Bacteria Total Maximum Daily Load Development for North Fork Hardware River and Hardware River

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Executive Summary

Background

The Hardware River watershed lies within both Albemarle and Fluvanna Counties and the North Fork Hardware River flows entirely within Albemarle County. The Hardware River (below the confluence with the North and South Forks) and the North Fork Hardware River both have a bacteria impairment. To differentiate between the two impaired reaches (and the watershed areas associated with those reaches), 'Lower' Hardware refers to the mainstem Hardware River below the confluence with the North Fork Hardware River (see Figure 1.1). The Hardware River is a tributary to the Middle James River (USGS Hydrologic Unit Code 02080203, Middle James - Buffalo), which flows into the Chesapeake Bay at Hampton Roads harbor in southeast Virginia. The North Fork Hardware River is a tributary to Hardware River.

Hardware River has been on the 303(d) impaired waters list since 2002; the North Fork Hardware River has been on list since 2006, and both were most recently listed in the 2006 303(d) Report on Impaired Waters (VADEQ, 2006). Water quality samples collected in the impaired reaches during the 2004 Assessment Period yielded impaired results as shown in Table ES. 1. The interim instantaneous freshwater water quality standard for fecal coliform specifies that fecal coliform concentration in the stream water should not exceed 400 colony forming units (cfu) per 100 mL; the instantaneous standard for *Escherichia coli* specifies that the *E. coli* concentration should not exceed 235 cfu/100 mL. Due to the frequency of water quality violations at the stations listed in Table ES. 1, Lower Hardware River and the North Fork Hardware River remained on Virginia's 2004 303(d) list of impaired water bodies for fecal coliform. These impaired segments have been assessed as not supporting the Clean Water Act's Primary Contact Recreational Use Goal.

Table ES.1. Bacteria standard exceedances during the 2006 assessment period (2000-2004).

Station ID	Exceedances of Interim Fecal Coliform Standard
2-HNF008.28	2 of 9 (22%)
2-HRD011.57	9 of 36 (25%)

This document describes the Total Maximum Daily Loads (TMDLs) for bacteria that were developed for the Lower Hardware and North Fork Hardware watersheds in order to remedy the bacteria water quality impairments. The TMDL was developed for the new water quality standard for bacteria, which states that the calendar-month geometric mean concentration of *E. coli* shall not exceed 126 cfu/100 mL, and that no single sample can exceed a concentration of 235 cfu/100mL. A glossary of terms used in the development of these TMDLs is listed in Appendix A.

Sources of Bacteria

There are two point sources permitted to discharge bacteria into the Hardware River; both of these are located on the South Branch of the North Fork Hardware River. The majority of the bacteria load, however, originates from nonpoint sources. Nonpoint sources of bacteria are often agricultural and include land-applied animal waste and manure deposited on pastures by livestock. A significant bacteria load comes from cattle and wildlife directly depositing feces in streams. Wildlife also contribute to bacteria loadings on all land uses, in accordance with the habitat range for each species. Non-agricultural nonpoint sources of bacteria loadings include straight pipes, failing septic systems, and pet waste. The bacteria load produced in different locations (e.g., confinement, pasture, forest) was estimated on a monthly basis to account for seasonal variability in wildlife behavior and livestock production and practices. Livestock management and production factors, such as the fraction of time cattle spend in confinement, pastures, or streams; the amount of manure storage; and spreading schedules for manure application, were also considered on a monthly basis. These sources of bacteria can be summarized in two ways. First, Table ES. 2

summarizes the bacteria produced in each location (stream, cropland, pasture, residential, and forest). Land-deposited sources of bacteria then undergo die-off and must be transported by runoff from rainfall events into the stream. Direct-deposited sources enter the stream immediately without die-off and without the need for a rainfall event. The relative contributions given in Tables ES. 3-4 reflect the results of modeling (see next section) that takes into account these varied fate and transport processes and represents the fraction of in-stream bacteria attributable to each source.

Table ES. 2. Annual fecal coliform loadings to the stream and the various land use categories for existing conditions in the Lower Hardware and North Fork Hardware watersheds.

Source	Fecal coliform loading ($x10^{12}$ cfu/yr)		Percent of total loading	
	Lower Hardware River	North Fork Hardware River	Lower Hardware River	North Fork Hardware River
Direct loading to streams				
Cattle in stream	326	35	2%	1%
Wildlife in stream	107	0.06	1%	<1%
Straight pipes	33	200	<1%	5%
Point Sources	0	4	0	<1%
Loading to land surfaces				
Cropland	17	0.06	<1%	<1%
Pasture	14,527	3,323	91%	89%
Residential	568	174	4%	5%
Forest	471	16	3%	<1%
Total	16,049	3,753		

Table ES. 3. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in the North Fork Hardware River.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100 mL	Relative Contribution by Source
All Sources	249	
Nonpoint source loadings from pervious land segments	180	72%
Direct nonpoint source loadings to the stream from wildlife	14	6%
Direct nonpoint source loadings to the stream from livestock	55	22%
Interflow and groundwater contribution	< 0.1	<1%
Straight-pipe discharges to stream	< 0.1	<1%
Nonpoint source loadings from impervious land use	< 0.1	<1%
Point sources	< 0.1	<1%

Table ES. 4. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in Lower Hardware River.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100 mL	Relative Contribution by Source
All Sources	249	
Nonpoint source loadings from pervious land segments	32	13%
Direct nonpoint source loadings to the stream from wildlife	44	18%
Direct nonpoint source loadings to the stream from livestock	141	57%
Interflow and groundwater contribution	16	6%
Straight-pipe discharges to stream	16	6%
Nonpoint source loadings from impervious land use	< 0.1	<1%
Point sources	0	0

Modeling

The Hydrological Simulation Program – FORTRAN (HSPF) (Bicknell et al., 2001) was used to simulate the fate and transport of fecal coliform bacteria in the Lower Hardware and North Fork Hardware River watersheds. HSPF is a continuous model that can represent fate and transport of pollutants on both the land surface and in the stream. As recommended by VADEQ, water quality modeling was conducted with fecal coliform inputs, and a translator equation was used to convert the output to *E. coli* for the final TMDL. To identify localized sources of fecal coliform within the watershed, the Lower Hardware watershed was divided into 24 sub-watersheds based on homogeneity of land use, stream network connectivity, and monitoring station locations. The North Fork Hardware River watershed was likewise divided into 20 sub-watersheds.

The hydrology component of HSPF was calibrated using flow data from September 1, 1989 to August 31, 1995; it was validated using data from September 1, 1997 to August 31, 2001. Initial estimates of hydrologic parameters were generated according to the guidance in BASINS Technical Note 6 (USEPA, 2000). These parameters were refined during calibration. The combination of the optimization program PEST and Expert System for the Calibration of HSPF (HSPEXP) was used to aid calibration, and after the successful calibration the default calibration criteria in HSPEXP were met for both the calibration and validation periods.

The water quality component of the HSPF model was calibrated and validated for Lower Hardware River at a monitoring station near the watershed outlet. The model was calibrated during the period from 2000 to 2005 and validated from 1995 to 1998. The North Fork River was calibrated with data from one monitoring station within the watershed, from 1995 to 2005. Inputs to the model included fecal coliform loadings on land and in the stream. A comparison of simulated and observed fecal coliform loadings in the stream indicated that the model adequately simulated the fate and transport of fecal coliform bacteria.

Existing Conditions

Contributions from various sources in the Lower Hardware and the North Fork Hardware River watersheds were represented in HSPF to establish the existing conditions for a representative 3-year period that included both low and high-flow conditions. Monthly bacteria loadings to different land use categories were calculated for each sub-watershed. Direct seasonal bacteria loadings to streams by cattle were calculated for pastures adjacent to streams. Bacteria loadings to streams and land by wildlife were estimated for several species. Bacteria loadings to land from failing septic systems were estimated based on information on failing septic systems from the Department of Health; contributions of bacteria directly to the stream from straight pipes were also estimated based on information from the 2000 Census data, as well as information from other local sources. Bacteria contributions from pet waste were also considered. Meteorological data from 1989-2005 were paired with bacterial loading and land use data for existing conditions to establish this baseline scenario. Results from the calibrated HSPF model showed routine high signatures from livestock direct deposit, wildlife direct deposit, and pervious land surfaces.

Allocation Scenarios

Different source reduction scenarios were evaluated to identify scenarios that meet both the calendar-month geometric mean *E. coli* criterion (126 cfu/100 mL) and the single sample maximum *E. coli* criterion (235 cfu/100 mL) with zero violations. These scenarios were conducted using meteorological data from 1996-1998 to represent a variety of high and low flow conditions. The reductions required for each impaired segment are presented in Table ES. 5 and Table ES. 6. Details on the loads to be reduced from each source are given in Table ES. 7 through Table ES. 10.

Table ES. 5. Successful allocation scenario for the North Fork Hardware River.

Required Fecal Coliform Loading Reductions to Meet the *E. coli* Standards,%					
Cattle DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential
100	99	99	0	100	99

*DD = direct deposit

Table ES. 6. Successful allocation scenario for the Lower Hardware River.

Required Fecal Coliform Loading Reductions to Meet the *E. coli* Standards,%					
Cattle DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential
100	100	100	25	100	100

*DD = direct deposit

Table ES.7. Annual nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation for Lower Hardware River.

	Existing Conditions		Future Conditions		Allocation Scenario	
Land use category	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	Future Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Future Load
Cropland	16	0.1%	16	0.1%	0	100%
Pasture	13,450	93%	8,070	56%	0	100%
Residential*	550	4%	6,108	42%	0	100%
Forest	445	3%	267	2%	267	0%
Total	14,461		14,461		267	98%

*Includes loads applied to pervious areas of both High and Low Density Residential

Table ES. 8. Annual direct nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation for Lower Hardware River.

Source	Existing Conditions		Future Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	Future Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Future Load
Livestock in Streams	302	61%	302	60%	0	100%
Straight Pipes	65	13%	65	13%	0	100%
Wildlife in Streams	131	26%	131	26%	97	25%
Point Sources	0	0	6*	0.01%	6*	0
Total	498		504		103	80%

* 1% of TMDL

Table ES.9. Annual nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation for North Fork Hardware RIver.

Land use category	Existing Conditions		Future Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	Future Conditions Load ($x10^{12}$ cfu/yr)	Percent of total land deposited load from nonpoint sources	TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Future Load
Cropland	22	0.13%	22	0.13%	0.22	99%
Pasture	16,550	94%	16,550	94%	165	99%
Residential*	535	3%	535	3%	5	99%
Forest	431	2%	431	2%	4	0%
Total	17,538		17,538		174	99%

*Includes loads applied to pervious areas of both High and Low Density Residential

Table ES. 10. Annual direct nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation for North Fork Hardware River.

Source	Existing Conditions		Future Conditions		Allocation Scenario	
	Existing Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	Future Conditions Load ($x10^{12}$ cfu/yr)	Percent of total direct deposited load from direct nonpoint source	TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)	Percent Reduction from Future Load
Livestock in Streams	372	58%	372	58%	0	100%
Straight Pipes	94	15%	94	15%	0	100%
Wildlife in Streams	173	27%	173	27%	173	0%
Point Sources	0.06	<0.01%	6*	0.9%	6*	0%
Total	643		645		179	72%

* 1% of TMDL

For North Fork Hardware River, there is one general permit point source and one small point source discharging at or below their permit requirements. For Lower Hardware River, there are no permitted point sources discharging into the river. Therefore, the proposed scenario requires load reductions only for nonpoint sources of fecal coliform. The TMDL was determined as the average annual *E. coli* load at the watershed outlet for the chosen allocation scenarios. The WLA for the North Fork Hardware River watershed was obtained by taking the product of the permitted point sources' *E. coli* discharge concentrations and allowable annual discharges. The WLA for the Lower Hardware River watershed was determined as <1% of the total TMDL load. The LA was then determined as the TMDL-WLA. Equation ES.1 was used to calculate the TMDL allocation shown in Table ES. 11.

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

where:

WLA = wasteload allocation (point source contributions);

LA = load allocation (nonpoint source contributions); and

MOS = margin of safety.

Table ES. 11. Annual *E. coli* loadings (cfu/yr) for the TMDLs.

Impaired Segment	ΣWLA	ΣLA	MOS*	TMDL
Lower Hardware River	0.04×10^{14}	3.64×10^{14}	--	3.68×10^{14}
North Fork Hardware River	0.03×10^{14}	3.48×10^{14}	--	3.51×10^{14}

*Implicit MOS

Transitional Scenario

The implementation of a transitional scenario, or staged implementation, will allow for an evaluation of the effectiveness of management practices and accuracy of model assumptions through data collection. Staged implementation was developed without reductions for wildlife; a target of a 10.5% violation rate of the single sample *E. coli* water quality standard (235 cfu/100 mL) was used where the elimination of wildlife reductions did not prohibit it. A staged scenario for each impaired segment is presented in Tables ES. 12 and 13.

Table ES. 12. Allocation scenario for Stage 1 implementation for Lower Hardware River.

Required Fecal Coliform Loading Reductions to Meet the Instantaneous *E. coli* Standard 89.5% of the Time					
Cattle DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential
75	75	75	0	100	75

*DD = Direct Deposit

Table ES. 13. Allocation scenario for Stage 1 implementation for North Fork Hardware River.

Required Fecal Coliform Loading Reductions to Meet the Instantaneous *E. coli* Standard 89.5% of the Time					
Cattle DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential
70	70	70	0	100	70

*DD = Direct Deposit

Implementation

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in attainment of water quality standards. This report represents the culmination of that effort for the bacteria impairment on Lower Hardware River and North Fork Hardware River. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan and to monitor stream water quality to determine if water quality standards are being attained.

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

Public Participation

Public participation was solicited at every stage of TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In September 2006, members of the Center for TMDL and Watershed Studies at Virginia Tech traveled to Hardware River to become acquainted with the watershed. Throughout the process, personnel from Virginia Tech contacted stakeholders and local agency personnel via telephone and in person to acquire their input. Two public meetings were held to inform stakeholders of the TMDL process and solicit feedback. The first was held on November 30, 2006 in Scottsville, Virginia with 25 people in attendance. The second is to be scheduled. Two Local Steering Committee meetings were also held, on November 8, 2006 and June 6, 2007 in Charlottesville, Virginia. These meetings gathered a group of interested stakeholders and agency personnel who provided more detailed feedback on the estimates and methods used in these TMDLs.

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Chapter 1: Introduction

1.1. Background

1.1.1. TMDL Definition and Regulatory Information

Section 303(d) of the Federal Clean Water Act and the U.S. Environmental Protection Agency's (USEPA) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to identify water bodies that violate state water quality standards and to develop Total Maximum Daily Loads (TMDLs) for such water bodies. A TMDL reflects the total pollutant loading a water body can receive and still meet water quality standards. A TMDL establishes the maximum allowable pollutant loading from both point and nonpoint sources for a water body, allocates the load among the pollutant contributors, and provides a framework for taking actions to restore water quality.

1.1.2. Impairment Listing

Hardware River (VAV-H19R-01) and North Fork Hardware River (VAV-H18R-01) are listed as impaired on Virginia's 2006 Section 303(d) Total Maximum Daily Load Priority List and Report (VADEQ, 2006) due to water quality violations of the bacteria standard (Figure 1.1). The Virginia Department of Environmental Quality (VADEQ) has described the impaired segments as presented in Table 1.1.

Table 1.1. Impaired Segments Addressed in this TMDL report.

Impaired Segment	Size	Target Date for TMDL Development	Description
Hardware River	23.03 miles	2010	Extending from the confluence with the North Fork Hardware River to the confluence with the James River
North Fork Hardware River	10.42 miles	2010	Extending from the headwaters to the South Fork Hardware River confluence

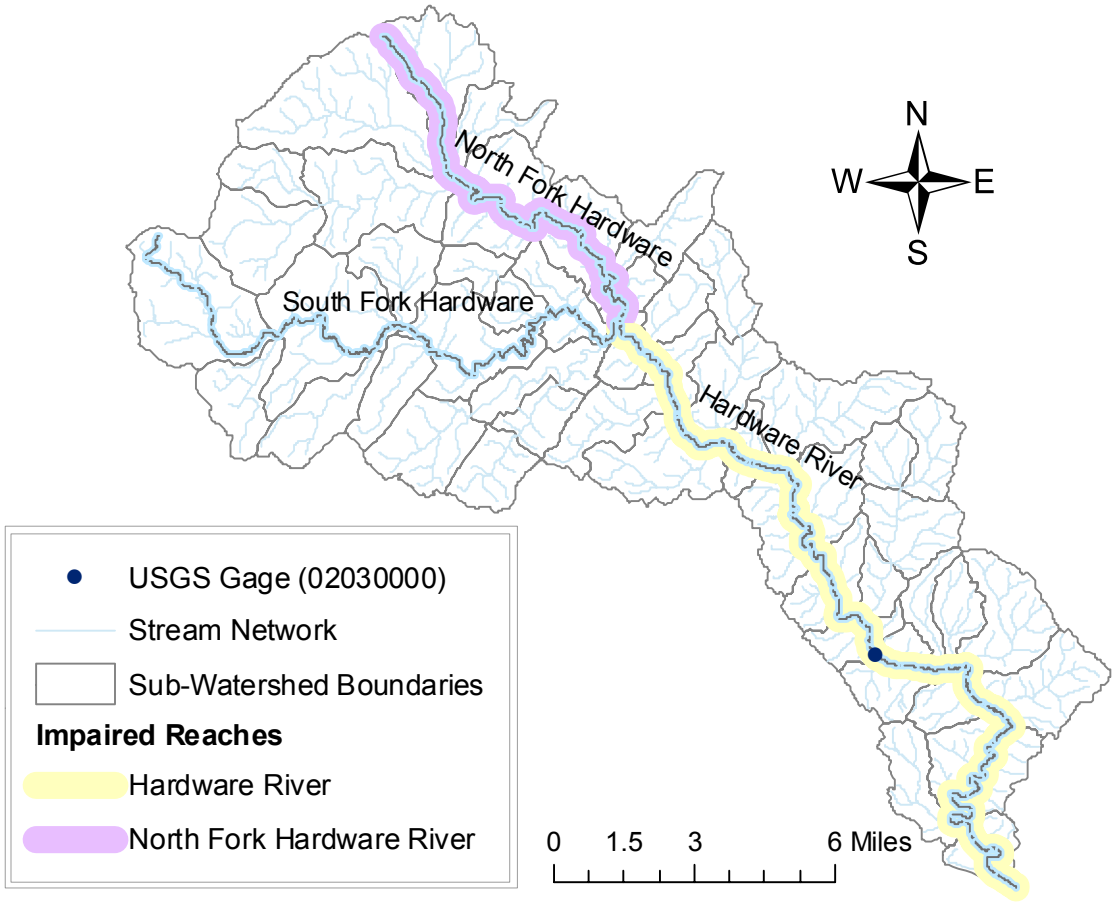

Figure 1.1. Impaired segments in the North Fork Hardware River and Lower Hardware River watersheds.

1.1.3. Watershed Location and Description

The North Fork Hardware and Hardware River are part of the James River basin. The hydrologic units composing the watersheds are H18 for North Fork Hardware River and H19 for Hardware River. For clarity, the H19 hydrologic unit will be referred to as the Lower Hardware watershed and the stream flowing through H19 as the Lower Hardware River in this report. The entire Hardware River watershed stretches across Albemarle and Fluvanna Counties (Figure 1.2).

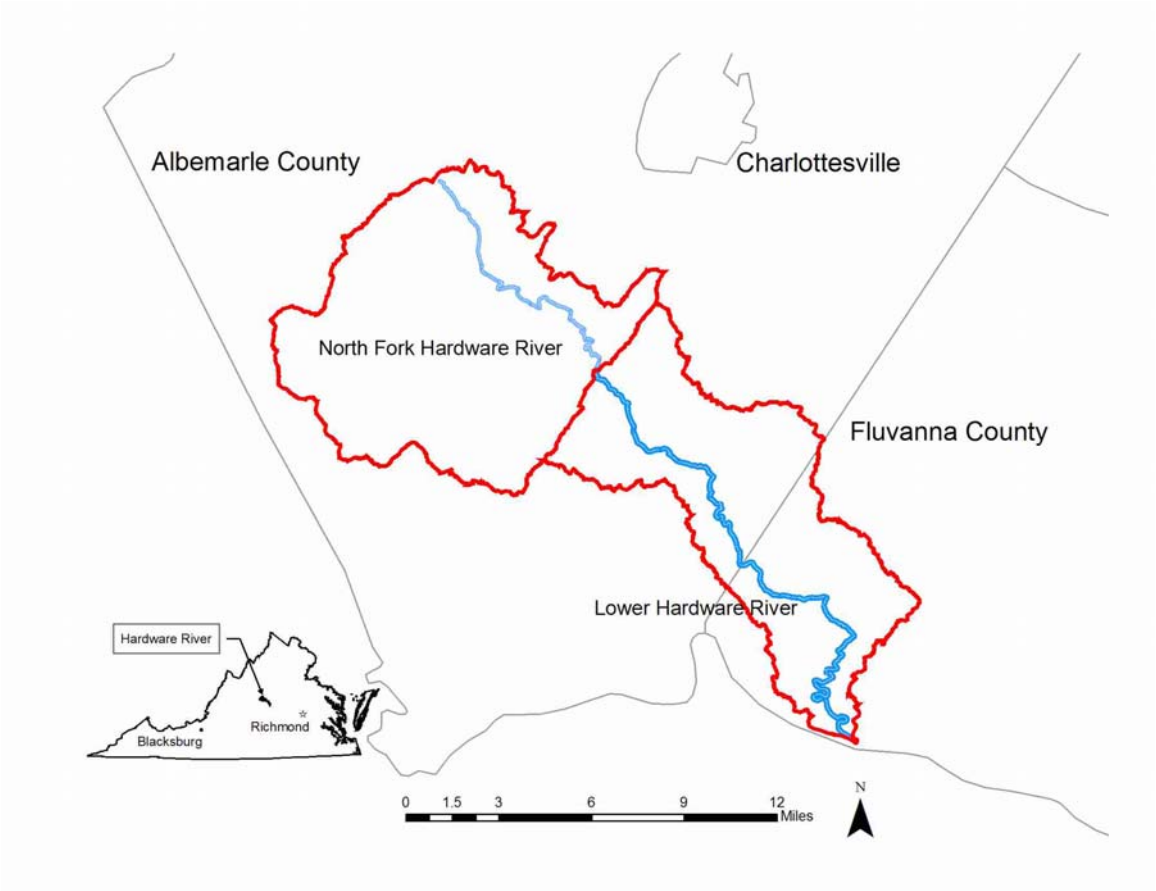

Figure 1.2. North Fork Hardware River (H18) and Lower Hardware River (H19) watershed locations.

The land use distribution in the North Fork and Lower Hardware watersheds are very similar (Table 1.2), mainly composed of forest but with a significant portion of agricultural area. Residential areas are small, primarily low density and scattered within the watersheds. The North Fork of the Hardware River flows south southeast, and becomes the Hardware River at the confluence with the South Fork; the North Fork/South Fork confluence is the modeled outlet of the North Fork watershed. The Lower Hardware River flows into the James River (USGS Hydrologic Unit Code 11010002), which discharges into the Chesapeake Bay at Hampton Roads harbor in southeast Virginia.

Table 1.2. Land use description in TMDL watersheds.

Watershed	Forest	Agriculture	Residential
Lower Hardware River	78%	20%	2%
North Fork Hardware River	77%	19%	4%

1.1.4. Pollutants of Concern

Pollution from both point and nonpoint sources can lead to fecal coliform bacteria contamination of water bodies. Fecal coliform bacteria are found in the intestinal tract of warm-blooded animals; consequently, fecal waste of warm-blooded animals contains fecal coliform. Even though most fecal coliform are not pathogenic, their presence in water indicates contamination by fecal material. Because fecal material may contain pathogenic organisms, water bodies with fecal coliform bacteria are potential sources of pathogenic organisms. For contact recreational activities such as boating and swimming, health risks increase with increasing fecal coliform counts. If the fecal coliform concentration in a water body exceeds state water quality standards, the water body is listed for violation of the state bacteria standard for contact recreational uses. As will be discussed in Section 1.1.2, Virginia has adopted an *Escherichia coli* (*E. coli*) water quality standard. The concentration of *E. coli* (a subset of the fecal coliform group) in water is considered to be a better indicator of pathogenic exposure than the concentration of the entire fecal coliform group in the water body.

1.2. Designated Uses and Applicable Water Quality Standards

1.2.1. Designation of Uses (9 VAC 25-260-10)

"A. All State waters, 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." SWCB, 2006.

North Fork Hardware River and Lower Hardware River do not support the recreational (primary contact) designated use due to violations of the bacteria standard.

1.2.2. Bacteria Standard (9 VAC 25-260-170)

EPA has recommended that all states adopt an *E. coli* or enterococci standard for fresh water and enterococci criteria for marine waters, because there is a stronger correlation between the concentration of these organisms (*E. coli* and enterococci) and the incidence of gastrointestinal illness than there is with fecal coliform. *E. coli* and enterococci are bacteria that can be found in the intestinal tract of warm-blooded animals and are subsets of the fecal coliform and fecal streptococcus groups, respectively. In line with this recommendation, Virginia adopted and published revised bacteria criteria on June 17, 2002. The revised criteria became effective on January 15, 2003. As of that date, the *E. coli* standard described below applies to all freshwater streams in Virginia. Additionally, prior to June 30, 2008, the interim fecal coliform standard must be applied at any sampling station that has fewer than 12 samples of *E. coli*.

For a non-shellfish water body to be in compliance with Virginia's revised bacteria standards (as published in the Virginia Register Volume 18, Issue 20) the following criteria shall apply to protect primary contact recreational uses (SWCB, 2006):

Interim Fecal Coliform Standard:

Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 mL of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar month exceed 400 fecal coliform bacteria per 100 mL of water.

***Escherichia coli* Standard:**

E. coli bacteria concentrations for freshwater shall not exceed a geometric mean of 126 counts per 100 mL for two or more samples taken during any calendar month and shall not exceed a single sample maximum of 235 cfu/100mL.

During any assessment period, if more than 10.5% of a station's samples exceed the applicable standard, the stream segment associated with that station is classified as impaired and a TMDL must be developed and implemented to bring the station into compliance with the water quality standard. There is one

ambient monitoring station on the North Fork and one on the Lower Hardware River; both of these stations are in violation of the bacteria standard, leading to the impairment on the North Fork Hardware and Lower Hardware River segments.

The bacteria TMDL for the impaired segments will be developed to meet the *E. coli* standard. As recommended, the modeling will be conducted with fecal coliform inputs, and then a translator equation will be used to convert the output to *E. coli* concentrations.

Chapter 2: Watershed Characterization

2.1. Selection of Sub-watersheds

To account for the spatial distribution of fecal coliform sources, both the North Fork and Lower Hardware watersheds were subdivided. The North Fork and Lower Hardware watersheds were subdivided into 20 and 24 sub-watersheds, respectively, as shown in Figure 2.1. The stream network used to help define the sub-watersheds was obtained from the National Hydrography Dataset. Sub-watersheds were delineated based on a number of factors: continuity of the stream network, similarity of land use distribution, and monitoring station locations. It is preferable to have a sub-watershed outlet at or near monitoring station locations in order to calibrate the model chosen for this study (to be discussed in Chapter 4:); the three monitoring stations used in modeling are shown in Figure 2.1.

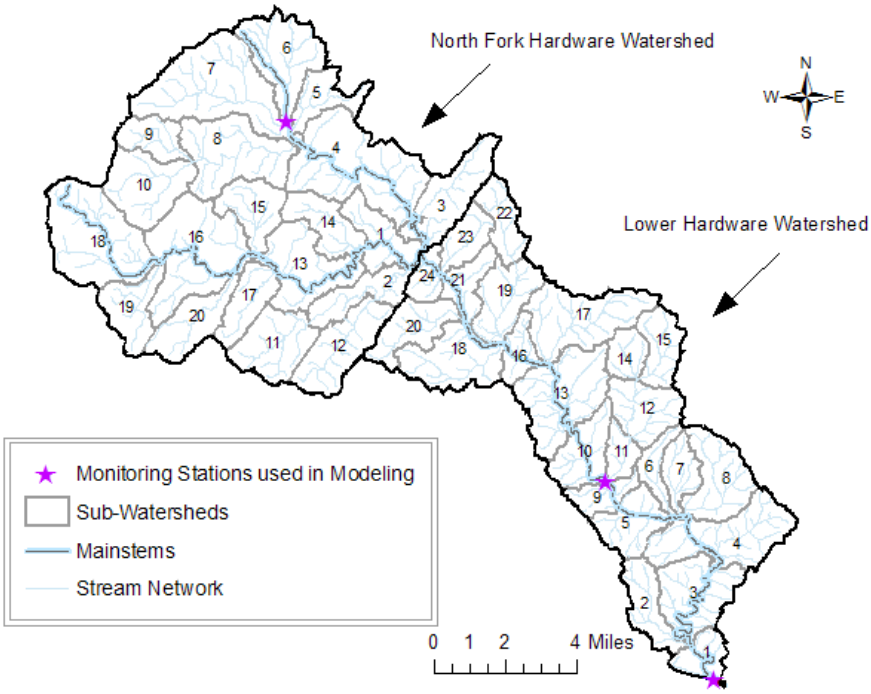

Figure 2.1. Sub-watersheds for North Fork and Lower Hardware River watersheds.

2.2. Eco Region

Eco regions in this section are classified at two levels: level III eco regions and the subgroup level IV eco regions. The majority of the North Fork watershed is located in the Piedmont Uplands level IV eco region of the Northern Piedmont level III eco region (Figure 2.2). This level IV eco region is composed of "rounded hills, low ridges, relative high relief, and narrow valleys and is underlain by metamorphic rock" (Woods et al., 1999). Natural vegetation is composed of Appalachian Oak Forest (white and red oaks) and Mixed Mesophytic Forest (temperate broadleaf and mixed forest of oak, hemlock, beech, sugar, and basswood) (Woods et al., 1999). The headwaters of the South Fork and several upper reaches of the North Fork lie in the Northern Igneous Ridges level IV eco region, of the level III Blue Ridge Mountains, which is characterized by steep, well-dissected ridges and high gaps with natural vegetation dominated by Appalachian Oak Forest (Woods et al., 1999). The Lower Hardware River lies in the level IV Northern Inner Piedmont within the Piedmont level III eco region. The Northern Inner Piedmont "is a dissected upland composed of hills, irregular plains, and isolated ridges and mountains" and commonly, shortleaf pine forests (Woods et al., 1999).

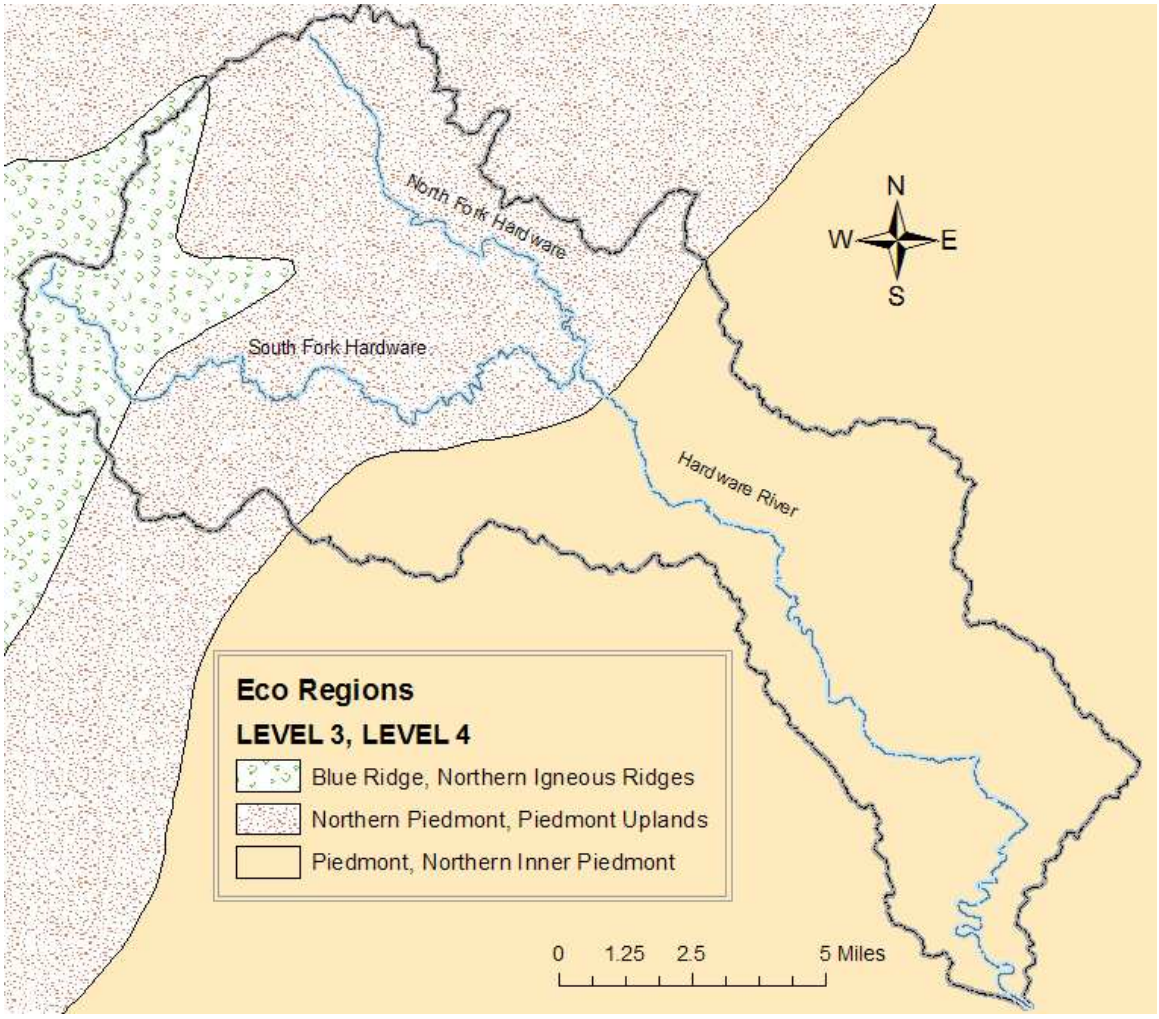

Figure 2.2. Hardware River watershed Eco Regions

2.3. Soils and Geology

The Hardware River watershed lies entirely in the Piedmont Upland section of the Piedmont province of the Appalachian Highlands. This physiographic section is characterized by igneous and metamorphic rocks. "Most of the province is uplands, which are typically low, rounded hills and shallow valleys underlain by a complex assortment of metamorphic and igneous rocks of Paleozoic and Precambrian age" (USGS, 1997). In both Fluvanna and Albemarle Counties, the saprolite layer generally serves as groundwater storage and therefore, given its unconfined nature, almost all recharge is from precipitation, which then moves laterally through the regolith and discharges to

nearby streams during or shortly after rainfall events (Woods et al, 1999; OEHS, 2004). A small percentage of rainfall, however, does percolate into bedrock and therefore, in some cases, precipitation events and stormflow may not be wholly concomitant (USGS, 1997).

The three predominant State Soil Geographic (STATSGO) soil groups found in the Hardware River watersheds closely mimic the eco region boundaries (Figure 2.3). There are three additional soil groups, each comprising 2% or less of the Hardware watershed. Hydrologic soil groups describe soil texture in terms of potential for surface runoff and infiltration rates (Table 2.1). For example, soils in hydrologic group "A" pass a larger proportion of rainfall through to ground water than soils in hydrologic group "B." Conversely, soils in hydrologic group "D" inhibit infiltration such that a large proportion of rainfall contributes to surface runoff and therefore a more direct path to stream channels. These processes have consequences for bacteria residing on the land surface in terms of the potential bacteria loads transported to streams during storm events.

Table 2.2 is a summary of STATSGO soil characteristics in the Hardware River watershed. In the table, "% of Soil Types" is the percent of soils in the given soil name category that have the properties given in the remaining four columns (texture, hydrologic group, slope range, and mean slope). Minimum and maximum slopes are taken directly from fields within the STATSGO database; mean slope is the calculated average of minimum and maximum slopes. The dominant textures in Haysville-Parker-Peaks and Buckjall-Occoquan-Meadowville soils, which together comprise 61% of the watershed soils, are loam to sandy loam. Hydrologic group B dominates within these soil types, with some occurrences of groups C and D. Nason-Manteo-Goldston soils (34% of the watershed) are more silty, and therefore produce higher runoff, which is reflected in the more pronounced presence of hydrologic groups C and D. The last three soils listed in Table 2.2, which together total only 4% of the watershed, are more clay-rich soils, which again produce higher runoff, reflected by the presence of hydrologic soils groups C and D.

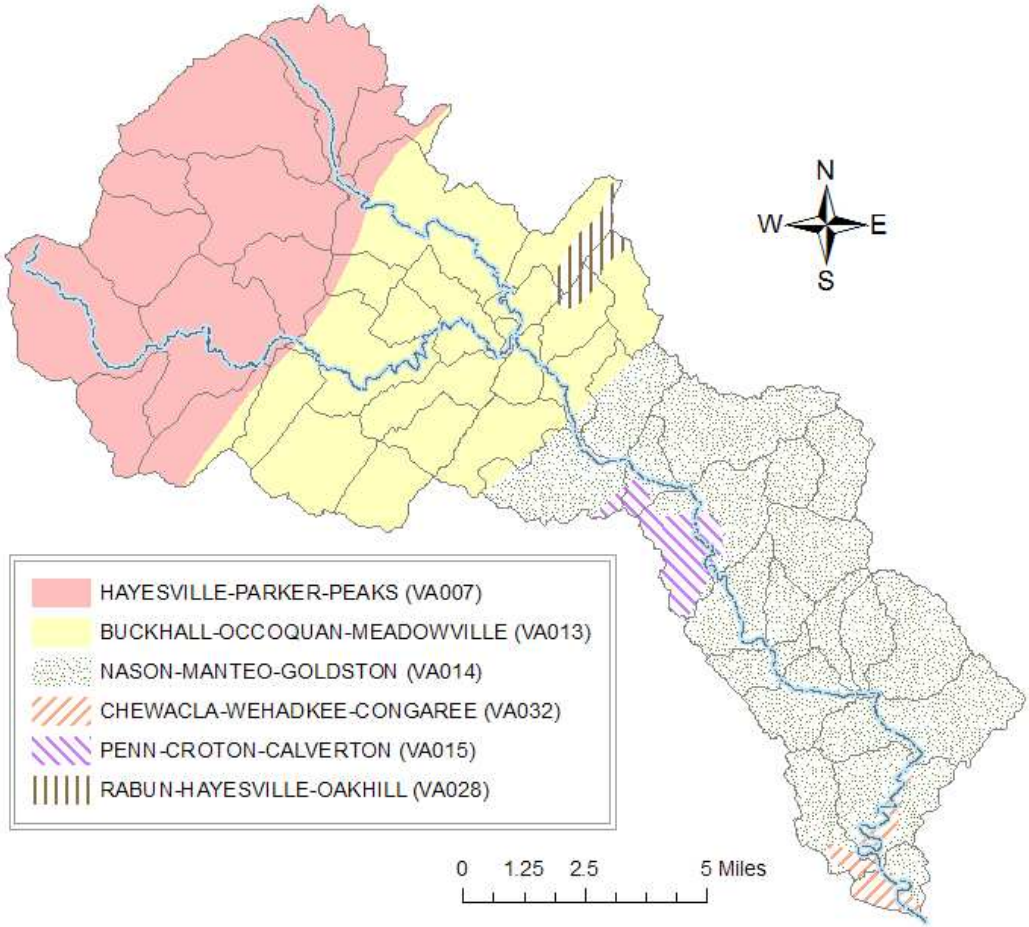

Figure 2.3. STATSGO soil groups in the North Fork and Lower Hardware watersheds.

Table 2.1. Soil Hydrologic Groups

Hydrologic Group	Description
A	Low runoff potential, high infiltration rates. Soils are deep, well drained to excessively drained sand, loamy sand or sandy loam, and gravels.
B	Moderate infiltration rates. Deep to moderately deep, moderately well and well-drained silt or silt loam soils (moderately coarse textures).
C	Moderate to Slow infiltration rates. Sandy clay loam soils (soils with moderately fine or fine textures) or soils with layers impeding downward movement of water.
D	High runoff potential, very slow infiltration rates. Soils are clayey (sandy clay to silty clay loam), have high water table, or are shallow over an impervious cover.

Table 2.2. Summary of STATSGO data for Hardware River watershed.

Soil Name	% of Watershed	% of Soil Types	Texture	Hydrologic Group	%Slope, Range	%Slope, Mean
HAYESVILLE-PARKER-PEAKS	33	80	Loam	B	2 – 35	13
		20	Stony, gravelly, sandy loam	B,C	2 – 75	30
BUCKHALL-OCCOQUAN-MEADOWVILLE	28	68	Sandy loam to coarse sandy loam	B	2 – 25	14
		32	Stony to coarse sandy loam with minor silt	B, C, minor D	0 - 45	13
NASON-MANTEO-GOLDSTON	34	74	Silt to channery* silt	C,D	2 – 60	18
		26	Silt to channery silt to clay loam	B, C, D	2 - 60	16
PENN-CROTON-CALVERTON	2	100	Clay to silt loam, channery silt loam	B, C, minor D	0 - 45	13
CHEWACLA-WEHADKEE-CONGAREE	1	100	Clay loam to fine sandy or silt loam	B, C, minor D	0- 15	5
RABUN-HAYESVILLE-OAKHILL	1	100	Stony to silty clay loam, silty loam to loam	B	2 - 45	16

*coarse, flat fragments

2.4. Climate

The climate of the watershed was characterized based on the meteorological observations acquired from the National Climatic Data Center (NCDC) for “nearby” weather stations. Meteorological data were obtained primarily from the National Weather Service COOP station at Bremo Bluff (COOP ID 440993) in Fluvanna County. Bremo Bluff is located approximately 6.5 miles east southeast of the watershed outlet. Data from the following stations were used to address the missing data: Charlottesville 2W, Monticello, North Garden, Piedmont Research Station, Staunton Sewage Plant, Montebello Fish Hatchery, Dale Enterprise, and Lynchburg Regional Airport. A 30-year record summary (1971 - 2000) at the Bremo Bluff station shows an average annual precipitation of 43.07 inches, with 53% of the precipitation occurring during the cropping season (May-October). Mean annual snowfall at Bremo Bluff is 2.07 inches. Average annual daily temperature is 55.8°F, with a highest average daily temperature of

88.5°F occurring in July, and a lowest average daily temperature of 23.1°F occurring in January (SERCC, 2007).

