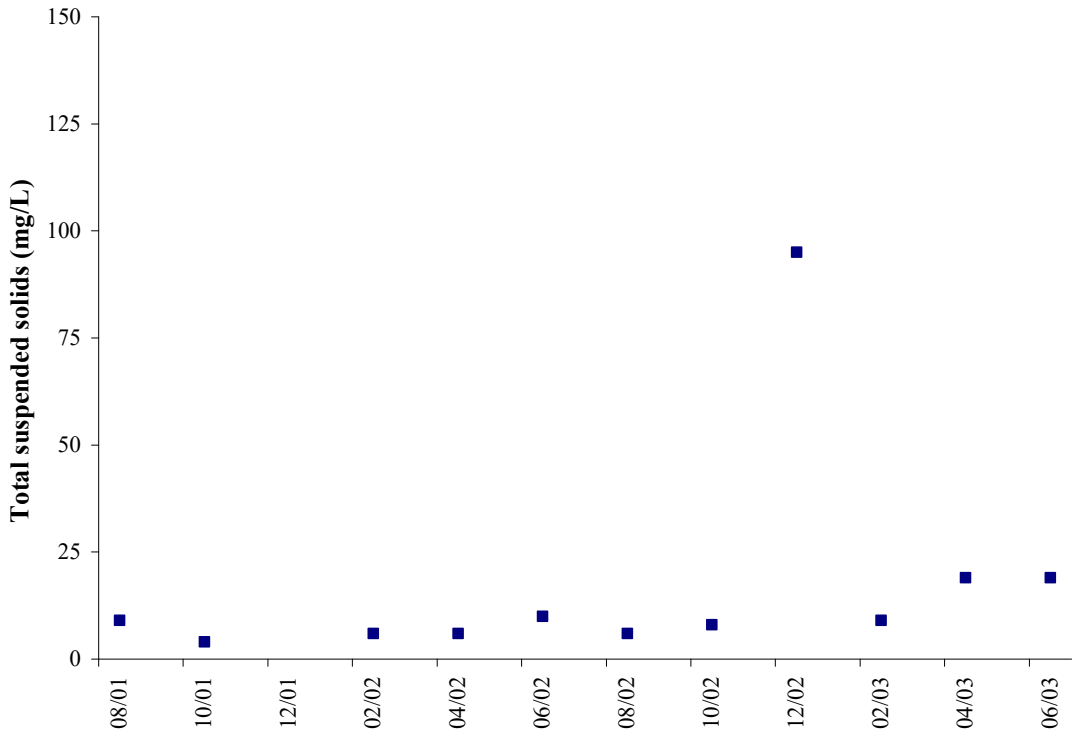

Figure 7-9. TSS concentrations at VADEQ station 6CBEV022.29.

Table 7.2. Summary of low embeddedness and pool sediment scores at VADEQ benthic monitoring station 6CBEV023.99.

Habitat Metric	Apr-2002	Dec-2002	May-2007	Sept-2007
Embeddedness	10	10	OK	OK
Pool Sediment	8	8	9	10

OK – score was in the satisfactory range.

Table 7.3. Summary of low embeddedness and pool sediment scores at VADEQ benthic monitoring station 6CBEV022.29.

Habitat Metric	May-2012	November-2012
Embeddedness	OK	OK
Pool Sediment	6	6

OK – score was in the satisfactory range.

8. REFERENCE WATERSHED SELECTION

A reference watershed approach was used to estimate the necessary sediment load reductions that are needed to restore a healthy aquatic community and allow Beaver Creek to achieve its designated uses. This approach is based on selecting a non-impaired watershed that has similar land use, soils, watershed characteristics, size, and located in or near the same ecoregion as the impaired watershed. The modeling process uses load rates or pollutant concentrations 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 establish what reductions are necessary to meet the load rates of the non-impaired watershed.

8.1 Reference Watershed Selection

The original TMDL submitted in 2004 used Walker Creek in Bland County, VA as the reference watershed for developing the endpoint for the sediment TMDL (**Figure 8-1**). Further analysis was completed comparing the impaired watershed with the original reference watershed (**Table 8.1**)

It was determined that Walker Creek is a good candidate as a reference stream for Beaver Creek due to similarities in ecoregion, soil characteristics, watershed characteristics and size. Both Beaver Creek and Walker Creek watersheds are largely within the Southern Limestone/Dolomite Valleys and Low Rolling Hills ecoregion. This is important as the benthic communities should be comparable to similar order streams in the same ecoregion. The soil and watershed characteristics are very similar between Beaver Creek and Walker Creek, being comprised of largely the same soil type and having very similar average slope and aspect values. Due to these similarities and in an effort to maintain consistency with the original TMDL, it was determined to keep Walker Creek as the reference watershed for this TMDL revision.

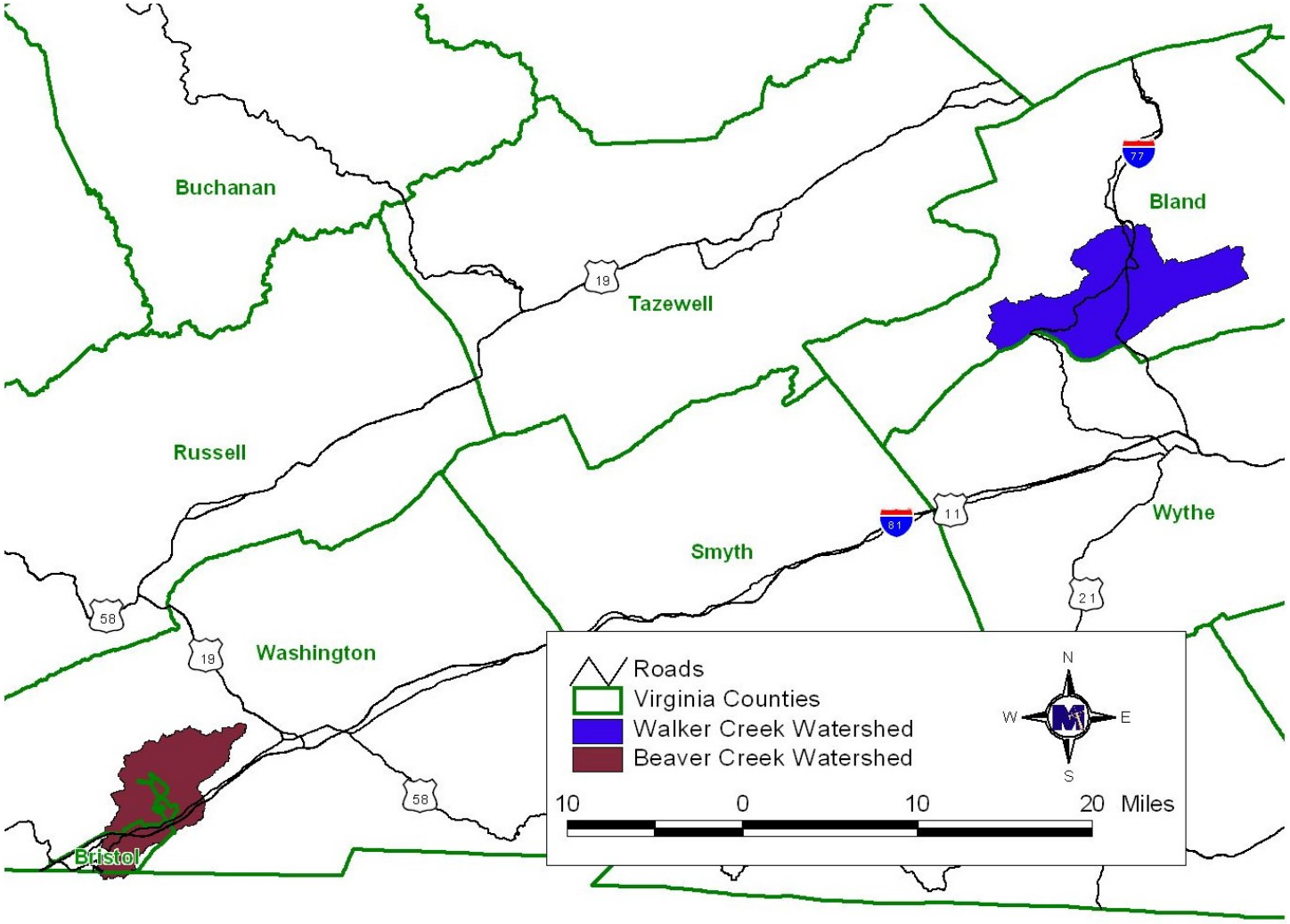

Figure 8-1. Location of the Beaver Creek watershed and selected reference watershed, Walker Creek.

Table 8.1. Reference watershed selection for the Beaver Creek watershed.

Watershed Properties	Beaver Creek	Walker Creek
Location:		
County*	Washington/City of Bristol/Sullivan, TN	Bland
HUC	6010102	5050002
Land use acreage:**		
Barren	10.24	36.69
Commercial	932.40	125.70
Crops	264.24	97.39
Forest	6,910.22	20,086.52
Pasture	9,644.85	12,426.40
Residential	4,786.39	1,550.46
Water	29.98	14.34
Wetlands	19.93	14.53
Total Acres	22,598.25	34,352.02
Watershed Characteristics:		
Stream Order	4th	4th
Slope (degrees)	14.33	20.82
Aspect (degrees)	190.03	190.56
Soil Characteristics:		
Hydrologic Group (avg)	2.18	2.32
Erodibility Kf factor	0.26	0.25
Available Water Capacity	0.14	0.12
EcoRegion:		
Southern Sandstone Ridges		37.59%
Southern Limestone/Dolomite Valleys and Low Rolling Hills	100%	62.41%
Soil Type:		
VA001		16.77%
VA003	100%	75.27%
VA004		0.30%
VA005		7.66%

*Virginia counties unless otherwise noted.

**All land use is MRLC 2006 data.

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9. SEDIMENT MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Computer modeling was used in this study as a tool for simulating the sediment loads to Beaver Creek from various activities within the watershed. The sediment model used in this study was the *Visual Basic*™ version of the Generalized Watershed Loading Functions (GLWF) model with modifications for use with ArcView (Evans et al., 2001).

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 based on the daily water balance. In addition to runoff and sediment, the model can simulate 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. Land use 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.

GWLF uses daily precipitation records to simulate runoff based on the Soil Conservation Service's Curve Number method (SCS, 1986). Erosion is calculated from a modification of the Universal Soil Loss Equation (USLE) (Schwab et al., 1981; Wischmeier and Smith, 1978). The portion of estimated erosion that reaches waterbodies is calculated based on a delivery ratio which is calculated as a function of watershed area.

A brief summary of the modeling procedure is presented in this section. A complete description of the sediment modeling procedures can be found in **APPENDIX C: Sediment Modeling Procedure**.

A reference watershed approach was used in this study to develop a benthic TMDL for sediment for Beaver Creek. As noted in **Chapter 7**, sediment was identified as the most probable stressor for the Beaver Creek watershed. Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The sediment TMDL was

then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios.

Although the GWLF model was originally developed for use in ungauged watersheds, calibration was performed to ensure that the watershed hydrology was being simulated accurately. This process was performed in order to minimize errors in sediment simulations due to potential gross errors in hydrology. The model's parameters were assigned based on available soil information, land use, and topographic data. Parameters were adjusted during calibration to obtain the best match between simulated and observed hydrology.

At this point, the model was used in the allocation process where reductions were simulated for various sources until the impaired watershed sediment loads met the numeric endpoint developed from the reference watershed. A sensitivity analysis was run on the model to determine the impacts of changing certain parameters on the resulting pollutant loads. The results of these analyses can be used in planning and prioritizing implementation strategies.

Critical conditions were considered directly during model development. The period of rainfall selected for modeling was chosen as a multi-year period that was representative of typical weather conditions for the area and included "dry", "average", and "wet" years. The model, therefore, incorporated the variable inputs needed to represent critical conditions during low flow – generally associated with point source loads – as well as critical conditions during high flow – generally associated with nonpoint source loads.

Throughout the modeling process, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. For example, modeling periods extended across high and low flow seasons over a period of several years. Daily time steps were used for weather data and water balance calculations. The GWLF model also used monthly-variable parameter inputs for evapotranspiration cover coefficients, daylight hours per day, and rainfall Erosivity coefficients for user-specified growing season months.

10. SEDIMENT ALLOCATION

Total Maximum Daily Loads consist of waste load allocations (WLAs, permitted point sources) and load allocations (Las, non-permitted sources), including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for uncertainties in the process. 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 waterbody during a specific period of time and still achieve water quality standards. For benthic impairments in Beaver Creek, the TMDL is expressed in terms of annual load in metric tons per year (t/yr).

The evaluated stressors included conditions that may have natural background and/or anthropogenic origin: sediment, toxics, low dissolved oxygen, pH, conductivity/total dissolved solids, sediment metals, and temperature. Sediment, the responsible stressor of the aquatic life impairment, originates in stream channel erosion and nonpoint loading from the different land covers. Reference watersheds in which there are no aquatic life use impairments were used to estimate natural background sediment loads expected in the Beaver Creek TMDL watershed.

The Beaver Creek sediment TMDL was developed using Walker Creek (Bland County, VA) as a reference watershed. The models were run over the period of 10/1/2007 to 9/30/2010 for modeling sediment allocations. The target sediment TMDL load for the Beaver Creek watershed is the average annual load in metric tons per year (t/yr) from the area-adjusted Walker Creek watershed under existing conditions, minus a margin of safety (MOS).

10.1 Margin of Safety (MOS)

In order to account for uncertainty in modeled output, a margin of safety (MOS) was explicitly 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. For example, the typical method of assessing water quality through monitoring involves the collection and analysis of grab samples. The results of water quality analyses on grab samples collected from the stream may or may not reflect the "average" condition in the stream at the time of sampling. Calibration to observed data derived from grab samples introduces modeling uncertainty.

A MOS 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 MOS for the sediment TMDLs was explicitly expressed as 10% of the area-adjusted reference watershed load and was incorporated for the Beaver Creek watershed. Sediment load trapped by existing buffers surrounding streams was not accounted for in the model, which helps in providing a conservative allocation.

10.2 Permitted Sediment Sources

There are three individual VPDES permits in the Beaver Creek watershed study area and one proposed permit for a new wastewater treatment facility. These permits each have associated design flow rates and permitted sediment concentrations (**Table 10.1**).

Table 10.1. VPDES permits within the Beaver Creek watershed study area.

Permit ID	Type	Name	Design Flow MGD	Permitted TSS Concentration mg/L
VAG400012	Individual	Domestic	0.001	30
VAG400209	Individual	Domestic	0.001	30
VAG400210	Individual	Domestic	0.001	30
-	General	Proposed WWTP	1.5	30

Nine industrial stormwater permits are within the study area (**Table 10.2**). A large portion of the Bristol City Municipal Separate Sewer System (MS4) permit is also included in the study area. This is land with stormwater runoff collection that discharges into surface waters. The land area within the permit boundaries has sediment from land-based sources which can be present in the runoff.

Table 10.2. Stormwater permits in the Beaver Creek watershed study area.

Permit ID	Name	Permitted TSS Concentration mg/L
VAR050028	Universal Fibers Inc	100
VAR050043	Bristol Compressors Incorporated	100
VAR050053	Bristol Integrated Solid Waste Management Facility	100
VAR050080	Federal Pacific Transformer Company	100
VAR050081	Line Power Manufacturing Corporation	100
VAR050084	Carolina Steel Group LLC - Abingdon	100
VAR050468	Sandvik Mining and Construction USA	100
VAR051522	AZZ Incorporated - Bristol	100
VAR051907	Wise Recycling - Bristol	100
VAR040048	Bristol City MS4	n/a

Several construction stormwater permits currently exist within the watershed. A list of these permits is presented in **Table 10.3**.

Table 10.3. Construction stormwater permits currently present in the study area.

Permit Number	Disturbed Acreage	Estimated Project Start Date	Estimated Project End Date
VAR10-10-100439	3	12/1/2005	12/31/2013
VAR10-13-100307	3.1	9/17/2012	11/15/2013

10.3 Future Growth Considerations

The land use within the impaired watershed is not expected to change significantly in the next 25 years. The upper portion of the watershed is mostly rural and it is assumed that residential and commercial growth in the watershed will not have considerable impact on future sediment loads.

A sediment load value for future growth was determined as 1% of the total TMDL. This was incorporated into the WLA for future permits that may discharge sediment.

10.4 Final Total Maximum Daily Loads (TMDLs)

The target TMDL load for impaired watersheds is the average annual load in metric tons per year (t/yr) from the corresponding area-adjusted reference watershed under existing

conditions. To reach the TMDL target load, three different scenarios were run (**Table 10.4**). Scenario 1 shows similar reductions from developed areas, barren land, agricultural land, and channel erosion. The greatest proportion of the existing sediment load in the model came from agricultural areas, thus Scenario 2 shows reductions to these land uses preferentially. A third allocation scenario is presented which reduces channel erosion contribution to a similar level as shown in the reference watershed (**Table C. 11**), with some additional reduction to pasture loads to bring the watershed total down to the TMDL target. All three scenarios meet the TMDL goal. Scenario 1 was chosen to use for the final TMDL because it has reasonable reductions on all types of land uses.

Table 10.4. TMDL allocation scenarios for the impaired Beaver Creek watershed.

Sediment Source	Existing Beaver Creek Loads	Scenario 1 Reductions	Scenario 1 Allocated Loads	Scenario 2 Reductions	Scenario 2 Allocated Loads	Scenario 3 Reductions	Scenario 3 Allocated Loads
	t/yr	%	t/yr	%	t/yr	%	t/yr
Pervious Area							
Row Crop - High Till	317.81	16.7	264.73	21.2	250.43	0.0	317.81
Row Crop - Low Till	32.41	16.7	27.00	21.2	25.54	0.0	32.41
Pasture	1457.01	16.7	1213.69	21.2	1148.13	11.0	1296.74
Hay	53.13	0.0	53.13	0.0	53.13	0.0	53.13
Forest	19.22	0.0	19.22	0.0	19.22	0.0	19.22
Barren	12.93	16.7	10.77	0.0	12.93	0.0	12.93
Developed	84.03	16.7	69.99	0.0	84.03	0.0	84.03
Commercial	10.44	16.7	8.70	0.0	10.44	0.0	10.44
Impervious Area							
Developed	33.47	16.7	27.88	0.0	33.47	0.0	33.47
Commercial	25.27	16.7	21.05	0.0	25.27	0.0	25.27
Direct Sources							
Channel Erosion	323.75	16.7	269.68	0.0	323.75	73.0	87.41
Permitted Sources							
General Permits	0.12	0.0	0.12	0.0	0.12	0.0	0.12
Construction Permits	6.48	0.0	6.48	0.0	6.48	0.0	6.48
Stormwater Permits	56.60	0.0	56.60	0.0	56.60	0.0	56.60
MS4	159.97	0.0	159.97	0.0	159.97	0.0	159.97
Proposed Permit	0.00	0.0	62.22	0.0	62.22	0.0	62.22
Future Load	0.00	0.0	25.52	0.0	25.52	0.0	25.52
Margin of Safety	0.00	0.0	255.24	0.0	255.24	0.0	255.24
Watershed Totals	**2592.64**	**1.57**	**2552.01**	**1.55**	**2552.49**	**2.07**	**2539.02**

The active construction stormwater permits regulated by Virginia DEQ are shown in **Table 10.5** with the annual sediment loads. The sediment load in **Table 10.4** shown above for construction stormwater permits was estimated based on the average disturbed

area over the modeling period, which was greater than the disturbed acreage from existing permits.

Table 10.5. Annual sediment loads for current construction stormwater permits within the Beaver Creek watershed study area.

Permit Number	Annual Sediment Load (t/yr)
VAR10-10-100439	0.10
VAR10-13-100307	0.10
Total	**0.20**

The sediment TMDL for Beaver Creek includes three components – WLA, LA, and the 10% MOS. The WLA was calculated as the sum of all permitted point discharges as well as the future load allocation of 1% of the TMDL. The LA was calculated as the target TMDL load minus the WLA load minus the MOS (**Table 10.6**)

Table 10.6. Final annual sediment TMDL for the Beaver Creek watershed.

Impairment	WLA	LA	MOS	TMDL
	t/yr	t/yr	t/yr	t/yr
Beaver Creek	310.91	1985.74	255.24	2551.90
VAG400012	0.041			
VAG400209	0.041			
VAG400210	0.041			
VPG210001	0			
City of Bristol MS4 (VAR040048)	159.97			
VAR050028	8.65			
VAR050043	12.99			
VAR050053	7.04			
VAR050080	3.41			
VAR050081	2.55			
VAR050084	11.26			
VAR050468	6.49			
VAR051522	1.29			
VAR051907	2.93			
Construction Permits	6.48			
Proposed Permit	62.22			
Future Load	25.52			

Starting in 2007, the USEPA has mandated that TMDL studies include a maximum "daily" load (MDL) as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach found in the 2007 document titled Options for Expressing Daily Loads in TMDLs (USEPA, 2007). The procedure involved calculating the MDL from the long-term average annual TMDL load in addition to a coefficient of variation (VC) estimated from the annual load for ten years. The long-term annual sediment load for Beaver Creek had a coefficient of variation (CV) of 0.353. A multiplier was calculated based on the USEPA guidance that was used to estimate the MDL from the long-term average. The multiplier estimated for Beaver Creek was 2.47. The annual TMDL divided by 365 days (6.99 t/day) was multiplied by the 2.47, resulting in an MDL of 17.28 t/day. The daily WLA was

estimated as the annual WLA divided by 365. The daily MOS was estimated as 10% of the MDL. Finally, the daily LA was estimated as the MDL minus the daily MOS and the daily WLA. These results are shown in **Table 10.7**.

Table 10.7. Final daily sediment TMDL for the Beaver Creek watershed.

Impairment	WLA t/day	LA t/day	MOS t/day	TMDL t/day
Beaver Creek	0.85	14.70	1.73	17.28
VAG400012	0.00011			
VAG400209	0.00011			
VAG400210	0.00011			
VPG210001	0			
City of Bristol MS4 (VAR040048)	0.438			
VAR050028	0.024			
VAR050043	0.036			
VAR050053	0.019			
VAR050080	0.009			
VAR050081	0.007			
VAR050084	0.031			
VAR050468	0.018			
VAR051522	0.004			
VAR051907	0.008			
Construction Permits	0.018			
Proposed Permit	0.170			
Future Load	0.070			

11. TMDL IMPLEMENTATION AND REASONABLE ASSURANCE

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. EPA requires that there is reasonable assurance that TMDLs can be implemented. TMDLs represent an attempt to quantify the pollutant load that might be present in a waterbody and still ensure attainment and maintenance of water quality standards. The Commonwealth intends to use existing programs in order to attain water quality goals.

The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

11.1 Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, VADEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board (SWCB) for inclusion in the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on the VADEQ web site under http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/FeaturedTopics/WQMP_PPP_Final.pdf.

11.2 Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those

sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. It enables tracking of water quality improvements following 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 implementation levels 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.

11.3 Implementation of Waste Load Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

11.3.1 Stormwater

Prior to July 1, 2013, VADEQ and VADCR coordinated separate state permitting programs that regulated the management of pollutants carried by stormwater runoff. Since that date, VADEQ regulates both stormwater discharges associated with industrial activities through its VPDES program, and stormwater discharges from construction sites and from municipal separate storm sewer systems (MS4s) through its VSMP program. As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented. More

information regarding these programs can be found at http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx.

11.3.2 TMDL Modifications for New or Expanding Discharges

Permits issued for facilities with wasteload allocations developed as part of a Total Maximum Daily Load (TMDL) must be consistent with the assumptions and requirements of these wasteload allocations (WLA), as per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at www.deq.virginia.gov/waterguidance/.

11.4 Implementation of Load Allocations

The TMDL program does not impart new implementation authorities. Therefore, the Commonwealth intends to use existing programs to the fullest extent in order to attain its water quality goals. The measures for non-point source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the TMDL implementation plan.

11.4.1 Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". 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.

In order to qualify for other funding sources, such as EPA's Section 319 grants, additional plan requirements may need to be met. The detailed process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003. It is available upon request from the VADEQ TMDL project staff or at www.deq.virginia.gov/tmdl/implans/ipguide.pdf.

Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of VADEQ and other cooperating agencies are technical resources to assist in this endeavor.

With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

11.4.2 Staged Implementation Scenarios

The purpose of staged implementation scenarios is to identify one or more combinations of implementation actions that result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. For example, among the most efficient bacterial BMPs for both urban and rural watersheds are stream side fencing for cattle farms, pet waste clean-up programs, and government or grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes.

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

If water quality standards are not met upon implementation of all cost-effective and reasonable BMPs, a Use Attainability Analysis (UAA) may need to be initiated since Virginia's water quality standards allow for changes to use designations if existing water quality standards cannot be attained by implementing effluent limits required under §301b and §306 of Clean Water Act, and by implementing cost effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in **Section 6.6**.

11.4.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality within, and downstream of, the Beaver Creek Watershed.

11.4.4 Implementation Funding Sources

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

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), the Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions.

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding source for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems.

11.5 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring plan. The VADEQ Office of Water Quality Monitoring and Assessment (WQMA) operates an ambient network of monitoring stations known as "trend stations," designed to measure long term water quality trends. The design of the trend network is such that key water quality variables are measured at targeted locations approximately every month. This monitoring station network and potentially other monitoring stations will be utilized in monitoring water quality throughout and following implementation.

VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, monthly for one year. In accordance with *DEQ Guidance Memo No. 03-2004* (www.deq.virginia.gov/waterguidance/pdf/032004.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The details of the follow-up ambient monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office.

The objective of the Statewide Fish Tissue and Sediment Monitoring Program is to systematically assess and evaluate, using a multi-tier screening, waterbodies in Virginia in order to identify toxic contaminant(s) accumulation with the potential to adversely affect human users of the resource. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

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

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plans. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or to monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on VADEQ's citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx.

To demonstrate that the watershed is meeting water quality standards in watersheds where corrective actions have taken place (whether or not a TMDL or Implementation plan has been completed), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, pH, etc.) is bimonthly monitoring for two consecutive years.

11.6 Attainability of Designated Uses

In some streams for which TMDLs have been developed, factors may prevent the stream from attaining its designated use.

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

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

1. Naturally occurring pollutant concentration prevents the attainment of the use;

2. Natural, ephemeral, intermittent or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation;

3. Human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place;

4. Dams, diversions or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;

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

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

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

The process to address potentially unattainable reductions based on the above is as follows:

As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation is that all controllable sources would be reduced to the maximum extent possible using the implementation approaches described above. VADEQ will continue to monitor water quality in the stream during and subsequent to the implementation of these measures to determine if the water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

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

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12. PUBLIC PARTICIPATION

Public participation during TMDL revision for the Beaver Creek Watershed was encouraged; a summary of the meetings is presented in **Table 12.1**. Two Technical Advisory Committee (TAC) meetings took place (May 23, 2013 and November 13, 2013) at the Southwest Virginia Higher Education Center, Abingdon, VA. Twenty people attended the first TAC meeting, and twelve attended the second. The final public meeting was held on XXXX and X people attended. The meetings were publicized by placing notices in the Virginia Register, signs in the watershed, and emailing notices to local stakeholders and representatives.

Table 12.1 Public participation during TMDL revision for the Beaver Creek Watershed.

Date	Location	Attendance[1]	Meeting Type
5/23/2013	Southwest Virginia Higher Education Center, Abingdon, VA	20	1st Technical Advisory Committee (TAC)
11/13/2013	Southwest Virginia Higher Education Center, Abingdon, VA	12	2nd TAC
xx/xx/xx	Southwest Virginia Higher Education Center, Abingdon, VA	x	Final Public

[1]The number of attendants is estimated from signup 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' committees, with committee and public meetings. Public participation is critical to promote reasonable assurances that the implementation activities will occur. Stakeholder committees will have the express purpose of formulating the TMDL Implementation Plan. The committees will consist of, but not be limited to, representatives from VADEQ, VADCR and local governments. These committees will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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GLOSSARY

Note: All entries in italics are taken from USEPA (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 waste load 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.*

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.*

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.*

Biosolids. Biologically treated solids originating from municipal wastewater treatment plants. Also known as "sludge". Applications to farmland are permitted by VADEQ.

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

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

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.

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)

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.*

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.*

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.*

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

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 USEPA 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.*

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.*

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 USEPA on quantities, rates, and concentrations in pollutant discharges.*

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).*

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.

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.

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.*

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.*

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 earth's 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.*

Impairment. A detrimental effect on the biological integrity of a water body that prevents attainment of the designated use.

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.*

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.

