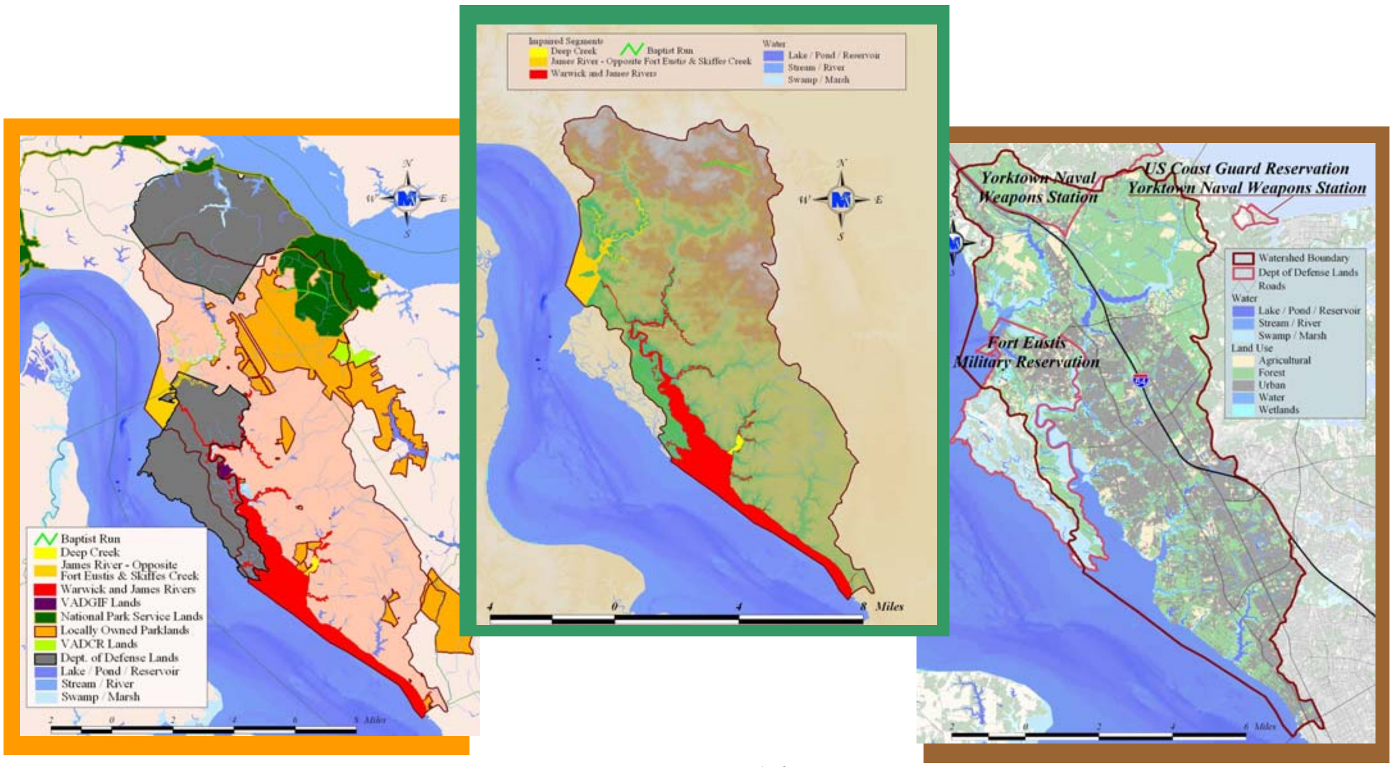
# Fecal Bacteria Total Maximum Daily Load Development for Warwick River

## Primary Contact Recreational Use and Shellfish Harvesting Use




Prepared for:

Virginia Department of Environmental Quality

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New River-Highlands RC & D
100 USDA Drive, Suite F
Wytheville, VA 24382
Phone: 276.228.2879

MapTech, Inc.
3154 State Street
Blacksburg, VA 24060
Phone: 540.961.7864

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# ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ, Tidewater Regional Office

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City of Newport News

James City County

York County

Fort Eustis

New River – Highlands RC & D

Local citizens and stakeholders in the Warwick River watershed

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# EXECUTIVE SUMMARY

## *Background and Applicable Standards*

The Warwick River watershed, which is contained in USGS Hydrologic Unit Code 02080206, contains parts of the City of Newport News, York county, and James City County. Fort Eustis Military Reserve and a portion of the Naval Weapons Station are located within the Warwick River watershed. The Warwick River drains to the lower James River basin.

The Warwick and James Rivers impairment (waterbody ID# VAT-G11E) was first listed as impaired in the Virginia Department of Environmental Quality's (VADEQ) *1998 303(d) Total Maximum Daily Load Priority List and Report*. This segment, Condemned Shellfish Area Number 34A and B, does not support the Virginia Department of Health (VDH) fecal coliform standards for shellfish harvesting as of October 1, 1993. This segment is referred to as the Warwick River impairment throughout this document.

Also first listed on the *1998 303(d) Total Maximum Daily Load Priority List and Report* was the James River – opposite Fort Eustis & Skiffes Creek segment (waterbody ID# VAT-G11E). This segment is Condemned Shellfish Area Number #059-023 and is also impaired for not supporting the VDH shellfish harvesting use as of December 5, 2005. This segment is referred to as the Skiffes Creek impairment throughout this document.

Deep Creek (waterbody ID# VAT-G11E), a tributary to the Warwick River, was listed for not supporting the VADEQ primary contact recreational (swimming) use for estuarine (tidal) streams. Deep Creek is also a section in the Warwick River shellfishing impairment.

Baptist Run (waterbody ID# VAT-G11R) is a headwater tributary initially listed in the *2004 305(b)/303(d) Water Quality Assessment Integrated Report* for not supporting the VADEQ primary contact recreational use for riverine (non-tidal) streams.

### *TMDL Endpoint and Water Quality Assessment*

Potential sources of fecal coliform include both point source and nonpoint source contributions. Nonpoint sources include: wildlife, grazing livestock, urban/suburban runoff, failed and malfunctioning septic systems, and uncontrolled discharges (*i.e*. straight pipes). One point source is permitted to discharge water and fecal bacteria into the Warwick River watershed through the Virginia Pollutant Discharge Elimination System (VPDES). Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. One method for achieving this goal is chlorination.

In the Baptist Run TMDL development, the in-stream *E. coli* targets were a geometric mean not exceeding a value of 126-cfu/100 ml and a single sample maximum of 235-cfu/100 ml. Translator equations developed by VADEQ were used to convert fecal coliform values to *E. coli* values.

In the Deep Creek TMDL development, the in-stream *enterococci* targets were a geometric mean not exceeding a value of 35-cfu/100 ml and a single sample maximum of 104-cfu/100 ml. Translator equations developed by VADEQ were used to convert fecal coliform values to *enterococci* values.

The VDH standards for meeting the shellfish harvesting use are: a 30-month geometric mean of 14 MPN (most probable number) and a 30-month 90$^{th}$ percentile of 49 MPN. These were the endpoints for the Warwick River and Skiffes Creek impairments.

### *Water Quality Modeling*

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions in riverine and estuarine areas. The HSPF model is a continuous simulation model that can account for nonpoint source pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed for consideration of seasonal aspects of precipitation patterns within the watershed. In establishing the existing and allocation conditions, seasonal variations in hydrology, climate, and watershed activities were explicitly accounted for in the model. Due to the requirements of HSPF the Warwick River watershed was divided into 16 subwatersheds for the purpose of modeling hydrology and water quality. The rationale for choosing these subwatersheds was based on the availability of water quality data, the impairment lengths and locations, and the limitations of the HSPF model. The flow period used for hydrologic calibration depended on the data available. Data from Skiffes Creek Reservoir Dam was used from October 1, 1999 through September 30, 2003 for the hydrology calibration. The water quality calibration period was conducted using monitored data collected at VADEQ and VDH monitoring stations between July 1995 and June 2003.

### *Existing Conditions*

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

Contributions from all of these sources were updated to 2006 conditions to establish existing conditions for the watershed. All runs were made using a representative precipitation record. Under existing conditions (2006), the HSPF model provided a comparable match to the VADEQ and VDH monitoring data, with output from the model indicating violations of the water quality standards throughout the watershed.

### *Load Allocation Scenarios*

The next step in the TMDL process was to determine how to proceed from existing watershed conditions in order to reduce the various source loads to levels that would result in attainment of the water quality standards. Because the United States Environmental Protection Agency (USEPA) requires a zero percent violation load allocation in TMDLs, modeling was conducted for a target value of 0% exceedance of the applicable VADEQ and the VDH standards. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Modeling of these scenarios provided predictions of whether the reductions would achieve the goal of 0% exceedance.

Baptist Run requires an 89% reduction from land-based wildlife loads, a 91% reduction from land-based agricultural loads, a 99% reduction from land-based residential loads, and a 100% reduction from direct human sources (straight pipes and sewer overflows). Deep Creek (swimming use) requires a 29% reduction from land-based agriculture, a 64% reduction from land-based residential, and a 100% reduction from direct human sources. Skiffes Creek requires a 91% reduction from direct wildlife loads, an 85% reduction from land-based wildlife loads, 96% reductions from land-based agriculture, 99% reductions from land-based residential, a 96% reduction from direct livestock, and a 100% reduction from direct human sources. The Warwick River requires a 37% reduction from direct wildlife loads; a 36% reduction from land-based wildlife loads; 91% reductions from land-based agriculture, a 99% reduction from land-based residential, an 86% reduction from direct livestock, and a 100% reduction from direct human sources. Since the final TMDL reductions to meet the VDH shellfishing use are more strict than the reductions for Deep Creek to meet the tidal swimming use, Deep Creek should follow the Warwick River reductions during implementation. The final in-stream TMDL values are shown in Tables ES.1 through 4.

**Table ES.1 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Baptist Run impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Baptist Run** | **3.89E+09** | **6.42E+10** | *Implicit* | **6.81E+10** |
| *York County MS4 VAR040028* | 3.21E+09 | | | |
| *Future Load* | 6.81E+08 | | | |

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

**Table ES.2 Final average annual in-stream *Enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Deep Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Deep Creek** | **5.59E+12** | **2.67E+13** | *Implicit* | **3.23E+13** |
| *Newport News MS4 VA0088641* | 5.27E+12 | | | |
| *Future Load* | *3.23E+11* | | | |

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

**Table ES.3 Final average annual in-stream fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Warwick And James Rivers impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Warwick River** | **1.16E+14** | **1.53E+14** | | **2.69E+14** |
| *VA0081272* | *2.31E+13* | | | |
| *Newport News MS4 VA0088641* | *3.19E+11* | | *Implicit* | |
| *York County MS4 VAR040028* | *6.39E+09* | | | |
| *Fort Eustis MS4 VAR040035* | *2.52E+10* | | | |
| *Future Load* | *9.24E+13* | | | |

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

**Table ES.4 Final average annual in-stream fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the James River – Opposite Fort Eustis & Skiffes Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **James River – Opposite Fort Eustis & Skiffes Creek** | **2.46E+12** | **2.36E+14** | | **2.38E+14** |
| Newport News MS4 VA0088641 | 4.24E+10 | | | |
| Fort Eustis MS4 VAR040035 | 1.05E+10 | | *Implicit* | |
| York County MS4 VAR040028 | 7.11E+09 | | | |
| James City Co MS4 VAR040037 | 3.33E+10 | | | |
| Future Load | 2.38E+12 | | | |

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

### *Implementation*

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. This report represents the culmination of that effort for the bacteria impairments on the Warwick River watershed. The second step is to develop a TMDL Implementation Plan (IP). The final step is to implement the TMDL IP, and to monitor stream water quality to determine if water quality standards are being attained.

While section 303(d) of the Clean Water Act (CWA) and current United States Environmental Protection Agency regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the load and waste load allocations can and will be implemented. Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval to implement the pollutant allocations and reductions contained in the TMDL. Also, VADEQ will request SWCB authorization to incorporate the TMDL Implementation Plan into the appropriate waterbody. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

In general, Virginia intends that the required reductions be implemented in an iterative process that first addresses those sources with the largest impact on water quality. To address the bacteria TMDL, reducing the human bacteria loading from straight pipes and failing septic systems should be a primary implementation focus because of the human health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system installation/repair program. Livestock exclusion from streams has been shown to be very effective in lowering bacteria concentrations in streams, both by reducing the direct cattle deposits and by providing additional riparian buffers. Reduced trampling and soil shear on streambanks by livestock has been shown to reduce bank erosion.

There is a measure of uncertainty associated with the final allocation development process. Monitoring performed upon completion of specific implementation milestones can provide insight into the effectiveness of implementation strategies, the need for amending the plan, and/or progress toward the eventual removal of the impairment from the 303(d) list.

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. The state must also demonstrate that attaining the designated use is not feasible. Information is collected through a special study called a Use Attainability Analysis (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 EPA will be able to provide comment during this process.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL Implementation Plan. While specific goals for Best Management Practices (BMPs) implementation will be established as part of the implementation plan development, the Stage I scenarios are targeted at controllable, anthropogenic bacteria.

### *Public Participation*

During development of this report, public involvement was encouraged through two public meetings and a technical advisory committee (TAC) meeting. An introduction of the agencies involved, an overview of the TMDL process, and the specific approach to developing the Warwick River TMDL were presented at the first of the public meetings. Details of the pollutant sources were also presented at this meeting. Public understanding of, and involvement in, the TMDL process was encouraged. Input from this meeting was utilized in the development of the TMDL and improved confidence in the allocation scenarios. The final model simulations and the TMDL load allocations were presented during the final public meeting. There was a 30-day public comment period beginning when the TMDL was available to the public on the VADEQ website and two letters with written comments were received, answered and incorporated into this final document. Watershed stakeholders will have the opportunity to participate in the development of the TMDL IP.

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# 1. INTRODUCTION

## *1.1 Background*

The Clean Water Act (CWA) that became law in 1972 requires that all U.S. streams, rivers, and lakes meet certain water quality standards. The CWA also requires that states conduct monitoring to identify polluted waters or those that do not meet standards. Through this required program, the state of Virginia has found that many stream segments do not meet state water quality standards for protection of the five beneficial uses: recreation, aquatic life, wildlife, fishing/shellfishing, and drinking.

When streams fail to meet standards, Section 303(d) of the CWA and the U.S. Environmental Protection Agency's (EPA) Water Quality Management and Planning Regulation (40 CFR Part 130) both require that states develop a Total Maximum Daily Load (TMDL) for each pollutant. A TMDL is a "pollution budget" for a stream. That is, it sets limits on the amount of pollution that a stream can tolerate and still maintain water quality standards. In order to develop a TMDL, background concentrations, point source loadings, and non-point source loadings are considered. A TMDL accounts for seasonal variations and must include a margin of safety (MOS). Through the TMDL process, states establish water-quality based controls to reduce pollution and meet water quality standards.

Once a TMDL is developed and approved by EPA, measures must be taken to reduce pollution levels in the stream. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states in section 62.1-44.19:7 that the "Board shall develop and implement a plan to achieve fully supporting status for impaired waters". The TMDL Implementation Plan (IP) describes control measures, which can include the use of better treatment technology and the installation of best management practices (BMPs), to be implemented in a staged process.

The Warwick River watershed, which is contained in USGS Hydrologic Unit Code 02080206, drains to the lower James River basin. It is mainly located in Newport News, Virginia with portions in York County. The Skiffes Creek watershed is adjacent to the

Warwick River watershed to the northwest with portions in York County and James City County and Newport News, Virginia. Skiffes Creek drains to the James River. In this report, these watersheds together will be referred to as the Warwick River watershed and are shown together in Figure 1.1.

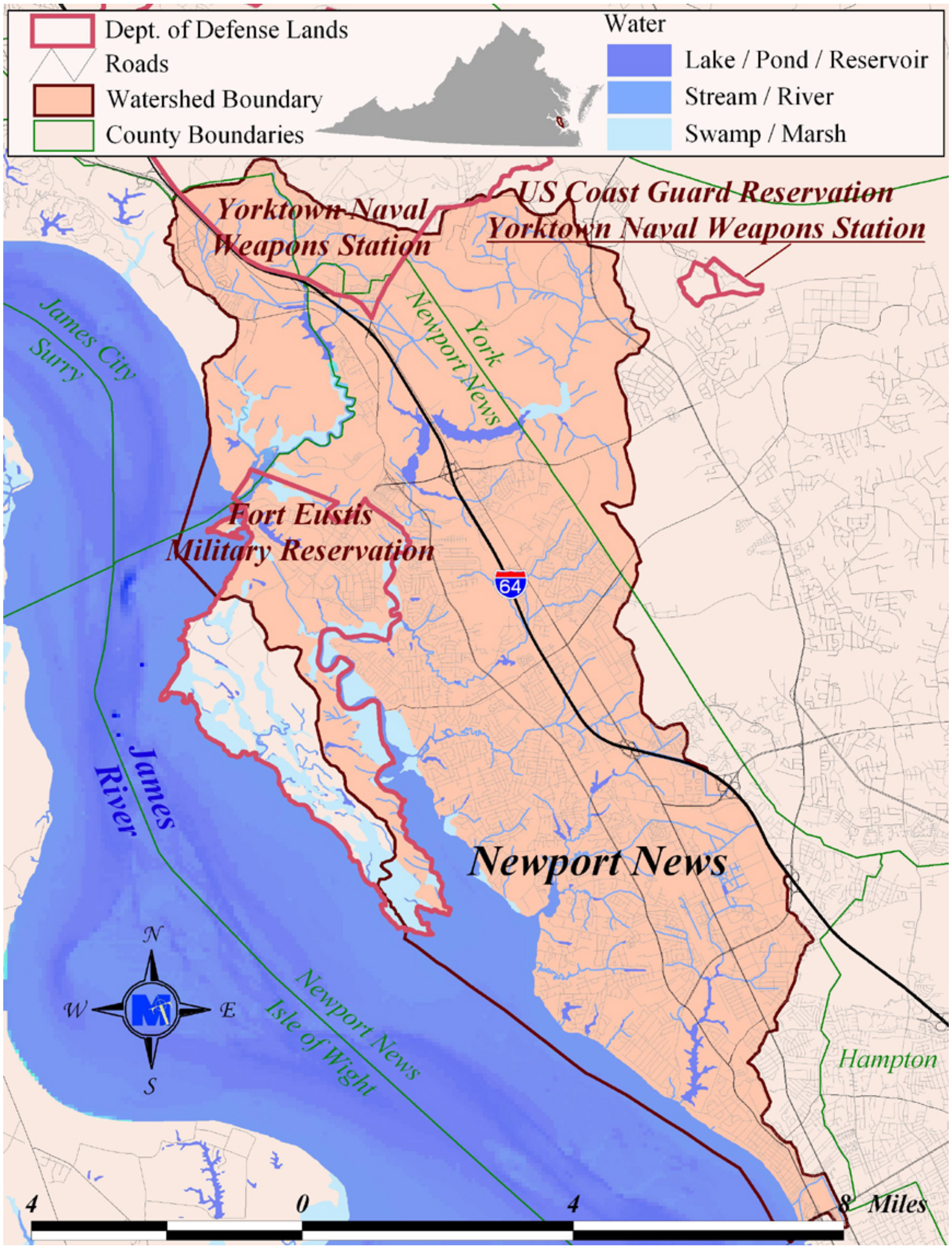


**Figure 1.1 Location of the Warwick River watershed.**

There are only minor agricultural operations in the watershed consisting mostly of cattle and horses on family farms. The Warwick River watershed has experienced urban growth in the Newport News area in the last 10 years. Many sewer overflows have been reported that have spilled raw sewage into Skiffes Creek, Deep Creek, and the Warwick River, as well as the residential land near these streams.

Portions of two military installations are in the watershed: 59.3% of Fort Eustis Military Reservation (4,661.3 acres) and 22.0% of Yorktown Naval Weapons Station (2,292.9 acres). Much of the non-urban land in the watershed is parks and recreational land. The City of Hampton owns the Sandy Bottom Nature Park, of which 58.2 acres or 12.8% is in the Warwick River watershed. The Virginia Department of Game and Inland Fisheries (VDGIF) manages the Balthrope Marsh Wildlife Management Area, which is completely in the watershed (78.3 acres). The Colonial National Historic Park is a federal park with 26.6% or 2,532.3 acres within the Warwick River watershed. The managed lands in the Warwick River watershed are illustrated in Figure 1.2. Portions of the following parks owned by the City of Newport News are in the Warwick River watershed:

- Charles Brown County Park (68.8% or 6.88 acres),
- Deer Park (100% or 47.0 acres),
- Endview Plantation (100% or 30.0 acres),
- Grafton Ponds State Natural Area Preserve (51.3% or 192.4 acres),
- Hilton Pier/Ravine (100% or 3.0 acres),
- Huntington Park (100% or 56.0 acres),
- Lake Maury Natural Park (96.2% or 127.0 acres),
- Lee Hall Plantation City Park (100% or 13.0 acres),
- Lees Mill (100% or 8 acres),
- Municipal Lane Park (100% or 3.0 acres),
- Newport News City Parks (62.6% or 5052.8 acres),
- Nicewood Park (100% or 9.8 acres),
- Potters Field (100% or 3.0 acres),
- Queens Hithe (100% or 30.0 acres),
- Riverview Farm Park (100% or 267.0 acres),
- Skiffes Creek Park and Skiffes Creek Redoubt (100% or 24.0 acres),
- Stony Run Park (100% or 228.0 acres),
- Tear Drop Park (100% or 0.82 acres),
- Youngs Mill (100% or 0.40 acres), and an
- unnamed park (100% or 13.0 acres).

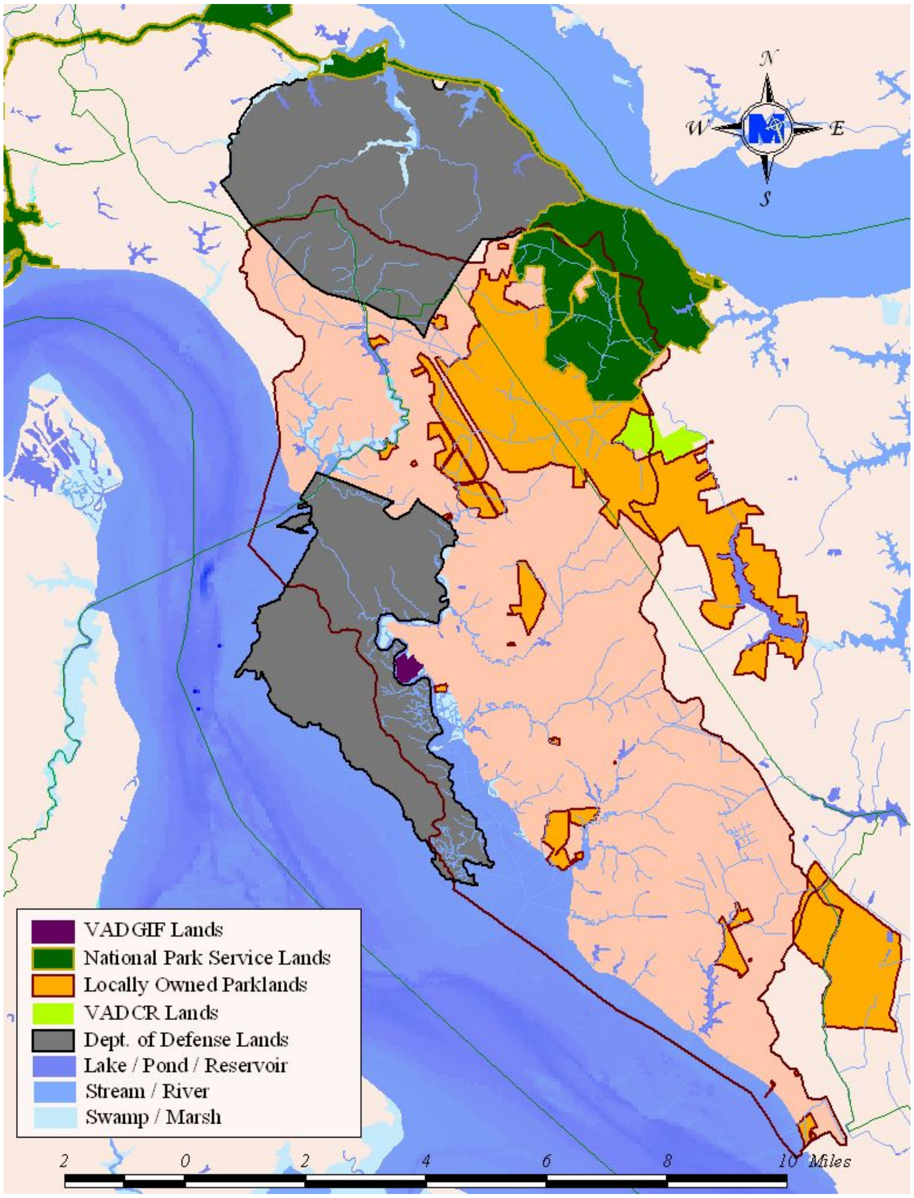


**Figure 1.2 Location of the managed lands in the Warwick River watershed.**

The Warwick and James Rivers impairment (waterbody ID# VAT-G11E) was first listed as impaired in the Virginia Department of Environmental Quality's (VADEQ) *1998 303(d) Total Maximum Daily Load Priority List and Report*. This segment, Condemned Shellfish Area Number 34A and B, is impaired due to violations of the Virginia Department of Health (VDH) fecal coliform standards and is not supporting the shellfish harvesting use. Condemnation area #34A and B became effective on October 1, 1993. This area of water extends from Jail Point on Mulberry Island downstream to the James

River Bridge (red area in Figure 1.3). This segment is referred to as the Warwick River impairment throughout this document. The area in Figure 1.3 shows both #34A and B areas together. The #34B section is a polygon from the points "Prison" to "Land's End" to "Jail Point" to a point with Warwick River (navigational aid R"4") back to "Prison".

Also listed on the *1998 303(d) Total Maximum Daily Load Priority List and Report* was the James River – opposite Fort Eustis & Skiffes Creek segment (waterbody ID# VAT-G11E). This segment is condemnation area #059-023 and is also impaired for not supporting the VDH shellfish harvesting use. Condemnation area #059-023 as described here became effective on December 5, 2005. This area of water extends from the tidal limits of Skiffes Creek and its tributaries to the end of Goose Island and into the James River (mustard area in Figure 1.3). This segment is referred to as the Skiffes Creek impairment throughout this document.

These segments were again listed in the 2002 and 2004 lists as not supporting the shellfish harvesting use. This was based on monitoring results from the VDH.

Two new segments were included in the *2002 303(d) Report on Impaired Waters,* Warwick River (Upper) and Deep Creek. Warwick River (Upper) (waterbody ID# VAT-G11E) was listed for not supporting the VADEQ primary contact recreational use for estuarine (tidal) streams. This segment began at the end of tidal waters (river mile 10.88) and extended downstream to the confluence with Lukas Creek (river mile 3.48). The Warwick River (Upper) segment was de-listed in the 2006 report and does not require a TMDL.

Deep Creek (waterbody ID# VAT-G11E), a tributary to the Warwick River, was also listed for not supporting the VADEQ primary contact recreational use for estuarine (tidal) streams. This segment begins at the Warwick Yacht Club (river mile 0.76) and extends to the outlet of Deep Creek where it drains to the Warwick River (bright yellow area in Figure 1.3). These VADEQ impairments were again included in the *2004 305(b)/303(d) Water Quality Assessment Integrated Report.*

Baptist Run (waterbody ID# VAT-G11R) is a headwater tributary initially listed in the *2004 305(b)/303(d) Water Quality Assessment Integrated Report* for not supporting the VADEQ primary contact recreational use for riverine (non-tidal) streams.  This segment begins at the outlet of a pond near Crawford Drive and ends at the confluence with Great Run and Beaverdam Creek  (green line in Figure 1.3).

A total of four total maximum daily load values will be calculated and reported in this document.  The four impaired stream segments are shown in Figure1.3.


**Figure 1.3 Impaired stream segments (2006) in the Warwick River watershed.**

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# 2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

## *2.1 Applicable Water Quality Standards*

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

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

> *A. All state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish.*
>
> ♦
>
> *D. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Virginia adopted its current *E. coli* and *enterococci* standard in January 2003. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals; there is a strong correlation between these and the incidence of gastrointestinal illness. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

The criteria which were used in developing the bacteria TMDL in this study are outlined in 9 VAC 25-260-170 and read as follows:

> *A. In surface waters, except shellfish waters and certain waters identified in subsection B of this section, the following criteria shall apply to protect primary contact recreational uses:*
>
> *1. Fecal coliform bacteria shall not exceed a geometric mean of 200 fecal coliform bacteria per 100 ml of water for two or more samples over a calendar month nor shall more than 10% of the total samples taken during any calendar*

*month exceed 400 fecal coliform bacteria per 100 ml of water. This criterion shall not apply for a sampling station after the bacterial indicators described in subdivision 2 of this subsection have a minimum of 12 data points or after June 30, 2008, whichever comes first.*

*2. E. coli and enterococci bacteria per 100 ml of water shall not exceed the following:*

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

[1] For two or more samples taken during any calendar month.
[2] No single sample maximum for *enterococci* and *E. coli* shall exceed a 75% upper one-sided confidence limit based on a site-specific log standard deviation. If site data are insufficient to establish a site-specific log standard deviation, then 0.4 shall be used as the log standard deviation in freshwater and 0.7 shall be as the log standard deviation in saltwater and transition zone. Values shown are based on a log standard deviation of 0.4 in freshwater and 0.7 in saltwater.
[3] See 9 VAC 25-260-140 C for freshwater and transition zone delineation.

For shellfish, the criteria used for developing TMDLs are outlined in 9 VAC 25-260-160 and read as follows:

*In all open ocean or estuarine waters capable of propagating shellfish or in specific areas where public or leased private shellfish beds are present, and including those waters on which condemnation or restriction classifications are established by the State Department of Health, the following criteria for fecal coliform bacteria shall apply:*

*The geometric mean fecal coliform value for a sampling station shall not exceed an MPN (most probable number) of 14 per 100 milliliters. The 90th percentile shall not exceed an MPN of 43 for a 5-tube, 3-dilution test or 49 for a 3-tube, 3-dilution test.*

These standards are calculated using a 30-month window, which means every consecutive 30-month data group must have a geometric mean of 14 MPN or less and a 90th percentile of 49 MPN or less to meet both standards.

### 2.2 Selection of a TMDL Endpoint

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the Warwick River watershed TMDLs, the applicable endpoints and associated target values can be determined directly from Virginia water quality regulations (Section 2.1). In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's water quality standard.

The TMDL for the estuarine Deep Creek VADEQ primary contact recreational use impairment was made using both the *enterococci* VADEQ geometric mean standard and the $90^{th}$ percentile standard. Therefore, the in-stream *enterococci* targets for this TMDL was a monthly geometric mean not exceeding 35 cfu/100 ml and a $90^{th}$ percentile not exceeding 104 cfu/100 ml. The TMDL for the riverine VADEQ primary contact recreational use, Baptist Run, was made using both the *E. coli* VADEQ geometric mean standard and the instantaneous standard. Therefore, the in-stream *E. coli* targets for this TMDL was a 30-day geometric mean not exceeding 126 cfu/100 ml and an instantaneous value not exceeding 235 cfu/100 ml.

The VDH shellfish harvesting use impairments was assessed using both the VDH fecal coliform geometric mean standard and the $90^{th}$ percentile standard. Therefore, the in-stream fecal coliform targets for the VDH TMDLs were a monthly geometric mean not exceeding 14 MPN and a $90^{th}$ percentile not exceeding 49 MPN.

## *2.3 Discussion of In-stream Water Quality*

This section provides an inventory and analysis of available observed in-stream fecal coliform monitoring data throughout the Warwick River watershed. An examination of data from water quality stations used in the 303(d) assessment was performed and data collected by VDH were analyzed. Sources of data and pertinent results are discussed below.

### 2.3.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- bacteria enumerations from nine VADEQ in-stream monitoring stations used for TMDL assessment;
- bacteria enumerations from 39 VDH in-stream monitoring stations used for shellfish condemnation area determination; and
- bacteria enumerations and bacterial source tracking from three VDH in-stream monitoring stations.

#### 2.3.1.1 VADEQ Water Quality Monitoring for TMDL Assessment

Data from in-stream fecal coliform samples collected at nine VADEQ monitoring stations (Figure 2.1) were analyzed from January 1980 through November 2005 and are included in this analysis. Samples were taken for the express purpose of determining compliance with the current VADEQ fecal coliform instantaneous standard limiting concentrations to 400 cfu/100 mL or less. Therefore, as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 ml or in excess of a specified cap (*e.g.*, 8,000 or 16,000 cfu/100 ml, depending on the laboratory procedures employed for the sample) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 100 cfu/100 ml most likely represent concentrations below 100 cfu/100 ml, and reported concentrations of 8,000 or 16,000 cfu/100 ml most likely represent concentrations in excess of these values. Table 2.1 summarizes the fecal coliform samples collected at the in-stream monitoring stations, Table 2.2 summarizes the *E. coli* samples collected, and Table 2.3 summarizes the *enterococci* samples collected. Graphs of this data are shown in Appendix C.

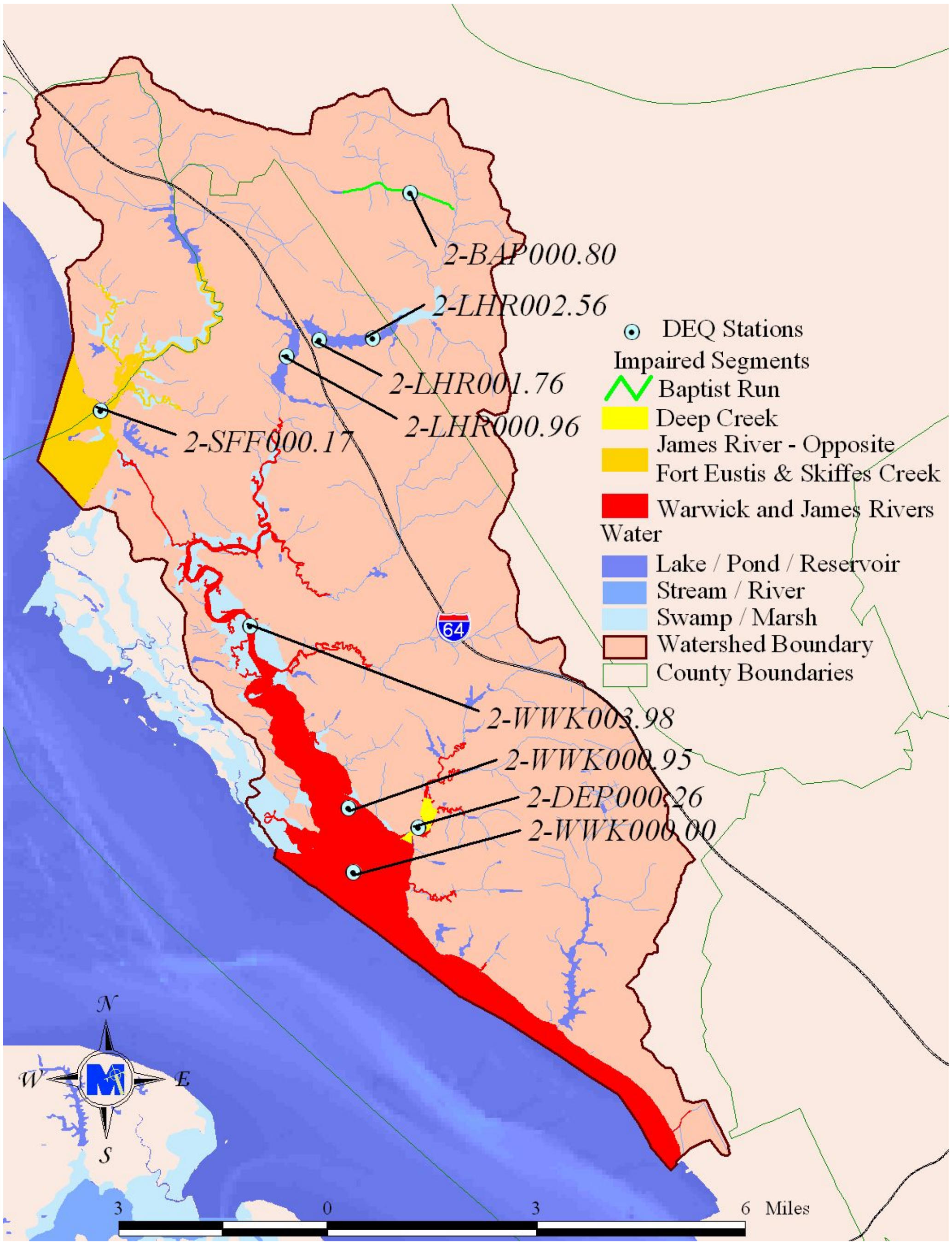


**Figure 2.1 Location of VADEQ water quality monitoring stations in the Warwick River watershed.**

**Table 2.1 Summary of fecal coliform monitoring conducted by VADEQ for Warwick River from January 1980 through November 2005.**

| Stream | VADEQ Station | Count (#) | Minimum (cfu/100mL) | Maximum (cfu/100mL) | Mean (cfu/100mL) | Median (cfu/100mL) | Standard Deviation | Violations[1] (%) |
|---|---|---|---|---|---|---|---|---|
| Deep Creek | 2-DEP000.26 | 92 | 2 | 1,600 | 320 | 90 | 494 | 22 |
| Skiffes Creek | 2-SFF000.17 | 40 | 3 | 230 | 54 | 22 | 69 | 0 |
| Warwick River | 2-WWK000.00 | 44 | 2 | 100 | 22 | 6 | 33 | 0 |
| Warwick River | 2-WWK000.95 | 1 | 25 | 25 | 25 | 25 | NA | 0 |
| Warwick River | 2-WWK003.98 | 93 | 2 | 1,600 | 235 | 79 | 407 | 15 |
| Baptist Run | 2-BAP000.80 | 6 | 300 | 3,800 | 1,317 | 800 | 1,309 | 83 |
| Lee Hall Reservoir | 2-LHR000.96 | 7 | 25 | 100 | 36 | 25 | 28 | 0 |
| Lee Hall Reservoir | 2-LHR001.76 | 7 | 25 | 50 | 29 | 25 | 9 | 0 |
| Lee Hall Reservoir | 2-LHR002.56 | 10 | 25 | 3,400 | 390 | 25 | 1,059 | 10 |

[1]Violations are based on the fecal coliform instantaneous standard (400 cfu/100mL).