2.5. Land Use

From the Regional Earth Science Application Center (RESAC) (RESAC, 2000), land uses in Hardware River were grouped into five major categories based on similarities in hydrologic features and waste application/production practices (Table 2.3). The five land use categories were assigned pervious and impervious percentages for use in the watershed model. Land uses for the North Fork and Lower Hardware River watersheds are presented graphically in Figure 2.4. Land uses are tabulated for the watersheds in Table 2.4 and Table 2.5 for the North Fork and Lower Hardware Rives, respectively.

Table 2.3. NLCD aggregation.

TMDL Land Use Categories	Pervious/Impervious (Percentage)	RESAC Land Use Categories (Class No.)
Cropland	Pervious (100%)	Row Crops (82)
Pasture	Pervious (100%)	Pasture/Hay (81)
Low Density Residential (LDR)	Pervious (70%) Impervious (30%)	Low Intensity Residential (21) Transitional (33) Urban/Recreational Grasses (85)
High Density Residential (HDR)	Pervious (20%) Impervious (80%)	High Intensity Residential (22) Commercial/Industrial/Transport (23) Quarries/strip mines/gravel pits (32)
Forest	Pervious (100%)	Open Water (11) Deciduous Forest (41) Evergreen Forest (42) Mixed Forest (43) Woody Wetlands (91) Emergent Herbaceous Wetlands (92)

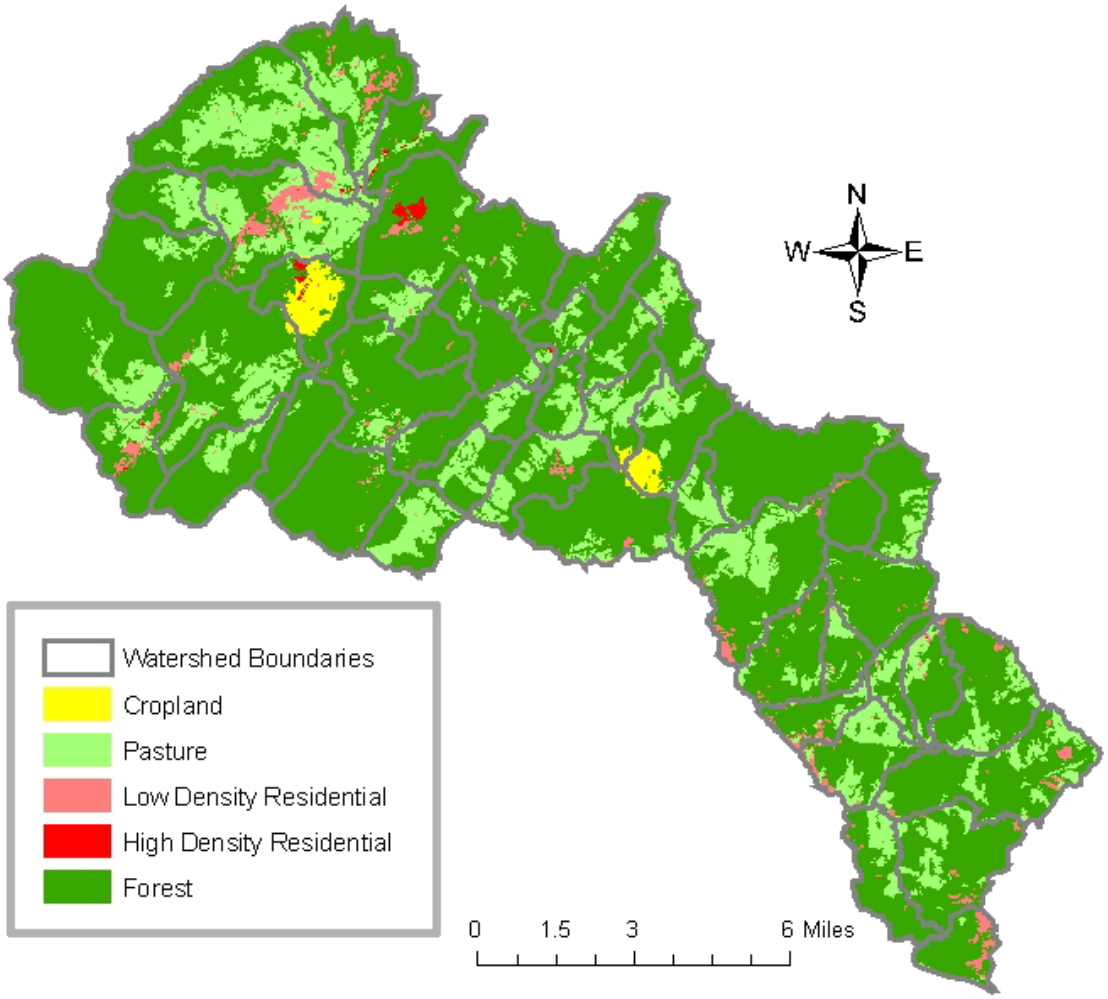

Figure 2.4. Land use in North Fork and Lower Hardware River watersheds.

Table 2.4. Land use areas in North Fork Hardware River (acres).

Sub-watershed	Cropland	Forest	HDR*	LDR†	Pasture
1	0	1,394	7	5	190
2	0	1,155	0	11	337
3	0	1,913	2	40	331
4	0	4,258	106	132	333
5	0	1,036	18	28	148
6	0	1,679	0	176	724
7	0	2,396	7	127	2,167
8	21	1,325	4	359	1,510
9	0	759	0	0	415
10	0	2,212	0	0	231
11	0	2,151	0	29	59
12	0	1,447	0	18	956
13	0	2,431	0	38	285
14	0	1,212	0	14	292
15	601	904	50	13	24
16	31	3,169	0	74	855
17	0	1,381	0	0	25
18	0	3,527	0	8	530
19	0	1,176	5	140	299
20	0	1,460	0	2	320
Total	**654**	**36,985**	**199**	**1,215**	**10,030**

*High Density Residential
†Low Density Residential

Table 2.5. Land use areas in Lower Hardware River (acres).

Sub-watershed	Cropland	Forest	HDR*	LDR†	Pasture
1	6	768	0	164	36
2	0	1,077	0	42	341
3	0	1,937	0	85	487
4	4	2,452	0	103	758
5	1	872	0	110	705
6	0	478	0	15	313
7	0	714	0	34	289
8	0	1,748	0	73	457
9	0	612	0	101	171
10	0	1,454	0	53	225
11	0	510	0	11	203
12	0	1,642	0	23	141
13	0	2,251	0	162	884
14	0	844	0	27	0
15	0	1,081	0	2	293
16	0	443	0	2	442
17	0	2,957	0	13	141
18	45	2,159	1	27	231
19	282	1,165	0	10	422
20	0	1,033	0	50	628
21	42	583	0	3	448
22	0	896	0	8	366
23	0	826	0	3	262
24	0	472	0	8	278
Total	**381**	**28,976**	**1**	**1,129**	**8,520**

*High Density Residential
†Low Density Residential

2.6. Stream Flow Data

USGS monitors average daily flow rates on Hardware River at station 02030000 near Scottsville, VA, approximately 11 miles upstream from the watershed outlet and the confluence with the James River (Figure 2.5). This station drains 116 mi² of the Hardware River basin. The station record extends from 1939 to the present, with a daily average flow of 129 cfs over the period of record.

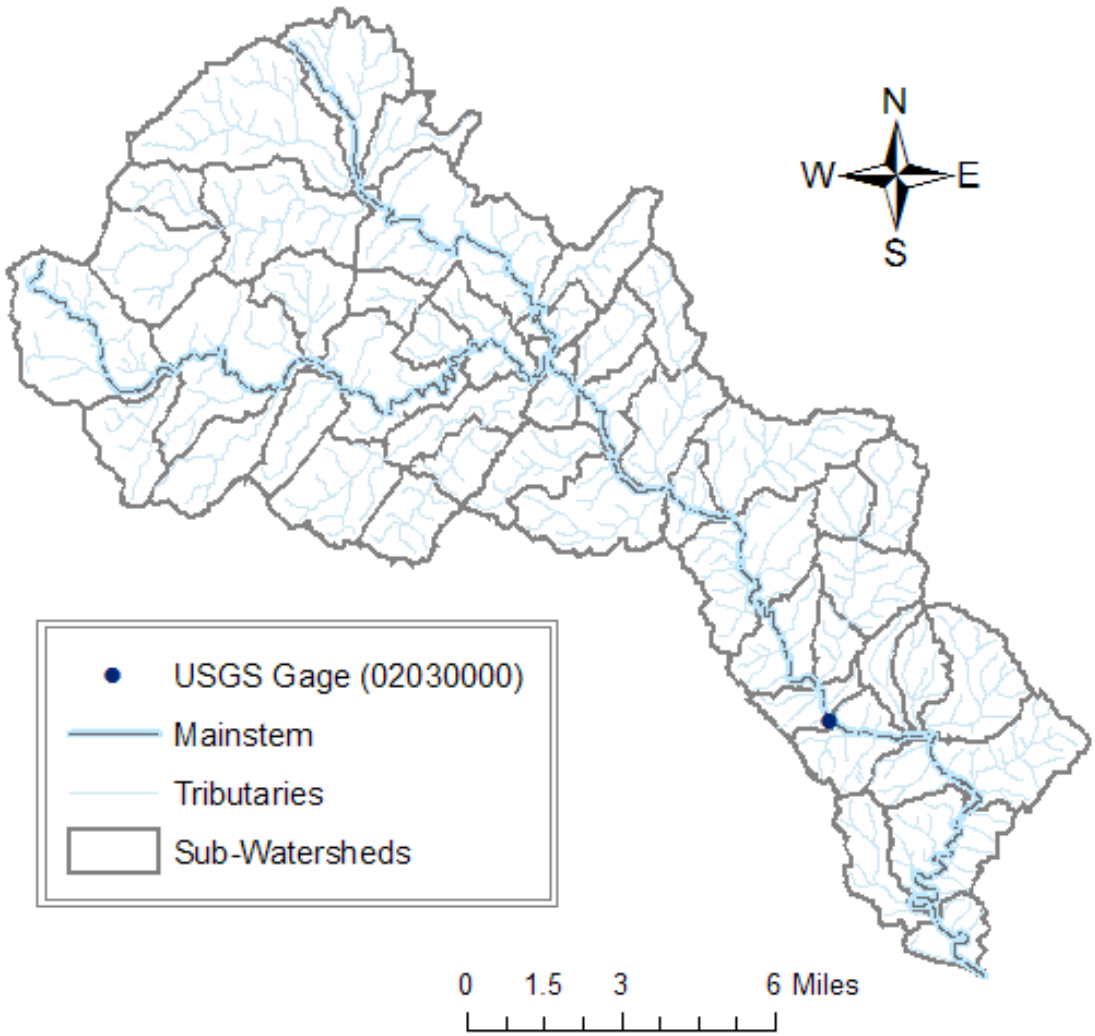

Figure 2.5. USGS flow monitoring station on Hardware River.

2.7. Water Quality Data

The Virginia Department of Environmental Quality (VADEQ) monitors Hardware River water quality at several stations (Table 2.6). Only three stations have a lengthy period of record of fecal coliform samples; the remaining stations have less than 2 years of *E. coli* data. Fecal coliform data are available for station 2-HNF008.28, on the North Fork Hardware River, from 1995 to present. Fecal coliform data are available for stations 2-HRD011.57 and 2-HRD000.36, in the Lower Hardware River, from 1991 to present and 2005-2006, respectively. The locations of the three monitoring stations used in the TMDL are shown in Figure 2.1. Details for each station are given in Table 2.7.

Table 2.6. VADEQ monitoring stations on the North Fork Hardware and Hardware Rivers.

POR*	Water shed Code	Station ID	No. Fecal Coliform Samples	Station Description	Stream Name	County
1995 - 2006	H18	2-HNF008.28	28	Rt. 708 Bridge	North Fork Hardware	Albemarle
1979 - 2007	H19	2-HRD011.57	145	Rt. 637 Bridge at Gaging Station	Hardware River	Fluvanna
2004- 2006	H19	2-HRD000.36	39	Rt. 646 Bridge at State Wildlife Area	Hardware River	Fluvanna
2005- 2006	H18	2-HAK001.34	1	Rt. 717 Bridge	South Fork Hardware	Albemarle
2005 - 2006	H18	2-HNF000.10	0†	Rt. 708 Bridge	North Fork Hardware	Albemarle
2005 - 2006	H18	2-HNF005.03	0†	Rt. 708 Bridge	North Fork Hardware	Albemarle
2005 - 2006	H18	2-HNS002.40	0†	Rt. 712 Bridge	S. Branch, N. Fork Hardware	Albemarle

*POR = period of record
†Only *E. coli* samples were collected at this site

Table 2.7. Details of fecal coliform data collected at monitoring stations in Hardware River.

Station ID	Sample Date†		No. of Samples	Sample Value (cfu/100 mL)			Exceedances of Single Sample Standard	
	First	Last		Min	Max	Avg	No.	%
2-HNF008.28	12/13/1995	9/20/2006	28	68	5600	919	9	28
2-HRD011.57	7/24/1991	9/20/2006	145	25	8000*	510	31	21
2-HRD000.36	7/20/2004	9/20/2006	39	20	3600	151	1	3

*Capped value
†As of November 2006

As part of the TMDL effort, bacterial source tracking (BST) data were collected at the stations shown in Table 2.7. The commonly used Antibiotic Resistance Analysis (ARA) method was used to analyze these samples (Harwood et al., 2003; Stoeckel, et al., 2004; Hagedorn, 2006). This method is lower in cost and faster than many of the other available methods. The ARA method is classified as a biochemical or phenotype analysis. It relies on the response of the fecal bacteria to various antibiotics. The results of the BST analyses are presented at the end of Chapter 4:, where they are compared with modeled results.

The assessments for the North Fork and Lower Hardware River show a potential for bacteria contributions from agriculture, wildlife, and urban sources. The exceedance rates for the stations causing the impairment listings on these watersheds are given in Table 2.8. As a consequence of these exceedances, North Fork Hardware River and Lower Hardware River were assessed as not supporting the Clean Water Act's Primary Contact Recreational Use Goal for the 2006 305(b) report and were included on the 2006 303(d) list (VADEQ, 2006). Bacteria concentrations from the monitoring stations used for model calibration and validation, 2-HNF008.28 and 2-HRD011.57, are shown in

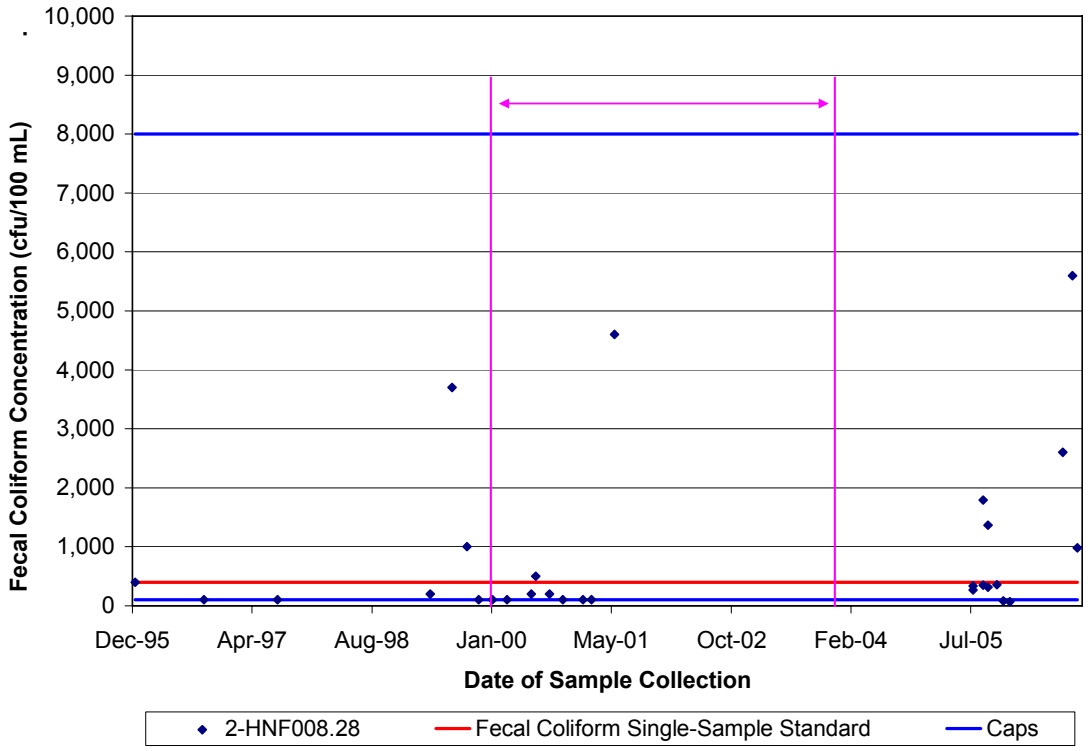

Figure 2.6 and Figure 2.7 along with the 2004 assessment period and interim fecal coliform standard. Data from 2-HRD000.36 were used for BST comparison only.

Table 2.8. Bacteria standard exceedances during the 2004 assessment period (2000-2004).

Station ID	Exceedances of Interim Fecal Coliform Standard
2-HNF008.28	2 of 9 (22%)
2-HRD011.57	9 of 36 (25%)

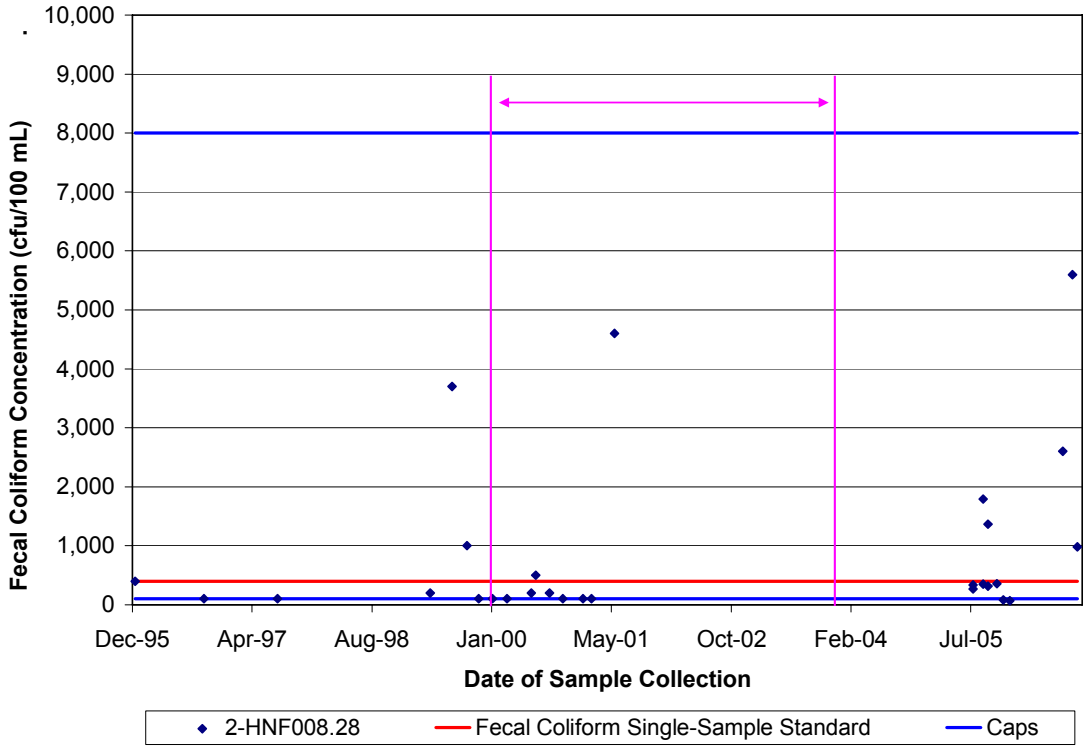

Figure 2.6. Bacteria data for Station 2-HNF008.28.

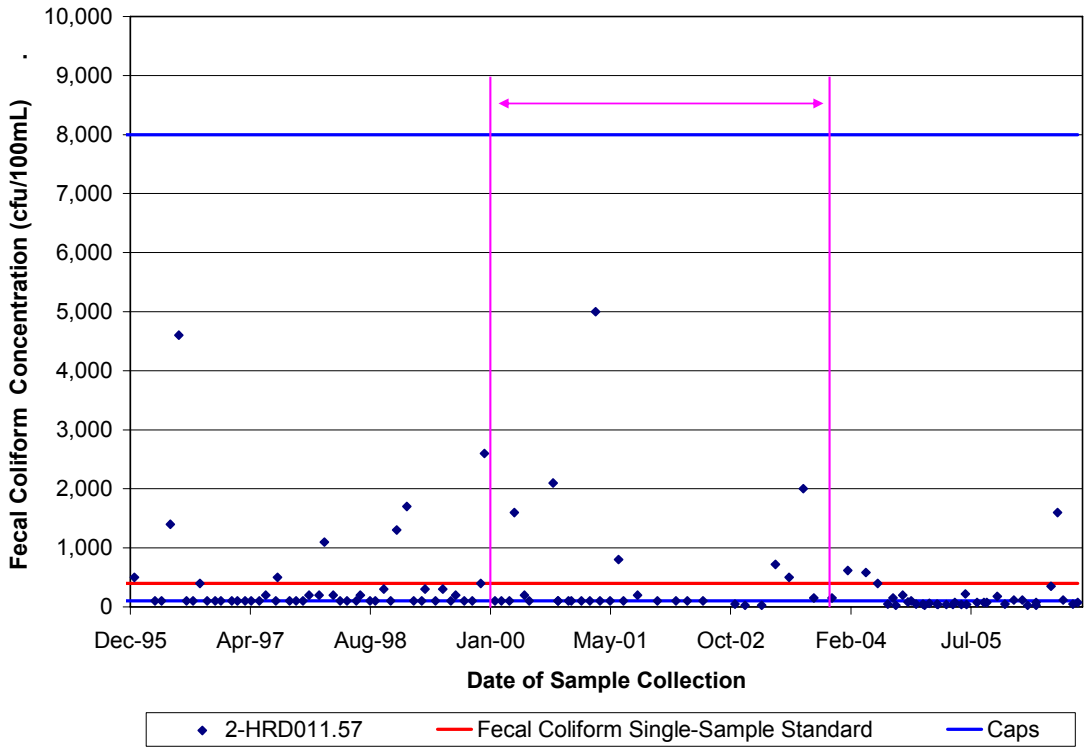

Figure 2.7. Bacteria data for Station 2-HRD011.57.

Until 2000, the Most Probable Number (MPN) method was used for the analysis of the bacteria samples presented in the previous figures. After 2000, the Membrane Filter Method (MFM) method was used to analyze the bacteria samples. The former method imposed a cap of 8,000 cfu/100 mL as a maximum and 100 cfu/100 mL as a minimum. The MFM imposed a cap of 2,000 cfu/100 mL and lower cap of 100 cfu/100 mL. In 2002, the lower cap was decreased to 25 cfu/100 mL and in 2004, the upper cap was increased to 16,000 cfu/100 mL.

Seasonality of fecal coliform concentrations in the streams was evaluated by plotting the mean monthly fecal coliform concentrations observed at the listing stations (Figure 2.8). Mean monthly fecal coliform concentration was determined as the mean of all values in any given month for the period of record. Data are not available for station 2-HNF008.28 in two of the twelve months and the maximum number of values for any month is six. All months are represented for station 2-HRD011.57 and the maximum number of values is 14.

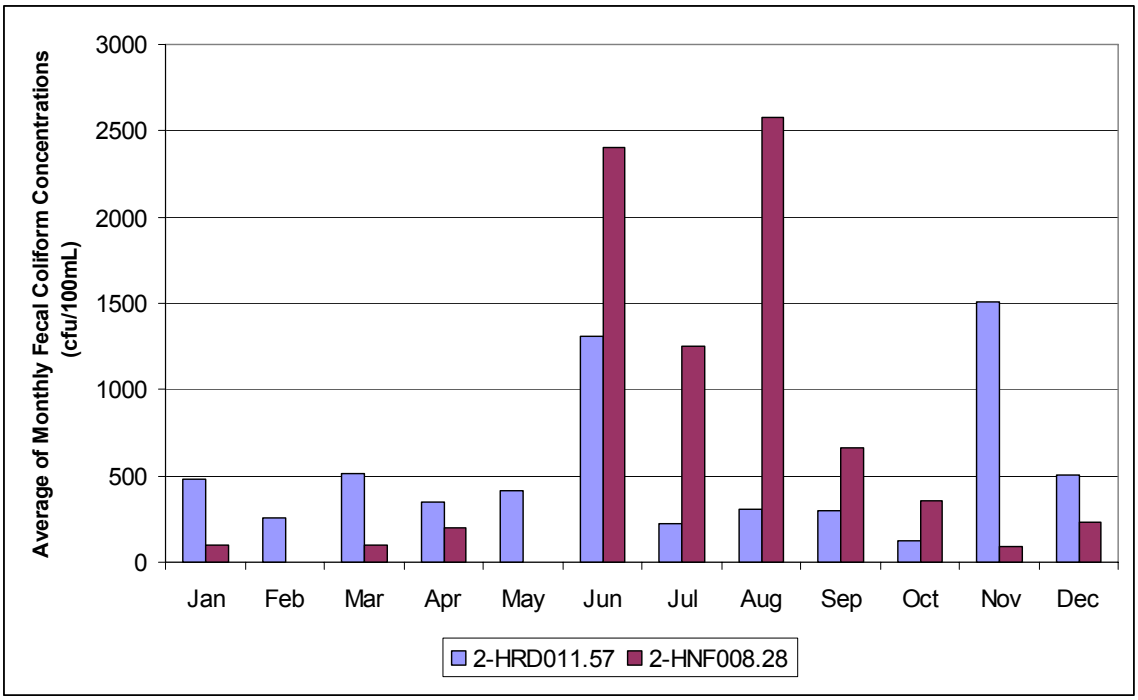

Figure 2.8. Average fecal coliform concentrations by month.

In general, both stations show lower values between late winter and late spring. Summer months may show an increase in fecal coliform concentrations; however, June and August data at station 2-HNF008.28 contain only two values for each month, so an average value is suspect. Thus, any perceived seasonality may be due to lack of data, rather than the suggestion that sources of bacteria to the impaired watersheds are affected by seasonal trends (precipitation, management practices, and migration patterns).

Chapter 3: Source Assessment of Fecal Coliform

Fecal coliform sources and production rates in the North Fork and Lower Hardware River watersheds were assessed using information from the following sources: VADEQ, VADCR, Virginia Department of Game and Inland Fisheries (VADGIF), Virginia Department of Agricultural and Consumer Services (VDACS), Virginia Cooperative Extension (VCE), Natural Resources Conservation Service (NRCS), Soil and Water Conservation Districts (SWCD), public participation, watershed reconnaissance and monitoring, published information, and professional judgment. Potential nonpoint sources of fecal coliform in Lower Hardware and the North Fork Hardware River watersheds are summarized in Table 3.2 and Table 3.1.

Point sources of fecal coliform bacteria in the Hardware River watershed include one sewage treatment plant and one single family domestic sewage discharge (application pending), both located on the South Branch of the North Fork Hardware River (See Table 3.3). Virginia issues Virginia Pollutant Discharge Elimination System (VPDES) permits for point sources of pollution. In Virginia, point sources that treat human waste are required to maintain an *E. coli* concentration of 126 cfu/100 mL or less in their effluent. In allocation scenarios for bacteria, the entire allowable point source discharge concentration of 126 cfu/100 mL was used.

Table 3.1. Potential fecal coliform sources and daily fecal coliform production by source for existing conditions in the Lower Hardware River watershed.

Potential Source	Population in Lower Hardware River	Fecal coliform produced (x 10^6 cfu/head/day)
Humans	2317	2000[a]
Beef	985[b]	10000[c]
Pets	1910	450[d]
Deer	1644	380
Horses	494	420[e]
Raccoons	557	5
Wild Turkeys	275	9.3
Muskrats	2207	2.5[e]
Beavers	65	0.20
Ducks[f]	643	2400
Geese[f]	773	800

[a] Source: Geldreich (1978)
[b] Includes calves
[c] Source: Weiskel *et al.* (1996)
[d] Source: ASAE(1998)
[e] Source: Yagow (2001)
[f] Population given as winter; summer population

Table 3.2. Potential fecal coliform sources and daily fecal coliform production by source for existing conditions in the North Fork Hardware River watershed.

Potential Source	Population in North Fork Hardware River	Fecal coliform produced (x 10^6 cfu/head/day)
Humans	2319	2000[a]
Beef	1163[b]	10000[c]
Pets	1910	450
Deer	195	380
Horses	583	420[d]
Raccoons	756	5
Wild Turkeys	205	9.3
Muskrats	2157	2.5[e]
Beavers	78	0.20
Ducks[f]	866	2400
Geese[f]	1041	800

[a] Source: Geldreich (1978)
[b] Includes calves
[c] Source: Weiskel *et al.* (1996)
[d] Source: ASAE(1998)
[e] Source: Yagow (2001)
[f] Population given as winter; summer population

Table 3.3. Permitted facilities discharging into streams of the North Fork Hardware River watershed.

Permit Number	Facility Name	Sub-water shed	Design Flow (mgd*)	Permitted *E. coli* Conc. (cfu/100 mL)	*E. coli* Load (cfu/year)
VA0083291	Crossroads Village Center STP	12	0.02	126	3.48×10^{11}
VAG408054	North Garden Post Office SFH‡	12	0.001	126	1.74×10^{9}

*million gallons per day
‡SFH = Single Family Home

3.1. Humans and Pets

The Lower Hardware River watershed has an estimated population of 2,317 (942 households with an average of 2.43 people per household; actual people per household varies by sub-watershed). The North Fork Hardware River watershed has an estimated population of 2,319 people (943 households with an average of 2.46 people per household). The number of people per household for both watersheds was determined from the 2000 Census of Population and Housing for Virginia. Fecal coliform from humans can be transported to streams from failing septic systems, and via straight pipes discharging directly into streams. Although leaky sewer lines are not explicitly accounted for in modeling for this TMDL, they are considered to be part of the residential load, and should be addressed where found during implementation. Professional judgment was used to specify 2 pets per household for both Lower Hardware and North Fork Hardware Rivers.

3.1.1. Failing Septic Systems

Septic system failure can result in the rise of effluent to the soil surface. Surface runoff can transport the effluent, containing fecal coliform, to receiving waters. In order to estimate the number of failing septic systems, it is necessary to determine both the number and age of houses in the watersheds. The 2000 Census classification contains decadal data for houses built between 1940 and March 2000. It was estimated that there were no households in Lower Hardware

River or North Fork Hardware River that were connected to sewer lines. It was assumed that septic system failure rate for old (pre-1974) houses is 40% (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Estimates of these failure rates were also supported by the Holmans Creek Watershed Study (a watershed located in Rockingham County), which found that over 30% of all septic systems checked in the watershed were either failing or not functioning at all).

Daily total fecal coliform load to the land from a failing septic system in each sub-watershed was determined by multiplying the average occupancy rate for that sub-watershed (occupancy rate of houses ranged from 2.13 to 2.73 persons per household for both Lower Hardware River and North Fork Hardware River (Census Bureau, 2000)) by the per capita fecal coliform production rate of 2.0×10^9 cfu/day (Geldreich, 1978). Hence, the total fecal coliform loading to the land from a single failing septic system in a sub-watershed with an occupancy rate of 1 person/household is 2.0×10^9 cfu/day. Transport of some portion of the fecal coliform to a stream by runoff may occur. The number of failing septic systems in the watersheds is given in for Lower Hardware River Table 3.4 and Table 3.5 for the North Fork Hardware River.

3.1.2. Straight Pipes

Bacteria discharged from straight pipes enter the stream directly, without treatment or die-off. Of the houses in the old and mid-age (1974-1980) categories, 10% and 2%, respectively, were estimated to have straight pipes (R.B. Reneau, personal communication, 3 December 1999, Blacksburg, Va.). Based on these criteria, it was estimated that 19 houses with straight pipes exist in the Lower Hardware River watershed and 21 exist in the North Fork Hardware River watershed. The number of straight pipes in the Lower Hardware watershed is given in Table 3.4 and Table 3.5 for Lower Hardware and the North Fork Hardware Rivers.

Table 3.4. Estimated Household and Pet Population Breakdown by Sub-watershed for Lower Hardware River.

Sub-watershed	Sewered Houses	People per House (un-sewered)	Unsewered houses in each age category				Failing Septic Systems	Pet Population
			Straight Pipes	Old	Mid-age	New		
1	0	2.39	1	14	10	5	8	50
2	0	2.13	2	33	18	8	17	106
3	0	2.32	2	40	28	13	22	140
4	0	2.47	2	40	34	18	24	152
5	0	2.25	2	30	19	9	16	102
6	0	2.73	0	6	8	4	4	28
7	0	2.73	0	8	11	5	5	38
8	0	2.72	1	18	21	12	11	80
9	0	2.18	1	23	12	5	11	72
10	0	2.35	1	17	17	4	10	70
11	0	2.67	0	5	8	3	4	26
12	0	2.63	1	12	17	8	8	60
13	0	2.47	1	15	32	11	12	96
14	0	2.47	0	4	9	3	4	26
15	0	2.51	0	7	14	5	6	42
16	0	2.47	0	4	9	3	4	26
17	0	2.47	1	14	32	10	12	94
18	0	2.46	1	11	24	8	9	72
19	0	2.44	1	15	20	6	10	72
20	0	2.43	0	10	17	5	7	54
21	0	2.43	0	9	13	3	7	44
22	0	2.41	1	16	15	4	9	64
23	0	2.41	1	14	13	3	9	56
24	0	2.45	0	5	8	2	4	26
Total	0	2.46*	19	370	409	157	233	1,596

* Average

Table 3.5. Estimated Household and Pet Population Breakdown by Sub-watershed for North Fork Hardware River.

Sub-watershed	Sewered Houses	People per House (un-sewered)	Unsewered houses in each age category				Failing Septic Systems	Pet Population
			Straight Pipes	Old	Mid-age	New		
1	0	2.39	1	13	11	5	8	58
2	0	2.13	2	31	20	8	17	118
3	0	2.32	2	40	28	13	22	162
4	0	2.47	2	40	34	18	23	184
5	0	2.22	3	51	32	15	27	196
6	0	2.73	1	14	17	10	9	82
7	0	2.72	1	17	21	13	11	102
8	0	2.35	1	16	17	5	10	76
9	0	2.67	0	5	7	4	4	32
10	0	2.63	1	12	16	9	8	74
11	0	2.47	1	19	42	13	16	148
12	0	2.47	0	4	9	3	3	32
13	0	2.51	0	7	14	5	6	52
14	0	2.47	1	14	31	11	12	112
15	0	2.46	1	11	24	8	9	86
16	0	2.44	1	15	20	6	10	82
17	0	2.43	0	10	17	5	8	64
18	0	2.44	1	13	20	6	9	78
19	0	2.41	1	16	15	4	10	70
20	0	2.41	1	13	13	4	8	60
Total	0	2.46*	21	361	408	165	230	1,868

* Average

3.2. Cattle

Fecal coliform in cattle waste can be directly excreted to the stream, or it can be transported to the stream via surface runoff from animal waste deposited on pastures or applied to crops or pasture. Changes may have occurred in the cattle populations between the calibration, validation, and existing conditions periods. Future conditions, however, were assumed to be the same as the existing conditions; local information suggests that cattle farming is on a decline in the watersheds, but in keeping with conservative assumptions, a steady cattle population for future conditions was assumed.

3.2.1. Distribution of Beef Cattle

There are currently no dairy farms and only beef farms in the Lower Hardware and North Fork Hardware River watersheds. The lack of dairy farms was estimated from the from VDACS data and then confirmed at the first Local Steering Committee (LSC) meeting. The number of beef farms was estimated from communication with extension agents and from 2000 Agricultural Census; it was assumed that all were cow-calf operations.

Extension agents provided rough approximations of herd sizes for beef cattle operations. The total number of beef cows modeled throughout the year varied due to the presence or absences of calves and their weights relative to the adult cattle. The number of beef cattle and the distribution of animals among the sub-watersheds are listed in Table 3.6 and Table 3.7 for Lower Hardware and the North Fork Hardware Rivers, respectivley.

Beef cattle spend varying amounts of time in confinement, streams, and pastures depending on the time of year. Accordingly, the proportion of fecal coliform deposited in any given land area varies throughout the year. Details about confinement of beef cattle are listed in Table 3.8 and Table 3.10. Stream access for all beef farms was estimated based on pasture land proximity to streams.

Table 3.6. Beef Cattle Population in Lower Hardware River.

Sub-watershed	Beef[a]
1	4
2	39
3	56
4	88
5	82
6	36
7	33
8	53
9	20
10	26
11	24
12	16
13	102
14	0
15	34
16	51
17	16
18	27
19	49
20	73
21	52
22	42
23	30
24	32
Total	**985**

[a] Cow-calf pairs

Table 3.7. Beef Cattle Population in North Fork Hardware River.

Sub-watershed	Beef[a]
1	22
2	39
3	38
4	39
5	17
6	84
7	251
8	175
9	48
10	27
11	7
12	111
13	33
14	34
15	3
16	99
17	3
18	61
19	35
20	37
Total	**1163**

[a] Cow-calf pairs

The following assumptions and procedures were used to estimate the distribution of cattle (and thus, fecal coliform produced by cattle) among different land use types and in streams:

a) Cows are confined according to the schedule given in Table 3.8.
b) When cattle are not confined, they are on pasture.
c) Cows with stream access (determined as described earlier) will spend varying amounts of time in the stream during different seasons (Table 3.8). Cows spend more time in the stream during the three summer months to protect their hooves from hornflies, among other reasons.
d) Thirty percent of cows in and around streams directly deposit fecal coliform into the stream. The remaining 70% of the feces is deposited on pastures.

A sample calculation for determining the distribution of cattle to different land use types and to the stream in sub-watershed 7 of the North Fork Hardware River is shown in Appendix B.

Table 3.8. Time spent by cattle in confinement and in the stream.

Month	Beef Cattle[1] (range; typical)	Time spent in the stream (hours/day)
January	0%-40%; 0%	0.5
February	0%-40%; 0%	0.5
March	0%	0.75
April	0%	1
May	0%	1.5
June	0%	3.5
July	0%	3.5
August	0%	3.5
September	0%	1.5
October	0%	1
November	0%	0.75
December	0%-40%; 0%	0.5

[1] Fraction of day spent in confinement

Table 3.9. Distribution of beef cow (adult and calf) populations among the three possible land areas in Lower Hardware River.

Month	Confinement	Pasture	Streams*
January	394	587	4
February	394	587	4
March	0	975	10
April	0	972	13
May	0	966	19
June	0	941	44
July	0	941	44
August	0	941	44
September	0	966	19
October	0	972	13
November	0	975	10
December	394	587	4

*Number of cow equivalent defecations in the stream

Table 3.10. Distribution of beef cow (adult and calf) populations among the three possible land areas in North Fork Hardware River.

Month	Confinement	Pasture	Streams*
January	465	693	4
February	465	693	4
March	0	1152	11
April	0	1148	15
May	0	1141	22
June	0	1112	51
July	0	1112	51
August	0	1112	51
September	0	1142	21
October	0	1148	15
November	0	1153	10
December	465	693	4

*Number of cow equivalent defecations in the stream

3.2.2. Direct Manure Deposition in Streams

Direct manure loading to streams is due to beef cattle (Table 3.8 and Table 3.10) defecating in the stream. Manure loading increases during the warmer months, when cattle spend more time in water. The potential average annual manure loading directly deposited by cattle in the stream for Lower Hardware River watershed, using the tables above, is 5.9×10^5 lb. The load to the stream from cattle in the North Fork Hardware River watershed is 6.4×10^4 lb. The associated average daily fecal coliform loading to the stream for the North Fork is 8.9×10^{11} and Lower Hardware River is 9.6×10^{10} cfu. The loads for both watersheds will vary according to streamflow (due to the imposed cutoff discussed in the modeling chapter). Part of the fecal coliform deposited in the stream stays suspended, while the remainder adsorbs to the sediment in the streambed. Under base flow conditions, it is likely that suspended fecal coliform bacteria are the primary form transported with the flow. Sediment-bound fecal coliform bacteria are likely to be re-suspended and transported to the watershed outlet under high flow conditions. Die-off of fecal coliform in the stream depends on sunlight, predation, turbidity, and other environmental factors.

3.2.3. Direct Manure Deposition on Pastures

Beef cattle (Table 3.10) that graze on pastures but do not deposit in streams contribute the majority of fecal coliform loading on pastures. Manure loading on pasture was estimated by multiplying the total number of cattle on pasture by the amount of manure produced per day. The total amount of manure produced by all types of cattle was divided by the pasture acreage to obtain manure loading (lb/ac-day) on pasture. Fecal coliform loading (cfu/ac-day) on pasture was calculated by multiplying the manure loading (lb/ac-day) by the fecal coliform content (cfu/lb) of the manure. Because the confinement schedule of cattle changes with season: loading on pasture also changes with season.

Pasture has average annual cattle manure loadings of 3054 lb/ac for the Lower Hardware River watershed and 5252 lb/ac for the North Fork Hardware River watershed. The associated fecal coliform loadings from cattle to pasture on a daily basis, averaged over the year, are 9.9×10^{11} and 7.2×10^{11} cfu/ac-day for Lower Hardware the North Fork Hardware River watersheds, respectively. Fecal coliform bacteria deposited on the pasture surface are subject to die-off due to desiccation and ultraviolet (UV) radiation. Runoff can transport part of the remaining fecal coliform to receiving waters.