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 the USEPA 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.*

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

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

Model. Mathematical representation of hydrologic and water quality processes. Effects of land use, 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.

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.*

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.*

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 land use segment within a subwatershed (*e.g.*, pasture, urban land, or crop land).

Permit. *An authorization, license, or equivalent control document issued by the USEPA 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 waste load 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.*

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.*

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 the USEPA 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.

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, land use distribution, and other related characteristics. Reference conditions are used to describe reference sites.

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.*

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.*

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

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

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

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

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

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 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).

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

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

Stream 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.*

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.*

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 Maximum Daily Load (TMDL). *The sum of the individual waste load 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 remediate 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.

Waste load 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 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 the USEPA 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.

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APPENDIX A: FREQUENCY ANALYSIS OF BACTERIA DATA

FREQUENCY ANALYSIS OF BACTERIA DATA

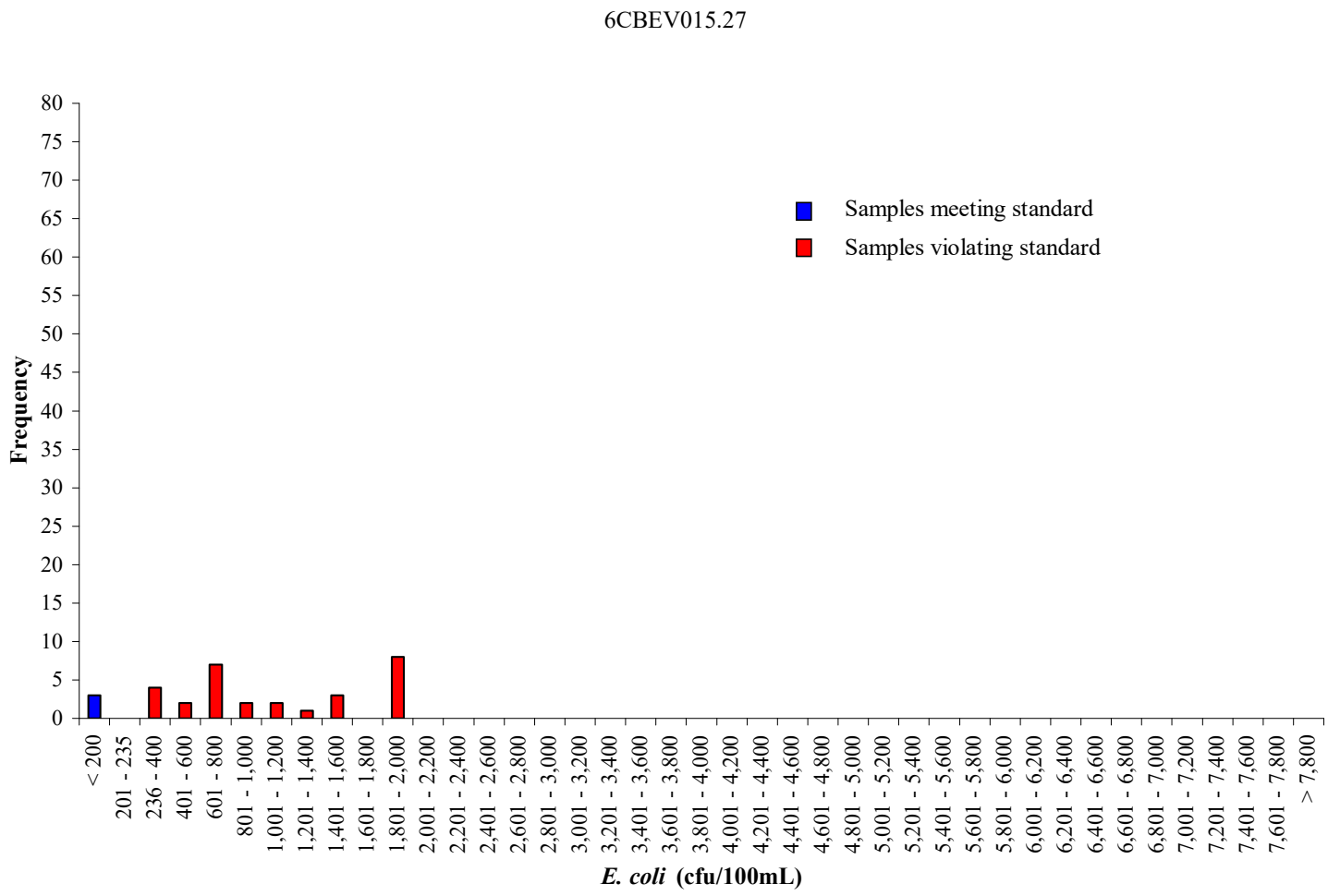

Figure A. 1 Frequency analysis of *E. coli* concentrations at station 6CBEV015.27 in Beaver Creek for the period from March 2000 to October 2012.

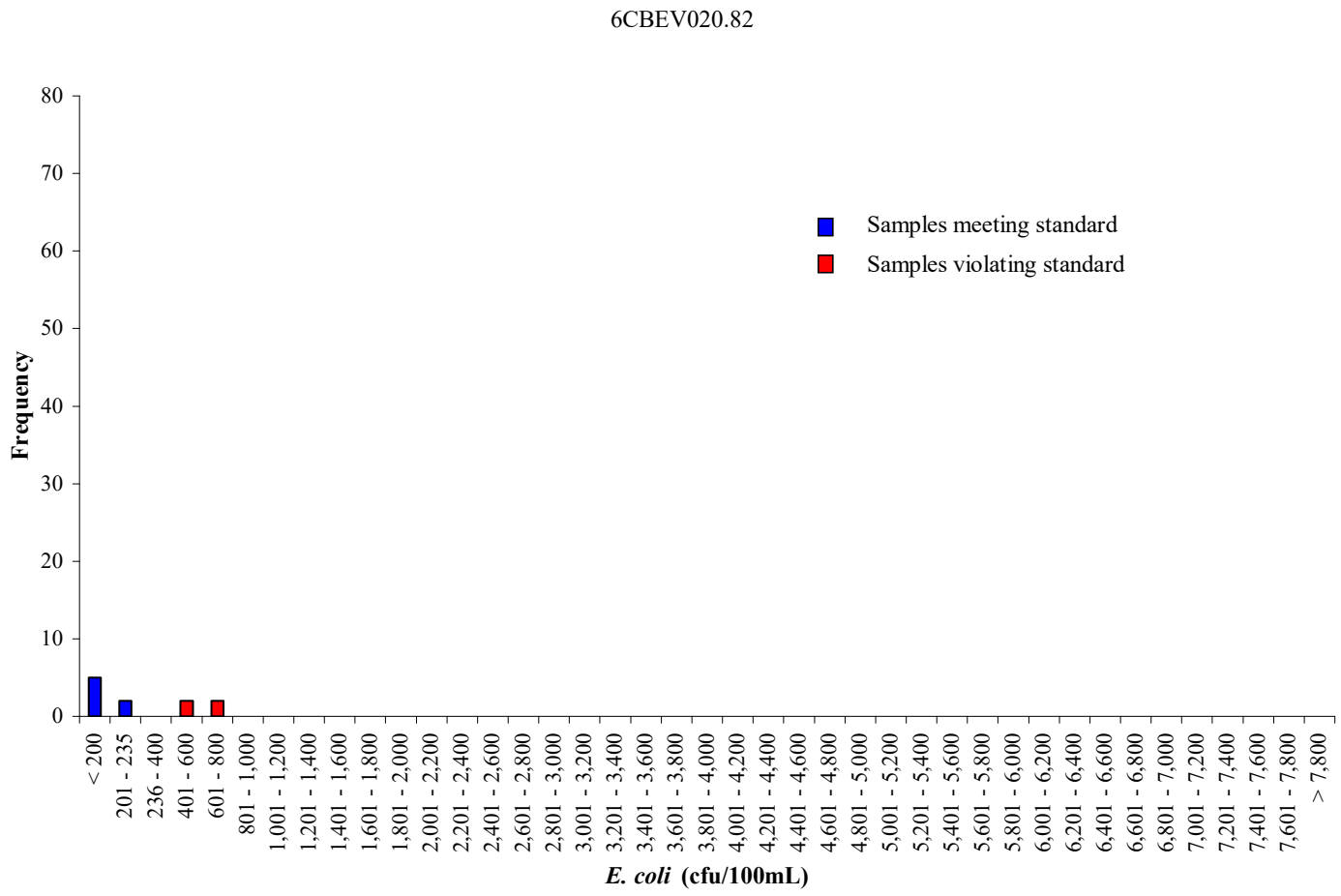

Figure A. 2 Frequency analysis of *E. coli* concentrations at station 6CBEV020.82 in Beaver Creek for the period from July 2002 to June 2003.

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APPENDIX B: BACTERIA MODELING PROCEDURE

BACTERIA MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Bacteria 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 the TMDL for the Beaver Creek watershed study area, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are five basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

Model selection involves identifying an approved model that is capable of simulating the pollutants of interest with the available data. Source assessment involves identifying and quantifying the potential sources of pollutants in the watershed. Selection of a representative period involves the identification of a time period that accounts for critical conditions associated with all potential sources within the watershed. Calibration is the process of comparing modeled data to observed data and making appropriate adjustments to model parameters to minimize the error between observed and simulated events. Validation is the process of comparing modeled data to observed data during a period other than that used for calibration, with the intent of assessing the capability of the model in hydrologic conditions other than those used during calibration. During validation, no adjustments are made to model parameters. Once a suitable model is constructed, the model is then used to predict the effects of current loadings and potential management practices on water quality.

Modeling Framework Selection - HSPF

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate streamflow, overland runoff and to perform TMDL allocations.

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 land uses 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.

The HSPF model is a continuous simulation model that can account for nonpoint source (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.

HSPF Model Setup

Daily precipitation data was available within the watershed at the Abingdon NCDDC Coop station # 440021. Missing values were filled using daily precipitation from the Lebanon NCDC Coop station #444777 and the Bristol Tri City Airport NCDC Coop station #013877. The final filled daily precipitation was disaggregated using hourly station data from the Bristol Tri City Airport Coop station #401094.

To adequately represent the spatial variation in the watershed, the Beaver Creek watershed drainage area was divided into fifteen (15) subwatersheds

(**Figure B. 1**). The rationale for choosing these subwatersheds was based on the availability of water quality data, the stream network configuration, and the limitations of the HSPF model. **Figure B. 1** shows all subwatersheds, which were used to achieve the unified model. **Table B. 1** notes the subwatersheds contained within each impairment, the impaired stream segments, and the outlet subwatershed for each impairment.

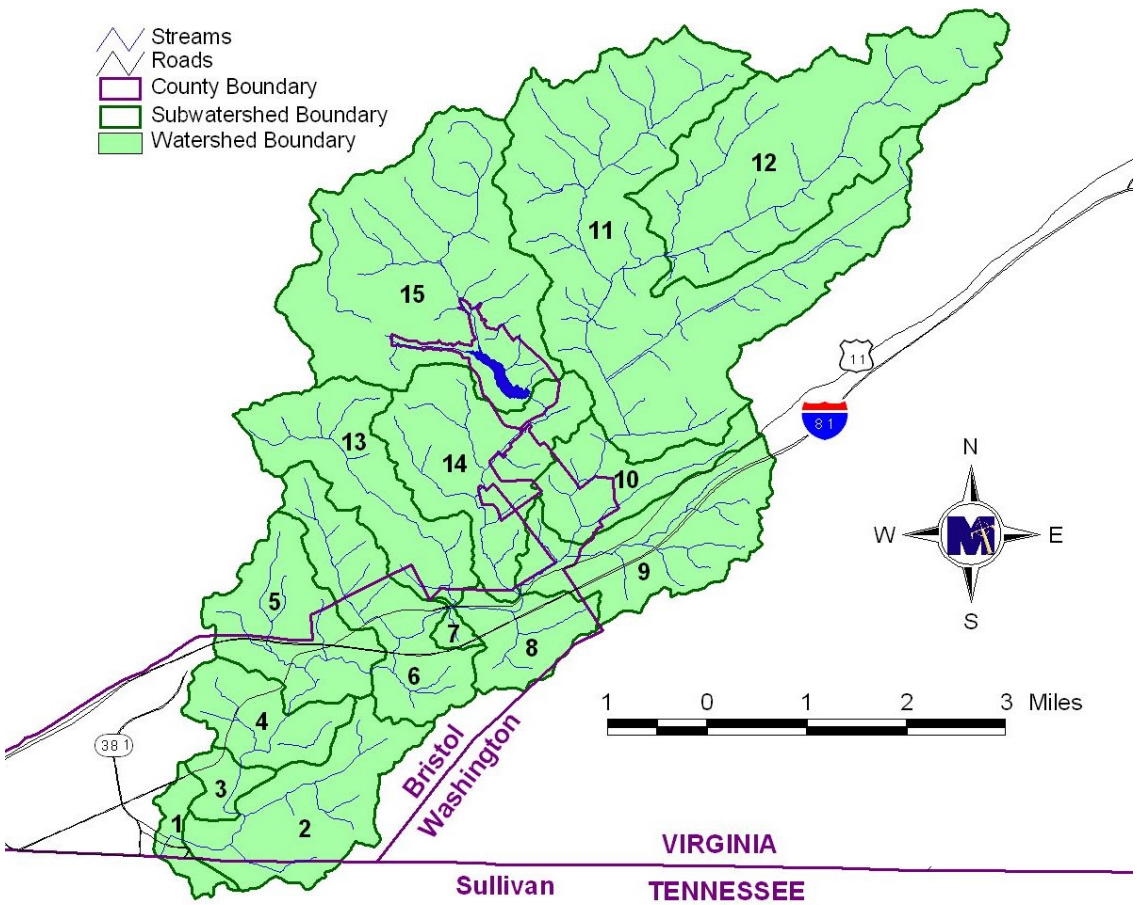

Figure B. 1 All subwatersheds delineated for modeling in the Beaver Creek watershed study area.

Table B. 1 Bacterial impairments and subwatersheds within the Beaver Creek watershed study area.

Impairment	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds
Beaver Creek VAS-O07R_BEV01A94	1,2,3,4,5,6,7,8,9	1	all
Beaver Creek VAS-O07R_BEV02A94	10,11,12	10	10,11,12

In an effort to standardize modeling procedures 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 watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

Land Uses

Eight land uses were identified in the watershed. These land uses were obtained by merging different sources including the MRLC land use grid, and aerial photography of the region. The eight land use types are given in **Table B. 2**. Within each subwatershed, up to the nine land use types were represented. Each land use in each subwatershed has hydrologic parameters (*e.g.,* average slope length) and pollutant behavior parameters (*e.g.,* fecal coliform accumulation rate) associated with it. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in three IMPLND types, while there are nine PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with the season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Table B. 2 Consolidated land use categories for the Beaver Creek watershed drainage area used in HSPF modeling.

TMDL Land use Categories	Pervious / Impervious (%)
Water	Pervious (100%)
Developed	Pervious (90%) Impervious (10%)
Commercial	Pervious (20%) Impervious (80%)
Barren	Pervious (94%) Impervious (6%)
Forest	Pervious (100%)
Pasture	Pervious (100%)
Cropland	Pervious (100%)
Livestock Access	Pervious (100%)

Figure B. 2 shows the land uses used in modeling the Beaver Creek watershed study area. **Table B. 3** shows the breakdown of land uses within the watershed. These acreages represent only what is within the boundaries of the Beaver Creek watershed study area.

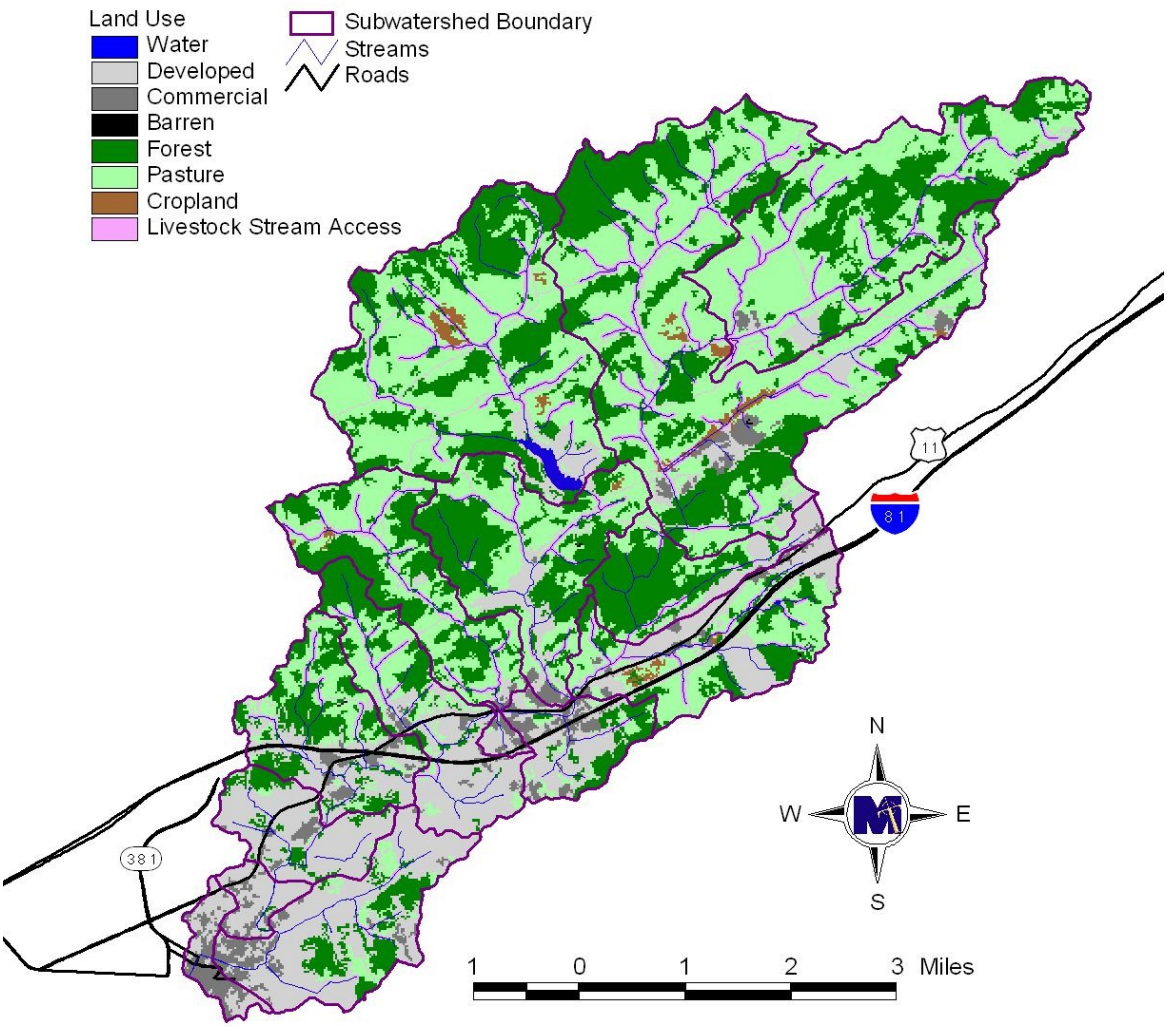

Figure B. 2 Land use in the Beaver Creek watershed study area.

Table B. 3. Spatial distribution of land use types in acres in the Beaver Creek watershed study area.

Subwatershed	Water	Developed	Commercial	Barren	Forest	Pasture	Cropland	LAX*
1	0.96	130.05	123.48					
2	13.65	861.68	134.95	0.04	241.58	104.52		8.35
3	1.61	180.90	49.55		5.12			
4	7.35	555.83	38.68		104.96	12.38		1.27
5	13.40	402.07	103.06	1.11	409.69	254.90		26.13
6	16.90	581.13	56.67		288.87	263.93		43.71
7	1.01	47.84	30.28			3.74		
8	6.52	270.83	141.55		140.68	62.68		8.90
9	18.72	545.11	71.73	0.82	262.89	466.44	24.51	69.00
10	10.11	167.36	15.45		464.51	145.18		24.82
11	65.15	343.15	109.79	1.11	1592.11	2550.86	81.10	400.88
12	29.00	149.05	16.64		937.62	1579.51	0.04	227.51
13	14.68	78.65	12.12		563.02	612.87	7.84	103.06
14	20.44	236.38	36.30	1.11	724.62	582.61	4.45	76.44
15	66.08	292.05			1174.76	1621.98	59.17	191.73
Total	**285.58**	**4842.10**	**940.24**	**4.19**	**6910.43**	**8261.61**	**177.11**	**1181.78**

*LAX is livestock access to a stream.

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

Stream Characteristics

HSPF requires that each stream reach be represented by constant characteristics (*e.g.,* stream geometry and resistance to flow). These data are entered into HSPF via the Hydraulic Function Tables (F-tables). The F-tables developed consist of four columns: depth (ft), area (ac), volume (ac-ft), and discharge (ft^3/s). The depth represents the possible range of flow, with a maximum value beyond what would be expected for the reach. The area listed is the surface area of the flow in acres. The volume corresponds to the total volume in the reach, and is reported in acre-feet. The discharge is simply the stream outflow, in cubic feet per second.

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (Keaton et al, 2005), and Digital Elevation Model (DEM) data was used. The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the Beaver Creek watershed. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each subwatershed outlet.

A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet (**Figure B. 3**). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example of an F-table used in HSPF is shown in **Table B. 4**.

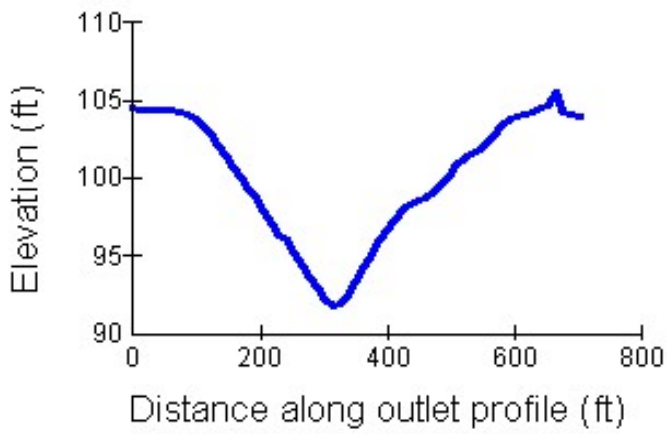

Figure B. 3 Stream profile representation in HSPF.

Table B. 4 Example of an F-table calculated for the HSPF model.

Depth (ft)	Area (ac)	Volume (ac-ft)	Outflow (ft^3/s)
0	0	0	0
3.28	0.71	1.41	17.07
6.56	1.89	5.15	45.23
9.84	2.54	12.18	85.02
13.12	4.77	24.80	152.82
16.40	56.55	77.51	637.72
19.68	1,047.22	1,635.10	18,846.85
22.96	2,875.31	7,405.99	69,827.77
26.24	3,495.32	18,464.40	133,806.76
29.52	4,426.89	31,720.10	160,393.97

Bacterial 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 land use 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. 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 estimates were used. Data were obtained for the appropriate timeframe for water quality calibration and validation. Data representing 2012 were used for the allocation runs in order to represent current conditions.

Permitted Sources

There are currently several sources permitted to discharge water containing fecal bacteria into surface waters in the Beaver Creek watershed study area. There is also one proposed point source currently in the permitting process that is included in this project (**Table 3.1**). During water quality calibration and validation phases of the modeling effort, the proposed discharge was not included, as it was not contributing to historical loads. During the allocation phase of modeling, however, the proposed source was included at its maximum design flow of 1.5 million gallons per day (MGD) with a fecal coliform concentration of 200 cfu/100mL to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels.

There are three single family home permits, shown in **Table B. 5**. The bacteria load contributed by the Bristol City MS4 (VAR040048) was calculated based on the modeled results for urban lands within the watershed that are considered part of the City of Bristol.

Table B. 5 Flow rates and bacterial loads used to model active VADEQ single family home permits in the study area.

Permit Number	Flow Rate gallons per day	Fecal Coliform Concentration cfu/100mL
VAG400012	1000	200
VAG400209	1000	200
VAG400210	1000	200

There is one confined animal feeding operation (CAFO) facility in the area (VPG210001). Manure from this facility was spread on cropland in the study area, which is elaborated upon in the following sections.

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.

Private Residential Sewage Treatment

The number of septic systems in the Beaver Creek watershed study area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000; USCB 2010) with the subwatersheds. During allocation runs, the number of households was projected to 2012, based on current growth rates (USCB, 2010) resulting in 1696 septic systems and 76 straight pipes (**Table B. 6**).

Table B. 6 Estimated failing septic systems and straight pipes for 2012 in the Beaver Creek watershed study area.

Subwatershed	Septic Systems	Failing Septic Systems	Straight Pipes
1	0	0	0
2	14	0	5
3	3	0	1
4	17	1	0
5	112	4	5
6	105	4	2
7	11	0	0
8	2	0	0
9	213	7	6
10	141	5	7
11	397	13	9
12	191	6	1
13	108	4	4
14	152	5	12
15	230	8	24
Total	**1696**	**57**	**76**

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. The initial estimates of the number of failing septic systems were based on the assumption that each septic system fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with the region's Health Department and feedback was obtained and used in adjusting numbers. 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 to account for more frequent failures during wet months.

Straight pipes 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 straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Initial estimates obtained using this method were shared with the region's

Health Departments and feedback was obtained and used in adjusting numbers. The loadings from straight pipes were modeled in the same manner as direct discharges to the stream.

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 amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Different livestock populations were estimated for each water quality modeling period (calibration/validation/allocation). The numbers are based on data provided by Virginia Agricultural Statistics (VASS), with values updated and discussed by VADCR, NRCS and SWCDs as well as taking into account growth rates in these counties as determined from data reported by the National Agricultural Statistics Service (NASS, 2013). 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 3.9**). 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.

Land Application of Collected Manure

Dairy cows are typically confined for portions of the day, and the waste they produce when confined was modeled as being collected and applied to cropland and pasture throughout the year. The time allocations and manure distributions for dairy cattle in the two dairy operations within the study area used were the same as determined in the original TMDL.

The average daily waste production for the poultry operation was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.2.4. This information, along with fecal coliform content of waste (**Table 3.9**)

and a die-off factor to account for bacterial death during storage was used to calculate the amount of fecal coliform in the litter. The amount of litter from the poultry operation that was applied within the watershed was determined from information made available by VADEQ on the application sites and rates within the watershed study area.

Stored waste, either dairy or poultry, was spread on cropland only. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

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 (MapTech, 2002). 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, sheep) were assumed to deposit all feces on pasture. The total amount of fecal matter deposited on the pasture land was area-weighted.

Direct Deposition to Streams

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" land use, 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 land-use area (stream access) allows the model to consider the

proximity of the deposition to the stream. The 30% that was directly deposited to the stream was modeled in the same way that point sources are handled in the model.

Biosolids

Investigation of VADEQ data indicated that biosolids applications have not occurred within the Beaver Creek watershed study area during the modeling periods.

Wildlife

For each species of wildlife, 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 B. 4**. This layer was overlaid with the land use layer and the resulting area was calculated for each land use 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 wasteload, fecal coliform densities, and number of animals for each species.

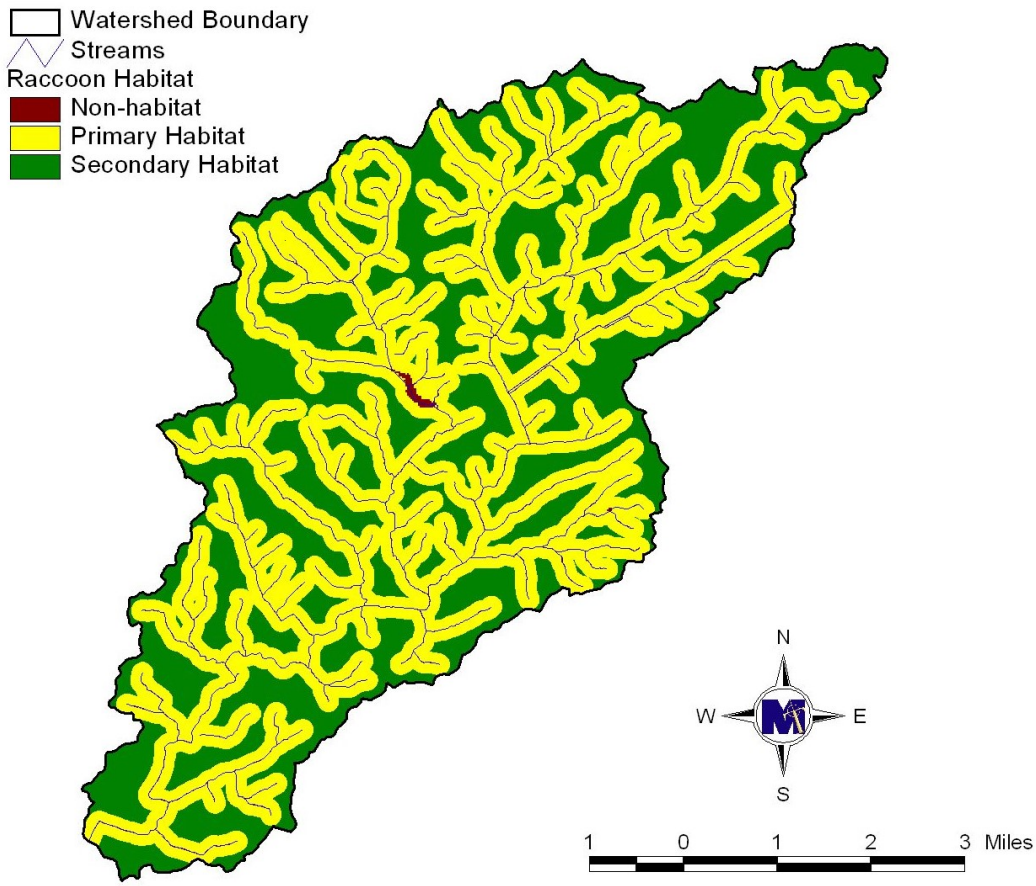

Figure B. 4 Example of raccoon habitat layer in the Beaver Creek watershed study area, as developed by MapTech.