**Table 2.2 Summary of *E. coli* monitoring conducted by VADEQ for Warwick River from July 2002 through July 2004.**

| Stream | VADEQ Station | Count (#) | Minimum (cfu/100mL) | Maximum (cfu/100mL) | Mean (cfu/100mL) | Median (cfu/100mL) | Standard Deviation | Violations[1] (%) |
|---|---|---|---|---|---|---|---|---|
| Deep Creek | 2-DEP000.26 | 9 | 10 | 180 | 61 | 20 | 66 | 0 |
| Warwick River | 2-WWK000.95 | 1 | 10 | 10 | 10 | 10 | NA | 0 |
| Warwick River | 2-WWK003.98 | 9 | 10 | 120 | 37 | 30 | 37 | 0 |

[1]Violations are based on the current *E. coli* instantaneous standard (235 cfu/100mL).

**Table 2.3 Summary of *enterococci* monitoring conducted by VADEQ for Warwick River from March 2000 through December 2005.**

| Stream | VADEQ Station | Count (#) | Minimum (cfu/100mL) | Maximum (cfu/100mL) | Mean (cfu/100mL) | Median (cfu/100mL) | Standard Deviation | Violations[1] (%) |
|---|---|---|---|---|---|---|---|---|
| Warwick River | 2-WWK003.98 | 22 | 10 | 1,000 | 114 | 28 | 231 | 18 |
| Deep Creek | 2-DEP000.26 | 22 | 10 | 420 | 84 | 40 | 108 | 18 |

[1]Violations are based on the current *enterococci* instantaneous standard (104 cfu/100mL).

### *2.3.1.2 VDH Water Quality Monitoring for TMDL Assessment*

Data from 39 VDH in-stream monitoring stations (Figure 2.2) were analyzed from December 1984 through February 2006 and are included in the analysis. These stations were chosen because they are within or near the VDH impairments. Samples were taken for the express purpose of determining compliance with the state standards for shellfish harvesting (geomean of 14 fecal coliform MPN and a 90$^{th}$ percentile of 49 fecal coliform MPN). As a matter of economy, samples showing fecal coliform concentrations below 2.9 cfu/100 ml or in excess of a specified cap (1,200 cfu/100 ml) were not further analyzed to determine the precise concentration of fecal coliform bacteria. The result is that reported concentrations of 2.9 cfu/100 ml most likely represent concentrations below 2.9 cfu/100 ml, and reported concentrations of 1,200 cfu/100 ml most likely represent concentrations in excess of this value. Table 2.4 summarizes the fecal coliform samples collected at the VDH in-stream monitoring stations used for condemnation area and TMDL assessment. Graphs of this data are shown in Appendix C.

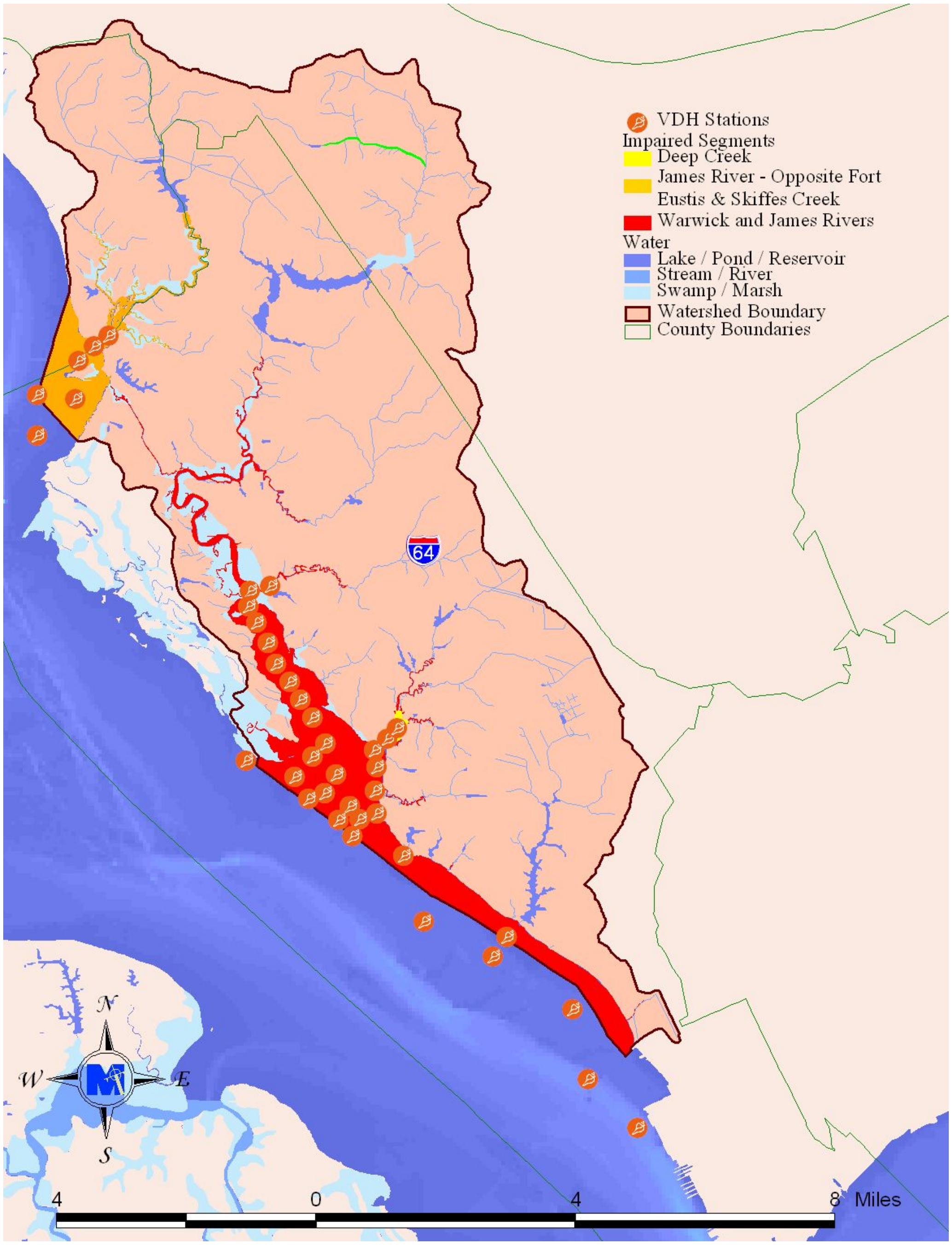


**Figure 2.2 Location of VDH water quality monitoring stations in the Warwick River watershed.**

**Table 2.4 Summary of fecal coliform monitoring conducted by VDH from December 1984 through January 2006.**

| River | VDH Station | Impairment | Count (#) | Minimum (MPN) | Maximum (MPN) | Mean (MPN) | Median (MPN) | Geomean[1] Violation (%) | 90th Percentile[2] Violation (%) |
|---|---|---|---|---|---|---|---|---|---|
| James River | 57-E57 | Warwick and James Rivers | 178 | 2.9 | 1200 | 36.14 | 3.6 | 0 | 29 |
| James River | 57-E61 | None | 182 | 2.9 | 93 | 8.09 | 3.6 | 0 | 0 |
| James River | 57-F58 | None | 210 | 2.9 | 150 | 9.45 | 3 | 0 | 3 |
| James River | 57-I54 | None | 182 | 2.9 | 1,100 | 18.19 | 3.6 | 0 | 1 |
| James River | 57-M53 | None | 182 | 2.9 | 1,100 | 15.61 | 3 | 0 | 0 |
| James River | 57-O50 | None | 182 | 2.9 | 240 | 10.73 | 3.6 | 0 | 0 |
| James River | 58-A62 | Warwick and James Rivers | 163 | 2.9 | 1,200 | 22.01 | 3.6 | 0 | 0 |
| James River | 58--A65 | Warwick and James Rivers | 164 | 2.9 | 240 | 11.47 | 3.6 | 0 | 10 |
| James River | 58--B64 | Warwick and James Rivers | 155 | 2.9 | 240 | 14.14 | 3.6 | 0 | 20 |
| James River | 58--B65 | Warwick and James Rivers | 155 | 2.9 | 240 | 11.07 | 3.6 | 0 | 0 |
| James River | 58--C67 | Warwick and James Rivers | 164 | 2.9 | 75 | 7.14 | 2.9 | 0 | 0 |
| James River | 58--E70 | None | 164 | 2.9 | 150 | 11.47 | 3.6 | 0 | 0 |
| Warwick River | 58-1.5A | Warwick and James Rivers | 161 | 2.9 | 1,200 | 33.46 | 9.1 | 8 | 47 |
| Warwick River | 58-1Z | Warwick and James Rivers | 163 | 2.9 | 240 | 11.93 | 3.6 | 0 | 0 |
| Warwick River | 58-2A | Warwick and James Rivers | 160 | 2.9 | 1,200 | 49.43 | 9.1 | 30 | 52 |
| Warwick River | 58-4 | Warwick and James Rivers/ Deep Creek | 194 | 2.9 | 1,200 | 187.04 | 43 | 100 | 100 |
| Warwick River | 58-5 | Warwick and James Rivers | 164 | 2.9 | 460 | 19.5 | 3.6 | 0 | 3 |
| Warwick River | 58-6 | Warwick and James Rivers | 164 | 2.9 | 1,200 | 23.37 | 3.6 | 0 | 8 |
| Warwick River | 58-7 | Warwick and James Rivers | 155 | 2.9 | 1,200 | 24.79 | 7.3 | 0 | 0 |
| Warwick River | 58-8 | Warwick and James Rivers | 164 | 2.9 | 1,100 | 41.82 | 9.1 | 17 | 25 |
| Warwick River | 58-9 | Warwick and James Rivers | 155 | 2.9 | 1,200 | 52.29 | 9.1 | 22 | 24 |
| Warwick River | 58-10 | Warwick and James Rivers | 164 | 2.9 | 1,200 | 44.2 | 9.1 | 45 | 78 |
| Warwick River | 58-11 | Warwick and James Rivers | 155 | 2.9 | 1,200 | 72.78 | 23 | 100 | 94 |
| Warwick River | 58-12 | Warwick and James Rivers | 155 | 2.9 | 1,200 | 84.13 | 23 | 100 | 100 |
| Warwick River | 58-13 | Warwick and James Rivers | 155 | 2.9 | 1,200 | 126.98 | 43 | 100 | 100 |

[1]Violations are based on the current fecal coliform 30-month geomean standard (14 MPN).
[2]Violations are based on the current fecal coliform 30-month 90th percentile standard (49 MPN).

**Table 2.4 Summary of fecal coliform monitoring conducted by VDH from December 1984 through January 2006. (cont.)**

| Stream | VDH Station | Impairment | Count (#) | Minimum (MPN) | Maximum (MPN) | Mean (MPN) | Median (MPN) | Geomean[1] Violation (%) | 90th Percentile[2] Violation (%) |
|---|---|---|---|---|---|---|---|---|---|
| Warwick River | 58-13A | Warwick and James Rivers | 147 | 2.9 | 1,200 | 263.5 | 93 | 100 | 100 |
| Warwick River | 58-JRSTP | Warwick and James Rivers | 164 | 2.9 | 1,200 | 27.68 | 9.1 | 15 | 24 |
| Warwick/ James conf. | 58-1A | Warwick and James Rivers | 153 | 2.9 | 460 | 27.91 | 9.1 | 20 | 36 |
| Warwick/ James conf. | 58-0.5 | Warwick and James Rivers | 164 | 2.9 | 460 | 14.56 | 3.6 | 0 | 0 |
| Warwick/ James conf. | 58-0.5Y | Warwick and James Rivers | 164 | 2.9 | 43 | 6.99 | 3.6 | 0 | 0 |
| Warwick/ James conf. | 58-0.5Z | Warwick and James Rivers | 155 | 2.9 | 210 | 12.17 | 3.6 | 0 | 0 |
| Deep Creek | 58-3 | Warwick and James Rivers \| Deep Creek | 164 | 2.9 | 1,200 | 122.82 | 23 | 78 | 99 |
| Deep Creek/ Warwick conf. | 58-2.5 | Warwick and James Rivers \| Deep Creek | 155 | 2.9 | 1,200 | 56.7 | 9.1 | 53 | 89 |
| Skiffes Creek | 59--BB77 | James River – Opposite Fort Eustis | 65 | 2.9 | 1,200 | 90.79 | 23 | 100 | 100 |
| Skiffes Creek/ James conf. | 59--AA78 | James River – Opposite Fort Eustis | 65 | 2.9 | 1,200 | 81.41 | 15 | 39 | 64 |
| James River | 59--V81 | None | 210 | 2.9 | 240 | 11.66 | 3.6 | 0 | 0 |
| James River | 59--X79 | James River – Opposite Fort Eustis | 69 | 2.9 | 1,100 | 32.33 | 3.6 | 0 | 0 |
| James River | 59--X81 | James River – Opposite Fort Eustis | 69 | 2.9 | 43 | 7.33 | 3.6 | 0 | 0 |
| James River | 59--Z79 | James River – Opposite Fort Eustis | 69 | 2.9 | 1,200 | 72.07 | 9.1 | 28 | 78 |

[1]Violations are based on the current fecal coliform 30-month geomean standard (14 MPN).
[2]Violations are based on the current fecal coliform 30-month 90th percentile standard (49 MPN).

#### *2.3.1.3 Water Quality Monitoring Conducted During BST Report Development*

MapTech, Inc. was contracted to perform Bacterial Source Tracking (BST) analyses in the Warwick River watershed. BST is intended to aid in identifying sources (*i.e.,* humans, pets, livestock, wildlife) of fecal contamination in water bodies. The data collected provided insight into the likely sources of fecal contamination, aided in distributing fecal loads from different sources during model calibration, and will improve the chances for success in implementing water quality solutions. Water quality monitoring was performed by VDH from October 2004 through September 2005 at three sites throughout the Warwick River watershed for the purpose of BST analyses (Figure 2.3). MapTech's Environmental Diagnostics Laboratory (EDL) analyzed samples for fecal coliform and *E. coli* concentrations as well as for bacteria source (human, livestock, pet, and wildlife). The data collected were analyzed for frequency of violations, patterns in fecal source identification, and seasonal impacts. Results of the analyses are presented in the following sections.

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

The BST results of water samples collected at three VDH stations in the Warwick River drainage area are reported in Tables 2.5, 2.6 and 2.7. The proportions reported are formatted to indicate statistical significance (*i.e.*, **BOLD** numbers indicate a statistically significant result). The statistical significance was determined through two tests. The first was based on the sample size. A z-test was used to determine if the proportion was significantly different from zero (alpha = 0.10). Second, the rate of false positives was calculated for each source category in each library, and a proportion was not considered significantly different from zero unless it was greater than the false-positive rate plus three standard deviations. Table 2.8 summarizes the results with load-weighted average proportions of bacteria originating from the four source categories. The load-weighted average considers the concentration of *E. coli* measured and the number of bacterial isolates analyzed in the BST analysis.

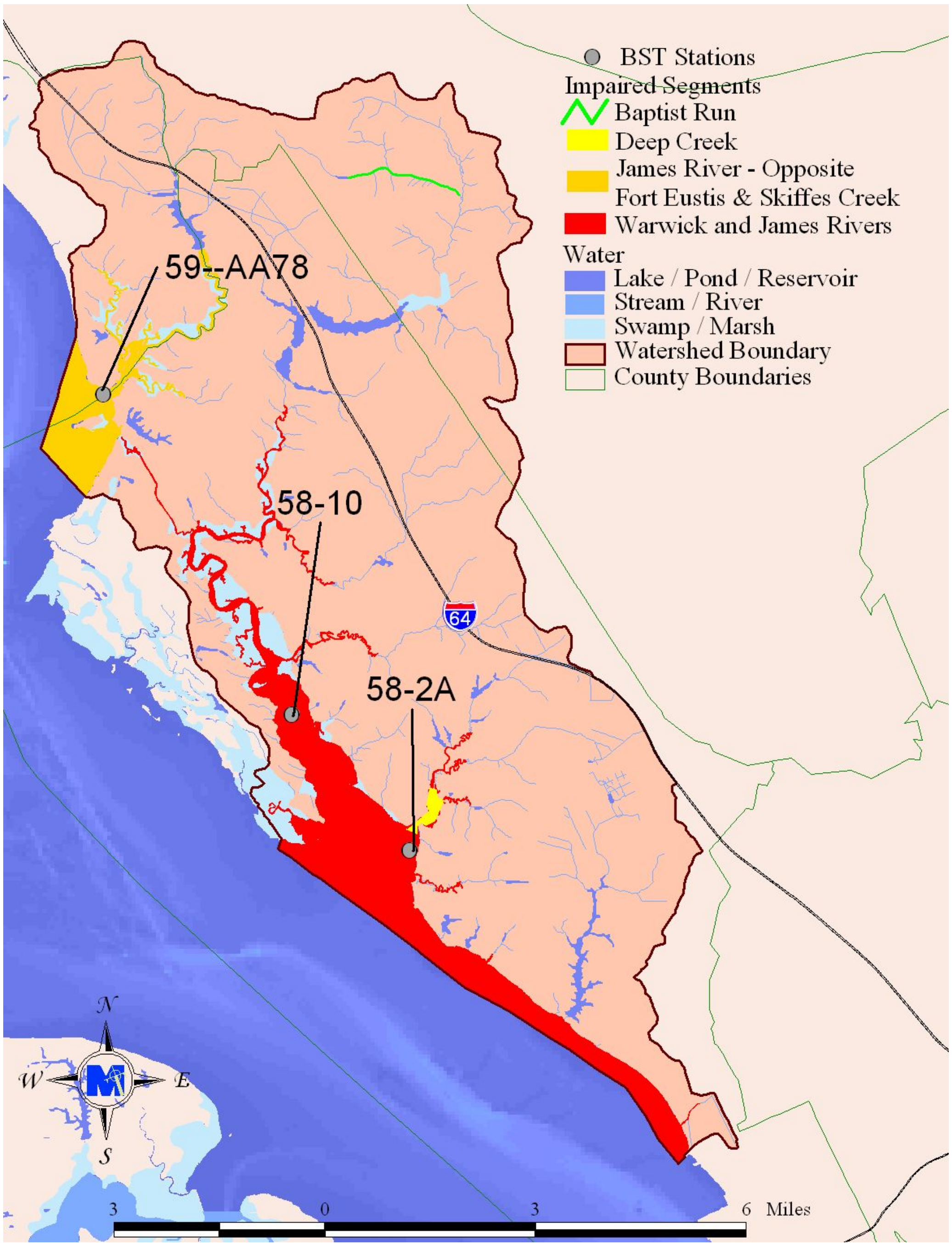


**Figure 2.3 Location of BST water quality monitoring stations in the Warwick River watershed.**

**Table 2.5 Bacterial Source Tracking for Warwick River at Station 58-10.**

| Station ID | Date of Sample | Lab ID | HUP ID | Number of Isolates | Wildlife | Human | Livestock | Pet |
|---|---|---|---|---|---|---|---|---|
| 58-10 | 10/6/04 | D3816 | G11 | NVI | NVI | NVI | NVI | NVI |
| 58-10 | 11/8/04 | D3916 | G11 | 8 | 0% | 100% | 0% | 0% |
| 58-10 | 12/7/04 | D3976 | G11 | 2 | 100% | 0% | 0% | 0% |
| 58-10 | 1/5/05 | D4064 | G11 | 3 | 0% | 0% | 33% | 67% |
| 58-10 | 2/2/05 | D4118 | G11 | 22 | **81%** | **14%** | 5% | 0% |
| 58-10 | 3/7/05 | D4206 | G11 | 8 | 38% | 0% | 38% | 24% |
| 58-10 | 4/4/05 | D4267 | G11 | 24 | **25%** | **41%** | **17%** | **17%** |
| 58-10 | 5/3/05 | D4361 | G11 | 17 | **29%** | **29%** | **36%** | 6% |
| 58-10 | 6/1/05 | D4437 | G11 | 24 | 0% | **100%** | 0% | 0% |
| 58-10 | 7/13/05 | D4537 | G11 | 9 | 0% | 11% | 11% | **78%** |
| 58-10 | 8/16/05 | D4665 | G11 | 24 | **12%** | **17%** | **38%** | **33%** |
| 58-10 | 9/13/05 | D4785 | G11 | 24 | **46%** | 4% | 8% | **42%** |

**BOLD** type indicates a statistically significant value.
NVI – No viable isolates.

**Table 2.6 Bacterial Source Tracking for Deep Creek at Station 58-2A.**

| Station ID | Date of Sample | Lab ID | HUP ID | Number of Isolates | Wildlife | Human | Livestock | Pet |
|---|---|---|---|---|---|---|---|---|
| 58-2A | 10/6/04 | D3815 | G11 | 6 | 17% | 50% | 0% | 33% |
| 58-2A | 11/8/04 | D3915 | G11 | 8 | 0% | 100% | 0% | 0% |
| 58-2A | 12/7/04 | D3975 | G11 | 23 | **48%** | **30%** | 0% | **22%** |
| 58-2A | 1/5/05 | D4063 | G11 | 5 | 60% | 20% | 20% | 0% |
| 58-2A | 2/2/05 | D4117 | G11 | 6 | 66% | 17% | 0% | 17% |
| 58-2A | 3/7/05 | D4205 | G11 | 2 | 0% | 0% | 50% | 50% |
| 58-2A | 4/4/05 | D4266 | G11 | 24 | **33%** | **21%** | **17%** | **29%** |
| 58-2A | 5/3/05 | D4360 | G11 | 9 | **33%** | 22% | **45%** | 0% |
| 58-2A | 6/1/05 | D4436 | G11 | 8 | 12% | 63% | 0% | 25% |
| 58-2A | 7/13/05 | D4536 | G11 | 5 | 0% | 0% | 0% | 100% |
| 58-2A | 8/16/05 | D4664 | G11 | 15 | 7% | **53%** | 13% | **27%** |
| 58-2A | 9/13/05 | D4784 | G11 | 11 | **36%** | 0% | 0% | **64%** |

**BOLD** type indicates a statistically significant value.

**Table 2.7 Bacterial Source Tracking for Skiffes Creek at Station 59-AA78.**

| Station ID | Date of Sample | Lab ID | HUP ID | Number of Isolates | Wildlife | Human | Livestock | Pet |
|---|---|---|---|---|---|---|---|---|
| 59-AA78 | 11/8/04 | D3918 | G11 | 7 | 29% | 42% | 29% | 0% |
| 59-AA78 | 12/7/04 | D3978 | G11 | 24 | **46%** | **29%** | 0% | **25%** |
| 59-AA78 | 1/5/05 | D4066 | G11 | 17 | 12% | **70%** | **18%** | 0% |
| 59-AA78 | 2/2/05 | D4120 | G11 | 1 | 100% | 0% | 0% | 0% |
| 59-AA78 | 4/4/05 | D4269 | G11 | 24 | **33%** | **17%** | **42%** | 8% |
| 59-AA78 | 5/3/05 | D4363 | G11 | 3 | 0% | 33% | 67% | 0% |
| 59-AA78 | 6/1/05 | D4439 | G11 | 2 | 0% | 50% | 50% | 0% |
| 59-AA78 | 7/13/05 | D4539 | G11 | 20 | 5% | **30%** | **40%** | **25%** |
| 59-AA78 | 8/16/05 | D4667 | G11 | 24 | 0% | **12%** | **33%** | **55%** |
| 59-AA78 | 9/13/05 | D4787 | G11 | 22 | **23%** | **41%** | 9% | **27%** |

**BOLD** type indicates a statistically significant value.

**Table 2.8 Load-weighted average proportions of fecal bacteria originating from wildlife, human, livestock, and pet sources.**

| Impairment | Station ID | Weighted Averages: Wildlife | Human | Livestock | Pet |
|---|---|---|---|---|---|
| Warwick River | 58-10 | 18% | 35% | 23% | 24% |
| Deep Creek | 58-2A | 19% | 39% | 14% | 28% |
| Skiffes Creek | 59-AA78 | 3% | 21% | 36% | 40% |

### 2.3.2 Trend and Seasonal Analyses

Trend and seasonal analyses were performed on precipitation, stream flow, and bacteria concentrations. A Seasonal Kendall Test, which ignores seasonal cycles, was used to examine long-term trends. This test improves the chances of finding existing trends in data that are likely to have seasonal patterns.

Total monthly precipitation measured at National Climatic Data Center (NCDC) stations #446054 Newport News, #444720 Langley Air Force Base, and #447864 Smithfield were analyzed and no overall, long-term trends were found (Appendix A, Table A.1).

All VADEQ stations had no overall trends (Appendix A, Table A.5). Significant trends were observed for VDH stations 57-E57, 57-O50, 58- -E70, 58-1.5A, 58-2A, 58-JRSTP, 58-0.5Z (Appendix A, Table A.6). All trends indicated a statistically significant increase in fecal coliform concentrations over time except for station 58-2A. This station showed a statistically significant decrease.

Even though data from all stations did not show a statistically significant trend, Figure A.2 in Appendix A shows that generally the fecal coliform concentrations in the Warwick River decrease from upstream to downstream. The data from the James River and Skiffes Creek show a slight increase and Deep Creek shows a slight decrease from upstream to downstream stations (Appendix A, Figures A.3, A.4 and A.5). To create these graphs, the data from the VADEQ stations were capped at the VDH levels of 2.9 and 1,200 FC/100mL in order to compare VADEQ and VDH data.

A seasonal analysis of precipitation and fecal coliform concentration data were conducted using the Mood's Median Test (Minitab, 1995). This test was used to compare median values of precipitation and fecal coliform concentrations in each month. Significant differences between months within years were reported.

Mood's Median tests were preformed to show seasonality effects in the Warwick River data. Significant seasonality effects were found at all precipitation stations. Differences in mean monthly precipitation are indicated in Tables A.2 through A.4 (Appendix A). Precipitation values, at a given station, in months with the same median group letter are not significantly different from each other at a 95% significance level.

No VADEQ stations showed statistically significant seasonality differences; however, many VDH stations showed significant seasonality (Appendix A, Tables A.7 through A.29). There was not enough data to perform the Moods Median analysis on *E. coli* or *enterococci* data.

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# 3. SOURCE ASSESSMENT

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

## *3.1 Watershed Characterization*

The National Land Cover Data (NLCD) produced cooperatively between the U.S. Geological Survey (USGS) and the EPA was utilized for this study. The collaborative effort to produce this dataset is part of a Multi-Resolution Land Characteristics (MRLC) Consortium project led by four U.S. government agencies: EPA, USGS, the Department of the Interior National Biological Service (NBS), and the National Oceanic and Atmospheric Administration (NOAA). Using 30-meter resolution Landsat 7 Thematic Mapper (TM) satellite images taken between 1999 and 2001, digital land use coverage was developed identifying up to 29 possible land use types. Classification, interpretation, and verification of the land cover dataset involved several data sources when available including: aerial photography; soils data; population and housing density data; state or regional land cover data sets; USGS land use and land cover (LUDA) data; 3-arc second Digital Terrain Elevation Data (DTED) and derived slope, aspect and shaded relief; and National Wetlands Inventory (NWI) data. Approximate acreages and land use proportions for each impaired segment are given in Table 3.1 and shown in Figure 3.1.

**Table 3.1 Contributing land use area for the Warwick River watershed.**

| Stream | Barren (acres) | Commercial (acres) | Cropland (acres) | Forest (acres) | High Intensity Residential (acres) | LAX (acres) | Low Intensity Residential (acres) | Pasture (acres) | Water (acres) | Wetland (acres) | Total (acres) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Warwick River | 674 | 1,175 | 1,798 | 17,612 | 3,374 | 56.6 | 12,139 | 2,860 | 5,239 | 3,324 | 48,252 |

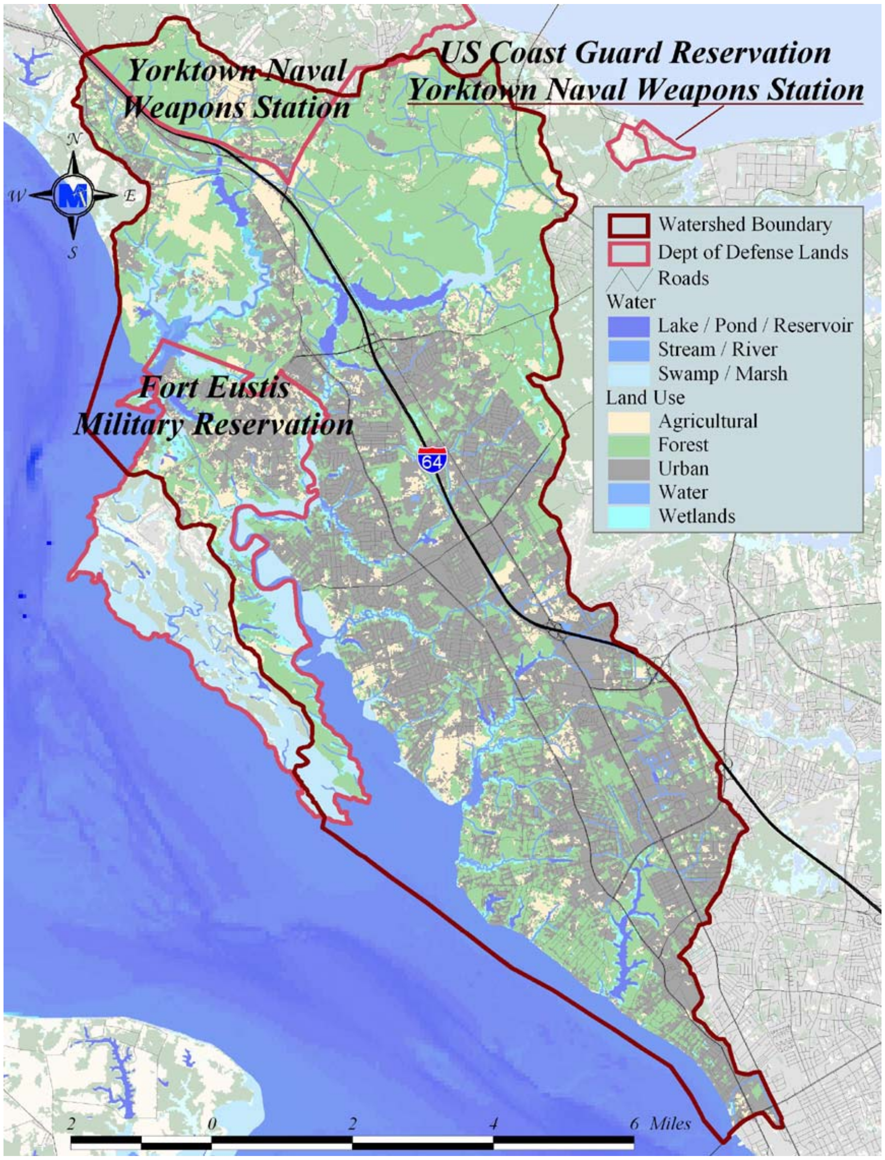


**Figure 3.1 Land uses in the Warwick River watershed.**

The estimated human population within the Warwick River drainage area currently is 133,218. Newport News is home to 416 species of wildlife including 45 types of mammals (*e.g.*, beaver, raccoon, and white - tailed deer) and 218 types of birds (*e.g.*, wood duck, wild turkey) (VDGIF, 2006).

For the period from 1948 to 2004, the Warwick River watershed received an average annual precipitation of approximately 45.06 inches, with 55% of the precipitation occurring during the May through October growing season (SERCC, 2006). Average annual snowfall is 3.3 inches, with the highest snowfall occurring during February (SERCC, 2006). Average annual daily temperature is 60.51 ºF. The highest average daily temperature of 88.9 ºF occurs in July, while the lowest average daily temperature of 32.3 ºF occurs in January (SERCC, 2006).

### *3.2 Assessment of Permitted Sources*

Ten point sources are permitted to discharge water into surface waters in the Wariwck River watershed through the Virginia Pollutant Discharge Elimination System (VPDES) (Table 3.2). Figure 3.2 shows the permit locations. One of the ten point sources (Permit number VA0081272) also has fecal coliform (FC) limitations. Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain a fecal coliform concentration below 200 cfu/100 ml. Currently, these permitted discharges are expected not to exceed the VADEQ standards: 126 cfu/100ml *E. coli* and 104 cfu/100ml *enterococci*. One method for achieving these goals is chlorination. Chlorine is added to the discharge stream at levels intended to kill off any pathogens. The HRSD- James River Sewage Treatment Plant (permit VA0081272) effluent is monitored for both total residual chlorine (TRC) and fecal coliforms to ensure these goals will be met. If the concentration is high enough, pathogen concentrations (including fecal coliform concentrations) are considered reduced to acceptable levels. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard. The data from the permits in Table 3.2 was used in the modeling to account for additional water and FC to the receiving streams.

Table 3.3 summarizes data from the stormwater permits. These are areas permitted for construction or industrial runoff. These 33 permitted sources do not have direct discharges to waterways but runoff from the area could contain sediment or other toxins. They were not modeled as adding water or FC directly to surfaces waters, but are shown here for comprehensiveness.

Table 3.4 summarizes data from water withdrawal permits. These are facilities that take water from surface water bodies or groundwater wells for industrial, commercial, or drinking water uses. These were modeled as water leaving the system. Two of these permits (1883-SR 0423 and 1881-SR 0423) are discharges into subwatershed 3. They were modeled as adding water to the system.

Table 3.5 shows the active Municipal Separate Storm Sewer System (MS4) permits in the Warwick River watershed. These permits allows for the collection and discharge of urban stormwater runoff into a surface water body. The estimated drainage area for each permit is shown in the table. This area includes the impervious portion of the commercial, LIR, and HIR land uses in the drainage area for each permit. This area was used to calculate the final allowable fecal bacteria load (wasteload allocation, WLA) portion of the TMDL. The MS4 discharge points for the Newport News MS4 are shown in Figure 3.3.