3.2.4. Land Application of Solid Manure

Solid manure produced by beef cattle during confinement is collected for land application. The number of cattle, their typical weights, amounts of solid manure produced, and fecal coliform concentration in fresh manure are given in Table 3.11. The amount of solid manure produced in each sub-watershed was estimated based on the populations of beef cattle in the sub-watershed (Table 3.6 and Table 3.7) and their confinement schedules (Table 3.8).

Table 3.11. Solid manure production characteristics.

Type of cattle	Typical weight (lb)	Solid manure produced (lb/animal-day)	Fecal coliform concentration in fresh manure (x 10^6 cfu/lb)
Beef*	800†	46.4†	207§

* Cow calf pairs
†Source: ASAE (1998)
§Based on per capita fecal coliform production per day and manure production

Solid cattle manure is applied at the rate of 15 tons/ac-year to both cropland and pasture, with priority given to cropland. Solid manure is only applied to cropland from January through May, and October through December. Solid manure can be applied to pasture anytime of the year. The application schedule for solid manure is given in Table 3.12. Based on availability of land and solid manure, as well as the assumptions regarding application rates and priority of application, it was estimated that solid cattle manure was applied to 21 acres (5%) of cropland and 86 acres (1%) of pasture in Lower Hardware River watershed and to 31 acres (50%) of cropland and 95 acres (10%) of pasture in the North Fork Hardware River watershed.

Table 3.12. Monthly application schedule for the North Fork and Lower Hardware Rivers.

Month	Solid Manure applied (%)*
January	0
February	5
March	25
April	20
May	5
June	5
July	5
August	5
September	10
October	10
November	10
December	0

*As percent of annual load

3.3. Horses

Horse populations for the watersheds were estimated from population numbers in the 2000 Agricultural Census for Albemarle and Fluvanna Counties.

The populations were area-weighted according to pasture areas in the counties and in each sub-watershed of Lower and North Fork Hardware Rivers. The total horse population was deemed satisfactory by local stakeholders during the public and LSC meetings. The distribution of horses among the sub-watersheds is given in Table 3.13 for Lower Hardware River and Table 3.14 for the North Fork Hardware River. The fecal coliform originating from horses contributes to the pasture load. Fecal coliform loadings from horses on a daily basis averaged over the year and over all pastures in the watershed are 2.4 x 10^7 cfu/day for both Lower Hardware and North Fork Hardware Rivers.

Table 3.13. Horse Population in Lower Hardware River.

Sub-watershed	Horses
1	2
2	20
3	28
4	44
5	41
6	18
7	17
8	27
9	10
10	13
11	12
12	8
13	51
14	0
15	17
16	26
17	8
18	13
19	25
20	36
21	26
22	21
23	15
24	16
Total	494

Table 3.14. Horse Population in North Fork Hardware River.

Sub-watershed	Horses
1	11
2	20
3	19
4	19
5	9
6	42
7	126
8	88
9	24
10	13
11	3
12	56
13	17
14	17
15	1
16	50
17	1
18	31
19	17
20	19
Total	583

3.4. Wildlife

Wildlife fecal coliform contributions can come from excretion of waste on land and from excretion directly into streams. Information provided by VADGIF and watershed residents was used to estimate wildlife populations. Wildlife species that were found in quantifiable numbers in the watershed included deer, raccoon, muskrat, beaver, wild turkey, goose, and wood duck. Population numbers for each species and fecal coliform amounts were determined along with preferred habitat and habitat area.

Professional judgment was used in estimating the percent of each wildlife species depositing directly into streams, by considering each habitat area occupied (Table 3.15). Fecal loading from wildlife was estimated for each sub-watershed. The wildlife populations were distributed among the sub-watersheds based on the area of appropriate habitat in each sub-watershed. For example, the deer population was evenly distributed across the watershed, whereas muskrat and raccoons had variable population densities based on land use and

proximity to a water source. Therefore, a sub-watershed with more stream length and impoundments and more area in crop land use would have more muskrats than a sub-watershed with shorter stream length, fewer impoundments, and less area in crop land use. Distribution of wildlife among sub-watersheds is given in Table 3.16 for Lower Hardware River and Table 3.17 for the North Fork Hardware River.

Table 3.15. Wildlife habitat, population density, and direct fecal deposition in streams.

Wildlife type	Habitat and Estimation Method	Population Density (animal / mi² - habitat)	Direct fecal deposition in streams (%)
Deer	Entire Watershed	30	1%
Raccoon	low density on forests not in high density area; high density on forest within 600 ft of a permanent water source or 0.5 mile of cropland; highest density in residential areas	Low density: 10 High density: 30 Highest density: 50	10%
Muskrat	16/mile of ditch or medium sized stream intersecting cropland; 8/mile of ditch or medium sized stream intersecting pasture; 10/mile of pond or lake edge; 50/mile of slow-moving river edge	-see habitat column-	25%
Beaver	3/mile of perennial streams; and 3.8/mile of lake or pond shore	-see habitat column-	50%
Geese	300 ft buffer around main streams	50 – off season 70 – peak season	25%
Wood Duck	300 ft buffer around main streams	40 – off season 60 – peak season	25%
Wild Turkey	Forest; based on kill rate per square mile of forest for each county, assuming the killed birds are 10% of the total population	28 (Albemarle) 23 (Fluvanna)	0%

Table 3.16. Wildlife populations in Lower Hardware River watershed.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Goose		Wood Duck		Wild Turkey
					Off-peak	Peak	Off-peak	Peak	
1	41	19	91	2	12	16	9	14	7
2	62	34	144	4	20	27	16	23	10
3	106	42	189	5	26	36	21	31	18
4	140	22	94	3	13	18	10	16	24
5	71	19	76	2	12	16	9	14	12
6	34	31	119	3	18	25	14	21	6
7	44	25	84	3	14	20	11	17	7
8	96	26	79	3	14	20	12	17	16
9	37	8	35	1	5	6	4	5	6
10	73	23	100	3	14	19	11	17	12
11	30	15	67	2	9	12	7	10	5
12	76	18	75	2	10	14	8	12	13
13	139	26	94	3	15	21	12	18	23
14	37	16	70	2	9	12	7	11	6
15	58	25	111	3	14	20	11	17	10
16	37	14	59	2	9	12	7	10	6
17	131	42	179	5	24	33	19	28	22
18	104	14	67	1	8	12	7	10	17
19	79	26	86	3	15	20	12	17	13
20	72	38	127	4	22	30	17	26	12
21	45	16	70	2	9	13	7	11	8
22	54	24	82	3	13	19	11	16	9
23	46	24	65	3	14	19	11	17	8
24	32	10	44	1	6	8	5	7	5
Total	1644	557	2207	65	325	448	258	385	275

Table 3.17. Wildlife populations in North Fork Hardware River watershed.

Sub-watershed	Deer	Raccoon	Muskrat	Beaver	Goose		Wood Duck		Wild Turkey
					Off-peak	Peak	Off-peak	Peak	
1	24	78	152	8	44	61	35	52	7
2	13	40	36	3	22	31	18	27	6
3	29	88	291	9	51	71	41	61	10
4	16	66	148	7	38	54	31	46	20
5	13	50	139	3	27	38	21	32	20
6	3	13	66	2	8	11	7	10	5
7	16	50	122	5	28	39	22	34	10
8	7	37	97	4	22	31	18	26	12
9	1	6	31	1	4	6	3	5	5
10	4	16	11	2	9	12	7	10	11
11	5	21	39	2	12	17	9	14	10
12	15	71	260	8	41	57	33	49	10
13	16	79	361	9	47	65	37	56	6
14	3	13	18	1	7	9	5	8	12
15	3	16	76	2	9	13	8	11	7
16	6	19	91	2	12	16	9	14	17
17	10	31	82	3	17	24	14	20	6
18	5	26	46	3	15	21	12	18	17
19	5	28	85	3	17	23	13	20	6
20	1	8	6	1	5	7	4	6	8
Total	195	756	2157	78	435	606	347	519	205

3.5. Summary: Contributions from All Sources

Based on the inventory of sources discussed in this chapter, a summary of the contribution by the different direct nonpoint sources to the annual fecal coliform loading to the streams is given in Table 3.18. Distribution of annual fecal coliform loading from nonpoint sources among the different land use categories is also given in Table 3.18.

From Table 3.18, it is clear that nonpoint source loadings to the land surface are greater than direct nonpoint source loadings to the stream; approximately 30 and 15 times greater for Lower Hardware and North Fork Hardware River, respectively. Pastures receive the greatest portion of this load, close to 90% for both watersheds. However, factors such as precipitation

amount and pattern, die-off rates, manure application activities, type of waste, and proximity to the streams impact the amount of fecal coliform from upland areas that reaches the streams. Due to their nature, direct nonpoint source loadings to streams are not modified before transmission to the stream. The HSPF model discussed in Chapter 4 considers these factors when estimating fecal coliform loadings in the receiving waters.

Table 3.18. Annual fecal coliform loadings to the stream and the various land use categories for Lower Hardware River and North Fork Hardware River watersheds.

Source	Fecal coliform loading ($x10^{12}$ cfu/yr)		Percent of total loading	
	Lower Hardware River	North Fork Hardware River	Lower Hardware River	North Fork Hardware River
Direct loading to streams				
Cattle in stream	326	35	2%	1%
Wildlife in stream	107	0.06	1%	<1%
Straight pipes	33	200	<1%	5%
Point Sources	0	4	0	<1%
Loading to land surfaces				
Cropland	17	0.06	<1%	<1%
Pasture	14,527	3,323	91%	89%
Residential	568	174	4%	5%
Forest	471	16	3%	<1%
Total	16,049	3,752		

Chapter 4: Modeling Process for Bacteria TMDL Development

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

4.1. Model Description

TMDL development requires the use of a watershed-based model that integrates both point and nonpoint sources and simulates in-stream water quality processes. The Hydrologic Simulation Program – FORTRAN (HSPF) version 12 (Bicknell *et al.*, 2001; Duda *et al.*, 2001) was used to model fecal coliform transport and fate in the Hardware River watershed. The ArcGIS 9.1 GIS program was used to display and analyze landscape information for the development of input for HSPF.

The HSPF model simulates nonpoint source runoff and pollutant loadings, performs flow routing through streams, and simulates in-stream water quality. HSPF estimates runoff from both pervious and impervious surfaces in the watershed and stream flow in the channel network. The sub-module PWATER within the module PERLND simulates runoff, and hence, estimates the water budget on pervious areas (e.g., agricultural land). Runoff from impervious areas is modeled using the IWATER sub-module within the IMPLND module. The simulation of flow through the stream network is performed using the sub-

modules HYDR and ADCALC within the module RCHRES. HYDR routes the water through the stream network, and ADCALC calculates variables used for simulating convective transport of the pollutant in the stream. Fate of fecal coliform on pervious and impervious land segments is simulated using the PQUAL (PERLND module) and IQUAL (IMPLND module) sub-modules, respectively. Fate of fecal coliform in stream water is simulated using the general constituent pollutant (GQUAL) sub-module within RCHRES module. Fecal coliform bacteria are simulated as dissolved pollutants in the GQUAL sub-module.

4.2. Input Data Requirements

The HSPF model requires a wide variety of input data to describe hydrology, water quality, and land use characteristics of the watershed. The sources of input data discussed in Chapters 2 and 3 were used to develop the TMDLs for the Lower Hardware River and North Fork Hardware River.

4.2.1. Climatological Data

Hourly precipitation data were obtained from nine National Weather Service COOP stations. The majority of the precipitation data came from Bremo Bluff (440993). Bremo Bluff is located approximately 6.5 miles east southeast of the watershed outlet. The remaining were used to fill in missing records of Bremo Bluff and included: North Garden (445700), Charlottesville 2W (441593), Monticello (445700), Piedmont Research (446712), Staunton Sewage Plant (448062), Montebello Fish Hatchery (445690), Dale Enterprise (442208), and Lynchburg Regional Airport (445120). Charlottesville 2W is located approximately 9 miles northeast of the watershed, Monticello - 11 miles northeast of the watershed, Piedmont Research - 34 miles northeast of the watershed, Staunton Sewage Plant - 29 miles northwest of the watershed, Montebello Fish Hatchery - 26 miles west of the watershed, Dale Enterprise - 38 miles northwest of the watershed, and Lynchburg Regional Airport - 54 miles southwest of the

watershed. Detailed descriptions of the weather data and the procedure for converting the raw data into the required data set are presented in Appendix D.

4.2.2. Model Parameters

The hydrology parameters required by HSPF were defined for all land use categories within each sub-watershed. Required hydrology parameters are listed in the HSPF Version 12 User's Manual (Bicknell *et al.*, 2001). Initial estimates for the hydrology parameters were generated based on guidance in BASINS Technical Note 6 (USEPA, 2000); these parameters were refined during calibration. Each reach requires a function table (FTABLE) to describe the relationship between water depth, surface area, volume, and discharge (Bicknell *et al.*, 2001). FTABLE parameters were estimated from cross-section data collected during a windshield survey of the watershed. Information on the calculated stream geometry for each sub-watershed is presented in Table 4.1 and Table 4.2 for the bankfull condition.

Required water quality parameters are also given in the HSPF User's Manual (Bicknell *et al.*, 2001). Initial estimates for bacteria loading parameters were based on estimates of bacteria production in the watershed; estimates of die-off rates and subsurface bacteria concentrations were based on values commonly used in previous TMDLs.

Table 4.1. Reach characteristics for North Fork Hardware River.

Sub-watershed	Stream length (mile)	Slope (ft/ft)
1	3.01	0.002273
2	5.02	0.001294
3	6.61	0.001598
4	5.98	0.001911
5	3.01	0.014763
6	3.26	0.003890
7	5.78	0.002862
8	4.06	0.002044
9	2.70	0.011060
10	2.99	0.012366
11	2.44	0.002629
12	3.59	0.002552
13	5.74	0.001696
14	2.87	0.005334
15	2.60	0.005463
16	7.29	0.002379
17	2.95	0.011860
18	5.03	0.011962
19	2.04	0.003132
20	3.92	0.014127

Table 4.2. Reach characteristics for Lower Hardware River.

Sub-watershed	Stream length (mile)	Slope (ft/ft)
1	2.08	0.003148
2	3.43	0.003649
3	4.65	0.001648
4	2.43	0.002302
5	2.17	0.001447
6	3.14	0.004247
7	2.50	0.004811
8	2.52	0.004085
9	0.83	0.005109
10	2.44	0.002237
11	1.58	0.002156
12	1.78	0.002928
13	2.81	0.001760
14	1.59	0.005303
15	2.53	0.003381
16	1.59	0.001340
17	4.22	0.003003
18	1.57	0.001226
19	2.59	0.003073
20	3.85	0.003961
21	1.67	0.002287
22	2.30	0.007350
23	2.49	0.007827
24	1.03	0.007500

4.3. Accounting for Pollutant Sources

4.3.1. Overview

There were 2 VPDES facilities permitted to discharge bacteria into North Fork: Cross-Roads Village (VA0083291) and North Garden Post Office (VAG408054). The fecal coliform concentration in the discharges from these facilities cannot exceed 200 cfu/100 mL. During calibration, reported concentrations from these facilities were incorporated into the model; during allocation, concentrations from these facilities were set at their permitted limits.

Point sources permitted to discharge bacteria in the watershed were incorporated into the simulations at the stream locations designated in the permit. Bacteria loads that are directly deposited by cattle and wildlife in streams were

treated as direct nonpoint sources in the model. Direct nonpoint source loading was applied to the stream reach in each sub-watershed as appropriate. Bacteria that were land-applied or deposited on land were treated as nonpoint source loadings; all or part of that load may be transported to the stream as a result of surface runoff during rainfall events.

The nonpoint source loading was applied in the form of fecal coliform counts to each land use category in a sub-watershed. Fecal coliform die-off was simulated while manure was being stored, while it was on the land, and while it was transported in streams. Both direct nonpoint and nonpoint source loadings were varied by month to account for seasonal differences such as cattle and wildlife access to streams.

We used the Bacteria Source Load Calculator (Zeckoski et al., 2005) to generate the nonpoint source fecal coliform inputs to the HSPF model. This spreadsheet program takes inputs of animal numbers, land use, and management practices by sub-watershed and outputs hourly direct deposition to streams and monthly loads to each land use type. The program only allows direct deposition in the stream by dairy cows, beef cattle, ducks, and geese to occur during daylight hours. The spreadsheet program calculates the manure produced in confinement by each animal type (dairy cows, beef cattle, and poultry) and distributes this manure to available lands (crops and pasture) within each sub-watershed. If a sub-watershed does not have sufficient land to apply all the manure its animals generate, the excess manure is distributed equally to other sub-watersheds that have land that has not yet received manure.

4.4. Model Calibration and Validation Procedure

Model calibration is the process of selecting model parameters that provide an accurate representation of the watershed. In this section, the procedures followed for calibrating the hydrology and water quality components of the Hydrological Simulation Program-FORTRAN (HSPF) model are discussed.

4.4.1. Hydrology

A combination of manual calibration using HSPEXP and automatic calibration using the Parameter Estimation (PEST) software were used to calibrate and validate the model to the Hardware River watershed. The Lower and North Fork River watersheds were treated as one watershed for the calibration and validation processes. The default HSPEXP criteria are listed in Table 4.3; the equations for the Goodness-of-Fit parameters used with PEST are listed in Table 4.4. The equations for the objective functions required for PEST are listed in Table 4.5; these functions were designed to mimic the HSPEXP statistics given in Table 4.3. In accordance with a procedure described in Kim et al. (2007a), a combination of Goodness-of-Fit measures and multi-objective functions were used in the portion of the hydrologic calibration of HSPF that was performed using PEST. Further refinement of the input parameters was performed manually considering the HSPEXP statistics given in Table 4.3.

Table 4.3. Default criteria for HSPEXP.

Variable	Percent Error
Total Volume	±10%
50 % Lowest Flows	±10%
10 % Highest Flows	±15%
Storm Peaks	±15%
Seasonal Volume Error	±10%
Summer Storm Volume Error	±15%

Table 4.4. Goodness-of-Fit Measures.

Name	Symbol	Formula
R-squared	R^2	$\left\{ \frac{\sum_{i=1}^{N} \left(Q_{Obs,i} - \overline{Q}_{Obs}\right)\left(Q_{Sim,i} - \overline{Q}_{Sim}\right)}{\left[\sum_{i=1}^{N} \left(Q_{Obs,i} - \overline{Q}_{Obs}\right)^2\right]^{0.5} \left[\sum_{i=1}^{N} \left(Q_{Sim,i} - \overline{Q}_{Sim}\right)^2\right]^{0.5}} \right\}^2$
Nash-Sutcliff Efficiency	*E*	$1.0 - \frac{\sum_{i=1}^{N} \left(Q_{Obs,i} - Q_{Sim,i}\right)^2}{\sum_{i=1}^{N} \left(Q_{Obs,i} - \overline{Q}_{Obs}\right)^2}$
Root-Mean-Square-Error	RMSE	$\left[\frac{1}{N} \sum_{i=1}^{N} \left(Q_{Obs,i} - \overline{Q}_{Obs}\right)^2\right]^{0.5}$

Table 4.5. Multi-Objective Function Components

Description	Formula
Squared error of daily flows	$f_1(\theta) = \sum_{i=1}^{N} \left[\left(Q_{Obs,i} - Q_{Sim,i}\right) \cdot w_{1,i}\right]^2$
Squared error of 50% lowest flow exceedences	$f_2(\theta) = \sum_{i=1}^{N} \left[\left(EX_{Obs,50\%lowestflow} - EX_{Sim,50\%lowestflow}\right) \cdot w_{2,i}\right]^2$
Squared error of 10% highest flow exceedences	$f_3(\theta) = \sum_{i=1}^{N} \left[\left(EX_{Obs,10\%highestflow} - EX_{Sim,50\%highstflow}\right) \cdot w_{3,i}\right]^2$
Squared error of storm peaks	$f_4(\theta) = \sum_{i=1}^{N} \left[\left(P_{Obs,i} - P_{Sim,i}\right) \cdot w_{4,i}\right]^2$
Squared error of seasonal volume	$f_5(\theta) = \sum_{j=1}^{N_{SS}} \left[\left(\sum_{i=1}^{n_j} Q_{Obs,i} - \sum_{i=1}^{n_j} Q_{Sim,i}(\theta)\right) \cdot w_{5,i}\right]^2$
Squared error of storm volume	$f_6(\theta) = \sum_{j=1}^{N_{SS}} \left[\left(\sum_{i=1}^{m_j} Q_{Obs,i} - \sum_{i=1}^{m_j} Q_{Sim,i}(\theta)\right) \cdot w_{6,i}\right]^2$

4.4.2. Hydrologic Calibration

The hydrologic calibration period for HSPF was 09/01/1989 through 08/31/1995. The output from the HSPF model calibration period was daily average flow in cubic feet per second (cfs). Calibration parameters were adjusted within the recommended range (USEPA, 2000).

There was good agreement between observed and simulated flow for the calibration period based on visual comparisons and the HSPEXP and Goodness-of-Fit parameter values. The observed and simulated flows for the calibration period are shown in Figure 4.1. The agreement is further illustrated in Figure 4.2, which presents the observed and simulated flows for a representative year. The quality of the calibration is further illustrated Figure 4.3, which presents the observed and simulated flows for a representative storm. A final visual comparison was made using the cumulative frequency curves of the observed and simulated flows (Figure 4.4). The calibration is satisfactory based on the visual comparisons of the simulated and observed flow.

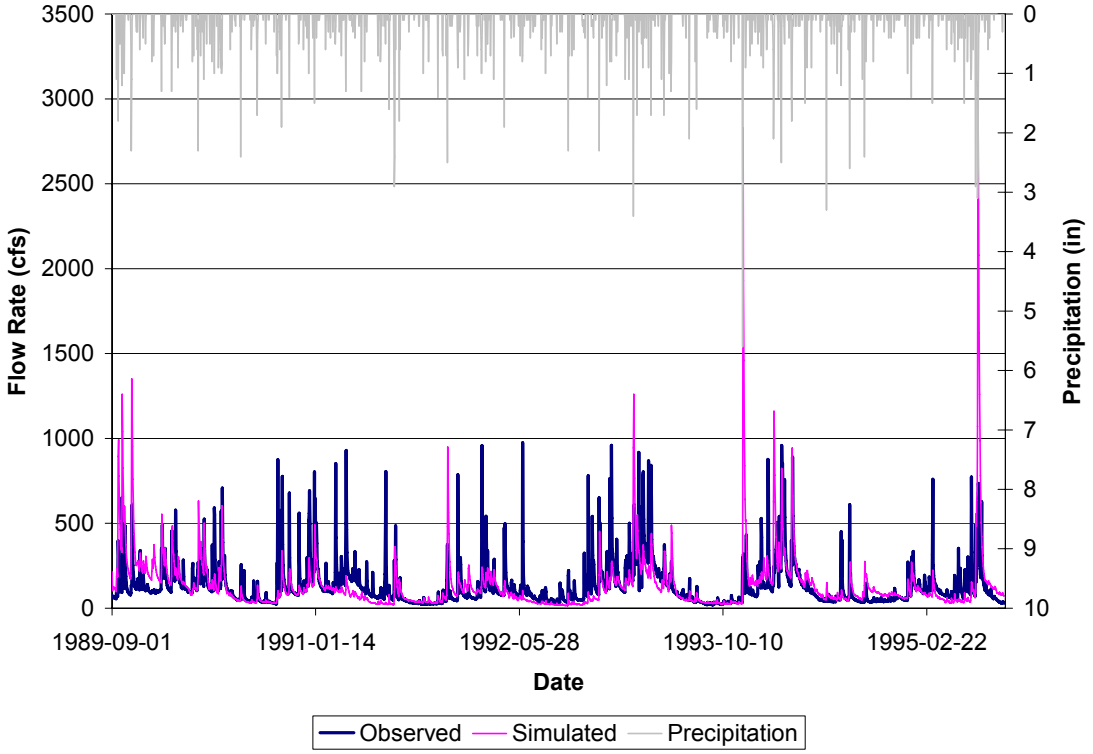

Figure 4.1. Observed and simulated flows and precipitation for Hardware River for the calibration period.

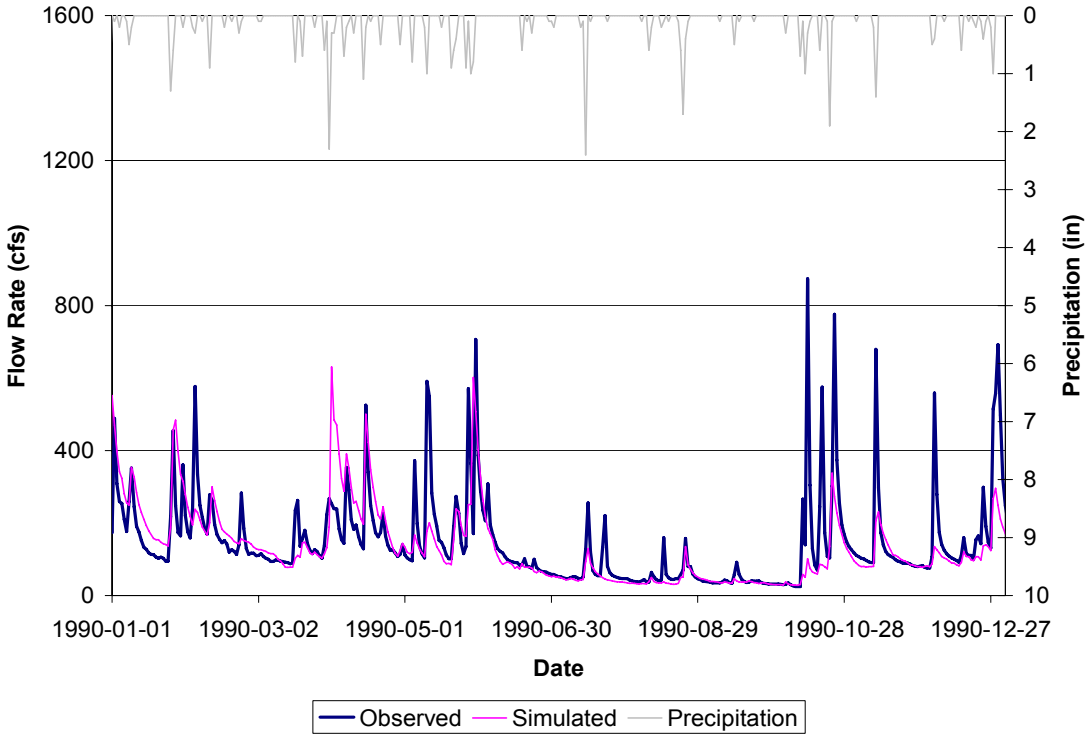

Figure 4.2. Observed and simulated flows and precipitation for Hardware River for a representative year in the calibration period.

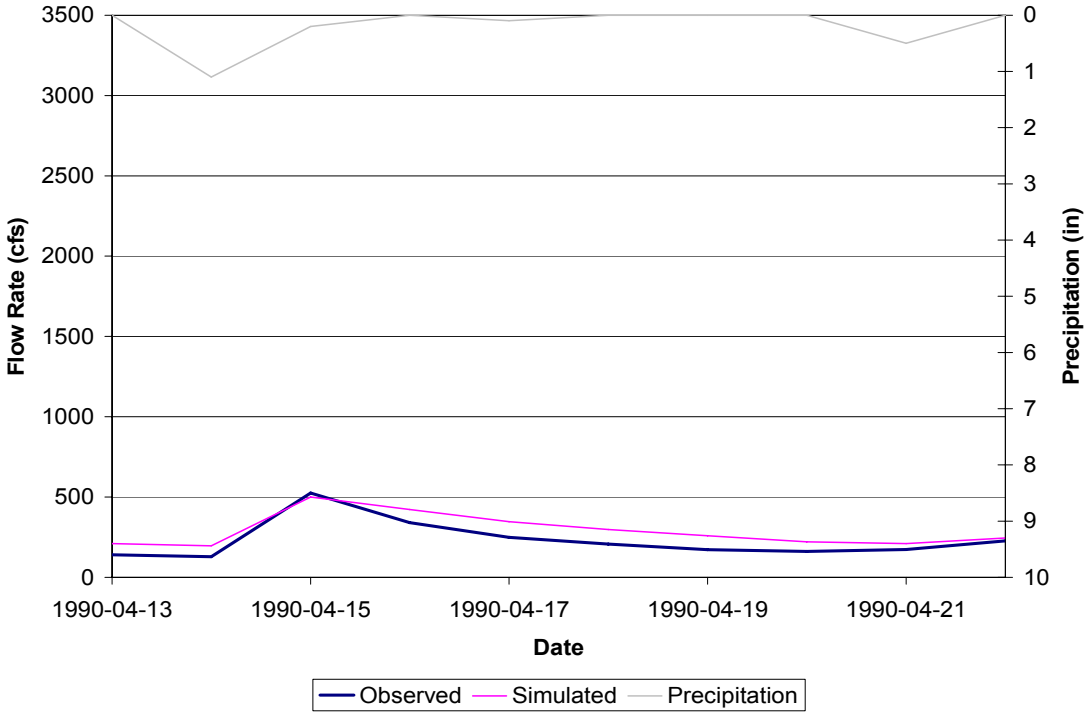

Figure 4.3. Observed and simulated flows and precipitation for Hardware River for a representative storm in the calibration period.

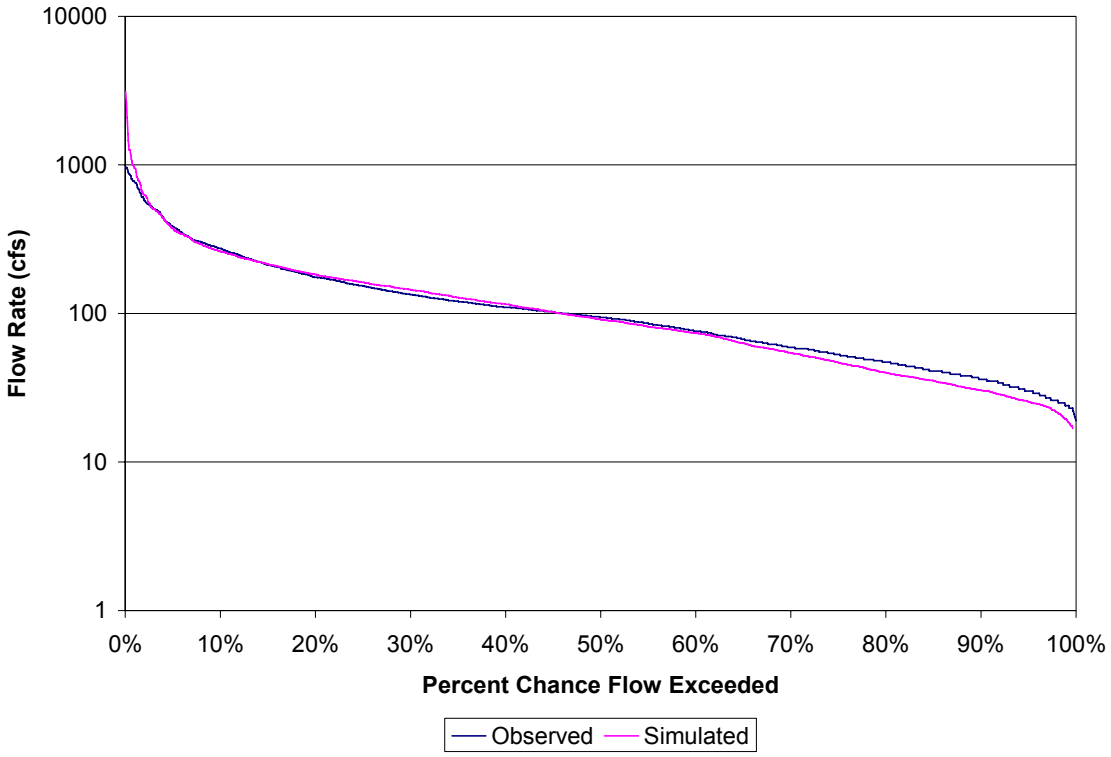

Figure 4.4. Cumulative frequency curves for the calibration period for Hardware River.

The quality of the calibration is demonstrated further in the HSPEXP and Goodness-of-Fit values. The values for the HSPEXP criteria are listed in Table 4.6. There is small positive error for the Total Runoff (+4.3%) and likewise with the Average Annual Runoff (+4.3%). There was a larger error of +14.6% for the Total of the 10% Highest of Flows (14.6%), but this was still within ±15% criterion. The values for the Goodness-of-Fit parameters are listed in Table 4.7.

Table 4.6. Results for HSPEXP criteria for Calibration.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	99.670	95.553	+4.3	10%
Average Annual Total Runoff (in)	16.612	15.926	+4.3	10%
Total of Highest 10% of Flows (in)	37.440	32.676	+14.6	15%
Total of Lowest 50% of Flows (in)	18.220	20.030	-9.0	10%
Total Winter Runoff (in)	31.160	29.035	+7.3	na
Total Summer Runoff (in)	18.360	16.676	+10.1	na

na = not applicable; these are not criteria directly considered by HSPEXP

Table 4.7. Goodness-of-Fit Measures for Calibration.

Goodness-of-Fit Parameter	Value
R^2	0.21
E	-0.704
RMSE (in)	0.0572

4.4.3. Hydrologic Validation

The hydrologic validation period was 09/01/1997 through 08/31/2004. The output from the HSPF model for validation was daily average flow in cubic feet per second (cfs). There was good agreement between observed and simulated flow for the validation period based on the visual comparisons and the HSPEXP and Goodness-of-Fit parameter values. The observed and simulated flows for the validation period are shown in Figure 4.5. Both peak flows and low flows were captured by the model (see Figure 4.5). The agreement is further illustrated in Figure 4.6, which shows the observed and simulated flows for a representative year. Also, the quality of the validation is evident in Figure 4.7, which shows the observed and simulated flows for a representative storm. A final visual comparison was made using the cumulative frequency curves of the observed and simulated flows (Figure 4.8). The model slightly underpredicted high flows and overpredicted low flows (see Figure 4.8). The visual comparisons of the simulated and observed flow support a satisfactory validation.

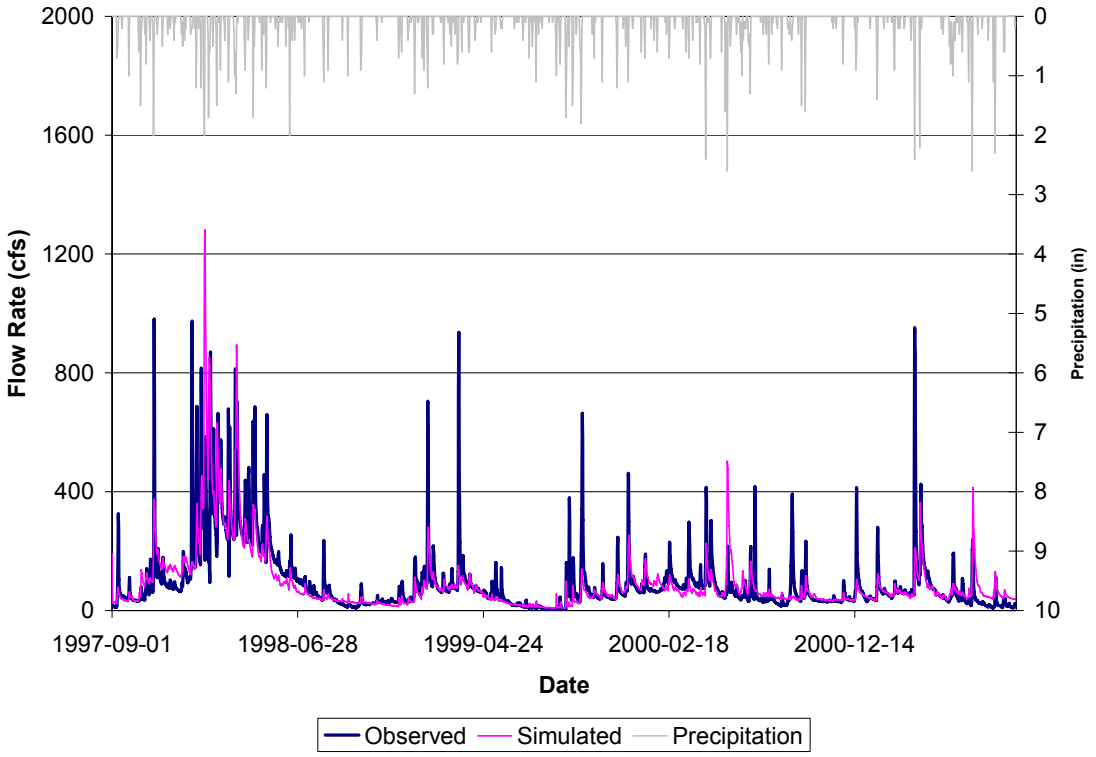

Figure 4.5. Observed and simulated flows and precipitation for Hardware River for the validation period.

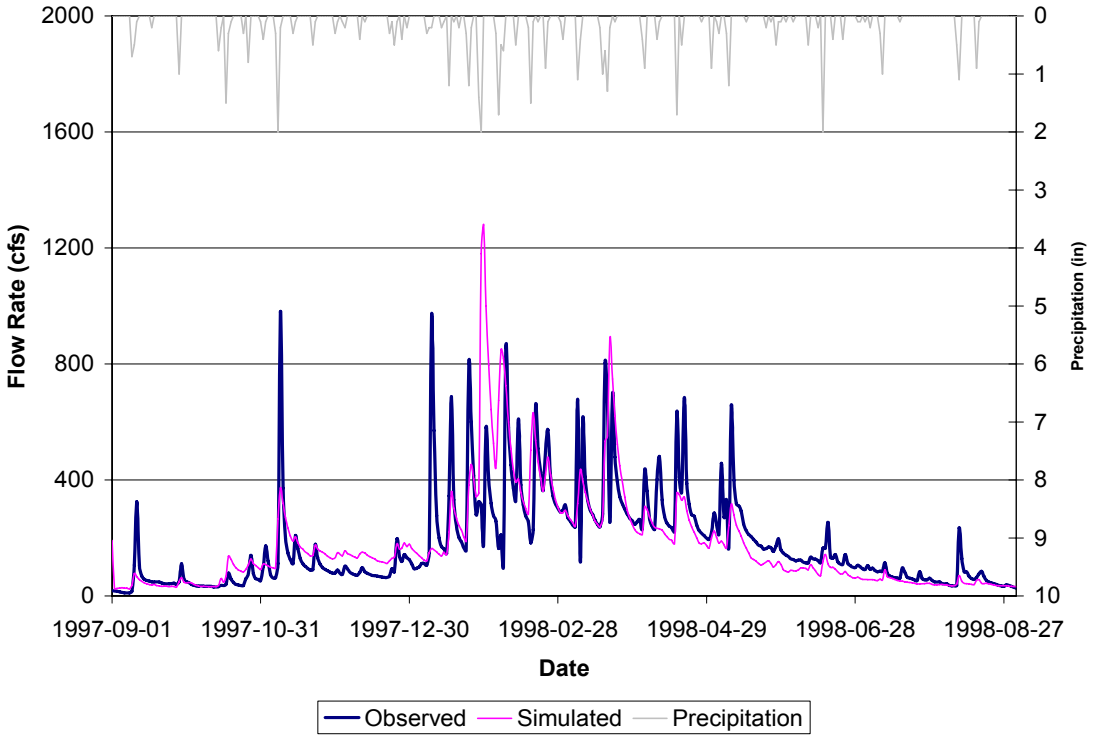

Figure 4.6. Observed and simulated flows and precipitation for Hardware River for a representative year in the validation period.

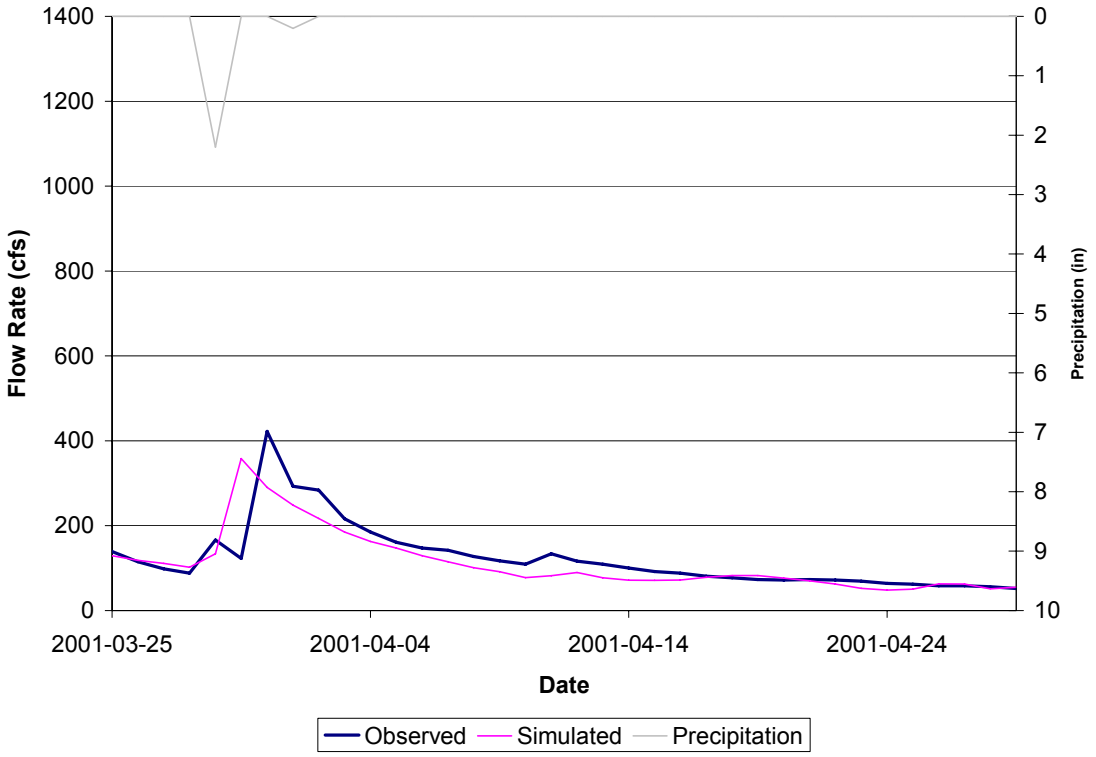

Figure 4.7. Observed and simulated flows and precipitation for Hardware River for a representative storm in the validation period.