For each species, a portion of the total wasteload was considered 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 3.13**). It was estimated that, for all animals other than beaver, 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.

Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in **Section 3.2.3**. Waste from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 2010 Census (USCB, 1990 and USCB, 2010). The

number of animals per subwatershed was determined by multiplying the number of households by the pet population density. The amount of fecal coliform deposited daily by pets in each subwatershed was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 2010 data to 2012.

Unidentified Bacteria Source

During the water quality calibration process, an unidentified source of bacteria loading in the Bristol area near the state line was detected. While the model could be adequately calibrated in the upper parts of the watershed, identified sources in the watershed could not account for the historically high levels of bacteria reported in the two most downstream monitoring stations (6CBEV015.27 and 6CBEV015.62). The load does not appear to be associated with storm events (**APPENDIX E: Unidentified Source Investigation**). For purposes of this project, the unidentified source was modeled as a constant point load of fecal coliform at a rate of 4.11E11 cfu/day.

Bacteria TMDL Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs 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 the Beaver Creek watershed study area 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 in order to meet water quality standards. Fecal bacteria sources within the Beaver Creek watershed study area are attributed to both point and non-point sources. Critical conditions for waters impacted by land-based non-point 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 non-point sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A description of the data used in these analyses is shown in **Table 2.1** and **Table 2.2** in **Chapter** 2. Graphical analyses of fecal bacteria concentrations and flow duration intervals showed that water quality standard violations occurred in a range of conditions at all VADEQ monitoring stations in the Beaver Creek watershed study area (**Figure B. 5**, **Figure B. 6**, and **Figure B. 7**). This demonstrates that this stream should have all flow regimes represented in the allocation modeling time period.

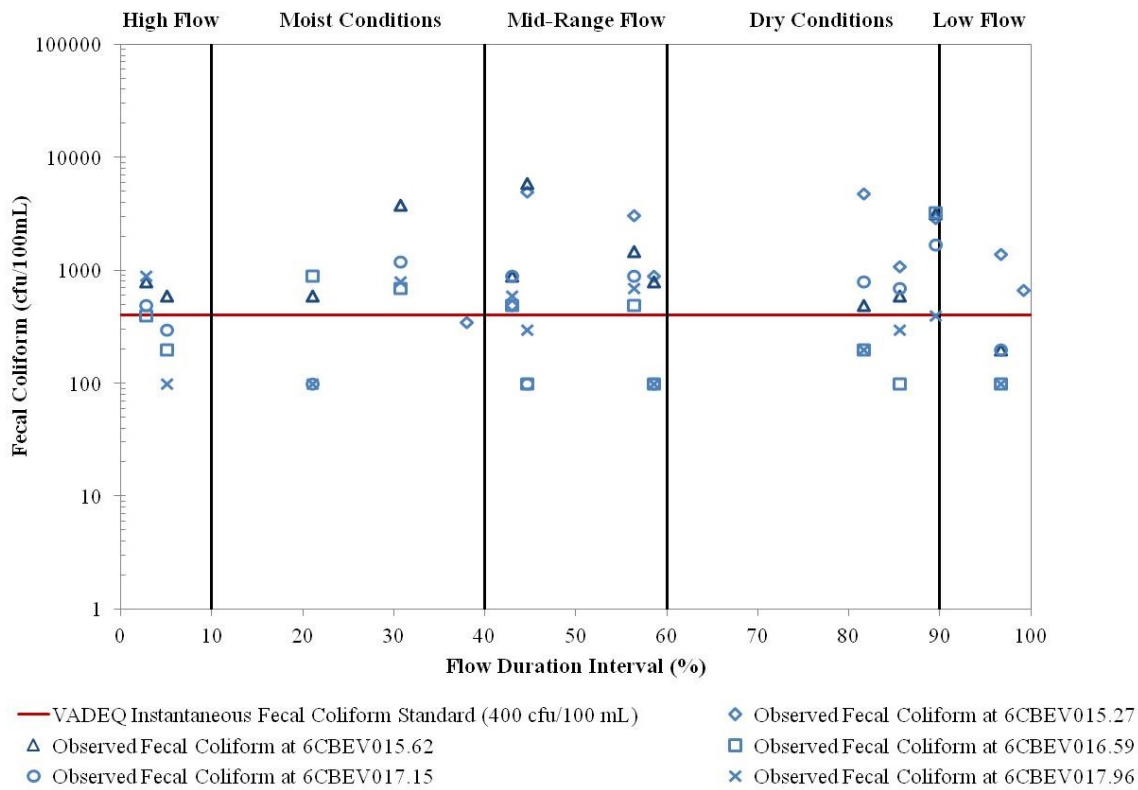

Figure B. 5 Fecal coliform bacteria concentrations at 6CBEV015.27, 6CBEV015.62, 6CBEV016.59, 6CBEV017.15, and 6CBEV0117.96 in the Beaver Creek watershed versus discharge at USGS Gauging Station #03478400.

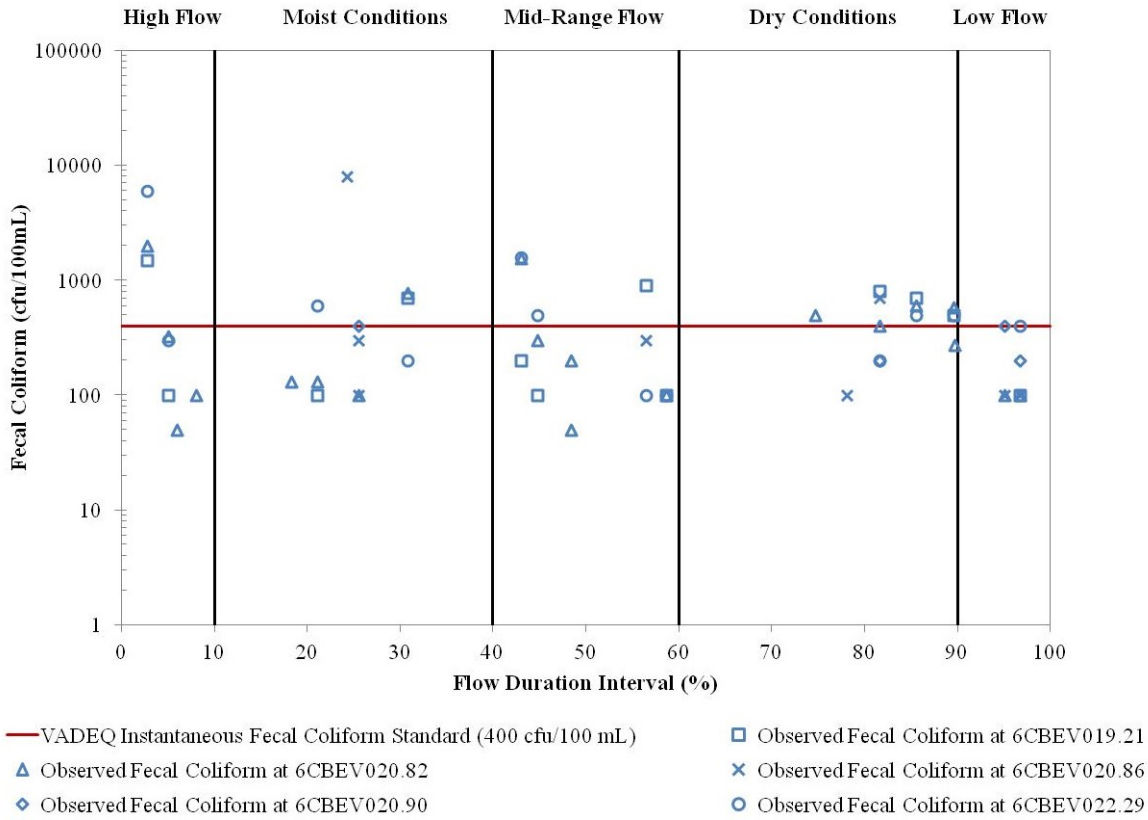

Figure B. 6 Fecal bacteria concentrations at 6CBEV019.21, 6CBEV020.82, 6CBEV020.86, 6CBEV020.90, and 6CBEV022.29 in the Beaver Creek watershed versus discharge at USGS Gauging Station #03478400.

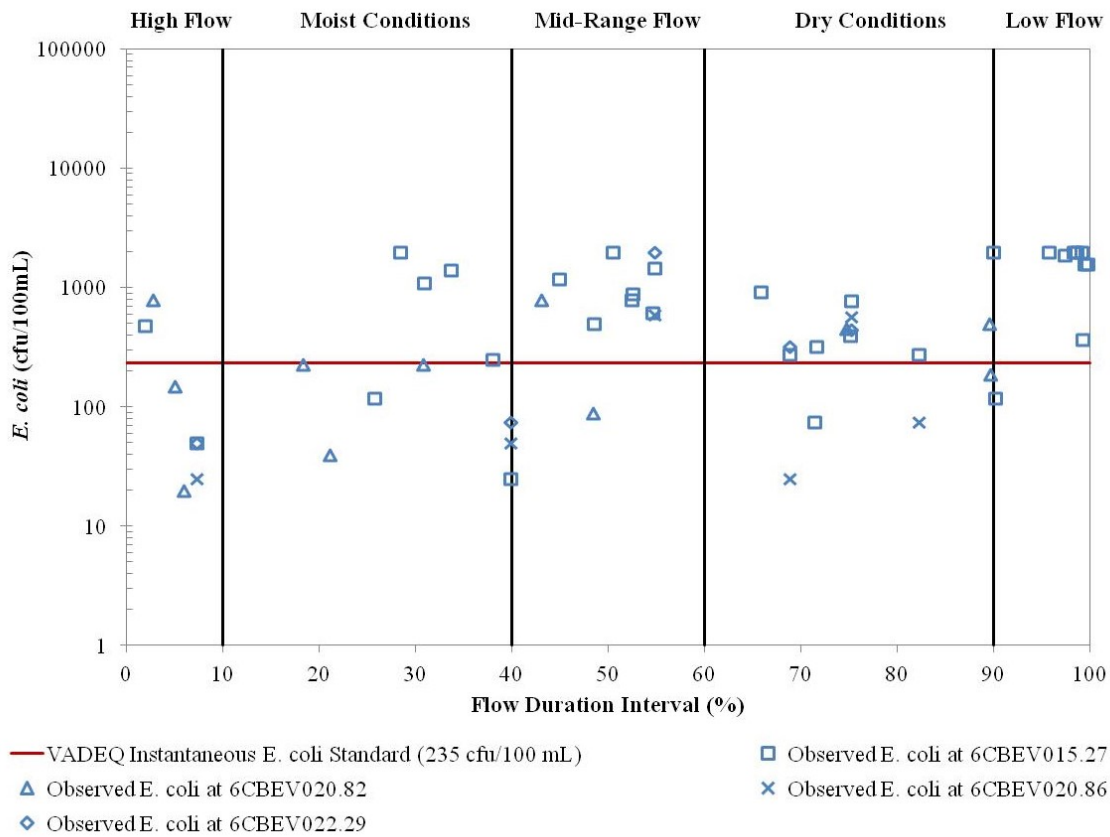

Figure B. 7 *E. coli* concentrations at 6CBEV015.27, 6CBEV020.82, 6CBEV020.86, and 6CBEV022.29 in the Beaver Creek watershed versus discharge at USGS Gauging Station #03478400.

Based on this analysis, a time period for calibration, validation and allocation of the model was chosen based on the overall distribution of wet and dry seasons in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area.

Selection of Representative Modeling Periods

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Modeling periods were selected for hydrology calibration and validation, water quality calibration and validation, and modeling of allocation scenarios. As shown in the critical conditions

section (**Figure B. 5**, **Figure B. 6**, and **Figure B. 7**), there is no single critical flow level where the majority of the bacterial standard exceedances occurred. This indicates that the modeling time periods must include low and high stream flow regimes.

Representative flow periods were chosen for hydrology calibration and validation based on precipitation and flow data for the Beaver Creek watershed. Daily precipitation data was available near the Beaver Creek watershed at the Abingdon NCDC Coop station #440021. The few missing values were filled with daily precipitation from the Lebanon NCDC Coop #444777, with any remaining gaps filled with daily precipitation data from the Bristol Airport Coop station #013877. Continuous stream flow data was available in the watershed at USGS station #03478400 on Beaver Creek in Bristol, VA from 12/1/1957-3/7/2013. The hydrologic calibration period was chosen to be 1 October 2007 through 30 September 2010, and the hydrologic validation period was chosen to be 1 October 2000 through 30 September 2003. The hydrology calibration and validation periods have a range of both high and low stream flow and precipitation, which represent the high and low flow critical regimes (**Figure B. 8** and **Figure B. 9**). The figures are shown here to demonstrate the historical annual and seasonal stream flow and precipitation and how the selected time periods encompass a representative range of values. **Table B. 7** shows the statistical comparison between calibration/validation time periods and historic time period.

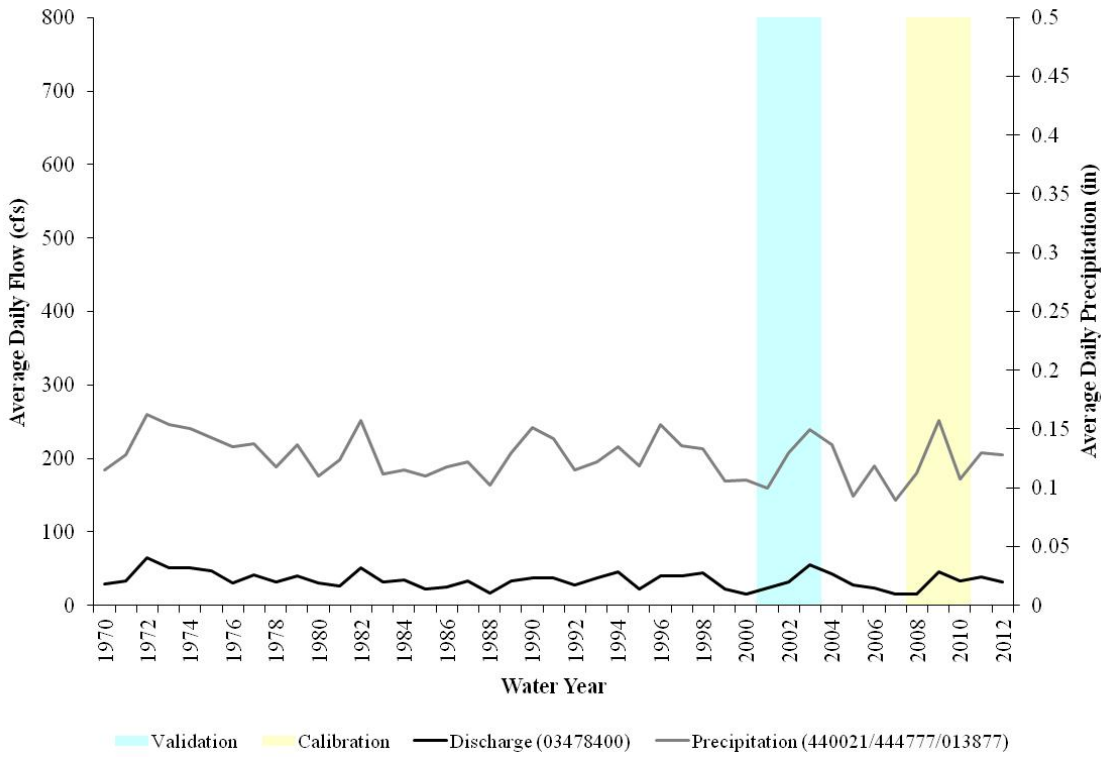

Figure B. 8 Hydrology calibration and validation time periods, annual historical flow (USGS Station 03478400), and precipitation (Station 440021/444777/013877) data.

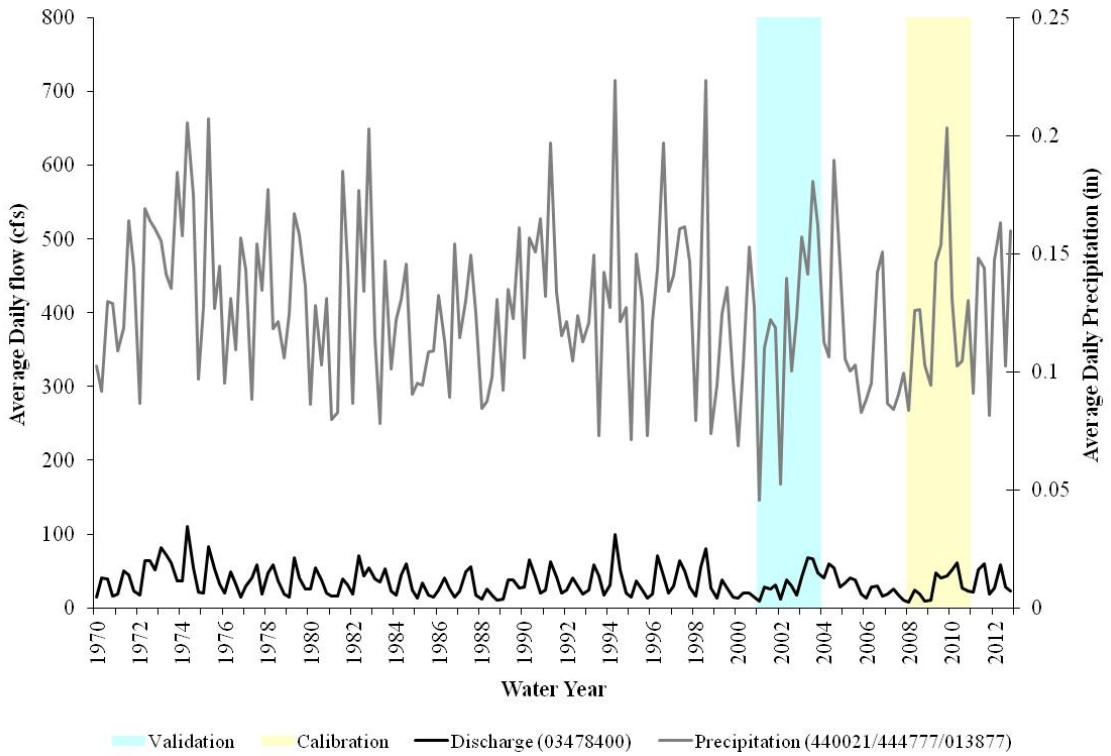

Figure B. 9 Hydrology calibration and validation time periods, seasonal historical flow (USGS Station 03478400), and precipitation (Station 440021/444777/013877) data.

Table B. 7 Comparison of modeled period to historical records for the Beaver Creek watershed.

	Discharge (03478400)				Precipitation (440021/444777/013877)			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1958-2013)				Historical Record (1948-2013)			
Mean	23	50	41	22	0.104	0.132	0.129	0.128
Variance	168	364	218	98	0.001	0.001	0.001	0.001
	Calibration and Validation Time Periods (10/07-9/10; 10/00-9/03)				Calibration and Validation Time Periods (10/07-9/10; 10/00-9/03)			
Mean	22	44	35	29	0.094	0.128	0.131	0.140
Variance	373	316	295	220	0.002	0.000	0.001	0.001
	p-values				p-values			
Mean	0.465	0.229	0.212	0.133	0.289	0.295	0.422	0.213
Variance	0.065	0.492	0.257	0.064	0.066	0.087	0.547	0.298

Availability of water quality data was a limiting factor in choosing a representative period for water quality calibration for the Beaver Creek watershed. The vast majority of the available DEQ monitoring data was collected during the hydrologic validation period. Thus, October 2000 through September 2003 was chosen as the water quality calibration period. October 2007 through September 2010 served as a validation period. These time periods were already shown encompass a representative range of precipitation and flow rate values (**Figure B. 8**, **Error! Reference source not found.**, **Figure B. 9**, and **Table B. 7**).

The hydrologic calibration period/water quality validation period, 1 October 2007 to 30 September 2010, was chosen as the allocation period for the impaired watershed. This period represented the optimal range of both high and low flow conditions, and having been used as a calibration/validation period, the confidence in values generated for this period is high.

The same selection process was used to determine the allocation period for the impaired watershed area as was used for selecting the hydrologic calibration and validation periods to ensure that both low and high flow conditions are represented. **Table B. 8** shows the statistical comparison between the allocation time period and historic time period.

Table B. 8 Comparison of modeled period to historical records for the Beaver Creek watershed.

	Discharge (03478400)				Precipitation (440021/444777/013877)			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Historical Record (1958 - 2013)				**Historical Record (1948-2013)**			
Mean	23	50	41	22	0.104	0.132	0.129	0.128
Variance	168	364	218	98	0.001	0.001	0.001	0.001
	Allocation Time Period (10/07-9/10)				**Allocation Time Period (10/07-9/10)**			
Mean	24	44	29	26	0.103	0.125	0.128	0.145
Variance	600	344	128	292	0.001	0.000	0.001	0.003
	p-values				**p-values**			
Mean	0.483	0.292	0.045	0.354	0.470	0.293	0.489	0.278
Variance	0.035	0.605	0.439	0.060	0.505	0.354	0.451	0.090

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, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

Hydrologic Calibration and Validation

The model calibrated for hydrologic accuracy using daily flow data for the period October 2007 through September 2010. The modeled output from subwatershed 7 was compared against Beaver Creek USGS Gauging Station #03478400 data.

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (LSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), groundwater recession flow (KVARY), and active groundwater storage PET (AGWETP). **Table B. 9** contains the possible range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

Table B. 9 Initial hydrologic parameters estimated for the Beaver Creek watershed study area and resulting final values after calibration.

Parameter	Units	Possible Range of Parameter Value	Initial Parameter Estimate	Final Calibrated Parameter Value
LZSN	in	2.0 – 15.0	7	5
INFILT	in/hr	0.001 – 0.50	0.1982	0.2973
KVARY	1/in	0.0 – 5.0	0	0
AGWRC	1/day	0.85 – 0.999	0.98	0.975
DEEPFR	---	0.0 – 0.50	0.01	0.19
BASETP	---	0.0 – 0.20	0.01	0.05
AGWETP	---	0.0 – 0.20	0	0
INTFW	---	1.0 – 10.0	1.0	1
IRC	1/day	0.30 – 0.85	0.5	0.5
MON-INTERCEPT	in	0.01 – 0.40	0 – 0.2	0 – 0.2
MON-UZSN	in	0.05 – 2.0	0.2– 0.5	0.2– 0.5
MON-LZETP	---	0.1 – 0.9	0 – 0.8	0 – 0.8

Error! Reference source not found. shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated. **Figure B. 10** and **Figure B. 11** graphically show these comparisons.

Table B. 10 Hydrology calibration model performance from 10/1/2007 through 9/30/2010 at USGS Gaging Station #03478400 on Beaver Creek.

Criterion*	Observed	Modeled	Error
Total In-stream Flow	35.11	38.36	9.26%
Upper 10% Flow Values	10.33	11.72	13.47%
Lower 50% Flow Values	8.26	9.01	9.00%
Winter Flow Volume	12.51	13.86	10.81%
Spring Flow Volume	8.26	9.03	9.32%
Summer Flow Volume	7.44	7.78	4.64%
Fall Flow Volume	6.91	7.70	11.37%
Total Storm Volume	27.85	32.08	15.18%
Winter Storm Volume	10.71	12.30	14.84%
Spring Storm Volume	6.45	7.46	15.66%
Summer Storm Volume	5.61	6.19	10.36%
Fall Storm Volume	5.09	6.13	20.58%

*Flow value units are cfs, flow volume units are inches.

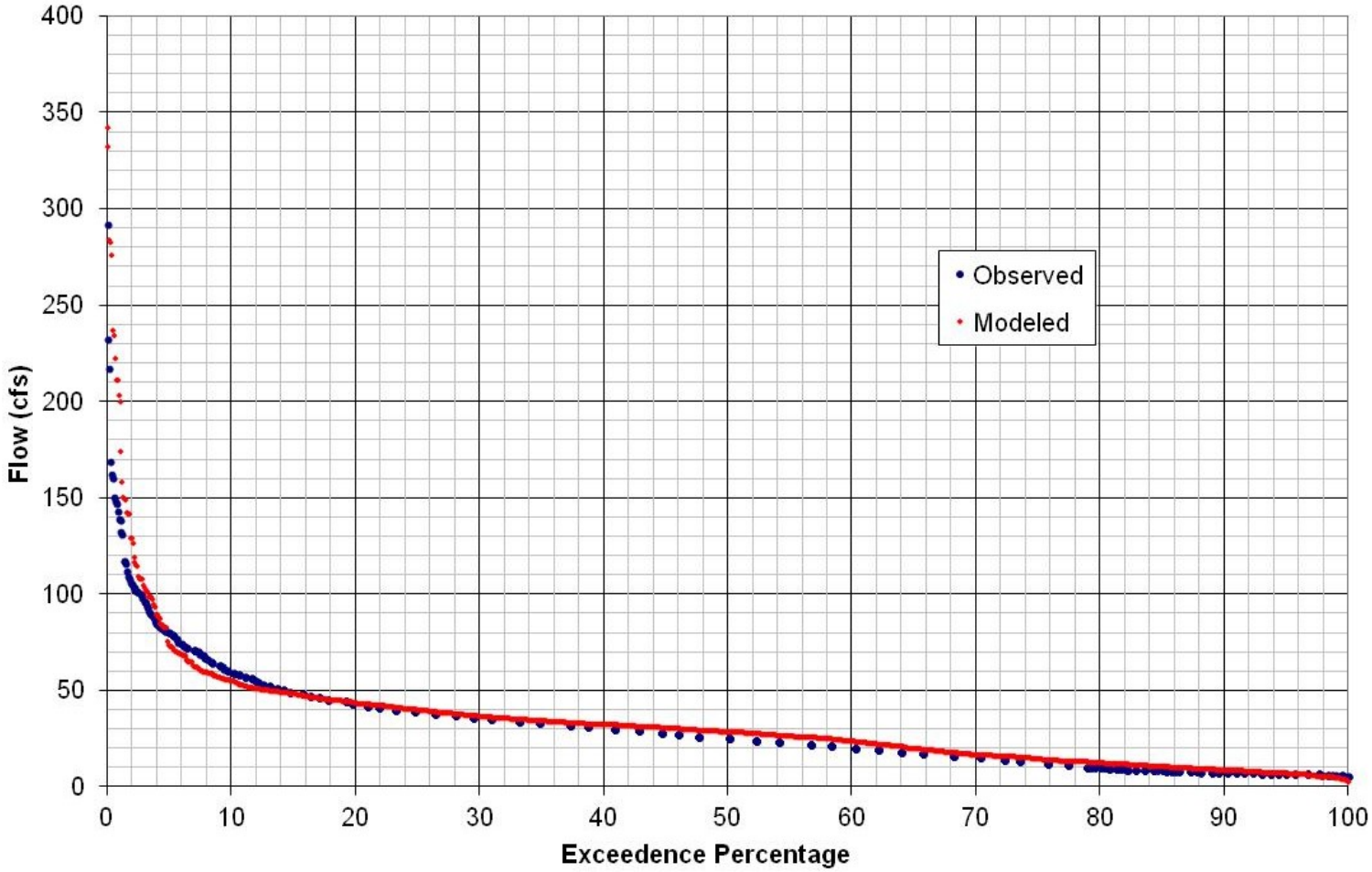

Figure B. 10 Beaver Creek modeled flow duration versus USGS Gaging Station #03478400 data from 10/1/2007 to 9/30/2010 for calibration.