**Table 3.2 Summary of VPDES permitted point sources discharging water and/or FC in the Warwick River watershed used in modeling.**

| Permit Number[1] | Name | Type[2] | Receiving Stream[3] | Permitted for Fecal Coliform Control | Design Flow (MGD)[4] |
|---|---|---|---|---|---|
| VA0081272 | HRSD- James River Sewage Treatment Plant | WWTF | Warwick River | YES | 20.003 |
| VAG110039(A)/ VAG113000 (H) | Ready Mix Concrete Company – Plant 47 | Ready Mix | UT to Skiffes Creek | NO | 0.000001 |
| VAG110113(A)/ VAG110150(A)/ VAG113036(H)/ | E.V. Williams Concrete Plant – Oyster Point | Ready Mix | Ditch to UT to Deep Creek | NO | 0.0002 |
| VAG113044(H)/ VAG110129(A) | TCS Materials – Newport News | Ready Mix | UT to Jones Run | NO | 0.0026 |
| VAG110148(A)/ VAG113038(H) | Titan Virginia Ready Mix LLC – Skiffes Creek | Ready Mix | Skiffes Creek | NO | 0.12 |
| VAG523013 (Permit expired 7/24/01) | Menchville Marine Supply Corporation | Seafood | Deep Creek | NO | 0.0025 |
| VAG750051(A)/ VAG753000(H) | Enterprise Rent a Car | Car Wash | UT to Stoney Run | NO | 0.00005 |
| VAG830192 (Terminated 9/28/04) | Gasoline Station | Petroleum | Lake Maury | NO | 0.0864 |
| VAG830227(A) | Miller Mart #37 | Petroleum | Stoney Run Creek | NO | 0.015 |
| VAG750039(A)/ VAG753029(H) | Newport News City Public Works Operation | Car Wash | MS4 to Sluice Mill Pond to Deep Creek | NO | 0.005 |

[1] A = Active; H = Historical
[2] WWTF = Waste water treatment facility
[3] UT = Unnamed Tributary
[4] MGD = Millions gallons per day

**Table 3.3 Summary of VPDES permitted industrial or construction stormwater areas in the Warwick River watershed.**

| Permit Number | Name | Type[1] | Receiving Stream[2] | Number of Outfalls |
|---|---|---|---|---|
| VAR050002 | Chase Packaging Incorporated | SW IND | Ditch to UT James River | 1 |
| VAR050296 | United Parcel Service Newport News | SW IND | Detention Pond to Kettle Pond to James River | 2 |
| VAR050331 | Shorewood Packaging Corporation - Newport News | SW IND | Warwick River | 2 |
| VAR050402 | Basic Construction - Newport News | SW IND | UT to Warwick River | 3 |
| VAR050403 | Newport News City - YWCF - Warwick Blvd | SW IND | UT to Stony Run Creek | 2 |
| VAR050405 | Newport News City - YWCF 2 - McManus Blvd | SW IND | UT to Lucas Creek | 1 |
| VAR050494 | Bubba's Automotive Incorporated | SW IND | Ditch to Stoney Run to Warwick River | 2 |
| VAR051542 | Pliant Corporation | SW IND | Bailey Ck to Skiffes Ck | 3 |
| VAR051615 | Kinyo Virginia Incorporated | SW IND | Skiffes Creek | 1 |
| VAR550072 | Ball Metal Beverage Container Corporation | SW IND | Skiffes Creek Reservoir | 1 |
| VAR100008 | WalMart Bulk Storage Facility No 88 | SW CONSTR | Skiffes Creek Reservoir | NA |
| VAR100157 | Summerlake Shores | SW CONSTR | Yoder Pond to Deep Creek | NA |
| VAR100165 | Haynes Furniture Store | SW CONSTR | Detention Pond to Lucas Creek | NA |
| VAR100324 | Courthouse Green Subdivision | SW CONSTR | Stoney Run to Warwick River | NA |
| VAR100395 | Marina Bluff | SW CONSTR | Deep Creek | NA |
| VAR100409 | Anheuser Busch Inc | SW CONSTR | Skiffes Creek | NA |
| VAR100415 | Newport News City - Lee Hall WTP | SW CONSTR | Warwick River to Lee Hall Reservoir | NA |
| VAR100417 | Ashton Green Apartments | SW CONSTR | Warwick River | NA |
| VAR100532 | Newport News City - Lee Hall WTP | SW CONSTR | UT to Warwick River | NA |

[1] SW IND = Industrial Stormwater; SW CONSTR = Construction Stormwater

[2] UT = Unnamed Tributary

**Table 3.3 Summary of VPDES permitted industrial or construction stormwater areas in the Warwick River watershed (cont).**

| Permit Number | Name | Type[1] | Receiving Stream[2] | Number of Outfalls |
|---|---|---|---|---|
| VAR101271 | CNU - Newport News | SW CONSTR | Ditch to Lake Maury | NA |
| VAR101279 | Newport News Williamsburg International Airport | SW CONSTR | Ditch to Lucas Creek to Warwick River | NA |
| VAR101356 | General Stanford Elementary School | SW CONSTR | UT to Warwick River to James River | NA |
| VAR101501 | US Army - Fort Eustis - Transportation Center | SW CONSTR | Warwick River | NA |
| VAR101964 | Peach Orchard Subdivision | SW CONSTR | Lucas Creek | NA |
| VAR102029 | Sonic Drive In - Newport News | SW CONSTR | Lucas Creek | NA |
| VAR102118 | Colony Pines Subdivision | SW CONSTR | Stoney Run | NA |
| VAR102509 | Dorothy’s Landing | SW CONSTR | Ditch to Stoney Run | NA |
| VAR102578 | US Army - Fort Eustis - Transportation Center | SW CONSTR | Warwick River | NA |
| VAR102619 | Christopher Newport University - Delete P2 | SW CONSTR | UT to Lake Maury and James River | NA |
| VAR102622 | Christopher Newport University - Delete P2 | SW CONSTR | Lake Maury | NA |
| VAR102773 | Peninsula Gasto Enterology | SW CONSTR | Lake Maury | NA |
| VAR102832 | Hampton Roads Academy | SW CONSTR | UT to Deep Creek | NA |
| VAR103496 | Checed Creek | SW CONSTR | BMP on Property to Warwick River | NA |
| VAR103518 | Pocahontas Square | SW CONSTR | Skiffes Creek | NA |

[1] SW IND = Industrial Stormwater; SW CONSTR = Construction Stormwater
[2] UT = Unnamed Tributary

**Table 3.4 Summary of permitted water withdrawals in the Warwick River watershed.**

| ID | Owner / Facility Name | Owner Address | WELL # | subwatershed |
|---|---|---|---|---|
| 1643-WL 371100076321101 | CITY OF NEWPORT NEWS | NEWPORT NEWS GOLF CLUB AT DEER RUN | | 3 |
| 1648-WL 370316076303401 | JAMES RIVER COUNTRY CLUB | NEWPORT NEWS, VA 23606 | 1 | 6 |
| 1648-WL370316076303303 | | | 2 | 6 |
| 1648-WL 370325076301101 | | | JRCC POND | 6 |
| 1648-WL 370316076303302 | | | 4 | 6 |
| 1648-WL 370316076303301 | | | 8 | 6 |
| 1648-WL 370316076303306 | | | 9 | 6 |
| 1648-WL 370316076303304 | | | 7 | 6 |
| 1648-WL 370324076300601 | | | 5 | 6 |
| 1648-WL 370323076302201 | | | 6 | 6 |
| 2047-WL 370500076280001 | US DEPARTMENT OF ENERGY | THOMAS JEFFERSON NATIONAL ACCELERATOR FACILITY | dewatering | 14 |
| 0423-WL 371005076331801 | CITY OF NEWPORT NEWS | NEWPORT NEWS WATERWORKS / LEE HALLWTP | lee hall reservoir | 4 |
| 0423-SR 0527 | | | to SA from lee hall wtp | 3 |
| 0526-SR 0527 | | | to SA from harwood's mill wtp | 3 |
| 0527-WL 371039076351701 | | | BGD 1 | 16 |
| 0527-WL 371042076351701 | | | BGD 1B | 16 |
| 0527-WL 371110076341201 | | | BGD 2 | 3 |
| 0527-WL 371112076341201 | | | BGD 2B | 3 |
| 0527-WL 371000076331501 | | | BGD 3 | 4 |
| 0527-WL 370959076331501 | | | BGD 3B | 4 |
| 1882-SR 0423 | | | to lee hall from diascund | 3 |
| 1884-SR 0423 | | | to lee hall from little cr | 3 |
| 1883-SR 0423 | CITY OF NEWPORT NEWS | NEWPORT NEWS WATERWORKS / LEE HALLWTP | to lee hall from skiffes cr | from 15 to 3 |
| 1881-SR 0423 | | | to lee hall from chickahomy | not in wshed |

**Table 3.5 Summary of Active MS4 permits in the Warwick River watershed.**

| Permit | Phase | Facility Name | Estimated Drainage Area (ac) | Subwatershed(s) | Receiving Water |
|---|---|---|---|---|---|
| VA0088641 | Phase I | VPDES Municipal Major Stormwater / MS4 | 2,468 | all | Warwick River |
| VAR040035 | Phase II | US Army - Fort Eustis - Transportation Center | 178 | 4, 5, 6, 7, 16 | Warwick River, James River...Skiffes Creek...Eustis Lake… |
| VAR040037 | Phase II | James City County | 70 | 15, 16 | James River...Skiffes Creek |
| VAR040028 | Phase II | York County | 67 | 1, 2, 3, 13, 15 | ...Beaverdam Creek to Lee Hall Reservoir to Warwick River, Stony Run… |
| VAR040098 | | Newport News Williamsburg International Airport | 37 | 8, 10 | UT to Lucas Creek to Warwick River to James River… |
| VAR040079 | | US DOE - Thomas Jefferson National Accelerator Facility | 26 | 11, 14 | ...a small portion to Deep Creek |
| VAR040090 | | Christopher Newport University | 24 | 6, 14 | Lake Maury |
| VAR040044 | | Virginia Department of Transportation - Hampton Rd | NA | all | ...Warwick River… James River...Skiffes Creek… |

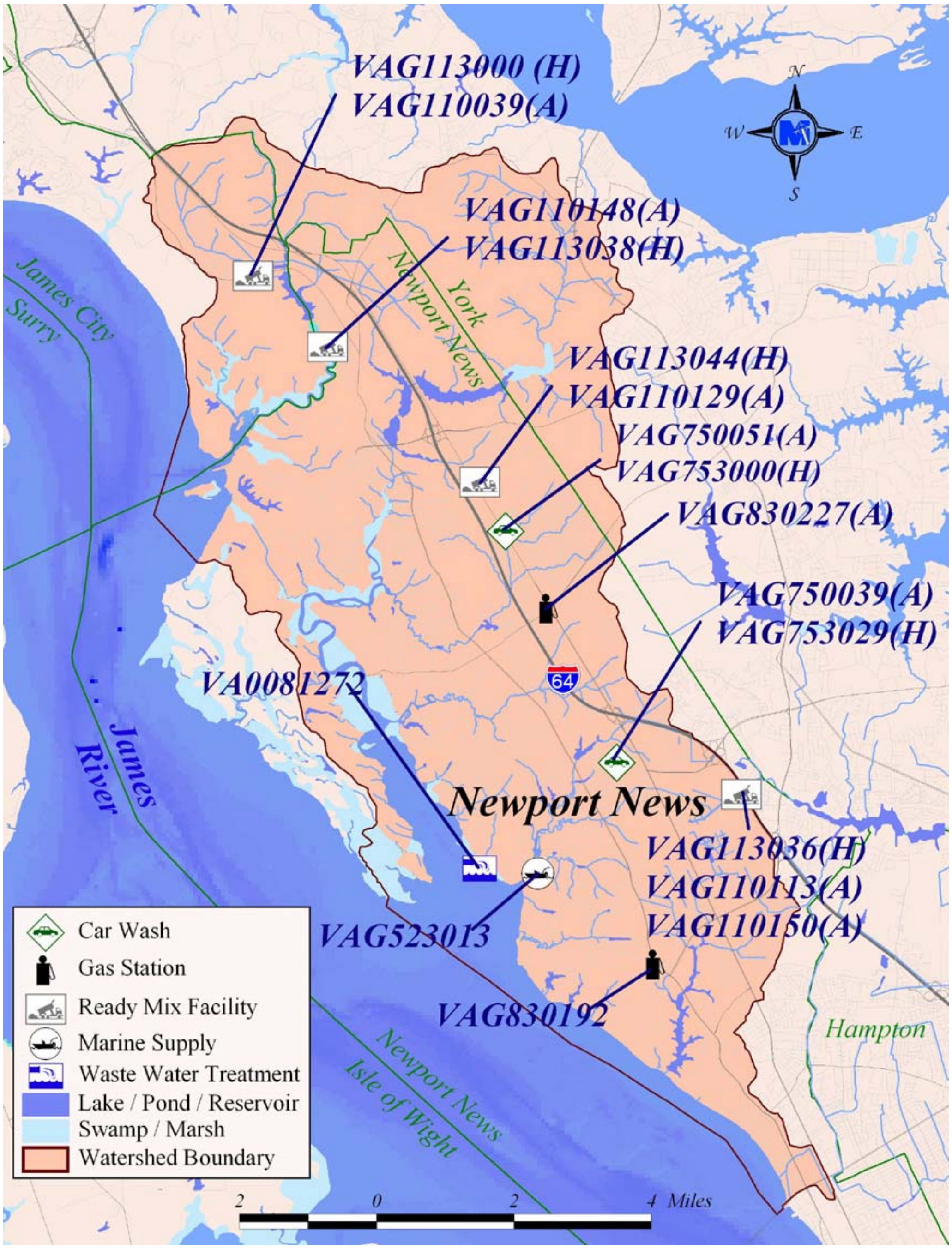


**Figure 3.2 Locations of VPDES discharge points within the watershed.**

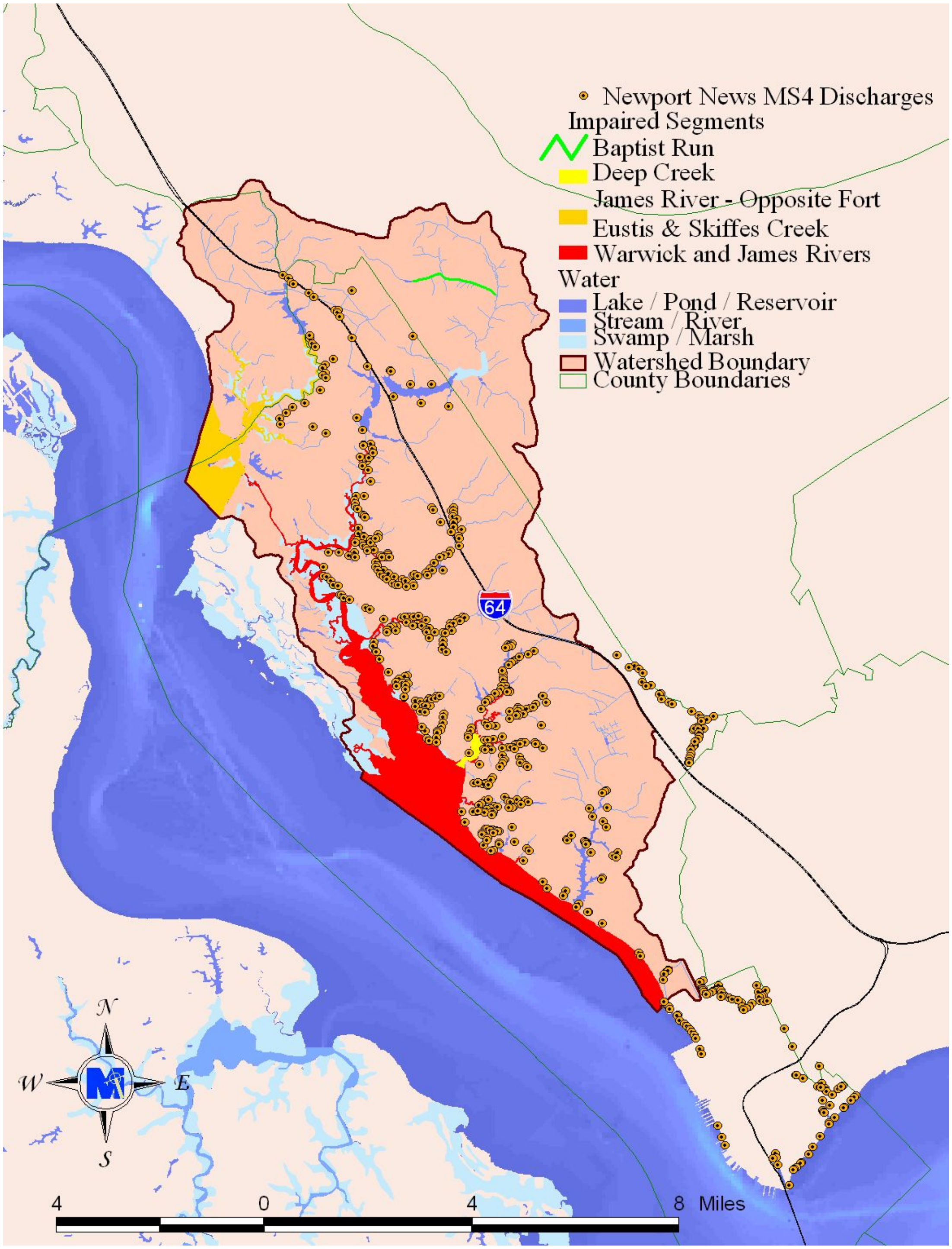


**Figure 3.3 Locations of MS4 discharge points for Newport News.**

## 3.3 Assessment of Nonpoint Sources

In the Warwick River watershed, both urban and rural nonpoint sources of fecal coliform bacteria were considered. Sources include residential sewage treatment systems, livestock, wildlife, and pets. MapTech previously collected samples of fecal coliform sources (*i.e.,* wildlife, livestock, pets, and human waste) and enumerated the density of fecal coliform bacteria to support the modeling process. Where appropriate, spatial distribution of sources was also determined.

### 3.3.1 Private Residential Sewage Treatment

In the U.S. Census questionnaires, housing occupants were asked which type of sewage disposal existed. Houses can be connected to a public sanitary sewer, a septic tank, or a cesspool, or the sewage is disposed of in some other way. The Census category "Other Means" includes the houses that dispose of sewage other than by public sanitary sewer or a private septic system. The houses included in this category are assumed to be disposing of sewage via a pit-privy or through the use of a straight pipe (direct stream outfall). Population, housing units, and type of sewage treatment from U.S. Census Bureau were summarized using GIS (Table 3.6). Census data from 1990 and 2000 were used to project forward to the year 2006.

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses and carry it to a wastewater treatment plant. Sewer systems are designed to carry a specific "peak flow" volume of wastewater to the treatment plant. Within this design parameter, sanitary collection systems are not expected to overflow, surcharge or otherwise release sewage before their waste load is successfully delivered to the wastewater treatment plant.

When the flow of wastewater exceeds the design capacity, the collection system will "back up" and sewage discharges through the nearest escape location. These discharges into the environment are called overflows. Wastewater can also enter the environment through exfiltration caused by line cracks, joint gaps, or breaks in the piping system.

Typical private residential sewage treatment systems (septic systems) consist of a septic tank, distribution box, and a drainage field. Waste from the household flows first to the septic tank, where solids settle out and are periodically removed by a septic tank pump-out. The liquid portion of the waste (effluent) flows to the distribution box, where it is distributed among several buried, perforated pipes that comprise the drainage field. Once in the soil, the effluent flows downward to groundwater, laterally to surface water, and/or upward to the soil surface. Removal of fecal coliform is accomplished primarily by die-off during the time between introduction to the septic system and eventual introduction to naturally occurring waters. Properly designed, installed, and functioning septic systems contribute virtually no fecal coliform to surface waters.

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

MapTech sampled waste from septic tank pump-outs and found an average fecal coliform density of 1,040,000 cfu/100 ml (MapTech, 2001). An average fecal coliform density for human waste of 13,000,000 cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

**Table 3.6 Human population, housing units, houses on sanitary sewer, septic systems, and other sewage disposal systems for 2006 in the Warwick River watershed.**

| Impaired Segment | Population | Housing Units | Sanitary Sewer | Septic Systems | Other * |
|---|---|---|---|---|---|
| Baptist Run | 518 | 230 | 97 | 132 | 1 |
| Deep Creek | 21,688 | 9,290 | 8,558 | 721 | 12 |
| Warwick River | 126,544 | 51,225 | 49,022 | 2,123 | 80 |
| Skiffes Creek | 6,674 | 2,481 | 2,307 | 166 | 8 |

* Houses with sewage disposal systems other than sanitary sewer and septic systems.

### 3.3.2 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Warwick River watershed and were the only pets considered in this analysis. Cat and dog populations by household were derived from American Veterinary Medical Association Center for Information Management demographics in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured during the Blackwater River TMDL study conducted by MapTech (MapTech, Inc., 1999). Fecal coliform density for dogs and cats was measured from samples collected throughout Virginia by MapTech. A summary of the data collected is given in Table 3.7. Table 3.8 lists the domestic animal populations for all impairments.

**Table 3.7 Domestic animal population density, waste load, and fecal coliform density.**

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

**Table 3.8 Estimated domestic animal populations in the Warwick River watershed for 2006.**

| Impaired Segment | Dogs | Cats |
|---|---|---|
| Baptist Run | 123 | 138 |
| Deep Creek | 4,961 | 5,556 |
| Warwick River | 27,354 | 30,633 |
| Skiffes Creek | 1,325 | 1,484 |

### 3.3.3 Livestock

The predominant types of livestock in the Warwick River watershed are horses and beef cattle although all types of livestock identified were considered in modeling the watershed. Operations are small hobby farms with few animals. Table 3.9 gives a summary of livestock populations in the Warwick River watershed during the period for source assessment. Animal populations were based on estimations from Virginia Agricultural Statistics (Virginia Agricultural Statistics, 2002) and were verified via communication with the Colonial Soil and Water Conservation District (CSWCD).

Values of fecal coliform density of livestock sources were based on sampling performed by MapTech (MapTech, 1999a). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in Table 3.10.

**Table 3.9 Livestock populations in the Warwick River watershed for 2006.**

| Impairment | Beef | Beef Calves | Dairy Milker | Dairy Dry | Dairy Calves | Hog | Horse | Sheep |
|---|---|---|---|---|---|---|---|---|
| Baptist Run | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Deep Creek | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Warwick River | 11 | 1 | 0 | 0 | 0 | 12 | 0 | 44 |
| Skiffes Creek | 6 | 1 | 6 | 2 | 2 | 17 | 0 | 6 |

**Table 3.10 Average fecal coliform densities and waste loads associated with livestock.**

| Type | Waste Load (lb/d/an) | Fecal Coliform Density (cfu/g) | Waste Storage Die-off factor | Fecal Coliform Produced (cfu/day) |
|---|---|---|---|---|
| Beef stocker (850 lb) | 51.0 | 101,000 | NA | 2.34E09 |
| Beef calf (350 lb) | 21.0 | 101,000 | NA | 9.62E08 |
| Dairy milker (1,400 lb) | 120.4 | 271,329 | 0.5 | 1.48E10 |
| Dairy heifer (850 lb) | 70.0 | 271,329 | 0.25 | 8.62E09 |
| Dairy calf (350 lb) | 29.0 | 271,329 | 0.5 | 3.57E09 |
| Hog (135 lb) | 11.3 | 400,000 | 0.8 | 2.05E09 |
| Horse (1,000 lb) | 51.0 | 94,000 | NA | 2.17E09 |
| Sheep (60 lb) | 2.4 | 43,000 | NA | 4.68E07 |
| Poultry (broiler; 1 lb) | 0.17 | 586,000 | 0.5 | 4.52E07 |

Fecal coliform produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.,* pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. Based on discussions with the CSWCD, it was concluded that there is not enough collected livestock waste to land-apply it in this watershed. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Most livestock were expected to deposit some portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was reported by the CSWCD (Tables 3.11 and 3.12) and local stakeholders. Beef stockers, beef calves, horses and sheep were assumed to be in pasture 100% of the time.

Based on discussions with the CSWCD, it was concluded that replacement (dry) dairy cattle are confined half the day and in pasture during the other half; however, they do not have access to streams or wetlands (Table 3.11).

**Table 3.11 Average time replacement dairy cattle spend in different areas per day.**

| Month | Pasture (hr) | Stream Access (hr) | Confinement (hr) |
|---|---|---|---|
| January | 12 | 0 | 12 |
| February | 12 | 0 | 12 |
| March | 12 | 0 | 12 |
| April | 12 | 0 | 12 |
| May | 12 | 0 | 12 |
| June | 12 | 0 | 12 |
| July | 12 | 0 | 12 |
| August | 12 | 0 | 12 |
| September | 12 | 0 | 12 |
| October | 12 | 0 | 12 |
| November | 12 | 0 | 12 |
| December | 12 | 0 | 12 |

Based on discussions with the CSWCD, it was concluded that beef cattle were expected to make small (0.5 hours a day) fecal contributions through direct deposition to streams in areas where the water flowed freely. In areas with stream fencing BMPs in place, or areas with large amounts of standing or slowly moving water (*i.e.,* swamps) it was concluded that direct deposition was minimal to non-existent. For areas where direct deposition by cattle is assumed, the average amount of time spent by beef cattle in stream access areas (*i.e.*, within 50 feet of the stream) for each month is given in Table 3.12.

**Table 3.12 Average time beef cows spend in pasture and stream access areas per day.**

| Month | Pasture (hr) | Stream Access (hr) |
|---|---|---|
| January | 23.5 | 0.5 |
| February | 23.5 | 0.5 |
| March | 23.5 | 0.5 |
| April | 23.5 | 0.5 |
| May | 23.5 | 0.5 |
| June | 23.5 | 0.5 |
| July | 23.5 | 0.5 |
| August | 23.5 | 0.5 |
| September | 23.5 | 0.5 |
| October | 23.5 | 0.5 |
| November | 23.5 | 0.5 |
| December | 23.5 | 0.5 |

### 3.3.4 Wildlife

The predominant wildlife species in the Warwick River watershed were determined through consultation with wildlife biologists from the Virginia Department of Game and Inland Fisheries (VDGIF), United States Fish and Wildlife Service (FWS), citizens from the watershed, and source sampling. Population densities were calculated from data provided by VDGIF and FWS, and are listed in Table 3.13 (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987).

**Table 3.13 Wildlife population densities for the Warwick River watershed.**

| Deer (an/ac of habitat) | Turkey (an/ac of habitat) | Goose (an/ac of habitat) | Duck (an/ac of habitat) | Muskrat (an/ac of habitat) | Raccoon (an/ac of habitat) | Beaver (an/mi of stream) |
|---|---|---|---|---|---|---|
| 0.0185 | 0.0026 | 0.0116 | 0.0296 | 1.7126 | 0.0225 | 3.8 |

The numbers of animals estimated to be in the Warwick River watershed are reported in Table 3.14. Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999b).

**Table 3.14 Wildlife populations in the Warwick River watershed.**

| Deer | Turkey | Goose | Duck | Muskrat | Raccoon | Beaver |
|---|---|---|---|---|---|---|
| 699 | 67 | 162 | 414 | 23,938 | 952 | 963 |

The fecal coliform density of beaver waste was taken from sampling done for the Mountain Run TMDL development (Yagow, 1999a). Percentage of time spent in stream access areas and percentage of waste directly deposited to streams was based on habitat information and location of feces during source sampling. Fecal coliform densities and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream) are reported in Table 3.15.

**Table 3.15 Average fecal coliform densities and percentage of time spent in stream access areas for wildlife.**

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

Table 3.16 summarizes the habitat and fecal production information that was obtained. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech. The only value that was not obtained from MapTech sampling in the watershed was for beaver.

**Table 3.16 Wildlife fecal production rates and habitat.**

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

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

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

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of the TMDL in the Warwick River watershed, the relationship was defined through computer modeling based on data collected throughout the watershed. Monitored flow and water quality data were then used to verify that the relationships developed through modeling were accurate. There are six basic steps in the development and use of a water quality model: model selection, source assessment, selection of a representative modeling period, model calibration, model validation, and model simulation.

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

## *4.1 Modeling Framework Selection*

The Warwick River watershed contains a broad range of hydrologic systems, and thus requires a very robust and versatile modeling platform. The upstream areas are riverine segments with the streamflow influenced by several dams, while downstream segments are tidally influenced and contain more swampland.

The USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to simulate existing conditions in riverine and estuarine areas. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climate, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed. The Steady State Tidal Prism Model operations were applied within the HSPF model files to model tidally influenced stream segments as explained in section 4.1.2.

### 4.1.1 Modeling Free Flowing Streams

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

### 4.1.2 Modeling Tidal Impairments

The Steady State Tidal Prism Model, which is currently used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model tidally influenced impairments (shellfish and recreational) in conjunction with upstream free-flowing impairments. MapTech's implementation of the Tidal Prism Model uses the same basic principal of a control volume with ebb and flood tides based on monitored tide data and bathymetry. However, die-off and mixing are controlled within HSPF. This results in a time series of concentration within the impacted waterbody. Allocations can then be determined based directly on the 90$^{th}$ percentile or geometric mean standard.

## 4.2 Model Setup

Daily precipitation data was available within the Warwick River watershed at the Newport News NCDC Coop station #446054. Missing values were filled first with daily precipitation from the Langley Air Force Base NCDC Coop station #444720, then with data from the Smithfield NCDC Coop station #447864. The resulting daily precipitation was disaggregated into hourly precipitation using the distribution from the Williamsburg 2N NCDC Coop station #449151.

To adequately represent the spatial variation in the watershed, the Warwick River drainage area was divided into 16 subwatersheds (Figure 4.1) for the purpose of modeling hydrology and water quality. The rationale for choosing these subwatersheds was based on the availability of water quality data, the impairment lengths and locations, and the limitations of the HSPF model. The length of the recreational use impairment Baptist Run is in subwatershed 1. The length of the recreational use impairment Deep Creek is in subwatershed 12. The area of the shellfishing use impairment Warwick and James Rivers spans subwatersheds 4, 5, 6, 7, 9, and 12. The area of the shellfishing use impairment James River – opposite Fort Eustis & Skiffes Creek segment is in subwatershed 16. Subwatersheds 4, 5, 6, 7, 9, 12, and 16 contain the estuarine or tidally influenced streams. Subwatersheds 1, 2, 3, 8, 10, 11, 13, 14, and 15 contain free flowing streams with the exception of two man-made dams. The Lee Hall Reservoir drainage area is represented by subwatershed 1, 2, and 3. The flow over this dam is regulated by the withdrawals for drinking water treatment. Discharges are only allowed when a storm larger than one inch per hour is forecasted (personal communication, R. Harris, 12/05/2006). The Skiffes Creek Reservoir drainage area is represented by subwatershed 15. This dam is not equipped with gates so the discharge over the dam is regulated only by stream depth; when the stream is at a certain depth, discharge over the dam will occur.

All the waterbodies in subwatershed 2, 3, 8, 10, 11, 13, 14, and 15 are not impaired for both the VADEQ primary contact recreational use or the VDH shellfish harvesting use.

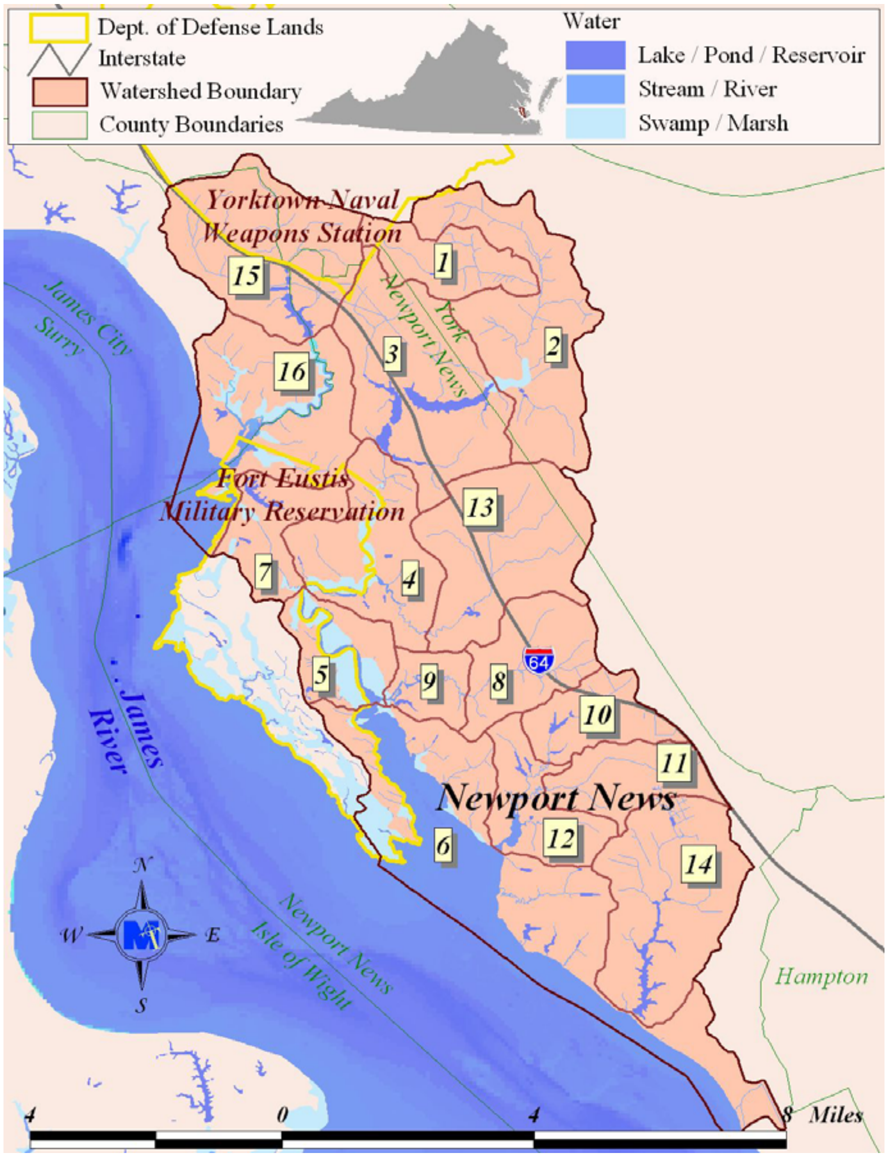


**Figure 4.1 Subwatersheds delineated for modeling the Warwick River watershed.**

In an effort to standardize modeling efforts across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

Using aerial photographs and MRLC, 15 land use types were identified in the watershed. The 14 land use types were consolidated into ten categories based on similarities in hydrologic and waste application/production features (Table 4.1). Within each subwatershed, up to ten land use types were represented. Each land use had parameters associated with it that described the hydrology of the area (*e.g.,* average slope length) and the behavior of pollutants (*e.g.,* fecal coliform accumulation rate). Table 4.2 shows the consolidated land use types and the area existing in the impairments. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in four IMPLND types, while there are ten PERLND types, each with parameters describing a particular land use. Some IMPLND and PERLND parameters (*e.g.*, slope length) vary with the particular subwatershed in which they are located. Others vary with season (*e.g.*, upper zone storage) to account for plant growth, die-off, and removal.

**Table 4.1 Consolidation of MRLC land use categories for the Warwick River watershed modeling.**

| TMDL Land use Categories | Pervious / Impervious (%) | Land use Classifications (MRLC Class No. where applicable) |
|---|---|---|
| Barren | Pervious (80%)<br>Impervious (20%) | Transitional (33)<br>Quarries/Strip Mines/Gravel Pits (32) |
| Commercial | Pervious (60%)<br>Impervious (40%) | Commercial/Industrial/Transportation (23) |
| Cropland | Pervious (100%) | Row Crops (82) |
| Forest | Pervious (100%) | Deciduous Forest (41)<br>Evergreen Forest (42)<br>Mixed Forest (43) |
| Livestock Access (LAX) | Pervious (100%) | Pasture/Hay (81) near streams |
| Pasture | Pervious (100%) | Pasture/Hay (81) |
| HIR | Pervious (80%)<br>Impervious (20%) | High Intensity Residential (HIR) (22) |
| LIR | Pervious (90%)<br>Impervious (10%) | Low Intensity Residential (LIR) (21)<br>Urban/Recreational Grasses (85) |
| Water | Pervious (100%) | Open Water (11) |
| Wetlands | Pervious (100%) | Woody Wetlands (91)<br>Emergent Herbaceous Wetlands (92) |

**Table 4.2 Contributing land use area for the impairments in the Warwick River watershed.**

| Impairment | Contributing Subwatersheds | Land use<br>Barren/ Transitional | Commercial | Forest | HIR | LAX |
|---|---|---|---|---|---|---|
| | | acres | acres | acres | acres | acres |
| Baptist Run | 1 | 5.31 | 4.48 | 1,197.36 | 6.39 | 1.05 |
| Deep Creek | 10, 11, 12 | 78.81 | 270.74 | 1,259.25 | 633.14 | 10.32 |
| Skiffes Creek | 15, 16 | 122.65 | 82.09 | 3,716.67 | 229.16 | 4.56 |
| Warwick River | 1 - 14 | 551.87 | 1,093.29 | 13,895.40 | 3,145.21 | 52.11 |

**Table 4.2 Contributing land use area for the impairments in the Warwick River watershed (cont.).**

| Impairment | Contributing Subwatersheds | Land use<br>LIR | Pasture | Cropland | Water | Wetland | Total |
|---|---|---|---|---|---|---|---|
| | | acres | acres | acres | acres | acres | acres |
| Baptist Run | 1 | 99.74 | 113.58 | 36.05 | 0.00 | 39.25 | 1,503.22 |
| Deep Creek | 10, 11, 12 | 1,754.08 | 281.88 | 137.84 | 93.24 | 216.92 | 4,736.22 |
| Skiffes Creek | 15, 16 | 1,163.78 | 721.41 | 695.18 | 1,124.96 | 678.93 | 8,539.39 |
| Warwick River | 1 - 14 | 10,975.05 | 2,138.43 | 1,102.66 | 4,114.33 | 2,645.06 | 39,713.41 |

Die-off of fecal coliform can be handled implicitly or explicitly. For land-applied fecal matter (fecal matter deposited directly on land), die-off occurring in the field was represented implicitly through model parameters such as the maximum accumulation and the 90% wash off rate, which were adjusted during the calibration of the model. These parameters were assumed to represent not only the delivery mechanisms, but the bacteria die-off as well. Once the fecal coliform entered the stream, the general decay module of HSPF was incorporated, thereby explicitly addressing the die-off rate. The general decay module uses a first order decay function to simulate die-off.

## 4.3 Stream Characteristics

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

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2006), Digital Elevation Models (DEM), and bathymetry data was used. Bathymetry data includes the elevation of stream and rivers below mean sea level (negative elevations). The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the Warwick watershed. The NRCS equations developed from data in the coastal plains of North Carolina were implemented. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each non-tidal subwatershed outlet.

The other entries in each non-tidal F-table, and all entries in the tidal F-tables, were calculated from the Digital Elevation Modal (DEM) and bathymetry data. A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet (Figure 4.2). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example is shown in Figure 4.2.

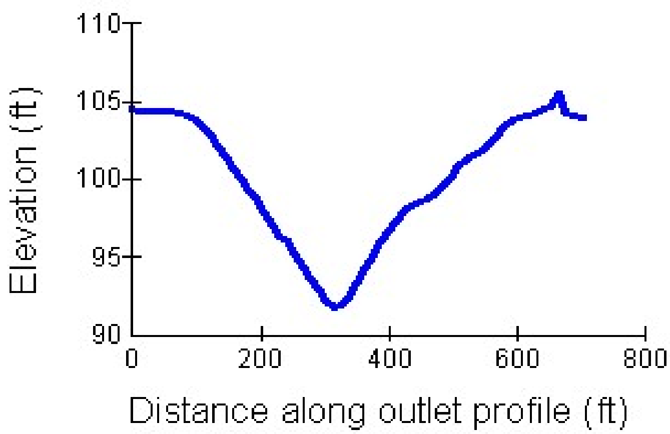


**Figure 4.2 Stream profile representation in HSPF.**

Conveyance was used to facilitate the calculation of discharge in the reach with values for resistance to flow (Manning's *n*) assigned based on recommendations by Brater and King (1976) and shown in Table 4.3. The conveyance was calculated for each of the two floodplains and the main channel; these figures were then added together to obtain a total conveyance. Calculation of conveyance was performed following the procedure described by Chow (1959). Average reach slope and reach length were obtained from GIS layers of the watershed, which included elevation from DEMs and a stream-flow network based on National Hydrography Dataset (NHD) data. The total conveyance was then multiplied by the square root of the average reach slope to obtain the discharge (in $ft^3/s$) at a given depth. An example of an F-table used in HSPF is shown in Table 4.4.

**Table 4.3 Summary of Manning's roughness coefficients for channel cells*.**

| Section | Upstream Area (ha) | Manning's *n* |
|---|---|---|
| Intermittent stream | 18 - 360 | 0.06 |
| Perennial stream | 360 and up | 0.05 |

*Brater and King (1976)

**Table 4.4 Example of an F-table calculated for the HSPF model.**

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

## *4.4 Selection of a TMDL Critical Condition.*

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

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

A description of the data used in this critical period analysis is shown in Tables 2.1 through 2.3. A graphical analysis of fecal coliform concentrations and flow duration intervals showed obvious critical flow levels for some stations and no critical flow levels at others (Figures 4.3 and 4.4). VADEQ station 2-WWK003.98 is shown here to represent a station with no critical flow levels when looking at the current fecal coliform standard. Other stations with no critical flow levels are 2-WWK000.00, 2-SFF000.17, 2-DEP000.26

(Appendix B Figures B.1 through B.4). There is not enough data collected from the station in Baptist Run (2-BAP000.80) to determine if there are any critical flow levels. The locations of the VADEQ stations are shown in Figure 2.1.

The flow regimes were also observed for the VDH stations. Due to the large number of stations, they were grouped together by subwatershed (Figure 4.1). The graph for VDH stations 57-E57, 58-0.5, 58-0.5Y, 58-0.5Z, 58-1.5A, 58-10, 58-11, 58-12, 58-1A, 58-1Z, 58-2.5A, 58-5, 58-6, 58-7, 58-8, 58-9, 58-A62, 58-65A, 58-B64, 58-B65, 58-C67, 58-JRSTP (subwatershed 6) in the outlet of the Warwick River is shown in Figure 4.4. The other VDH station graphs look similar to this one (B.5 through B.8). For comparison, the VDH 30-month 90$^{th}$ percentile fecal coliform standard (49 MPN) is shown on these graphs. The locations of the VDH stations are shown in Figure 2.2.

Due to the facts that within the primary contact recreational use impairment the VADEQ stations showed that all flow regimes had violations of the standard, and that the VDH stations showed high and low concentrations at all flow regimes, the model calibration and validation time periods must contain all flow regimes. A time period for water quality calibration and validation of the model was chosen based on the overall distribution of wet and dry seasons (Section 4.5) in order to capture a wide range of hydrologic circumstances for all impaired streams in this study area.