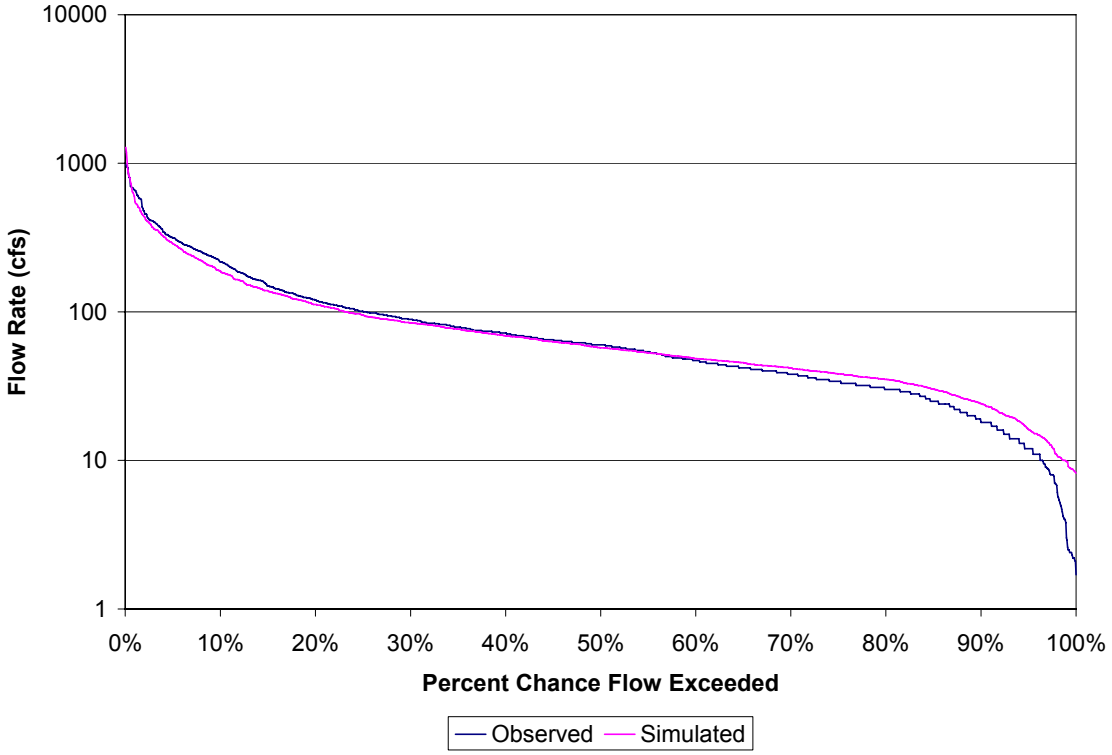

Figure 4.8. Cumulative frequency curves for the validation period for Hardware River.

The quality of the validation is demonstrated further in the HSPEXP and Goodness-of-Fit values. There is small negative error for the Total Runoff (-4.1%) and likewise with the Average Annual Runoff (-4.1%). There was a moderate size error of -7.9% for the Total of the 10% Low of Flows. The values for the HSPEXP criteria are listed in Table 4.8. The values for the Goodness-of-Fit parameters are listed in Table 4.9.

Table 4.8. Default criteria for HSPEXP for Validation.

	Simulated	Observed	Error (%)	Criterion
Total Runoff (in)	43.780	45.668	-4.1	10%
Average Annual Total Runoff (in)	10.945	11.417	-4.1	10%
Total of Highest 10% of Flows (in)	16.820	18.270	-7.9	15%
Total of Lowest 50% of Flows (in)	8.800	8.000	+10.0	10%
Total Winter Runoff (in)	15.840	14.801	+7.02	na
Total Summer Runoff (in)	6.320	5.404	+16.95	na

na = not applicable; these were not criteria directly considered by HSPEXP

Table 4.9. Goodness-of-Fit Measures for Validation.

Goodness-of-Fit Parameter	Value
R^2	0.48
E	0.41
RMSE (in)	0.0296

4.5. Flow Partitioning

Flow partitioning for the Hardware River hydrologic model calibration and validation is shown in Table 4.10. When the observed flow data were evaluated using HYSEP, the baseflow indices for the calibration and validation periods were both 0.65. The baseflow indices for the simulated data are presented in Table 4.10. We feel the simulated baseflow indices shown in Table 4.10 match

the observed values well. The final calibrated hydrology parameters can be found in Table 4.11.

Table 4.10. Flow partitioning for the calibration and validation periods for Hardware River.

Average Annual Flow	Calibration	Validation
Total Annual Runoff (in)	*16.61*	*10.95*
Surface Runoff (in)	*0.45 (2.7%)*	*0.29 (2.7%)*
Interflow (in)	*5.76 (34.7%)*	*2.71 (24.7%)*
Baseflow (in)	*10.40 (62.6%)*	*7.95 (72.6%)*
Baseflow Index (HSPF)	*0.63*	*0.73*
Baseflow Index (HYSEP)	*0.65*	*0.65*

The calibrated output from HSPF met all the criteria in both the calibration period and the validation period. This indicates that the developed hydrologic model produces an acceptable prediction of Hardware River flows.

Table 4.11. Final calibrated parameters for Hardware River.

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix E Table (if applicable)
PERLND					
PWAT-PARM2					
FOREST	Fraction forest cover	none	1.0 forest, 0.0 other	Forest cover	
LZSN	Lower zone nominal soil moisture storage	inches	7.8	Soil properties	
INFILT	Index to infiltration capacity	in/hr	0.128	Soil and cover conditions	1
LSUR	Length of overland flow	feet	219-459	Topography	1
SLSUR	Slope of overland flowplane	none	0.03-0.08	Topography	1
KVARY	Groundwater recession variable	1/in	0.0	Calibrate	
AGWRC	Base groundwater recession	none	0.99	Calibrate	
PWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
INFEXP	Exponent in infiltration equation	none	2	Soil properties	
INFILD	Ratio of max/mean infiltration capacities	none	2	Soil properties	
DEEPFR	Fraction of GW inflow to deep recharge	none	0.0	Geology	
BASETP	Fraction of remaining ET from baseflow	none	0.10	Riparian vegetation	
AGWETP	Fraction of remaining ET from active GW	none	0.001	Marsh/wetland s ET	
PWAT-PARM4					
CEPSC	Interception storage capacity	inches	Monthly[a]	Vegetation	2
UZSN	Upper zone nominal soil moisture storage	inches	Monthly[a]	Soil properties	3
NSUR	Mannings' n (roughness)	none	0.45 forest; 0.25 pasture; 0.30 crop; 0.15 LDR and HDR	Land use, surface condition	
INTFW	Interflow/surface runoff partition parameter	none	10.0	Soils, topography, land use	
IRC	Interfiow recession parameter	none	0.74	Soils, topography, land use	
LZETP	Lower zone ET parameter	none	Monthly[a]	Vegetation	4

Table 4.11. Final calibrated parameters for Hardware River.(continued).

Parameter	Definition	Units	FINAL CALIBRATION	FUNCTION OF…	Appendix E Table (if applicable)
IMPLND					
IWAT-PARM2					
LSUR	Length of overland flow	feet	50	Topography	
SLSUR	Slope of overland flowplane	none	0.08	Topography	
NSUR	Mannings' n (roughness)	none	0.1	Land use, surface condition	
RETSC	Retention/interception storage capacity	inches	0.125	Land use, surface condition	
IWAT-PARM3					
PETMAX	Temp below which ET is reduced	deg. F	40	Climate, vegetation	
PETMIN	Temp below which ET is set to zero	deg. F	35	Climate, vegetation	
RCHRES					
HYDR-PARM2					
KS	Weighting factor for hydraulic routing		0.5		

[a]Varies by month

4.6. Water Quality Calibration for Hardware River

The water quality calibration was performed at an hourly time step using the HSPF model. There were four water quality monitoring stations available for North Fork: 2-HNF000.10, 2-HNF005.03, 2-HNF008.28, and 2-HNS002.40. Only station 2-HNF008.28, which is located in the upper portion of North Fork Hardware River (see Figure 4.9), was used for calibration. This station has 26 observations of fecal coliform data across 11 years. The other stations have less than 2 years of *E. coli* data. The period of January 1, 1995 to December 31, 2005 includes all of the data from station 2-HNF008.28 and for that reason this period was selected for calibration. The North Fork Hardware River was calibrated first and then output from the calibrated North Fork Hardware River model run was treated as an inflow to Lower Hardware River calibration. Two water quality monitoring stations were considered for the calibration of the Lower Hardware River water quality simulations. Data from Station 2-HRD011.57 (see Figure 4.9) includes over 100 observations. The other station has less than 2

years of *E. coli* data. The large dataset available at station 2-HRD011.57 allowed for both calibration and validation of the model for the Lower Hardware River watershed. The calibration period was January 1, 2000 to December 31, 2005 and the validation period was January 1, 1995 to December 31, 1998. Output from the HSPF model was generated as an hourly timeseries and daily average timeseries of fecal coliform concentration at the two subwatershed outlets corresponding to the two monitoring station locations.

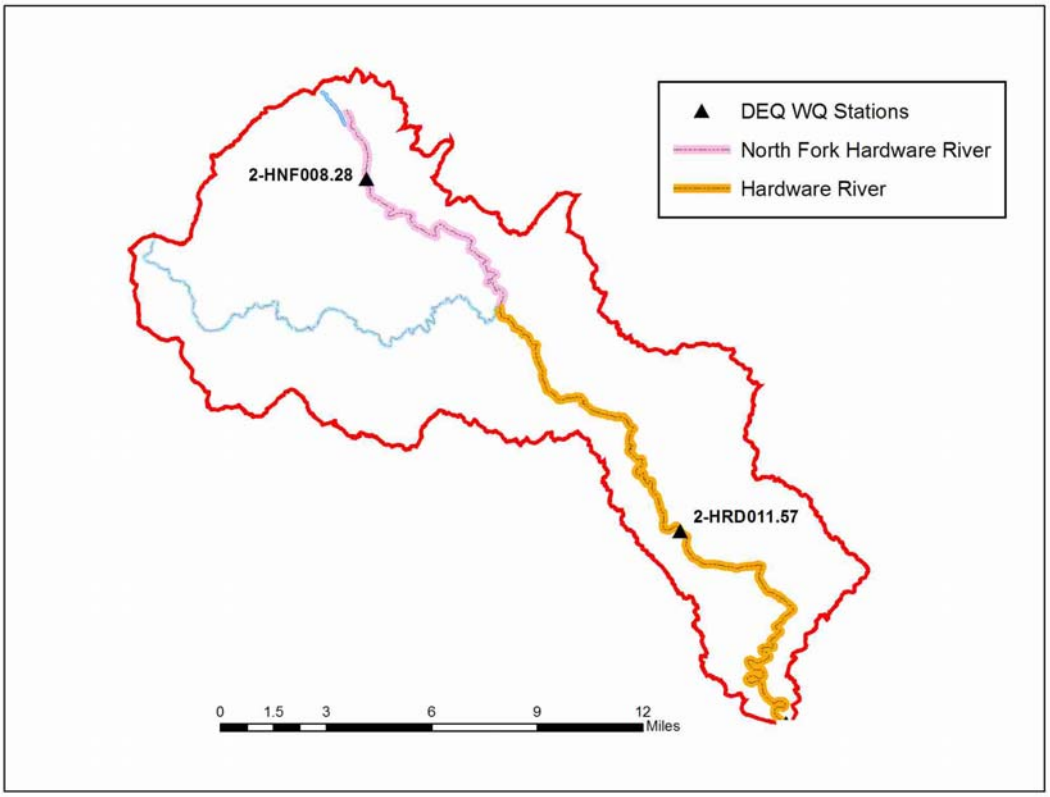

Figure 4.9. Hardware River Watershed Boundaries and Locations of DEQ Monitoring Stations.

E. coli concentrations, not directly considered in the water quality calibration, but necessary for the allocation scenarios, were determined using the following translator equation supplied by DEQ:

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad (1)$$

The *E. coli* translator will be implemented in the HSPF simulation using the GENER block. During allocation, the geometric mean will be calculated on a monthly basis.

Calibration Results

Several key input parameters were altered during the calibration process. These parameters included: the washoff factor (WSQOP); fecal coliform production rates for livestock and wildlife; and the volume used to represent flow stagnation in the reaches. During the entire calibration process, both the simulated geometric mean and instantaneous violation rate compared well with the observed statistics. The simulated geometric mean was 231 cfu/100 mL and the observed was 307 cfu/100 mL, resulting in an -25% relative error. The instantaneous criterion violation rates were 40% (simulated) and 37% (observed), resulting in a 3% error. Finally, the percent of observed values which fell inside the five-day range of simulated values was 80%. The parameters that were adjusted during model calibration are listed in Table 4.13. It should be noted that the parameters altered during the calibration process were those that had the most uncertainty in their initial estimation.

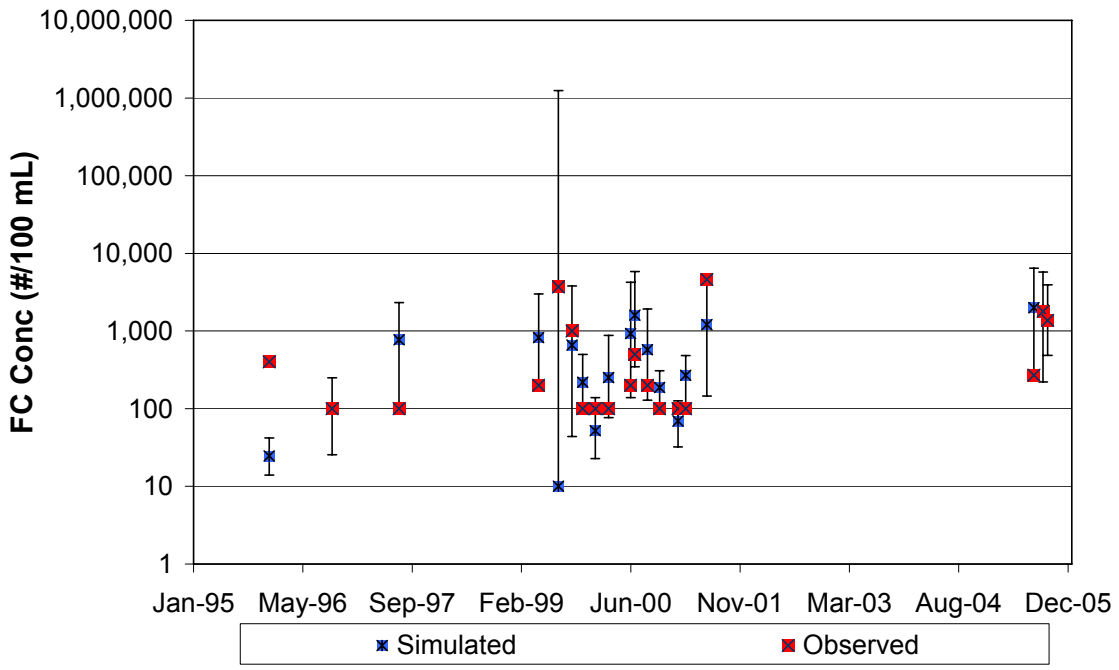

Figure 4.10. Five-day window of simulated in-stream bacteria concentrations surrounding each observed value at station 2-HNF008.28 for the calibration period.

Table 4.12. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the calibration period for North Fork Hardware River.

2-HNF008.28	Geometric Mean	Average	Median	MIN	MAX	IVR* (%)	% in Range
	(cfu/100 mL)						
Observed	307	791	200	100†	4,600	37	
Simulated	231	760	607	10	1,247,889	40	80

*IVR = instantaneous violation rate
†Capped value

Table 4.13. Parameters altered during calibration of North Fork Hardware River.

Parameter	Adjustment
WSQOP	Decreased to 0.01
Fecal Coliform Production Rates for Wildlife	Reduced
Stagnation Volume	Discharge from an individual reach was set to zero when its flow volume fell below a value corresponding to a 0.04 ft depth

A plot of the observed data with the simulated average daily fecal coliform concentrations is shown in Figure 4.11. It is important to note in Figure 4.11 that the lower cap on observed values is 100 cfu/100 mL and the upper cap is 8,000

cfu/100 mL. Figure 4.12 presents the min-max range of concentrations simulated on each day. One would expect the observed values to fall within this min-max range and most of the observed data are within the range of maximum and minimum simulated values shown in Figure 4.12.

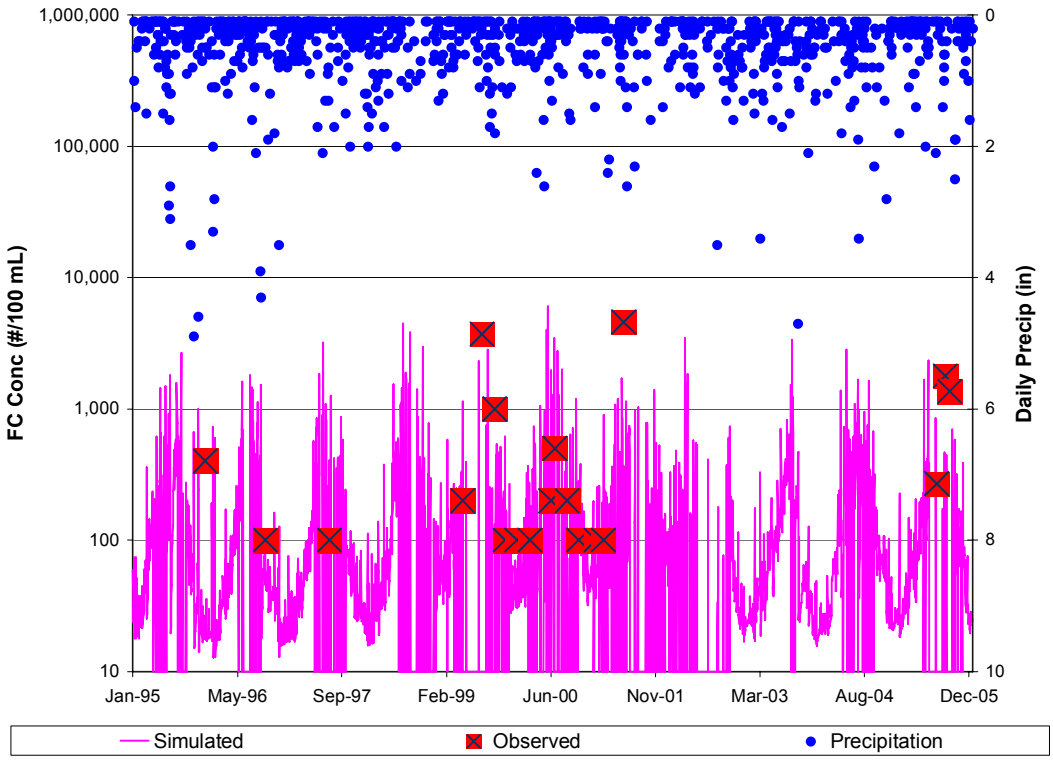

Figure 4.11. Observed and simulated fecal coliform concentrations at station 2-HNF008.28 for North Fork Hardware River.

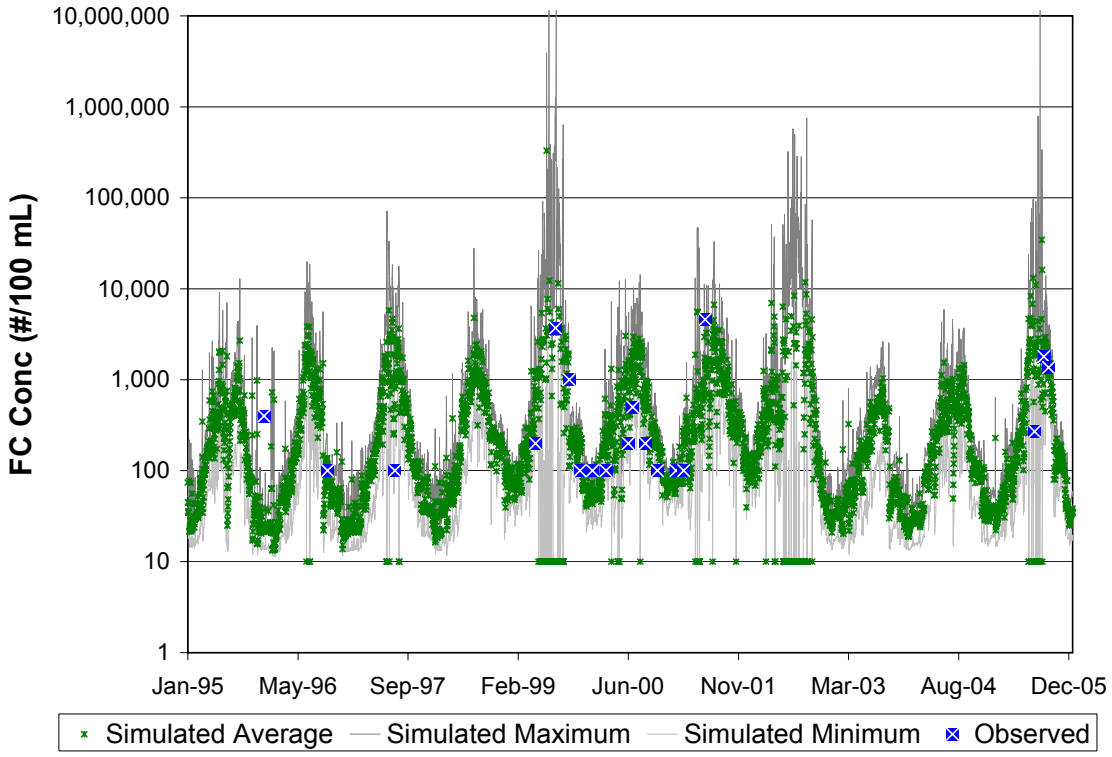

Figure 4.12. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 2-HNF008.28 for North Fork Hardware River.

BST Comparison

Bacterial Source Tracking (BST) data were collected from July 2005-June 2006 at station 2-HNF008.28 in the North Fork Hardware River watershed. BST results are reported as a flow- and concentration-weighted average of the twelve samples. For comparison, model outputs from different bacteria sources were generated for January 1995 - December 2005 and were also flow- and concentration-weighted. The BST results for 2-HNF008.28 are presented in Table 4.14, along with the breakdown of the simulated concentrations. The minimum and maximum observed and simulated values are also presented in this table.

Table 4.14. Bacterial source breakdown – percent contribution for North Fork Hardware River.

Station ID	Observed/ Simulated	Livestock (Min; Max)	Wildlife (Min; Max)	Human (Min; Max)	Pet (Min; Max)
2-HNF008.28	Observed	12 (12; 100)	51 (0; 66)	4 (0; 37)	33 (0; 59)
	Simulated	96 (0; 99)	1 (0; 16)	1 (0; 10)	0.4 (0; 9)

It is difficult to draw direct conclusions from the comparison of the BST data and the simulated results. The observed BST indicate that wildlife are the primary contributors to the bacteria concentrations in the river and pets are the second largest contributor. The simulated values clearly indicate that livestock are the primary contributors to the bacteria concentrations in the river. It should be noted that the Min-Max ranges of both the BST and simulated data are very large. This variance is largely dependent on the time since the last storm event – the relative contributions from sources at high flows are not the same as those at low flows. The flow- and concentration-weighting method used by DEQ and thus used in analysis of the simulated data gives higher weight to samples taken at higher flows and concentrations – i.e., those more likely to correspond to a recent storm event. One of the samples used in the BST analysis had a concentration of 200,000 cfu/100 mL and this heavily biased the weighted results. The unweighted breakdown of the sources is: Livestock 45% (12-100); Wildlife 26% (0-66); Human 10% (0-37); Pets 20% (0-59). As an additional complicating factor, pet and human bacteria sources are often difficult to distinguish in BST analysis, which means that the actual breakdown between the two might not be the same as that presented in Table 4.14.

4.6.1. Water Quality Calibration for the Lower Hardware River Watershed

Two water quality monitoring stations were considered for the calibration of the Lower Hardware River water quality simulations. Data from Station 2-HRD011.57 (see Figure 4.9) includes over 100 observations. The other station has less than 2 years of *E. coli* data. The large dataset available at station 2-HRD011.57 allowed for both calibration and validation of the model. The calibration period was 2000 to 2005 and the validation period was 1995 to 1998. The same procedures as outlined in Kim et al. (2007b) that were used for the calibration of the North Fork Hardware River were used in the calibration and validation for Lower Hardware River.

Calibration Process

As with the North Fork Hardware River calibration, several key input parameters were altered during the calibration of the Lower Hardware River. These parameters included: the washoff factor (WSQOP); fecal coliform production rates; and the volume used to represent flow stagnation in the reaches. These parameters and the calibrated values are listed in Table 4.15.

Table 4.15. Parameters altered during calibration of Lower Hardware River.

Parameter	Adjustment
WSQOP	Decreased to 0.25
Fecal Coliform Production Rates for Wildlife	Reduced
Stagnation Volume	Discharge from an individual reach was set to zero when its flow volume fell below a value corresponding to a 0.04 ft depth

Figure 4.13 shows the five-day range of simulated values for the calibration period. For the first three years, the observed concentrations did not vary as much as the simulated values due to the minimum cap. Additionally, the simulated minimum values were much lower than the observed concentrations for most of the calibration period (see Figure 4.13). The goodness of fit statistics

for the calibration run are listed in Table 4.16. The simulated geometric mean was 221 cfu/100 mL and the observed was 156 cfu/100 mL, resulting in a 42% relative error. The instantaneous criterion violation rates were 36% (simulated) and 22% (observed), resulting in a 14% error. Finally, the percent of observed values which fell inside the five-day range of simulated values was 59%.

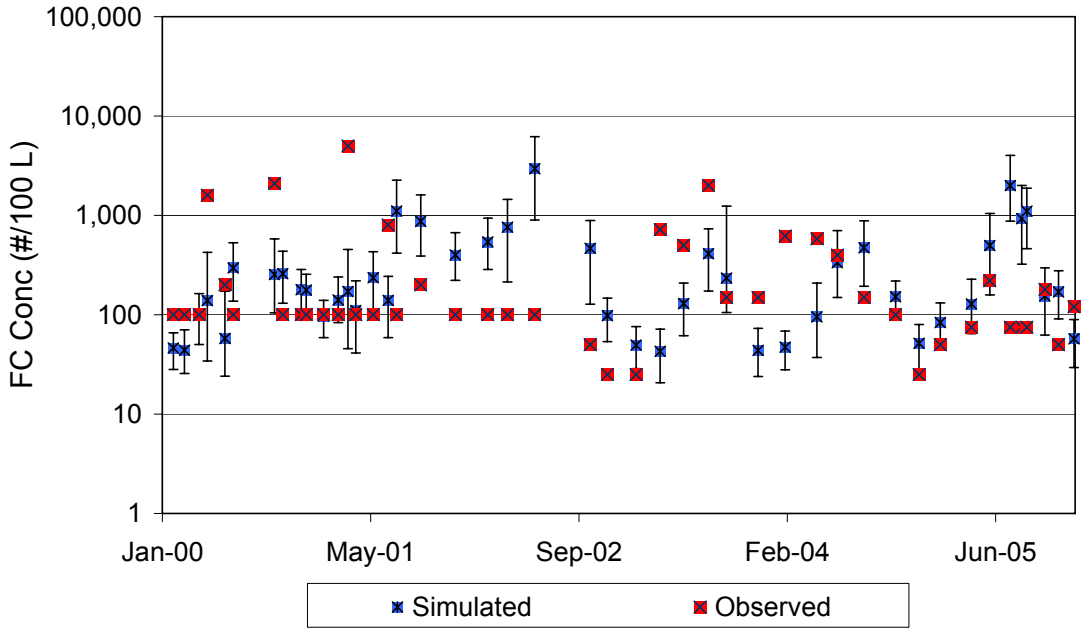

Figure 4.13. Five-day window of simulated in-stream bacteria concentrations surrounding each observed value at station 2-HRD011.57 for the calibration period.

Table 4.16. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for the calibration period for Lower Hardware River.

2-HRD011.57	Geometric Mean	Average	Median	MIN	MAX	IVR* (%)	% in Range
	(cfu/100 mL)						
Observed	156	398	100	100†	5,000	22	
Simulated	221	423	226	10	24,485	36	59

*IVR = instantaneous violation rate
†Capped value

The observed data are plotted with average daily simulated fecal coliform concentrations in Figure 4.14. Figure 4.15 presents the min-max range for the simulated concentrations. The observed values tend to fall within this min-max range. Also, the simulated data follow the seasonal variation of the observed

data as seen in Figure 4.15. The seasonal variation is most evident after year 2000 and most of the observed values fall within the min-max range during this period (see Figure 4.15). One note, the maximum concentration listed in Table 4.16 is much lower than the maximum shown in Figure 4.15. This is because the maximum listed in Table 4.16 is not the maximum of all of the simulated values. It is the maximum of the simulated values that are nearest to the observed values (within the 5-day window).

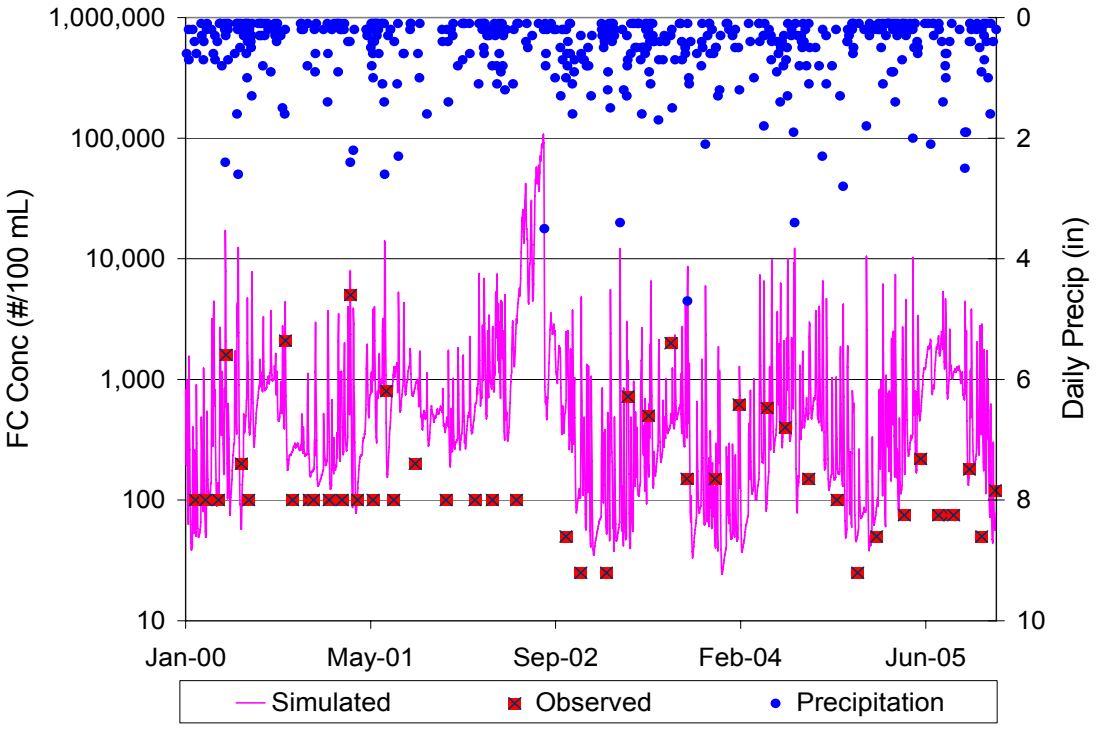

Figure 4.14. Observed and simulated fecal coliform concentrations at station 2-HRD011.57 for the calibration period for Lower Hardware River.

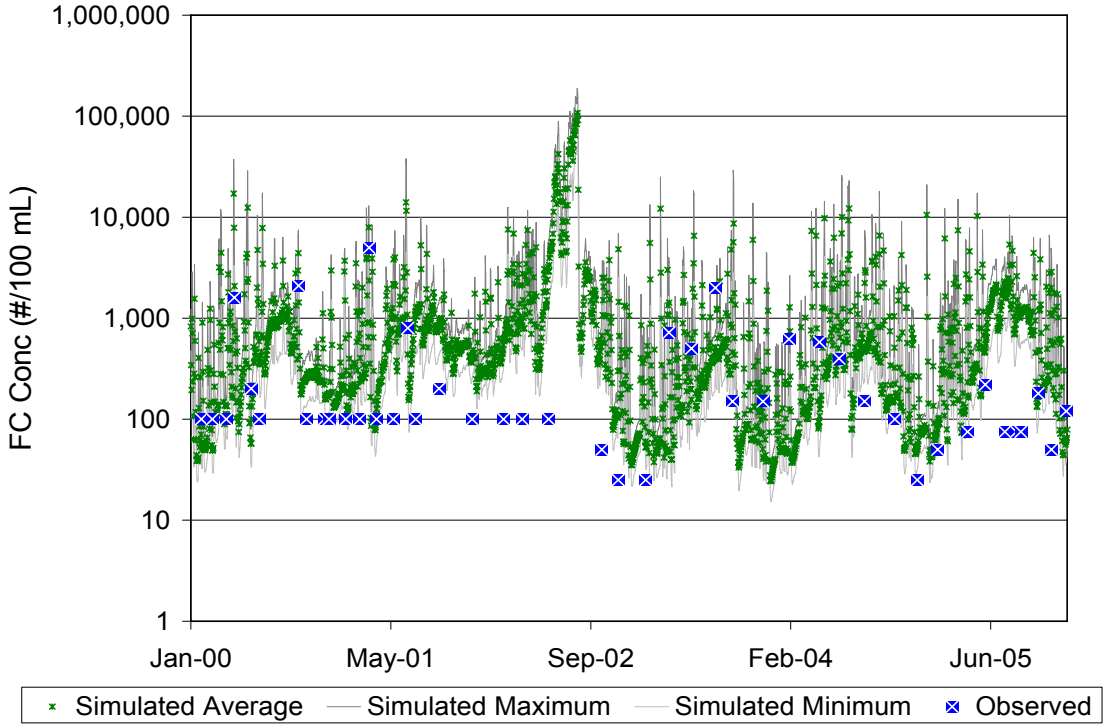

Figure 4.15. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 2-HRD011.57 for the calibration period.

Water Quality Validation

Figure 4.16 shows the five-day window of simulated bacteria concentrations for the validation period. There is very good agreement between the simulated and observed values for the first two years (see Figure 4.16), but it is more difficult to assess the quality of the simulation after 1996 due to the observed concentrations at the lower cap. The goodness of fit statistics for the validation period are listed in Table 4.17. The simulated geometric mean was 357 cfu/100 mL and the observed was 193 cfu/100 mL, resulting in an 85% relative error. The instantaneous criterion violation rates were 45% (simulated) and 23% (observed), resulting in a 22% error. Lastly, the percent of observed values which fell inside the five-day range of simulated values was 33%.

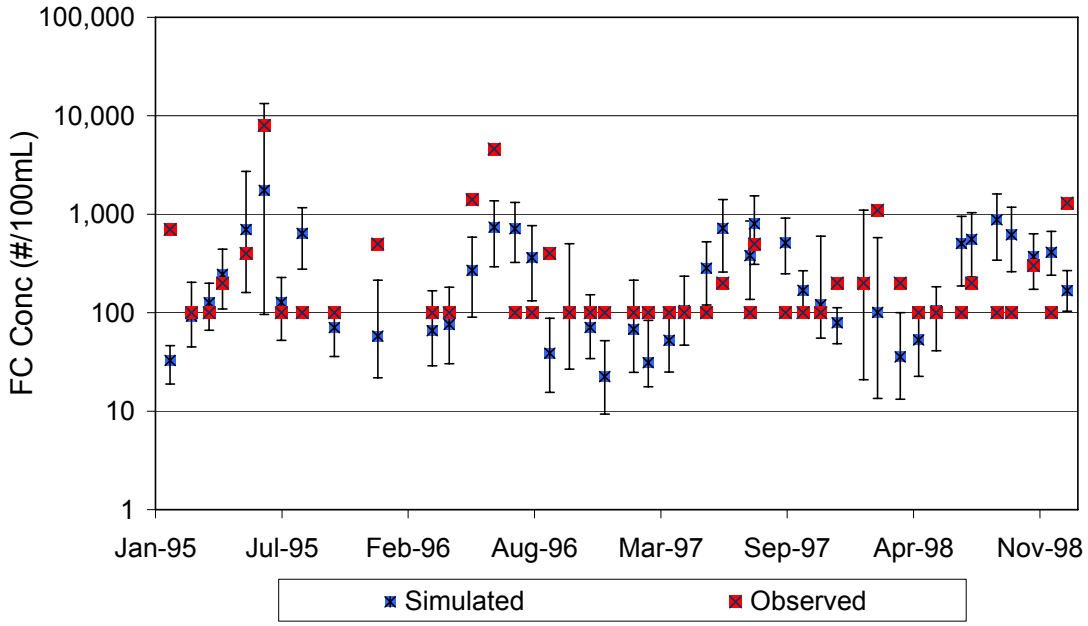

Figure 4.16. Five-day window of simulated in-stream bacteria concentrations surrounding each observed value at station 2-HRD011.57 for the validation period for Lower Hardware River.

Table 4.17. Summarized goodness-of-fit measures for simulated and observed fecal coliform concentrations for validation period for Lower Hardware River.

2-HRD011.57	Geometric Mean	Average	Median	MIN	MAX	IVR* (%)	% in Range
	(cfu/100 mL)						
Observed	193	525	100	100†	8,000	23	
Simulated	357	627	452	26	24,964	45	33

*IVR = instantaneous violation rate
†Capped value

A plot of the observed data with average daily simulated fecal coliform concentrations is shown in Figure 4.17. It is important to note in this figure that the lower cap on observed values is 100 cfu/100 mL for most of the period of record. Figure 4.18 presents the min-max range of simulated concentrations. There are many more values at the lower cap for the validation period than in the calibration period. The lower capped values do make it more difficult to assess the quality of the simulation. However, the simulated values do track the overall variation of the observed values (see Figure 4.18) and simulated values are generally less than the lower cap when the observed values are at the lower cap.

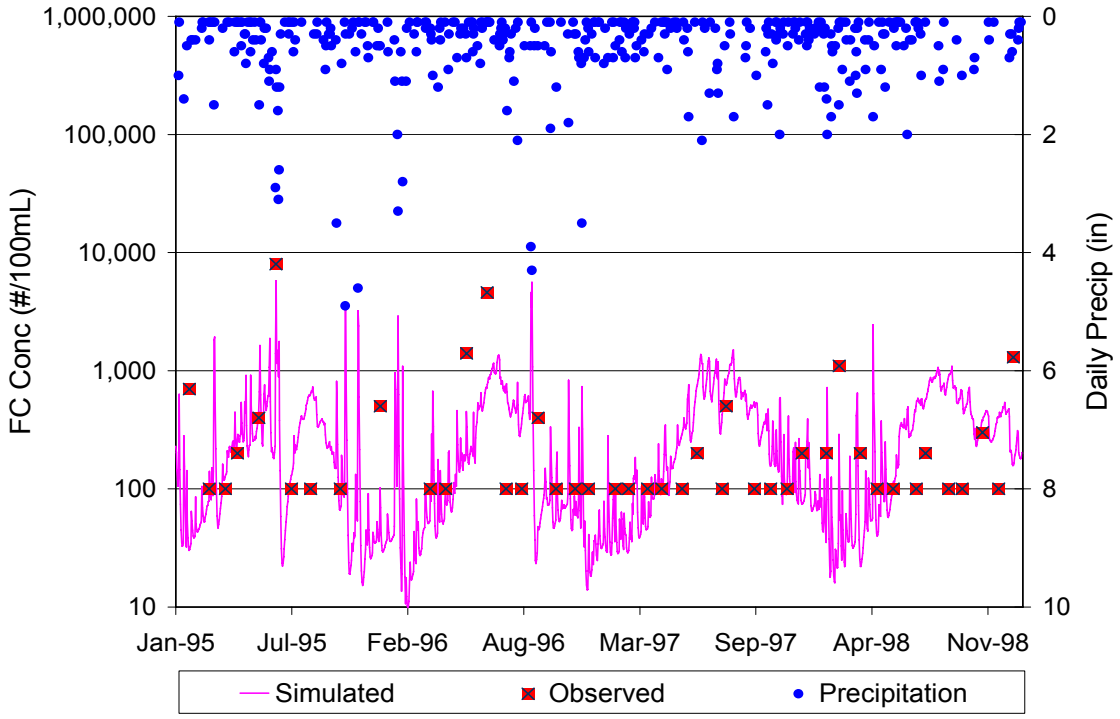

Figure 4.17. Observed and simulated fecal coliform concentrations at station 2-HRD011.57 for the validation period for Lower Hardware River.