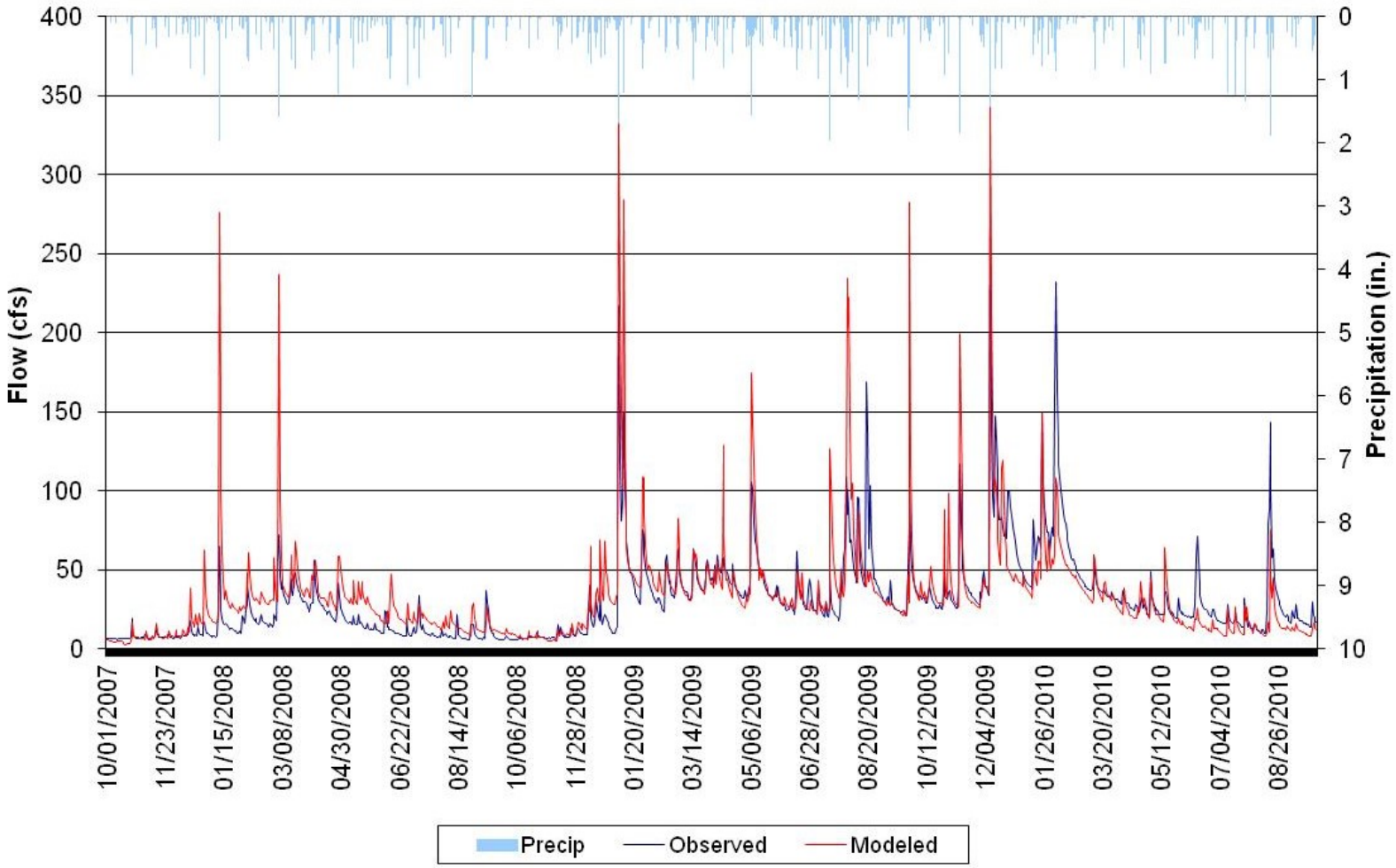

Figure B. 11 Beaver Creek modeled results versus USGS Gaging Station #03478400 data from 10/1/2007 to 9/30/2010 for calibration.

The modeled output was validated for the period of October 2000 through September 2003. Simulated flow at the outlet of subwatershed 7 was compared with daily flow at the Beaver Creek USGS Gauging Station #03478400. **Table B. 11** shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated and has been validated during a different time period. **Figure B. 12** and **Figure B. 13** graphically show these comparisons.

Table B. 11 Hydrology validation model performance from 10/1/2000 through 9/30/2003 at USGS Gaging Station #03478400 on Beaver Creek.

Criterion	Observed	Modeled	Error
Total In-stream Flow:	39.85	36.00	-9.67%
Upper 10% Flow Values:	12.45	11.90	-4.39%
Lower 50% Flow Values:	8.11	7.36	-9.25%
Winter Flow Volume	12.47	11.82	-7.18%
Spring Flow Volume	11.67	11.06	-5.20%
Summer Flow Volume	9.31	7.57	-18.63%
Fall Flow Volume	6.14	5.54	-9.75%
Total Storm Volume	30.83	30.24	-1.91%
Winter Storm Volume	10.51	10.39	-1.14%
Spring Storm Volume	9.42	9.62	2.13%
Summer Storm Volume	7.03	6.11	-13.06%
Fall Storm Volume	3.87	4.12	6.48%

*Flow value units are cfs, flow volume units are in.

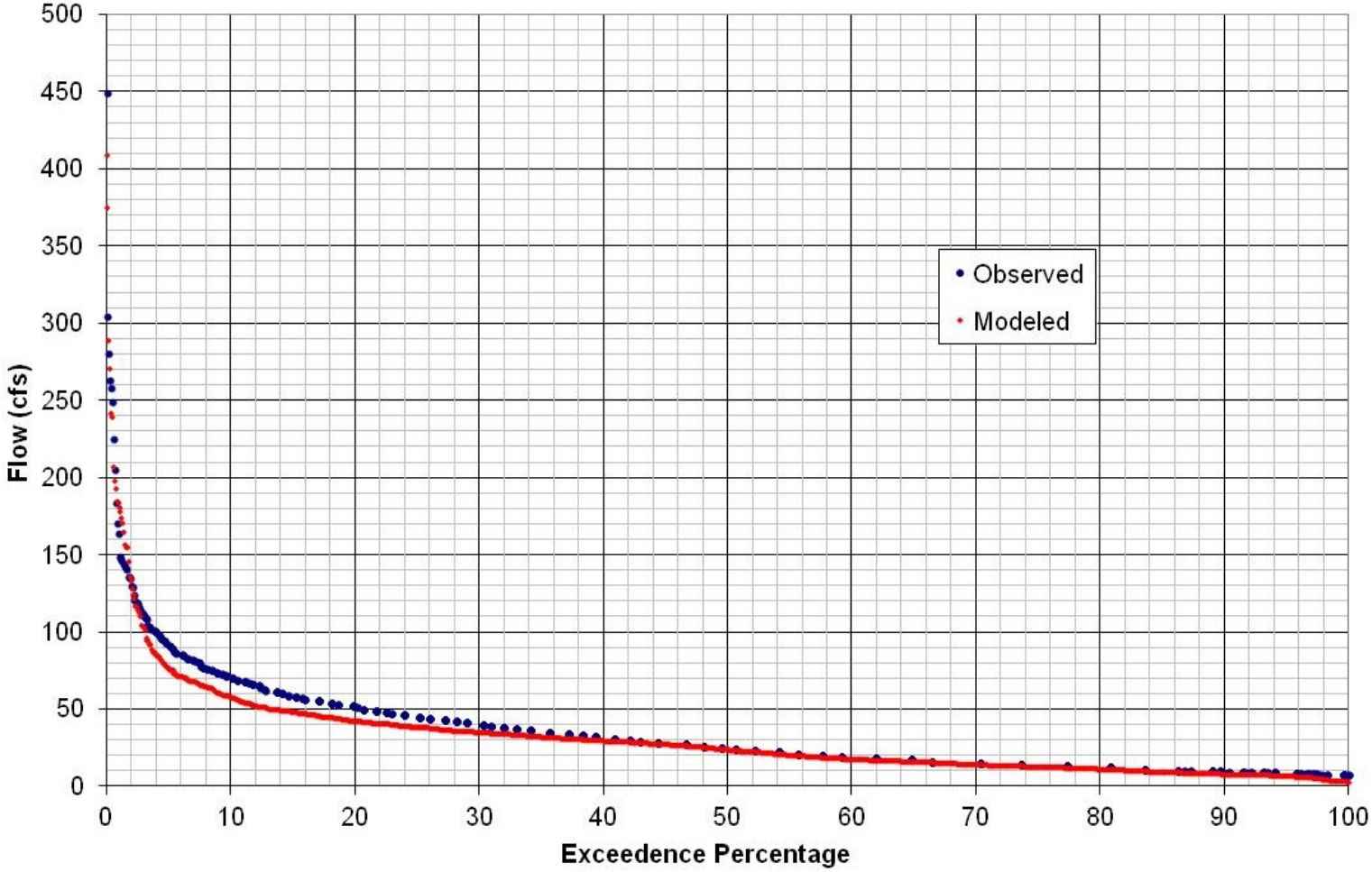

Figure B. 12 Beaver Creek modeled flow duration versus USGS Gaging Station #03478400 data from 10/1/2000 to 9/30/2003 for validation.

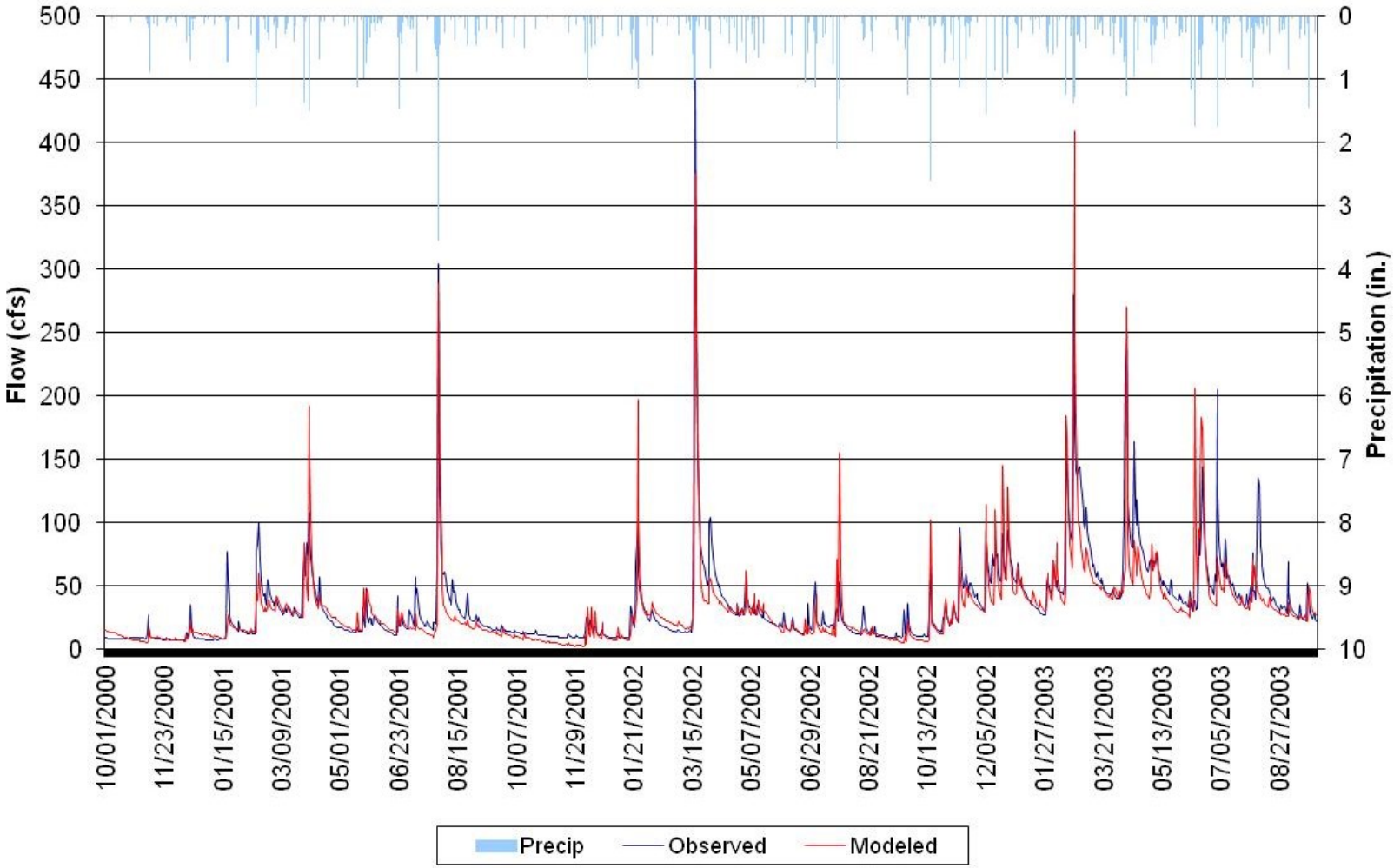

Figure B. 13 Beaver Creek modeled results versus USGS Gaging Station #03478400 data from 10/1/2000 to 9/30/2003 for validation.

Water Quality Calibration and Validation

Water quality calibration is complicated by a number of factors; first, water quality (*E. coli*) concentrations are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of *E. coli* is particularly variable. Variability in location and timing of fecal deposition, variability in the density of bacteria in feces (among species and for an individual animal), environmental impacts on re-growth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling *E. coli* concentrations. Additionally, the VADEQ data were censored at specific high and low values (e.g. 8,000 cfu/100ml or 16,000 cfu/100ml as high or 100 cfu/100ml as low value). Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

Three parameters were utilized for model adjustment: monthly maximum accumulation on land (MON-SQOLIM), the rate of surface runoff that will remove 90% of stored fecal bacteria per hour (WSQOP), and the in-stream first-order decay rate (FSTDEC). 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 bacteria concentrations was established. For water quality calibration, all monitored data was in terms of fecal coliform. **Table B. 12** shows the model parameters utilized in calibration with their typical ranges, initial estimates, and final calibrated values.

Table B. 12 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range	Initial Parameter Estimate	Calibrated Parameter Value
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 7.8E+9	0.0 – 3.6E+13
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.5	0.0 – 1.88
FSTDEC	1/day	0.01 – 10.00	1.0	1.0 – 5.0

Figure B. 14 through **Figure B. 21** show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the modeled values are daily averages based on hourly modeling. The monitored values may

have been sampled at the highest concentration of the day and thus correctly appear above the modeled daily average. Although the range of modeled daily average values may not reach every instantaneous monitored value, the modeled data follows the trend of monitored data, and typically includes the monitored extremes.

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. **Table B. 13** shows the predicted and observed values for the maximum value, geometric mean, and single sample maximum violations for the Beaver Creek watershed stream segments.

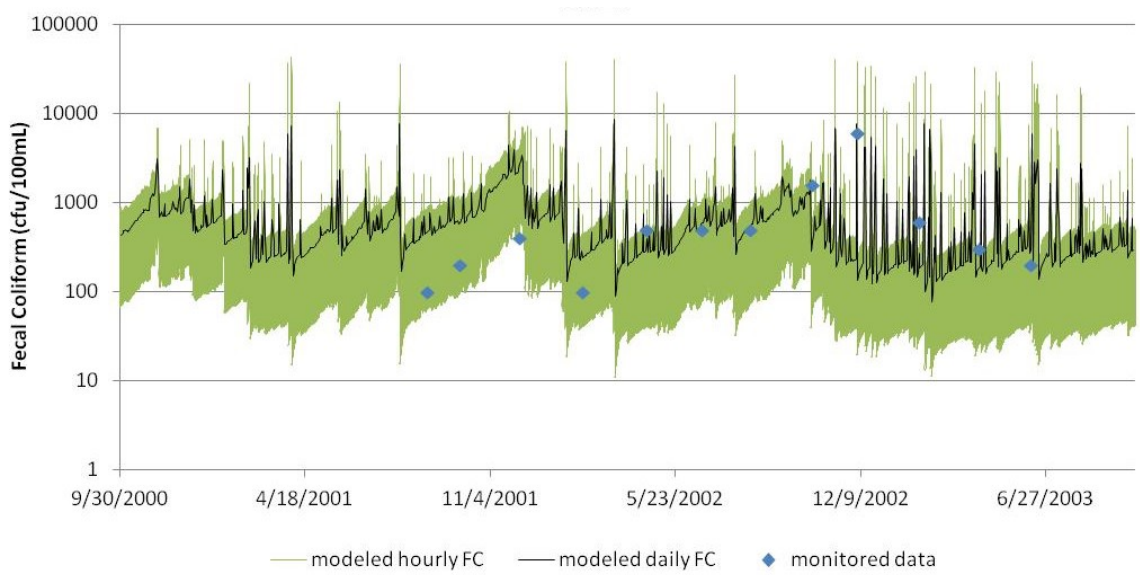

Figure B. 14 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN022.29 in subwatershed 10 on Beaver Creek.

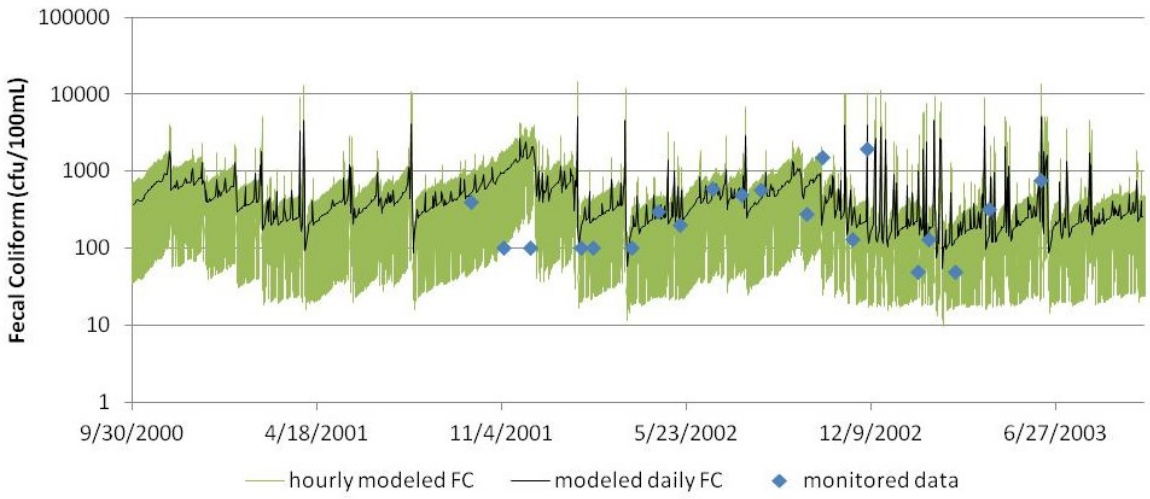

Figure B. 15 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN020.82 in subwatershed 7 on Beaver Creek.

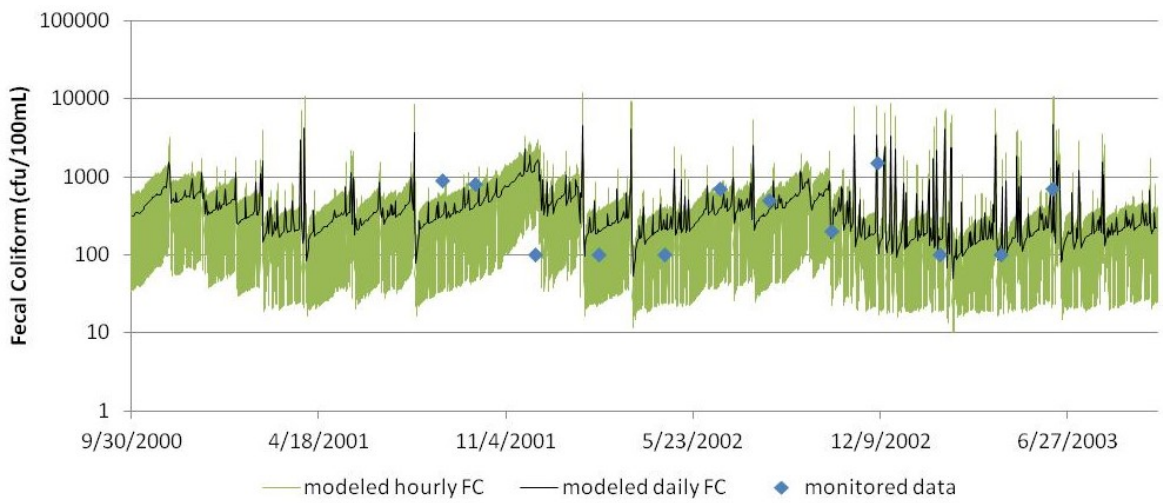

Figure B. 16 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN019.21 in subwatershed 6 on Beaver Creek.

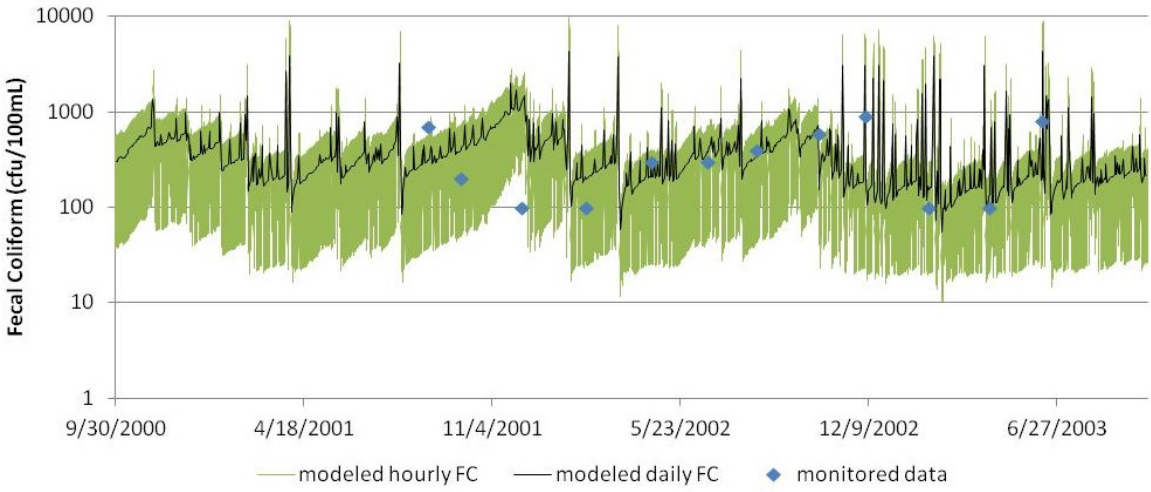

Figure B. 17 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN017.96 in subwatershed 5 on Beaver Creek.

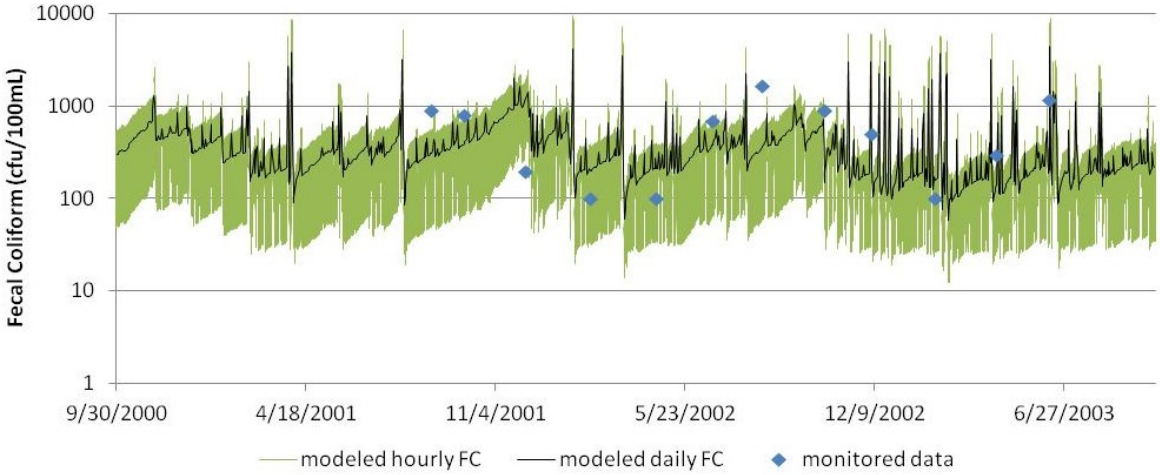

Figure B. 18 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN017.15 in subwatershed 4 on Beaver Creek.

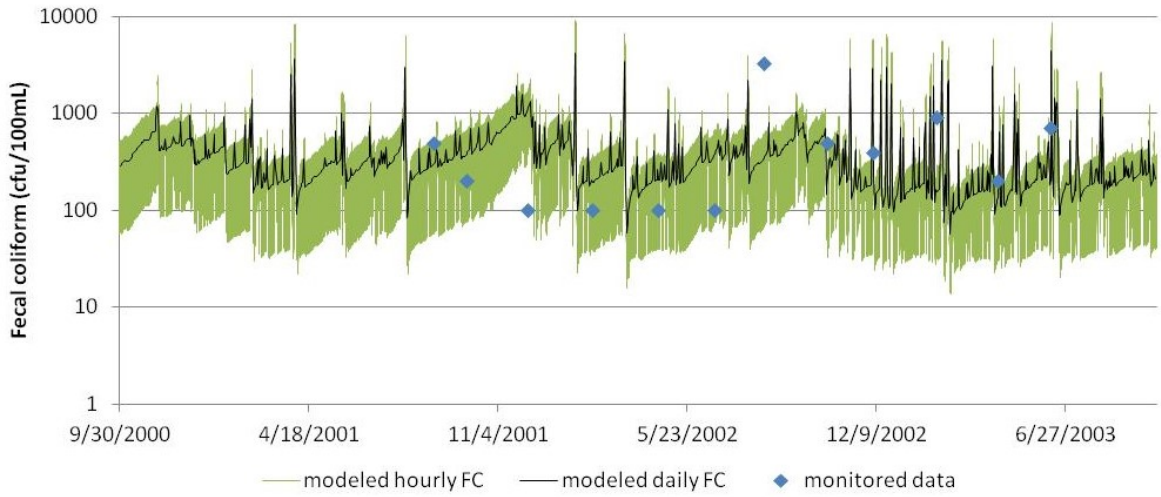

Figure B. 19 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN016.59 in subwatershed 3 on Beaver Creek.

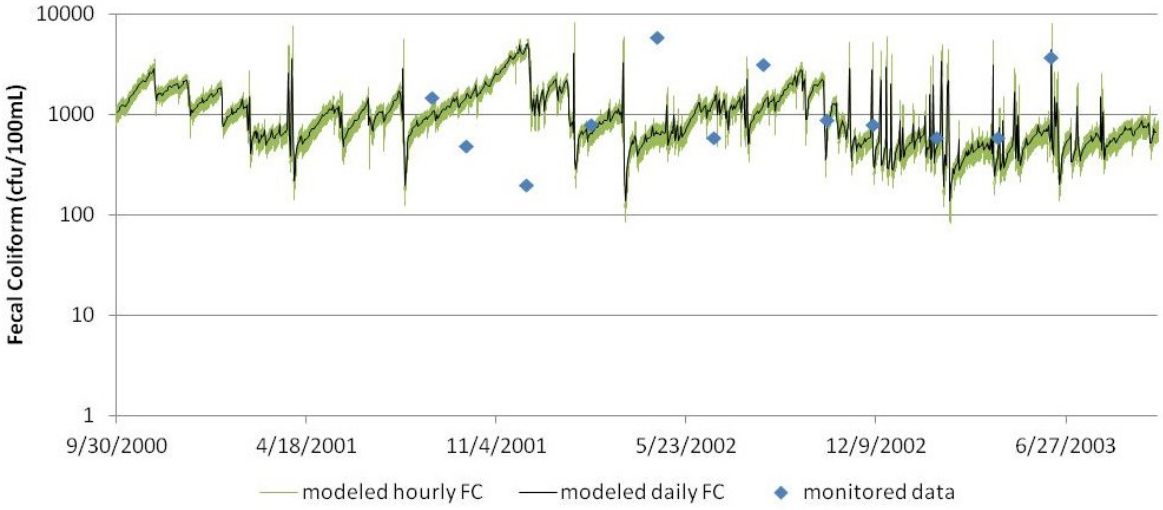

Figure B. 20 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEVN015.62 in subwatershed 2 on Beaver Creek.