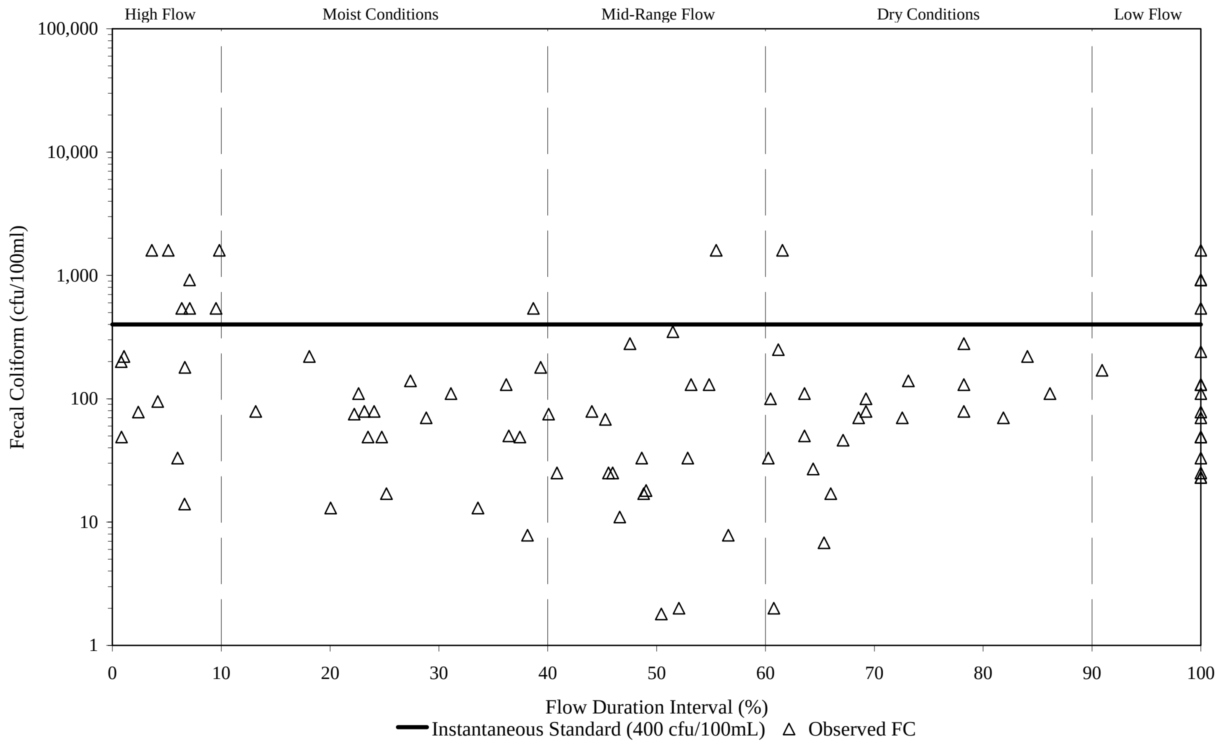


**Figure 4.3** **Relationship between fecal coliform concentrations (VADEQ Station 2-WWK003.98) and discharge (USGS Station #02047500) for the Warwick River.**

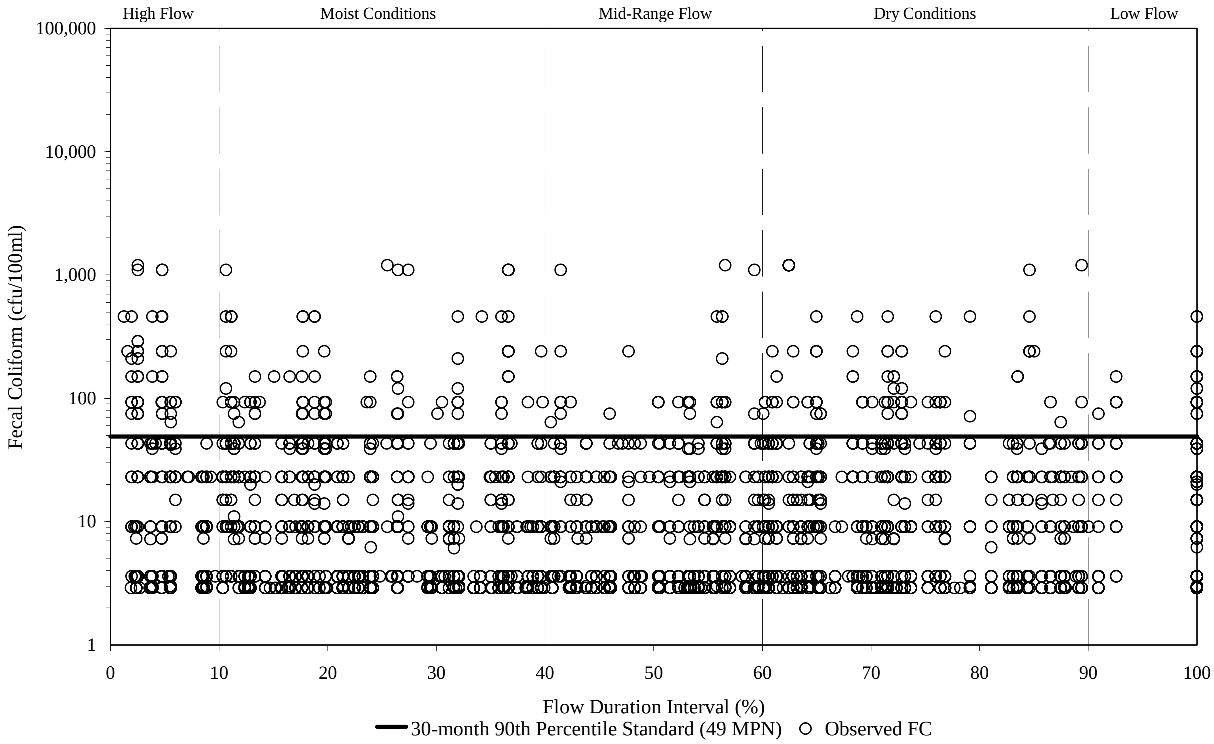


**Figure 4.4 Relationship between fecal coliform concentrations in subwatershed 6 (VDH stations 57-E57, 58-0.5, 58-0.5Y, 58-0.5Z, 58-1.5A, 58-10, 58-11, 58-12, 58-1A, 58-1Z, 58-2.5A, 58-5, 58-6, 58-7, 58-8, 58-9, 58-A62, 58-65A, 58-B64, 58-B65, 58-C67, 58-JRSTP) and discharge (USGS Station #02047500) for the Warwick River.**

## *4.5 Selection of Representative Modeling Period*

Selection of the modeling period was based on availability and quality of data (discharge and water-quality) and the need to represent critical hydrologic conditions. Using these criteria, modeling periods were selected for hydrology calibration and validation, water quality calibration and validation, and modeling of allocation scenarios.

The modeling periods were selected to include the VADEQ assessment period from July 1990 through June 2001 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002 and 2004 Section 303(d) lists. The fecal concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were recorded in all flow regimes, thus it was concluded that the critical, or representative, hydrological condition included a wide range of wet and dry seasons.

In order to select a modeling period representative of the critical hydrological condition from the available data, the mean daily precipitation for each season was calculated for the period January 1900 through February 2004. This resulted in 99 to 102 observations of precipitation for each season. The mean and variance of these observations were calculated. Next, a candidate period was chosen based on the availability of discharge data from the Skiffes Creek Dam (10/01/1994 to 07/10/2006). The representative period was chosen from this candidate period such that the mean and variance of each season in the modeled period was not significantly different from the historical data. Therefore, the period was selected as representing the hydrologic regime of the study area, accounting for critical conditions associated with all potential sources within the watershed. The results of these analyses are shown in Figures 4.5 and 4.6 and Table 4.5.

The hydrology calibration time period was chosen as the most representative period. This time period was also used for the allocation time period with existing conditions. The resulting period chosen for hydrologic calibration was 10/1/1999 to 9/30/2003 (yellow in Figures 4.5 and 4.6; Table 4.5). The second most representative period that did not overlap the calibration period was chosen as the validation period. For hydrologic model validation, the period selected was 10/1/1995 to 9/30/1999 (blue in Figures 4.5 and 4.6; Table 4.6).

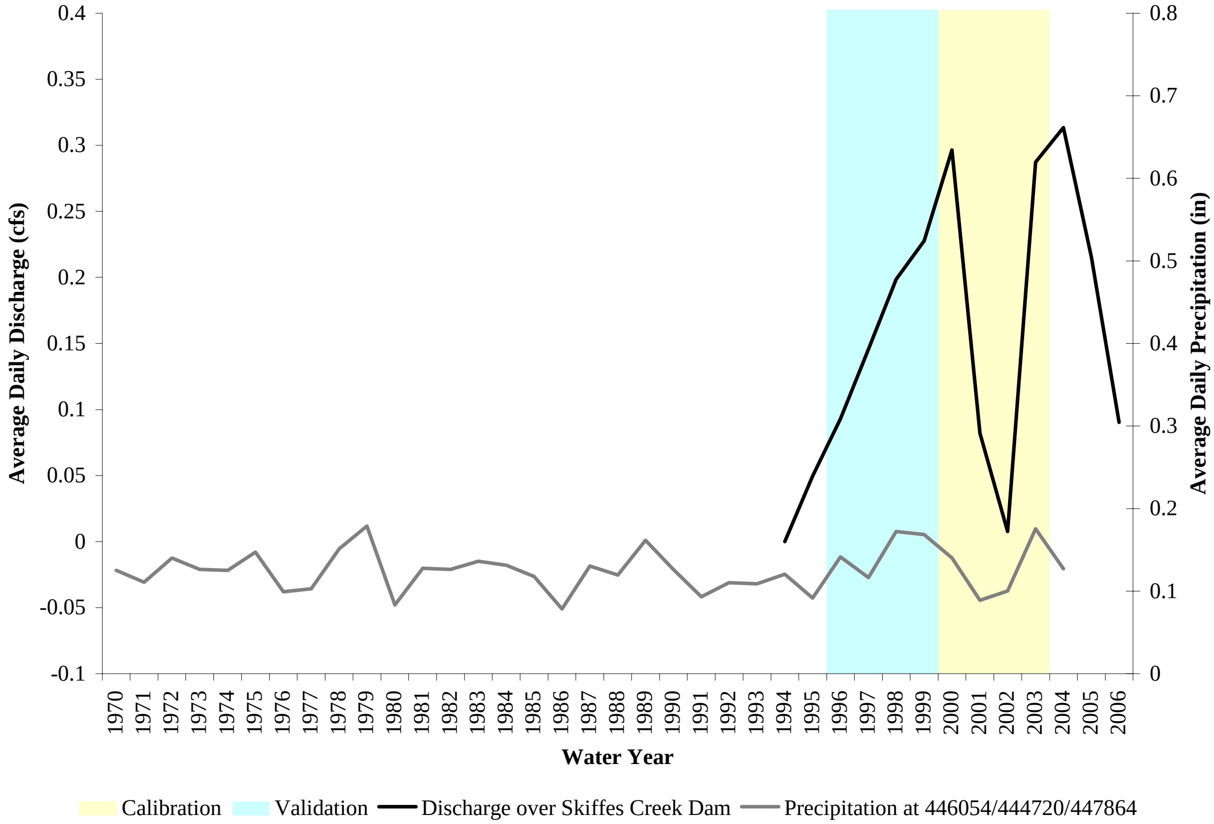


**Figure 4.5 Annual historical precipitation data (Stations 446054, 444720, 447864), average discharge over Skiffes Creek Dam, and representative modeling time periods for the Warwick River watershed.**

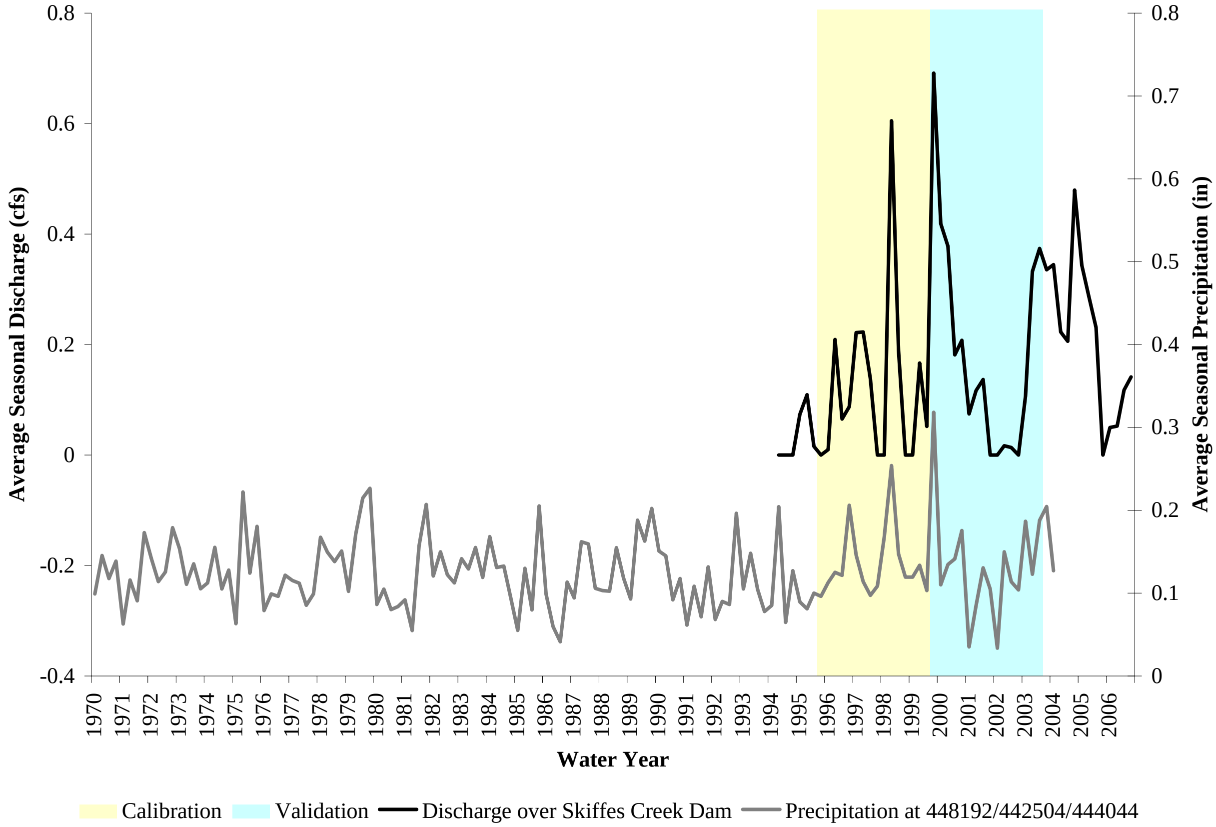


**Figure 4.6 Seasonal historical precipitation data (Stations 446054, 444720, 447864), average discharge over Skiffes Creek Dam, and representative modeling time periods for the Warwick River watershed.**

**Table 4.5 Comparison of hydrology calibration time period to historical records for the Warwick River watershed (10/1/1999 to 9/30/2003).**

| | Precipitation (446054/444720/447864)[1] | | | | Discharge over Skiffes Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | **Fall** | **Winter** | **Summer** | **Spring** | **Fall** | **Winter** | **Summer** | **Spring** |
| | **Historical Data** | | | | **Historical Data** | | | |
| **Mean** | 0.098 | 0.121 | 0.119 | 0.153 | 0.137 | 0.209 | 0.132 | 0.150 |
| **Variance** | 0.001 | 0.001 | 0.001 | 0.002 | 0.024 | 0.028 | 0.011 | 0.050 |
| | **Calibration Time Period Data** | | | | **Calibration Time Period Data** | | | |
| **Mean** | 0.091 | 0.123 | 0.143 | 0.147 | 0.150 | 0.211 | 0.177 | 0.136 |
| **Variance** | 0.005 | 0.001 | 0.001 | 0.003 | 0.034 | 0.030 | 0.022 | 0.027 |
| | **p-values** | | | | **p-values** | | | |
| **Mean** | 0.432 | 0.448 | 0.066 | 0.419 | 0.450 | 0.493 | 0.296 | 0.448 |
| **Variance** | 0.005 | 0.384 | 0.446 | 0.380 | 0.285 | 0.398 | 0.171 | 0.339 |

[1]Second and third stations utilized only when first station was off-line.

**Table 4.6 Comparison of hydrology validation time period to historical records for the Warwick River watershed (10/1/1995 to 9/30/1999).**

| | Precipitation (446054/444720/447864)[1] | | | | Discharge over Skiffes Dam | | | |
|---|---|---|---|---|---|---|---|---|
| | **Fall** | **Winter** | **Summer** | **Spring** | **Fall** | **Winter** | **Summer** | **Spring** |
| | **Historical Data** | | | | **Historical Data** | | | |
| **Mean** | 0.098 | 0.121 | 0.119 | 0.153 | 0.137 | 0.209 | 0.132 | 0.150 |
| **Variance** | 0.001 | 0.001 | 0.001 | 0.002 | 0.024 | 0.028 | 0.011 | 0.050 |
| | **Validation Time Period Data** | | | | **Validation Time Period Data** | | | |
| **Mean** | 0.137 | 0.157 | 0.117 | 0.188 | 0.058 | 0.301 | 0.111 | 0.195 |
| **Variance** | 0.001 | 0.004 | 0.001 | 0.009 | 0.012 | 0.042 | 0.004 | 0.111 |
| | **p-values** | | | | **p-values** | | | |
| **Mean** | 0.002 | 0.142 | 0.458 | 0.234 | 0.140 | 0.213 | 0.316 | 0.401 |
| **Variance** | 0.349 | 0.022 | 0.211 | 0.013 | 0.312 | 0.263 | 0.221 | 0.138 |

[1]Second and third stations utilized only when first station was off-line.

For fecal coliform water quality modeling, data availability was the governing factor in the choice of calibration and validation. The period containing the greatest amount of monitored data dispersed over the most stations, and for which the assessment of potential sources was most accurate (10/1/1999 to 9/30/2003), was chosen as the water quality calibration period. This period contained 1,404 water quality data points. The period from 1/1/1995 to 9/30/1999 was chosen as the validation period, with 1,169 data points. However, the Baptist Run headwater VADEQ impairment station (BAP000.80) does not have data during this time period. The calibration of the Baptist Run fecal coliform concentration contains only 2 data values, so the validation time period used was 5/1/1993 to 10/30/1994 to capture the remaining 4 data values. The Skiffes Creek (James River – opposite Fort Eustis & Skiffes Creek impairment) stations (59-Z79, 59-AA78, 59-BB77, 59-X81, 59-X79) also do not have data during the validation time period. Since the fecal coliform calibration contained 42 data values, it was decided that validation of this segment was not necessary if calibration was accurate and all other segments showed acceptable validation.

The period most representative of the watershed (10/1/1999 to 8/30/2003) not including a major hurricane (Isabel on 9/18 and 9/19/2003) was chosen as the allocation period to ensure that representative conditions in the watershed were being simulated during water quality allocations.

### 4.6 Source Representation

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

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different numbers should be used. Data representing 2001 or 2002 were used for the water quality calibration period (1999-2003) and data representing 1997 were used for validation period (1995-1999). Data representing 2006 were used for the allocation runs in order to represent current conditions.

Appendix B contains tables with existing monthly fecal coliform loadings to the different land use areas in each subwatershed by source.

### 4.6.1 Point Sources

Ten point sources are permitted to discharge water into surface waters in the Wariwck River watershed through the Virginia Pollutant Discharge Elimination System (VPDES) (Figure 3.2). One of the ten point sources, HRSD James River Sewage Treatment Plant (Permit number VA0081272), also has fecal coliform (FC) limitations at a design flow of 20.003 million gallons per day (MGD). For calibration and validation condition runs, recorded flow and fecal coliform concentration or Total Residual Chlorine (TRC) levels documented by the VADEQ were used as the input for each permit. The TRC data was related to fecal colifrom concentrations using a regression analysis. For calibration and validation, the James River Sewage Treatment Plant (VA0081272) was modeled as discharging between 3.65 and 13.86 cubic feet per second (cfs) (5.65 and 21.44 MGD) with a fecal coliform load ranging from 8.1E06 to 2.55E08 colony forming units (cfu) per hour (Table 4.7).

The design flow capacity was used for allocation runs. This flow rate was combined with a fecal coliform concentration of 200 cfu per 100 ml (when applicable) to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels. The James River Sewage Treatment Plant (VA0081272) was modeled as discharging 20.003 MGD (12.93 cfs) with a load of 2.64E09 cfu per hour. Modeled flow rates and bacterial loadings for all permitted dischargers are listed in Table 4.7.

**Table 4.7 Flow rates and bacteria loads used to model DEQ active permits in the Warwick River watershed.**

| DEQ Permit Number | Facility Name | Calibration/Validation: Flow Rate (cfs) Min | Calibration/Validation: Flow Rate (cfs) Max | Calibration/Validation: Bacteria Load (cfu/hr) Min | Calibration/Validation: Bacteria Load (cfu/hr) Max | Allocation: Flow Rate (cfs) | Allocation: Bacteria Load (cfu/hr) |
|---|---|---|---|---|---|---|---|
| VA0081272 | HRSD- James River Sewage Treatment Plant | 3.65 | 13.86 | 8.10E+06 | 2.55E+08 | 12.93 | 2.64E+09 |
| VAG110039 | Ready Mix Concrete Company – Plant 48 | 6.46E-07 | 2.84E-02 | 0 | 0 | 6.46E-07 | 0 |
| VAG110113 | E.V. Williams Concrete Plant – Oyster Point | 3.09E-04 | 3.09E-04 | 0 | 0 | 3.09E-04 | 0 |
| VAG110150 | E.V. Williams Concrete Plant – Oyster Point | 3.09E-04 | 3.09E-04 | 0 | 0 | 3.09E-04 | 0 |
| VAG110129 | TCS Materials – Newport News | 5.82E-04 | 4.07E-03 | 0 | 0 | 1.68E-03 | 0 |
| VAG110148 | Titan Virginia Ready Mix LLC – Skiffes Creek | 0.186 | 0.186 | 0 | 0 | 0.186 | 0 |
| VAG523013 Permit expired 7/24/01 | Menchville Marine Supply Corporation | 1.29E-04 | 1.29E-03 | 0 | 0 | 0 | 0 |
| VAG750039 | Newport News City Public Works Operation | 2.78E-03 | 3.23E-03 | 0 | 0 | 3.23E-03 | 0 |
| VAG750051 | Enterprise Rent a Car | 2.62E-03 | 2.62E-03 | 0 | 0 | 3.23E-05 | 0 |
| VAG830192 Terminated 9/28/04 | Gasoline Station | 1.94E-03 | 1.94E-03 | 0 | 0 | 0 | 0 |
| VAG830227 | Miller Mart #37 | 2.32E-02 | 2.32E-02 | 0 | 0 | 2.32E-02 | 0 |

Nonpoint sources of pollution that were not driven by runoff (*e.g.*, direct deposition of fecal matter to the the stream by wildlife) were modeled similarly to point sources. These sources, as well as land-based sources, are identified in the following sections.

### 4.6.2 Private Residential Sewage Treatment

The number of septic systems in the sixteen subwatersheds modeled for water quality in the Warwick River wastershed was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the watersheds to enumerate the septic systems. Each residential land use area was assigned a number of septic systems based on census data. A total of 1,922 septic systems were estimated in the watershed in 1990. During allocation runs, the number of households was projected to 2006 values, based on current growth rates (USCB, 2000) resulting in 2,289 septic systems (Table 4.8).

**Table 4.8 Estimated 2006 residential sewage treatment systems in the Warwick River watershed.**

| Impaired Segment | Septic Systems | Failing Septic Systems | Uncontrolled Discharges |
|---|---|---|---|
| Baptist Run | 132 | 28 | 1 |
| Deep Creek | 721 | 149 | 12 |
| Warwick River | 2,123 | 482 | 80 |
| Skiffes Creek | 166 | 36 | 8 |

#### *4.6.2.1 Failing Septic Systems*

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

#### *4.6.2.2 Uncontrolled Discharges*

Uncontrolled discharges were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via uncontrolled discharges. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Fecal coliform loads for each discharge were calculated based on the fecal density of human waste and the wasteload for the average size household in the subwatershed. The loadings from uncontrolled discharges were applied directly to the stream in the same manner that point sources are handled in the model.

#### *4.6.2.3 Sewer System Overflows*

From 9/1999 to 5/2006 there were 140 total reported sewer overflows. The majority of sewer overflow event reports contained an estimate of the volume of sewage discharged, so the model included these discharges. It was assumed that additional occurrences of sewer overflows were likely undetected; therefore, a statistical analysis of meteorological events and sewer overflows was performed to determine the flow of water and sewage to surface waters during rainfall events. The concentration of fecal bacteria discharged was considered equivalent to the concentration of septic tank effluent, and the magnitude of the discharge was estimated as the average discharge volume of reported sewer overflow events. As some biodegradation occurs in a septic system, it is felt that the estimate of concentration is conservative.

### 4.6.3 Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Livestock numbers determined for 2006 were used for the allocation runs, while values during 2002 were used for the calibration and 1997 for validation runs. The numbers are based on data provided by VASS and verified by CSWCD. For land-applied waste, the fecal coliform density as-excreted multiplied by the die-off factor was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (Table 3.8). The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

#### *4.6.3.1 Land Application of Collected Manure*

The number of livestock in the Warwick River watershed is not enough to require the collection and storage of manure. It was assumed that all livestock waste is deposited on pasture areas.

#### *4.6.3.2 Deposition on Land*

For cattle, the amount of waste deposited on land per day was a portion of the total waste produced per day. The portion was calculated based on the study entitled “Modeling Cattle Stream Access” conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for the Virginia Department of Conservation and Recreation (VADCR). The portion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

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

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

#### *4.6.3.3 Direct Deposition to Streams*

Beef cattle are the primary source of direct deposition by livestock in the Warwick River watershed. The amount of waste deposited in streams each day was a portion of the total waste produced per day by cattle. First, the portion of manure deposited in “stream access” areas was calculated based on the “Modeling Cattle Stream Access” study. The portion was calculated as follows:

*Portion = (time in stream access areas)/(24 hr)*

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

### 4.6.4 Biosolids

Investigation of VDH data indicated that no biosolids applications have occurred within the Warwick River watershed.

### 4.6.5 Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (section 3.3.4). An example of one of these layers is shown in Figure 4.7. This layer was used in conjunction with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal coliform loads for each land segment were calculated by multiplying the waste load, fecal coliform densities, and number of animals for each species.

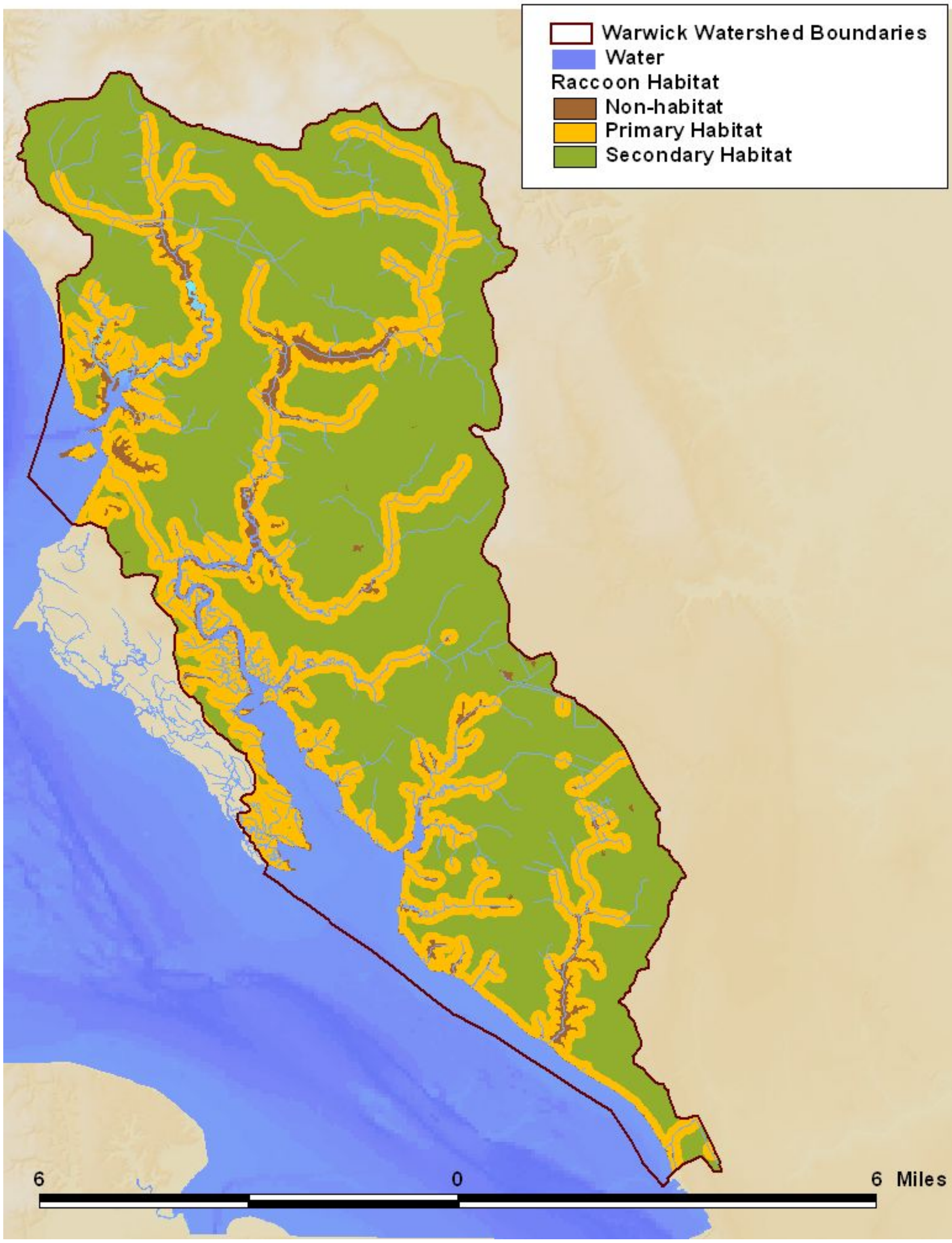


**Figure 4.7 Example of raccoon habitat layer in the Warwick River watershed as developed by MapTech.**

Goose and duck waste loads were not varied based on migration patterns to account for the resident population of birds. No seasonal variation was assumed for the remaining species. For each species, a portion of the total waste load was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (Table 3.13). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams. No long-term (2006) adjustments were made to wildlife populations, as there was no available data to support such adjustments.

### 4.6.6 Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), waste load, and fecal coliform density are reported in section 3.3.2. Waste from pets was distributed on residential land uses. The number of households was determined from the 1990 and 2000 Census (USCB, 1990 and USCB, 2000). The number of animals per subwatershed was determined by multiplying the number of households in each subwatershed by the population density of each animal. The amount of fecal coliform deposited daily by pets in each land use segment was calculated by multiplying the waste load, fecal coliform density, and number of animals for both cats and dogs. The waste load was assumed not to vary seasonally. The populations of cats and dogs were projected from 1990 data to 1997, 2002, and 2006 to coincide with modeling periods.

## *4.7 Sensitivity Analyses*

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. Sensitivity analyses were conducted to assess the sensitivity of the model to changes in hydrologic and water quality parameters as well as to assess the impact of unknown variability in source allocation (*e.g.,* seasonal and spatial variability of waste production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads). Additional analyses were performed to define the sensitivity of the modeled system to growth or technology changes that impact waste production rates.

### 4.7.1 Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in Table 4.9, with base values for the model runs given. The parameters were adjusted to -50%, -10%, 10%, and 50% of the base value (unless otherwise noted in Table 4.8), and the model was run for water years 2000-2003. Where an increase of 50% exceeded the maximum value for the parameters, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration such as INFILT (Infiltration) and LZSN (Lower Zone Storage), and to a lesser extent by UZSN (Upper Zone Storage), which governs surface transport, and LZETP (Lower Zone Evapotranspiration), which affects soil moisture. Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows were AGWRC (Groundwater Recession Rate), BASETP (Base Flow Evapotranspiration), LZETP and, to a lesser extent, Infiltration. The responses of these and other hydrologic outputs are reported in Table 4.10.

**Table 4.9 HSPF base parameter values used to determine hydrologic model response.**

| Parameter | Description | Units | Base Value |
|---|---|---|---|
| LZSN | Lower Zone Nominal Storage | in | 9.3427 – 12.891 |
| INFILT | Soil Infiltration Capacity | in/hr | 0.0490-0.0828 |
| AGWRC | Groundwater Recession Rate | --- | 0.980 |
| BASETP | Base Flow Evapotranspiration | --- | 0.01 |
| INTFW | Interflow Inflow | --- | 1.0 |
| DEEPFR | Groundwater Inflow to Deep Recharge | --- | 0.01 |
| MON-INTERCEP | Monthly Interception Storage Capacity | in | 0.01 – 0.20 |
| MON-UZSN | Monthly Upper Zone Nominal Storage | in | 0.50 – 1.29 |
| MON-MANNING | Monthly Manning's *n* for Overland Flow | --- | 0.01 – 0.37 |
| MON-LZETP | Monthly Lower Zone Evapotranspiration | in | 0.01 – 0.80 |

**Table 4.10 HSPF Sensitivity analysis results for hydrologic model parameters, subwatershed 6, Warwick River.**

| | | Percent Change In | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Model Parameter** | **Parameter Change (%)** | **Total Flow** | **High Flows** | **Low Flows** | **Winter Flow Volume** | **Spring Flow Volume** | **Summer Flow Volume** | **Fall Flow Volume** | **Total Storm Volume** |
| AGWRC[1] | 0.85 | -0.43 | 10.36 | -24.69 | 6.61 | -2.58 | 0.65 | -7.00 | 10.81 |
| AGWRC[1] | 0.92 | -0.25 | 5.28 | -15.53 | 5.01 | -1.41 | 0.35 | -5.48 | 9.62 |
| AGWRC[1] | 0.96 | 0.03 | 1.97 | -6.85 | 2.53 | -0.08 | -0.24 | -2.35 | 5.53 |
| AGWRC[1] | 0.999 | -17.61 | -7.10 | -19.65 | -18.00 | -20.21 | -13.62 | -18.74 | -28.89 |
| BASETP | -50 | 0.15 | -0.24 | 0.65 | -0.12 | 0.32 | 0.37 | 0.00 | -0.04 |
| BASETP | -10 | 0.03 | -0.05 | 0.13 | -0.02 | 0.06 | 0.08 | 0.00 | -0.01 |
| BASETP | 10 | -0.03 | 0.05 | -0.13 | 0.03 | -0.06 | -0.08 | 0.00 | 0.01 |
| BASETP | 50 | -0.15 | 0.25 | -0.66 | 0.13 | -0.32 | -0.37 | 0.01 | 0.04 |
| DEEPFR | -50 | 0.20 | 0.07 | 0.25 | 0.19 | 0.20 | 0.18 | 0.20 | 0.21 |
| DEEPFR | -10 | 0.04 | 0.01 | 0.05 | 0.04 | 0.04 | 0.04 | 0.04 | 0.04 |
| DEEPFR | 10 | -0.04 | -0.01 | -0.05 | -0.04 | -0.04 | -0.04 | -0.04 | -0.04 |
| DEEPFR | 50 | -0.20 | -0.07 | -0.25 | -0.19 | -0.20 | -0.18 | -0.20 | -0.21 |
| INFILT | -50 | -1.34 | 15.84 | -11.69 | 1.86 | -2.02 | -1.36 | -4.10 | 2.06 |
| INFILT | -10 | -0.24 | 2.37 | -1.81 | 0.28 | -0.30 | -0.25 | -0.73 | 0.29 |
| INFILT | 10 | 0.22 | -2.09 | 1.63 | -0.25 | 0.27 | 0.23 | 0.69 | -0.27 |
| INFILT | 50 | 1.02 | -8.58 | 6.97 | -0.94 | 1.05 | 1.06 | 3.17 | -1.24 |
| INTFW | -50 | -0.39 | 4.02 | -0.07 | -0.70 | -0.65 | -0.31 | 0.18 | -0.79 |
| INTFW | -10 | -0.06 | 0.54 | 0.05 | -0.10 | -0.11 | -0.04 | 0.03 | -0.18 |
| INTFW | 10 | 0.05 | -0.44 | -0.07 | 0.08 | 0.10 | 0.02 | -0.03 | 0.13 |
| INTFW | 50 | 0.21 | -1.58 | -0.33 | 0.37 | 0.44 | 0.09 | -0.13 | 0.18 |
| LZSN | -50 | 3.21 | 10.76 | -4.35 | 6.31 | 2.29 | 0.27 | 4.46 | 7.48 |
| LZSN | -10 | 0.57 | 1.69 | -0.59 | 0.98 | 0.45 | 0.18 | 0.72 | 1.21 |
| LZSN | 10 | -0.57 | -1.58 | 0.47 | -0.94 | -0.45 | -0.22 | -0.73 | -1.14 |
| LZSN | 50 | -1.10 | -3.01 | 0.79 | -1.80 | -0.84 | -0.46 | -1.43 | -2.14 |
| CEPSC | -50 | 0.36 | -0.16 | 0.70 | -0.15 | 0.77 | 0.56 | 0.17 | 0.56 |
| CEPSC | -10 | 0.06 | -0.03 | 0.10 | -0.03 | 0.14 | 0.09 | 0.00 | 0.10 |
| CEPSC | 10 | -0.06 | 0.02 | -0.11 | 0.04 | -0.16 | -0.10 | 0.01 | -0.09 |
| CEPSC | 50 | -0.59 | -0.15 | -0.97 | -0.15 | -0.94 | -0.79 | -0.41 | -0.62 |
| LZETP | -50 | 4.19 | 0.61 | 5.43 | 5.52 | 2.92 | 2.83 | 5.94 | 2.79 |
| LZETP | -10 | -0.31 | -4.54 | 2.51 | -0.84 | 0.29 | 0.16 | -1.02 | -1.56 |
| LZETP | 10 | -1.51 | -5.75 | 1.56 | -2.58 | -0.53 | -0.47 | -2.79 | -2.73 |
| LZETP | 50 | -2.22 | -6.48 | 0.95 | -3.70 | -1.09 | -0.83 | -3.69 | -3.53 |
| NSUR | -50 | 0.18 | 3.21 | -1.27 | 0.71 | 0.25 | 0.11 | -0.41 | 0.54 |
| NSUR | -10 | 0.03 | 0.51 | -0.19 | 0.08 | 0.05 | 0.05 | -0.10 | 0.08 |
| NSUR | 10 | -0.02 | -0.44 | 0.17 | -0.08 | -0.03 | -0.04 | 0.09 | -0.07 |
| NSUR | 50 | -0.11 | -1.96 | 0.81 | -0.47 | 0.13 | -0.09 | -0.04 | -0.35 |
| UZSN | -50 | 3.91 | 14.16 | -2.40 | 2.97 | 3.10 | 7.10 | 2.12 | 5.69 |
| UZSN | -10 | 0.57 | 2.07 | -0.28 | 0.49 | 0.39 | 1.08 | 0.28 | 0.89 |
| UZSN | 10 | -0.50 | -1.80 | 0.21 | -0.45 | -0.30 | -0.95 | -0.26 | -0.77 |
| UZSN | 50 | -1.96 | -7.15 | 0.76 | -2.00 | -1.02 | -3.61 | -1.08 | -2.91 |

[1]Actual parameter value used

### 4.7.2 Water Quality Parameter Sensitivity Analysis

The model was run during the corresponding water quality calibration time period for the fecal coliform water quality sensitivity analysis. The four HSPF parameters impacting the model's water quality response (Table 4.11) were increased and decreased by amounts that were consistent with the range of values for the parameter. Deviations from the base run are given in Table 4.12. First Order Decay (FSTDEC) and the mixing coefficient between tidal inputs and the RCHRES were the parameters with the greatest influence on the monthly fecal coliform average concentration, although MON-SQOLIM also showed potential to influence this value. The parameter wash off (WSQOP) was varied while staying within typical value range. Graphical depictions of the results of this sensitivity analysis can be seen in Figures 4.8 through 4.11.