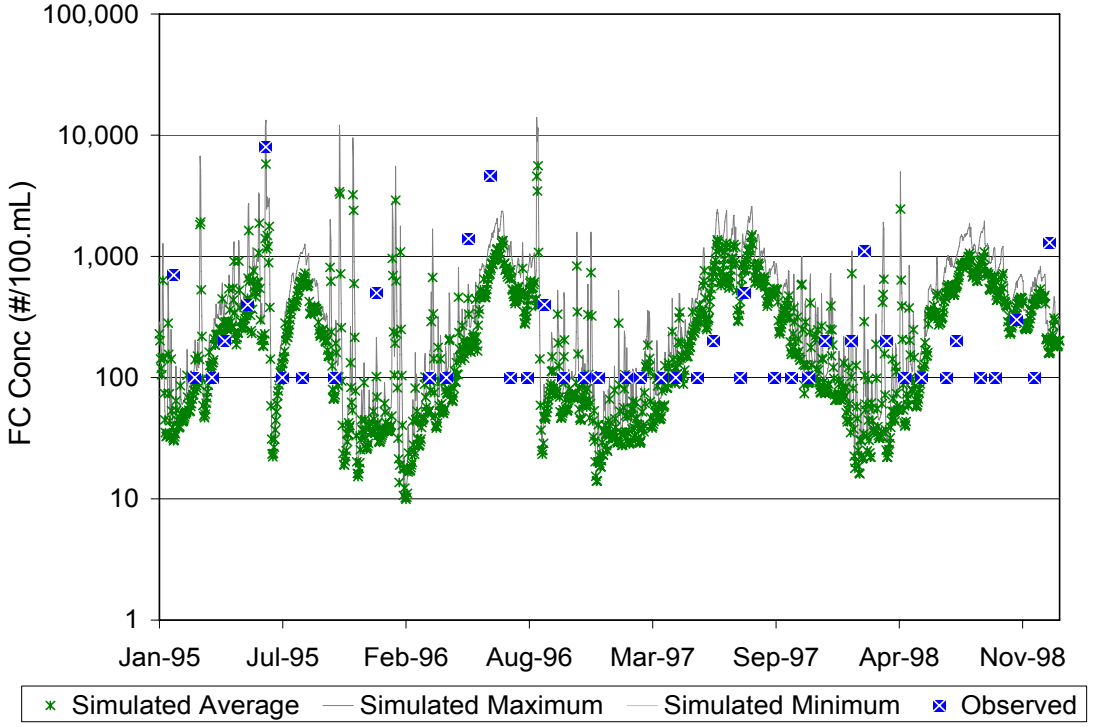

Figure 4.18. Observed fecal coliform data plotted with the daily maximum, minimum, and average simulated fecal coliform values for station 2-HRD011.57 for the validation period for Lower Hardware River.

BST Comparison

Bacterial Source Tracking (BST) data were collected from July 2004-June 2005 at station 2-HRD000.36 in the Lower Hardware River watershed. BST results are reported as a flow- and concentration-weighted average of the twelve samples. For comparison, model outputs from different sources were generated for January 1995 - December 2005 and were also flow- and concentration-weighted. The BST results for 2-HRD000.36 are presented in Table 4.18, along with the breakdown of the simulated concentrations. The minimum and maximum observed and simulated values are also presented in this table. There was agreement between the BST data and the simulated data about the major source of fecal coliform. The BST data indicate that livestock are the main source of fecal coliform followed by wildlife, pets, and then humans. The simulated data also indicate that livestock are the main source of fecal coliform, and wildlife, humans, and pets being are minor sources.

Table 4.18. Bacterial source breakdown – percent contribution for Lower Hardware River.

Station ID	Observed/ Simulated	Livestock (Min; Max)	Wildlife (Min; Max)	Human (Min; Max)	Pet (Min; Max)
2-HRD000.36	Observed	53 (0; 100)	25 (0; 59)	5 (0; 25)	17 (0; 100)
	Simulated	86 (0.1; 97)	10 (0.1; 60)	3 (0; 17)	0.1 (0; 8)

Chapter 5: TMDL Allocations

The objective of a TMDL is to allocate allowable loads among different pollutant sources such that the appropriate control actions can be taken to achieve water quality standards (USEPA, 1991).

5.1. Background

The objective of the bacteria TMDLs for the North Fork and Lower Hardware Rivers is to determine what reductions in fecal coliform and *E. coli* loadings from point and nonpoint sources are required to meet state water quality standards. The state water quality standards for *E. coli* used in the development of the TMDLs are 126 cfu/100 mL (calendar-month geometric mean) and 235 cfu/100 mL (single sample maximum). The TMDLs include all significant sources contributing bacteria and *E. coli* to the impaired streams. The sources can be separated into nonpoint and point sources. The different sources in the TMDL are defined in the following equation:

$$TMDL = WLA + LA + MOS \qquad [5.1]$$

Where: WLA = waste load allocation (point source contributions)
LA = load allocation (nonpoint source contributions); and
MOS = margin of safety.

An implicit MOS was used in these bacteria TMDLs by using conservative estimations of all factors that would affect bacteria loadings in the watershed (e.g., animal numbers, production rates, contributions to the stream). These factors were estimated in such a way as to represent the worst-case scenario; i.e., they result in the worst stream conditions that could exist in the watersheds. Creating TMDLs with conservative estimates ensures that the worst-case

scenario has been defined and that no water quality standard violations will occur if the TMDL plan is followed.

A translator equation developed by VADEQ (equation 5.2) was used to convert the fecal coliform model output to *E. coli* for comparison with the water quality standards. The *E. coli* translator equation was implemented in the HSPF simulation using the GENER block. In order to develop the actual TMDL equation, it was necessary to generate *loads* (rather than concentrations) of *E. coli*. Daily *E. coli* loads were obtained by using the *E. coli* concentrations calculated from the translator equation and multiplying them by the average daily flow. Annual loads were obtained by summing the daily loads and dividing by the number of years in the allocation period.

$$\log_2 EC(cfu/100mL) = -0.0172 + 0.91905 * \log_2 FC(cfu/100mL) \qquad [5.2]$$

When developing a bacteria TMDL, the required bacteria load reductions are modeled by decreasing the amount of bacteria applied to the land surface and directly to the stream; these reductions are presented in the tables in the following sections. In the model, this has the effect of reducing the amount of bacteria that reaches the stream, which is the ultimate goal of the TMDL. Thus, the reductions called for in the following sections indicate the need to decrease the amount of bacteria reaching the stream in order to meet the applicable water quality standard. The reductions shown in these sections are not intended to infer that agricultural producers should reduce their herd size, or limit the use of manures as fertilizer or soil conditioner. Rather, it is assumed that the required reductions from affected agricultural source categories (cattle direct deposit, pasture, etc.) will be accomplished by implementing BMPs such as filter strips, stream fencing, and off-stream watering; and that required reductions from residential source categories will be accomplished by repairing aging septic systems, eliminating straight pipe discharges, and other appropriate measures included in the TMDL Implementation Plan.

A period of three years was used for source allocations. Observed meteorological data from the Bremo Bluff weather station were extracted for the period 1996 - 1998 and used in the allocation. This period was selected because it incorporates average rainfall, low rainfall, and high rainfall years; and the climate during this period caused a wide range of hydrologic events including both low and high flow conditions. The bacteria loading in the model for allocation scenarios was representative of future conditions.

The calendar-month geometric mean values used in this report are geometric means of the simulated daily concentrations. Because HSPF was operated with a one-hour time step in this study, 24 hourly concentrations were generated each day. To estimate the calendar-month geometric mean from the hourly HSPF output, we took the arithmetic mean of the hourly values on a daily basis, and then calculated the geometric mean from these average daily values.

5.2. Future Conditions

The 2005 Residential Development Index from Albemarle County shows no new development proposed within the Hardware River watershed (Figure 5.1). In Fluvanna County, based on a 2007 Planning & Community Development Department map, there are designated Primary and Rural Residential areas within the Lower Hardware River watershed (Figure 5.2). Table 5.1 summarizes possible changes in land use as a result of these potential future conditions. The Community Development Department map delineates large, general regions of potential urban or rural growth (Table 5.1). These changes were included in the allocation scenarios for Lower Hardware River. To account for the future growth in Lower Hardware River, the waste load allocation was set equal to 1% of the TMDL load.

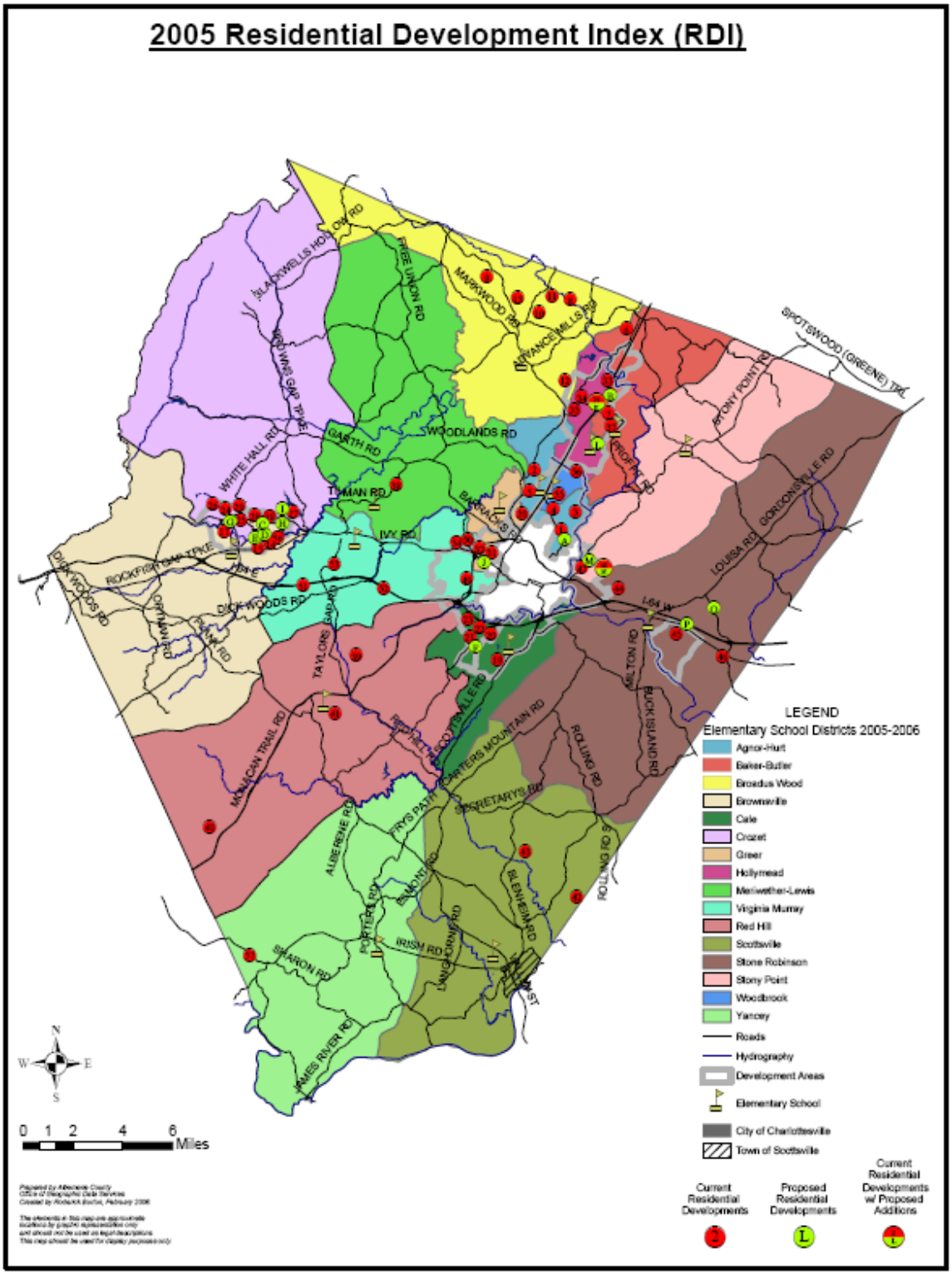

Figure 5.1. Projected future land use in Albemarle County. Courtesy of Albemarle County Planning & Community Development Department.

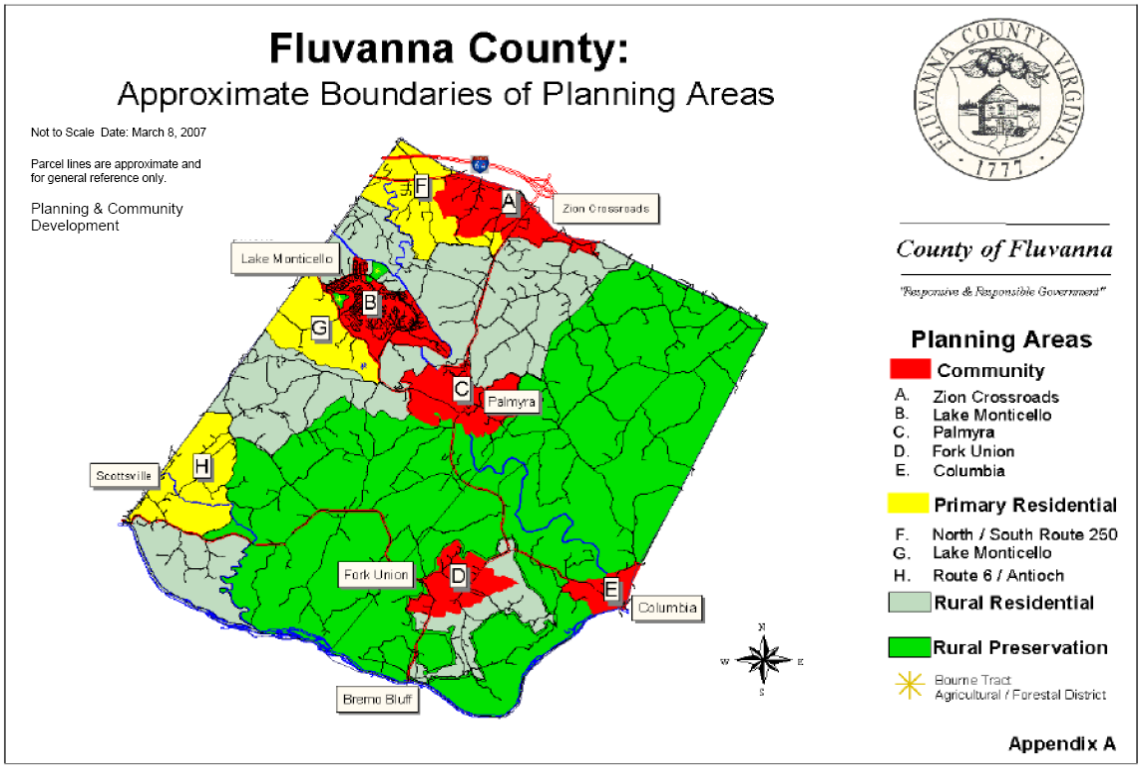

Figure 5.2. Projected future land use in Fluvanna County. Courtesy of Fluvanna County Planning & Community Development Department.

Table 5.1. Transfer of area from existing land use categories to future land use categories in Lower Hardware River.

Sub-watershed	Future Land Use	Existing Conditions Land Use acres (%)*		
		Cropland	Forest	Pasture
1	LDR	0 (0%)	384 (50%)	18 (50%)
2	LDR	0 (0%)	1077 (100%)	341 (100%)
3	LDR	0 (0%)	969 (50%)	438 (90%)
4	HDR	0 (0%)	368 (15%)	644 (85%)
5	HDR	1 (100%)	872 (100%)	705 (100%)
6	HDR	0 (0%)	478 (100%)	313 (100%)
7	HDR	0 (0%)	214 (30%)	289 (100%)
9	HDR	0 (0%)	490 (80%)	137 (80%)
10	HDR	0 (0%)	291 (20%)	45 (20%)
11	HDR	0 (0%)	383 (75%)	152 (75%)
12	HDR	0 (0%)	985 (60%)	85 (60%)

*Percent is the percent the recategorized area is of the total existing area of the land use in each sub-watershed

5.3. Lower Hardware River Bacteria TMDL

5.3.1. Existing Conditions

Analysis of simulation results for the existing conditions in the watershed (Table 5.2) shows that cattle direct deposits are a significant source of *E. coli* to the stream. Contributions from pervious land surfaces and from wildlife direct deposits are also contributors to the mean daily *E. coli* concentration. The results in this table are average daily contributions for the allocation simulation period, irrespective of the magnitude of the concentration or the flow rate (factors that were considered in the earlier section detailing the source breakdown used in the calibration). Table 5.2 indicates which sources will be the dominant contributors to the instantaneous *E. coli* concentrations, and thus which sources will control the violations of the single sample standard.

Table 5.2. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in the Lower Hardware River watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100 mL	Relative Contribution by Source
All Sources	249	
Nonpoint source loadings from pervious land segments	32	13%
Direct nonpoint source loadings to the stream from wildlife	44	18%
Direct nonpoint source loadings to the stream from livestock	141	57%
Interflow and groundwater contribution	16	6%
Straight-pipe discharges to stream	16	6%
Nonpoint source loadings from impervious land use	< 0.1	<1%

The contribution of each of the sources listed in Table 5.2 to the calendar-month geometric mean *E. coli* concentration is shown in Figure 5.3. The pervious land surface (PLS) category in Figure 5.3 includes both the 'nonpoint source loadings from pervious land segments' and the 'interflow and groundwater contribution' categories from Table 5.2. Because contributions from impervious surfaces only occur during rainfall events, there are many days with zero concentration from impervious areas; therefore, the calendar month geometric mean of impervious contributions is zero and does not appear in Figure 5.3.

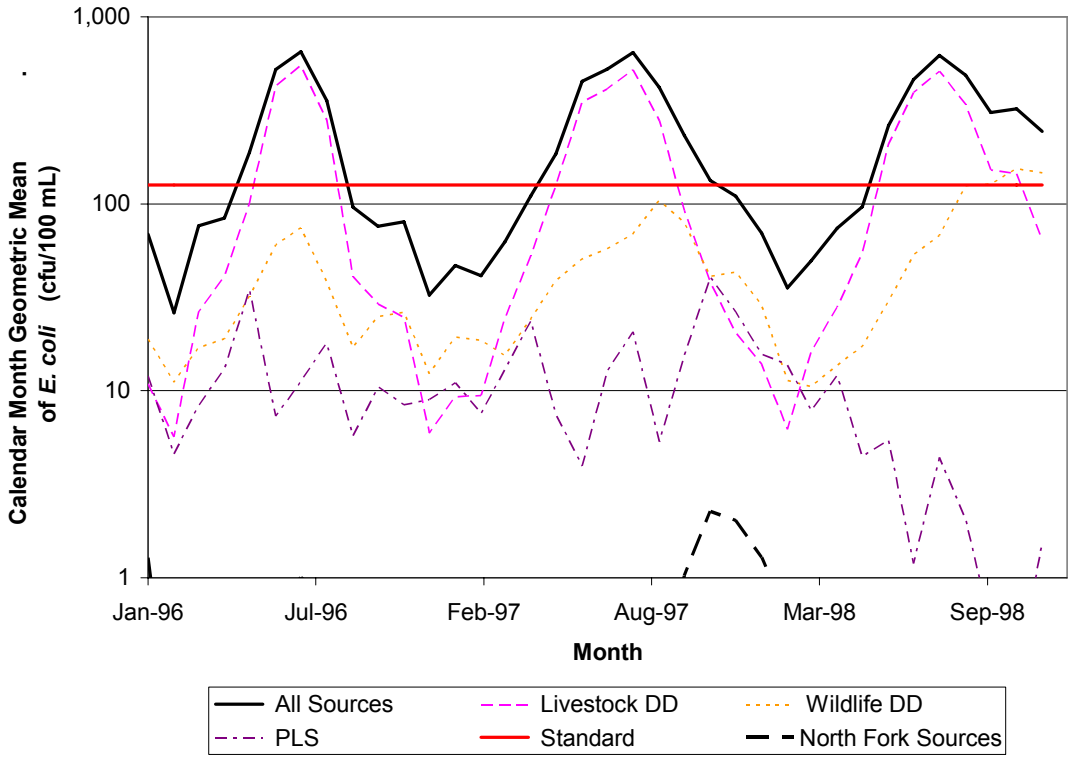

Figure 5.3. Contributions of different sources to the calendar-month geometric mean *E. coli* concentration at the outlet of Lower Hardware River for existing conditions.

Livestock and wildlife are the top two contributors to the calendar-month geometric mean concentration. The cyclic nature of livestock (direct deposit contributions increase during summer months due to increased time spent in streams by animals), and to a lesser extent wildlife, combined with lower flow volumes increase bacteria concentrations during the summer months. From this graph, it is evident that violations of the calendar-month geometric mean standard for Lower Hardware River will be most controlled by contributions from livestock direct deposit.

5.3.2. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean concentration less than 126 cfu/100 mL and a single-sample maximum concentration of less than 235 cfu/100 mL. The scenarios and results are summarized in Table 5.3; recall that these reductions are those used for modeling, and implementation of these reductions

will require implementation of BMPs as discussed at the beginning of this chapter. One successful scenario was found to meet the standards for Lower Hardware River (highlighted in Table 5.3).

Table 5.3. Bacteria allocation scenarios for Lower Hardware River watershed.

Scenario Number	Required Fecal Coliform Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard	
	Live-stock DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential	Geomean	Single Sample
Unsuccessful Scenarios								
Baseline Future Conditions	0	0	0	0	0	0	39%	40%
1	100	100	100	0	100	100	11%	1%
2	100	100	100	10	100	100	6%	1%
Successful Scenario								
3	100	100	100	25	100	100	0%	0%

*DD = Direct Deposit

Table 5.3 includes two categories of scenarios: those that were successful and those that were unsuccessful. Presentation of the unsuccessful scenarios illustrates the need for the reductions called for in the successful scenario. Unsuccessful scenario 1 shows, as supported by Figure 5.5, that large reductions from all sources excluding wildlife direct deposit are needed in order to bring the geometric mean concentrations into compliance. The reductions in livestock direct deposits have a noticeable effect on the single sample standard violations as well; however, even 100% livestock exclusion, coupled with 100% reductions from the major overland contributors (cropland, pasture and residential), is not sufficient to meet the standards. Scenario 2 shows that even with a 10% reduction in direct deposit from wildlife, compliance with both standards is not achievable. Figure 5.4 displays the simulated daily average and calendar-month geometric mean concentrations at the Lower Hardware River outlet for the successful allocation scenario (3), along with the two *E. coli* standards.

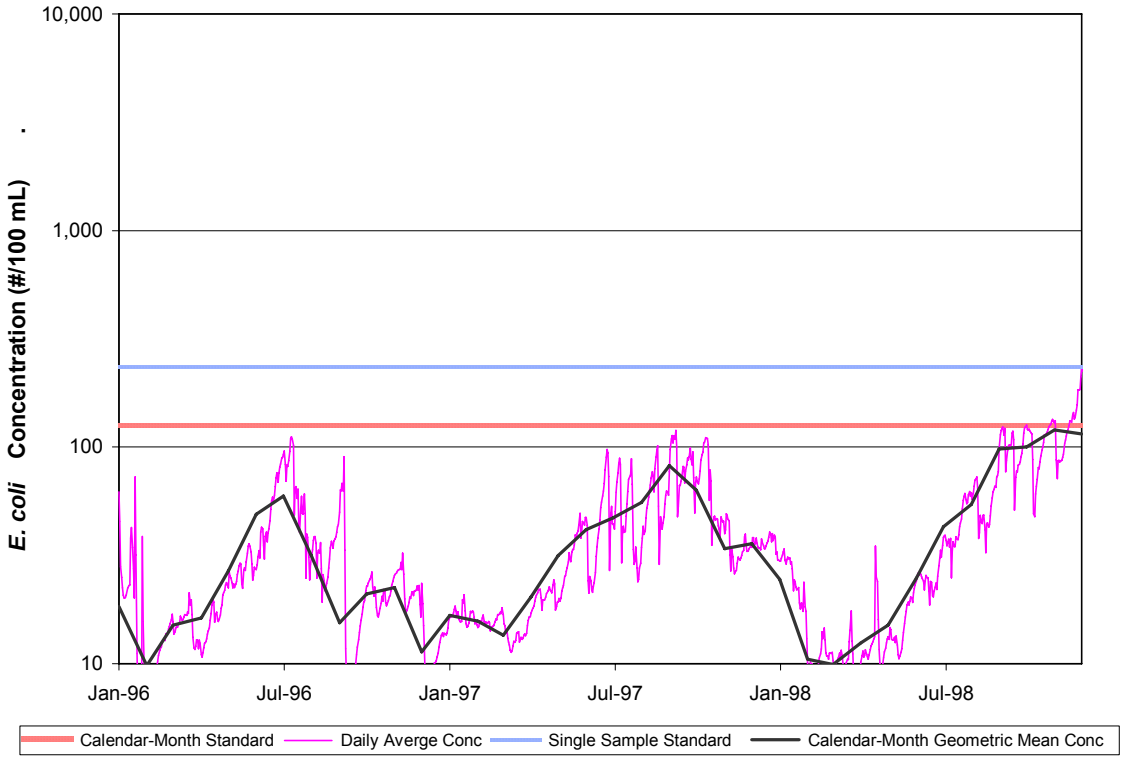

Figure 5.4. Simulated *E. coli* concentrations for the successful allocation scenario (3) for Lower Hardware River.

Loadings for existing conditions, baseline future conditions, and the successful TMDL allocation scenario (3) are presented for nonpoint sources by land use in Table 5.4 and for direct nonpoint sources in Table 5.5.

Table 5.4. Annual nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation scenario 3 for Lower Hardware River.

	Existing Conditions		Future Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**Future Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Future Load**
Cropland	16	0.1%	16	0.1%	0	100%
Pasture	13,450	93%	8,070	56%	0	100%
Residential*	550	4%	6,108	42%	0	100%
Forest	445	3%	267	2%	267	0%
Total	14,461		14,461		267	98%

*Includes loads applied to pervious areas of both High and Low Density Residential

Table 5.5. Annual direct nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation scenario 03 for Lower Hardware River.

	Existing Conditions		Future Conditions		Allocation Scenario	
Source	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**Future Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Future Load**
Livestock in Streams	302	61%	302	60%	0	100%
Straight Pipes	65	13%	65	13%	0	100%
Wildlife in Streams	131	26%	131	26%	97	25%
Point Sources	0	0	6*	0.01%	6*	0
Total	498		504		103	80%

* 1% of TMDL

The fecal coliform loads presented in Table 5.4 and Table 5.5 are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal

coliform to *E. coli* translator to the HSPF-predicted mean daily fecal coliform concentrations.

5.3.3. Waste Load Allocation

There are currently no permitted facilities in the Lower Hardware River watershed. However, to account for future growth in the area, a waste load allocation of 1% of the TMDL was modeled for Lower Hardware River.

5.3.4. Summary of Lower Hardware River TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed the Lower Hardware River. The TMDL addresses the following issues:

1. The TMDL meets both the calendar-month geometric mean and single sample water quality standards.
2. Because *E. coli* loading data were not available to quantify nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator equation was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations.
3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.
5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the Lower Hardware River watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; high stream flow conditions after storm events were most likely to cause violations of the single sample criterion; because the TMDL was developed using a continuous simulation model, results apply to both high- and low-flow conditions.

6. Both the flow regime and bacteria loading to Lower Hardware River are seasonal. The TMDL takes into account these seasonal effects.

The selected *E. coli* TMDL allocation that meets both *E. coli* criteria requires a 100% reduction in all anthropogenic sources (agricultural and residential). It also requires a 25% reduction in contributions from wildlife direct deposit. Since there were now permitted point sources in the Lower Hardware River watershed, DEQ directed that 1% of the TMDL should be used for the future waste load allocation. Using equation 5.1, the summary of the bacteria TMDL for Lower Hardware River for the selected allocation scenario (3) is given in Table 5.6.

Table 5.6. Annual *E. coli* loadings (cfu/year) at the watershed outlet used for the Lower Hardware River bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS*	TMDL
E. coli	0.04×10^{14}	3.64×10^{14}	--	3.68×10^{14}

*Implicit MOS

5.3.5. Daily *E. coli* TMDL

The USEPA has mandated that 2007 TMDL studies include a daily maximum load as well as the average annual load presented in the previous section. The daily load was determined as the product of a representative flow rate from the watershed and the appropriate concentration criterion from the water quality standard. This section summarizes the daily maximum load for Lower Hardware River.

Hydrologic Considerations

According to guidance from EPA (USEPA, 2006) it is necessary to assess the flow duration curve to determine an appropriate flow rate to use in the load calculation. EPA guidance suggests that the flow duration curve should be plotted using observed continuous flow data. Flow data from the USGS gage used in the hydrologic calibration were used to calculate the daily load. As is specified in the EPA guidance, the observed flows from Hardware River were multiplied by the ratio of the Lower Hardware River watershed area to the

drainage area above the USGS gage. The flow rate corresponding to the 99th percentile flow (that is, the flow rate exceeded by only 1% of the observed flows) was identified for the Lower Hardware River; this flow rate is 686 cfs.

Daily Load

The loadings in the annual load table (Table 5.6), being of a long-term nature, will more directly assure compliance with the geometric mean component of the standard. Setting a *maximum daily* load will help ensure that the annual load given in Table 5.6 is appropriately distributed such that on any given day the single sample component of the bacteria water quality standard will be met. Thus, the maximum daily load was computed as the product of the critical flow condition and the single sample criterion (235 cfu/100 mL). Flow data from the USGS gage used in the hydrologic calibration were used to calculate the daily load. The resulting daily maximum loadings are shown in Table 5.7; however, the actual maximum daily load is dependent upon flow conditions, and progress toward water quality improvement will be assessed against the numeric water quality criteria (126 cfu *E. coli*/100 mL for a calendar month geometric mean, and 235 cfu *E. coli*/100 mL for a single sample).

Table 5.7. Maximum daily *E. coli* loadings (cfu/day) at the the Lower Hardware watershed outlet.

Parameter	ΣWLA	ΣLA	MOS*	TMDL
E. coli	1.10×10^{10}	2.61×10^{12}	--	2.62×10^{12}

*Implicit MOS

5.4. North Fork Hardware River Bacteria TMDL

5.4.1. Existing Conditions

Analysis of simulation results for the existing conditions in the watershed (Table 5.8) shows that contributions from pervious land surfaces sources dominate the in-stream concentrations of *E. coli*. Contributions from livestock and wildlife direct deposits constitute a noticeable portion of the average daily *E.*

coli concentration. The results in this table are average daily contributions for the allocation simulation period, irrespective of the magnitude of the concentration or the flow rate (factors that were considered in the earlier section detailing the source breakdown used in the calibration). Table 5.8 indicates which sources will be the dominant contributors to the instantaneous *E. coli* concentrations, and thus which sources will control the violations of the single sample standard.

Table 5.8. Relative contributions of different *E. coli* sources to the overall *E. coli* concentration for existing conditions in the North Fork Hardware River watershed.

Source	Mean Daily *E. coli* Concentration by Source, cfu/100 mL	Relative Contribution by Source
All Sources	249	
Nonpoint source loadings from pervious land segments	180	72%
Direct nonpoint source loadings to the stream from wildlife	14	6%
Direct nonpoint source loadings to the stream from livestock	55	22%
Interflow and groundwater contribution	< 0.1	<1%
Straight-pipe discharges to stream	< 0.1	<1%
Nonpoint source loadings from impervious land use	< 0.1	<1%
Point sources*	< 0.1	<1%

*Contributions from point sources assumed to be discharging at their permitted limits

The contribution of each source listed in Table 5.8 to the calendar-month geometric mean *E. coli* concentration is shown in Figure 5.5. The 'PLS' category in Figure 5.5 includes both the 'nonpoint source loadings from pervious land segments' and the 'interflow and groundwater contribution' categories. Because contributions from impervious surfaces only occur during rainfall events, there are many days with zero concentration from impervious areas; therefore, the calendar month geometric mean of impervious contributions is zero and does not appear in Figure 5.5. The calendar month geometric mean for several of the sources listed in Table 5.8 were small relative to other sources, such as cattle direct deposit, and are not shown in Figure 5.5.

Contributions from livestock direct deposit and pervious lands dominate the calendar-month geometric mean concentration. The cyclic nature of livestock (direct deposit contributions increase during summer months due to increased time spent in streams by animals), and to a lesser extent wildlife, combined with lower flow volumes increase bacteria concentrations during the summer months. Pervious land surfaces also contribute to the calendar-month geometric mean concentration in North Fork Hardware River. Figure 5.5 illustrates that violations of the calendar-month geometric mean standard will be most controlled by contributions from livestock direct deposit and pervious lands and further that it will be impossible to meet the calendar-month geometric mean standard without reducing those contributions.

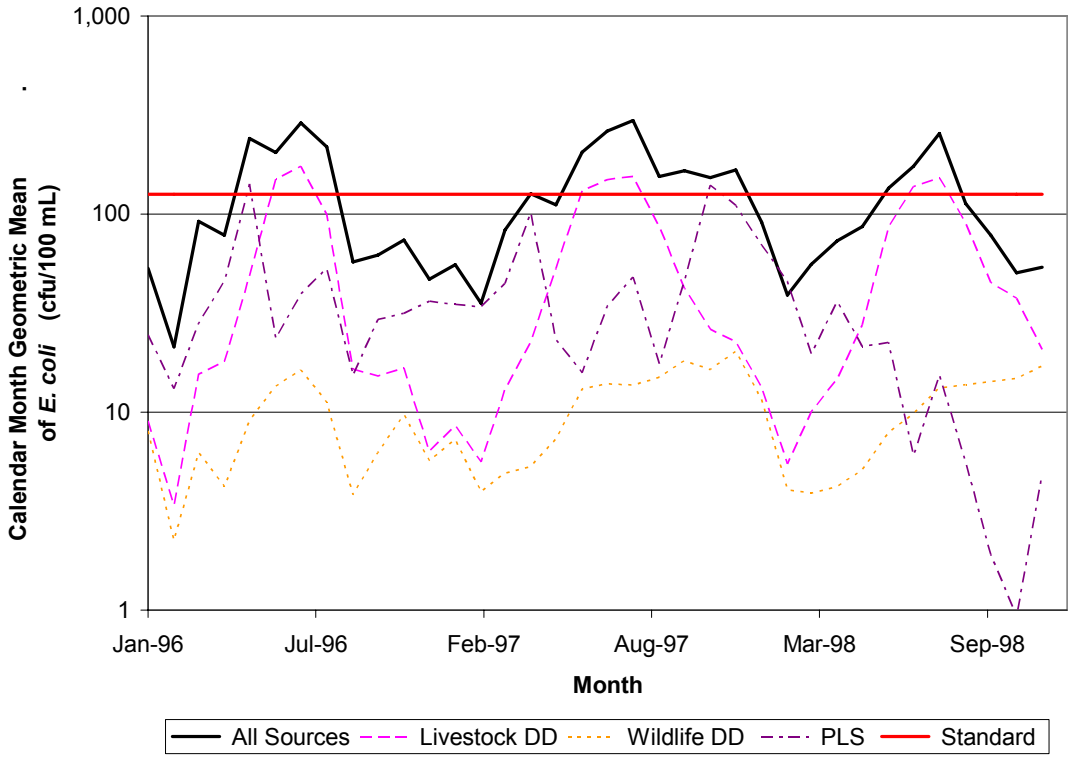

Figure 5.5. Contributions of different sources to the calendar-month geometric mean *E. coli* concentration at the outlet of North Fork Hardware River for existing conditions.

5.4.2. Allocation Scenarios

A variety of allocation scenarios were evaluated to meet the *E. coli* TMDL goal of a calendar-month geometric mean concentration less than 126 cfu/100

mL and a single-sample maximum concentration of less than 235 cfu/100 mL. The scenarios and results are summarized in Table 5.9; recall that these reductions are those used for modeling, and implementation of these reductions will require implementation of BMPs as discussed at the beginning of this chapter. One successful scenario was found to meet the standards for the North Fork Hardware River.

Table 5.9. Bacteria allocation scenarios for North Fork Hardware River watershed.

Scenario Number	Required Fecal Coliform Loading Reductions to Meet the *E. coli* Standards, %						% Violation of *E. coli* Standard	
	Live-stock DD*	Loads from Cropland	Loads from Pasture	Wildlife DD*	Straight Pipes	Loads from Residential	Geomean	Single Sample
Unsuccessful Scenarios								
Baseline Future Conditions	0	0	0	0	0	0	44%	26%
1	100	0	0	0	100	0	8%	21%
2	100	98	98	0	100	98	0%	1%
Successful Scenario								
3	100	99	99	0	100	99	0%	0%

*DD = direct deposit

Table 5.9 includes two categories of scenarios: those that were successful and those that were unsuccessful. Presentation of the unsuccessful scenarios illustrates the need for the reductions called for in the successful scenarios. Unsuccessful scenario 1 shows, that only eliminating cattle direct deposit and straight pipes will not bring the North Fork Hardware River into compliance with either *E. coli* standard. Scenario 2 demonstrates that even a 98% reduction from pervious lands is not sufficient to meet the instantaneous standard. Successful scenario 3 shows a small increase in reduction of contributions from pervious land sources (98% to 99%), achieving compliance with both standards.

As a general rule, direct deposit sources (livestock, wildlife, and straight pipes) control violations of the calendar-month geometric mean standard. These sources control the constant inputs to the water body, and thus control the

geometric mean of the daily average predictions over the entire month. Overland sources (runoff from pasture, cropland, forest, and residential areas) are generally more important to the violations of the single sample standard, as these sources control the large spikes in bacteria concentration predictions that occur after storm events. Figure 5.6 displays the simulated daily average and calendar-month geometric mean concentrations at the North Fork outlet for scenario 3, as well as the two *E. coli* standards.

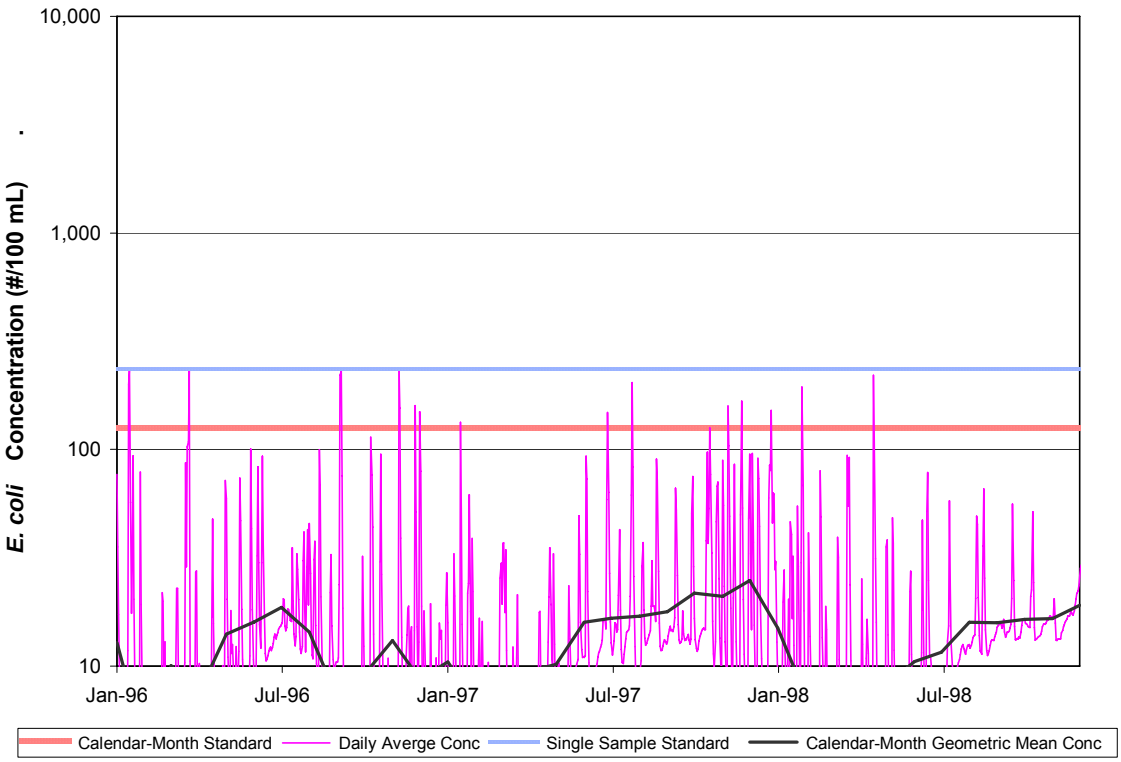

Figure 5.6. Simulated *E. coli* concentrations for the successful allocation scenario (3) for North Fork Hardware River.

Loadings for existing conditions, baseline future conditions, and the successful TMDL allocation scenario 3 are presented for nonpoint sources by land use in Table 5.10 and for direct nonpoint sources in Table 5.11. The fecal coliform loads presented in these tables are the fecal coliform loads that result in in-stream *E. coli* concentrations that meet the applicable *E. coli* water quality standards after application of the VADEQ fecal coliform to *E. coli* translator to the HSPF-predicted mean daily fecal coliform concentrations.

Table 5.10. Annual nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation scenario 3 for North Fork Hardware River.

	Existing Conditions		Future Conditions		Allocation Scenario	
Land use category	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**Future Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total land deposited load from nonpoint sources**	**TMDL nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Future Load**
Cropland	22	0.13%	22	0.13%	0.22	99%
Pasture	16,550	94%	16,550	94%	165	99%
Residential*	535	3%	535	3%	5	99%
Forest	431	2%	431	2%	4	0%
Total	17,538		17,538		174	99%

*Includes loads applied to pervious areas of both High and Low Density Residential

Table 5.11. Annual direct nonpoint source fecal coliform loads under existing and future conditions and corresponding reductions for TMDL allocation scenario 3 for North Fork Hardware River.

	Existing Conditions		Future Conditions		Allocation Scenario	
Source	**Existing Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**Future Conditions Load ($x10^{12}$ cfu/yr)**	**Percent of total direct deposited load from direct nonpoint source**	**TMDL direct nonpoint source allocation load ($x10^{12}$ cfu/yr)**	**Percent Reduction from Future Load**
Livestock in Streams	372	58%	372	58%	0	100%
Straight Pipes	94	15%	94	15%	0	100%
Wildlife in Streams	173	27%	173	27%	173	0%
Point Sources	0.06	<0.01%	6*	0.9%	6*	0%
Total	643		645		179	72%

* 1% of TMDL

5.4.3. Waste Load Allocation

There were two permitted point source facilities in the North Fork Hardware River watershed (Table 5.12). The loads from these sources were considered small relative to the load allocation ($3.48x10^{14}$ for the load allocation

compared to 3.65×10^{10} for the permitted sources). For the future waste load allocation, DEQ directed that 1% of the TMDL should be used for the waste load allocation. There were no reductions required in the TMDL from point sources.