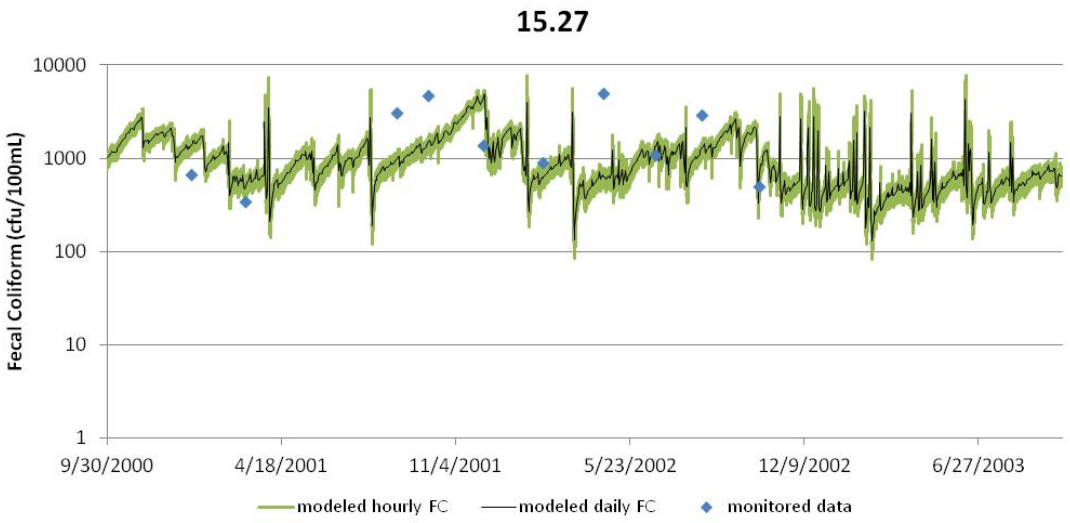

Figure B. 21 Fecal coliform calibration for 10/1/2000 to 9/30/2003 for VADEQ station 6CBEV015.27 in subwatershed 1 on Beaver Creek.

Table B. 13 Monitored and simulated fecal coliform maximum value, geometric mean, and single sample violation percentage for the water quality calibration period (10/1/2000-9/30/2003)

Station	Subwatershed	Number of Monitored Samples	Maximum Value (cfu/100mL)		Overall Geometric Mean (cfu/100mL)	Average Monthly Geometric Mean (cfu/100mL)	SS Violations** Percent	
			Monitored	Simulated*	Monitored	Simulated*	Monitored	Simulated*
6CBEV015.27	1	10	5000	4865	1429	977	90.00	90.96
6CBEV015.62	2	12	6000	5161	1026	1025	91.67	91.87
6CBEV016.59	3	12	3300	4379	311	327	41.67	30.05
6CBEV017.15	4	12	1700	4447	417	337	58.33	32.05
6CBEV017.96	5	12	900	4340	279	340	33.33	32.33
6CBEV019.21	6	12	1500	4692	300	359	50.00	35.07
6CBEV020.82	7	20	2000	5128	239	427	30.00	45.84
6CBEV022.29	11	12	6000	8666	425	546	50.00	57.08

*Based on average daily simulated data.
**SS = single sample maximum standard violations (>400 cfu/100mL for fecal coliform).

Only station 6CBEV015.27 had available monitored bacteria data during the water quality validation period. The data was in terms of *E. coli* in this case, rather than fecal coliform, so the modeled data was converted using the equation shown on **page 5-1**. **Figure B. 22** shows the results of water quality validation. **Table B. 14** shows the predicted and observed values for the maximum value, geometric mean, and single sample maximum violations for the Beaver Creek watershed stream segments.

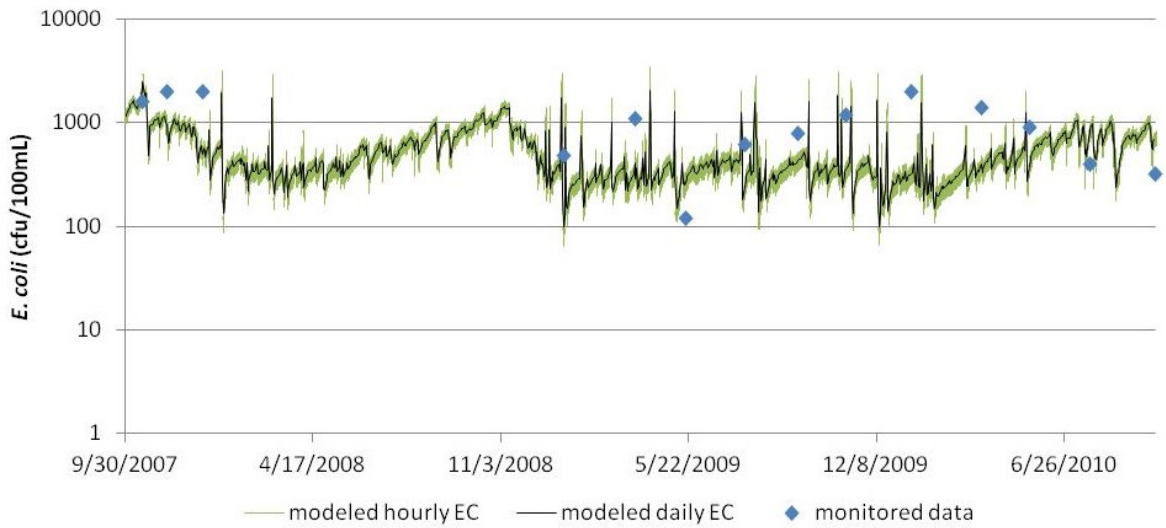

Figure B. 22 *E. coli* validation for 10/1/2007 to 9/30/2010 for VADEQ station 6CBEVN015.27 in subwatershed 1 on Beaver Creek.

Table B. 14 Monitored and simulated *E. coli* maximum value, geometric mean, and single sample violation percentage for the water quality calibration period (10/1/2007-9/30/2010)

Station	Subwatershed	Number of Monitored Samples	Maximum Value (cfu/100mL)		Overall Geometric Mean (cfu/100mL)	Average Monthly Geometric Mean (cfu/100mL)	SS Violations** Percent	
			Monitored	Simulated*	Monitored	Simulated*	Monitored	Simulated*
6CBEV015.27	1	15	2000	2489	613	508	84.38	92.10

*Based on average daily simulated data.
**SS = single sample maximum standard violations (>235 cfu/100mL for *E. coli*).

Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation or to guide prioritization of implementation efforts. 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).

Hydrology Sensitivity Analysis

For the hydrology sensitivity analysis, an initial base run was performed using precipitation data from water years 2008 – 2010. The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in **Table B. 15**, 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 2008-2010. Where an increase or decrease of 50% exceeded the possible range of values for the parameters, the maximum and/or minimum value was used and the parameter values used in the sensitivity analysis were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and LZETP (Lower Zone Evapotranspiration), which affects soil moisture as well as groundwater constants AGWRC (Groundwater Recession Rate) and KVARY which enables variable groundwater recession rates. 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 were AGWRC, LZETP, INFILT, KVARY, and DEEPFR (fraction of groundwater inflow lost to deep groundwater). The responses of these and other hydrologic outputs are reported in **Table B. 16**.

Table B. 15 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	5
INFILT	Soil Infiltration Capacity	in/hr	0.2973
BASETP	Base Flow Evapotranspiration	---	0.05
INTFW	Interflow Inflow	---	1
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.19
AGWRC	Groundwater Recession rate	---	0.975
KVARY	Groundwater Recession Flow	1/in	0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0 - 0.2
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.2 - 0.5
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0 – 0.8

Table B. 16 HSPF sensitivity analysis results for hydrologic model parameters.

Model Parameter	Parameter Change (%)	Percent Change in:							
		Total Flow	High Flows	Low Flows	Winter Flow Volume	Spring Flow Volume	Summer Flow Volume	Fall Flow Volume	Total Storm Volume
AGWRC*	0.85	0.40	23.41	-37.27	4.25	-12.46	-5.50	14.07	20.59
AGWRC*	0.88	0.34	19.34	-31.42	4.48	-11.65	-5.72	12.71	19.18
AGWRC*	0.95	0.18	6.68	-13.18	4.64	-6.43	-4.01	4.09	10.64
AGWRC*	0.999	-7.56	-11.16	26.90	-23.00	-13.68	4.84	13.40	-48.84
BASETP	-50	1.60	-1.67	6.64	-0.49	4.62	4.19	-0.78	0.62
BASETP	-10	0.32	-0.34	1.35	-0.10	0.92	0.84	-0.17	0.18
BASETP	10	-0.31	0.35	-1.34	0.09	-0.92	-0.82	0.17	-0.09
BASETP	50	-1.53	1.78	-6.69	0.49	-4.55	-4.03	0.90	0.32
DEEPFR	-50	9.03	4.01	13.09	8.38	10.62	9.47	7.95	7.98
DEEPFR	-10	1.81	0.80	2.62	1.68	2.12	1.89	1.59	1.60
DEEPFR	10	-1.81	-0.79	-2.62	-1.68	-2.12	-1.89	-1.59	-1.59
DEEPFR	50	-9.03	-3.93	-13.14	-8.38	-10.61	-9.47	-7.96	-7.59
INFILT	-50	1.10	27.61	-19.58	3.70	-3.92	-2.37	5.75	7.64
INFILT	-10	0.07	3.89	-2.79	0.45	-0.81	-0.45	0.92	0.78
INFILT	10	-0.02	-3.37	2.52	-0.38	0.83	0.45	-0.84	-0.60
INFILT	50	0.20	-13.41	10.38	-1.38	4.15	2.13	-3.45	-2.13
INTFW	-50	-0.12	3.79	-0.73	-0.29	-0.29	0.18	0.04	-0.33
INTFW	-10	-0.02	0.44	-0.07	-0.04	-0.04	0.01	0.01	-0.05
INTFW	10	0.02	-0.34	0.05	0.03	0.04	-0.02	0.00	0.04
INTFW	50	0.06	-1.33	0.16	0.13	0.16	-0.11	0.02	0.14
LZSN	-50	2.18	9.21	-7.55	8.28	2.29	-7.75	1.51	9.33
LZSN	-10	0.25	1.26	-1.39	1.14	0.51	-1.19	-0.13	1.35
LZSN	10	-0.21	-1.09	1.28	-0.99	-0.52	1.03	0.21	-1.23
LZSN	50	-0.90	-4.58	5.46	-3.89	-2.44	3.99	1.06	-5.10
CEPSC	-50	0.74	-2.66	4.07	-0.53	4.43	1.02	-1.48	1.20
CEPSC	-10	0.12	-0.55	0.80	-0.14	0.76	0.31	-0.33	0.18
CEPSC	10	-0.11	0.54	-0.74	0.13	-0.72	-0.28	0.33	-0.19
CEPSC	50	-0.97	2.83	-4.75	0.37	-3.75	-1.88	0.75	-0.75
LZETP	-50	11.24	12.36	19.61	8.18	2.68	16.71	20.56	0.41
LZETP	-10	1.48	1.29	2.86	1.23	0.39	1.91	2.69	-0.01
LZETP	10	-1.05	-0.89	-2.03	-0.96	-0.30	-1.31	-1.81	-0.03
LZETP	50	-5.00	-5.76	-8.04	-4.95	-1.28	-6.53	-7.70	-1.55
KVARY*	0.5	0.11	10.01	-16.23	5.30	-8.17	-3.93	4.50	7.29
KVARY*	1	0.18	16.18	-23.95	6.02	-11.02	-5.16	8.01	10.86
KVARY*	2	0.26	24.00	-33.14	5.78	-13.15	-5.88	11.94	16.01
KVARY*	5	0.39	36.97	-49.33	5.00	-14.56	-5.14	14.72	20.50
UZSN	-50	3.35	4.19	3.77	0.79	6.92	4.60	2.51	5.33
UZSN	-10	0.43	0.70	0.41	0.11	0.88	0.55	0.37	0.75
UZSN	10	-0.39	-0.71	-0.31	-0.14	-0.70	-0.47	-0.41	-0.70
UZSN	50	-1.52	-3.03	-0.91	-0.72	-2.44	-1.58	-1.79	-2.77

*Actual parameter value used rather than percent change.

Water Quality Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 2001 – 2003 and model parameters established for 2012 conditions. The three HSPF parameters impacting the model's water quality response (Table **B. 17**) were increased and decreased by amounts that were consistent with the range of values for the parameter. FSTDEC (first order decay) was the parameter with the greatest influence on monthly geometric mean concentration (**Table B. 18**). The reason behind the more pronounced impact of change in decay rate on concentration of bacteria in the stream is that changes in decay rate impact bacteria from nonpoint as well as point sources and direct-nonpoint sources. On the other hand, changes in maximum fecal coliform accumulation on the land (MON-SQOLIM) and wash-off rate for fecal coliform on land surface (WSQOP) only impact the nonpoint portion of the bacteria. Graphical depictions of the results of this sensitivity analysis can be seen in **Figure B. 23**, **Figure B. 24**, and **Figure B. 25**.

Table B. 17 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 – 3.6E13
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0 – 1.88
FSTDEC	In-stream First Order Decay Rate	1/day	1 - 5

Table B. 18 Percent change in average monthly *E. coli* geometric mean for water years 2001-2003.

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	19.57	23.64	23.60	24.11	21.40	20.98	23.80	17.70	15.69	14.59	14.45	18.74
FSTDEC	-10	3.10	3.56	3.62	3.65	3.39	3.27	3.64	2.87	2.59	2.42	2.41	2.97
FSTDEC	10	-2.80	-3.18	-3.25	-3.27	-3.07	-2.95	-3.26	-2.62	-2.38	-2.23	-2.22	-2.69
FSTDEC	50	-11.76	-13.19	-13.45	-13.52	-12.88	-12.30	-13.52	-11.14	-10.25	-9.63	-9.64	-11.32
MON-SQOLIM	-50	-2.90	-4.07	-3.23	-2.56	-3.18	-2.52	-3.68	-0.95	-0.67	-0.76	-1.06	-3.02
MON-SQOLIM	-10	-0.18	-0.21	-0.21	-0.16	-0.27	-0.22	-0.39	-0.09	-0.07	-0.08	-0.11	-0.27
MON-SQOLIM	10	0.79	1.22	0.77	0.58	0.55	0.55	0.80	0.17	0.07	0.13	0.18	0.69
MON-SQOLIM	50	2.70	3.96	2.93	2.15	2.48	1.96	2.90	0.61	0.39	0.58	0.80	2.71
WSQOP	-50	3.89	4.79	4.10	2.85	4.38	1.86	3.75	0.92	0.53	0.73	0.80	2.81
WSQOP	-10	0.52	0.69	0.56	0.42	0.59	0.30	0.54	0.13	0.07	0.09	0.11	0.40
WSQOP	10	-0.46	-0.63	-0.49	-0.38	-0.52	-0.27	-0.49	-0.11	-0.06	-0.08	-0.09	-0.36
WSQOP	50	-1.85	-2.62	-2.03	-1.62	-2.14	-1.20	-2.05	-0.46	-0.22	-0.33	-0.36	-1.53

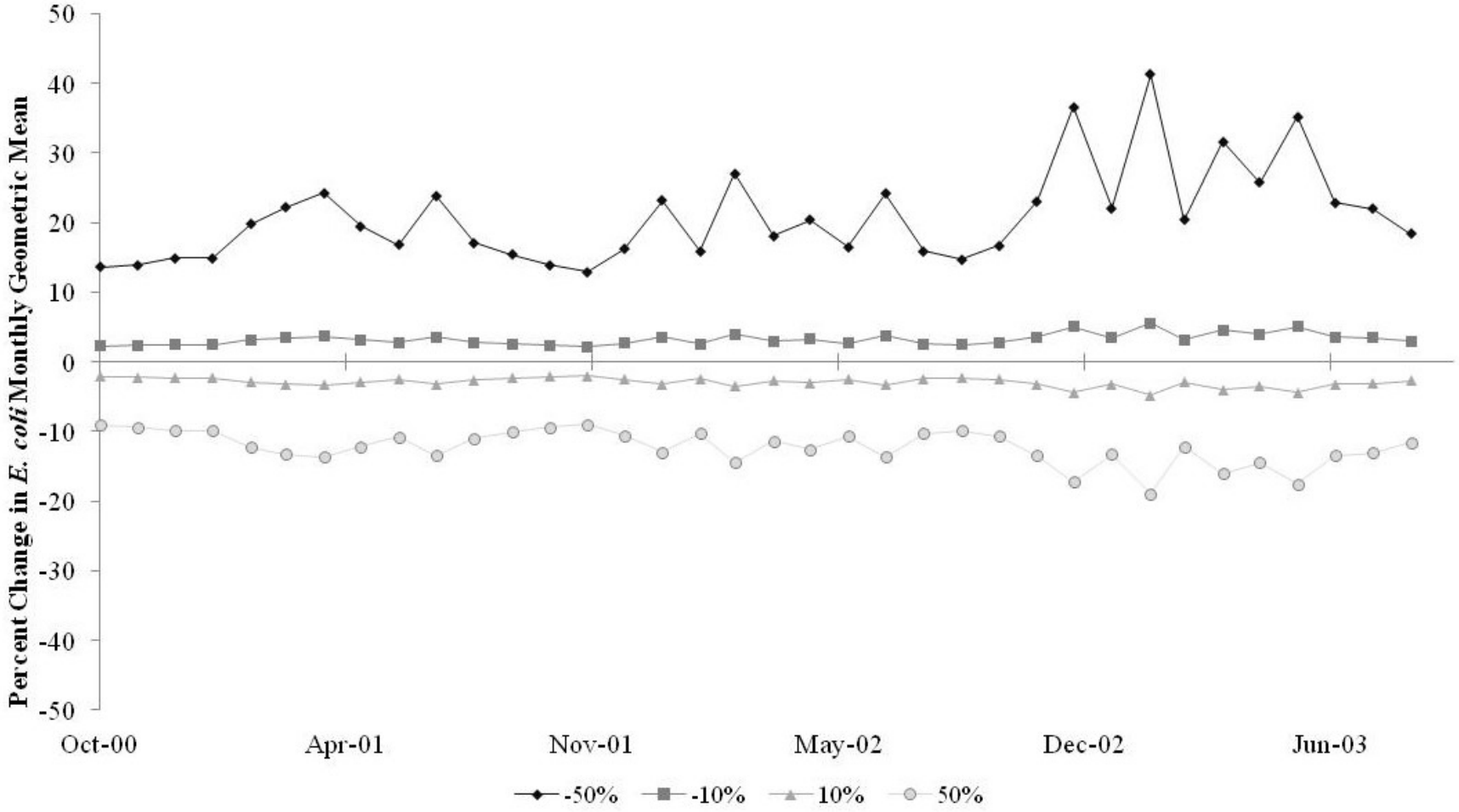

Figure B. 23 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in the in-stream first-order decay rate (FSTDEC).

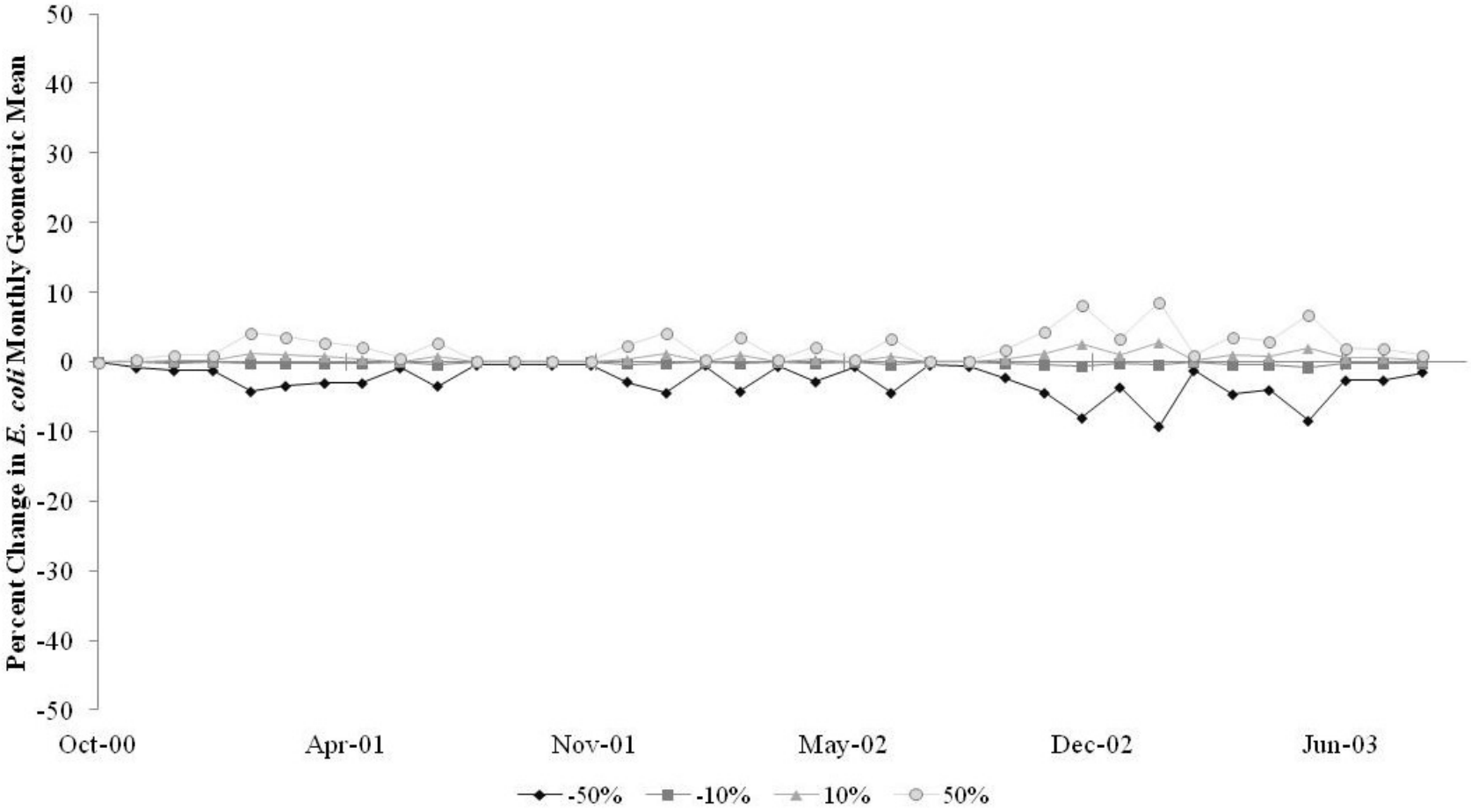

Figure B. 24 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

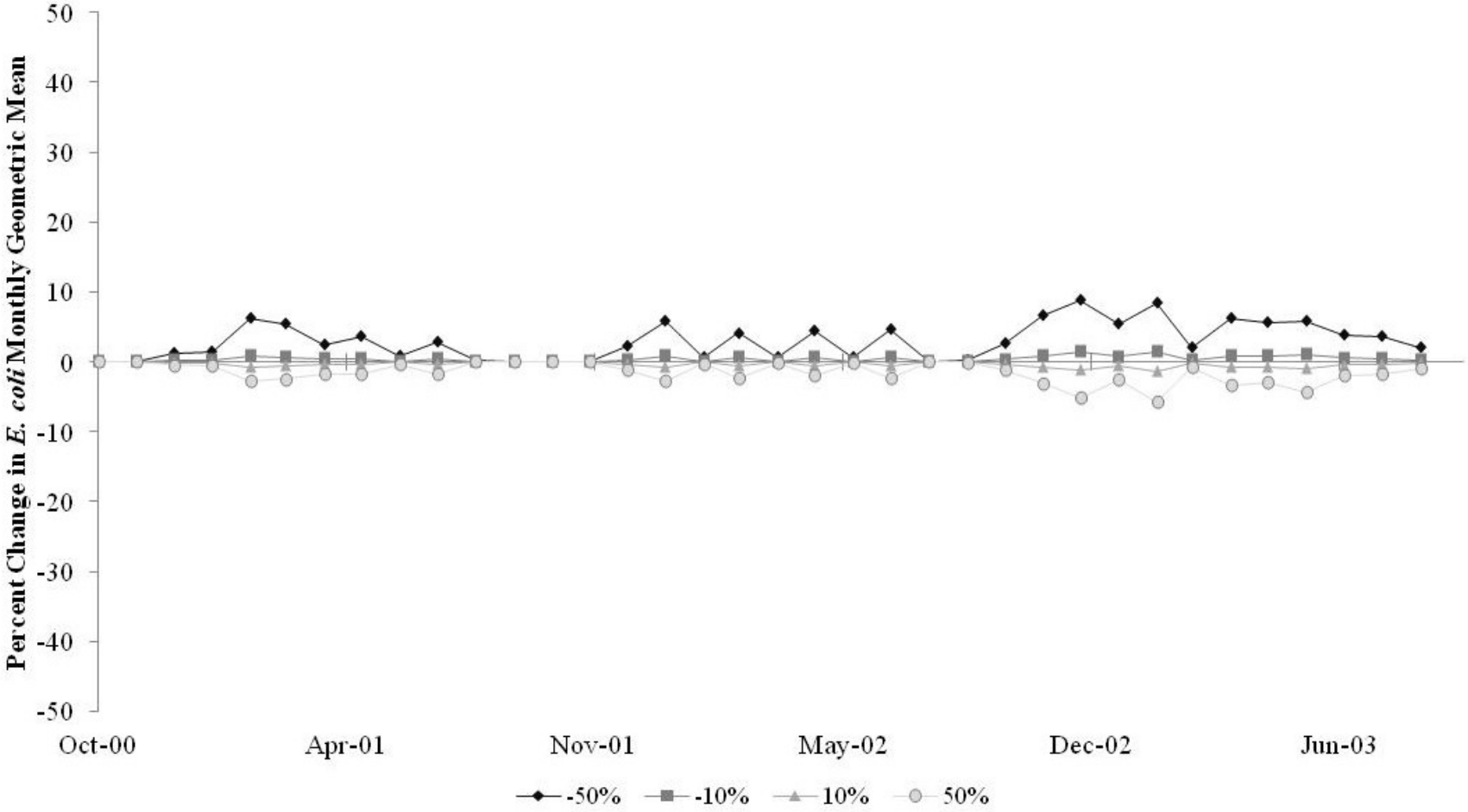

Figure B. 25 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in the wash-off rate from land surfaces (WSQOP).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in amount of land-based and direct loads was also analyzed. It is evident in **Figure B. 26** that the model predicts a linear relationship between increased fecal coliform concentrations in direct applications and total load reaching the stream. However, decreases in land-based loadings cause a drop in response significantly greater than the rise caused by similar increases in land-based loads. Both direct loads and land applied loads have a significant impact on the geometric mean concentrations (**Figure B. 27** and **Figure B. 28**).

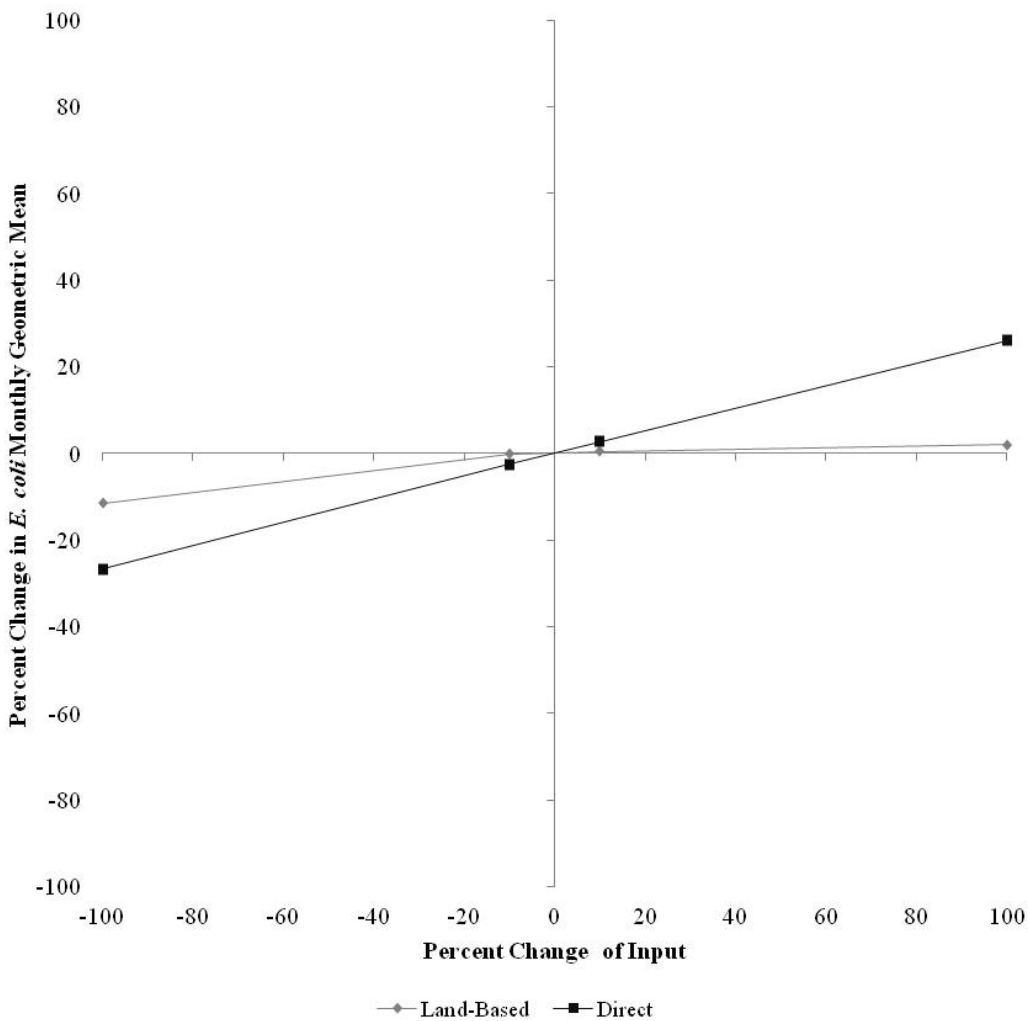

Figure B. 26 Results of total loading sensitivity analysis for outlet of the Beaver Creek watershed study area.