**Table 4.11 Base parameter values used to determine water quality model response.**

| Parameter | Description | Units | Typical Range of Parameter Value | Base Value |
|---|---|---|---|---|
| MON-SQOLIM | Maximum FC Accumulation on Land | FC/ac | 1.0E-02 – 1.0E+30 | 0 – 4.6E+10 |
| WSQOP | Wash-off Rate for FC on Land Surface | in/hr | 0.05 – 3.00 | 0 – 2.8 |
| FSTDEC | In-stream First Order Decay Rate | 1/day | 0.01 – 10.00 | 5.00 |
| Mixing coefficient | Mixing coefficient between tidal inputs and the RCHRES | -- | 0.3 – 0.7 | 0.5 |

**Table 4.12 Percent change in average monthly fecal coliform average for the years 1999 - 2003 for Subwatershed 6.**

| Model Parameter | Parameter % Change | Percent Change in Average Monthly FC Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| FSTDEC[1] | 0.01 | 166.86 | 135.60 | 164.22 | 196.33 | 161.36 | 154.06 | 191.48 | 238.18 | 184.41 | 150.67 | 206.34 | 188.61 |
| FSTDEC | -50% | 50.47 | 41.05 | 46.82 | 52.60 | 50.00 | 49.10 | 58.46 | 72.14 | 54.12 | 46.94 | 58.16 | 54.14 |
| FSTDEC | 50% | -27.56 | -23.63 | -25.42 | -27.37 | -27.38 | -27.30 | -30.81 | -36.27 | -28.54 | -26.16 | -29.73 | -28.32 |
| FSTDEC | 100% | -44.46 | -39.03 | -41.32 | -43.93 | -44.09 | -44.10 | -48.80 | -56.15 | -45.52 | -42.41 | -47.09 | -45.21 |
| | | | | | | | | | | | | | |
| SQOLIM | 10% | 0.80 | 0.29 | 0.42 | 0.14 | 0.13 | 0.74 | 0.20 | 0.20 | 0.17 | 0.22 | 0.08 | 0.22 |
| SQOLIM | 25% | 1.64 | 0.66 | 1.08 | 0.35 | 0.29 | 1.46 | 0.45 | 0.48 | 0.40 | 0.41 | 0.17 | 0.44 |
| SQOLIM | 50% | 2.56 | 0.98 | 1.64 | 0.60 | 0.46 | 2.45 | 0.71 | 0.75 | 0.64 | 0.70 | 0.27 | 0.69 |
| SQOLIM | 100% | 4.69 | 1.74 | 2.86 | 1.02 | 0.78 | 4.35 | 1.20 | 1.28 | 1.08 | 1.23 | 0.48 | 1.27 |
| | | | | | | | | | | | | | |
| WSQOP | -50% | 1.75 | 1.71 | 1.47 | 0.55 | 0.48 | 1.13 | 0.59 | 0.65 | 0.55 | 0.11 | 0.42 | 1.14 |
| WSQOP | -10% | 0.30 | 0.27 | 0.24 | 0.09 | 0.08 | 0.25 | 0.10 | 0.11 | 0.09 | 0.04 | 0.05 | 0.16 |
| WSQOP | 10% | -0.28 | -0.25 | -0.22 | -0.08 | -0.08 | -0.25 | -0.10 | -0.10 | -0.08 | -0.04 | -0.05 | -0.14 |
| WSQOP | 50% | -1.25 | -1.04 | -0.96 | -0.33 | -0.35 | -1.17 | -0.43 | -0.46 | -0.33 | -0.21 | -0.17 | -0.54 |
| | | | | | | | | | | | | | |
| Mixing coefficient | -40% | -10.63 | -5.48 | -5.39 | -21.19 | -26.29 | -11.35 | -16.95 | -23.92 | -15.63 | -20.74 | -23.49 | -20.00 |
| Mixing coefficient | -20% | -5.31 | -2.74 | -2.70 | -10.60 | -13.14 | -5.68 | -8.48 | -11.96 | -7.81 | -10.37 | -11.74 | -10.00 |
| Mixing coefficient | 20% | 5.31 | 2.74 | 2.70 | 10.60 | 13.14 | 5.68 | 8.48 | 11.96 | 7.81 | 10.37 | 11.74 | 10.00 |
| Mixing coefficient | 40% | 10.63 | 5.48 | 5.39 | 21.19 | 26.29 | 11.35 | 16.95 | 23.92 | 15.63 | 20.74 | 23.49 | 20.00 |

[1] Actual value

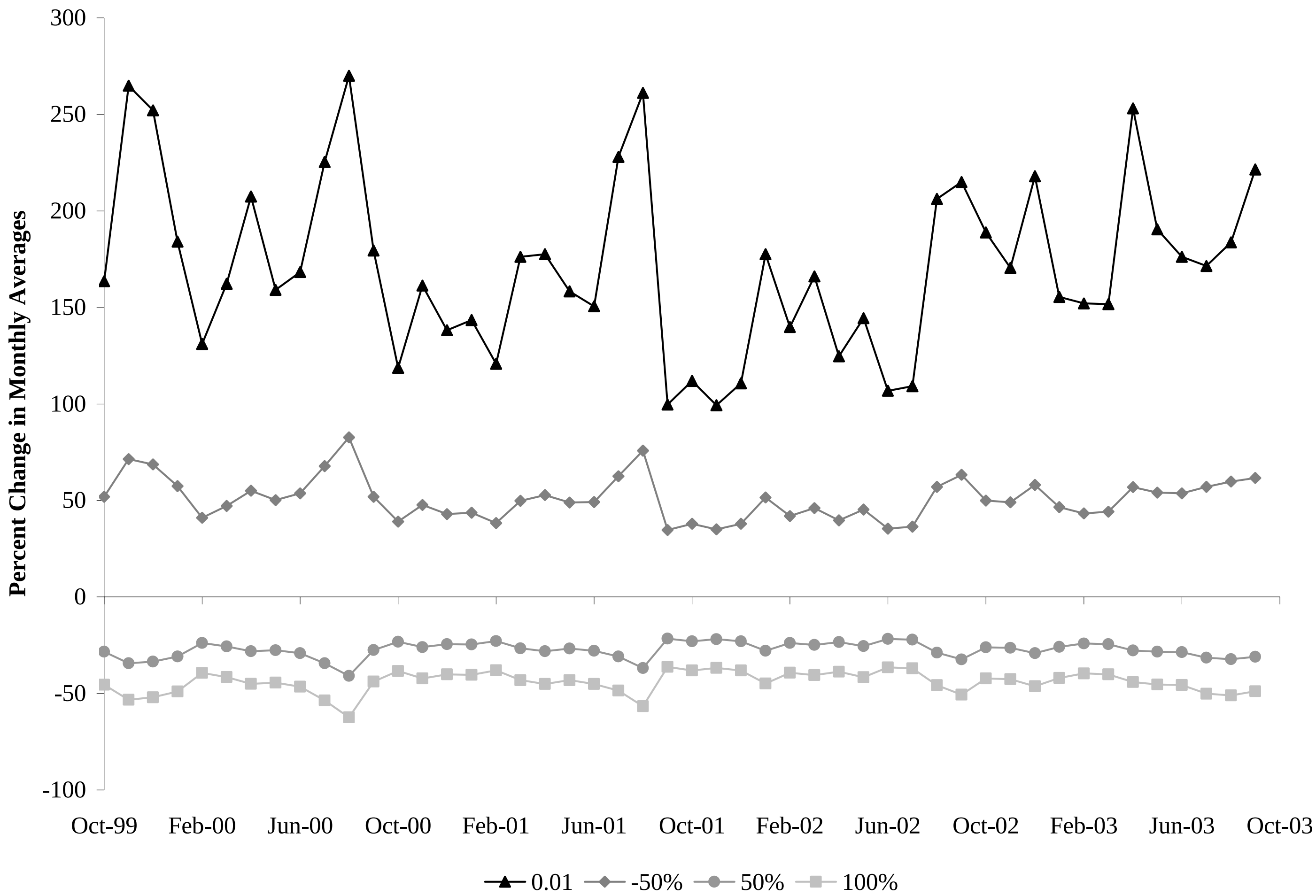


**Figure 4.8 Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, as affected by changes in the in-stream first-order decay rate (FSTDEC).**

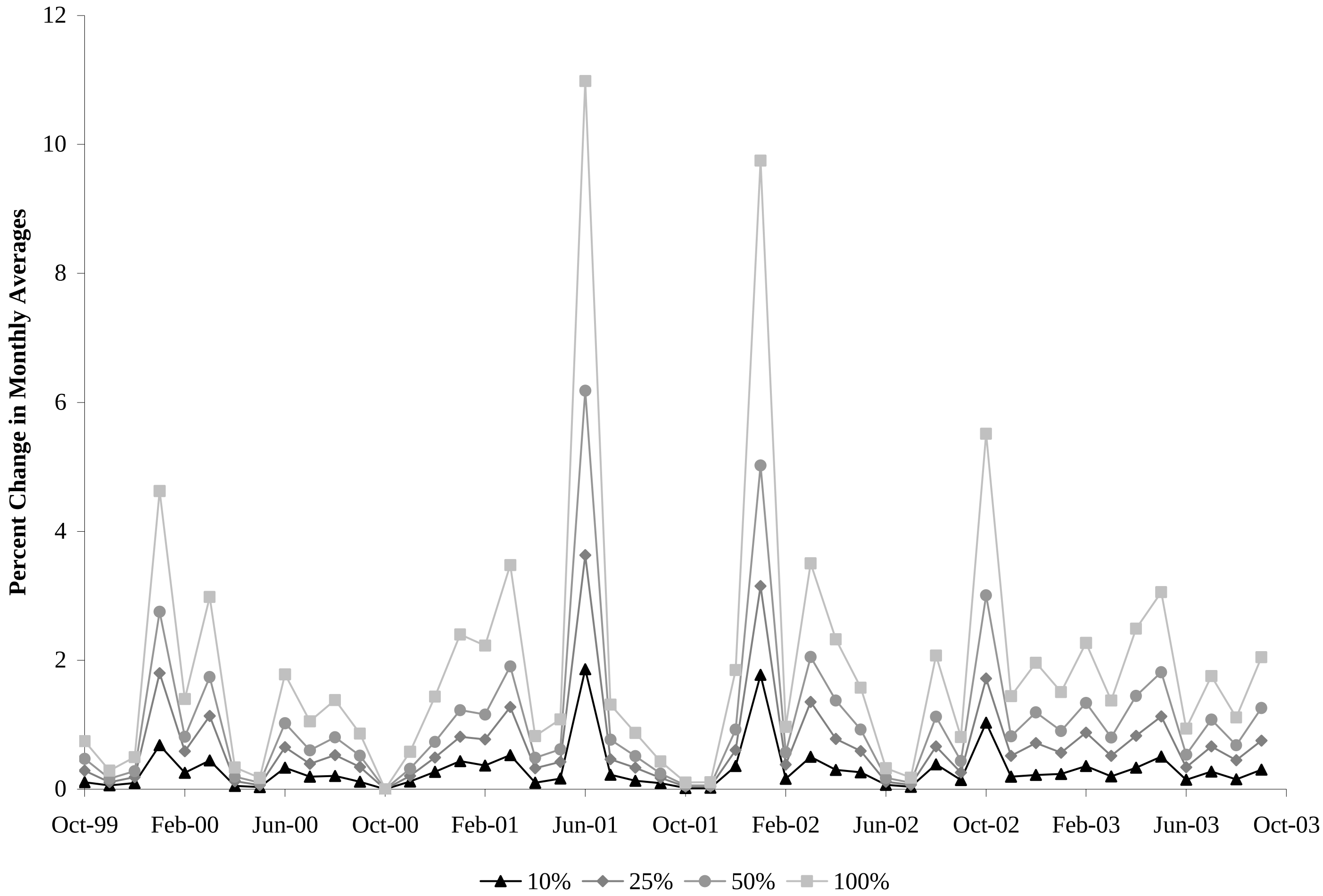


**Figure 4.9** **Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).**

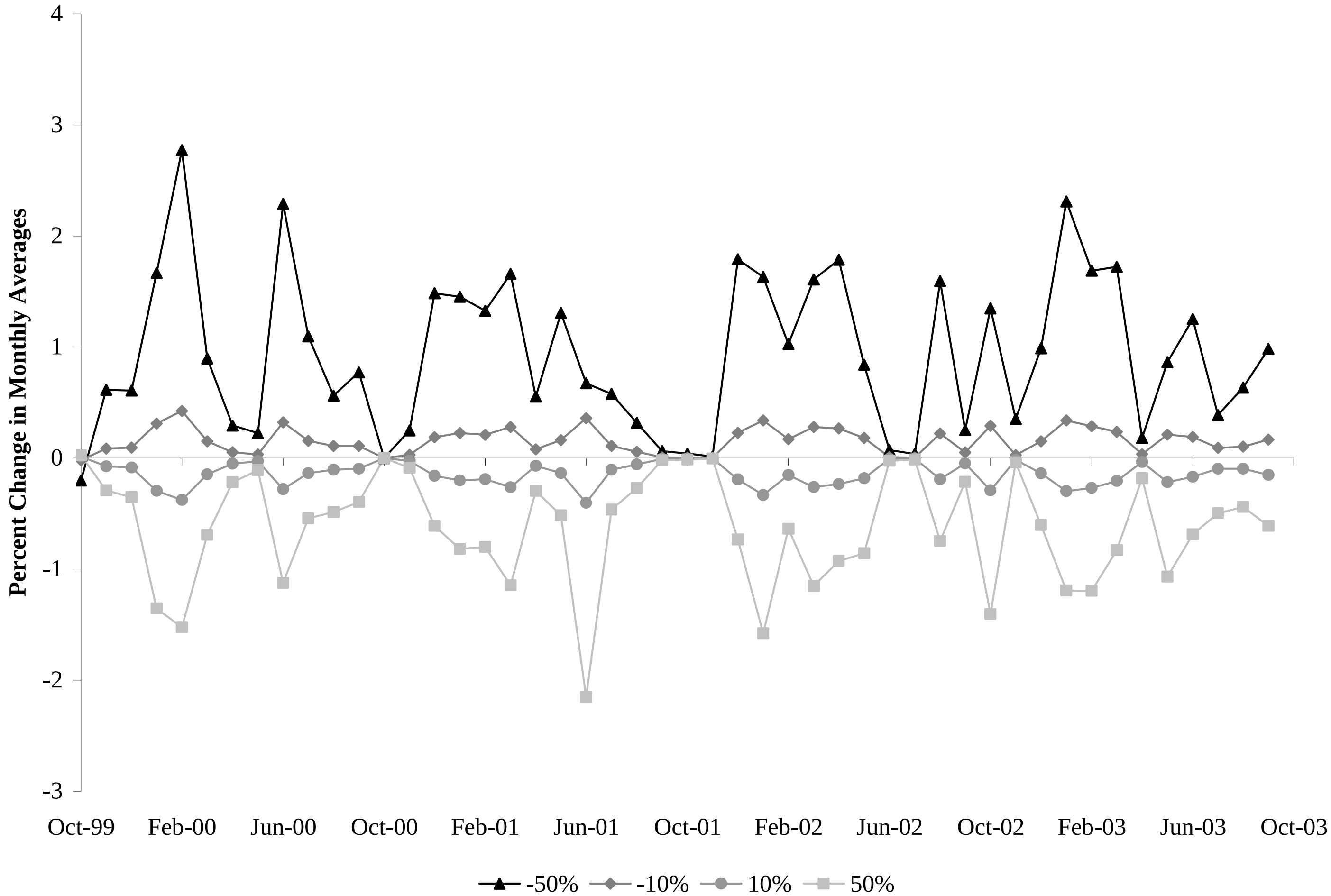


**Figure 4.10 Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, as affected by changes in the wash-off rate from land surfaces (WSQOP).**

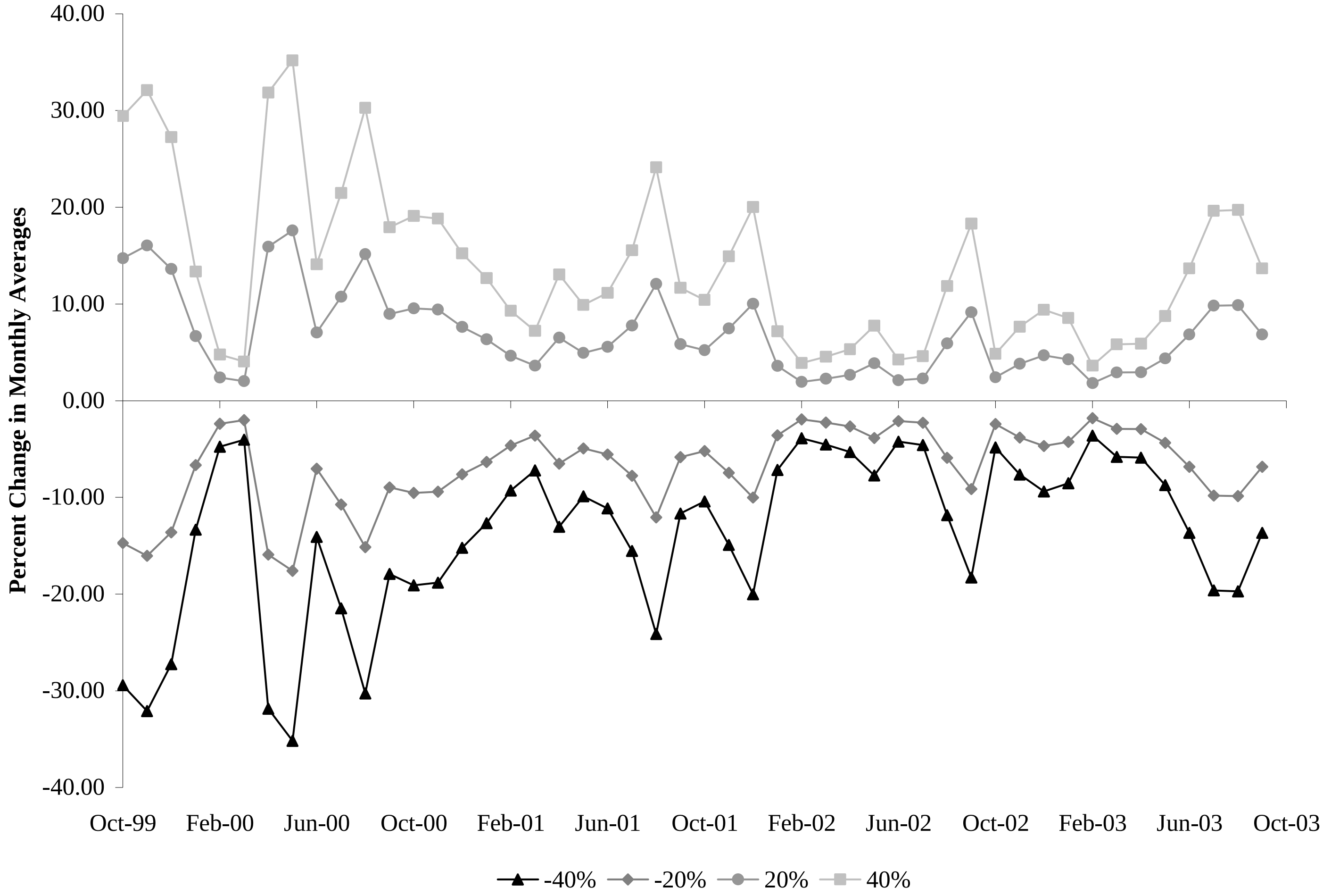


**Figure 4.11 Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, as affected by changes in the mixing coefficient between tidal inputs and the RCHRES.**

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. In Figure 4.12, the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs slightly between land applied and direct loadings; a 100% increase in the land-applied loads results in an increase of approximately 4.6% in stream loads, while a 100% increase in direct loads results in an increase approximately 43.7% for in-stream loads. In contrast, the sensitivity analysis of monthly fecal coliform average concentrations showed that land applied loads had a variable impact, while direct loads had a more consistent impact (Figures 4.13 and 4.14).

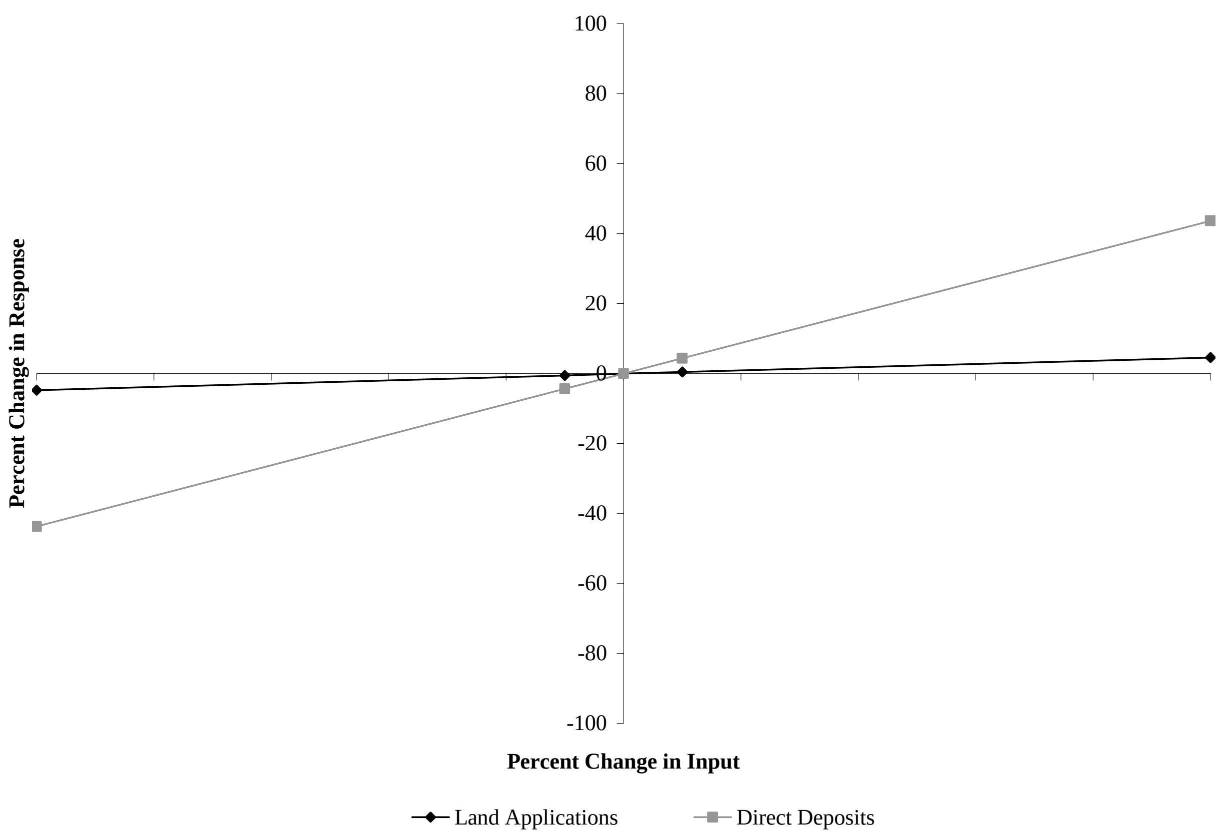


**Figure 4.12 Results of total loading sensitivity analysis at subwatershed 6, Warwick River.**

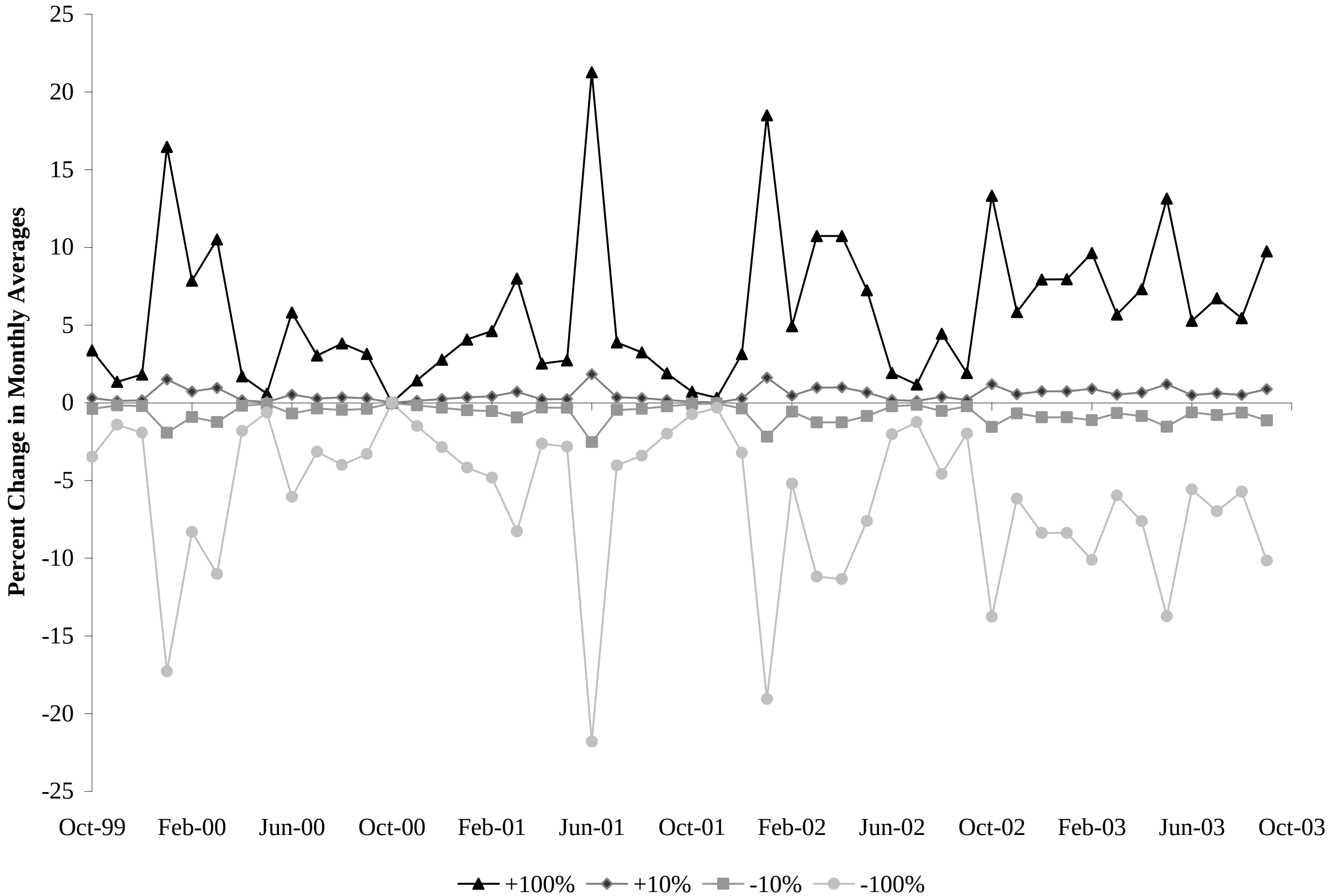


**Figure 4.13 Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, Warwick River watershed, as affected by changes in land-based loadings.**

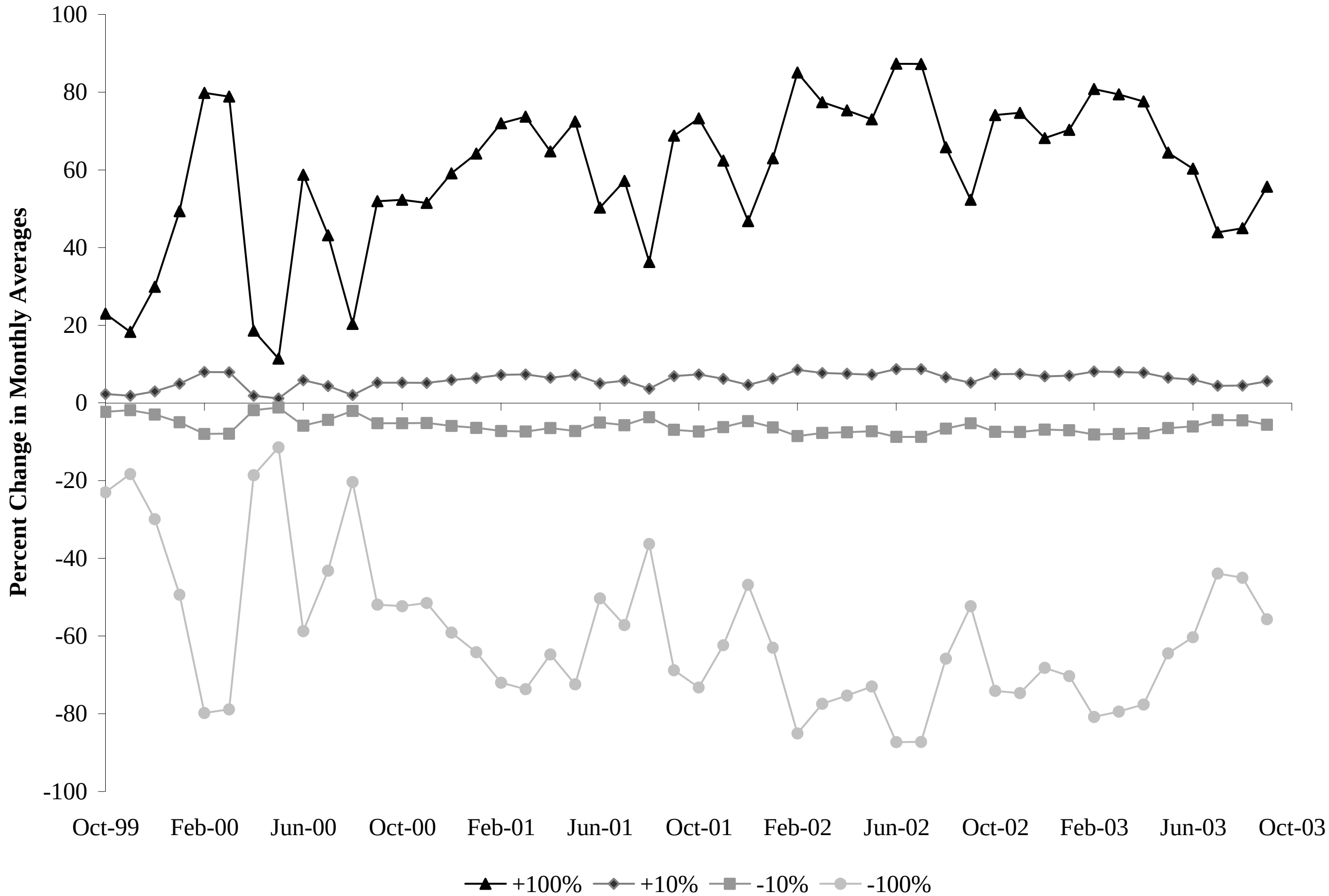


**Figure 4.14 Results of sensitivity analysis on monthly geometric-mean concentrations at subwatershed 6, Warwick River watershed, as affected by changes in loadings from direct nonpoint sources.**

## 4.8 Model Calibration and Validation Processes

Calibration and validation are performed in order to ensure that the model accurately represents the hydrologic and water quality processes in the watershed. The model's hydrologic parameters were set based on available soils, land use, and topographic data. Through calibration, these parameters were adjusted within appropriate ranges until the model performance was deemed acceptable.

### 4.8.1 Hydrologic Calibration and Validation

HSPF parameters that can be adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (SLSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), slope of overland flow plane (LSUR), groundwater recession flow (KVARY), maximum and minimum air temperature affecting PET (PETMAX, PETMIN, respectively), infiltration equation exponent (INFEXP), infiltration capacity ratio (INFILD), active groundwater storage PET (AGWETP), Manning's *n* for overland flow plane (NSUR), interception (RETSC), and the weighting factor for hydraulic routing (KS). Table 4.13 contains the typical range for the above parameters along with the initial estimate and final calibrated value. State variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

NCDC weather stations Newport News (446054), Langley Air Force Base (444720), and Smithfield (447864) were used to supply precipitation input for the HSPF model. For the entire modeling period, only daily precipitation values were available, thus daily rainfall values were interpolated to hourly values in order to provide model input on an hourly basis. This interpolation was performed in an HSPF utility called WDMUtil, and is referred to as disaggregation. In this process, a daily rainfall total is divided up into hourly values using a representative distribution scheme. Daily values were disaggregated using a station matching disaggregation scheme. This procedure involved identifying a rain gage reporting hourly data in close proximity to the Warwick River watershed. In this case, the distribution of rainfall at the station within the watershed was disaggregated based on the precipitation pattern reported at the hourly station Williamsburg 2N (449151).

The model was calibrated for hydrologic accuracy using discharge over the Skiffes Creek Reservoir Dam. These discharge values represented flow from subwatershed 15. The results of the hydrology calibration were acceptable as shown in Figure 4.15. When the observed data showed zero flow, HSPF simulated no flow as well.

**Table 4.13 Model parameters utilized for hydrologic calibration.**

| Parameter | Units | Possible Range of Parameter Value | Initial Parameter Estimate | Calibrated Parameter Value |
|---|---|---|---|---|
| FOREST | --- | 0.0 – 0.95 | 1 | 1 |
| LZSN | in | 2.0 – 15.0 | 9.427 – 12.891 | 9.427 – 12.891 |
| INFILT | in/hr | 0.001 – 0.50 | 0.0392 – 0.0662 | 0.0490 – 0.0828 |
| LSUR | ft | 100 – 700 | 9.97 – 700.0 | 9.97 – 700.0 |
| SLSUR | --- | 0.001 – 0.30 | 0.001 – 0.065 | 0.001 – 0.065 |
| KVARY | l/in | 0.0 – 5.0 | 0.0 | 0.0 |
| AGWRC | l/day | 0.85 – 0.999 | 0.980 | 0.980 |
| PETMAX | degF | 32.0 – 48.0 | 40.0 | 40.0 |
| PETMIN | degF | 30.0 – 40.0 | 35.0 | 35.0 |
| INFEXP | --- | 1.0 – 3.0 | 2.0 | 2.0 |
| INFILD | --- | 1.0 – 3.0 | 2.0 | 2.0 |
| DEEPFR | --- | 0.0 – 0.50 | 0.01 | 0.01 |
| BASETP | --- | 0.0 – 0.20 | 0.01 | 0.01 |
| AGWETP | --- | 0.0 – 0.20 | 0.0 – 0.01 | 0.0 – 0.01 |
| MON-INTERCEP | in | 0.01 - 0.40 | 0.0 – 0.20 | 0.01 – 0.20 |
| MON-UZSN | in | 0.05 – 2.0 | 0.50 – 2.0 | 0.50 – 2.0 |
| MON-MANNING | --- | 0.01 – 0.50 | 0.0 – 0.37 | 0.01 – 0.37 |
| INTFW | --- | 1.0 – 10.0 | 1.0 | 1.0 |
| IRC | l/day | 0.30 – 0.85 | 0.50 | 0.50 |
| MON-LZETP | --- | 0.1 – 0.9 | 0.0 – 0.80 | 0.01 – 0.80 |
| RETSC | in | 0.0 – 1.0 | 0.1 | 0.1 |
| KS | --- | 0.0 – 0.9 | 0.5 | 0.5 |

Hydrologic validation results are shown in Figure 4.16. These results show that the flow over the dam can be modeled at a different time period and still be accurate.