Table 5.12. Point source discharging into the North Fork Hardware River watershed.

Permit Number	Facility Name	Flow (gpd)	Permitted *E. coli* Conc. (cfu/100 mL)	Permitted *E. coli* Load (cfu/yr)	Allocated *E. coli* Load (cfu/yr)
VAG408054	North Garden Post Office	1×10^3	126	1.74×10^9	1.74×10^9
VA0083291	Crossroads Village Center STP	0.2×10^5	126	3.48×10^{10}	3.48×10^{10}
Total		0.21×10^5		3.65×10^{10}	3.65×10^{10}

5.4.4. Summary of North Fork Hardware River TMDL Allocation Scenario for Bacteria

A TMDL for *E. coli* has been developed for North Fork Hardware River. The TMDL addresses the following issues:

1. The TMDL meets both the calendar-month geometric mean and single sample water quality standards.
2. Because *E. coli* loading data were not available to quantify nonpoint source bacterial loads, available fecal coliform loading data were used as input to HSPF. HSPF was then used to simulate in-stream fecal coliform concentrations. The VADEQ fecal coliform to *E. coli* concentration translator equation was then used to convert the simulated fecal coliform concentrations to *E. coli* concentrations.
3. The TMDL was developed taking into account all fecal bacteria sources (anthropogenic and natural) from both point and nonpoint sources.
4. An implicit margin of safety (MOS) was incorporated by utilizing professional judgment and conservative estimates of model parameters.

5. Both high- and low-flow stream conditions were considered while developing the TMDL. In the North Fork Hardware River watershed, low stream flow was found to be the environmental condition most likely to cause a violation of the geometric mean criterion; high stream flow conditions after storm events were most likely to cause violations of the single sample criterion; because the TMDL was developed using a continuous simulation model, it applies to both high- and low-flow conditions.
6. Both the flow regime and bacteria loading to the North Fork Hardware River are seasonal. The TMDL takes into account these seasonal effects.

The selected *E. coli* TMDL allocation that meets both *E. coli* criteria requires a 100% reduction in cattle direct deposits to the stream; 100% reduction in straight pipe contributions; 99% reduction from cropland and pasture areas; and 99% reduction from residential surfaces. Using equation 5.1, the summary of the bacteria TMDL for North Fork for the selected allocation scenario (3) is given in Table 5.13.

Table 5.13. Annual *E. coli* loadings (cfu/yr) at the watershed outlet used for the North Fork Hardware River bacteria TMDL.

Parameter	ΣWLA	ΣLA	MOS*	TMDL
E. coli	0.03×10^{14}	3.48×10^{14}	--	3.51×10^{14}

*Implicit MOS

5.4.5. Daily *E. coli* TMDL

The USEPA has mandated that 2007 TMDL studies include a daily maximum load as well as the average annual load shown in the previous section. The daily load was determined as the product of a representative flow rate from the watershed and the appropriate concentration criterion from the water quality standard. This section summarizes the daily maximum load for North Fork Hardware River.

Hydrologic Considerations

According to guidance from EPA (USEPA, 2006) it is necessary to assess the flow duration curve to determine an appropriate flow rate to use in the load calculation. EPA guidance suggests that the flow duration curve should be plotted using observed continuous flow data. Flow data from the USGS gage used in the hydrologic calibration were used to calculate the daily load. As is specified in the EPA guidance, the observed flows from Hardware River were multiplied by the ratio of the North Fork Hardware River watershed area to the drainage area above the USGS gage. The flow rate corresponding to the 99th percentile flow (that is, the flow rate exceeded by only 1% of the observed flows) was identified in the North Fork Hardware River; this flow rate is 493 cfs.

Daily Load

The loadings in the annual load table (Table 5.13), being of a long-term nature, will more directly assure compliance with the geometric mean component of the standard. Setting a *maximum daily* load will help ensure that the annual load given in Table 5.13 is appropriately distributed such that on any given day the single sample component of the bacteria water quality standard will be met. Thus, the maximum daily load was computed as the product of the critical flow condition and the single sample criterion (235 cfu/100 mL). The daily WLA is calculated as the product of the maximum daily flow rate and maximum concentration specified in the permits of the permitted facilities; the LA is then the TMDL less the WLA. The resulting daily maximum loadings are shown in Table 5.13; however, the actual maximum daily load is dependent upon flow conditions, and progress toward water quality improvement will be assessed against the numeric water quality criteria (126 cfu *E. coli*/100 mL for a calendar month geometric mean, and 235 cfu *E. coli*/100 mL for a single sample).

Table 5.14. Maximum daily *E. coli* loadings (cfu/day) at the the North Fork watershed outlet.

Parameter	ΣWLA	ΣLA	MOS*	TMDL
E. coli	8.22×10^{9}	1.79×10^{13}	--	1.79×10^{13}

*Implicit MOS

Chapter 6: 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. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1. Continuing Planning Process and Water Quality Management Planning

As part of the Continuing Planning Process, DEQ 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.

DEQ 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 DEQ's web site under http://www.deq.state.va.us/tmdl/pdf/ppp.pdf

6.2. 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.

6.3. 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.

For the implementation of the WLA component of the TMDL, the Commonwealth utilizes the Virginia NPDES program. Requirements of the permit process should not be duplicated in the TMDL process, and permitted sources are not usually addressed through the development of any TMDL implementation plans.

6.4. 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.

6.4.1. 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 and available upon request from the DEQ and DCR TMDL project staff or at http://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 DEQ, DCR, 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.

6.4.2. Staged Implementation Scenarios

The purpose of the 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. 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 cost effective and reasonable BMPs for nonpoint source control. Additional information on UAAs is presented in section 6.8 Attainability of Designated Uses.

6.4.3. Staged Implementation Scenario for Lower Hardware River

There was one successful scenario selected for the Lower Hardware River watershed (Table 6.1). The staged implementation goal can be reached with 75% reduction in contributions from all anthropogenic sources and elimination of straight pipe discharges. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform concentrations are presented graphically in Figure 6.1.

Table 6.1. Allocation scenario for Stage 1 TMDL implementation for Lower Hardware River.

Single Sample Standard Percent Violation	Required Fecal Coliform Loading Reductions to Meet the Stage 1 Goal, %					
	Livestock DD	Loads from Cropland	Loads from Pasture	Wildlife DD	Straight Pipes	Loads from Residential
9	75	75	75	0	100	75

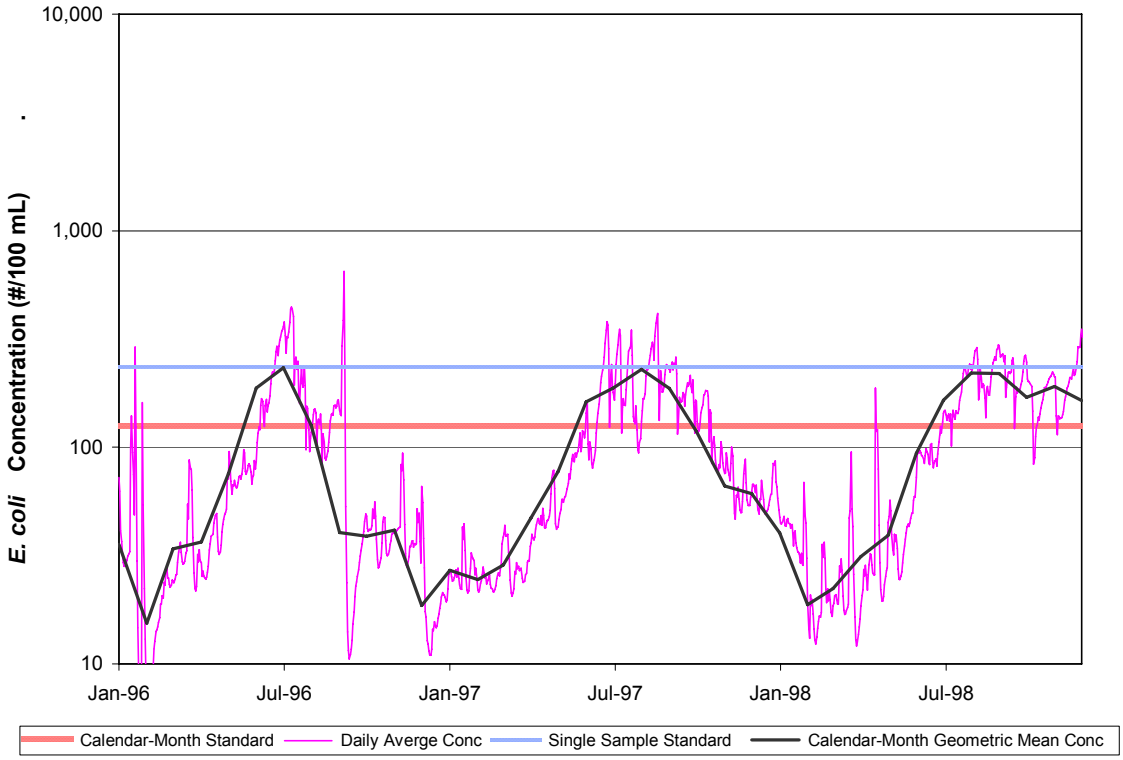

Figure 6.1. Simulated *E. coli* concentrations with the two bacteria standards for the Stage 1 implementation scenario for Lower Hardware River.

6.4.4. Staged Implementation Scenario for North Fork Hardware River

One scenario was selected for the North Fork Hardware River watershed (Table 6.2). The staged implementation goal for North Fork Hardware River can be reached with a 70% reduction in all anthropogenic sources and elimination of contributions from straight pipes. *E. coli* concentrations resulting from application of the fecal coliform to *E. coli* translator equation to the fecal coliform concentrations are presented graphically in Figure 6.2.

Table 6.2. Allocation scenario for Stage 1 TMDL implementation for North Fork Hardware River.

Single Sample Standard Percent Violation	Required Fecal Coliform Loading Reductions to Meet the Stage 1 Goal, %					
	Livestock DD	Loads from Cropland	Loads from Pasture	Wildlife DD	Straight Pipes	Loads from Residential
8	70	70	70	0	100	70

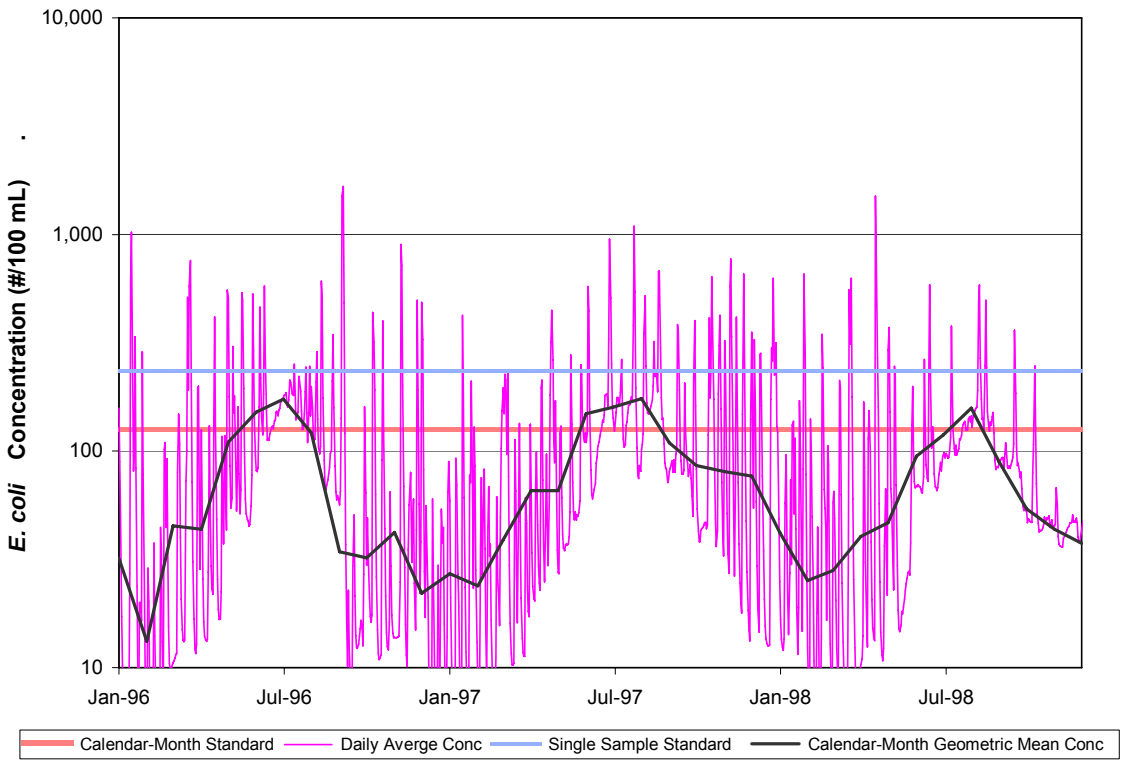

Figure 6.2. Simulated *E. coli* concentrations with the two bacteria standards for the Stage 1 implementation scenario for North Fork Hardware River.

6.5. Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay. Several BMPs known to be effective in controlling bacteria have been identified for implementation as part of the Tributary Strategy for the James River Basin. Management of on-site waste management systems, management of livestock and manure, and pet waste management are examples. Up-to-date information

on the tributary strategy can be found at the tributary strategy web site under: http://www.snr.state.va.us/Initiatives/TributaryStrategies/shenandoah.cfm.

6.6. Implementation Funding Sources

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

Some of the major potential sources of funding for non-regulated implementation actions may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, 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 (WQIF) during the last two legislative sessions, the Fund has become a significant funding stream for agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at http://www.dcr.virginia.gov/sw/wqia.htm.

6.7. Follow-Up Monitoring

Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, 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 purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

VADEQ will continue to monitor bacteria in the Hardware River watershed according to its ambient monitoring program. Under this program, the following stations are currently designated as watershed stations and will be sampled bimonthly for 2 years during every 6-year assessment period: 2-HNF000.10, 2-HAK001.34, and 2-HRD000.36. In addition, station 2-HRD011.57 is designated as a trend station and will be sampled bimonthly every year. When an Implementation Plan is developed for the Hardware River and implementation of that plan begins, VADEQ will increase the frequency of monitoring at specified sites to assess water quality progress as BMPs are implemented."

DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the 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 DEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bi-monthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

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), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bi-monthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one year period.

6.8. 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 during this process. Additional information can be obtained at http://www.deq.virginia.gov/wqs/pdf/WQS05A_1.pdf

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 would be for the reductions of all controllable sources to the maximum extent practicable using the implementation approaches described above. DEQ will continue to monitor biological health and water quality in the stream during and subsequent to the implementation of these measures to determine if 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 use attainability analysis 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.”

Chapter 7: Public Participation

Public participation was solicited at every stage of TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. In September 2006, members of the Center for TMDL and Watershed Studies at Virginia Tech traveled to Hardware River to become acquainted with the watershed. Throughout the process, personnel from Virginia Tech contacted stakeholders and local agency personnel via telephone and in person to acquire their input. Two public meetings were held to inform stakeholders of the TMDL process and solicit feedback. The first was held on November 30, 2006 in Scottsville, Virginia with 25 people in attendance. The second is to be scheduled. Two Local Steering Committee meetings were also held, on November 8, 2006 and June 6, 2007 in Charlottesville, Virginia. These meetings gathered a group of interested stakeholders and agency personnel who provided more detailed feedback on the estimates and methods used in these TMDLs.

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Appendix A: Glossary of Terms

Allocation

That portion of a receiving water's loading capacity that is attributed to one of its existing or future pollution sources (nonpoint or point) or to natural background sources.

Allocation Scenario

A proposed series of point and nonpoint source allocations (loadings from different sources), which are being considered to meet a water quality planning goal.

ARA (Antibiotic Resistance Analysis)

A bacterial source tracking technique that uses the expected varying antibiotic resistance of bacteria from different sources to identify the contributors of fecal bacteria. Bacteria from humans are expected to have the highest antibiotic resistance, while domestic and wildlife animal sources are expected to have lower antibiotic resistance (Hagedorn, 2006).

Background levels

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

BASINS (Better Assessment Science Integrating Point and Nonpoint Sources)

A computer-run tool that contains an assessment and planning component that allows users to organize and display geographic information for selected watersheds. It also contains a modeling component to examine impacts of pollutant loadings from point and nonpoint sources and to characterize the overall condition of specific watersheds.

Best Management Practices (BMP)

Methods, measures, or practices that are determined to be reasonable and cost-effective means for a land owner to meet certain, generally nonpoint source, pollution control needs. BMPs include structural and nonstructural controls and operation and maintenance procedures.

Bacteria Source Tracking

A collection of scientific methods used to track sources of fecal coliform.

Calibration

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

Die-off (of fecal coliform)

Reduction in the fecal coliform population due to predation by other bacteria as well as by adverse environmental conditions (e.g., UV radiation, pH).

Direct nonpoint sources

Sources of pollution that are defined statutorily (by law) as nonpoint sources that are represented in the model as point source loadings due to limitations of the model. Examples include: direct deposits of fecal material to streams from livestock and wildlife.

Failing septic system

Septic systems in which drain fields have failed such that effluent (wastewater) that is supposed to percolate into the soil, now rises to the surface and ponds on the surface where it can flow over the soil surface to streams or contribute pollutants to the surface where they can be lost during storm runoff events.

Fecal coliform

A type of bacteria found in the feces of various warm-blooded animals that is used as indicator of the possible presence of pathogenic (disease causing) organisms. *E. coli* bacteria are a subset of this group found to more closely correlate with human health problems.

Geometric mean

The geometric mean is simply the nth root of the product of n values. Using the geometric mean lessens the significance of a few extreme values (extremely high or low values). In practical terms, this means that if you have just a few bad samples, their weight is lessened.

Mathematically the geometric mean, $\bar{x}_g$, is expressed as:

$$\bar{x}_g = \sqrt[n]{x_1 \cdot x_2 \cdot x_3 \ldots \cdot x_n}$$

where n is the number of samples, and x_i is the value of sample i.

HSPF (Hydrological Simulation Program-Fortran)

A computer-based model that calculates runoff, sediment yield, and fate and transport of various pollutants to the stream. The model was developed under the direction of the U.S. Environmental Protection Agency (EPA).

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.

Instantaneous or Single Sample criterion

The instantaneous criterion or instantaneous water quality standard is the value of the water quality standard that should not be exceeded at any time. For example, the Virginia instantaneous water quality standard for *E. coli* is 235 cfu/100 mL. If this value is exceeded at any time, the water body is in violation of the state water quality standard.

Load allocation (LA)

The portion of a receiving water's loading capacity that is attributed either to one of its existing or future nonpoint sources of pollution or to natural background.

Margin of Safety (MOS)

A required component of the TMDL that accounts for the uncertainty about the relationship between the pollutant loads and the quality of the receiving waterbody. The MOS is normally incorporated into the conservative assumptions used to develop TMDLs (generally within the calculations or models).

Model

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

Nonpoint source

Pollution that is not released through pipes but rather originates from multiple sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.

Pathogen

Disease-causing agent, especially microorganisms such as bacteria, protozoa, and viruses.

Point source

Pollutant loads discharged at a specific location from pipes, outfalls, and conveyance channels from either municipal wastewater treatment plants or industrial waste treatment facilities. Point sources can also include pollutant loads contributed by tributaries to the main receiving water stream or river.

Pollution

Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act for example, the

term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.

Reach

Segment of a stream or river.

Runoff

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

Septic system

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

Simulation

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

Straight pipe

Delivers wastewater directly from a building, e.g., house, milking parlor, to a stream, pond, lake, or river.

Total Maximum Daily Load (TMDL)

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

Urban Runoff

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

Validation (of a model)

Process of determining how well the mathematical model's computer representation describes the actual behavior of the physical process under investigation. This follows the calibration of the model and ensures that the calibrated values adequately represent the watershed.

Wasteload allocation (WLA)

The portion of a receiving water's loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation.

Water quality standard

Law or regulation that consists of the beneficial designated use or uses of a water body, the numeric and narrative water quality criteria that are necessary to protect the use or uses of that particular water body, and an anti-degradation statement.

Watershed

A drainage area or basin in which all land and water areas drain or flow toward a central collector such as a stream, river, or lake at a lower elevation.

For more definitions, see the Virginia Cooperative Extension publications available online:

Glossary of Water-Related Terms. Publication 442-758.

http://www.ext.vt.edu/pubs/bse/442-758/442-758.html

and

TMDLs (Total Maximum Daily Loads) - Terms and Definitions. Publication 442-550.

http://www.ext.vt.edu/pubs/bse/442-550/442-550.html

Appendix B: Sample Calculation of Cattle (Sub-watershed 7 of the North Fork Hardware River Basin)

Sample Calculation: Distribution of Cattle

(Sub-watershed 7 of North Fork Hardware River during October)

(Note: Due to rounding, the numbers may not add up.)

There are 251 beef cows in sub-watershed 7.

1. During January, beef cattle in sub-watershed 7 are confined 46% of the time (Table 3.8).

   Beef cattle in confinement = 251 * 46% = 115

2. When not confined, cattle are on pasture or in the stream.

   Beef cattle on pasture and in the stream = 251 – 115 = 136

3. One hundred percent of beef cows in subwatershed 7 have stream access. Hence beef cattle with stream access are calculated as:

   Beef cattle on pastures with stream access = 136 * 100% = 136

4. Beef cattle in and around the stream are calculated using the numbers in Step 3 and the number of hours cattle spend in the stream in January (Table 3.10) as:

   Beef cattle in and around streams = 136 * 0.5/24 = 28.2

5. Number of cattle defecating in the stream is calculated by multiplying the number of cattle in and around the stream by 30% (Section 3.2.1):

   Beef cattle defecating in streams = 28.2 * 30% = 8.46

6. After calculating the number of cattle defecating in the stream, the number of cattle defecating on the pasture is calculated by subtracting the number of cattle defecating in the stream (Step 5) from the number of cattle in pasture and stream (Step 2):

   Beef cattle defecating on pasture = 136 -8.46 = 127.54

Now, obviously there are not fractions of cows standing and defecating in the stream. This number (8.46) represents the fraction of fecal coliform produced in one day by one cow that will be deposited in the stream.

Appendix C: Weather Data Preparation

A weather data file for providing the weather data inputs into the HSPF Model was created for the period January 1984 through December 2005 using the WDMUtil. Raw data required for creating the weather data file included hourly precipitation (in.), average daily temperatures (maximum, minimum, and dew point) (°F), average daily wind speed (mi/hr), total daily solar radiation (Langleys), and percent sun. The primary data source was the National Climatic Data Center's (NCDC) Cooperative Weather Station Albemarle County, Virginia, which was located near the Hardware River watershed. Data from other NCDC stations were also used to address the missing data. The raw data required varying amounts of preprocessing within WDMUtil to obtain the following hourly values: precipitation (PREC) (in), air temperature (ATEM) (°F), dew point temperature (DEWP) (°F), solar radiation (SOLR) (Langleys), wind speed (WIND) (mi/hr), potential evapotranspiration (PEVT) (in), potential evaporation (EVAP) (in), and cloud cover (CLOU) (tenths, range 0-10). The final WDM file contains these hourly datasets.

Raw data collection and processing

Weather data were obtained from the NCDC's weather stations in Charlottesville 2W, VA (441593, Lat./Long. 38°02'N / 78°31'W, elevation 870 ft); Monticello, VA (445700, Lat./Long. 38°01'N / 78°27'W, elevation 758 ft); North Garden, VA (446178, Lat./Long. 37°57'N / 78°38'W, elevation 686 ft), Bremo Bluff, VA (440993, Lat./Long. 37°43'N / 78°17'W, elevation 225 ft), Piedmont Research Station, VA (446712, Lat./Long. 38°14'N / 78°07'W, elevation 520 ft), Staunton Sewage Plant, VA (448062, Lat./Long. 38°11'N / 79°05'W, elevation 1640 ft), Montebello Fish Hatchery, VA (445690, Lat./Long. 37°51'N / 79°08'W, elevation 2649 ft), Dale Enterprise, VA (442208, Lat./Long. 38°27'N / 78°56'W, elevation 1400 ft), and Lynchburg Regional Airport, VA (445120, Lat./Long. 37°19'N / 79°12'W, elevation 940 ft). While deciding on the period of record for the weather WDM file, availability of flow and water quality data was considered in addition to the availability and quality of weather data. Data collection for many of the parameters did not being until 1984, which set the starting point of the period of

record. Percent sun data were available only through July 1996. The majority of the water quality data were collected from 1990-present. In order to make the best use of the available water quality data, the period of record was chosen to be 1984-2005. There are 7,670 days within this period. Substitutions for missing data are described below. The procedures used to process the raw data to obtain finished data required for input to HSPF are also described in the following sections.

1. Hourly Precipitation

   Hourly precipitation (HPCP) data were downloaded from NCDC's web site for North Garden and Bremo Bluff for the entire 1984-2005 period. Of the 184,086 possible hourly values in this period, 17,139 values were missing. The Montebello Fish Hatch, Piedmont Research Station, Staunton Sewage Plant, Dale Enterprise stations were patched with the hourly recorded precipitation; the combination still left 76 hourly values missing. For the hourly events that were still missing, the following procedure was followed to patch with the observed daily precipitation at Rocky Mount (PRCP):

   a. For precipitation depths less than or equal to 0.2 in, the entire daily precipitation event as was assumed to have occurred during the 6:00-7:00 pm hour of the previous day.
   b. For precipitation depths greater than 0.2 in and 3 or fewer hours of data missing, the difference between the total daily precipitation and the recorded hourly precipitation was evenly divided between the missing hours.
   c. For precipitation depths greater than 0.2 in and more than three hours of data missing, the daily precipitation total was divided into three even increments and assigned to the 3:00, 4:00, and 5:00 pm hours of the previous day.

The resulting file was imported into WDMUtil and given the constituent label “PREC.”

2. Temperature

   Separate daily maximum temperature (TMAX) and daily minimum temperature (TMIN) files were downloaded from the NCDC website for Charlottesville 2W for the entire 1984-2005 period. The TMAX dataset was missing 253 days of data; the TMIN dataset was missing 263 days of data. Data from the Piedmont Research Station and Monticello stations were used to fill in the missing days. Daily dew point temperature (DPTP) was taken from the Lynchburg Regional Airport station, the closest station that recorded dew point temperature. These data had units of tenths of degrees Fahrenheit and were divided by a factor of 10 prior to use in the WDM file. The *disaggregate temperature* function in WDMUtil was used to create an hourly average temperature file (ATEM). The *disaggregate dewpoint temperature* function in WDMUtil was used to create an hourly dewpoint temperature file (DEWP).

3. Average Daily Wind Speed

   Average daily wind speed (AWND) was not recorded at the Charlottesville 2W; therefore, average daily wind speed was obtained from the Lynchburg Regional Airport station. The units of the data were tenths of miles per hour; therefore, the timseries was divided by a factor of 10 prior to use in the WDM file. The *compute wind travel* function in WDMUtil was used to calculate the total wind travel in miles/day. Then the *disaggregate wind travel* function in WDMUtil was used to calculate the hourly wind speed throughout the day (WIND) using the distribution coefficients shown in Table C-1.

Table C-1. Hourly Distribution Coefficients for Wind Speed.

Hour	12	1	2	3	4	5	6	7	8	9	10	11
AM	0.035	0.034	0.034	0.034	0.034	0.034	0.034	0.034	0.035	0.037	0.041	0.046
PM	0.05	0.053	0.054	0.058	0.057	0.056	0.05	0.043	0.04	0.038	0.036	0.036

4. Cloud cover and solar radiation

   In the absence of daily cloud cover, percent sun (PSUN) can be used to estimate DCLO. DCLO is used by WDMUtil to estimate hourly cloud cover in tenths (CLOU) as well as solar radiation (SOLR) in Langleys. The closest weather station that recorded PSUN was Lynchburg Regional Airport station, and this data was used to develop the weather file. PSUN was only available at this station for the period January 1984-July 1996. It is the experience of the authors that the model is rather insensitive to the parameters derived from PSUN; therefore, to bridge the gap of missing data, values from August 1996-December 2005 were filled in by copying the values from the measured period.

   The *compute percent cloud cover* function in WDMUtil was used to calculate the daily percent cloud cover in tenths (DCLO) from PSUN. Because there is no *disaggregate percent cloud cover* function available, the *disaggregate wind travel* function was used with hourly distribution coefficients all set to 1 to calculate the hourly percent cloud cover in tenths (CLOU).

   The *compute solar radiation* function in WDMUtil was used to calculate the daily solar radiation in Langleys (DSOL) from DCLO and the Charlottesville 2W latitude (38°02'N). The *disaggregate solar radiation* function was then used to calculate the hourly solar radiation (SOLR).

5. Evaporation/Evapotranspiration

   Two types of evaporation/evapotranspiration are required for input to

HSPF: potential evaporation from a reach or reservoir surface (EVAP), represented as Penman pan evaporation; and potential evapotranspiration (PEVT), represented as Hamon potential evapotranspiration.

The *compute Penman pan evaporation* function in WDMUtil was used to calculate daily Penman pan evaporation (DEVP) from TMIN, TMAX, DPTP, TWND, and DSOL. Then the *disaggregate evapotranspiration* function was used to calculate EVAP from DEVP.

The *compute Hamon PET* function in WDMUtil was used to calculate daily potential evapotranspiration (DEVT) from TMIN, TMAX, the Charlottesville 2W latitude (38°02'N), and monthly coefficients all equal to 0.005. Then the *disaggregate evapotranspiration* function was used to calculate PEVT from DEVT.

Summary of weather data preparation

The weather data were prepared for input to HSPF as described in the previous section. A summary of the NCDC input parameters, WDMUtil functions used, and final HSPF parameters is presented in Table C-3.

Table C-3. Weather parameters and processing in WDMUtil required for HSPF modeling.

NCDC Input Parameters	Intermediate Input	WDMUtil Functions	Intermediate Output	Final HSPF Parameter
HPCP	--	None	--	PREC
TMAX, TMIN	--	Disaggregate temperature	--	ATEM
DPTP	--	Disaggregate dewpoint temperature	--	DEWP
PSUN	--	Compute percent cloud cover	DCLO	--
	DCLO	Disaggregate wind travel[1]	--	CLOU
	DCLO	Compute solar radiation	DSOL	--
	DSOL	Disaggregate solar radiation	--	SOLR
AWND	--	Compute wind travel	TWND	--
	TWND	Disaggregate wind travel	--	WIND
TMAX, TMIN, DPTP	TWND, DSOL	Compute Penman pan evaporation	DEVP	--
	DEVP	Disaggregate evapotranspiration	--	EVAP
TMAX, TMIN	--	Compute Hamon PET	DEVT	--
	DEVT	Disaggregate evapotranspiration	--	PEVT

[1]all hourly coefficients set to 1

Appendix D: HSPF Parameters that Vary by Month or Land Use

Table D.1. PWAT-PARM2 parameters varying by land use.

Parameter	Land Use				
	Forest	Pasture	Crop	HDR	LDR
INFILT	0.128	0.128	0.128	0.128	0.128
LSUR	219	348	407	453	459
SLSUR	0.141	0.081	0.053	0.032	0.029

Table D.2. MON-INTERCEP (monthly CEPSC) - Monthly Interception Storage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.05	0.05	0.15	0.2	0.2	0.2	0.2	0.2	0.2	0.15	0.05	0.05
HDR	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
LDR	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
Pasture	0.05	0.05	0.05	0.05	0.05	0.25	0.25	0.25	0.05	0.05	0.05	0.05
Crop	0.05	0.05	0.05	0.05	0.15	0.2	0.25	0.25	0.25	0.2	0.15	0.15

Table D.3. MON-UZSN - Monthly Upper Zone Nominal Storage.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.38	0.47	0.79	1.11	1.62	1.84	1.82	1.83	1.59	1.08	0.77	0
HDR	0.38	0.47	0.79	1.11	1.62	1.84	1.82	1.83	1.59	1.08	0.77	0
LDR	0.38	0.47	0.79	1.11	1.62	1.84	1.82	1.83	1.59	1.08	0.77	0
Pasture	0.38	0.47	0.79	1.11	1.62	1.84	1.82	1.83	1.59	1.08	0.77	0
Crop	0.38	0.47	0.79	1.11	1.62	1.84	1.82	1.83	1.59	1.08	0.77	0

Table D.4. MON-LZETP - Monthly Lower Zone Evapotranspiration Parameter.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Forest	0.11	0.16	0.28	0.46	0.62	0.75	0.79	0.74	0.61	0.44	0.27	0
HDR	0.11	0.16	0.28	0.46	0.62	0.75	0.79	0.74	0.61	0.44	0.27	0
LDR	0.11	0.16	0.28	0.46	0.62	0.75	0.79	0.74	0.61	0.44	0.27	0
Pasture	0.11	0.16	0.28	0.46	0.62	0.75	0.79	0.74	0.61	0.44	0.27	0
Crop	0.11	0.16	0.28	0.46	0.62	0.75	0.79	0.74	0.61	0.44	0.27	0

Table D.5. MON-ACCUM Table for Hardware River – Monthly Accumulation Rate of Bacteria on the Soil Surface (cfu/ac/day).

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Crop	5.90E+07	1.80E+08	6.10E+08	5.20E+08	1.70E+08	5.90E+07	5.90E+07	5.90E+07	5.90E+07	2.30E+08	2.30E+08	5.90E+07
1	Pasture	2.60E+09	3.00E+09	5.10E+09	5.20E+09	5.30E+09	5.30E+09	5.50E+09	5.60E+09	5.90E+09	3.70E+09	3.90E+09	2.50E+09
1	Forest	6.50E+07	6.50E+07	5.00E+07	5.00E+07	5.00E+07	5.00E+07	5.00E+07	5.00E+07	6.50E+07	6.50E+07	6.50E+07	6.50E+07
2	Pasture	2.60E+09	3.10E+09	5.30E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
2	Forest	7.10E+07	7.10E+07	5.50E+07	5.50E+07	5.50E+07	5.50E+07	5.50E+07	5.50E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07
3	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
3	Forest	5.70E+07	5.70E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07
4	Crop	1.80E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	2.40E+09	2.50E+09	1.80E+07
4	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	2.60E+09
4	Forest	3.20E+07	3.20E+07	2.70E+07	2.70E+07	2.70E+07	2.70E+07	2.70E+07	2.70E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07
5	Crop	1.80E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	1.80E+07	1.80E+07	1.80E+07	1.80E+07	2.40E+09	2.50E+09	1.80E+07
5	Pasture	2.70E+09	3.20E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.60E+09
5	Forest	5.70E+07	5.70E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07
6	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.60E+09	5.70E+09	5.80E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
6	Forest	1.30E+08	1.30E+08	9.40E+07	9.40E+07	9.40E+07	9.40E+07	9.40E+07	9.40E+07	1.30E+08	1.30E+08	1.30E+08	1.30E+08
7	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.60E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
7	Forest	7.70E+07	7.70E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	7.70E+07	7.70E+07	7.70E+07	7.70E+07
8	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.60E+09
8	Forest	4.10E+07	4.10E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	4.10E+07	4.10E+07	4.10E+07	4.10E+07
9	Pasture	2.70E+09	3.20E+09	5.40E+09	5.60E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.60E+09
9	Forest	3.80E+07	3.80E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07	3.80E+07	3.80E+07	3.80E+07	3.80E+07
10	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.60E+09
10	Forest	4.50E+07	4.50E+07	3.60E+07	3.60E+07	3.60E+07	3.60E+07	3.60E+07	3.60E+07	4.50E+07	4.50E+07	4.50E+07	4.50E+07
11	Pasture	2.70E+09	3.20E+09	5.50E+09	5.60E+09	5.70E+09	5.70E+09	5.80E+09	6.00E+09	6.30E+09	3.90E+09	4.10E+09	2.60E+09
11	Forest	6.60E+07	6.60E+07	5.20E+07	5.20E+07	5.20E+07	5.20E+07	5.20E+07	5.20E+07	6.60E+07	6.60E+07	6.60E+07	6.60E+07
12	Crop	2.50E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	2.50E+07	2.50E+07	2.50E+07	2.50E+07	2.40E+09	2.50E+09	2.50E+07
12	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.60E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
12	Forest	3.40E+07	3.40E+07	2.80E+07	2.80E+07	2.80E+07	2.80E+07	2.80E+07	2.80E+07	3.40E+07	3.40E+07	3.40E+07	3.40E+07
13	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.80E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
13	Forest	3.70E+07	3.70E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	3.70E+07	3.70E+07	3.70E+07	3.70E+07
14	Forest	4.90E+07	4.90E+07	3.80E+07	3.80E+07	3.80E+07	3.80E+07	3.80E+07	3.80E+07	4.90E+07	4.90E+07	4.90E+07	4.90E+07
15	Pasture	2.70E+09	3.20E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.60E+09

Table D.5. MON-ACCUM Table for Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DE
15	Forest	5.60E+07	5.60E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	4.20E+07	5.60E+07	5.60E+07	5.60E+07	5.60
16	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	3.20
16	Forest	7.30E+07	7.30E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	5.70E+07	7.30E+07	7.30E+07	7.30E+07	4.30
17	Crop	3.90E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	3.90E+07	3.90E+07	3.90E+07	3.90E+07	2.40E+09	2.50E+09	0.00
17	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.60E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	9.00
17	Forest	4.00E+07	4.00E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07	4.00E+07	4.00E+07	4.00E+07	3.40
18	Crop	2.00E+07	1.30E+08	5.30E+08	4.40E+08	1.20E+08	2.00E+07	2.00E+07	2.00E+07	2.00E+07	1.70E+08	1.80E+08	3.40
18	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	4.20
18	Forest	2.70E+07	2.70E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	2.70E+07	2.70E+07	2.70E+07	0.00
19	Crop	1.80E+07	5.00E+07	1.60E+08	1.40E+08	4.70E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07	6.20E+07	6.30E+07	9.60
19	Pasture	2.70E+09	3.10E+09	5.30E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	1.00
19	Forest	5.30E+07	5.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	5.30E+07	5.30E+07	5.30E+07	1.10
20	Pasture	2.70E+09	3.20E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	9.10
20	Forest	8.00E+07	8.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	8.00E+07	8.00E+07	8.00E+07	0.00
21	Crop	1.80E+07	2.50E+08	1.10E+09	8.80E+08	2.30E+08	1.80E+07	1.80E+07	1.80E+07	1.80E+07	3.40E+08	3.50E+08	8.80
21	Pasture	2.70E+09	3.10E+09	5.30E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	4.90
21	Forest	6.40E+07	6.40E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	6.40E+07	6.40E+07	6.40E+07	1.70
22	Crop	2.00E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	2.00E+07	2.00E+07	2.00E+07	2.00E+07	2.40E+09	2.50E+09	1.40
22	Pasture	2.60E+09	3.10E+09	5.30E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	0.00
22	Forest	6.20E+07	6.20E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	4.70E+07	6.20E+07	6.20E+07	6.20E+07	1.00
23	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	1.90
23	Forest	6.70E+07	6.70E+07	5.10E+07	5.10E+07	5.10E+07	5.10E+07	5.10E+07	5.10E+07	6.70E+07	6.70E+07	6.70E+07	1.90
24	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	9.10
24	Forest	5.30E+07	5.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	5.30E+07	5.30E+07	5.30E+07	8.40

Table D.6. MON-ACCUM Table for North Fork Hardware River.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
1	LDR	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10
1	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
1	Forest	1.00E+08	1.00E+08	7.20E+07	7.20E+07	7.20E+07	7.20E+07	7.20E+07	7.20E+07	1.00E+08	1.00E+08	1.00E+08	1.00E+08
2	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
2	LDR	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10	1.20E+10
2	Forest	6.30E+07	6.30E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	4.40E+07	6.30E+07	6.30E+07	6.30E+07	6.30E+07
3	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
3	LDR	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09
3	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
3	Forest	8.70E+07	8.70E+07	6.20E+07	6.20E+07	6.20E+07	6.20E+07	6.20E+07	6.20E+07	8.70E+07	8.70E+07	8.70E+07	8.70E+07
4	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.50E+09
4	LDR	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09	1.70E+09
4	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
4	Forest	2.90E+07	2.90E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.90E+07	2.90E+07	2.90E+07	2.90E+07
5	Pasture	2.60E+09	3.10E+09	5.30E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
5	LDR	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09	7.90E+09
5	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
5	Forest	8.50E+07	8.50E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	6.00E+07	8.50E+07	8.50E+07	8.50E+07	8.50E+07
6	Crop	2.30E+06	1.70E+09	7.80E+09	6.40E+09	1.60E+09	2.30E+06	2.30E+06	2.30E+06	2.30E+06	2.40E+09	2.50E+09	2.30E+06
6	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
6	LDR	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08
6	Forest	1.60E+07	1.60E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.60E+07	1.60E+07	1.60E+07	1.60E+07
7	Crop	2.50E+06	1.70E+09	7.80E+09	6.40E+09	1.60E+09	2.50E+06	2.50E+06	2.50E+06	2.50E+06	2.40E+09	2.50E+09	2.50E+06
7	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
7	LDR	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08
7	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Crop	2.40E+06	1.50E+09	6.90E+09	5.70E+09	1.40E+09	2.40E+06	2.40E+06	2.40E+06	2.40E+06	2.10E+09	2.20E+09	2.40E+06
8	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
8	LDR	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08
8	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
8	Forest	5.20E+07	5.20E+07	3.70E+07	3.70E+07	3.70E+07	3.70E+07	3.70E+07	3.70E+07	5.20E+07	5.20E+07	5.20E+07	5.20E+07