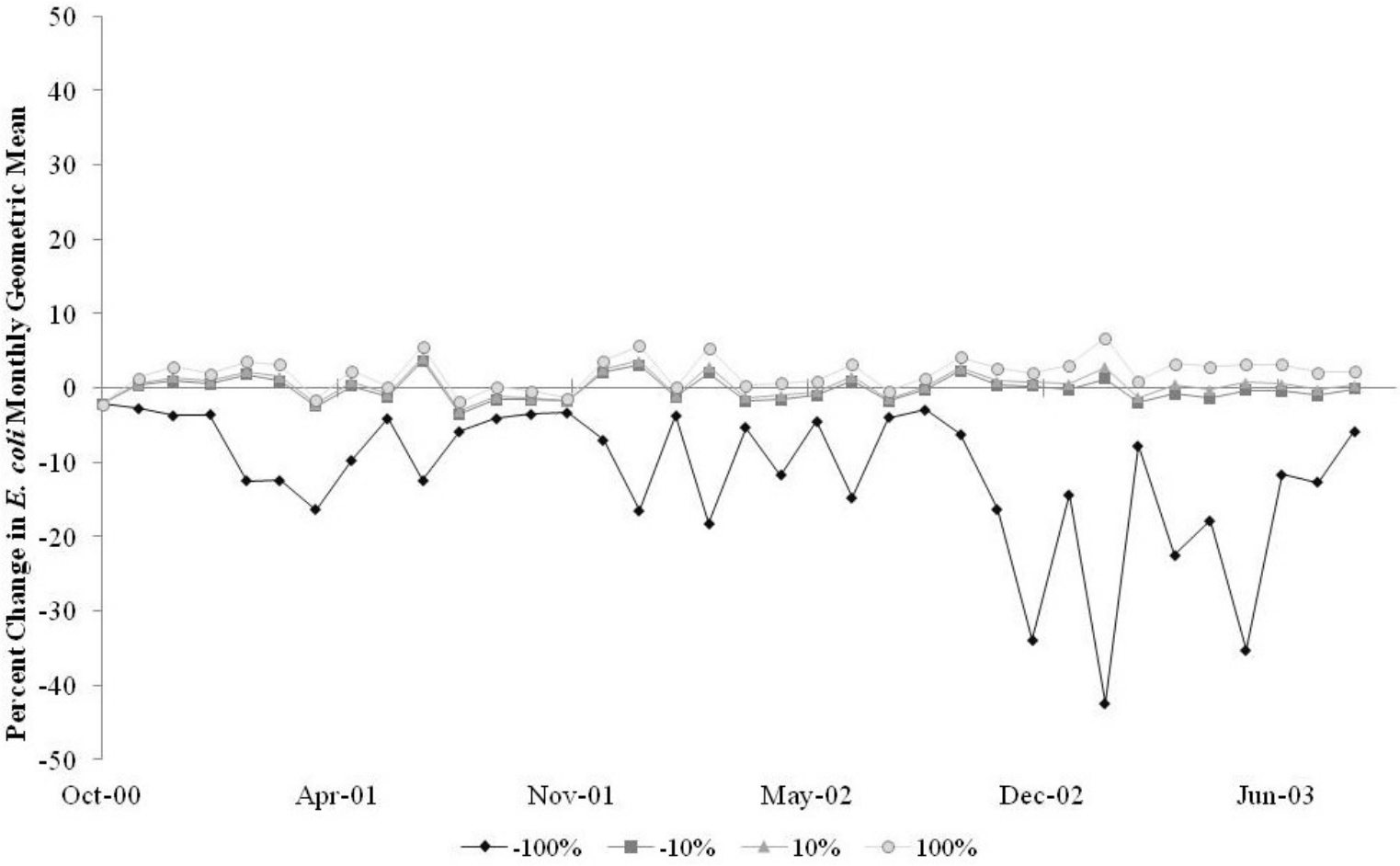

Figure B. 27 Results of sensitivity analysis on monthly geometric-mean concentrations in the Beaver Creek watershed study area, as affected by changes in land-based loadings.

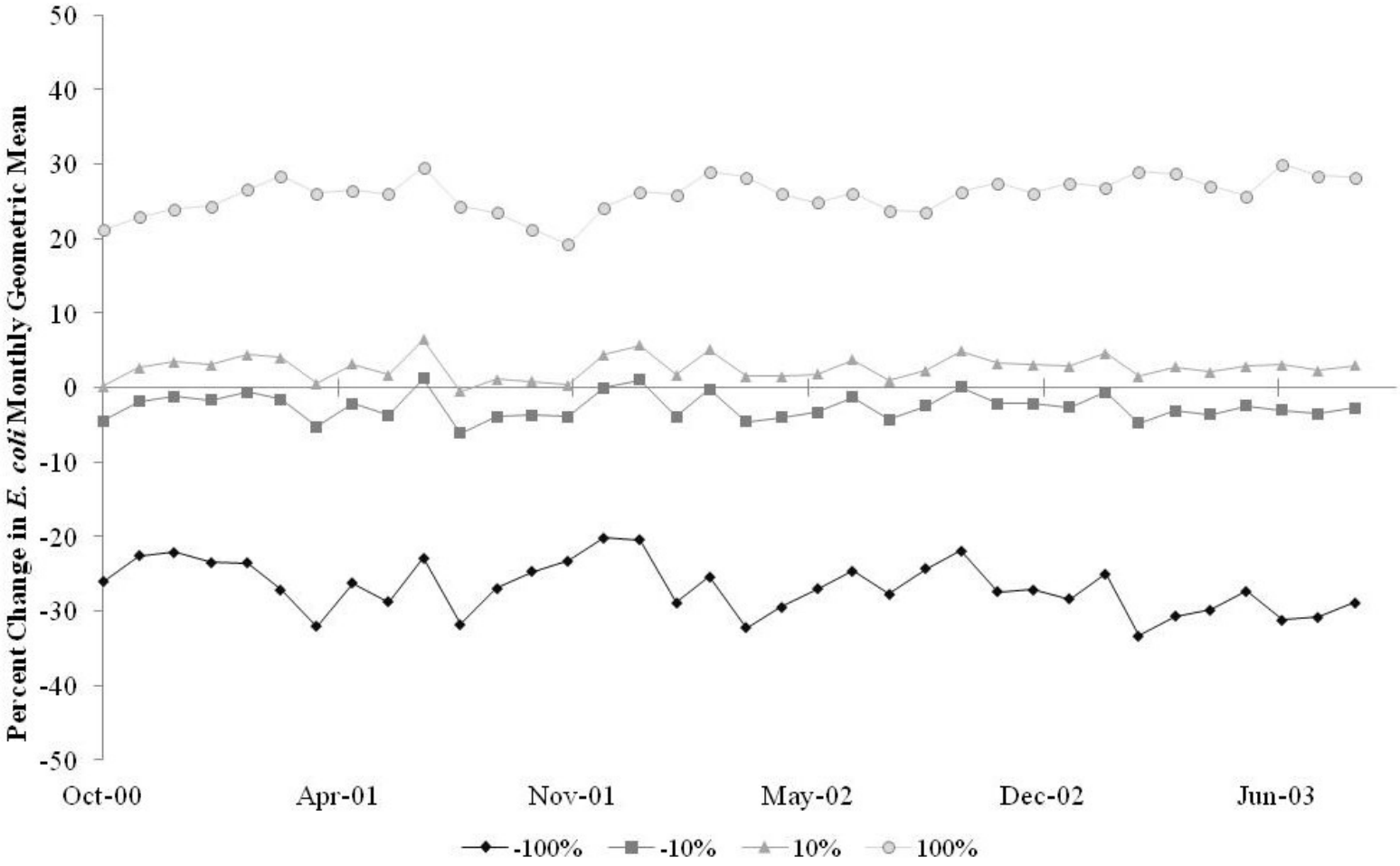

Figure B. 28 Results of sensitivity analysis on monthly geometric-mean concentrations in the Beaver Creek watershed study area, as affected by changes in loadings from direct nonpoint sources.

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APPENDIX C: SEDIMENT MODELING PROCEDURE

SEDIMENT MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT

Sediment Modeling Procedure: Linking the Sources to the Endpoint

Modeling Framework Selection - GWLF

A reference watershed approach was used in this study to develop a benthic TMDL for sediment for the Beaver Creek watershed. As noted in **Chapter** 7, sediment was identified as the most probable stressor for Beaver Creek. A watershed model was used to simulate sediment loads from potential sources in this watershed and in the reference watershed. The model used in this study was the *Visual Basic*™ version of the Generalized Watershed Loading Functions (GWLF) model with modifications for use with ArcView (Evans et al., 2001). The GWLF model was developed at Cornell University (Haith and Shoemaker, 1987; Haith, et al., 1992) for use in ungauged watersheds. The model also included modifications made by Yagow et al. (2002) and BSE (2003). Numeric endpoints were based on unit-area loading rates calculated for the reference watershed. The TMDL was then developed for the impaired watershed based on these endpoints and the results from load allocation scenarios. Parameters are described in the **GLOSSARY**.

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. Land use 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.

The GWLF model was developed to simulate runoff, sediment and nutrients in ungauged watersheds based on landscape conditions such as land use/land cover, 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, 1975;

England, 1970). In the GWLF model, the nonpoint source load calculation for sediment is affected by land use activity (*e.g.,* farming practices), topographic parameters, soil characteristics, soil cover conditions, stream channel conditions, livestock access, and weather. The model uses land use 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 land use topographic conditions that would be expected to give a homogeneous response to a given rainfall input. A number of parameters are included in the model to index the effect of varying soil-topographic conditions by land use entities. A description of model parameters is given in the **GLOSSARY** and a description of how parameters and other data were calculated and/or assembled is below.

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 (USLE) (Schwab et al., 1981; Wischmeier and Smith, 1978). Buildup and loss functions for impervious surfaces are also included in the model. 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 were based on a water year starting on October 1st and ending on September 30th. The transport file contains input data related to hydrology and sediment transport. The nutrient file contains nutrient values for the various land uses, point sources, and septic system types, and also urban sediment buildup rates.

GWLF Model Setup

Watershed data needed to run GWLF used in this study was generated using GIS spatial coverage, local weather data, streamflow data, literature values, and other data. Subwatersheds are not required to run the GWLF model. For the sediment TMDL development, the total area for the reference watershed was equated to the area of impaired watershed. To accomplish this, each land use category in reference watershed

was proportionately decreased by a fixed ratio based on the relative size of the reference watershed to the impaired watershed.

Source Representation

Three source areas were identified as the primary contributors to sediment loading in Beaver Creek that are the focus of this study – surface runoff, point sources, and streambank erosion. The sedimentation 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.

Surface Runoff

During runoff events (due to natural rainfall or irrigation), sediment is transported to streams from pervious land areas (*e.g.,* agricultural fields, lawns, forest.). 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), conventional tillage operations, livestock concentrations (*e.g.,* along stream edge, uncontrolled access to streams), forest harvesting, and land disturbance due to mining 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).

Channel and Streambank Erosion

An increase in impervious land without appropriate stormwater control increases runoff volume and peak flow rates, 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, 1989; Kaufman and Kruger, 1984). Increasing the bankfull width decreases

stream depth, increases sediment, and adversely affects aquatic habitat (USDI, 1998). Management practices that allow mowing, paving, building, or material storage up to the edge of a stream or bank cause instability as well. These practices do not allow natural stream migration across the floodplain and allow room for flood waters to dissipate. This makes banks and stream segments unstable and erosion from banks more prominent.

TSS Point Sources

Fine sediments are included in TSS loads that are permitted for various facilities within the Beaver Creek watershed. Sediment loads from permitted wastewater outflows and industrial and construction stormwater discharges are included in the WLA component of the TMDL, in compliance with 40 CFR§130.2(h).

Sediment Source Representation – Input Requirements

The GWLF model was developed to simulate runoff, sediment and nutrients in ungauged watersheds based on landscape conditions such as land use/land cover, topography, and soils. The following sections describe required inputs for the GWLF program.

Weather Data

Daily precipitation data was available near the Beaver Creek watershed at the Abingdon NCDC Coop station #440021. The few missing values were filled with daily precipitation from the Lebanon NCDC Coop #444777, with any remaining gaps filled with daily precipitation data from the Bristol Airport Coop station #013877.

Land Use and Land Cover

Land use distributions for the Beaver Creek watershed, and for the area-adjusted Walker Creek watershed are given in **Table C. 1**. Land use acreage for the reference watersheds were adjusted down by the ratio of impaired watershed to reference watershed maintaining the original land use distribution. These areas were used for modeling sediment.

Table C. 1 Land use areas used in the GWLF model for the Beaver Creek and area-adjusted Walker Creek watersheds.

Land Use	Beaver Creek ha	Area-Adjusted Walker Creek ha
Pervious Area		
Water	115.57	55.15
Row Crop - High Till	44.15	2.63
Row Crop - Low Till	27.52	7.21
Pasture	2827.59	2449.07
Hay	994.10	719.00
Forest	2796.61	5471.25
Barren	1.70	3.03
Developed	1693.77	359.50
Commercial	153.32	16.09
Impervious Area		
Developed	265.80	46.07
Commercial	227.20	18.33
Watershed Total	**9147.32**	**9147.32**

Erosion Parameters

Erosion parameters in GWLF include USLE parameters erodibility factor (K), combined slope length and gradient factor (LS), cover crop factor (C), and practice factor (P). The product of the USLE parameters, KLSCP, is entered as input to GWLF. Soils data used to estimate many of these parameters for the watersheds was obtained from the Soil Survey Geographic (SSURGO) database for Virginia (NRCS, 2012). The K factor relates to a soil's inherent erodibility and affects the amount of soil erosion from a given field. The area-weighted K-factor by land use category was calculated using GIS procedures. The combined LS factor was calculated from USGS National Elevation Dataset data using GIS techniques. The length of slope was estimated using GIS procedures developed by MapTech, Inc that consider the path of flow in raster-based GIS. The area-weighted LS factor was calculated for each land use category using procedures recommended by Wischmeier and Smith (1978). The weighted C-factor for each land use category was estimated following guidelines given in Wischmeier and Smith (1978), the GWLF User's Manual (Haith et al., 1992) and Kleene (1995). The

practice factor (P) was set at 1.0 for all lands except for conservation tillage were it was set to 0.5.

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). The value used for the Beaver Creek and area-adjusted Walker Creek watersheds was 0.1312.

SCS Runoff Curve Number

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

Parameters for Channel and Streambank Erosion

Parameters for streambank erosion include animal density, total length of perennial stream channel, fraction of developed land, mean stream depth, average watershed curve number, average watershed erodibility, and average watershed slope. The animal density was calculated by dividing the number of animal units by watershed area in acres. The total length of the perennial stream channel was estimated from USGS NHD hydrography

coverage using GIS techniques. The mean stream depth was estimated as a function of watershed area using regional curves (Keaton et al., 2005).

Evapotranspiration Cover Coefficients

Evapotranspiration (ET) cover coefficients were entered by month. Monthly ET cover coefficients were assigned each land use/land cover condition following procedures outlined in Novotny and Chesters (1981) and GWLF guidance. Area-weighted ET cover coefficients were then calculated for each month for both watersheds. These values were then adjusted during hydrology calibration.

TSS and Direct Sources

There are three individual VPDES permits in the Beaver Creek watershed study area and one proposed permit for a new wastewater treatment facility. These permits each have associated design flow rates and permitted sediment concentrations (**Table C. 2**). For domestic wastewater treatment (general) permits, the design discharge was multiplied by the permitted TSS concentration and then converted to get a permit load in metric tons per year (t/yr).

Table C. 2 VPDES permits within the Beaver Creek watershed study area.

Permit ID	Type	Name	Design Flow MGD	Permitted Concentration mg/L
VAG400012	Individual	Domestic	0.001	30
VAG400209	Individual	Domestic	0.001	30
VAG400210	Individual	Domestic	0.001	30
-	General	Proposed WWTP	1.5	30

Nine industrial stormwater permits are within the study area (**Table C. 3**). A large portion of the Bristol City Municipal Separate Sewer System (MS4) permit is also included in the study area. This is land with stormwater runoff collection that discharges into surface waters. The land area within the permit boundaries has sediment from land-based sources which can be present in the runoff. In the model, only impervious areas

within the City of Bristol which were present in the watershed study area were considered.

Industrial stormwater permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 100 mg/L. The modeled runoff for the construction stormwater discharge was estimated as equal to the annual runoff from impervious areas, except for permit VAR050053 (Bristol Integrated Solid Waste Management Facility) which was treated as barren land. The load from the Bristol City MS4 was calculated as the load coming from the total impervious area of the watershed that was within the City boundaries.

Table C. 3 Stormwater permits in the Beaver Creek watershed study area.

Permit ID	Name	Permitted Concentration (mg/L)
VAR050028	Universal Fibers Inc	100
VAR050043	Bristol Compressors Incorporated	100
VAR050053	Bristol Integrated Solid Waste Management Facility	100
VAR050080	Federal Pacific Transformer Company	100
VAR050081	Line Power Manufacturing Corporation	100
VAR050084	Carolina Steel Group LLC - Abingdon	100
VAR050468	Sandvik Mining and Construction USA	100
VAR051522	AZZ Incorporated - Bristol	100
VAR051907	Wise Recycling - Bristol	100
VAR040048	Bristol City MS4	n/a

Several construction stormwater permits currently exist within the watershed. A list of these permits is presented in **Table C. 4**. Construction stormwater permitted loads were calculated as the average annual modeled runoff times the area governed by the permit times a maximum TSS concentration of 60 mg/L. The modeled runoff for the construction stormwater discharge was estimated as equal to the annual runoff from barren areas.

Table C. 4 Construction stormwater permits currently present in the study area.

Permit Number	Disturbed Acreage	Estimated Project Start Date	Estimated Project End Date
VAR10-10-100439	3	12/1/2005	12/31/2013
VAR10-13-100307	3.1	9/17/2012	11/15/2013

Selection of Representative Modeling Period

In **APPENDIX B: Bacteria Modeling Procedure** , the time period of 1 October 2007 to 30 September 2010 was chosen as the hydrologic calibration and bacterial load allocation period. This same time period was chosen as the calibration and allocation period for the sediment model as well because it best represents the range of flows the watershed regularly experiences. **Figure B. 8** and **Figure B. 9** show how the selected time period encompasses a range of precipitation and flow conditions.

GWLF Hydrology Calibration

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

Flow output from the calibrated HSPF model (**APPENDIX B: Bacteria Modeling Procedure**) from 10/2007 through 9/2010 was used to calibrate the GWLF model. The nearest USGS stream gauge (Station 03478400), was located partway up the watershed, and it was determined that the calibrated HSPF model outputs would be more accurate than purely scaling up the flow measured at the stream gauge to the larger watershed size. The final GWLF calibration results for Beaver Creek are displayed in **Figure C. 1** and **Figure C. 2** for the calibration period with statistics showing the accuracy of fit given in **Table C. 5**. Model calibration was considered good for total runoff volume. Monthly

fluctuations were variable, but were still reasonable considering the general simplicity of GWLF. The same changes made to parameters in the Beaver Creek GWLF model were instituted in the reference watershed model, though there was no stream flow data available to use in assessing the calibration of the Walker Creek model.

Table C. 5 GWLF flow calibration statistics for Beaver Creek.

Watershed	Simulation Period	Correlation Coefficient	Total Volume Error (Sim-Obs)
Beaver Creek outlet, calibrated to HSPF output	10/1/2007 – 9/30/2010	0.9169	-2.29%

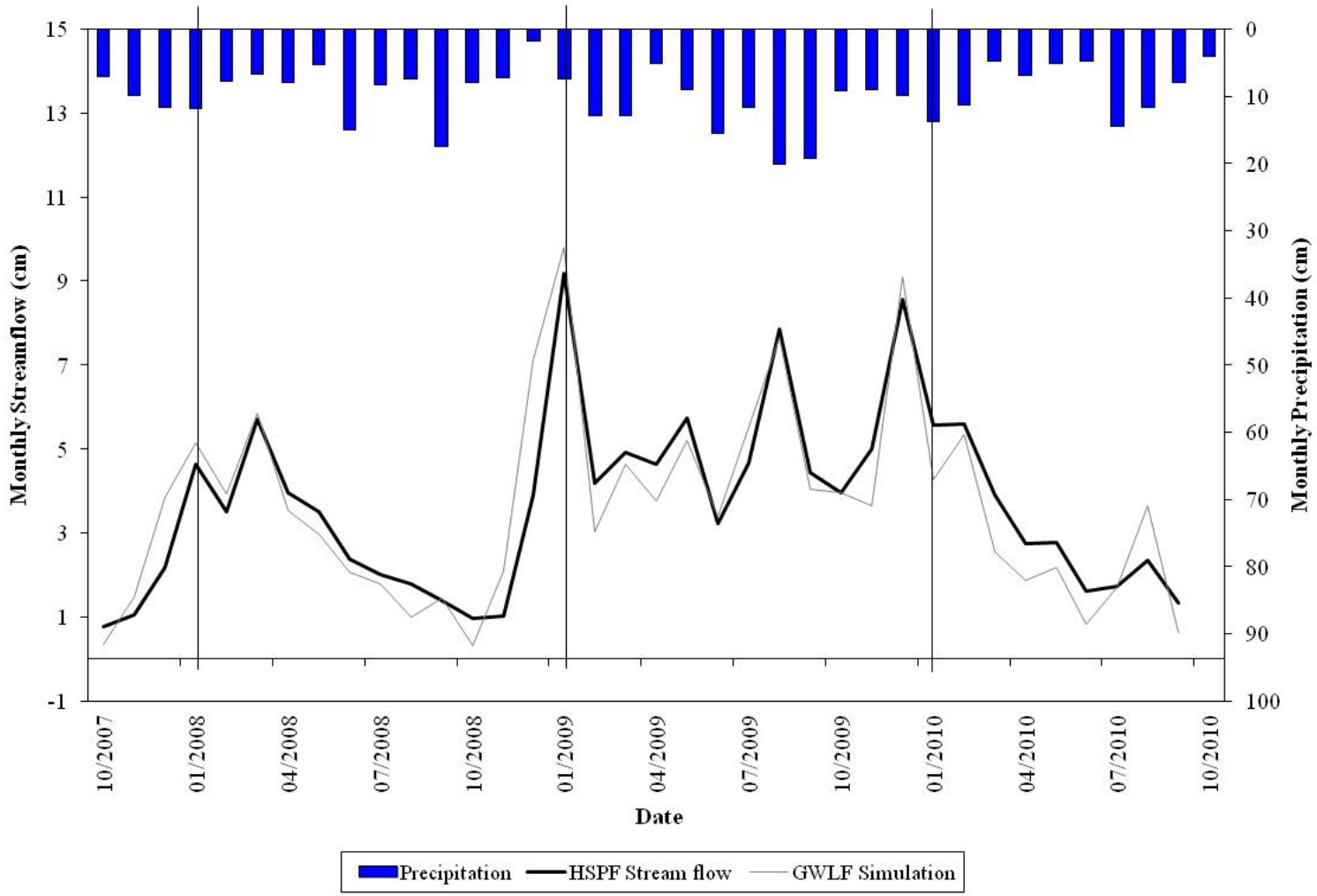

Figure C. 1 Comparison of monthly GWLF simulated and monthly HSPF simulated streamflow in Beaver Creek for calibration period (10/2007-9/2010).

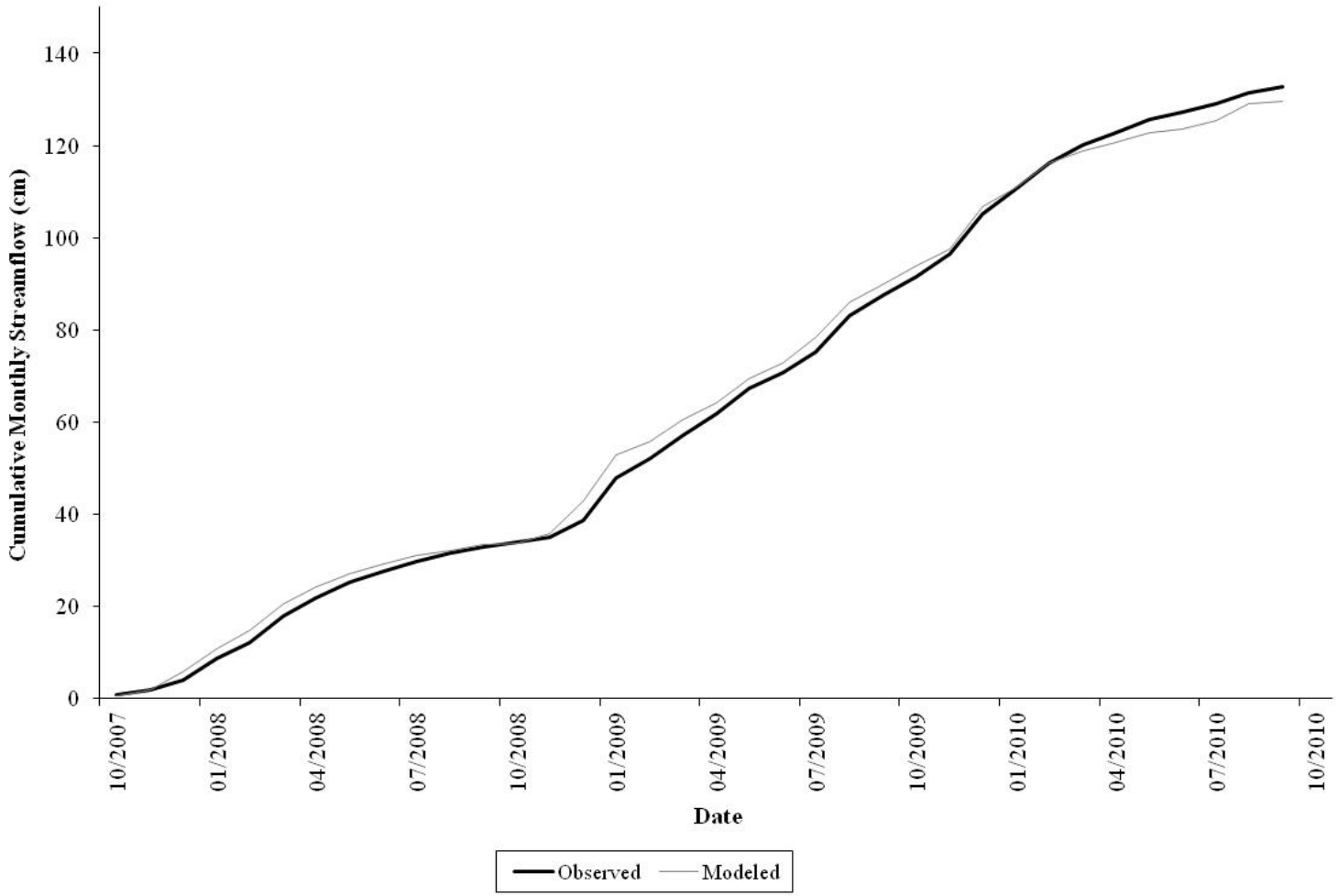

Figure C. 2 Comparison of cumulative monthly GWLF simulated (Modeled) and cumulative HSPF simulated (Observed) streamflow in Beaver Creek for calibration period (10/2007-9/2010).