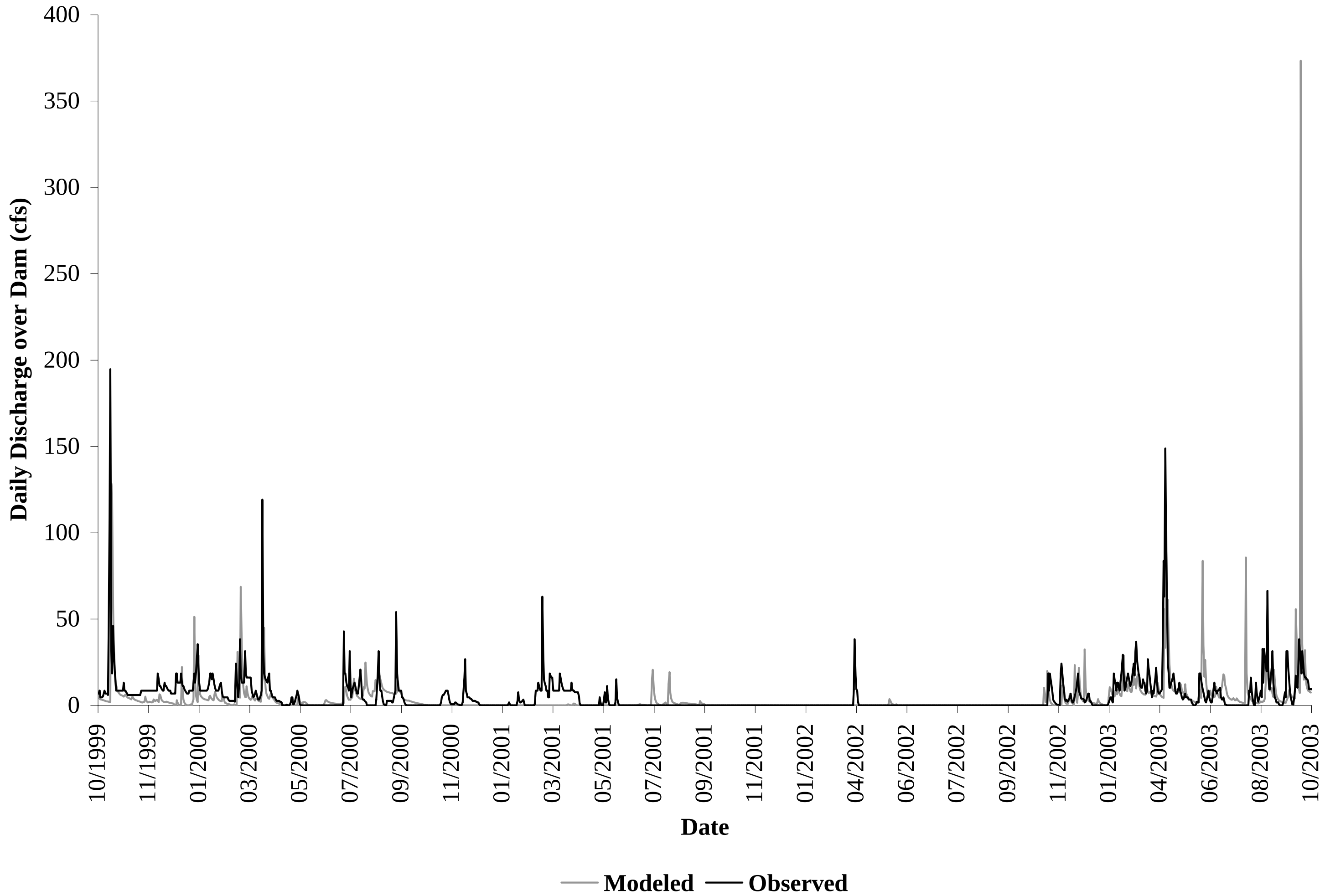


**Figure 4.15 Hydrology calibration results for period 10/01/1999 through 09/30/2003 for Skiffes Creek Reservoir Dam (subwatershed 15).**

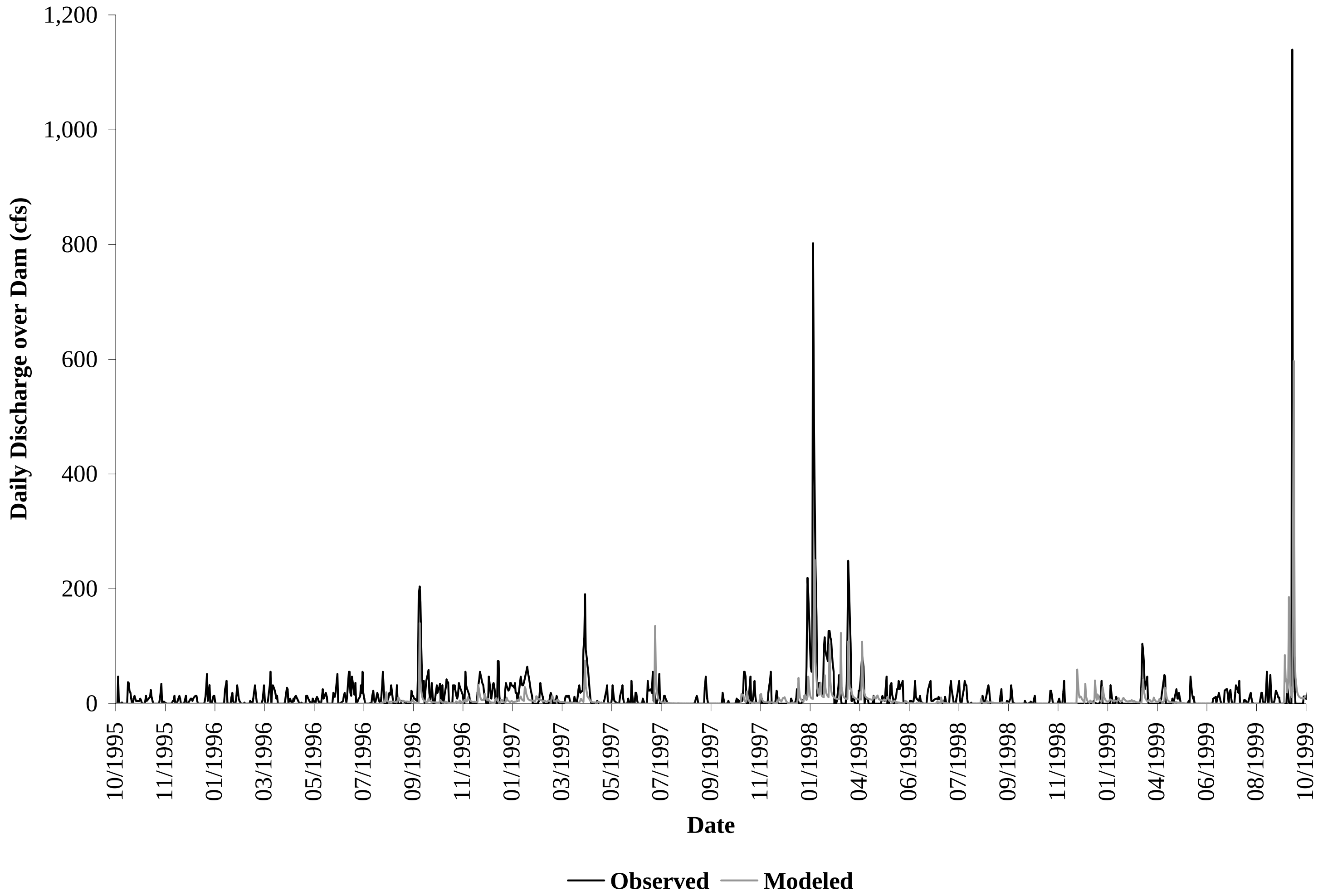


**Figure 4.16 Hydrology validation results for period 10/01/1995 through 09/30/1999 for Skiffes Creek Reservoir Dam (subwatershed 15).**

### 4.8.2 Fecal Coliform Water Quality Calibration

Water quality calibration is complicated by a number of factors; first, water quality concentrations (*e.g.,* fecal coliform) are highly dependent on flow conditions. Any variability associated with the modeling of stream flow compounds the variability in modeling water quality parameters. Second, the concentration of fecal coliform is particularly variable. Variability in location and timing of fecal deposition, variability in the density of fecal coliform bacteria in feces (among species and for an individual animal), environmental impacts on regrowth and die-off, and variability in delivery to the stream all lead to difficulty in measuring and modeling fecal coliform concentrations. Additionally, the VADEQ data were censored at 8,000 cfu/100ml at times and at 16,000 cfu/100ml at other times. The VDH data was censored at 1,200 cfu/100ml. Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

The water quality calibration was conducted from 10/1/1999 through 9/29/2003. Four parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), rate of surface runoff that will remove 90% of stored fecal coliform per hour (WSQOP), and the mixing coefficient between tidal inputs and the RCHRES. All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled fecal coliform concentrations was established (Table 4.14).

**Table 4.14 Model parameters utilized for water quality calibration.**

| Parameter | Units | Typical Range of Parameter Value | Initial Parameter Estimate | Calibrated Parameter Value |
|---|---|---|---|---|
| MON-SQOLIM | FC/ac | 1.0E-02 – 1.0E+30 | 0 – 1.1E+09 | 0 – 4.6E+10 |
| WSQOP | in/hr | 0.05 – 3.00 | 0 – 2.8 | 0 – 2.8 |
| FSTDEC | 1/day | 0.01 – 10.00 | 1.0 | 0.01 – 8.0 |
| Mixing coefficient | --- | 0.3 – 0.7 | 0.7 | 0.5 – 0.7 |

Figures 4.17 through 4.23 show the results of water quality calibration. The daily minimum and maximum fecal coliform concentrations are plotted with the daily average for all tidal subwatersheds. These graphs illustrate that although the range of daily average values may not reach every instantaneous monitored value, the daily minimum and maximum range does include the monitored extremes.

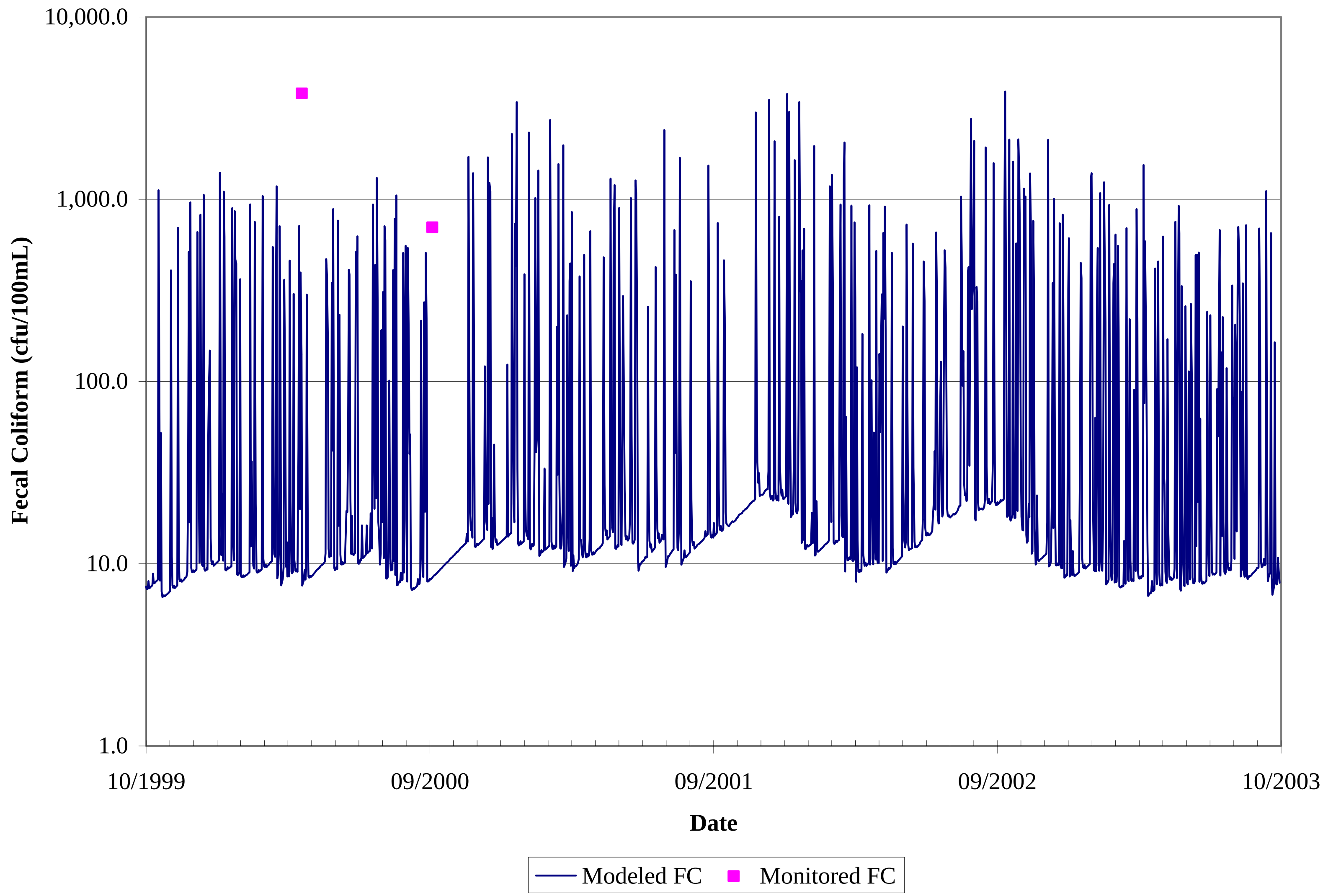


**Figure 4.17 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VADEQ station 2-BAP000.80 in subwatershed 1 in Baptist Run.**

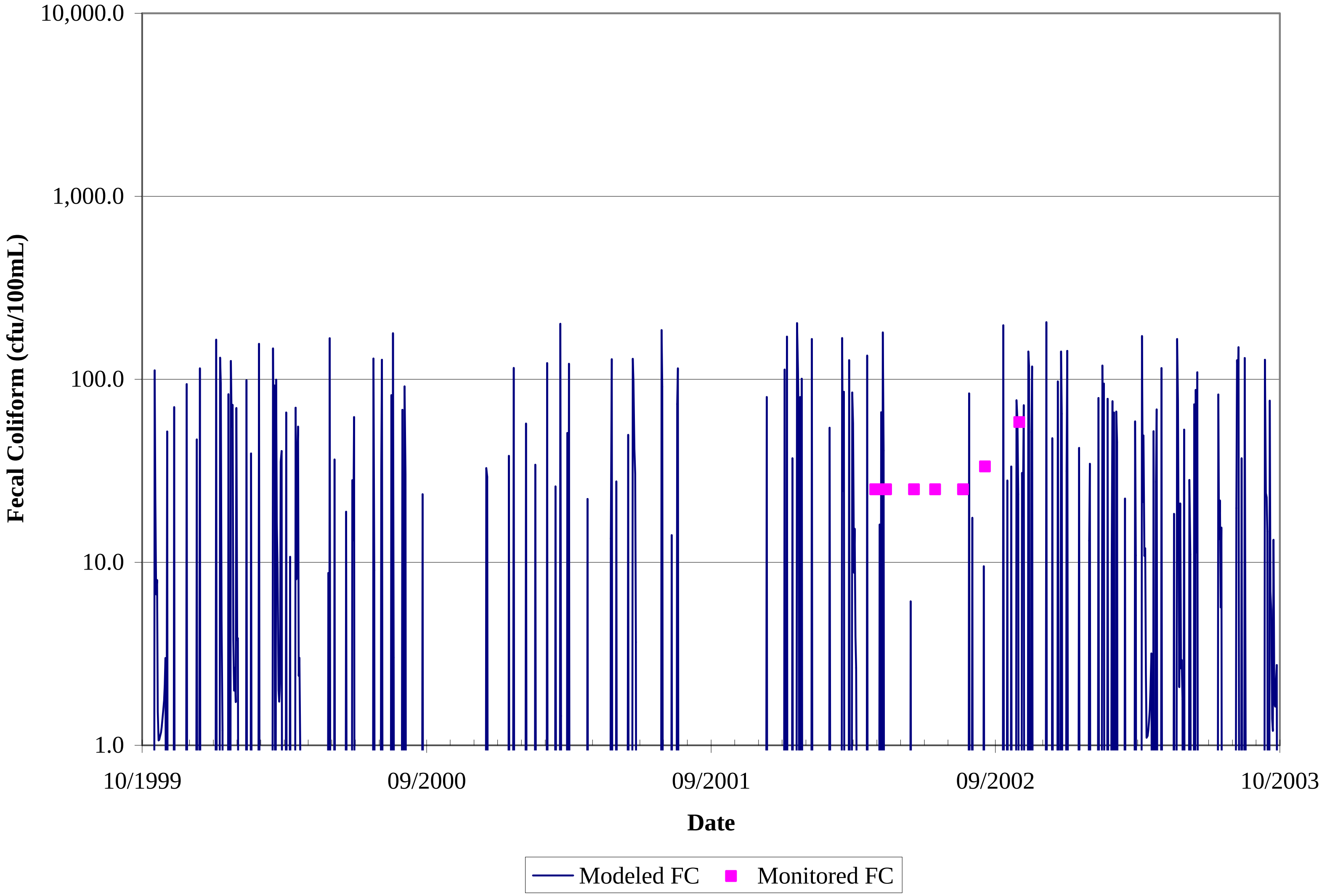


**Figure 4.18 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VADEQ stations 2-LHR000.96, 2-LHR001.76, and 2-LHR002.56 in subwatershed 3 in the Lee Hall Reservoir.**

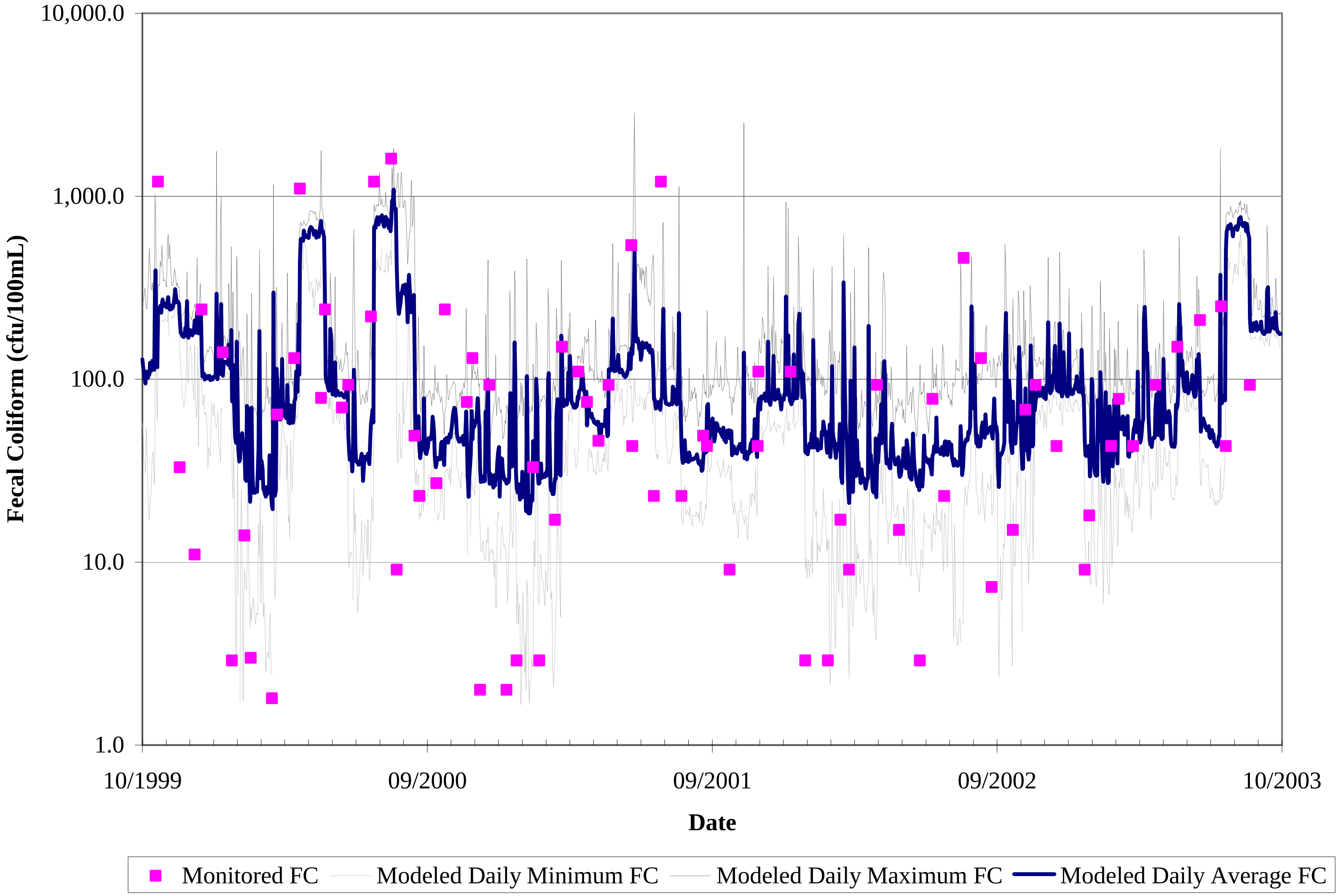


**Figure 4.19 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VADEQ station 2-WWK003.98 and VDH station 58-13 in subwatershed 5 in the Warwick River.**

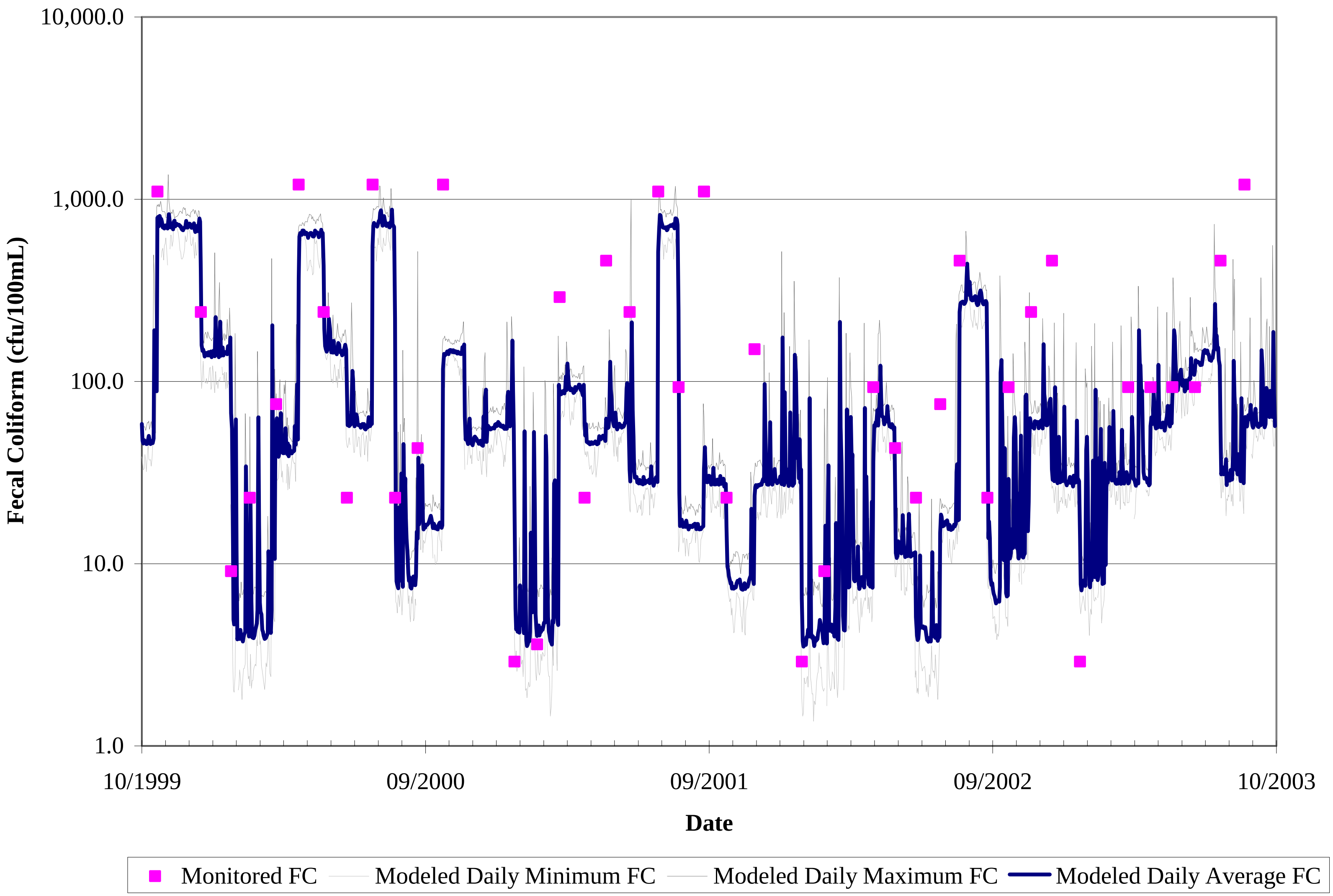


**Figure 4.20 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VDH station 58-13A in subwatershed 9 in Lucas Creek.**

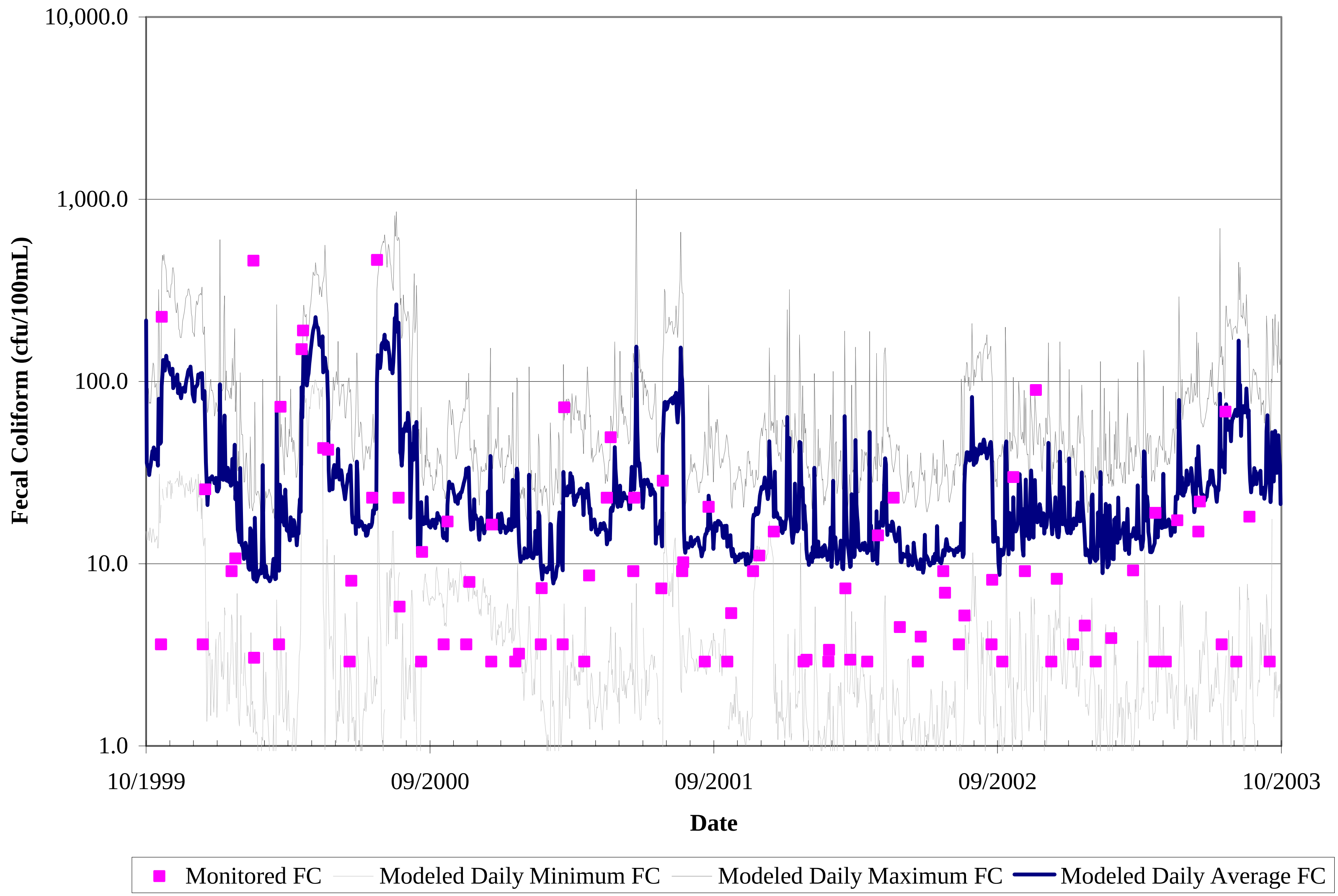


**Figure 4.21 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for numerous VDH stations in subwatershed 6 in the Warwick River and James River.**

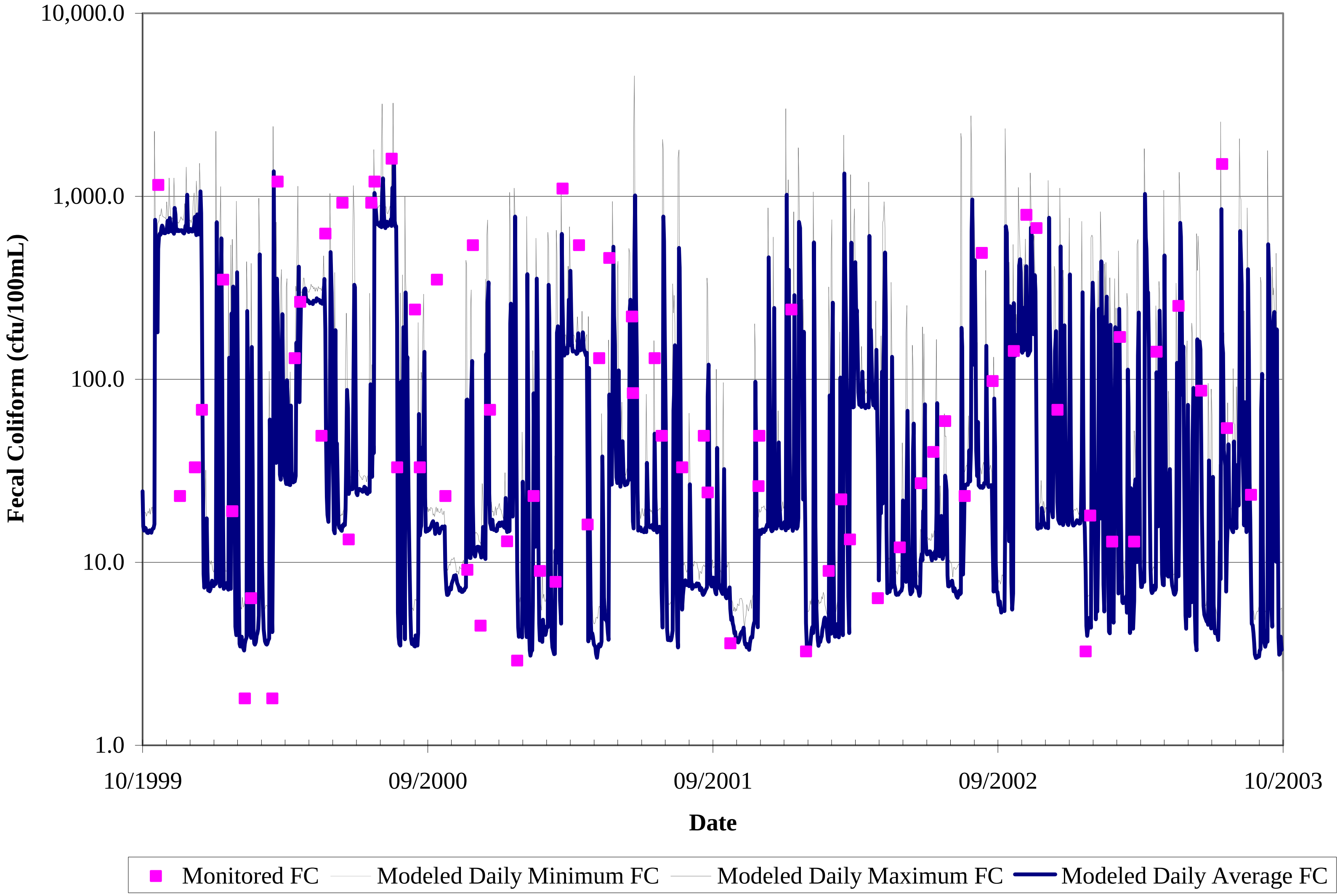


**Figure 4.22 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VDH stations 58-3 and 58-4 and VADEQ station 2-DEP000.26 in subwatershed 12 in Deep Creek.**

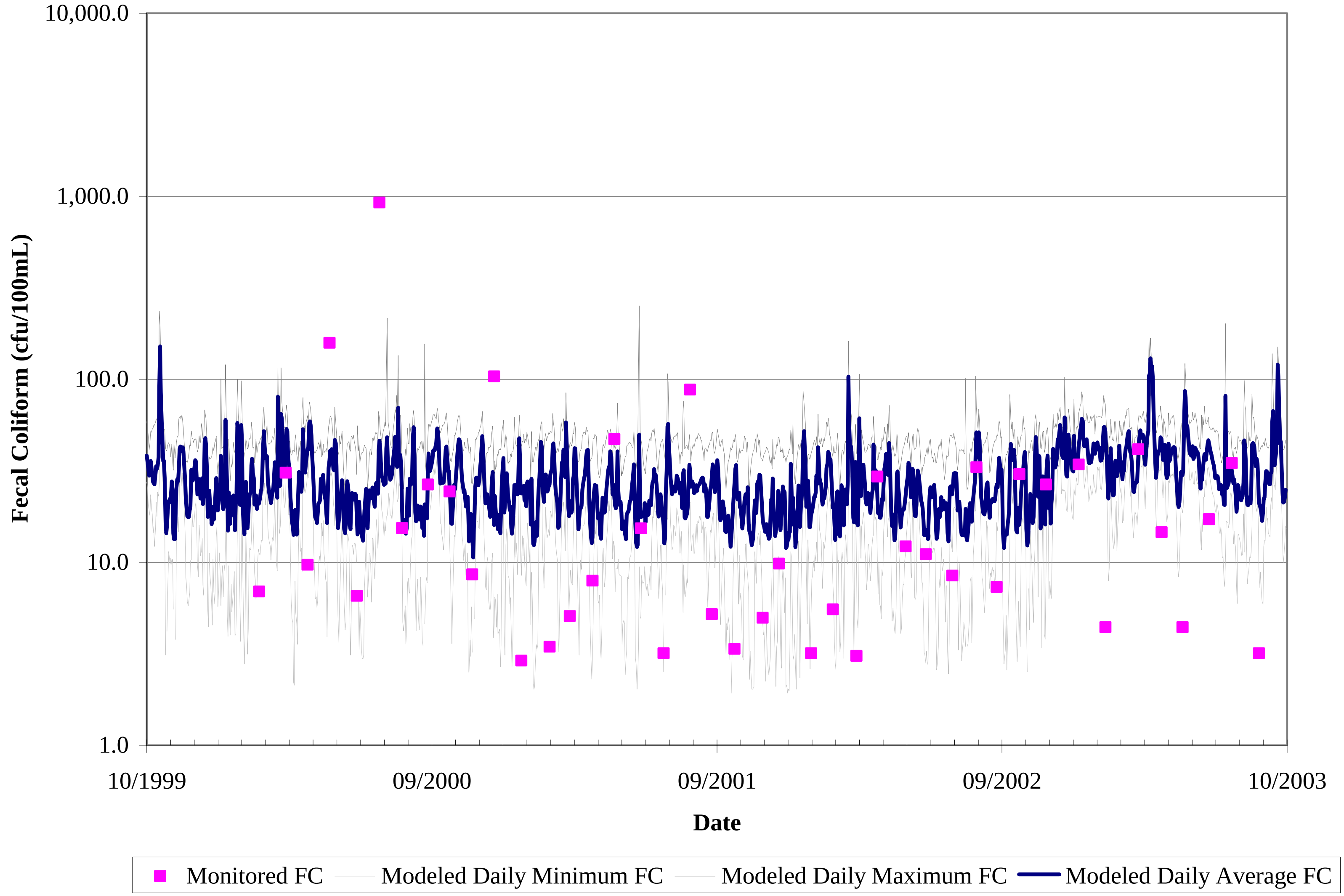


**Figure 4.23 Fecal coliform quality calibration results for 10/1/1999 to 9/29/2003 for VDH stations 59-Z79, 59-AA78, 59-BB77, 59-X81, 59-X79 in subwatershed 16 in Skiffes Creek.**

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

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

where

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

This is a non-traditional use of standard error, applied here to offer a quantitative measure of model accuracy. In this context, standard error measures the variability of the sample mean of the modeled values about an instantaneous observed value. The use of limited instantaneous observed values to evaluate continuous data introduces error and, therefore, increases standard error. The mean of all standard errors for each station analyzed was calculated. Additionally, the maximum concentration values observed in the simulated data were compared with maximum values obtained from uncensored data (Chapter 2) and found to be at reasonable levels (Table 4.15). The standard errors in Table 4.15 range from a low of 1.78 to a high of 75.74. Even the highest value in this range can be considered quite reasonable when one takes into account the censoring of maximum values that is practiced in the collection of actual water quality samples. The standard error will be biased upwards when an observed high value censored at 8,000 or 1,200 cfu/100mL is compared to a simulated high value that may be an order of magnitude or more above the censor limit. Thus, the standard errors calculated for these impairments are considered an indicator of strong model performance. The abbreviations PCRU stands for primary contact recreational use and SHU stands for shellfishing use.

**Table 4.15 Mean standard error of the fecal coliform calibrated model for the Warwick River watershed (10/1/1999 to 9/29/2003).**

| Stream | Sub | Impairment(s)[1] | Station ID(s) | Mean Standard Error | Maximum Simulated Value | Maximum Monitored Value |
|---|---|---|---|---|---|---|
| | | | | ----------(cfu/100 mL)---------- | | |
| Baptist Run | 1 | PCRU | BAP000.80 | 75.74 | 3,899.63 | 3,800.00 |
| Lee Hall Reservoir | 3 | none | LHR000.96, LHR001.76, LHR002.56 | 1.78 | 204.89 | 58.33 |
| Warwick River | 5 | SHU | WWK003.98, 58-13 | 10.69 | 1,085.58 | 1,600.00 |
| Warwick River | 6 | SHU | WWK000.00, 57-E57, 58-A65, 58-C67, 58-0.5, 58-0.5Y, 58-1.5A, 58-10, 58-1Z, 58-2.5A, 58-5, 58-6, 58-8, 58-A62, 58-JRSTP, 58-B64, 58-B65, 58-0.5Z, 58-11, 58-12, 58-1A, 58-7, 58-9 | 2.77 | 264.92 | 463.00 |
| Lucas Creek | 9 | SHU | 58-13A | 21.84 | 876.29 | 1,200.00 |
| Deep Creek | 12 | PCRU | LHR000.96, LHR001.76, LHR002.56 | 15.02 | 1,645.59 | 1,600.00 |
| Skiffes Creek | 16 | SHU | 59-Z79, 59-AA78, 59-BB77, 59-X81, 59-X79 | 4.52 | 151.04 | 921.82 |

[1]PCRU=primary contact recreational use; SHU=shellfishing use

Table 4.16 shows the predicted and observed values for the geometric mean, 90$^{th}$ percentile (of all data within the time period), and single sample (SS) instantaneous violations for the appropriate stream segments. The maximum percent difference between modeled and monitored geometric means, 90$^{th}$ percentiles, and instantaneous violations are within the standard deviation of the observed data at each station and, therefore, the fecal coliform calibration is acceptable.

**Table 4.16 Comparison of modeled and observed fecal coliform calibration results for the Warwick River watershed.**

| | Modeled Fecal Coliform 10/1/99 - 9/29/03 | | | | Monitored Fecal Coliform 10/1/99 - 9/30/03 | | | |
|---|---|---|---|---|---|---|---|---|
| **Subwatershed** | ***n*** | **Geometric Mean (cfu/100ml)** | **90th Percentile (cfu/100ml)** | **SS % violations (cfu/100ml) [1]** | ***n*** | **Geometric Mean (cfu/100ml)** | **90th Percentile (cfu/100ml)** | **SS % violations (cfu/100ml) [1]** |
| 1 | 1,460 | 25.25 | NA | 11.23% | 2 | 1,630.95 | NA | 100% |
| 3 | 1,460 | 24.38 | NA | 0% | 7 | 29.40 | NA | 0% |
| 5 | 1,460 | 75.45 | 247.72 | NA | 77 | 45.76 | 244.00 | NA |
| 6 | 1,460 | 22.75 | 77.18 | NA | 91 | 9.41 | 49.32 | NA |
| 9 | 1,460 | 42.61 | 363.79 | NA | 41 | 91.62 | 1,100.00 | NA |
| 12 | 1,460 | 27.64 | 355.27 | NA | 76 | 58.75 | 855.00 | NA |
| 16 | 1,460 | 26.22 | 43.02 | NA | 42 | 13.53 | 46.48 | NA |

[1] SS = single sample instantaneous standard violations (200 cfu/100mL)
NA = not applicable

### 4.8.3 Fecal Coliform Water Quality Validation

Fecal coliform water quality model validation was performed on data from 1/1/1995 to 9/30/1999 for all stations listed in Table 4.17, except those on Baptist Run. The validation for Baptist Run was 5/1/1993 to 10/30/1994. The Skiffes Creek VDH impairment (James River – opposite Fort Eustis & Skiffes Creek) was not validated because data was not available during either time period. Since the calibration and validations of all the other segments were acceptable, and the same techniques were used on all segments, validation was considered not necessary for this segment. The results are shown in Tables 4.17 and 4.18 and Figures 4.24 through 4.28. The standard errors in the Warwick River model validation range from 4.38 to 99.73 (Table 4.17).