Table D.6. MON-ACCUM Table for North Fork Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
9	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
9	LDR	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10	7.30E+10
9	Forest	1.80E+07	1.80E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.10E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07
10	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.50E+09
10	Forest	1.30E+07	1.30E+07	9.40E+06	9.40E+06	9.40E+06	9.40E+06	9.40E+06	9.40E+06	1.30E+07	1.30E+07	1.30E+07	1.30E+07
11	Crop	1.40E+07	1.70E+09	7.80E+09	6.50E+09	1.60E+09	1.40E+07	1.40E+07	1.40E+07	1.40E+07	2.40E+09	2.50E+09	1.40E+07
11	Pasture	2.70E+09	3.20E+09	5.50E+09	5.60E+09	5.70E+09	5.70E+09	5.80E+09	6.00E+09	6.30E+09	3.90E+09	4.10E+09	2.60E+09
11	LDR	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09
11	Forest	1.80E+07	1.80E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07
12	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
12	LDR	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09
12	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
12	Forest	8.90E+07	8.90E+07	6.30E+07	6.30E+07	6.30E+07	6.30E+07	6.30E+07	6.30E+07	8.90E+07	8.90E+07	8.90E+07	8.90E+07
13	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
13	LDR	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09	1.50E+09
13	Forest	6.10E+07	6.10E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	4.30E+07	6.10E+07	6.10E+07	6.10E+07	6.10E+07
14	Pasture	2.60E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.70E+09	5.90E+09	6.20E+09	3.80E+09	4.00E+09	2.50E+09
14	LDR	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09	8.60E+09
14	Forest	1.80E+07	1.80E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.30E+07	1.80E+07	1.80E+07	1.80E+07	1.80E+07
15	Crop	3.40E+06	4.30E+06	7.60E+06	6.90E+06	4.20E+06	3.40E+06	3.40E+06	3.40E+06	3.40E+06	4.70E+06	4.70E+06	3.40E+06
15	Pasture	2.80E+09	3.30E+09	5.70E+09	5.80E+09	5.90E+09	5.90E+09	6.10E+09	6.30E+09	6.60E+09	4.10E+09	4.30E+09	2.70E+09
15	LDR	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09	6.80E+09
15	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
15	Forest	3.20E+07	3.20E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	2.40E+07	3.20E+07	3.20E+07	3.20E+07	3.20E+07
16	Crop	2.80E+06	5.80E+08	2.60E+09	2.20E+09	5.30E+08	2.80E+06	2.80E+06	2.80E+06	2.80E+06	8.10E+08	8.30E+08	2.80E+06
16	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
16	LDR	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09	1.30E+09
16	Forest	1.20E+07	1.20E+07	8.60E+06	8.60E+06	8.60E+06	8.60E+06	8.60E+06	8.60E+06	1.20E+07	1.20E+07	1.20E+07	1.20E+07
17	Pasture	2.80E+09	3.30E+09	5.60E+09	5.80E+09	5.90E+09	6.00E+09	6.20E+09	6.30E+09	6.50E+09	4.00E+09	4.20E+09	2.70E+09
17	Forest	4.00E+07	4.00E+07	2.90E+07	2.90E+07	2.90E+07	2.90E+07	2.90E+07	2.90E+07	4.00E+07	4.00E+07	4.00E+07	4.00E+07
18	Pasture	2.60E+09	3.10E+09	5.30E+09	5.40E+09	5.50E+09	5.50E+09	5.60E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
18	LDR	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10

Table D.6. MON-ACCUM Table for North Fork Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
18	Forest	1.40E+07	1.40E+07	9.80E+06	9.80E+06	9.80E+06	9.80E+06	9.80E+06	9.80E+06	1.40E+07	1.40E+07	1.40E+07	1.40E+07
19	Pasture	2.70E+09	3.10E+09	5.40E+09	5.50E+09	5.60E+09	5.60E+09	5.80E+09	5.90E+09	6.20E+09	3.90E+09	4.10E+09	2.50E+09
19	LDR	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08
19	HDR	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
19	Forest	4.50E+07	4.50E+07	3.10E+07	3.10E+07	3.10E+07	3.10E+07	3.10E+07	3.10E+07	4.50E+07	4.50E+07	4.50E+07	4.50E+07
20	Pasture	2.60E+09	3.10E+09	5.30E+09	5.50E+09	5.50E+09	5.50E+09	5.70E+09	5.80E+09	6.10E+09	3.80E+09	4.00E+09	2.50E+09
20	LDR	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10	3.00E+10
20	Forest	1.10E+07	1.10E+07	7.80E+06	7.80E+06	7.80E+06	7.80E+06	7.80E+06	7.80E+06	1.10E+07	1.10E+07	1.10E+07	1.10E+07

Table D.7. MON-SQOLIM Table for Hardware River.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Crop	5.30E+08	1.60E+09	5.50E+09	4.70E+09	1.50E+09	5.30E+08	5.30E+08	5.30E+08	5.30E+08	2.00E+09	2.10E+09	5.30E+08
1	Pasture	2.30E+10	2.70E+10	4.60E+10	4.70E+10	4.80E+10	4.80E+10	4.90E+10	5.00E+10	5.30E+10	3.30E+10	3.50E+10	2.20E+10
1	Forest	5.80E+08	5.80E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	4.50E+08	5.80E+08	5.80E+08	5.80E+08	5.80E+08
2	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
2	Forest	6.40E+08	6.40E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08	6.40E+08	6.40E+08	6.40E+08	6.40E+08
3	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
3	Forest	5.10E+08	5.10E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08
4	Crop	1.60E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	2.10E+10	2.20E+10	1.60E+08
4	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
4	Forest	2.90E+08	2.90E+08	2.40E+08	2.40E+08	2.40E+08	2.40E+08	2.40E+08	2.40E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08
5	Crop	1.60E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	1.60E+08	1.60E+08	1.60E+08	1.60E+08	2.10E+10	2.20E+10	1.60E+08
5	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
5	Forest	5.10E+08	5.10E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08
6	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.50E+10	3.50E+10	3.60E+10	2.30E+10
6	Forest	1.20E+09	1.20E+09	8.40E+08	8.40E+08	8.40E+08	8.40E+08	8.40E+08	8.40E+08	1.20E+09	1.20E+09	1.20E+09	1.20E+09
7	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	4.90E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
7	Forest	6.90E+08	6.90E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	6.90E+08	6.90E+08	6.90E+08	6.90E+08
8	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
8	Forest	3.70E+08	3.70E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.00E+08	3.70E+08	3.70E+08	3.70E+08	3.70E+08
9	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.10E+10	5.10E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
9	Forest	3.40E+08	3.40E+08	3.10E+08	3.10E+08	3.10E+08	3.10E+08	3.10E+08	3.10E+08	3.40E+08	3.40E+08	3.40E+08	3.40E+08
10	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
10	Forest	4.10E+08	4.10E+08	3.20E+08	3.20E+08	3.20E+08	3.20E+08	3.20E+08	3.20E+08	4.10E+08	4.10E+08	4.10E+08	4.10E+08
11	Pasture	2.40E+10	2.90E+10	4.90E+10	5.10E+10	5.10E+10	5.10E+10	5.30E+10	5.40E+10	5.70E+10	3.50E+10	3.70E+10	2.30E+10
11	Forest	5.90E+08	5.90E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08	5.90E+08	5.90E+08	5.90E+08	5.90E+08
12	Crop	2.30E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.20E+10	2.20E+10	2.30E+08
12	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	4.90E+10	4.90E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
12	Forest	3.10E+08	3.10E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08	3.10E+08	3.10E+08	3.10E+08	3.10E+08
13	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
13	Forest	3.30E+08	3.30E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08
14	Forest	4.40E+08	4.40E+08	3.40E+08	3.40E+08	3.40E+08	3.40E+08	3.40E+08	3.40E+08	4.40E+08	4.40E+08	4.40E+08	4.40E+08
15	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10

Table D.7. MON-SQOLIM Table for Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
15	Forest	5.00E+08	5.00E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	5.00E+08	5.00E+08	5.00E+08	5.00E+08
16	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
16	Forest	6.60E+08	6.60E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	5.10E+08	6.60E+08	6.60E+08	6.60E+08	6.60E+08
17	Crop	3.50E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	3.50E+08	3.50E+08	3.50E+08	3.50E+08	2.20E+10	2.20E+10	3.50E+08
17	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	4.90E+10	4.90E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
17	Forest	3.60E+08	3.60E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08	3.60E+08	3.60E+08	3.60E+08	3.60E+08
18	Crop	1.80E+08	1.20E+09	4.70E+09	4.00E+09	1.10E+09	1.80E+08	1.80E+08	1.80E+08	1.80E+08	1.60E+09	1.60E+09	1.80E+08
18	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.10E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
18	Forest	2.50E+08	2.50E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.50E+08	2.50E+08	2.50E+08	2.50E+08
19	Crop	1.60E+08	4.50E+08	1.50E+09	1.20E+09	4.20E+08	1.60E+08	1.60E+08	1.60E+08	1.60E+08	5.60E+08	5.70E+08	1.60E+08
18	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.40E+10	3.60E+10	2.30E+10
19	Forest	4.80E+08	4.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	4.80E+08	4.80E+08	4.80E+08	4.80E+08
20	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
20	Forest	7.20E+08	7.20E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	7.20E+08	7.20E+08	7.20E+08	7.20E+08
21	Crop	1.60E+08	2.20E+09	9.60E+09	7.90E+09	2.00E+09	1.60E+08	1.60E+08	1.60E+08	1.60E+08	3.00E+09	3.10E+09	1.60E+08
21	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.40E+10	3.60E+10	2.30E+10
21	Forest	5.70E+08	5.70E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08
22	Crop	1.80E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	1.80E+08	1.80E+08	1.80E+08	1.80E+08	2.20E+10	2.20E+10	1.80E+08
22	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
22	Forest	5.50E+08	5.50E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	4.30E+08	5.50E+08	5.50E+08	5.50E+08	5.50E+08
23	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
23	Forest	6.10E+08	6.10E+08	4.60E+08	4.60E+08	4.60E+08	4.60E+08	4.60E+08	4.60E+08	6.10E+08	6.10E+08	6.10E+08	6.10E+08
24	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
24	Forest	4.80E+08	4.80E+08	3.90E+08	3.90E+08	3.90E+08	3.90E+08	3.90E+08	3.90E+08	4.80E+08	4.80E+08	4.80E+08	4.80E+08

Table D.8. MON-SQOLIM Table for North Fork Hardware River.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1	Pasture	2.40E+10	2.80E+10	4.80E+10	5.00E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
1	LDR	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11	1.20E+11
1	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
1	Forest	9.10E+08	9.10E+08	6.50E+08	6.50E+08	6.50E+08	6.50E+08	6.50E+08	6.50E+08	9.10E+08	9.10E+08	9.10E+08	9.10E+08
2	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
2	LDR	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11	1.10E+11
2	Forest	5.70E+08	5.70E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08
3	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
3	LDR	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10	4.40E+10
3	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
3	Forest	7.80E+08	7.80E+08	5.50E+08	5.50E+08	5.50E+08	5.50E+08	5.50E+08	5.50E+08	7.80E+08	7.80E+08	7.80E+08	7.80E+08
4	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
4	LDR	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10	1.50E+10
4	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
4	Forest	2.60E+08	2.60E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	1.90E+08	2.60E+08	2.60E+08	2.60E+08	2.60E+08
5	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
5	LDR	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10	7.10E+10
5	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
5	Forest	7.70E+08	7.70E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	5.40E+08	7.70E+08	7.70E+08	7.70E+08	7.70E+08
6	Crop	2.10E+07	1.50E+10	7.00E+10	5.80E+10	1.40E+10	2.10E+07	2.10E+07	2.10E+07	2.10E+07	2.10E+10	2.20E+10	2.10E+07
6	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
6	LDR	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09	4.80E+09
6	Forest	1.40E+08	1.40E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.40E+08	1.40E+08	1.40E+08	1.40E+08
7	Crop	2.20E+07	1.50E+10	7.00E+10	5.80E+10	1.40E+10	2.20E+07	2.20E+07	2.20E+07	2.20E+07	2.10E+10	2.20E+10	2.20E+07
7	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
7	LDR	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09	8.20E+09

Table D.8. MON-SQOLIM Table for North Fork Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
7	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
7	Forest	3.40E+08	3.40E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	2.30E+08	3.40E+08	3.40E+08	3.40E+08	3.40E+08
8	Crop	2.20E+07	1.40E+10	6.20E+10	5.10E+10	1.20E+10	2.20E+07	2.20E+07	2.20E+07	2.20E+07	1.90E+10	1.90E+10	2.20E+07
8	Pasture	2.40E+10	2.80E+10	4.70E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
8	LDR	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09	2.10E+09
8	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
8	Forest	4.70E+08	4.70E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	3.30E+08	4.70E+08	4.70E+08	4.70E+08	4.70E+08
9	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
9	LDR	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11	6.60E+11
9	Forest	1.60E+08	1.60E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.00E+08	1.60E+08	1.60E+08	1.60E+08	1.60E+08
10	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
10	Forest	1.10E+08	1.10E+08	8.50E+07	8.50E+07	8.50E+07	8.50E+07	8.50E+07	8.50E+07	1.10E+08	1.10E+08	1.10E+08	1.10E+08
11	Crop	1.20E+08	1.60E+10	7.00E+10	5.80E+10	1.40E+10	1.20E+08	1.20E+08	1.20E+08	1.20E+08	2.10E+10	2.20E+10	1.20E+08
11	Pasture	2.40E+10	2.90E+10	4.90E+10	5.00E+10	5.10E+10	5.10E+10	5.20E+10	5.40E+10	5.70E+10	3.50E+10	3.70E+10	2.30E+10
11	LDR	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10	4.80E+10
11	Forest	1.60E+08	1.60E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.10E+08	1.60E+08	1.60E+08	1.60E+08	1.60E+08
12	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.40E+10	3.60E+10	2.30E+10
12	LDR	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10	1.90E+10
12	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
12	Forest	8.00E+08	8.00E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08	5.70E+08	8.00E+08	8.00E+08	8.00E+08	8.00E+08
13	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
13	LDR	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10	1.40E+10
13	Forest	5.50E+08	5.50E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	3.80E+08	5.50E+08	5.50E+08	5.50E+08	5.50E+08
14	Pasture	2.40E+10	2.80E+10	4.80E+10	5.00E+10	5.00E+10	5.00E+10	5.10E+10	5.30E+10	5.60E+10	3.50E+10	3.60E+10	2.30E+10
14	LDR	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10	7.70E+10
14	Forest	1.60E+08	1.60E+08	1.20E+08	1.20E+08	1.20E+08	1.20E+08	1.20E+08	1.20E+08	1.60E+08	1.60E+08	1.60E+08	1.60E+08
15	Crop	3.00E+07	3.90E+07	6.80E+07	6.20E+07	3.80E+07	3.00E+07	3.00E+07	3.00E+07	3.00E+07	4.20E+07	4.20E+07	3.00E+07

Table D.8. MON-SQOLIM Table for North Fork Hardware River – Continued.

Sub-watershed	Land Use	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
15	Pasture	2.50E+10	3.00E+10	5.10E+10	5.20E+10	5.30E+10	5.30E+10	5.50E+10	5.60E+10	5.90E+10	3.70E+10	3.90E+10	2.40E+10
15	LDR	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10	6.10E+10
15	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
15	Forest	2.90E+08	2.90E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.10E+08	2.90E+08	2.90E+08	2.90E+08	2.90E+08
16	Crop	2.50E+07	5.30E+09	2.40E+10	2.00E+10	4.80E+09	2.50E+07	2.50E+07	2.50E+07	2.50E+07	7.30E+09	7.50E+09	2.50E+07
16	Pasture	2.40E+10	2.80E+10	4.70E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
16	LDR	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10	1.10E+10
16	Forest	1.10E+08	1.10E+08	7.70E+07	7.70E+07	7.70E+07	7.70E+07	7.70E+07	7.70E+07	1.10E+08	1.10E+08	1.10E+08	1.10E+08
17	Pasture	2.50E+10	2.90E+10	5.00E+10	5.20E+10	5.30E+10	5.40E+10	5.50E+10	5.70E+10	5.80E+10	3.60E+10	3.80E+10	2.40E+10
17	Forest	3.60E+08	3.60E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	2.70E+08	3.60E+08	3.60E+08	3.60E+08	3.60E+08
18	Pasture	2.30E+10	2.80E+10	4.80E+10	4.90E+10	4.90E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.20E+10
18	LDR	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10	9.90E+10
18	Forest	1.30E+08	1.30E+08	8.80E+07	8.80E+07	8.80E+07	8.80E+07	8.80E+07	8.80E+07	1.30E+08	1.30E+08	1.30E+08	1.30E+08
19	Pasture	2.40E+10	2.80E+10	4.90E+10	5.00E+10	5.00E+10	5.00E+10	5.20E+10	5.30E+10	5.60E+10	3.50E+10	3.70E+10	2.30E+10
19	LDR	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09	5.30E+09
19	HDR	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01	1.00E-01
19	Forest	4.00E+08	4.00E+08	2.80E+08	2.80E+08	2.80E+08	2.80E+08	2.80E+08	2.80E+08	4.00E+08	4.00E+08	4.00E+08	4.00E+08
20	Pasture	2.40E+10	2.80E+10	4.80E+10	4.90E+10	5.00E+10	5.00E+10	5.10E+10	5.20E+10	5.50E+10	3.40E+10	3.60E+10	2.30E+10
20	LDR	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11	2.70E+11
20	Forest	1.00E+08	1.00E+08	7.10E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07	7.10E+07	1.00E+08	1.00E+08	1.00E+08	1.00E+08

Appendix E: Fecal Coliform Loading in Sub-watersheds for Future Conditions

Table E-1. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 01.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	145	95	240
Feb.	0	155	141	295
Mar.	0	287	135	421
Apr.	0	284	152	436
May.	0	300	241	540
Jun.	0	291	140	431
Jul.	0	308	203	511
Aug.	0	316	140	455
Sep.	0	321	75	396
Oct.	0	207	87	293
Nov.	0	211	63	274
Dec.	0	139	39	178
Total	0	2,961	1,508	4,468

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

Table E-2. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 02.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	0	0	3,023
Feb.	0	0	0	3,207
Mar.	0	0	0	5,823
Apr.	0	0	0	5,755
May.	0	0	0	6,009
Jun.	0	0	0	5,821
Jul.	0	0	0	6,167
Aug.	0	0	0	6,320
Sep.	0	0	0	6,491
Oct.	0	0	0	4,265
Nov.	0	0	0	4,332
Dec.	0	0	0	2,904
Total	0	0	0	60,118

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

Table E-3. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 03.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	145	19	467
Feb.	0	155	28	437
Mar.	0	287	27	526
Apr.	0	284	30	512
May.	0	300	48	518
Jun.	0	291	28	520
Jul.	0	308	41	534
Aug.	0	316	28	554
Sep.	0	321	15	636
Oct.	0	207	17	530
Nov.	0	211	13	528
Dec.	0	139	8	472
Total	0	2,961	302	6,234

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

Table E-4. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 04.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	941	19	5,559
Feb.	0	1,008	28	5,906
Mar.	0	1,892	27	10,895
Apr.	0	1,874	30	10,783
May.	0	1,966	48	11,297
Jun.	0	1,905	28	10,963
Jul.	0	2,020	41	11,609
Aug.	0	2,072	28	11,914
Sep.	0	2,111	15	12,188
Oct.	0	1,355	17	7,909
Nov.	0	1,381	13	8,049
Dec.	0	901	8	5,342
Total	0	19,424	19	112,410

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

Table E-5. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 05.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	0	0	6,307
Feb.	0	0	0	6,694
Mar.	0	0	0	12,244
Apr.	0	0	0	12,105
May.	0	0	0	12,654
Jun.	0	0	0	12,260
Jul.	0	0	0	12,988
Aug.	0	0	0	13,309
Sep.	0	0	0	13,591
Oct.	0	0	0	8,908
Nov.	0	0	0	9,051
Dec.	0	0	0	6057
Total	0	0	0	126,167

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

Table E-6. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 06.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	0	0	2,855
Feb.	0	0	0	3,019
Mar.	0	0	0	5,435
Apr.	0	0	0	5,371
May.	0	0	0	5,607
Jun.	0	0	0	5,432
Jul.	0	0	0	5,753
Aug.	0	0	0	5,894
Sep.	0	0	0	6,054
Oct.	0	0	0	4,001
Nov.	0	0	0	4,061
Dec.	0	0	0	2,745
Total	0	0	0	56,226

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

Table E-7. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 07.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	707	0	1,938
Feb.	0	759	0	2,034
Mar.	0	1,431	0	3,583
Apr.	0	1,415	0	3,538
May.	0	1,478	0	3,693
Jun.	0	1,432	0	3,577
Jul.	0	1,518	0	3,787
Aug.	0	1,557	0	3,877
Sep.	0	1,589	0	3,987
Oct.	0	1,022	0	2,673
Nov.	0	1,041	0	2,708
Dec.	0	677	0	1,867
Total	0	14,626	0	37,262

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

Table E-8. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 08.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	3,780	221	258
Feb.	0	4,059	201	235
Mar.	0	7,656	182	258
Apr.	0	7,572	176	250
May.	0	7,908	182	258
Jun.	0	7,662	176	250
Jul.	0	8,124	182	258
Aug.	0	8,331	182	258
Sep.	0	8,504	214	250
Oct.	0	5,468	221	258
Nov.	0	5,569	214	250
Dec.	0	3,618	221	258
Total	0	78,252	2,373	3,041

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

Table E-9. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 09.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	285	38	1,176
Feb.	0	306	56	1,479
Mar.	0	578	54	2,583
Apr.	0	572	61	2,548
May.	0	597	96	2,659
Jun.	0	578	56	2,576
Jul.	0	613	81	2,724
Aug.	0	629	56	2,786
Sep.	0	642	30	2,837
Oct.	0	413	35	1,929
Nov.	0	420	25	1,951
Dec.	0	273	16	1,371
Total	0	5,907	603	26,619

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

Table E-10. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 10.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1486	152	624
Feb.	0	1595	225	542
Mar.	0	3007	215	898
Apr.	0	2974	242	851
May.	0	3106	385	753
Jun.	0	3010	224	878
Jul.	0	3191	324	835
Aug.	0	3272	223	956
Sep.	0	3340	120	1,106
Oct.	0	2148	138	803
Nov.	0	2188	101	837
Dec.	0	1423	62	697
Total	0	30,741	2,412	9,781

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

Table E-11. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 11.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	428	26	1,451
Feb.	0	460	24	1,531
Mar.	0	867	20	2,751
Apr.	0	857	20	2,718
May.	0	896	20	2,837
Jun.	0	868	20	2,748
Jul.	0	920	20	2,910
Aug.	0	943	20	2,980
Sep.	0	963	25	3,050
Oct.	0	619	26	2,024
Nov.	0	631	25	2,054
Dec.	0	410	26	1,396
Total	0	8,862	274	28,450

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

Table E-12. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 12.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	458	70	974
Feb.	0	491	63	999
Mar.	0	924	58	1,656
Apr.	0	914	56	1,632
May.	0	956	58	1,704
Jun.	0	926	56	1,650
Jul.	0	982	58	1,743
Aug.	0	1,007	58	1,780
Sep.	0	1,027	67	1,820
Oct.	0	661	70	1,279
Nov.	0	673	67	1,288
Dec.	0	438	70	945
Total	0	9,454	750	17,471

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

Table E-13. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 13.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	7,271	255	266
Feb.	0	7,809	232	242
Mar.	0	14,731	210	266
Apr.	0	14,569	204	257
May.	0	15,216	210	266
Jun.	0	14,742	204	257
Jul.	0	15,631	210	266
Aug.	0	16,030	210	266
Sep.	0	16,362	247	257
Oct.	0	10,519	255	266
Nov.	0	10,714	247	257
Dec.	0	6,960	255	266
Total	0	150,555	2,740	3,131

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

Table E-14. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 14.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	0	127	83
Feb.	0	0	116	76
Mar.	0	0	99	83
Apr.	0	0	96	81
May.	0	0	99	83
Jun.	0	0	96	81
Jul.	0	0	99	83
Aug.	0	0	99	83
Sep.	0	0	123	81
Oct.	0	0	127	83
Nov.	0	0	123	81
Dec.	0	0	127	83
Total	0	0	1,335	984

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

Table E-15. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 15.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,427	187	130
Feb.	0	2,607	170	118
Mar.	0	4,914	142	130
Apr.	0	4,860	138	125
May.	0	5,076	142	130
Jun.	0	4,918	138	125
Jul.	0	5,214	142	130
Aug.	0	5,347	142	130
Sep.	0	5,458	181	125
Oct.	0	3,510	187	130
Nov.	0	3,575	181	125
Dec.	0	2,324	187	130
Total	0	50,231	1,936	1,527

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

Table E-16. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 16.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	3,635	101	83
Feb.	0	3,905	92	76
Mar.	0	7,366	79	83
Apr.	0	7,285	76	81
May.	0	7,608	79	83
Jun.	0	7,371	76	81
Jul.	0	7,816	79	83
Aug.	0	8,015	79	83
Sep.	0	8,181	98	81
Oct.	0	5,259	101	83
Nov.	0	5,357	98	81
Dec.	0	3,480	101	83
Total	0	75,278	1,055	984

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

Table E-17. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 17.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1,150	364	263
Feb.	0	1,231	331	240
Mar.	0	2,310	297	263
Apr.	0	2,286	287	255
May.	0	2,394	297	263
Jun.	0	2,320	287	255
Jul.	0	2,459	297	263
Aug.	0	2,522	297	263
Sep.	0	2,572	352	255
Oct.	0	1,655	364	263
Nov.	0	1,686	352	255
Dec.	0	1,101	364	263
Total	0	23,687	3,888	3,101

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

Table E-18. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 18.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	3	1,925	183	199
Feb.	17	2,055	167	181
Mar.	73	3,835	159	199
Apr.	59	3,805	154	192
May.	17	4,015	159	199
Jun.	3	3,890	154	192
Jul.	3	4,125	159	199
Aug.	3	4,231	159	199
Sep.	3	4,306	178	192
Oct.	24	2,759	183	199
Nov.	24	2,811	178	192
Dec.	3	1,843	183	199
Total	230	39598	2,018	2,343

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

Table E-19. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 19.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	15	3,493	191	210
Feb.	40	3,728	174	191
Mar.	143	6,958	154	210
Apr.	117	6,904	149	203
May.	41	7,286	154	210
Jun.	15	7,058	149	203
Jul.	15	7,485	154	210
Aug.	15	7,677	154	210
Sep.	15	7,813	185	203
Oct.	54	5,006	191	210
Nov.	54	5,100	185	203
Dec.	15	3,343	191	210
Total	540	71,850	2,029	2,469

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

Table E-20. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 20.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	5,205	256	150
Feb.	0	5,591	234	137
Mar.	0	10,545	191	150
Apr.	0	10,429	185	145
May.	0	10,892	191	150
Jun.	0	10,553	185	145
Jul.	0	11,189	191	150
Aug.	0	11,475	191	150
Sep.	0	11,712	248	145
Oct.	0	7,530	256	150
Nov.	0	7,670	248	145
Dec.	0	4,983	256	150
Total	0	107,772	256	150

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

Table E-21. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 21.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	2	3,706	115	140
Feb.	29	3,956	105	128
Mar.	138	7,384	86	140
Apr.	111	7,326	83	136
May.	29	7,732	86	140
Jun.	2	7,490	83	136
Jul.	2	7,943	86	140
Aug.	2	8,147	86	140
Sep.	2	8,291	112	136
Oct.	44	5,312	115	140
Nov.	43	5,412	112	136
Dec.	2	3,548	115	140
Total	408	76,246	1,182	1,653

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

Table E-22. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 22.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,996	171	185
Feb.	1	3,216	156	168
Mar.	5	6,063	132	185
Apr.	4	5,997	128	179
May.	1	6,267	132	185
Jun.	0	6,071	128	179
Jul.	0	6,437	132	185
Aug.	0	6,602	132	185
Sep.	0	6,737	165	179
Oct.	2	4,331	171	185
Nov.	2	4,412	165	179
Dec.	0	2,868	171	185
Total	15	61,997	1,783	2,176

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

Table E-23. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 23.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,996	171	185
Feb.	1	3,216	156	168
Mar.	5	6,063	132	185
Apr.	4	5,997	128	179
May.	1	6,267	132	185
Jun.	0	6,071	128	179
Jul.	0	6,437	132	185
Aug.	0	6,602	132	185
Sep.	0	6,737	165	179
Oct.	2	4,331	171	185
Nov.	2	4,412	165	179
Dec.	0	2,868	171	185
Total	15	61,997	1,783	2,176

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

Table E-24. Monthly nonpoint fecal coliform loadings in Lower Hardware River sub-watershed 24.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,140	173	178
Feb.	0	2,298	157	162
Mar.	0	4,334	130	178
Apr.	0	4,287	126	172
May.	0	4,477	130	178
Jun.	0	4,338	126	172
Jul.	0	4,599	130	178
Aug.	0	4,717	130	178
Sep.	0	4,814	167	172
Oct.	0	3,095	173	178
Nov.	0	3,153	167	172
Dec.	0	2,049	173	178
Total	0	44,301	1,782	2,093

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

Table E-25. Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 01.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1,555	439	146
Feb.	0	1,673	400	133
Mar.	0	3,164	312	146
Apr.	0	3,130	302	141
May.	0	3,269	312	146
Jun.	0	3,167	302	141
Jul.	0	3,359	312	146
Aug.	0	3,445	312	146
Sep.	0	3,517	425	141
Oct.	0	2,256	439	146
Nov.	0	2,299	425	141
Dec.	0	1,488	439	146
Total	0	1,555	4,421	1,715

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

Table E-26. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 02.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,767	226	296
Feb.	0	2,974	206	270
Mar.	0	5,620	159	296
Apr.	0	5,558	154	287
May.	0	5,805	159	296
Jun.	0	5,625	154	287
Jul.	0	5,964	159	296
Aug.	0	6,117	159	296
Sep.	0	6,244	219	287
Oct.	0	4,009	226	296
Nov.	0	4,084	219	287
Dec.	0	2,648	226	296
Total	0	57,417	2,266	3,492

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

Table E-27. Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 03.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,712	514	432
Feb.	0	2,912	468	394
Mar.	0	5,491	365	432
Apr.	0	5,431	353	418
May.	0	5,672	365	432
Jun.	0	5,496	353	418
Jul.	0	5,827	365	432
Aug.	0	5,976	365	432
Sep.	0	6,099	497	418
Oct.	0	3,922	514	432
Nov.	0	3,995	497	418
Dec.	0	2,596	514	432
Total	0	56,131	5,169	5,093

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

Table E-28. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 04.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,771	388	499
Feb.	0	2,977	353	454
Mar.	0	5,623	274	499
Apr.	0	5,562	265	483
May.	0	5,809	274	499
Jun.	0	5,628	265	483
Jul.	0	5,967	274	499
Aug.	0	6,120	274	499
Sep.	0	6,247	375	483
Oct.	0	4,013	388	499
Nov.	0	4,088	375	483
Dec.	0	2,652	388	499
Total	0	57,456	3,893	5,875

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

Table E-29. Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 05.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1,215	273	499
Feb.	0	1,304	249	455
Mar.	0	2,458	192	499
Apr.	0	2,431	185	483
May.	0	2,539	192	499
Jun.	0	2,460	185	483
Jul.	0	2,608	192	499
Aug.	0	2,675	192	499
Sep.	0	2,730	265	483
Oct.	0	1,756	273	499
Nov.	0	1,789	265	483
Dec.	0	1,163	273	499
Total	0	25,127	2,736	5,877

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

Table E-30. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 06.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	5,952	81	211
Feb.	0	6,398	74	192
Mar.	0	12,091	59	211
Apr.	0	11,960	57	204
May.	0	12,495	59	211
Jun.	0	12,105	57	204
Jul.	0	12,836	59	211
Aug.	0	13,165	59	211
Sep.	0	13,438	79	204
Oct.	0	8,625	81	211
Nov.	0	8,787	79	204
Dec.	0	5,696	81	211
Total	0	123,549	826	2,485

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

Table E-31. Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 07.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	17,787	280	258
Feb.	0	19,120	255	235
Mar.	0	36,140	192	258
Apr.	0	35,747	186	250
May.	0	37,339	192	258
Jun.	0	36,176	186	250
Jul.	0	38,360	192	258
Aug.	0	39,342	192	258
Sep.	0	40,160	271	250
Oct.	0	25,778	280	258
Nov.	0	26,263	271	250
Dec.	0	17,022	280	258
Total	0	369,234	2,777	3,040

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

Table E-32. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 08.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	12,401	213	186
Feb.	0	13,247	194	169
Mar.	0	24,777	152	186
Apr.	0	24,587	147	180
May.	0	25,949	152	186
Jun.	0	25,138	147	180
Jul.	0	26,661	152	186
Aug.	0	27,346	152	186
Sep.	0	27,832	206	180
Oct.	0	17,805	213	186
Nov.	0	18,143	206	180
Dec.	0	11,868	213	186
Total	0	255,753	2,145	2,186

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

Table E-33 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 09.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	3,401	42	72
Feb.	0	3,656	38	66
Mar.	0	6,912	27	72
Apr.	0	6,836	26	70
May.	0	7,140	27	72
Jun.	0	6,918	26	70
Jul.	0	7,335	27	72
Aug.	0	7,523	27	72
Sep.	0	7,680	40	70
Oct.	0	4,929	42	72
Nov.	0	5,022	40	70
Dec.	0	3,255	42	72
Total	0	70,607	401	848

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

Table E-34. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 10.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	1,912	87	183
Feb.	0	2,056	79	167
Mar.	0	3,887	65	183
Apr.	0	3,845	63	178
May.	0	4,015	65	183
Jun.	0	3,890	63	178
Jul.	0	4,125	65	183
Aug.	0	4,231	65	183
Sep.	0	4,319	84	178
Oct.	0	2,772	87	183
Nov.	0	2,824	84	178
Dec.	0	1,830	87	183
Total	0	39,707	894	2,162

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

Table E-35 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 11.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	497	121	350
Feb.	0	534	110	319
Mar.	0	1,004	83	350
Apr.	0	994	81	338
May.	0	1,042	83	350
Jun.	0	1,009	81	338
Jul.	0	1,070	83	350
Aug.	0	1,098	83	350
Sep.	0	1,119	117	338
Oct.	0	718	121	350
Nov.	0	732	117	338
Dec.	0	476	121	350
Total	0	10,294	1,201	4,120

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

Table E-36. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 12.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	7,882	401	84
Feb.	0	8,470	365	76
Mar.	0	16,000	282	84
Apr.	0	15,825	273	81
May.	0	16,529	282	84
Jun.	0	16,014	273	81
Jul.	0	16,980	282	84
Aug.	0	17,414	282	84
Sep.	0	17,776	388	81
Oct.	0	11,416	401	84
Nov.	0	11,630	388	81
Dec.	0	7,543	401	84
Total	0	163,480	4,015	985

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

Table E-37 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 13.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,360	461	130
Feb.	0	2,533	420	118
Mar.	0	4,774	322	130
Apr.	0	4,721	311	125
May.	0	4,931	322	130
Jun.	0	4,777	311	125
Jul.	0	5,065	322	130
Aug.	0	5,194	322	130
Sep.	0	5,301	446	125
Oct.	0	3,411	461	130
Nov.	0	3,474	446	125
Dec.	0	2,259	461	130
Total	0	48,799	4,607	1,527

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

Table E-38. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 14.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,409	69	263
Feb.	0	2,590	62	240
Mar.	0	4,896	48	263
Apr.	0	4,843	47	255
May.	0	5,058	48	263
Jun.	0	4,900	47	255
Jul.	0	5,196	48	263
Aug.	0	5,329	48	263
Sep.	0	5,440	66	255
Oct.	0	3,492	69	263
Nov.	0	3,558	66	255
Dec.	0	2,306	69	263
Total	0	50,018	686	3,102

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

Table E-39 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 15.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	6	212	91	199
Feb.	7	227	83	181
Mar.	14	424	67	199
Apr.	12	421	65	192
May.	8	444	67	199
Jun.	6	430	65	192
Jul.	6	456	67	199
Aug.	6	468	67	199
Sep.	6	477	88	192
Oct.	9	305	91	199
Nov.	8	310	88	192
Dec.	6	203	91	199
Total	96	4,377	927	2,341

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

Table E-40. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 16.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	7,017	119	210
Feb.	52	7,495	109	191
Mar.	258	14,018	84	210
Apr.	207	13,910	81	203
May.	52	14,681	84	210
Jun.	0	14,222	81	203
Jul.	0	15,084	84	210
Aug.	0	15,471	84	210
Sep.	0	15,746	116	203
Oct.	79	10,074	119	210
Nov.	79	10,265	116	203
Dec.	0	6,715	119	210
Total	728	144,699	1,197	2,473

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

Table E-41 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 17.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	218	173	150
Feb.	0	234	157	137
Mar.	0	440	126	150
Apr.	0	437	122	145
May.	0	459	126	150
Jun.	0	456	122	145
Jul.	0	483	126	150
Aug.	0	496	126	150
Sep.	0	493	167	145
Oct.	0	316	173	150
Nov.	0	321	167	145
Dec.	0	209	173	150
Total	0	4,561	1,760	1,769

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

Table E-42. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 18.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	4,323	152	192
Feb.	0	4,647	139	175
Mar.	0	8,785	107	192
Apr.	0	8,689	104	186
May.	0	9,075	107	192
Jun.	0	8,792	104	186
Jul.	0	9,323	107	192
Aug.	0	9,562	107	192
Sep.	0	9,761	147	186
Oct.	0	6,266	152	192
Nov.	0	6,384	147	186
Dec.	0	4,137	152	192
Total	0	89,745	1,526	2,262

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

Table E-43 Monthly nonpoint fecal coliform loadings in North Fork Hardware River sub-watershed 19.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,484	164	185
Feb.	0	2,669	149	168
Mar.	0	5,043	114	185
Apr.	0	4,988	110	179
May.	0	5,210	114	185
Jun.	0	5,048	110	179
Jul.	0	5,352	114	185
Aug.	0	5,489	114	185
Sep.	0	5,604	159	179
Oct.	0	3,598	164	185
Nov.	0	3,666	159	179
Dec.	0	2,377	164	185
Total	0	51,529	1,633	2,176

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

Table E-44. Monthly nonpoint fecal coliform loadings in North Fork Lower Hardware River sub-watershed 20.