GWLF 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 land disturbance, runoff curve number, etc.). Sensitivity analyses were run on the runoff curve number (CN), , the recession coefficient, the seepage coefficient, the unsaturated available water capacity (AWC), the Evapotranspiration (ET) Coefficient, and the combined erosion factor (KLSCP) that encompasses the effects of soil erodibility, land slope, land cover, and management practices (**Table C. 6**).

Table C. 6 Base parameters used in GWLF sensitivity analysis.

Land use	CN	KLSCP	Recession Coefficient (1/d)	Seepage Coefficient (1/d)	Unsaturated Available Water Capacity (AWC)	Evapotranspiration (ET) Coefficient
Entire Watershed			0.13	0.1	8.0527	0.5 – 0.8
Pervious Area						
Water	98.00	0				
Row Crop - High Till	78.90	0.25835				
Row Crop - Low Till	75.26	0.05066				
Pasture	65.16	0.02684				
Hay	60.34	0.00382				
Forest	57.86	0.00079				
Barren	84.72	0.23062				
Developed	63.34	0.00369				
Commercial	63.34	0.00507				
Impervious Area						
Developed	98.00	0				
Commercial	98.00	0				

For a given simulation, the model parameters in **Table C. 6** were set at the base value except for the parameter being evaluated. The parameters were adjusted individually to -10% and +10% of the base value and then the output values from the base run and the

adjusted run were compared. The results in **Table C. 7** show that the parameters are directly correlated with runoff volume and sediment load. The relationships show fairly linear responses with the exception of curve number. Changes in curve numbers have the most influence on the sediment load, while the ET coefficient has the greatest influence on runoff volume. Changes in KLSCP had no impact on hydrology and fair impact on sediment load. Changes in other hydrologic parameters had more impact on runoff volume than on sediment load. Changes in unsaturated AWC were not significant enough to change the model response.

Table C. 7 Sensitivity of GWLF model response to changes in selected parameters for the Beaver Creek watershed.

Model Parameter	Parameter Change (%)	Total Runoff Volume Percent Change (%)	Total Sediment Load Percent Change (%)
CN	+10	4.47	23.18
CN	-10	-4.28	-27.44
KLSCP	+10	0.00	7.80
KLSCP	-10	0.00	-7.80
Recession Coefficient	+10	3.47	0.26
Recession Coefficient	-10	-3.89	-0.30
Seepage Coefficient	+10	-3.49	-0.27
Seepage Coefficient	-10	3.81	0.29
ET Coefficient	+10	-6.08	-0.65
ET Coefficient	-10	6.08	0.60
Unsaturated AWC	+10	0.00	0.00
Unsaturated AWC	-10	0.00	0.00

Sediment Existing Conditions

The GWLF model was parameterized to represent exiting sediment conditions within the impaired and reference watersheds. A list of parameters from the GWLF transport input files that were finalized for existing conditions are given in **Table C. 8**. Monthly evaporation cover coefficients are listed in **Table C. 9**.

Table C. 8 GWLF watershed parameters in the calibrated impaired and area-adjusted reference watersheds.

GWLF Watershed Parameter	Units	Beaver Creek	Walker Creek
Recession Coefficient	day^{-1}	0.13	0.13
Seepage Coefficient	day^{-1}	0.1	0.1
Sediment Delivery Ratio	---	0.1312	0.1312
Unsaturated Water Capacity	(cm)	8.0527	7.662347488
Rainfall Erosivity Coefficient (Apr-Sep)	---	0.28	0.28
Rainfall Erosivity Coefficient (Oct-Mar)	---	0.1	0.1
% Developed land	(%)	11.8	1.0
Livestock density	(AU/ac)	0.23954	0.08849
Area-weighted soil erodibility (K)	---	0.264352	0.266542
Area-weighted Curve Number	---	64.319	63.226
Total Stream Length	(m)	161857	161857
Mean channel depth	(m)	0.42599	0.42599

Table C. 9 Calibrated GWLF monthly evaporation cover coefficients.

Watershed	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar
Beaver Creek	0.7	0.7	0.5	0.7	0.6	0.5	0.6	0.8	0.9	0.7	0.8	0.8
Walker Creek	0.7	0.7	0.5	0.7	0.6	0.5	0.6	0.8	0.9	0.7	0.8	0.8

Table C. 10 lists the area-weighted USLE erosion parameter (KLSCP) and runoff curve number by land use for each watershed. The curve number values are area weighted by land use.

Table C. 10 GWLF curve numbers and KLSCP values for existing conditions in the Beaver Creek and area-adjusted Walker Creek watersheds.

Land Use	Beaver Creek		Area-Adjusted Walker Creek	
	CN	KLSCP	CN	KLSCP
Pervious Area				
Water	98.00	0	98.00	0
Row Crop - High Till	78.90	0.25835	78.90	0.12775
Row Crop - Low Till	75.26	0.05066	75.26	0.02505
Pasture	65.16	0.02684	66.91	0.04347
Hay	60.34	0.00382	60.51	0.00420
Forest	57.86	0.00079	61.07	0.00086
Barren	84.72	0.23062	85.42	0.70291
Developed	63.34	0.00369	64.31	0.00623
Commercial	63.34	0.00507	63.80	0.01623
Impervious Area				
Developed	98.00	0	98.00	0
Commercial	98.00	0	98.00	0

The sediment loads were modeled for existing conditions in Beaver Creek and the reference watershed, Walker Creek. The existing condition is the combined sediment load, which compares to the area-adjusted reference watershed load (**Table C. 11**).

Table C. 11 Existing sediment loads for the Beaver Creek and area-adjusted Walker Creek watersheds.

Sediment Source	Beaver Creek		Area-adjusted Walker Creek	
	t/yr	t/ha/yr	t/yr	t/ha/yr
Pervious Area				
Row Crop - High Till	317.81	7.20	9.46	3.60
Row Crop - Low Till	32.41	1.18	4.24	0.59
Pasture	1457.01	0.52	2209.21	0.90
Hay	53.13	0.05	44.69	0.06
Forest	19.22	0.01	56.49	0.01
Barren	12.93	7.62	71.37	23.52
Developed	84.03	0.05	35.14	0.10
Commercial	10.44	0.07	3.86	0.24
Impervious Area				
Developed	33.47	0.49	22.35	0.49
Commercial	25.267	0.49	8.89	0.49
Direct Sources				
Channel Erosion	323.750	na	86.69	na
Permitted Sources				
General Permits	0.12	na		
Construction Permits	6.48	na		
Stormwater Permits	56.60	na		
MS4	159.97	na		
Watershed Totals	**2592.64**	**0.28**	**2552.41**	**0.28**

APPENDIX D: CURRENT CONDITIONS FECAL COLIFORM LOADS

CURRENT CONDITIONS FECAL COLIFORM LOADS

Table D. 1 Current conditions of land applied fecal coliform load for the Beaver Creek watershed by land use.

Land-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Developed	5.9E+12	5.3E+12	5.9E+12	5.7E+12	5.9E+12	5.7E+12	5.9E+12	5.9E+12	5.7E+12	5.9E+12	5.7E+12	5.9E+12	6.9E+13
Commercial	6.4E+12	5.7E+12	6.4E+12	6.2E+12	6.4E+12	6.2E+12	6.4E+12	6.4E+12	6.2E+12	6.4E+12	6.2E+12	6.4E+12	7.5E+13
Barren	8.8E+12	7.9E+12	8.8E+12	8.5E+12	8.8E+12	8.5E+12	8.8E+12	8.8E+12	8.5E+12	8.8E+12	8.5E+12	8.8E+12	1.0E+14
Cropland	2.0E+13	2.2E+13	1.6E+14	1.6E+14	1.6E+14	6.5E+12	6.7E+12	6.7E+12	5.2E+13	1.6E+14	1.6E+14	2.0E+13	9.4E+14
Pasture	5.0E+14	4.6E+14	5.0E+14	4.7E+14	4.9E+14	4.8E+14	5.0E+14	5.0E+14	4.7E+14	5.0E+14	4.8E+14	5.0E+14	5.8E+15
LAX	1.2E+13	1.1E+13	1.7E+13	2.3E+13	2.4E+13	2.8E+13	2.9E+13	2.9E+13	2.3E+13	1.7E+13	1.7E+13	1.2E+13	2.4E+14
Forest	2.2E+13	2.0E+13	2.2E+13	2.1E+13	2.2E+13	2.1E+13	2.2E+13	2.2E+13	2.1E+13	2.2E+13	2.1E+13	2.2E+13	2.6E+14

Table D. 2 Monthly, direct deposition fecal coliform loads in each reach of the Beaver Creek watershed.

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Livestock	1	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Wildlife	1	3.1E+09	2.8E+09	3.1E+09	3.0E+09	3.1E+09	3.0E+09	3.1E+09	3.1E+09	3.0E+09	3.1E+09	3.0E+09	3.1E+09	3.6E+10
Human/Pet	2	9.1E+11	8.3E+11	9.1E+11	8.9E+11	9.1E+11	8.9E+11	9.1E+11	9.1E+11	8.9E+11	9.1E+11	8.9E+11	9.1E+11	1.1E+13
Livestock	2	1.6E+10	1.4E+10	2.1E+10	3.0E+10	3.1E+10	3.5E+10	3.6E+10	3.6E+10	3.0E+10	2.1E+10	2.0E+10	1.6E+10	3.1E+11
Wildlife	2	3.9E+10	3.5E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	4.6E+11
Human/Pet	3	9.1E+10	8.3E+10	9.1E+10	8.9E+10	9.1E+10	8.9E+10	9.1E+10	9.1E+10	8.9E+10	9.1E+10	8.9E+10	9.1E+10	1.1E+12
Livestock	3	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Wildlife	3	4.9E+09	4.4E+09	4.9E+09	4.7E+09	4.9E+09	4.7E+09	4.9E+09	4.9E+09	4.7E+09	4.9E+09	4.7E+09	4.9E+09	5.7E+10
Human/Pet	4	9.1E+10	8.3E+10	9.1E+10	8.9E+10	9.1E+10	8.9E+10	9.1E+10	9.1E+10	8.9E+10	9.1E+10	8.9E+10	9.1E+10	1.1E+12
Livestock	4	1.7E+09	1.5E+09	2.3E+09	3.3E+09	3.4E+09	3.8E+09	4.0E+09	4.0E+09	3.3E+09	2.3E+09	2.2E+09	1.7E+09	3.4E+10
Wildlife	4	2.2E+10	1.9E+10	2.2E+10	2.1E+10	2.2E+10	2.1E+10	2.2E+10	2.2E+10	2.1E+10	2.2E+10	2.1E+10	2.2E+10	2.5E+11
Human/Pet	5	1.0E+12	9.1E+11	1.0E+12	9.7E+11	1.0E+12	9.7E+11	1.0E+12	1.0E+12	9.7E+11	1.0E+12	9.7E+11	1.0E+12	1.2E+13
Livestock	5	3.9E+10	3.5E+10	5.2E+10	7.5E+10	7.7E+10	8.7E+10	9.0E+10	9.0E+10	7.5E+10	5.2E+10	5.0E+10	3.9E+10	7.6E+11
Wildlife	5	3.9E+10	3.5E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	4.6E+11
Human/Pet	6	3.7E+11	3.3E+11	3.7E+11	3.5E+11	3.7E+11	3.5E+11	3.7E+11	3.7E+11	3.5E+11	3.7E+11	3.5E+11	3.7E+11	4.3E+12
Livestock	6	4.2E+10	3.8E+10	5.6E+10	8.1E+10	8.4E+10	9.5E+10	9.8E+10	9.8E+10	8.1E+10	5.6E+10	5.4E+10	4.2E+10	8.3E+11
Wildlife	6	4.6E+10	4.1E+10	4.6E+10	4.4E+10	4.6E+10	4.4E+10	4.6E+10	4.6E+10	4.4E+10	4.6E+10	4.4E+10	4.6E+10	5.4E+11
Human/Pet	7	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Livestock	7	5.2E+08	4.7E+08	7.0E+08	1.0E+09	1.1E+09	1.2E+09	1.2E+09	1.2E+09	1.0E+09	7.0E+08	6.8E+08	5.2E+08	1.0E+10
Wildlife	7	3.1E+09	2.8E+09	3.1E+09	3.0E+09	3.1E+09	3.0E+09	3.1E+09	3.1E+09	3.0E+09	3.1E+09	3.0E+09	3.1E+09	3.6E+10

Table D. 3 Monthly, direct deposition fecal coliform loads in each reach of the Beaver Creek watershed (continued).

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	8	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Livestock	8	9.7E+09	8.7E+09	1.3E+10	1.9E+10	1.9E+10	2.2E+10	2.3E+10	2.3E+10	1.9E+10	1.3E+10	1.3E+10	9.7E+09	1.9E+11
Wildlife	8	1.9E+10	1.7E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	1.9E+10	2.3E+11
Human/Pet	9	1.4E+12	1.2E+12	1.4E+12	1.3E+12	1.4E+12	1.3E+12	1.4E+12	1.4E+12	1.3E+12	1.4E+12	1.3E+12	1.4E+12	1.6E+13
Livestock	9	7.4E+10	6.6E+10	9.8E+10	1.4E+11	1.5E+11	1.7E+11	1.7E+11	1.7E+11	1.4E+11	9.8E+10	9.5E+10	7.4E+10	1.4E+12
Wildlife	9	5.1E+10	4.6E+10	5.1E+10	4.9E+10	5.1E+10	4.9E+10	5.1E+10	5.1E+10	4.9E+10	5.1E+10	4.9E+10	5.1E+10	6.0E+11
Human/Pet	10	1.4E+12	1.2E+12	1.4E+12	1.3E+12	1.4E+12	1.3E+12	1.4E+12	1.4E+12	1.3E+12	1.4E+12	1.3E+12	1.4E+12	1.6E+13
Livestock	10	2.3E+10	2.1E+10	3.1E+10	4.5E+10	4.7E+10	5.3E+10	5.4E+10	5.4E+10	4.5E+10	3.1E+10	3.0E+10	2.3E+10	4.6E+11
Wildlife	10	2.9E+10	2.6E+10	2.9E+10	2.8E+10	2.9E+10	2.8E+10	2.9E+10	2.9E+10	2.8E+10	2.9E+10	2.8E+10	2.9E+10	3.4E+11
Human/Pet	11	1.8E+12	1.7E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	1.8E+12	2.2E+13
Livestock	11	4.1E+11	3.7E+11	5.4E+11	7.9E+11	8.1E+11	9.2E+11	9.5E+11	9.5E+11	7.9E+11	5.4E+11	5.2E+11	4.1E+11	8.0E+12
Wildlife	11	1.8E+11	1.6E+11	1.8E+11	1.7E+11	1.8E+11	1.7E+11	1.8E+11	1.8E+11	1.7E+11	1.8E+11	1.7E+11	1.8E+11	2.1E+12
Human/Pet	12	2.7E+11	2.5E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	2.7E+11	3.2E+12
Livestock	12	2.5E+11	2.2E+11	3.3E+11	4.8E+11	5.0E+11	5.6E+11	5.8E+11	5.8E+11	4.8E+11	3.3E+11	3.2E+11	2.5E+11	4.9E+12
Wildlife	12	8.3E+10	7.5E+10	8.3E+10	8.1E+10	8.3E+10	8.1E+10	8.3E+10	8.3E+10	8.1E+10	8.3E+10	8.1E+10	8.3E+10	9.8E+11
Human/Pet	13	9.1E+11	8.3E+11	9.1E+11	8.9E+11	9.1E+11	8.9E+11	9.1E+11	9.1E+11	8.9E+11	9.1E+11	8.9E+11	9.1E+11	1.1E+13
Livestock	13	9.8E+10	8.9E+10	1.3E+11	1.9E+11	2.0E+11	2.2E+11	2.3E+11	2.3E+11	1.9E+11	1.3E+11	1.3E+11	9.8E+10	1.9E+12
Wildlife	13	4.3E+10	3.9E+10	4.3E+10	4.1E+10	4.3E+10	4.1E+10	4.3E+10	4.3E+10	4.1E+10	4.3E+10	4.1E+10	4.3E+10	5.0E+11
Human/Pet	14	2.5E+12	2.2E+12	2.5E+12	2.4E+12	2.5E+12	2.4E+12	2.5E+12	2.5E+12	2.4E+12	2.5E+12	2.4E+12	2.5E+12	2.9E+13
Livestock	14	9.0E+10	8.2E+10	1.2E+11	1.8E+11	1.8E+11	2.0E+11	2.1E+11	2.1E+11	1.8E+11	1.2E+11	1.2E+11	9.0E+10	1.8E+12
Wildlife	14	5.8E+10	5.2E+10	5.8E+10	5.6E+10	5.8E+10	5.6E+10	5.8E+10	5.8E+10	5.6E+10	5.8E+10	5.6E+10	5.8E+10	6.8E+11

Table D. 4 Monthly, direct deposition fecal coliform loads in each reach of the Beaver Creek watershed (continued).

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	15	4.9E+12	4.5E+12	4.9E+12	4.8E+12	4.9E+12	4.8E+12	4.9E+12	4.9E+12	4.8E+12	4.9E+12	4.8E+12	4.9E+12	5.8E+13
Livestock	15	8.0E+11	7.2E+11	1.4E+12	1.8E+12	1.8E+12	2.2E+12	2.2E+12	2.2E+12	1.6E+12	1.2E+12	1.2E+12	7.2E+11	1.8E+13
Wildlife	15	1.1E+11	1.0E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.3E+12

Table D. 5 Existing annual loads from land based sources for the Beaver Creek watershed.

Source	Barren	Water	Forest	Cropland	Commercial	Developed	Pasture	LAX
Beaver	0E+00	6E+10	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00
Beef Calf	0E+00	2E+12	0E+00	0E+00	0E+00	0E+00	5E+14	2E+13
Beef Cattle	0E+00	2E+13	0E+00	0E+00	0E+00	0E+00	4E+15	2E+14
Dairy Calf	0E+00	0E+00	0E+00	7E+13	0E+00	0E+00	8E+13	2E+12
Dairy Milker	0E+00	1E+13	0E+00	6E+14	0E+00	0E+00	7E+14	5E+12
Dairy Replacement Heifer	0E+00	0E+00	0E+00	2E+14	0E+00	0E+00	2E+14	6E+12
Deer	1E+13	0E+00	4E+13	5E+12	1E+13	6E+12	1E+12	0E+00
Duck	1E+09	0E+00	1E+09	2E+09	6E+08	7E+08	3E+08	0E+00
Goose	5E+10	0E+00	8E+10	1E+11	3E+10	4E+10	2E+10	0E+00
Horse	0E+00	1E+12	0E+00	0E+00	0E+00	0E+00	2E+14	1E+13
Muskrat	2E+13	0E+00	3E+13	4E+13	1E+13	1E+13	6E+12	0E+00
People with Straight Pipes	0E+00	2E+14	0E+00	0E+00	0E+00	0E+00	0E+00	0E+00
Raccoon	7E+13	0E+00	2E+14	4E+13	5E+13	5E+13	9E+12	0E+00
Sheep	0E+00	7E+10	0E+00	0E+00	0E+00	0E+00	1E+13	6E+11
Turkey	7E+09	0E+00	5E+09	2E+09	6E+09	3E+09	4E+08	0E+00

Table D. 6 Existing annual loads from direct deposition sources for the Beaver Creek watershed.

Source	Annual Total Load (cfu/yr)
Beaver	6.4E+10
Beef Calf	2.5E+12
Beef Cattle	2.2E+13
Dairy Calf	0.0E+00
Dairy Milker	1.3E+13
Dairy Replacement Heifer	0.0E+00
Deer	2.0E+11
Duck	3.3E+08
Goose	1.2E+10
Horse	1.3E+12
Muskrat	6.9E+12
People with Straight Pipes	1.8E+14
Raccoon	1.4E+12
Sheep	7.0E+10
Turkey	5.8E+07

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APPENDIX E: UNIDENTIFIED SOURCE INVESTIGATION

UNIDENTIFIED SOURCE INVESTIGATION

Beaver Creek TMDL Revision Project

Field Investigation Results

Beaver Creek TMDL Revision Project
Field Investigation Results

Background

As calibration of the Beaver Creek water quality model progressed, we discovered a complication. While the model could be adequately calibrated in the upper parts of the watershed, calibration of the model at the watershed outlet (state line) was questionable at best. The results indicated that there may be some significant bacterial load in the Bristol area that is unaccounted for in the model. The load appears to be unassociated with storm events. In order to assess any uncertainty in the current source assessment, the direct loads that have been identified in this area (*e.g.*, wildlife direct deposition and straight pipes) were increased by a factor of 10, as an informal sensitivity analysis. While the model did respond to this increase, the modeled output still did not approach the concentrations that have been monitored.

Further analysis of the monitored data indicates that there is a likely source between station 6CBEV015.62 and station 6CBEV016.59 (**Figure 1**). **Figure 2** shows the data collected from the stations on Beaver Creek during the time period being used for water quality calibration. **Tables 1 and 2** provide a summary of fecal coliform and *E. coli* sampling, respectively. The violation rates, means, and medians are all considerably higher at the two furthest downstream stations (6CBEV015.27 and 6CBEV015.62) than at any of the upstream locations. Rainfall recorded on the sampling days and the two days previous is presented in **Table 3**. Relatively few of the samples were impacted by rainfall events. For those sample events where rainfall occurred on the day of sampling, the total daily rainfall is shown on **Figure 2**, above the water quality results. Concentrations greater than 2,000 cfu/100mL occurred at the downstream station on three occasions when no rainfall was recorded in the three days leading up to sampling. This indicates a "large" source of bacteria that is not storm driven.

In order to further investigate this phenomena, a monitoring plan was developed and executed.

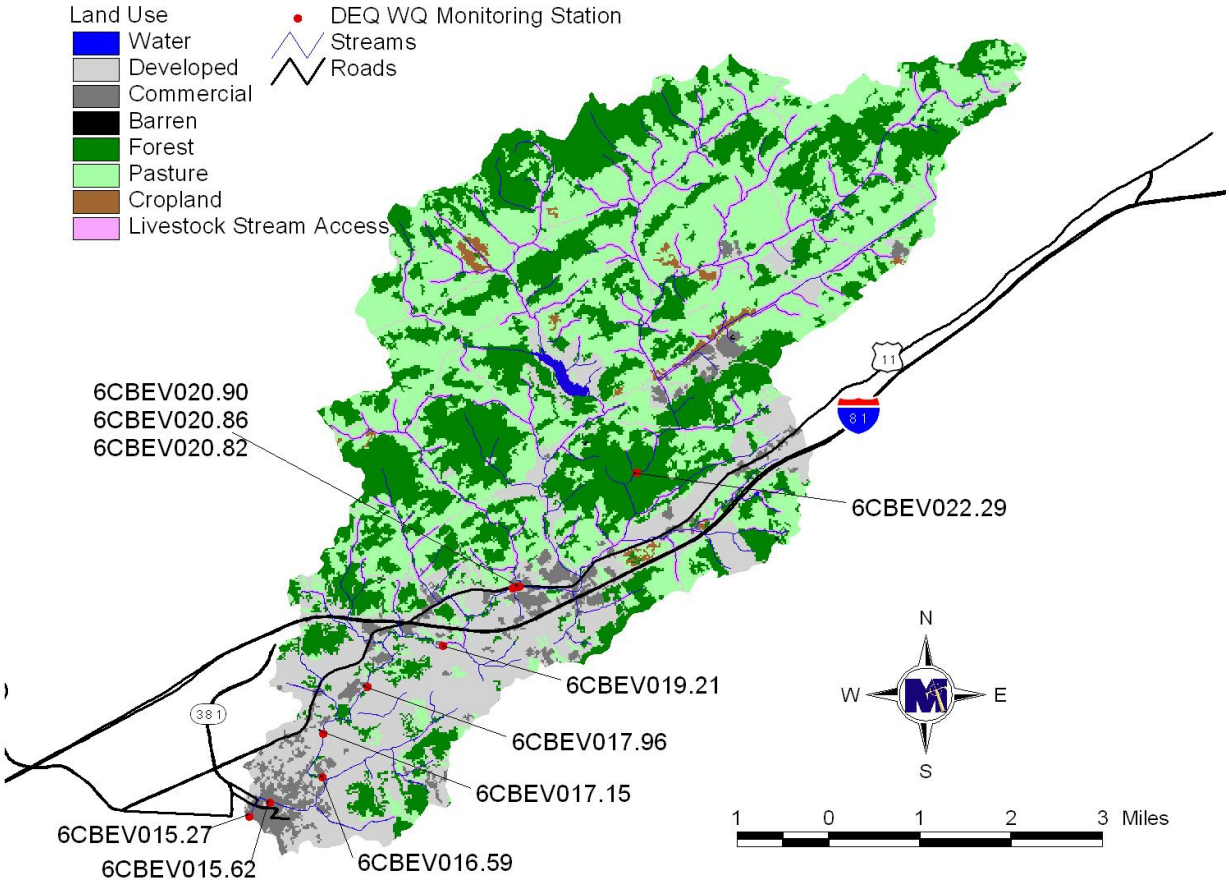

Figure 1. Location of DEQ monitoring stations in the Beaver Creek watershed.

Table 1. Summary of fecal coliform concentrations in samples collected from Beaver Creek.

Station	Date	Count	Minimum	Maximum	Mean	Median	% Violation*
6CBEV015.27	1/01 - 10/02	10	350	5000	2073	1250	90.0
6CBEV015.62	8/01 - 6/03	12	200	6000	1625	800	91.7
6CBEV016.59	8/01 - 6/03	12	100	3300	592	300	41.7
6CBEV017.15	8/01 - 6/03	12	100	1700	625	600	58.3
6CBEV017.96	8/01 - 6/03	12	100	900	383	300	33.3
6CBEV019.21	8/01 - 6/03	12	100	1500	483	350	50.0
6CBEV020.82	10/01 - 6/03	20	50	2000	418	238	30.0
6CBEV020.86	2/01 - 1/02	8	100	8000	1213	200	25.0
6CBEV020.90	10/01 - 1/02	4	200	400	300	300	0.0
6CBEV022.29	8/01 - 6/03	12	100	6000	917	450	50.0

*Based on an instantaneous fecal coliform standard of 400 cfu/100mL.

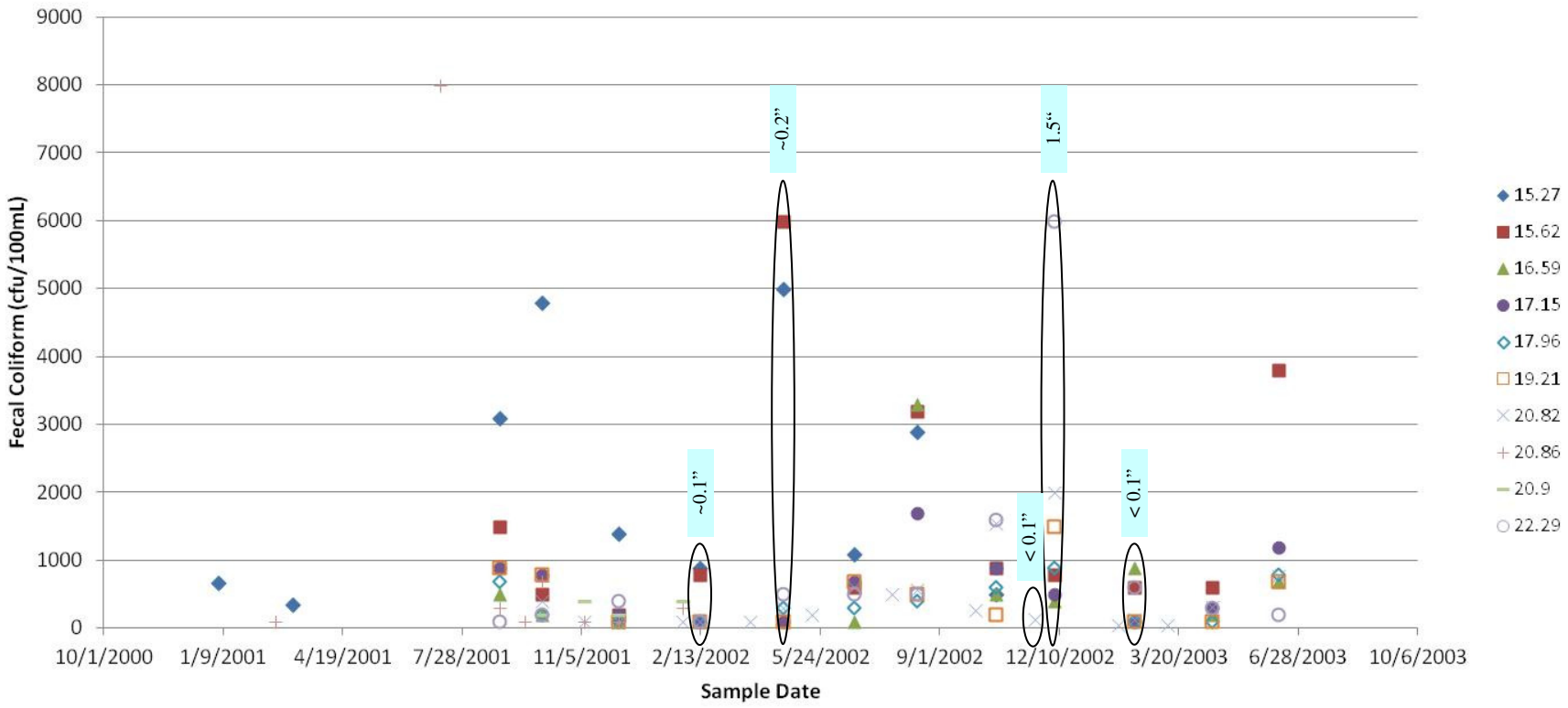

Figure 2. **Fecal coliform concentrations at DEQ monitoring stations in the Beaver Creek watershed (10/1/2000 – 10/6/2003). Monitoring dates that coincided with recorded rainfall are circled, and the total daily rainfall is shown in blue highlight.**

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Table 2. Summary of *E. coli* concentrations in samples collected from Beaver Creek.