**Table 4.17 Mean standard error of the fecal coliform validation model for impairments in the Warwick River watershed.**

| Stream | Sub | Impairment(s)[1] | Station ID(s) | Mean Standard Error | Maximum Simulated Value | Maximum Monitored Value |
|---|---|---|---|---|---|---|
| | | | | ----------(cfu/100 mL)---------- | | |
| Baptist Run | 1 | PCRU | BAP000.80 | 99.73 | 4,233.10 | 1,700.00 |
| Lee Hall Reservoir | 3 | none | LHR000.96, LHR001.76, LHR002.56 | NA | 282.07 | no data |
| Warwick River | 5 | SHU | WWK003.98, 58-13 | 13.86 | 709.64 | 1,600.00 |
| Warwick River | 6 | SHU | WWK000.00, 57-E57, 58-A65, 58-C67, 58-0.5, 58-0.5Y, 58-1.5A, 58-10, 58-1Z, 58-2.5A, 58-5, 58-6, 58-8, 58-A62, 58-JRSTP, 58-B64, 58-B65, 58-0.5Z, 58-11, 58-12, 58-1A, 58-7, 58-9 | 4.38 | 188.37 | 1,200.00 |
| Lucas Creek | 9 | SHU | 58-13A | 21.09 | 956.67 | 1,200.00 |
| Deep Creek | 12 | PCRU & SHU | LHR000.96, LHR001.76, LHR002.56 | 15.43 | 2,140.55 | 1,600.00 |
| Skiffes Creek | 16 | SHU | 59-Z79, 59-AA78, 59-BB77, 59-X81, 59-X79 | NA | 252.19 | no data |

[1]PCRU=primary contact recreational use; SHU=shellfishing use

Table 4.18 shows the predicted and observed values for the geometric mean, 90$^{th}$ percentile (of all data within the time period), and single sample (SS) instantaneous violations for the appropriate stream segments. The maximum percent difference between modeled and monitored geometric means, 90$^{th}$ percentiles, and instantaneous violations are within the standard deviation of the observed data at each station and, therefore, the fecal coliform calibration is acceptable.

**Table 4.18 Comparison of modeled and observed fecal coliform validation results for the Warwick River watershed.**

| | Modeled Fecal Coliform | | | | Monitored Fecal Coliform | | | |
|---|---|---|---|---|---|---|---|---|
| **Subwatershed** | ***n*** | **Geometric Mean (cfu/100ml)** | **90th Percentile (cfu/100ml)** | **SS % violations (cfu/100ml) [1]** | ***n*** | **Geometric Mean (cfu/100ml)** | **90th Percentile (cfu/100ml)** | **SS % violations (cfu/100ml) [1]** |
| 1 | 549 | 35.12 | NA | 100.00% | 4 | 692.14 | NA | 75% |
| 3 | 1,461 | 14.57 | NA | 0% | 0 | No data | No data | No data |
| 5 | 1,461 | 86.94 | 281.06 | NA | 89 | 74.57 | 540.00 | NA |
| 6 | 1,461 | 23.58 | 64.83 | NA | 85 | 13.34 | 82.82 | NA |
| 9 | 1,461 | 37.80 | 284.50 | NA | 42 | 84.76 | 1,036.00 | NA |
| 12 | 1,461 | 24.71 | 182.15 | NA | 88 | 81.40 | 974.00 | NA |
| 16 | 1,461 | 32.91 | 153.56 | NA | 0 | No data | No data | No data |

[1] SS = single sample instantaneous standard violations (200 cfu/100mL)
NA = not applicable
No data = no observed data during the modeled time period

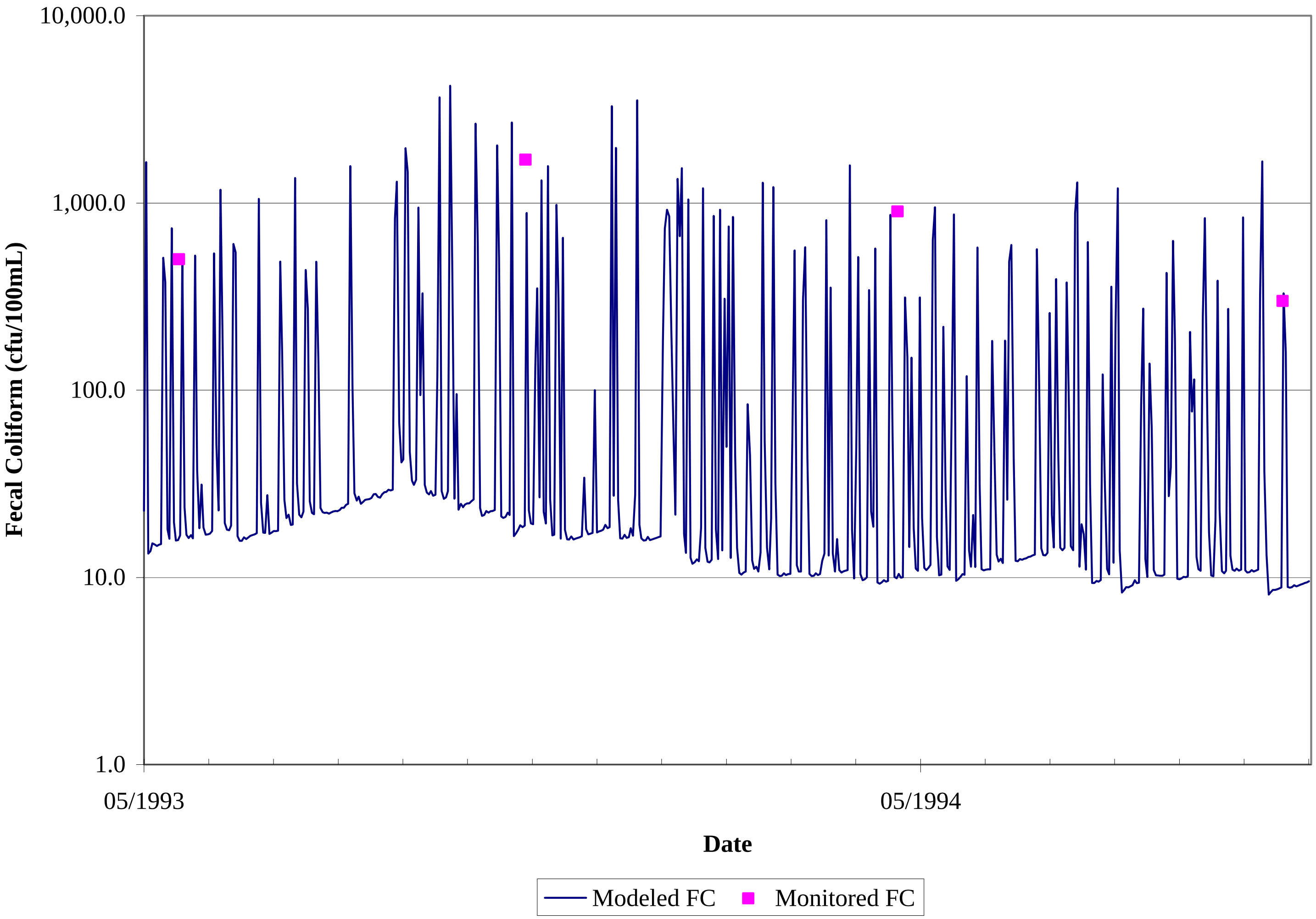


**Figure 4.24 Fecal coliform quality validation results for 5/1/1993 to 10/30/1994 for VADEQ station 2-BAP000.80 in subwatershed 1 in Baptist Run.**

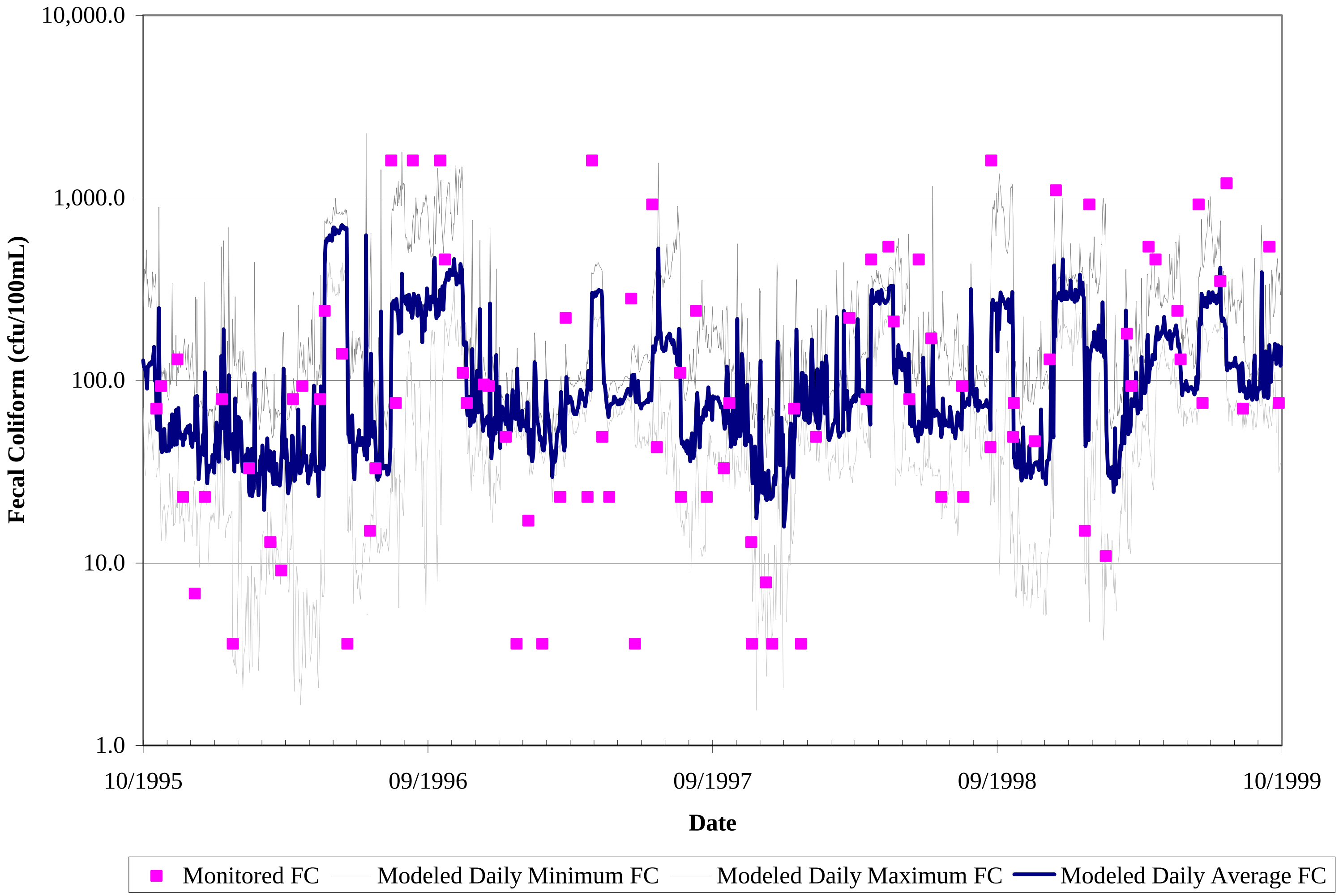


**Figure 4.25 Fecal coliform quality calibration results for 10/1/1995 to 9/30/1999 for VADEQ station 2-WWK003.98 and VDH station 58-13 in subwatershed 5 in the Warwick River.**

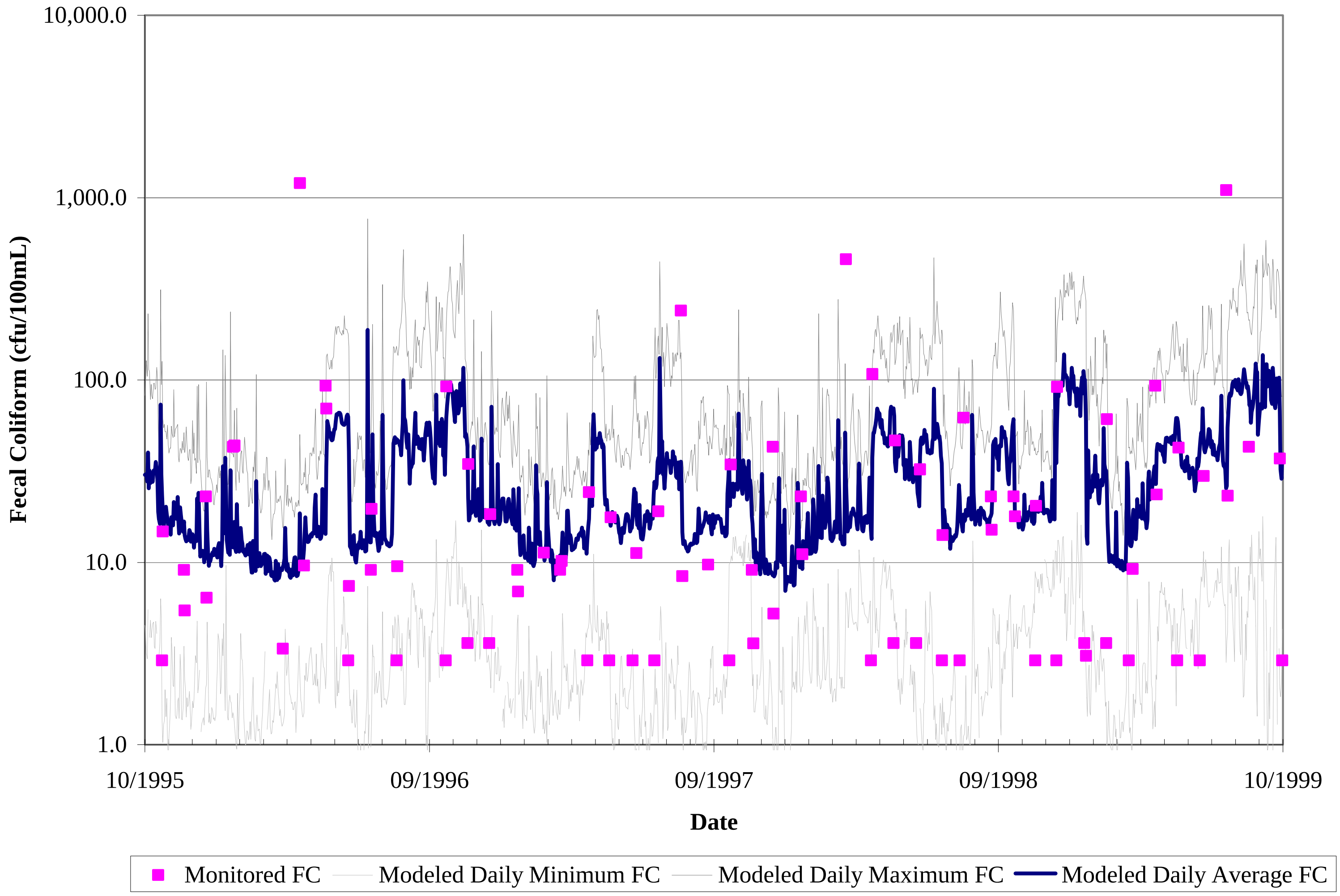


**Figure 4.26 Fecal coliform quality calibration results for 10/1/1995 to 9/30/1999 for numerous VDH stations in subwatershed 6 in the Warwick River and James River.**

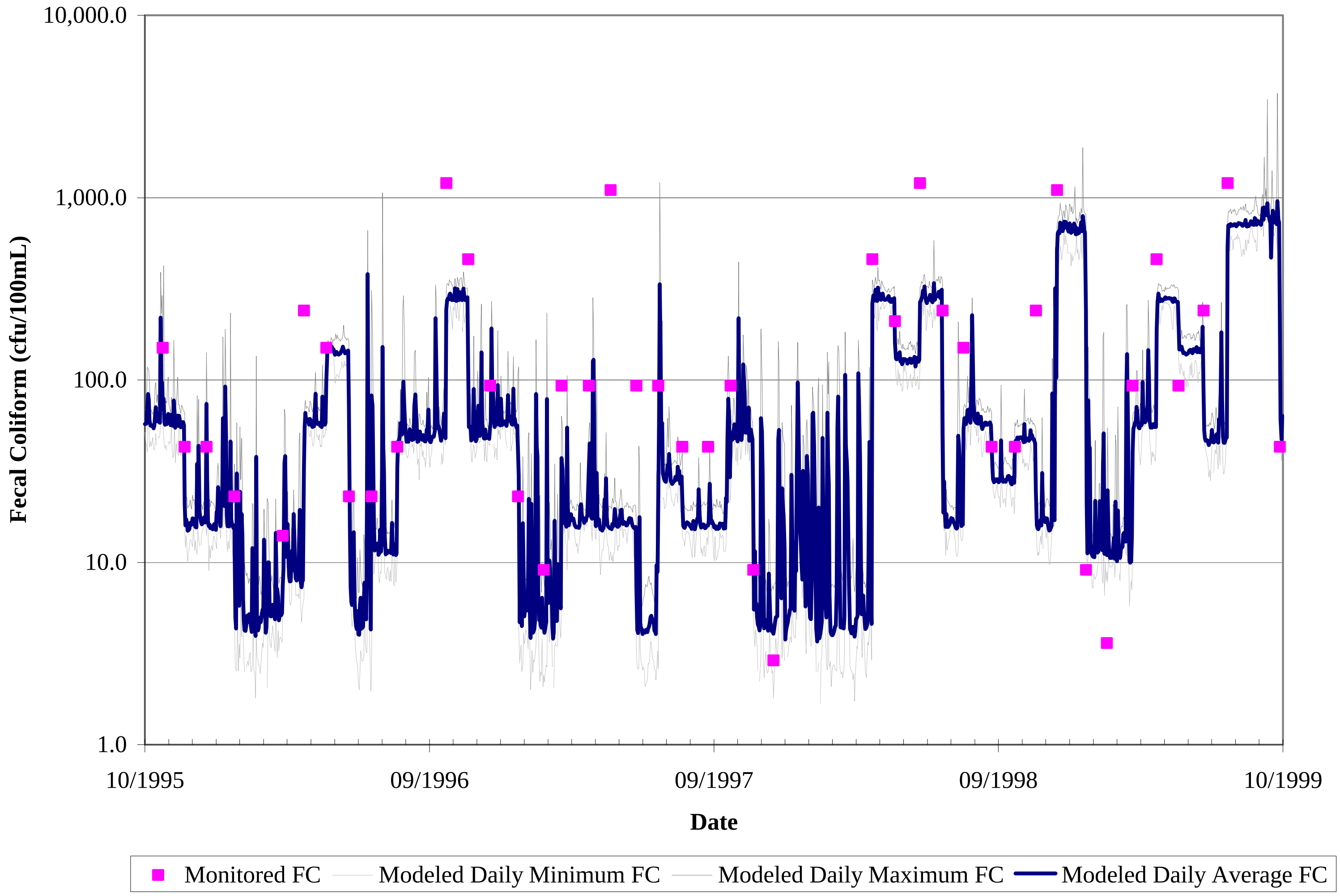


**Figure 4.27 Fecal coliform quality calibration results for 10/1/1995 to 9/30/1999 for VDH station 58-13A in subwatershed 9 in Lucas Creek.**

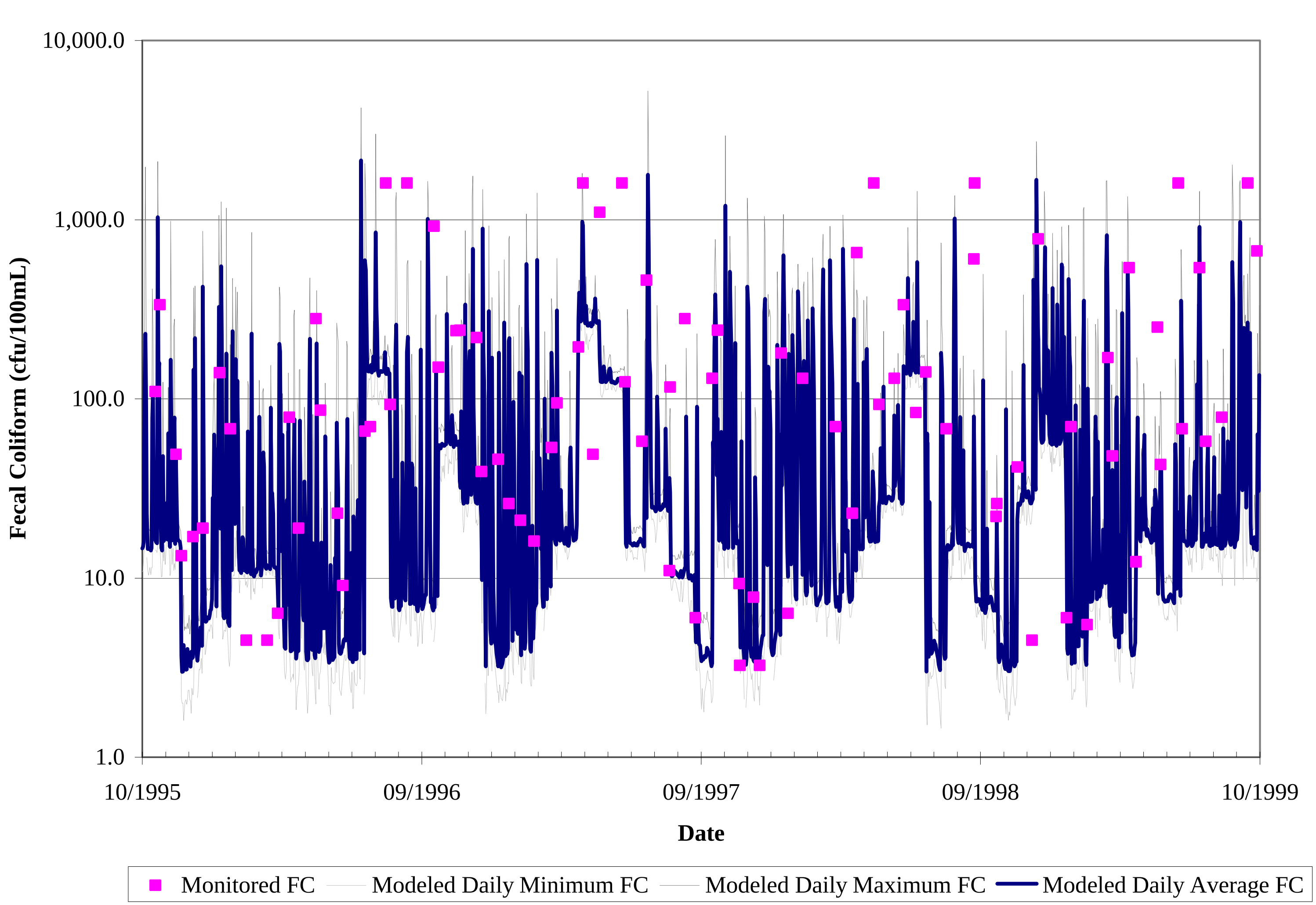


**Figure 4.28** **Fecal coliform quality calibration results for 10/1/1995 to 9/30/1999 for VDH stations 58-3 and 58-4 and VADEQ station 2-DEP000.26 in subwatershed 12 in Deep Creek.**

## 4.9 Existing Loadings

All appropriate inputs were updated to 2006 conditions. Figure 4.29 shows the monthly geometric mean of *E. coli* concentrations in relation to the 126-cfu/100mL standard at the outlet of the Baptist Run DEQ impairment (subwatershed 1). Figure 4.30 shows the instantaneous values of *E. coli* concentrations in relation to the 235-cfu/100mL standard at the outlet of the Baptist Run DEQ impairment (subwatershed 1).

Figure 4.31 shows the monthly geometric mean of *enterococci* concentrations in relation to the 35-cfu/100mL standard at the outlet of the Deep Creek (subwatershed 12). Figures 4.32 shows the instantaneous values of *enterococci* concentrations in relation to the 104-cfu/100mL standard at the outlet of the Deep Creek (subwatershed 12). Gaps shown in the instantaneous graphs represent *enterococci* values of zero due to zero stream flow out of the reach during high tide periods.

The Deep Creek stream segment plus the segments in subwatersheds 4,7,9, and 6 are impaired for the VDH shellfishing use, which uses fecal coliform standards. Figure 4.33 shows the monthly geometric mean of fecal coliform concentrations in relation to the 14-MPN standard at the outlet of the Warwick & James River VDH impairment (subwatershed 6). Figure 4.34 shows the existing modeled fecal coliform values for the $90^{th}$ percentile standard 49 MPN.

The Skiffes Creek stream segment below the dam is impaired for the VDH shellfishing use also. Figure 4.35 shows the monthly geometric mean of fecal coliform concentrations in relation to the 14-MPN standard at the outlet of the James River opposite Ft Eustis & Skiffes Creek VDH impairment (subwatershed 16). Figure 4.36 shows the existing modeled fecal coliform values for the $90^{th}$ percentile standard 49 MPN.

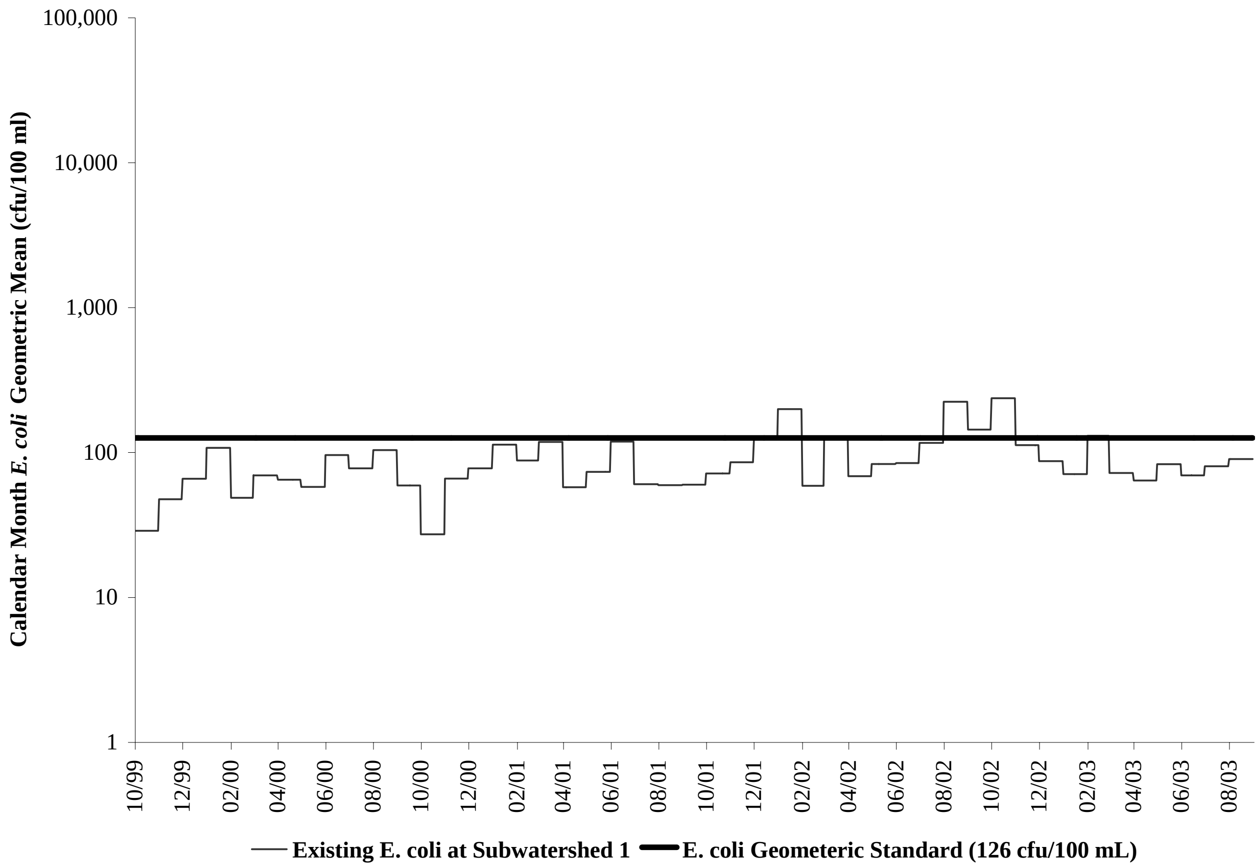


**Figure 4.29 Monthly geometric mean of *E. coli* concentrations for existing conditions at the Baptist Run swimming use impairment outlet (subwatershed 1).**

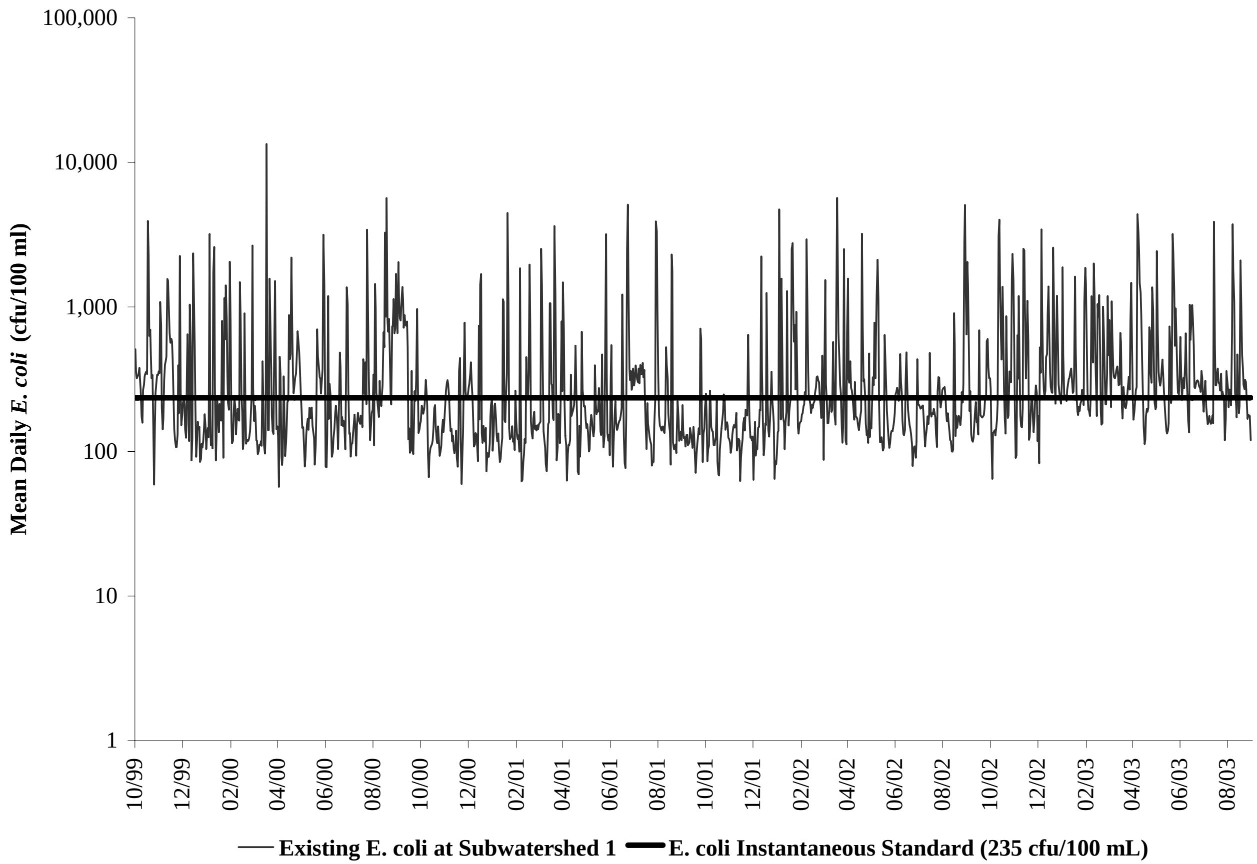


**Figure 4.30 Instantaneous *E. coli* concentrations for existing conditions at the Baptist Run swimming use impairment outlet (subwatershed 1).**

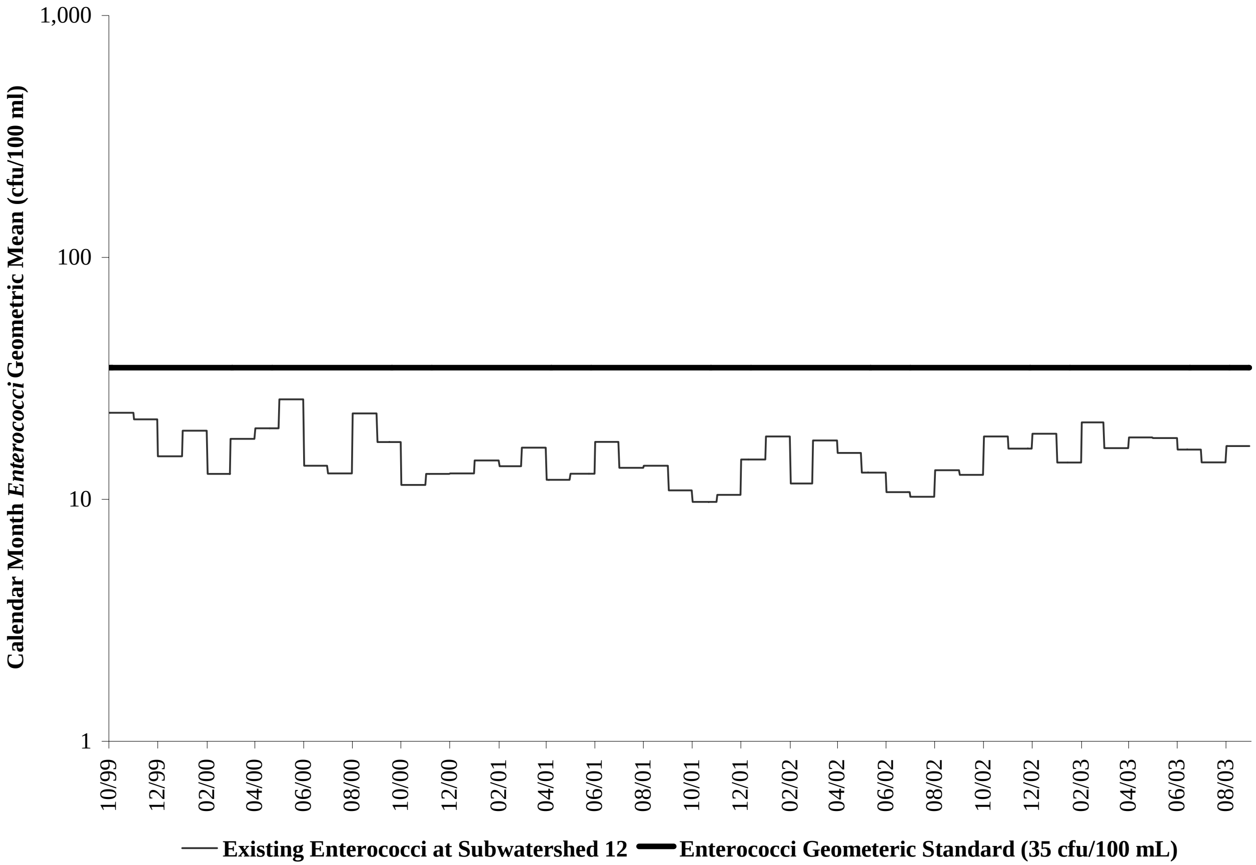


**Figure 4.31 Monthly geometric mean of *enterococci* concentrations for existing conditions at the Deep Creek swimming use impairment outlet (subwatershed 12).**

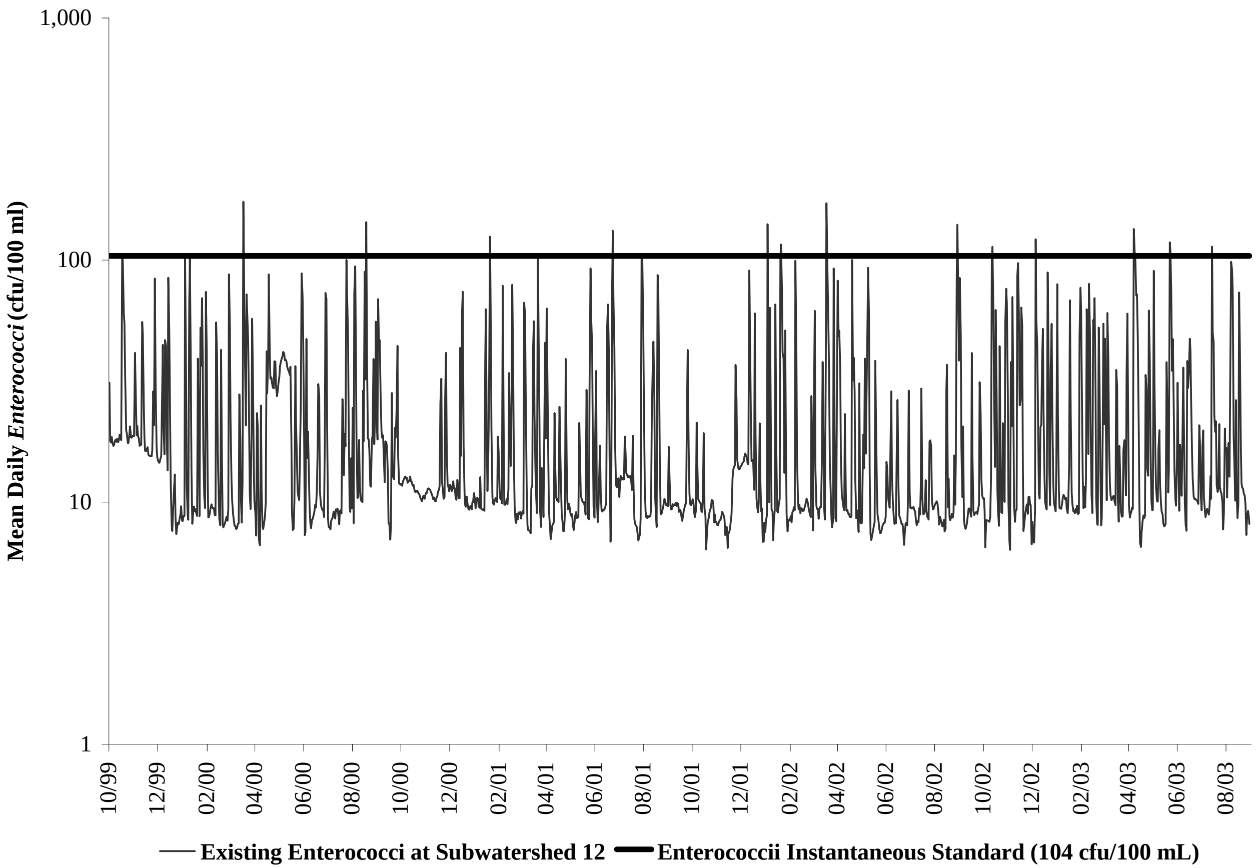


**Figure 4.32 Instantaneous *enterococci* concentrations for existing conditions at the Deep Creek swimming use impairment outlet (subwatershed 12).**