Month	Fecal Coliform loadings ($x10^{10}$ cfu/month)			
	Cropland	Pasture	Forest	Residential[1]
Jan.	0	2,621	50	163
Feb.	0	2,818	46	148
Mar.	0	5,327	35	163
Apr.	0	5,269	34	158
May.	0	5,503	35	163
Jun.	0	5,332	34	158
Jul.	0	5,654	35	163
Aug.	0	5,799	35	163
Sep.	0	5,919	49	158
Oct.	0	3,799	50	163
Nov.	0	3,871	49	158
Dec.	0	2,508	50	163
Total	0	54,421	505	1,918

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

Appendix F: Required Reductions in Fecal Coliform Loads by Sub-watershed – Allocation Scenario

Table F-1a. Required annual reductions in nonpoint sources in sub-watershed NF-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	203,863	1%	2,038	99%
Pasture	5,049,818	36%	2,525	99%
Forest	5,916,724	42%	5,916,724	0%
Residential	2,865,167	20%	2,865	99%
Total	14,035,571	100%	5,924,152	60%

Table F-1b. Required annual reductions in direct nonpoint sources in sub-watershed NF -1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	79,174	11%	0	100%
Wildlife in Streams	657,182	89%	657,182	0%
Straight Pipes	0	0%	0	100%
Total	736,356	100%	657,182	10%

Table F-2a. Required annual reductions in nonpoint sources in sub-watershed NF-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,658	0.4%	16	99%
Pasture	12,053	3%	0.6	99%
Forest	332,924	74%	332,924	0%
Residential	104,681	23%	104	99%
Total	451,315	100%	333,045	30%

Table F-2b. Required annual reductions in direct nonpoint sources in sub-watershed NF-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	33,956	100%	33,956	0%
Straight Pipes	0	0%	0	100%
Total	33,956	100%	33,956	0%

Table F-3a. Required annual reductions in nonpoint sources in sub-watershed NF-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	95,527	0.1%	955	99%
Pasture	114,940,787	100%	1,149,041	99%
Forest	134,792	0.1%	134,792	0%
Residential	80,209	0.1%	802	99%
Total	115,251,314	100%	1,285,957	99%

Table F-3b. Required annual reductions in direct nonpoint sources in sub-watershed NF-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	7,129	100%	7,129	0%
Straight Pipes	0	0%	0	100%
Total	7,129	100%	7,129	0%

Table F-4a. Required annual reductions in nonpoint sources in sub-watershed NF-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	65,130	1%	651	99%
Pasture	3,615,616	63%	36,156	99%
Forest	1,426,992	25%	1,426,992	0%
Residential	669,540	12%	6,695	99%
Total	5,777,278	100%	1,470,494	75%

Table F-4b. Required annual reductions in direct nonpoint sources in sub-watershed NF-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	22,268	13%	0	100%
Wildlife in Streams	146,952	87%	146,952	0%
Straight Pipes	0	0%	0	100%
Total	169,219	100%	146,952	87%

Table F-5a. Required annual reductions in nonpoint sources in sub-watershed NF-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,221	0.4%	42	99%
Pasture	960,108	84%	9,601	99%
Forest	131,978	12%	131,978	0%
Residential	46,350	4%	464	99%
Total	1,142,657	100%	142,085	88%

Table F-5b. Required annual reductions in direct nonpoint sources in sub-watershed NF-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	6,215	100%	6,215	0%
Straight Pipes	0	0%	0	100%
Total	6,215	100%	6,215	0%

Table F-6a. Required annual reductions in nonpoint sources in sub-watershed NF-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	22,090	1%	221	99%
Pasture	135,107	8%	1,351	999%
Forest	959,656	58%	959,656	0%
Residential	542,762	33%	5,428	99%
Total	1,659,614	100%	966,656	42%

Table F-6b. Required annual reductions in direct nonpoint sources in sub-watershed NF-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	53,754	100%	53,754	0%
Straight Pipes	0	0%	0	100%
Total	53,754	100%	37,628	0%

Table F-7a. Required annual reductions in nonpoint sources in sub-watershed NF-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	264,547	1%	2,645	99%
Pasture	20,557,566	84%	205,576	99%
Forest	2,359,387	10%	2,359,387	0%
Residential	1,237,978	5%	12,380	99%
Total	24,419,478	100%	2,579,988	89%

Table F-7b. Required annual reductions in direct nonpoint sources in sub-watershed NF-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	277,110	69%	0	100%
Wildlife in Streams	126,603	31%	126,603	0%
Straight Pipes	0	0%	0	100%
Total	403,713	100%	126,603	69%

Table F-8a. Required annual reductions in nonpoint sources in sub-watershed NF-8.†

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	6,799	3%	68	0%
Pasture	17,163	9%	172	95%
Forest	127,552	64%	127,552	0%
Residential	47,921	24%	479	95%
Total	199,435	100%	128,271	36%

†Sub-watershed is part of Snow Creek

Table F-8b. Required annual reductions in direct nonpoint sources in sub-watershed NF-8.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	0%
Wildlife in Streams	7,013	100%	7,013	0%
Straight Pipes	0	0%	0	100%
Total	7,013	100%	7,013	0%

Table F-9a. Required annual reductions in nonpoint sources in sub-watershed NF-9.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	273,517	0.4%	2,735	99%
Pasture	59,400,976	88%	594,010	99%
Forest	5,089,765	8%	5,089,765	0%
Residential	2,889,675	4%	28,897	99%
Total	67,653,933	100%	5,715,407	92%

Table F-9b. Required annual reductions in direct nonpoint sources in sub-watershed NF-9.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	696,733	56%	0	100%
Wildlife in Streams	555,413	44%	555,413	0%
Straight Pipes	0	0%	0	100%
Total	1,252,146	100%	555,413	56%

Table F-10a. Required annual reductions in nonpoint sources in sub-watershed NF-10.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	114,085	0.2%	1,141	99%
Pasture	41,513,313	91%	415,133	99%
Forest	2,508,800	5%	2,508,800	0%
Residential	1,711,342	4%	17,113	99%
Total	45,847,540	100%	4,784,118	94%

Table F-10b. Required annual reductions in direct nonpoint sources in sub-watershed NF-10.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	880,813	86%	0	100%
Wildlife in Streams	130,915	13%	130,915	0%
Straight Pipes	17,970	2%	0	100%
Total	1,029,699	100%	130,915	87%

Table F-11a. Required annual reductions in nonpoint sources in sub-watershed NF-11.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,612,981	5%	1,613	99%
Pasture	22,935,855	70%	229,359	99%
Forest	5,348,033	16%	5,348,033	0%
Residential	2,834,596	9%	28,346	99%
Total	32,731,464	100%	5,621,868	83%

Table F-11b. Required annual reductions in direct nonpoint sources in sub-watershed NF-11.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	227,626	44%	0	100%
Wildlife in Streams	274,797	53%	274,797	0%
Straight Pipes	18,116	3%	0	100%
Total	520,539	100%	274,797	47%

Table F-12a. Required annual reductions in nonpoint sources in sub-watershed NF-12.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	579,244	0.8%	5,792	99%
Pasture	62,438,984	85%	624,390	99%
Forest	6,401,970	9%	6,401,970	0%
Residential	3,946,344	5%	39,463	99%
Total	73,366,541	100%	7,071,615	90%

Table F-12b. Required annual reductions in direct nonpoint sources in sub-watershed NF-12.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	950,090	73%		0%
Wildlife in Streams	341,780	26%	341,780	0%
Straight Pipes	17,751	1%	0	100%
Total	1,309,621	100%	341,780	74%

Table F-13a. Required annual reductions in nonpoint sources in sub-watershed NF-13.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	4,698	0.5%	47	99%
Pasture	40,713	4%	407	99%
Forest	390,084	41%	390,084	0%
Residential	520,664	54%	5,207	99%
Total	956,158	100%	448,884	59%

Table F-13b. Required annual reductions in direct nonpoint sources in sub-watershed NF-13.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	42,260	100%	42,260	0%
Straight Pipes	0	0%	0	100%
Total	42,260	100%	42,260	0%

Table F-14a. Required annual reductions in nonpoint sources in sub-watershed NF-14.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	27,459	0.3%	275	99%
Pasture	5,750,700	61%	57,507	99%
Forest	2,231,939	24%	2,231,939	0%
Residential	1,460,270	15%	14,603	99%
Total	9,470,367	100%	2,304,324	76%

Table F-14b. Required annual reductions in direct nonpoint sources in sub-watershed NF-14.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	23,752	17%	0	100%
Wildlife in Streams	116,722	83%	116,722	0%
Straight Pipes	0	0%	0	100%
Total	140,474	100%	116,722	17%

Table F-15a. Required annual reductions in nonpoint sources in sub-watershed NF-15.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	873,195	1%	8,732	99%
Pasture	52,690,820	84%	526,908	99%
Forest	2,846,287	5%	2,846,287	0%
Residential	5,982,211	10%	59,822	99%
Total	62,392,512	100%	3,441,794	94%

Table F-15b. Required annual reductions in direct nonpoint sources in sub-watershed NF-15.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	657,380	64%	0	100%
Wildlife in Streams	333,871	33%	333,871	0%
Straight Pipes	35,648	3%	0	100%
Total	1,026,900	100%	333,871	67%

Table F-16a. Required annual reductions in nonpoint sources in sub-watershed NF-16.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	58,701	0.3%	587	99%
Pasture	15,185,499	74%	151,855	99%
Forest	1,619,211	8%	1,619,211	0%
Residential	3,596,872	18%	35,969	99%
Total	20,460,283	100%	1,807,622	91%

Table F-16b. Required annual reductions in direct nonpoint sources in sub-watershed NF-16.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	237,523	73%	0	100%
Wildlife in Streams	86,395	27%	86,395	0%
Straight Pipes	0	0%	0	100%
Total	323,918	100%	86,395	73%

Table F-17a. Required annual reductions in nonpoint sources in sub-watershed NF-17.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	37,948	0.3%	379	99%
Pasture	5,878,860	53%	58,789	99%
Forest	2,412,569	22%	2,412,569	0%
Residential	2,801,066	25%	28,011	99%
Total	11,130,442	100%	2,499,748	78%

Table F-17b. Required annual reductions in direct nonpoint sources in sub-watershed NF-17.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	123,841	100%	123,841	0%
Straight Pipes	0	0%	0	100%
Total	123,841	100%	86,689	0%

Table F-18a. Required annual reductions in nonpoint sources in sub-watershed NF-18.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	61,371	0.3%	614	99%
Pasture	11,627,429	56%	116,274	99%
Forest	4,915,530	24%	4,915,530	0%
Residential	4,061,836	20%	40,618	99%
Total	20,666,166	100%	5,073,036	75%

Table F-18b. Required annual reductions in direct nonpoint sources in sub-watershed NF-18.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	47,505	14%	0	100%
Wildlife in Streams	261,649	76%	261,649	0%
Straight Pipes	35,941	10%	0	100%
Total	345,094	100%	261,649	24%

Table F-19a. Required annual reductions in nonpoint sources in sub-watershed NF-19.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	14,762	0%	148	99%
Pasture	24,333,672	74%	243,337	99%
Forest	1,715,547	5%	1,715,547	0%
Residential	6,823,126	21%	68,231	99%
Total	32,887,107	100%	2,027,263	94%

Table F-19b. Required annual reductions in direct nonpoint sources in sub-watershed NF-19.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	318,433	70%	0	100%
Wildlife in Streams	83,538	18%	83,538	0%
Straight Pipes	53,034	12%	0	100%
Total	455,005	100%	83,538	82%

Table F-20a. Required annual reductions in nonpoint sources in sub-watershed NF-20.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	173,599	0.5%	1736	99%
Pasture	30,043,858	85%	300,439	99%
Forest	1,164,386	3%	1,164,386	0%
Residential	3,858,136	11%	38,581	99%
Total	35,239,979	100%	1,505,142	96%

Table F-20b. Required annual reductions in direct nonpoint sources in sub-watershed NF-20.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	442,940	84%	0	100%
Wildlife in Streams	63,807	12%	63,807	0%
Straight Pipes	18,628	4%	0	100%
Total	525,375	100%	63,807	88%

Table F-21a. Required annual reductions in nonpoint sources in sub-watershed LH-1.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	87,288	0.3%	0	100%
Pasture	26,391,412	80%	0	100%
Forest	2,239,682	7%	2,239,682	25%
Residential	4,252,387	13%	0	100%
Total	32,970,769	100%	2,239,682	93%

Table F-21b. Required annual reductions in direct nonpoint sources in sub-watershed LH-1.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	358,219	74%	0	100%
Wildlife in Streams	110,350	23%	82,762	25%
Straight Pipes	18,409	4%	0	100%
Total	486,978	100%	82,762	83%

Table F-22a. Required annual reductions in nonpoint sources in sub-watershed LH-2.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	437,208	1.0%	0	100%
Pasture	36,814,334	83%	0	100%
Forest	4,214,642	10%	4,214,642	0%
Residential	2,819,730	6%	0	100%
Total	44,285,914	100%	4,214,642	90%

Table F-22b. Required annual reductions in direct nonpoint sources in sub-watershed LH-2.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	212,274	49%	0	100%
Wildlife in Streams	199,938	46%	149,953	25%
Straight Pipes	18,701	4%	0	100%
Total	430,913	100%	149,953	65%

Table F-23a. Required annual reductions in nonpoint sources in sub-watershed LH-3.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,477	0%	0	100%
Pasture	1,871,983	50%	0	100%
Forest	227,951	6%	227,951	0%
Residential	1,622,915	44%	0	100%
Total	3,724,327	100%	227,951	94%

Table F-23b. Required annual reductions in direct nonpoint sources in sub-watershed LH-3.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	39,587	59%	0	100%
Wildlife in Streams	9,381	14%	7,036	25%
Straight Pipes	18,043	27%	0	100%
Total	67,012	100%	7,036	90%

Table F-24a. Required annual reductions in nonpoint sources in sub-watershed LH-4.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13	0%	0	100%
Pasture	982	3%	0	100%
Forest	15,843	41%	15,843	0%
Residential	21,623	56%	0	100%
Total	38,461	100%	15,843	59%

Table F-24b. Required annual reductions in direct nonpoint sources in sub-watershed LH-4.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	840	100%	277	25%
Straight Pipes	0	0%	0	100%
Total	840	100%	277	67%

Table F-25a. Required annual reductions in nonpoint sources in sub-watershed LH-5.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	856	0.4%	0	100%
Pasture	4,449	2%	0	100%
Forest	97,784	45%	97,784	0%
Residential	116,076	53%	0	100%
Total	219,166	100%	97,784	55%

Table F-25b. Required annual reductions in direct nonpoint sources in sub-watershed LH-5.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	5,490	100%	4,118	25%
Straight Pipes	0	0%	0	100%
Total	5,490	100%	4,118	25%

Table F-26a. Required annual reductions in nonpoint sources in sub-watershed LH-6.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	113	0.4%	0	100%
Pasture	8,330	27%	0	100%
Forest	20,408	67%	20,408	0%
Residential	1,644	5%	0	100%
Total	30,495	100%	20,408	33%

Table F-26b. Required annual reductions in direct nonpoint sources in sub-watershed LH-6.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	1,122	100%	841	25%
Straight Pipes	0	0%	0	100%
Total	1,122	100%	841	25%

Table F-27a. Required annual reductions in nonpoint sources in sub-watershed LH-7.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	22,938	0.6%	0	100%
Pasture	3,357,541	81%	0	100%
Forest	447,294	11%	447,294	0%
Residential	318,388	8%	0	100%
Total	4,146,162	100%	447,294	89%

Table F-27b. Required annual reductions in direct nonpoint sources in sub-watershed LH-7.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	26,986	54%	0	100%
Wildlife in Streams	22,703	46%	17,027	25%
Straight Pipes	0	0%	0	100%
Total	49,689	100%	17,027	25%

Table F-28a. Required annual reductions in nonpoint sources in sub-watershed LH-8.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	34,441	0.5%	0	100%
Pasture	6,040,980	89%	0	100%
Forest	359,090	5%	359,090	0%
Residential	326,862	5%	0	100%
Total	6,761,373	100%	359,090	95%

Table F-28b. Required annual reductions in direct nonpoint sources in sub-watershed LH-8.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	6,698	29%	0	100%
Wildlife in Streams	16,778	71%	12,583	25%
Straight Pipes	0	0%	0	100%
Total	23,477	100%	12,583	46%

Table F-29a. Required annual reductions in nonpoint sources in sub-watershed LH-9.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,885	0.5%	0	100%
Pasture	665,958	62%	0	100%
Forest	321,393	30%	321,393	0%
Residential	86,236	8%	0	100%
Total	1,079,471	100%	321,393	70%

Table F-29b. Required annual reductions in direct nonpoint sources in sub-watershed LH-9.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	7,228	33%	0	100%
Wildlife in Streams	14,798	67%	11,098	25%
Straight Pipes	0	0%	0	100%
Total	22,027	100%	11,098	50%

Table F-30a. Required annual reductions in nonpoint sources in sub-watershed LH-10.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,838	0.4%	0	100%
Pasture	727,382	67%	08	100%
Forest	294,908	27%	294,908	0%
Residential	53,107	5%	0	100%
Total	1,079,234	100%	294,908	73%

Table F-30b. Required annual reductions in direct nonpoint sources in sub-watershed LH-10.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	16,384	52%	0	100%
Wildlife in Streams	14,961	48%	11,221	25%
Straight Pipes	0	0%	0	100%
Total	31,345	100%	11,221	64%

Table F-31a. Required annual reductions in nonpoint sources in sub-watershed LH-11.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	87,288	0.3%	0	100%
Pasture	26,391,412	80%	0	100%
Forest	2,239,682	7%	2,239,682	0%
Residential	4,252,387	13%	0	100%
Total	32,970,769	100%	2,239,682	93%

Table F-31b. Required annual reductions in direct nonpoint sources in sub-watershed LH-11.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	358,219	74%	0	100%
Wildlife in Streams	110,350	23%	82,762	25%
Straight Pipes	18,409	4%	0	100%
Total	486,978	100%	82,762	83%

Table F-32a. Required annual reductions in nonpoint sources in sub-watershed LH-12.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	437,208	1.0%	0	100%
Pasture	36,814,334	83%	0	100%
Forest	4,214,642	10%	4,214,642	0%
Residential	2,819,730	6%	0	100%
Total	44,285,914	100%	4,214,642	90%

Table F-32b. Required annual reductions in direct nonpoint sources in sub-watershed LH-12.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	212,274	49%	0	100%
Wildlife in Streams	199,938	46%	149,954	25%
Straight Pipes	18,701	4%	0	100%
Total	430,913	100%	149,954	65%

Table F-33a. Required annual reductions in nonpoint sources in sub-watershed LH-13.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,477	0%	0	100%
Pasture	1,871,983	50%	0	100%
Forest	227,951	6%	227,951	0%
Residential	1,622,915	44%	0	100%
Total	3,724,327	100%	227,951	94%

Table F-33b. Required annual reductions in direct nonpoint sources in sub-watershed LH-13.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	39,587	59%	0	100%
Wildlife in Streams	9,381	14%	7,036	25%
Straight Pipes	18,043	27%	0	100%
Total	67,012	100%	7,036	90%

Table F-34a. Required annual reductions in nonpoint sources in sub-watershed LH-14.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13	0%	0	100%
Pasture	982	3%	0	100%
Forest	15,843	41%	15,843	0%
Residential	21,623	56%	0	100%
Total	38,461	100%	15,843	59%

Table F-34b. Required annual reductions in direct nonpoint sources in sub-watershed LH-14.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	840	100%	630	25%
Straight Pipes	0	0%	0	100%
Total	840	100%	277	25%

Table F-35a. Required annual reductions in nonpoint sources in sub-watershed LH-15.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	856	0.4%	0	100%
Pasture	4,449	2%	0	100%
Forest	97,784	45%	97,784	0%
Residential	116,076	53%	0	100%
Total	219,166	100%	97,784	55%

Table F-35b. Required annual reductions in direct nonpoint sources in sub-watershed LH-15.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	5,490	100%	4,118	25%
Straight Pipes	0	0%	0	100%
Total	5,490	100%	1,812	25%

Table F-36a. Required annual reductions in nonpoint sources in sub-watershed LH-16.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	113	0.4%	0	100%
Pasture	8,330	27%	0	100%
Forest	20,408	67%	20,408	0%
Residential	1,644	5%	0	100%
Total	30,495	100%	20,408	33%

Table F-36b. Required annual reductions in direct nonpoint sources in sub-watershed LH-16.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	1,122	100%	841	25%
Straight Pipes	0	0%	0	100%
Total	1,122	100%	841	25%

Table F-37a. Required annual reductions in nonpoint sources in sub-watershed LH-17.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	22,938	0.6%	0	100%
Pasture	3,357,541	81%	0	100%
Forest	447,294	11%	447,294	0%
Residential	318,388	8%	0	100%
Total	4,146,162	100%	447,294	89%

Table F-37b. Required annual reductions in direct nonpoint sources in sub-watershed LH-17.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	26,986	54%	0	100%
Wildlife in Streams	22,703	46%	17,027	25%
Straight Pipes	0	0%	0	100%
Total	49,689	100%	17,027	66%

Table F-38a. Required annual reductions in nonpoint sources in sub-watershed LH-18.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	34,441	0.5%	0	100%
Pasture	6,040,980	89%	0	100%
Forest	359,090	5%	359,090	0%
Residential	326,862	5%	0	100%
Total	6,761,373	100%	359,090	95%

Table F-38b. Required annual reductions in direct nonpoint sources in sub-watershed LH-18.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	6,698	29%	0	100%
Wildlife in Streams	16,778	71%	12,583	25%
Straight Pipes	0	0%	0	100%
Total	23,477	100%	12,583	46%

Table F-39a. Required annual reductions in nonpoint sources in sub-watershed LH-19.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	5,885	0.5%	0	100%
Pasture	665,958	62%	0	100%
Forest	321,393	30%	321,393	0%
Residential	86,236	8%	0	100%
Total	1,079,471	100%	321,393	70%

Table F-39b. Required annual reductions in direct nonpoint sources in sub-watershed LH-19.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	7,228	33%	0	100%
Wildlife in Streams	14,798	67%	11,098	25%
Straight Pipes	0	0%	0	100%
Total	22,027	100%	11,098	50%

Table F-40a. Required annual reductions in nonpoint sources in sub-watershed LH-20.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	3,838	0.4%	0	100%
Pasture	727,382	67%	0	100%
Forest	294,908	27%	294,908	0%
Residential	53,107	5%	0	100%
Total	1,079,234	100%	294,908	73%

Table F-40b. Required annual reductions in direct nonpoint sources in sub-watershed LH-20.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	16,384	52%	0	100%
Wildlife in Streams	14,961	48%	11,221	25%
Straight Pipes	0	0%	0	100%
Total	31,345	100%	11,221	64%

Table F-41a. Required annual reductions in nonpoint sources in sub-watershed LH-21.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	87,288	0.3%	0	100%
Pasture	26,391,412	80%	0	100%
Forest	2,239,682	7%	2,239,682	0%
Residential	4,252,387	13%	0	100%
Total	32,970,769	100%	2,239,682	93%

Table F-41b. Required annual reductions in direct nonpoint sources in sub-watershed LH-21.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	358,219	74%	0	100%
Wildlife in Streams	110,350	23%	82,762	25%
Straight Pipes	18,409	4%	0	100%
Total	486,978	100%	82,762	83%

Table F-42a. Required annual reductions in nonpoint sources in sub-watershed LH-22.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	437,208	1.0%	0	100%
Pasture	36,814,334	83%	0	100%
Forest	4,214,642	10%	4,214,642	0%
Residential	2,819,730	6%	0	100%
Total	44,285,914	100%	4,214,642	90%

Table F-42b. Required annual reductions in direct nonpoint sources in sub-watershed LH-22.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	212,274	49%	0	100%
Wildlife in Streams	199,938	46%	149,953	25%
Straight Pipes	18,701	4%	0	100%
Total	430,913	100%	149,953	65%

Table F-43a. Required annual reductions in nonpoint sources in sub-watershed LH-23.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	1,477	0%	0	100%
Pasture	1,871,983	50%	0	100%
Forest	227,951	6%	227,951	0%
Residential	1,622,915	44%	0	100%
Total	3,724,327	100%	227,951	94%

Table F-43b. Required annual reductions in direct nonpoint sources in sub-watershed LH-23.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	39,587	59%	0	100%
Wildlife in Streams	9,381	14%	7,036	25%
Straight Pipes	18,043	27%	0	100%
Total	67,012	100%	7,036	90%

Table F-44a. Required annual reductions in nonpoint sources in sub-watershed LH-24.

Land Use	Current conditions load (x 10^8 cfu/year)	Percent of total load from nonpoint sources	TMDL nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cropland	13	0%	0	100%
Pasture	982	3%	0	100%
Forest	15,843	41%	15,843	0%
Residential	21,623	56%	0	100%
Total	38,461	100%	15,843	59%

Table F-44b. Required annual reductions in direct nonpoint sources in sub-watershed LH-24.

Source	Current Conditions load (x 10^8 cfu/year)	Percent of total load to stream from direct nonpoint sources	TMDL direct nonpoint source allocation load (x 10^8 cfu/year)	Percent Reduction
Cattle in Streams	0	0%	0	100%
Wildlife in Streams	840	100%	630	25%
Straight Pipes	18,043	27%	0	100%
Total	840	100%	630	25%

Appendix G: Simulated Stream Flow Charts for TMDL Allocation Period

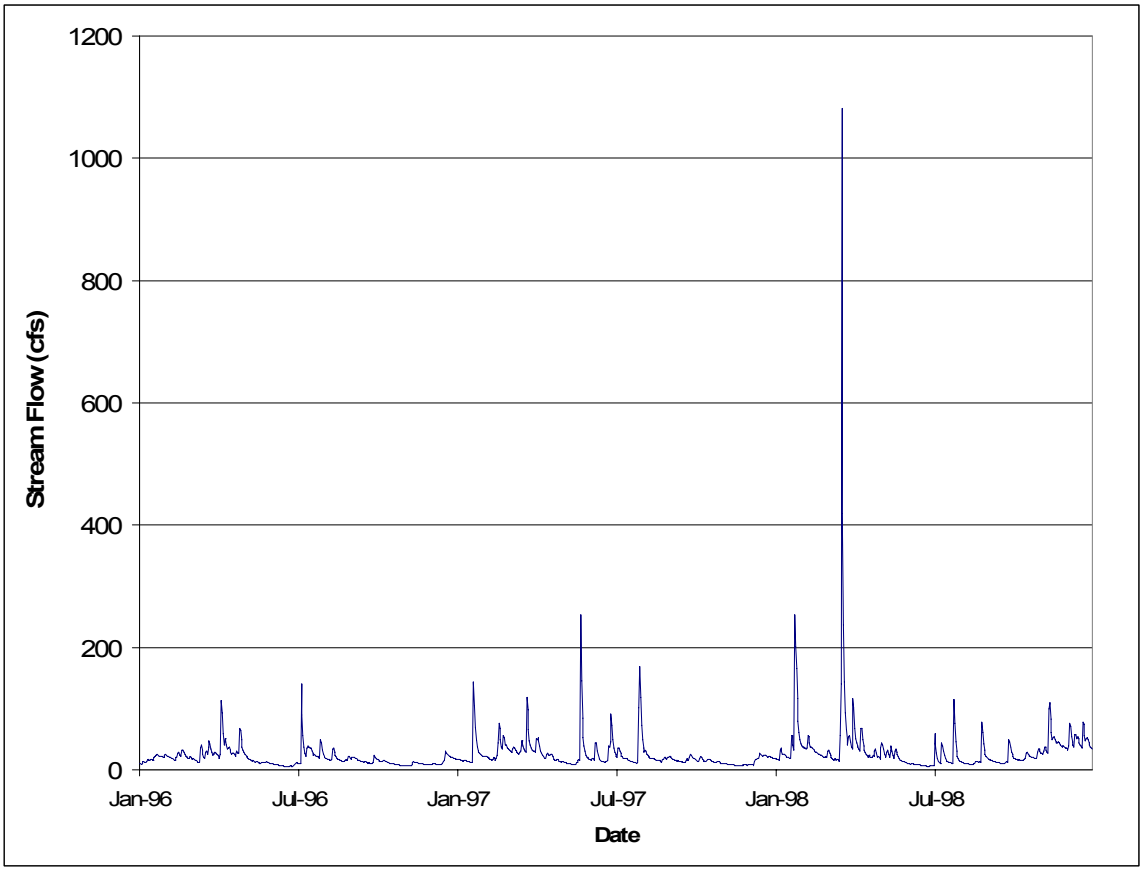

Figure G.1. Simulated stream flow for North Fork Hardware River.

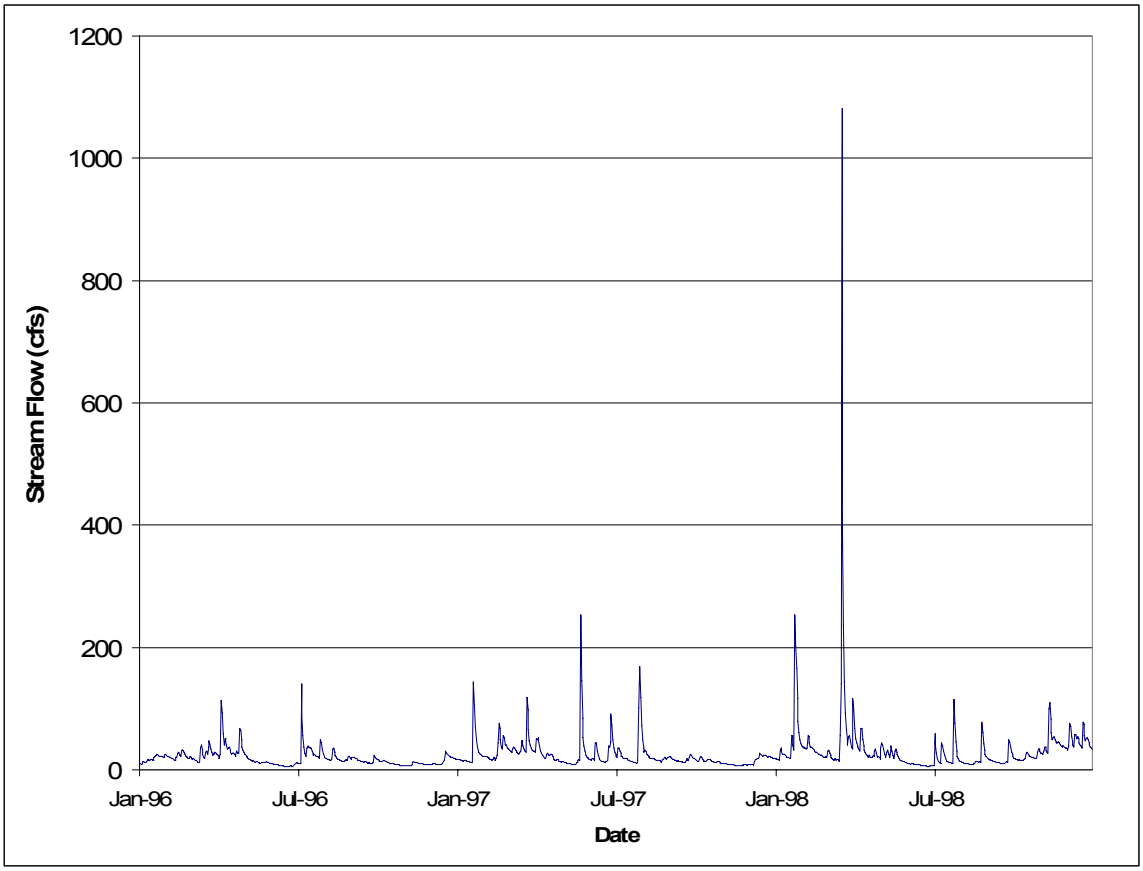

Figure G.2. Simulated stream flow for Lower Hardware River.

Appendix H: Observed Fecal Coliform Concentrations and Antecedent Rainfall

This appendix presents the observed fecal coliform concentrations and antecedent rainfall for the six stations that caused the impairment listings (Table H.1).

Table H.1. Observed fecal coliform concentrations and antecedent rainfall for the listing stations for North Fork and Lower Hardware Rivers.

Station	Date	Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 days (inches)
North Fork Hardware River			
2-NHF008.28	12/13/1995	400	0.0
2-NHF008.28	09/26/1996	100	0.0
2-NHF008.28	07/29/1997	100	0.0
2-NHF008.28	04/28/1999	200	0.1
2-NHF008.28	07/28/1999	3700	0.0
2-NHF008.28	09/28/1999	1000	0.0
2-NHF008.28	11/16/1999	100	0.5
2-NHF008.28	01/12/2000	100	0.9
2-NHF008.28	03/13/2000	100	0.2
2-NHF008.28	06/22/2000	200	0.6
2-NHF008.28	07/12/2000	500	0.0
2-NHF008.28	09/07/2000	200	0.7
2-NHF008.28	11/02/2000	100	0.0
2-NHF008.28	01/25/2001	100	0.0
2-NHF008.28	03/01/2001	100	0.2
2-NHF008.28	06/06/2001	4600	1.0
2-NHF008.28	07/11/2005	270	2.1
2-NHF008.28	08/22/2005	1790	0.6
2-NHF008.28	09/12/2005	1365	0.0
2-NHF008.28	10/18/2005	357	0.0
2-NHF008.28	11/14/2005	80	0.0
2-NHF008.28	12/12/2005	68	1.0
Lower Hardware River			
2-HRD011.57	01/24/1995	700	0.5
2-HRD011.57	02/27/1995	100	0.1
2-HRD011.57	03/27/1995	100	0.2
2-HRD011.57	04/17/1995	200	0.2
2-HRD011.57	05/24/1995	400	0.0
2-HRD011.57	06/22/1995	8000	2.9
2-HRD011.57	07/19/1995	100	0.4
2-HRD011.57	08/21/1995	100	0.0
2-HRD011.57	10/11/1995	100	0.0
2-HRD011.57	12/19/1995	500	1.2
2-HRD011.57	03/14/1996	100	0.5
2-HRD011.57	04/10/1996	100	0.1
2-HRD011.57	05/16/1996	1400	0.2
2-HRD011.57	06/20/1996	4600	0.2

Station	Date	Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 days (inches)
2-HRD011.57	07/23/1996	100	0.0
2-HRD011.57	08/19/1996	100	0.1
2-HRD011.57	09/16/1996	400	1.0
2-HRD011.57	10/17/1996	100	0.2
2-HRD011.57	11/19/1996	100	0.5
2-HRD011.57	12/12/1996	100	0.0
2-HRD011.57	01/27/1997	100	0.5
2-HRD011.57	02/19/1997	100	0.0
2-HRD011.57	03/24/1997	100	0.4
2-HRD011.57	04/17/1997	100	0.3
2-HRD011.57	05/22/1997	100	0.8
2-HRD011.57	06/17/1997	200	0.2
2-HRD011.57	07/30/1997	100	0.0
2-HRD011.57	08/06/1997	500	0.1
2-HRD011.57	09/24/1997	100	0.0
2-HRD011.57	10/22/1997	100	0.1
2-HRD011.57	11/19/1997	100	0.0
2-HRD011.57	12/15/1997	200	0.5
2-HRD011.57	01/26/1998	200	0.0
2-HRD011.57	02/17/1998	1100	0.4
2-HRD011.57	03/25/1998	200	0.0
2-HRD011.57	04/23/1998	100	0.1
2-HRD011.57	05/21/1998	100	1.7
2-HRD011.57	06/30/1998	100	1.7
2-HRD011.57	07/16/1998	200	0.3
2-HRD011.57	08/25/1998	100	0.5
2-HRD011.57	09/17/1998	100	0.0
2-HRD011.57	10/22/1998	300	0.2
2-HRD011.57	11/19/1998	100	0.1
2-HRD011.57	12/14/1998	1300	0.0
2-HRD011.57	01/25/1999	1700	1.0
2-HRD011.57	02/23/1999	100	0.0
2-HRD011.57	03/28/1999	100	0.0
2-HRD011.57	04/12/1999	300	0.9
2-HRD011.57	05/25/1999	100	1.8
2-HRD011.57	06/24/1999	300	0.9
2-HRD011.57	07/28/1999	100	0.0
2-HRD011.57	08/17/1999	200	0.7
2-HRD011.57	09/21/1999	100	0.5
2-HRD011.57	10/26/1999	100	0.1
2-HRD011.57	11/29/1999	400	0.3
2-HRD011.57	12/15/1999	2600	0.1
2-HRD011.57	01/27/2000	100	0.3
2-HRD011.57	02/23/2000	100	0.1
2-HRD011.57	03/29/2000	100	1.4
2-HRD011.57	04/18/2000	1600	0.0

Station	Date	Fecal Coliform Concentration (cfu/100mL)	Total Rainfall for Sampling Day and Preceding 5 days (inches)
2-HRD011.57	05/30/2000	200	1.4
2-HRD011.57	06/19/2000	100	0.4
2-HRD011.57	09/26/2000	2100	0.4
2-HRD011.57	10/16/2000	100	0.4
2-HRD011.57	11/29/2000	100	3.0
2-HRD011.57	12/11/2000	100	0.8
2-HRD011.57	01/22/2001	100	1.6
2-HRD011.57	02/26/2001	100	1.8
2-HRD011.57	03/21/2001	5000	0.0
2-HRD011.57	04/09/2001	100	0.9
2-HRD011.57	05/21/2001	100	0.0
2-HRD011.57	06/26/2001	800	2.1
2-HRD011.57	07/16/2001	100	0.5
2-HRD011.57	09/12/2001	200	2.8
2-HRD011.57	12/04/2001	100	0.0
2-HRD011.57	02/20/2002	100	2.0
2-HRD011.57	04/08/2002	100	2.6
2-HRD011.57	06/13/2002	100	0.0
2-HRD011.57	10/24/2002	50	0.0
2-HRD011.57	12/04/2002	25	0.0
2-HRD011.57	02/11/2003	25	0.0
2-HRD011.57	04/10/2003	720	0.0
2-HRD011.57	06/05/2003	500	0.0
2-HRD011.57	08/04/2003	2000	0.2
2-HRD011.57	09/16/2003	150	0.3
2-HRD011.57	12/01/2003	150	0.3
2-HRD011.57	02/04/2004	620	3.1
2-HRD011.57	04/20/2004	580	1.2
2-HRD011.57	06/08/2004	400	0.3
2-HRD011.57	08/11/2004	150	1.1
2-HRD011.57	10/26/2004	100	0.6
2-HRD011.57	12/21/2004	25	0.5
2-HRD011.57	02/10/2005	50	0.0
2-HRD011.57	04/26/2005	75	1.1
2-HRD011.57	06/09/2005	220	0.1
2-HRD011.57	07/28/2005	75	0.2
2-HRD011.57	08/25/2005	75	0.0
2-HRD011.57	09/06/2005	75	0.0
2-HRD011.57	10/19/2005	180	0.2
2-HRD011.57	11/21/2005	50	0.0
2-HRD011.57	12/28/2005	120	0.0

Appendix I: Scenarios for Fivefold Increase in Permitted Discharge Flows

To allow for future growth, a scenario was created for North Fork and Lower Hardware Rivers in which the point source flows were increased by a factor of 5, while retaining the 126 cfu/100 mL limit on *E. coli* bacteria. Since the WLA were small relative to the LA (and zero for Lower Hardware), 5% of the LA was used instead of multiplying the WLA by a factor of 5. Figures I.1-I.2 display the results for the impaired watersheds. The TMDL equations that would represent this situation are included in Table I.1.

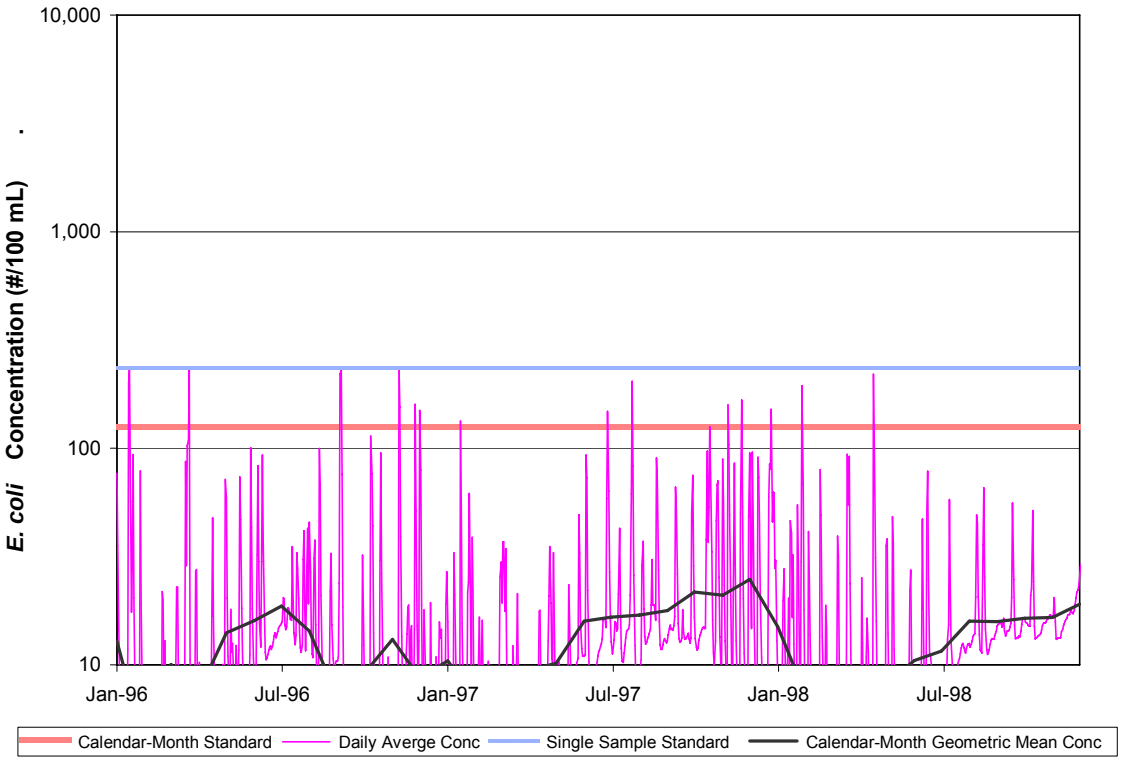

Figure I.1. Fivefold Increase Scenario for North Fork Hardware River.

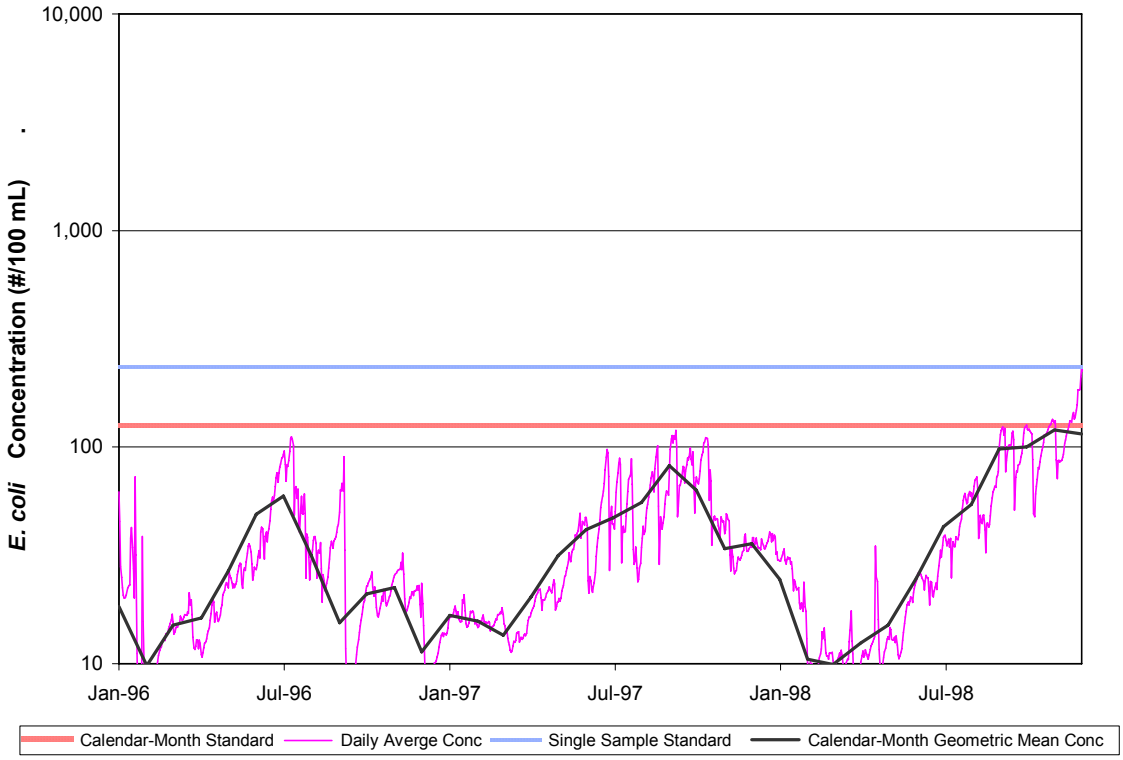

Figure I.2. Fivefold Increase Scenario for Lower Hardware River

Table I.1. Average annual *E.coli* loadings (cfu/yr) at the watershed outlet for the North Fork and Lower Hardware River watersheds under the fivefold WLA increase scenario.

Watershed	WLA	LA	MOS*	TMDL
Lower Hardware River	0.18×10^{14}	3.64×10^{14}	--	3.82×10^{14}
North Fork Hardware River	0.17×10^{14}	3.48×10^{14}	--	3.65×10^{14}

*Implicit MOS

As can be seen from Figures I.1-I.2, the new scenario results in no violations of the single sample or geometric mean standard. Therefore, it is assumed that future growth in point source dischargers with a consistent permitted bacteria concentration of 126 cfu/100 mL *E. coli* will not cause additional violations of the water quality standards.