Station	Date	Count	Minimum	Maximum	Mean	Median	% Violation*
6CBEV015.27	1/01 - 6/13	36	25	2000	901	738	77.8
6CBEV020.82	7/02 - 6/03	11	20	800	319	230	36.4
6CBEV020.86	9/12 - 6/13	10	25	600	195	63	40.0
6CBEV022.29	9/12 - 7/13	10	25	2000	510	100	40.0

*Based on the current instantaneous *E. coli* standard of 235 cfu/100mL.

Table 3. Precipitation recorded leading up to the sampling events.

Sampling Date	Precipitation (in)		
	day-of	day prior	two days prior
1/4/2001	0	0	0.051
3/7/2001	0	0.181	0.500
8/28/2001	0	0	0
10/2/2001	0	0	0
11/6/2001	0	0	0.039
12/5/2001	0	0	0
1/28/2002	0	0	0
2/11/2002	0.098	0	0
3/25/2002	0	0	0
4/22/2002	0.181	0	0.051
5/16/2002	0	0	0.661
6/20/2002	0	0	0
7/22/2002	0	0	0.760
8/12/2002	0	0	0
9/30/2002	0	0	0.098
10/17/2002	0	2.598	0.169
11/19/2002	0.039	0.098	0.681
12/5/2002	1.551	0	0
1/28/2003	0	0	0
2/10/2003	0.071	0	0
3/10/2003	0	0	0
4/16/2003	0	0	0
6/11/2003	0	0	0.240

Monitoring Approach

The following plan was laid out and executed. In the field, some adjustments to the plan were necessary, due to stream accessibility issues.

1. Field Work

   a. Conduct a stream walk of Beaver Creek, beginning at Moore Street and ending at Fairview Street, where accessible.

   b. Collect water samples and conductivity measurements at 16 sites along the route, including :

      - Most bridges along Beaver Creek, starting at Moore St. and ending at Fairview St.
      - Outlets of 2 tributaries to Beaver Creek
      - Three additional locations on the primary tributary (parallel to King Mill Pike)
      - Additional locations between bridges on Beaver Creek (where needed)

   c. At each location, measure conductivity using a hand-held portable probe, collect two 125-ml water samples for laboratory analysis, take notes/pictures, record coordinates.

   d. The general sampling scheme may be adjusted in the field. Specifically, if a potential/likely source is identified, samples will be collected upstream and downstream of the source, and from the source (if possible). Remaining samples will be redistributed as necessary to accommodate the potential change.

2. Lab Work

   a. For each water sample, enumerate E. coli, and perform single-point fluorometric analysis to evaluate the sample for the presence of optical brighteners.

   b. Conduct a more in-depth 3D fluorometric analysis of samples collected at Moore Street and at Fairview Street, and at 2 additional stations (upstream/downstream) where a shift is identified in the bacteria and single-point fluorometry.

3. Develop Analysis Report

   a. Synthesize data collected in the field and lab into a useful and informative format.

Field Work

The MapTech field team sampled the Beaver Creek watershed on September 24, 2013. Water samples were collected for bacterial and fluorometric analysis. Conductivity was measured on-site. Within a few days the optical brighteners, 3D fluorometry, and bacterial enumerations were completed. *E. coli* colonies were enumerated in MapTech's Environmental Diagnostics Laboratory (EDL).

Table 4 provides the location of the 16 sample collection sites. Sites with a prefix of "BEV" are on Beaver Creek. Sites with a prefix of "XBV" are on an unnamed tributary of Beaver Creek that merges with Beaver Creek just below BEV12. The site numbers ascend upstream in the watershed except BEV10, which is downstream of BEV9, and XBV02, which is downstream of XBV01.

Table 4. Collection site information.

Site ID	Decimal Latitude	Decimal Longitude	Description/comments
BEV01	36.59789551	-82.18242060	Moore St.
BEV02	36.59751936	-82.18117594	Lee St.
BEV03	36.59709315	-82.17937989	Martin Luther King Jr. Blvd.
BEV04	36.59659467	-82.17787528	Washington St.
BEV05	36.59621966	-82.17651023	Goodson St.
BEV06	36.59667942	-82.17326376	William St.
BEV07	36.59727577	-82.17212121	Behind church on Norfolk Ave.
BEV08	36.59827647	-82.17194706	E. Mary St.
BEV09	36.60093342	-82.16983624	Upstream end of parking lot previously owned by Necessary Oil
BEV10*	36.59946951	-82.17055407	Downstream end of parking lot previously owned by Necessary Oil
BEV11	36.60129225	-82.17003095	Upstream of Unnamed Tributary
BEV12	36.60161505	-82.17106832	20ft downstream of Fairview St bridge
XBV01	36.60157415	-82.16876705	Upstream of ford across unnamed tributary.
XBV02**	36.60132408	-82.16974741	Mouth of unnamed tributary.
XBV03	36.60516593	-82.16156441	Corner of Hillside Ave and Kings Mill Pk.
XBV04	36.61013510	-82.15004626	Near Sapling Grove Townhouses on Levina St

Note: * BEV10 is downstream of BEV09.
Note: ** XBV02 is downstream of XBV01.

While the field team was unable to identify with certainty a major pollution source, several potential sources were encountered. These included, in two locations, concrete structures capped with a manhole, which are assumed to be sanitary sewer access. In particular, at sampling location BEV03, located just upstream of the bridge on Martin Luther King Boulevard, the field team observed such a structure that was large and appeared to be fed by multiple PVC pipes (**Figure 3**).

Figure 3. Concrete sewer structure with feeder pipes, at BEV03, just upstream of the bridge on Martin Luther King Boulevard.

In several other locations, the field team encountered pipes running directly from buildings into the stream, although there was no indication that these pipes carried sewage. **Figure 4** and **Figure 5** are examples.

Figure 4. A pipe running from a building discharging into the stream at BEV07.

Figure 5. Pipes from a building discharging into the stream at BEV05. Similar pipes were found on a building on the immediate edge of the opposite bank of the stream.

The conductivity measurements taken at each sample site are listed in **Table 5**. For each site, the sensor portion of the instrument was submerged in the water for several seconds while the readout stabilized and before the value was recorded. Conductivity is a measure of the capacity of water to conduct electricity. Higher conductivity is associated with higher total dissolved solids (TDS), which may be an indication of a stream impairment. All intended conductivities were collected except at BEV08. At this site, the distance from the bridge to the water was

greater than the length of the cable attaching the probe to the display of the sensor, and there was no safe way to collect a sample. Consequently, the conductivity for BEV08 is missing.

Laboratory Analyses

Room-temperature samples were scanned for point optical brighteners (OB) and for 3D fluorescence. They did not need to be corrected for inner-filtering, or pH-adjusted. The samples appeared to have little suspended or colored material that would warrant dilution, and the field pH was not far from normal. No filtering was employed because filtration would remove OBs from solution.

For point-OB readings, the standard laboratory procedure was used. For 3D scans, the output was corrected for Ex:Em (Excitation:Emission) machine peculiarities (EEPROM corrections), masked, and blanked for water interference. Intensities were not normalized. The final matrices were reviewed for general features and intensities were extracted at multiple points for interpretation of known fluorophores.

A portion of the water from each sample was tested for OBs using the MapTech's fluorescence spectrophotometer. The fluorometric region scanned is one of the emission wavelengths for OBs. Optical brighteners are a group of chemicals found in a variety of household products and often associated with human contamination of a waterbody. They are today commonly referred to as fluorescent whitening agents (FWAs). They were introduced into the detergent industry during the early 1950s. Explosive growth in whitener consumption occurred in the 1960s heralded by the 'whiter than white' advertisement campaigns. FWAs remain a universal ingredient in heavy duty home laundry detergents today[1] and in bathroom paper. MapTech presently uses the original term, optical brighteners, for water column FWAs.

Bacteria samples were analyzed to quantify *E. coli* using the membrane filtration technique. Analysis began within 24 hours of collection. All measurements, including conductivity, are listed in **Table 5**. In **Table 5**, the *E. coli* enumerations are evaluated in terms of the primary contact recreation standard, which is 235 cfu/100 mL.

[1] Findley, W. R. July 1983. Whitener Selection for Today's Detergents. JAOCS 60(7):1367- 1369 ; http://www.springerlink.com/content/q62x7598032l53x1/ .

In general, the enumerations correspond with the historical data in that higher densities of bacteria tend to be found lower in the watershed. It is considered important that BEV01, the downstream-most station, had the highest bacterial count. The unnamed tributary results are those for stations with the prefix "XBV". The unnamed tributary appears to be somewhat less populated by bacteria than the sampled segment of Beaver Creek. In other words, although it contributes to the bacteria in the main stem, it does not appear to be a major source of bacteria.

Table 5. Conductivity and optical brightener intensity by fluorescence..

Site ID	Conductivity (µS/cm)	Fluorescence (A.U.)	*E. coli* Enumeration (cfu / 100 mL)	*Evaluation of Instantaneous Standard 235 cfu/100 mL*
BEV01	530	26.069	460	exceeds
BEV02	537	26.317	300	exceeds
BEV03	525	28.224	260	exceeds
BEV04	530	27.661	260	exceeds
BEV05	530	26.487	230	meets
BEV06	520	27.585	300	exceeds
BEV07	525	26.078	220	meets
BEV08	N/A	25.842	330	meets
BEV09	515	25.278	230	meets
BEV10	527	24.933	220	meets
BEV11	522	25.028	260	exceeds
BEV12	520	25.439	250	exceeds
XBV01	635	21.785	190	meets
XBV02	630	22.437	170	meets
XBV03	631	24.894	260	exceeds
XBV04	675	19.567	210	meets

Note: (µS/cm) .. microSiemens per centimeter.
Note: A.U. .. Ångström units
Note: cfu/100 mL .. colony-forming units per 100 milliliters.

Figure 6 demonstrates that the *E. coli* concentrations average near 250 cfu/100 ml, until the jump to 460 cfu/100 ml at Moore St. (BEV01). Several ducks (20-30) were observed in the water upstream of BEV01. Given the volume of water passing through the channel, and the typical fecal production rate of ducks, it is extremely unlikely that this number of ducks could consistently raise the *E. coli* levels to the values that have been seen historically. However, it is possible that this measurement was skewed by a random bit of fecal matter from a duck. The 3D fluorometric analysis, discussed in more detail later in this report, lends some insight into this

possibility. In short, the additional analysis points toward a more diffuse source of bacteria, rather than an actual bit of fecal matter.

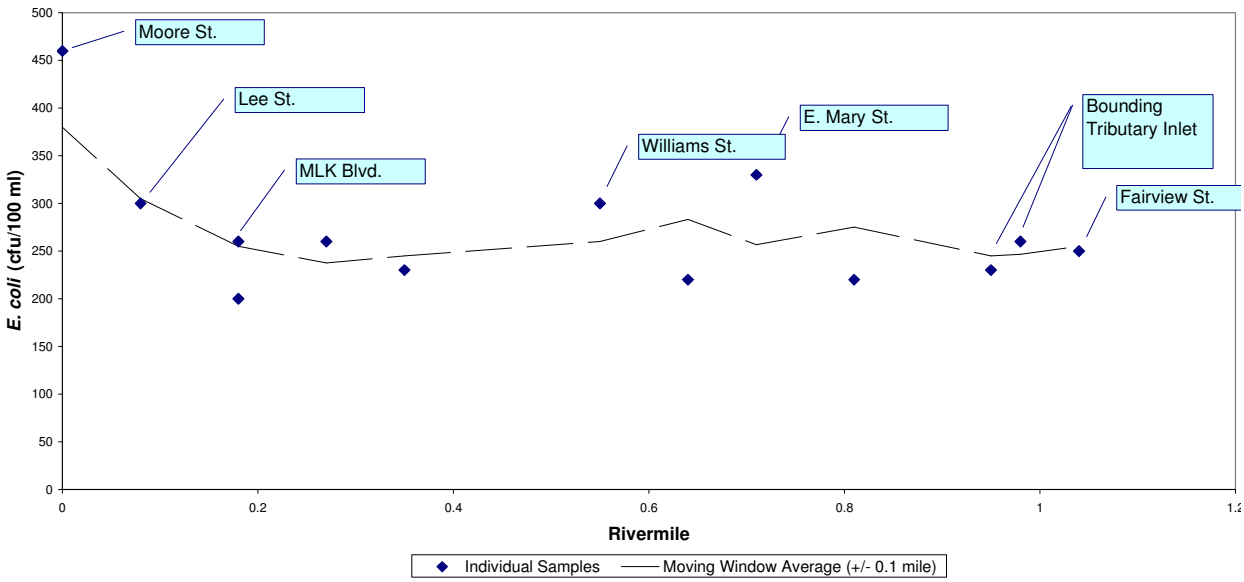

Figure 6. Longitudinal trend in *E. coli* concentrations along Beaver Creek.

In addition to OBs, there are many natural and anthropogenic chemicals that are also fluorescent at various wavelengths of excitation and emission. Thus, one of the interesting uses of fluorometry is in the detection and characterization of pollution. To this end, the final analysis was a 3D fluorometric scan of four sample locations. The four included the downstream-most (BEV01), and the upstream-most (BEV12) site. BEV12 was included in the 3D analysis because it was the farthest upstream and, therefore, a baseline. The remaining two sites were determined based on the OB scans and *E. coli* enumerations. While the OB and enumeration results proved somewhat inconclusive, the enumerations with the historical *E. coli* data suggested that BEV02 and BEV03 would help determine the nature of the source in the vicinity of BEV01 and possibly refine the potential source location.

In 3D fluorescence, a sample is exposed to a spectrum of excitation wavelengths from the far ultraviolet to the human-visible, and the fluorescence is measured across the same range of wavelengths. The results are captured as a matrix of intensities across the Excitation:Emission space. The matrix can be graphed as a three dimensional image, as in **Figure 7**, where the color indicates the intensity of the fluorescence. MapTech uses the Westerhoff et al. (2001) graphical

arrangement for displaying 3D fluorescence where emission is on the X-axis and excitation is on the Y-axis. Here it is useful to examine the 3D scans in six zones (**Figure 7**), which relate to four substances that occur in waterbodies: tryptophan, tyrosine, fulvic acid, and humic acid. These substances are indicators of pollutants in the water column.

Beaver Creek stations BEV01, 02, 03, and 12 are numbered in order, moving upstream. The 3D fluorometric images for these four stations are shown in **Figure 8** and **Figure 9**. Overall, the images reflect those observed in moderately polluted watersheds. The images exhibit about the same intensity for fulvic acid, which appears as a large green spot, and about the same intensity for humic acid which appears as a blotch of yellow color in the upper part of each image. BEV01 was the only sample with a substantial amount of tryptophan-like substance. The signal for the tryptophan is a tongue of green and yellow along the X-axis of the left image in **Figure 8** (left).

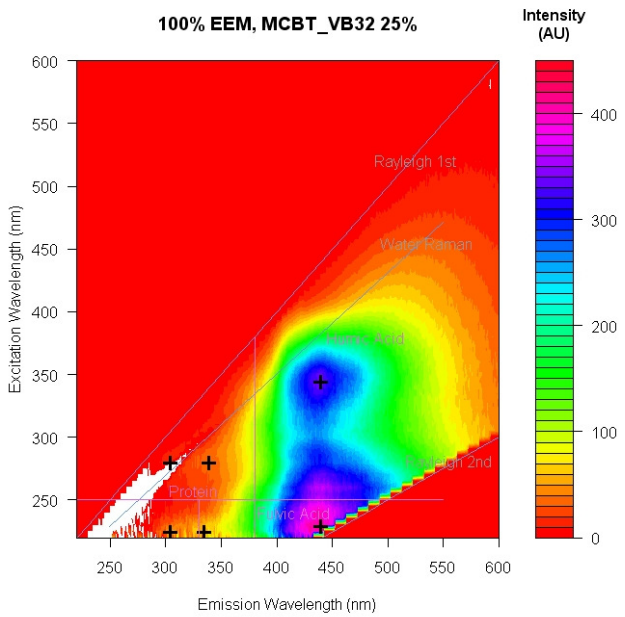

Figure 7. Locations of 6 key fluorophore points (+) on an EEM from the Blackwater River mouth in tidal Virginia.[2]

[2] Source: program: Evaluate MCBT BWR v02.r; input matrix: MCBT_VB32 25%Dil 01-08-10.csv; image: EEM_VB32.jpeg; table: Table14_BWR_Markers.csv.

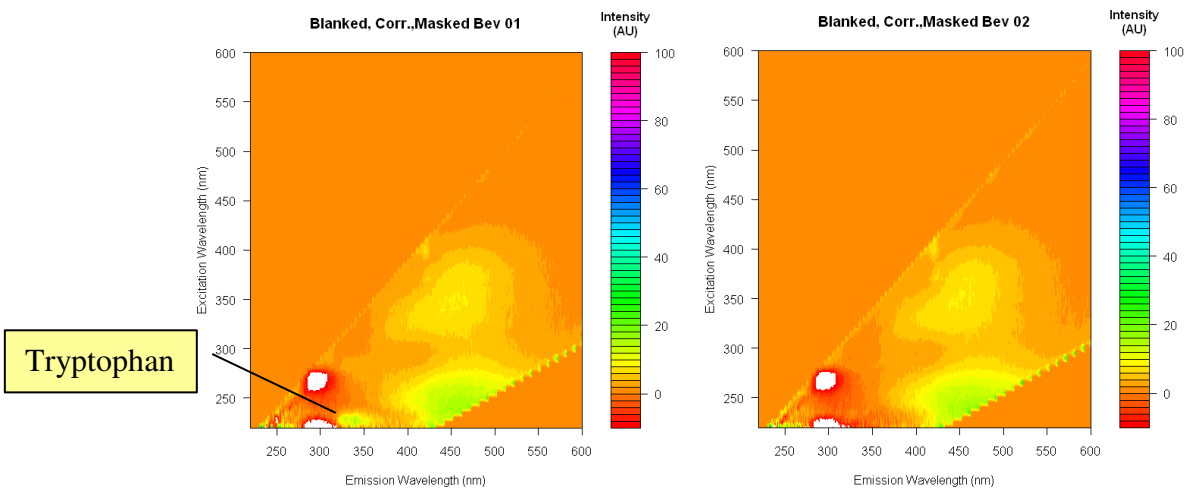

Figure 8. BEV01 (left)[3] and BEV02 (right)[4] fluorescence at 100 AU intensity.

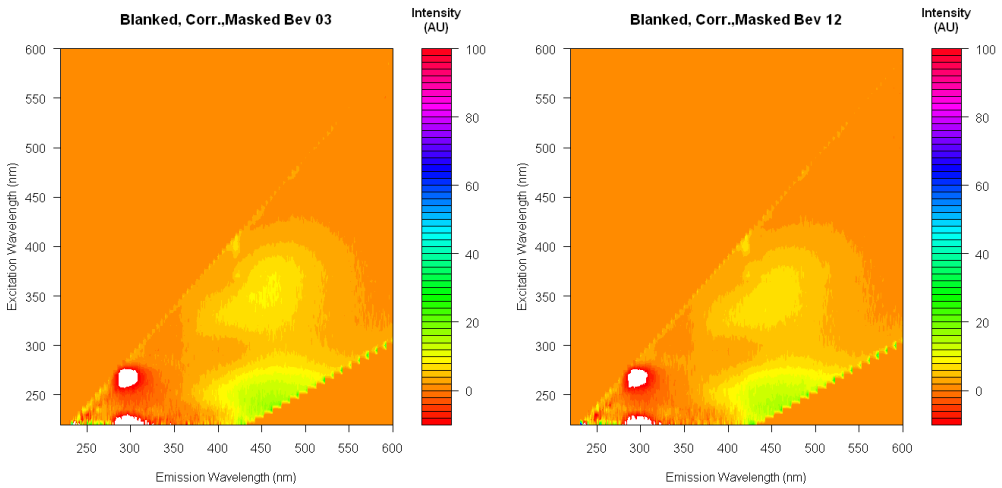

Figure 9. BEV03 (left)[5] and BEV12 (right)[6] fluorescence at 100 AU intensity.

While the overall scan is informative, the interpretation of the 3D image is aided by considering specific peaks and areas. Details from the 3D scans for the Beaver Creek stations, with emphasis on the six marker points from **Figure 7** are presented in **Table 6**.

3 BEV01 MCBT-100AU.jpeg.
4 BEV02 MCBT-100AU.jpeg.
5 BEV03 MCBT-100AU.jpeg.
6 BEV12 MCBT-100AU.jpeg.

Table 6. Selected 3D fluorophore intensities for Beaver Creek compared to standards from the Virginia mountains (Back Creek) and tidewater Virginia (Blackwater Swamp).

Type	Maximum Intens.	Tyrosine LoEx	Tyrosine HiEx*	Tryptophan Lo Ex	Tryptophan HiEx	Fulvic Acid	Humic Acid
Em:Ex Steps:	Max	85_2	85_13	116_2	130_13	210_13	210_23
BEV12, upstream-most point	88.85	-6.90**	-1.27**	0.16	2.16	12.34	6.88
BEV03	62.68	-11.16**	-2.33**	-5.25**	2.14	10.33	7.15
BEV02	82.44	-17.22**	-2.20**	-5.73**	1.95	13.55	7.43
BEV01, downstream-most point	90.00	-7.62**	-0.75**	12.32	2.93	13.15	6.66
References:							
Excitation	NA	225	280	225	280	230	345
Emission	NA	305	305	335	340	440	440
Em:Ex Codes:	Max	211_25	196_29	196_29	121_13	221_13	221_23
Back Creek, western VA	84.4	9.0	NA	9.1	7.9	54.6	22.3
Blackwater Swamp Average, VA	274	-1	10	24	15	230	102

Note: * .. from the final matrix.
**.. negative values are interpreted as zero intensity.

A comparison between intensities in Beaver Creek and the two reference points reveals that the fulvic acid and humic acid intensities are much lower than blackwater swamps of tidal Virginia. They are also lower than the intensities in Back Creek, a moderately organic- and bacteria-polluted stream below a dairy farm in western Virginia. The Back Creek reference was collected in the summer while the Beaver Creek samples were collected in autumn just before leaf fall. It is suspected that a seasonal difference in organic loading is partly responsible for the comparatively low organic matter in Beaver Creek. However, the difference is likely related to the recent low stream temperatures which tend to discourage aquatic life leading to clear streams with little dissolved organic material.

The fluorescence scans indicate that there is substantial low-excitation tryptophan ($tryptophan_{220}$) in BEV01, the downstream-most sample. Tryptophan, an amino acid that fluoresces strongly at an emission wavelength of 220 nm, is the basis for naming the signal tryptophan-like. Based on the values in **Table 6,** it is clear that the other samples contained essentially none of this material. The origin of this signal is tryptophan-like substances and low molecular weight dissolved organic matter typical of sewage. $Tryptophan_{220}$ peaks have also been linked to water quality parameters. In an extensive study of streams, $tryptophan_{220}$ fluorescence intensity was

negatively correlated with dissolved oxygen and positively correlated with ammonia (Baker, et. al. 2005).

Because the fluorometry results are not normalized, measurements will sometimes be negative as some of the tryptophan$_{220}$ values are. These values must be interpreted as zero intensity; that is, indicative of no fluorescence at that wavelength.

Humic acid, the generic term for high molecular weight solutes that fluoresce, is represented by the yellow blotch of color in the upper portion of the EEM for all four 3D stations (**Figure 8** and **Figure 9**). Although there was little humic acid in the samples, it is instructive to consider its source. Westerhoff et al. (2001) and others have employed a ratio called the Fluorescence Index (FI). This is the ratio of the fluorescence intensity after excitation at 370 nm at two emission wave lengths, Em450/Em500. Values around 1.3 indicated terrestrially-derived dissolved organic matter (DOM) while values ~1.45 were more microbe-derived. On that basis, the ratios around 1.3 in Beaver Creek (**Table 7**) suggest the higher molecular weight organics originate more from terrestrial sources than microbial sources. Because there is only a small amount of higher molecular weight solutes in these samples, the ratio interpretation must be viewed with caution. Further, this result does not necessarily mean that the low-excitation tryptophan-like substances have the same origin.

MapTech's point-OB readings in **Table 7** are about seven times larger than the measure from the 3D matrices. This is unsurprising since the point OB readings are collected at a much higher voltage. Meanwhile, the pattern from the 3D scan is the same. That is, the concentration of optical brighteners in Beaver Creek is low and about the same across the watershed.

Table 7. OB point measures and fluorophore intensities for microbial-DOC sources versus terrestrial.

Type	Dixon 2009 OB	MapTech OB From 3D Matrix	MapTech OB Point Measure	Ratio Numerator Reference Wavelength	Ratio Denominator Reference Wavelength	Microbial v.s. Terrestrial Ratio
Table_9b_ Row Step_Column Step (Em_Ex)	211_25	196_29	196_29	231_31	281_31	
BEV12, upstream-most point	6.74	4.55	25.44	6.51	5.15	1.26
BEV03	8.05	4.74	28.22	7.83	6.03	1.30
BEV02	7.01	4.55	26.32	7.54	5.66	1.33
BEV01, downstream-most point	7.43	4.31	26.07	8.06	5.97	1.35

Conclusions/Suggestions

The inherent problem with a one-time monitoring sweep is that it only provides a snapshot of conditions, making it difficult to draw decisive conclusions. However, some useful information can be derived from the data collected.

- While there is a contribution of fecal bacteria from the unnamed tributary to Beaver Creek, it does not appear to be a primary source of the specific issue being explored in this study.
- The additional bacteria load seems to be entering the system in the area below Martin Luther King, Jr. Blvd. (BEV03).
- The lack of a strong Optical Brightener (OB) signature tends to point "away" from human sewage. However, the presence of OBs can be episodic, and the highest value was recorded at the Martin Luther King, Jr. Blvd. location (BEV03).
- No "obvious" persistent sources were identified.
- Ducks near the Moore St. location (BEV01) could have skewed the results in this case, if a small sample of fecal material was inadvertently collected in the sample bottle. However, the 3D fluorometric analysis did not reveal a strong organic matter signature, which would be expected if fecal matter was in the sample. Additionally, the quantity of ducks was not sufficient to have been causing the persistently recorded problems at this station and the downstream (State St.) station.

The information collected suggests some possible actions in moving forward.

- Discussion(s) with stakeholders: It would be useful to determine if there are any suspected issues that could be contributing to the problem, or repairs that have been made in recent years that may negate the earlier high bacteria readings. For instance, has there been identification/correction of cross-connections? Any repair of sewer lines? Any history of clogs/failing pumps?

- Additional sampling: As discussed earlier in the report, it is hard to draw conclusions based on a single sample sweep, since this represents conditions at a single point in time, and loadings from various sources can be episodic in nature. Some potential sampling strategies include:

    - Intensive sampling and analysis for *E. coli* at State St., Moore St., Lee St., and MLK Blvd. Possibly twice weekly sampling for a month or two, in order to further characterize the load.
    - In order to better determine the source of the load, intensive sampling, as described above, with locations informed by any infrastructure maps that are available (*e.g.*, sanitary and storm sewer lines) would be useful. Additionally, Bacterial Source Tracking (BST) would help to determine the relative contributions from human, livestock, wildlife, and pet sources.

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