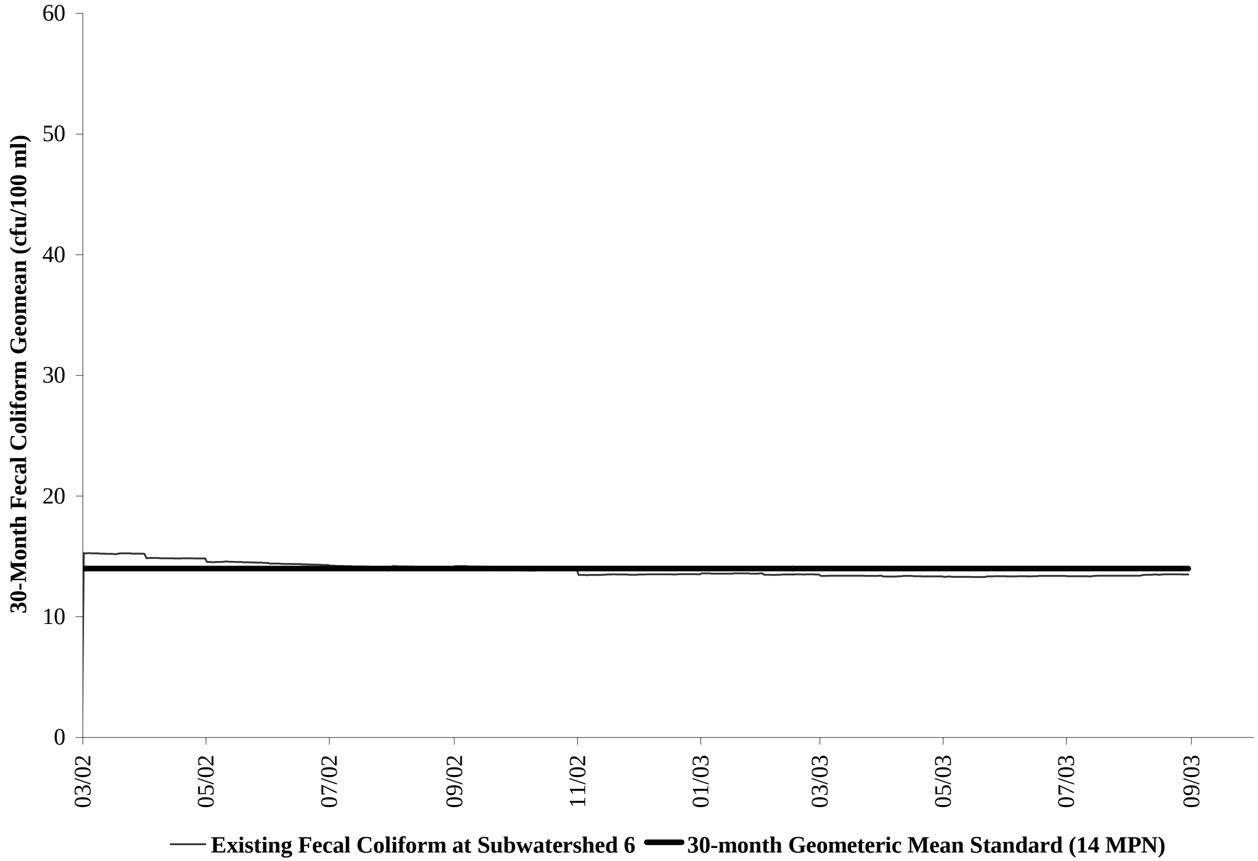


**Figure 4.33 30-month geometric mean of fecal coliform concentrations for existing conditions at the Warwick & James River shellfishing impairment outlet (subwatershed 6).**

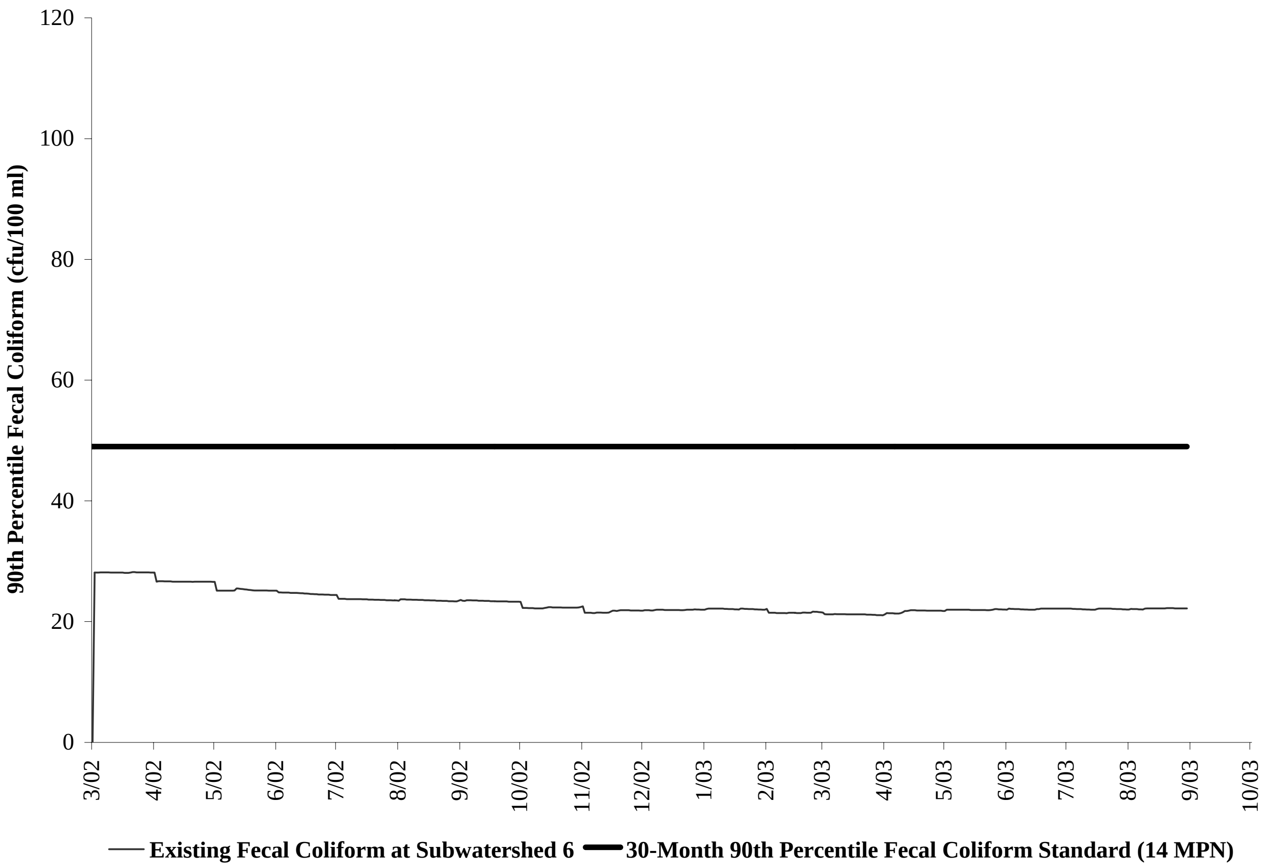


**Figure 4.34 Instantaneous fecal coliform concentrations for existing conditions at the Warwick & James River shellfishing impairment outlet (subwatershed 6).**

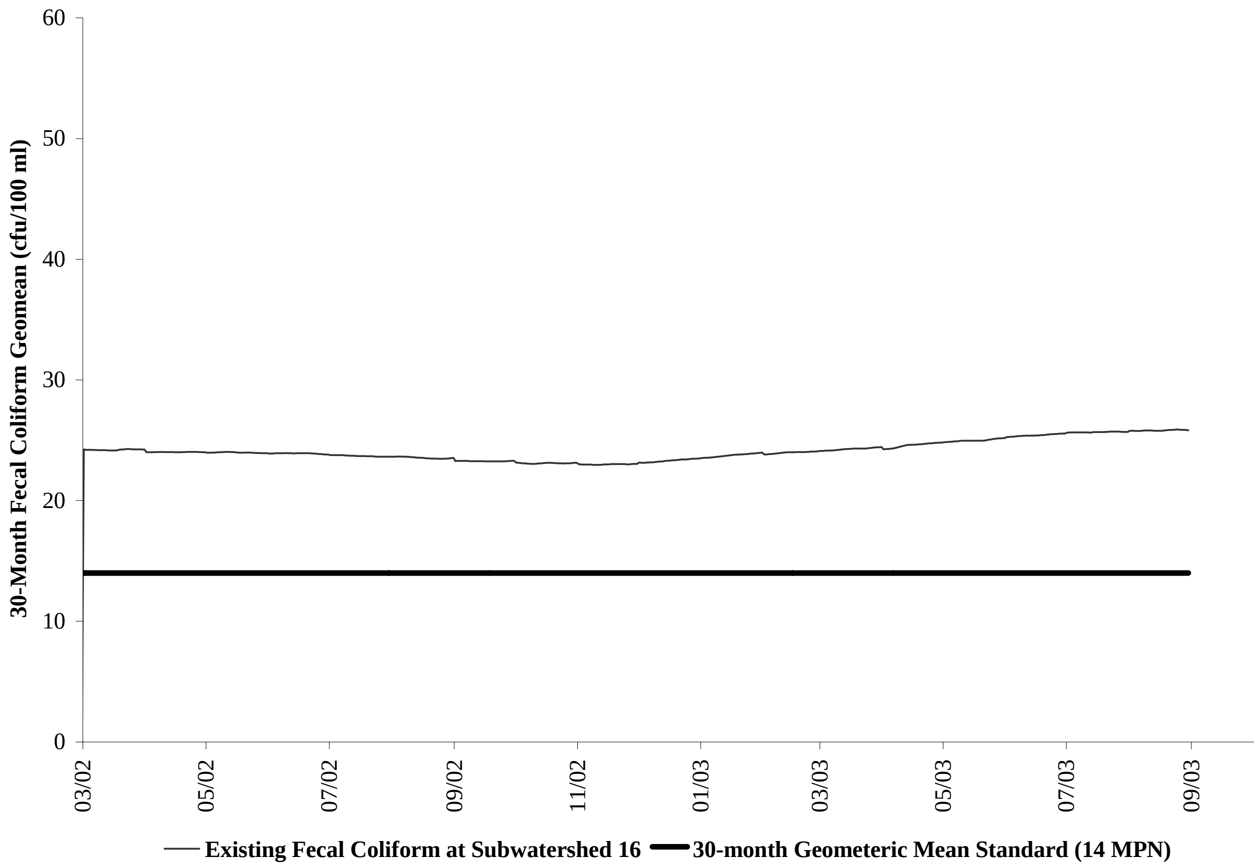


**Figure 4.35 30-month geometric mean of fecal coliform concentrations for existing conditions at the James River – opposite Fort Eustis & Skiffes Creek shellfishing impairment outlet (subwatershed 16).**

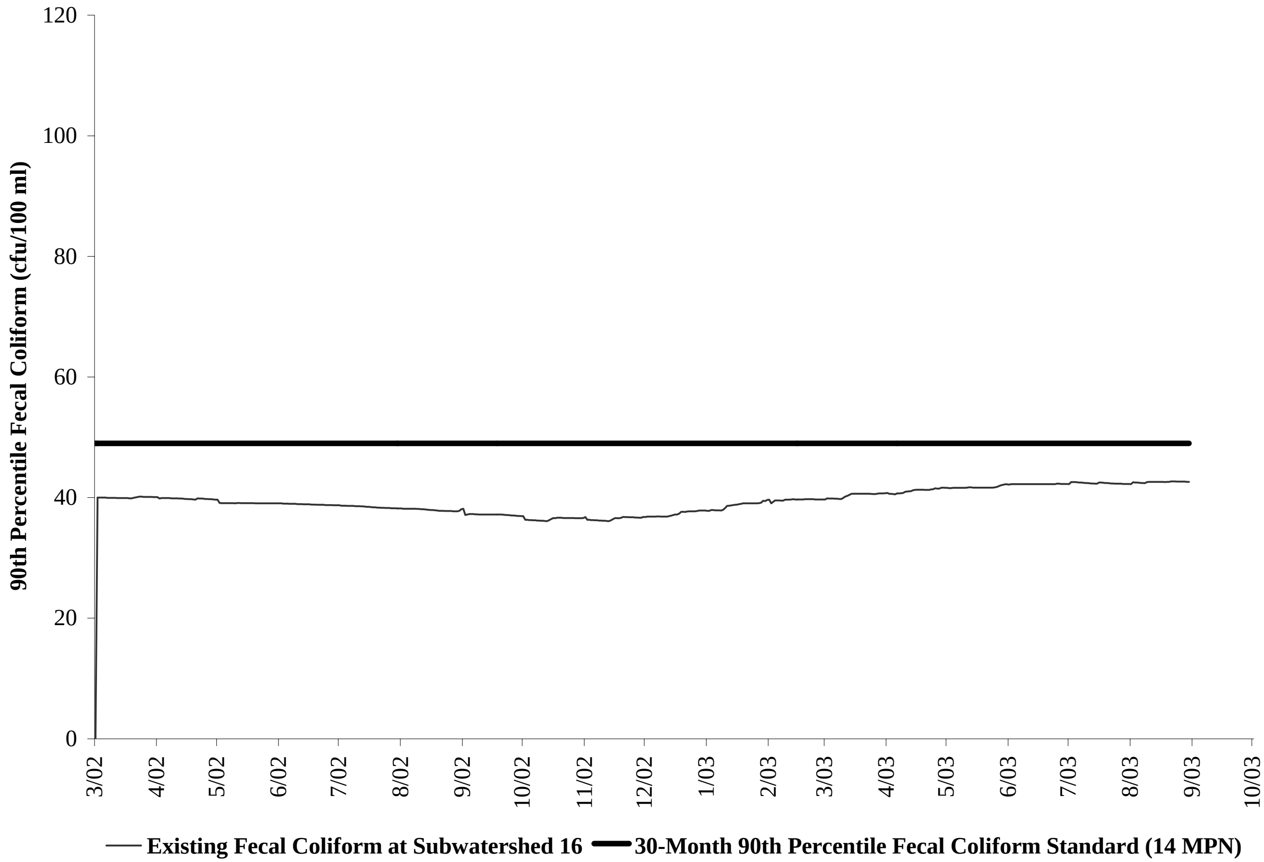


**Figure 4.36 Instantaneous fecal coliform concentrations for existing conditions at the James River – opposite Fort Eustis & Skiffes Creek shellfishing impairment outlet (subwatershed 16).**

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# 5. ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted sources) and load allocations (LAs, not permitted sources) including natural background levels. Additionally, the TMDL must include a margin of safety (MOS) that either implicitly or explicitly accounts for the uncertainties in the process (*e.g.*, accuracy of wildlife populations). The definition is typically denoted by the expression:

TMDL = WLAs + LAs + MOS

The TMDL becomes the amount of a pollutant that can be assimilated by the receiving waterbody and still achieve water quality standards. For these impairments, the TMDLs are expressed in terms of colony forming units (or resulting concentration).

Allocation scenarios were modeled using HSPF. The first change made to existing conditions was adjusting the flood tides (incoming) from the James River to subwatersheds 6 and 16 so that the bacteria from the tides alone did not result in water quality standards violations. More scenarios were created by reducing direct and land-based bacteria until the water quality standards were attained. The TMDLs developed for the impairments in the Warwick River watershed were based on three different Virginia State standards (*E. coli, enterococci*, and fecal coliform). As detailed in section 2.1, the DEQ riverine primary contact recreational use *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, and that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml. The DEQ estuarine primary contact recreational use *enterococci* standards state that the calendar month geometric-mean concentration shall not exceed 35 cfu/100 ml, and that a maximum single sample concentration of *enterococci* shall not exceed 104 cfu/100 ml. The VDH shellfishing use fecal coliform standards state that the 30-month geometric-mean concentration shall not exceed 14 MPN, and that the 30-month, 90$^{th}$ percentile concentration of fecal coliform shall not exceed 49 MPN.

According to the guidelines put forth by the VADEQ (VADEQ, 2003) for modeling bacteria with HSPF, the model was set up to estimate loads of fecal coliform, then the model output was converted to concentrations of *E. coli* and *enterococci* through the use of the following equations (developed from a data set containing 493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc}) \qquad \textit{E. coli}$$

$$\log_2(C_{ent}) = 1.2375 + 0.59984 \cdot \log_2(C_{fc}) \qquad \textit{Enterococci}$$

where $C_{ec}$ is the concentration of *E. coli* in cfu/100 mL, $C_{ent}$ is the concentration of *enterococci* in cfu/100 mL and $C_{fc}$ is the concentration of fecal coliform in cfu/100 mL.

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

## 5.1 Margin of Safety (MOS)

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

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

### *5.2 Waste Load Allocations (WLAs)*

The HRSD- James River Sewage Treatment Plant (VA0081272) outfall to the James and Warwick River confluence is not included in the Warwick and James River WLA. This is due to the fact that the area of water around the outfall, condemnation area 34B, is a permanent prohibited shellfishing area. No shellfish harvesting is allowed in this area even if this area meets the VDH fecal coliform standards due to the potential presence of viruses or other non-bacterial pathogens from the treatment plant. This is discussed more at the end of Section 5.4.3.

The City of Newport News (VA0088641), York County (VAR040028), James City County (VAR040037), and Fort Eustis (VAR040035) currently have Municipal Separate Storm Sewer System (MS4) permits with multiple outfalls. For this report, it was assumed that all impervious land within these boundaries drain to an MS4 outfall. All *E. coli*, fecal coliform, and *enterococci* from these areas were allocated to the MS4s in the TMDL tables. Table 5.1 shows the areas used to calculate the MS4 bacteria loads in the WLA for each impairment.

**Table 5.1 Impervious areas used to calculate the MS4 WLAs.**

| | | | Impervious Area Within MS4 Areas | | | |
|---|---|---|---|---|---|---|
| **Impairment** | **Contributing Subwatersheds** | **Total Drainage Area** | **Newport News** | **York County** | **James City County** | **Fort Eustis** |
| Baptist Run | 1 | 1,503 | 0 | 13.0 | 0 | 0 |
| Deep Creek | 10, 11, 12 | 4,736 | 410 | 0 | 0 | 0 |
| Skiffes Creek | 15, 16 | 8,540 | 88.7 | 14.9 | 69.5 | 21.9 |
| Warwick River | 2 - 14 | 38,211 | 1,968 | 39.5 | 0 | 155.7 |

The WLA load for each impairment also includes a load set aside for the future growth of the human population. This is calculated as one percent of the final TMDL load.

### *5.3 Load Allocations (LAs)*

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (*e.g.*, livestock, sewer overflows, and wildlife). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads had their most significant impact during high-flow conditions, while direct deposition NPS had their most significant impact on low flow concentrations. The BST results confirmed the presence of human, livestock, pet, and wildlife contamination. Load reductions were performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by land use. Reductions on agricultural land uses (pasture and cropland) include reductions required for land applied livestock wastes.

### 5.4 Final Total Maximum Daily Loads (TMDLs )

Allocation scenarios were run sequentially, beginning with headwater impairments, and then continuing with downstream impairments until all impairments were allocated to 0% exceedances of all applicable standards. The first table in each of the following sections represents a small portion of the scenarios developed to determine the TMDLs. The first five scenarios were run for all impairments simultaneously; subsequent runs were made after upstream impairments were allocated. Scenario 1 in each table describes a baseline scenario that corresponds to the existing conditions in the watershed.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife reductions. In each table, Scenario 2 eliminated direct human sources (straight pipes and/or sewer overflows). Most of the subwatersheds are entirely urban, so Scenario 3 shows if reducing direct livestock lowers the violations. Since part of the TMDL development is the identification of phased implementation strategies, typical management scenarios were explored as well. Scenario 4 in each contains reductions of 50% in all anthropogenic land-based loads, 100% reduction in sewer overflows and straight pipes, a 90% reduction in direct livestock deposition, and a 0% reduction in wildlife direct and land-based loading to the stream. Scenario 5 attempts to determine the impact of non-anthropogenic sources (*i.e.*, wildlife), by exploring 100% reductions in all anthropogenic land-based and direct loads. In most cases, the model predicts that water quality standards will not be met without reductions in wildlife loads. Further scenarios in each table explore a range of management scenarios, leading to the final allocation scenario that contains the predicted reductions needed to meet 0% exceedance of all applicable water quality standards.

The two graphs in the following sections depict the existing and allocated daily average in-stream bacteria concentrations, and the existing and allocated monthly geometric mean in-stream bacteria concentrations.

The second table in the following sections shows the existing and allocated fecal coliform land-based and direct loads that are input into the HSPF model. The third table shows the final in-stream allocated loads for the appropriate bacteria species. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The values in the second and third tables are the results of different modeling processes and it is not appropriate to directly compare values between the tables. The final table is an estimation of the in-stream daily load of bacteria.

The tables and graphs in the following sections all depict values at the corresponding impairment outlet unless otherwise noted. The impairment outlet is the mouth of the impaired segment as the segments are described in Section 1.1. It is the point at which the impaired stream flows out of the most downstream subwatershed. The impairment outlet for the Baptist Run segment is the mouth of subwatershed 1; the impairment outlet for the Deep Creek segment is the mouth of subwatershed 12; the impairment outlet for the Warwick and James Rivers segment is the mouth of subwatershed 6; the impairment outlet for the James River – Opposite Fort Eustis & Skiffes Creek segment is the mouth of subwatershed 16.

### 5.4.1 Baptist Run – VADEQ Riverine Primary Contact Recreational Use Impairment

Table 5.2 shows allocation scenarios used to determine the final TMDL for Baptist Run. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational (swimming) use standards. The existing condition, Scenario 1, shows both standards have violations. Although the existing conditions had violations for both standards, Scenario 2 (eliminating direct human inputs) showed dramatic improvement and met the geometric mean standard. Scenario 3 showed that eliminating direct livestock would not benefit water quality. The typical management scenario, Scenario 4, slightly improved water quality. This scenario showed improvement, but the standards were still not met. Scenario 5 shows 100% reductions to all anthropogenic sources; however, exceedances persisted. This scenario shows that reductions to wildlife loads must be made. The first 5 scenarios are explained in more detail in Section 5.4.

Scenario 6 had fewer reductions to agricultural and low intensity residential (LIR) nonpoint source loads to provide more obtainable scenarios (99%) with reductions to wildlife loads. The standards were still not met with this scenario. With one more percent reduction to wildlife land based loads, no reduction was required to the direct wildlife loads, as shown in Scenario 7. This scenario met both standards. The final Scenario 8 shows that zero reductions to direct livestock and a lower reduction of agricultural land uses still meets both standards. Therefore, the final TMDL was developed using Scenario 8 with a 91% reduction from agricultural land-based loads, a 99% reduction from residential land-based loads, and a 100% correction of straight pipes and sewer overflows.

Scenario 9 is the Stage I management scenario, which results in a violation rate close to 10% for the instantaneous standard. This scenario requires no reduction to wildlife loads and can be used as a goal for implementation.

**Table 5.2 Allocation scenarios for reducing current bacteria loads in Baptist Run (subwatershed 1).**

| | Percent Reductions to Existing Bacteria Loads | | | | | | VADEQ *E. coli* Standard percent violations | |
|---|---|---|---|---|---|---|---|---|
| | | Wildlife Land Based | | Agricultural Land Based | Human Direct | Human and Pet Land Based | | |
| Scenario | Wildlife Direct | Barren, Commercial, Forest, HIR, Wetlands | Livestock Direct | Cropland, Pasture, LAX | Straight Pipes | LIR | >126 Geometric Mean | >235 Instantaneous |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 12.72% | 19.85% |
| 2 | 0 | 0 | 0 | 0 | 100 | 0 | 0% | 19.57% |
| 3 | 0 | 0 | 100 | 0 | 100 | 0 | 0% | 19.57% |
| 4 | 0 | 0 | 90 | 50 | 100 | 50 | 0% | 17.89% |
| 5 | 0 | 0 | 100 | 100 | 100 | 100 | 0% | 4.82% |
| 6 | 88 | 88 | 100 | 99 | 100 | 99 | 0% | 0.07% |
| 7 | 0 | 89 | 100 | 99 | 100 | 99 | 0% | 0% |
| 8[1] | 0 | 89 | 0 | 91 | 100 | 99 | 0% | 0% |
| 9[2] | 0 | 0 | 0 | 90 | 100 | 94 | 0% | 9.99% |

[1]Final TMDL Scenario
[2]Stage I Implementation Scenario

Figures 5.1 and 5.2 show the existing and allocated daily average in-stream *E. coli* and monthly geometric mean *E. coli* concentrations, respectively, from Baptist Run impairment outlet. These graphs show existing conditions in black, with allocated conditions overlaid in gray.

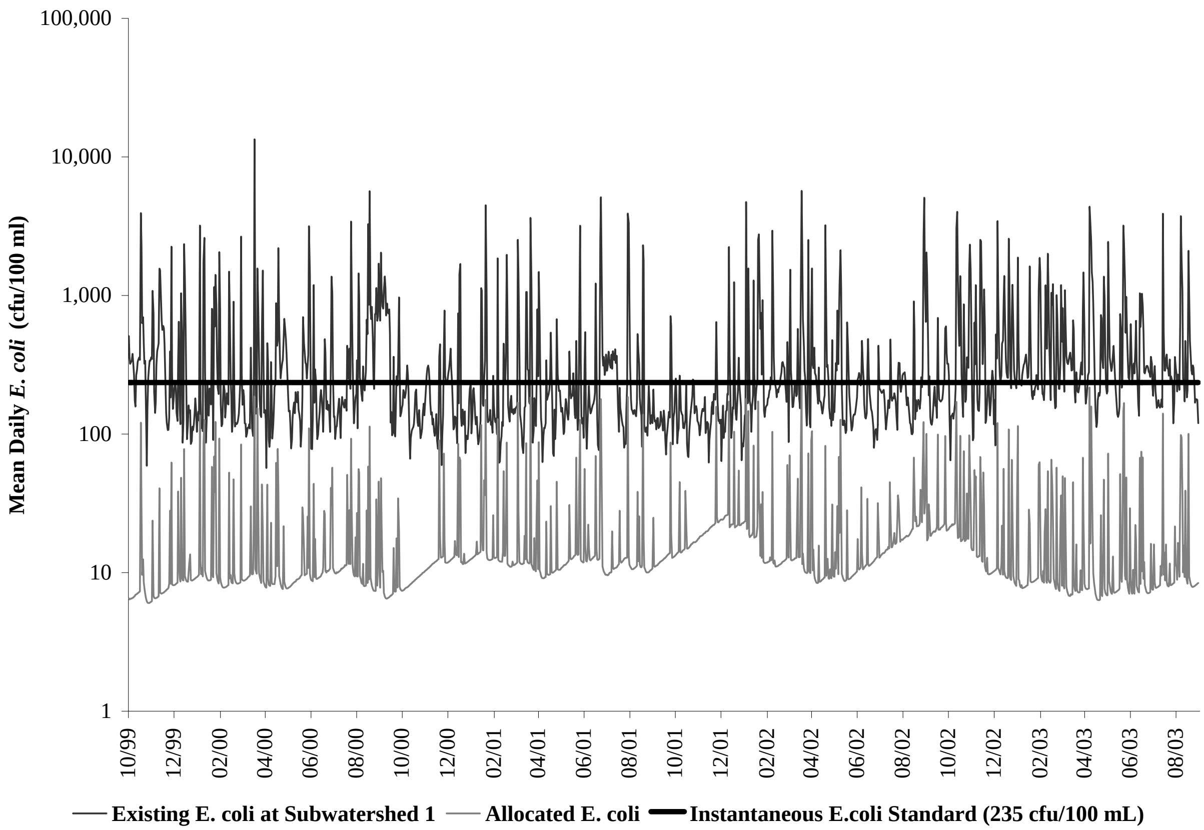


**Figure 5.1 Existing and allocated daily average in-stream *E. coli* concentrations in subwatershed 1, Baptist Run impairment outlet.**

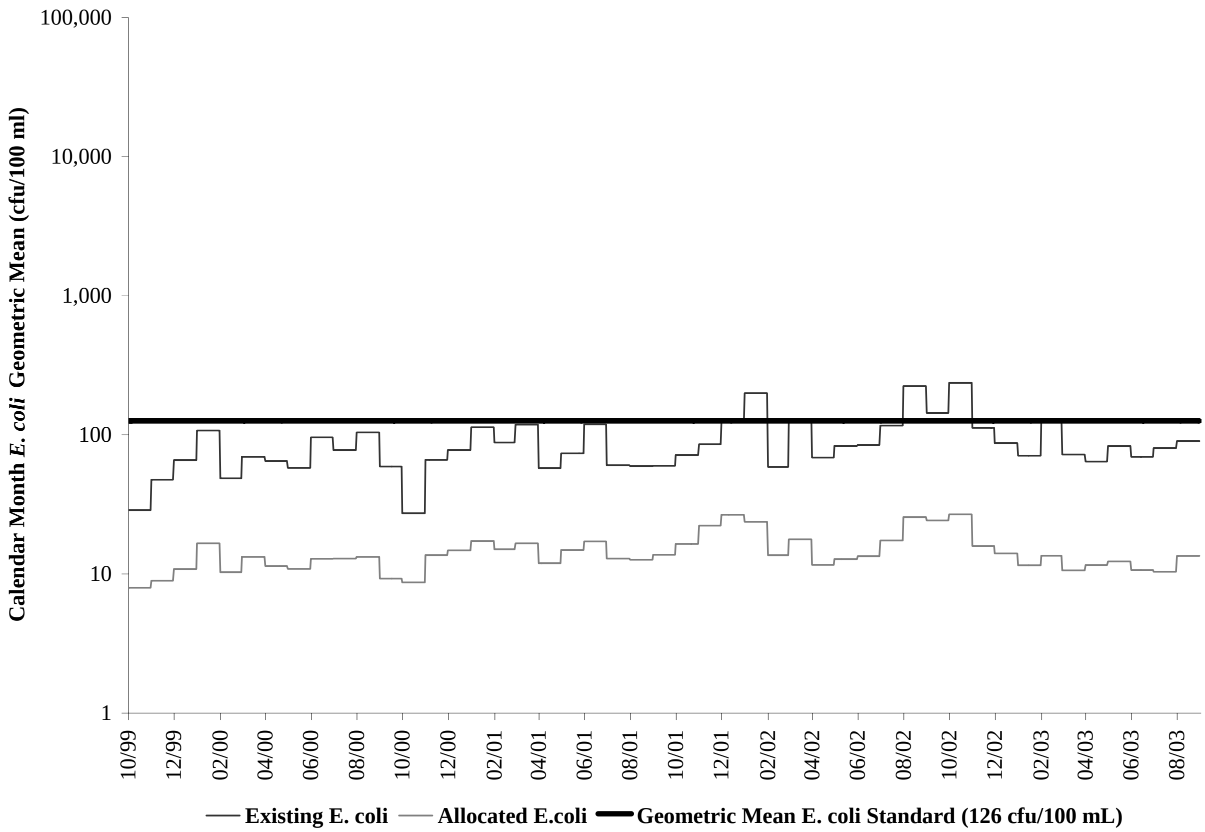


**Figure 5.2 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 1, Baptist Run impairment outlet.**

Table 5.3 contains estimates of existing and allocated in-stream *E. coli* loads at the Baptist Run impairment outlet reported as average annual cfu per year. These loads are distributed based on their land-based origins, as opposed to their source origins. The in-stream load estimates at the impairment outlet in Table 5.3 assume that the in-stream source distribution of *E. coli* is the same as the distribution of fecal coliform on the land. The HSPF model is calibrated to the build-up and wash-off rates by subwatershed, not by individual bacteria source or land use. The estimates in Table 5.3 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed.

Tables C.1 through C.4 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation.

The percent reductions needed to meet zero percent violations of all applicable water quality standards are given in the final column.

**Table 5.3 Estimated existing and allocated *E. coli* in-stream loads in the Baptist Run impairment.**

| Source | Total Annual Loading for Existing Run[1] (cfu/yr) | Total Annual Loading for Allocation Run[1] (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 3.99E+08 | 4.39E+07 | 89 |
| Commercial | 6.84E+08 | 7.52E+07 | 89 |
| Cropland | 8.07E+09 | 7.26E+08 | 91 |
| Forest | 4.06E+11 | 4.47E+10 | 89 |
| High Density Residential | 1.05E+09 | 1.16E+08 | 89 |
| Livestock Access | 1.70E+09 | 1.53E+08 | 91 |
| Low Density Residential | 2.75E+11 | 2.75E+09 | 99 |
| Pasture | 9.84E+09 | 8.85E+08 | 91 |
| Wetland | 2.47E+10 | 2.72E+09 | 89 |
| **Direct** | | | |
| Human | 2.16E+10 | 0.00E+00 | 100 |
| Livestock | 0.00E+00 | 0.00E+00 | 0 |
| Wildlife | 1.20E+10 | 1.20E+10 | 0 |
| Permitted Sources | 3.89E+09 | 3.89E+09 | 0 |
| **Total Loads** | 7.66E+11 | 6.81E+10 | 91 |

[1]Distribution of these in-stream loads are based on the distribution of fecal coliform deposited on the land and deposited directly in the stream as modeled in HSPF to determine the final TMDL.

Table 5.4 shows the average annual TMDL, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet existing water quality standards. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and steam routing techniques within the HSPF model framework. York County currently has a Municipal Separate Storm Sewer System (MS4) permit, which is partly in the Baptist Run drainage area. Therefore, York County has a WLA load in the Baptist Run TMDL. To account for future growth of urban and residential human populations, one percent of the final TMDL was set aside for future growth in the WLA portion.

**Table 5.4 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Baptist Run impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Baptist Run** | **3.89E+09** | **6.42E+10** | *Implicit* | **6.81E+10** |
| *York County MS4 VAR040028* | 3.21E+09 | | | |
| *Future Load* | 6.81E+08 | | | |

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

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily maximum in-stream loads for Baptist Run are shown in Table 5.5.

**Table 5.5 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Baptist Run impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL[2] |
|---|---|---|---|---|
| **Baptist Run** | **1.07E+07** | **7.98E+09** | *Implicit* | **7.99E+09** |
| *York County MS4 VAR040028* | 8.79E+06 | | | |
| *Future Load* | 1.86E+06 | | | |

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

### 5.4.2 Deep Creek – VADEQ Estuarine Primary Contact Recreational Use Impairment

Table 5.6 shows allocation scenarios used to determine the final TMDL for Deep Creek. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VADEQ estuarine primary contact recreational (swimming) use standards. The existing condition, Scenario 1, shows a low 1.4% violation of the *enterococci* instantaneous standard. This is reasonable because at station 2-DEP000.26, only four out of 22 VADEQ samples violated the standard. The Warwick River (Upper) VADEQ impairment had similar data with an 18% violation rate and it was recently de-listed based on further monitoring. Deep Creek may be on this same path; however, a TMDL is still required.

Scenario 2 (eliminating direct human inputs) showed improvement in meeting the geometric mean standard. This scenario is the suggested Stage I management goal for Deep Creek. Scenario 3 showed that eliminating direct livestock would not benefit water quality. A typical management scenario, Scenario 4, slightly improved water quality, but the standards were still not met. Scenario 5 shows 100% reductions to all anthropogenic sources met both standards, showing no reductions to wildlife loads are necessary. The first 5 scenarios are explained in more detail in Section 5.4. Scenario 6 shows that a 63% reduction from agricultural and residential land-based loads still does not meet the instantaneous standard. However, with one more percent reduction from residential land-based loads, fewer reductions are needed from agricultural lands and the standards are met (Scenario 7). The final TMDL scenario shows that a 29% reduction from agricultural lands, a 64% reduction from residential land, and a 100% correction of straight pipes and sewer overflows will meet both VADEQ *enterococci* swimming use standards.

It is important to note that Deep Creek is also part of the Warwick and James River VDH shellfishing use impairment. The final TMDL that meets the VADEQ swimming use still has 100% violations of the VDH fecal coliform geometric mean standard and an 84% violation of the VDH fecal coliform 90$^{th}$ percentile standard.

**Table 5.6 Allocation scenarios for reducing current bacteria loads in Deep Creek (subwatersheds 10-12).**

| | Percent Reductions to Existing Bacteria Loads | | | | | | VADEQ *Enterococci* Standard violations | |
|---|---|---|---|---|---|---|---|---|
| | Wildlife Land Based | | | Agricultural Land Based | Human Direct | Human and Pet Land Based | | |
| Scenario | Wildlife Direct | Barren, Commercial, Forest, HIR, Wetlands | Livestock Direct | Cropland, Pasture, LAX | Straight Pipes | LIR | >35 Geometric Mean | >104 Instantaneous |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0% | 1.40% |
| 2[2] | 0 | 0 | 0 | 0 | 100 | 0 | 0% | 0.91% |
| 3 | 0 | 0 | 100 | 0 | 100 | 0 | 0% | 0.91% |
| 4 | 0 | 0 | 90 | 50 | 100 | 50 | 0% | 0.14% |
| 5 | 0 | 0 | 100 | 100 | 100 | 100 | 0% | 0% |
| 6 | 0 | 0 | 0 | 63 | 100 | 63 | 0% | 0.07% |
| 7[1] | 0 | 0 | 0 | 29 | 100 | 64 | 0% | 0% |

[1]Final TMDL Scenario
[2]Stage I Implementation Scenario

Figures 5.3 and 5.4 show the existing and allocated daily average in-stream *enterococci* concentrations and monthly geometric mean *enterococci* concentrations, respectively, from Deep Creek impairment outlet. These graphs show existing conditions in black, with allocated conditions overlaid in gray.

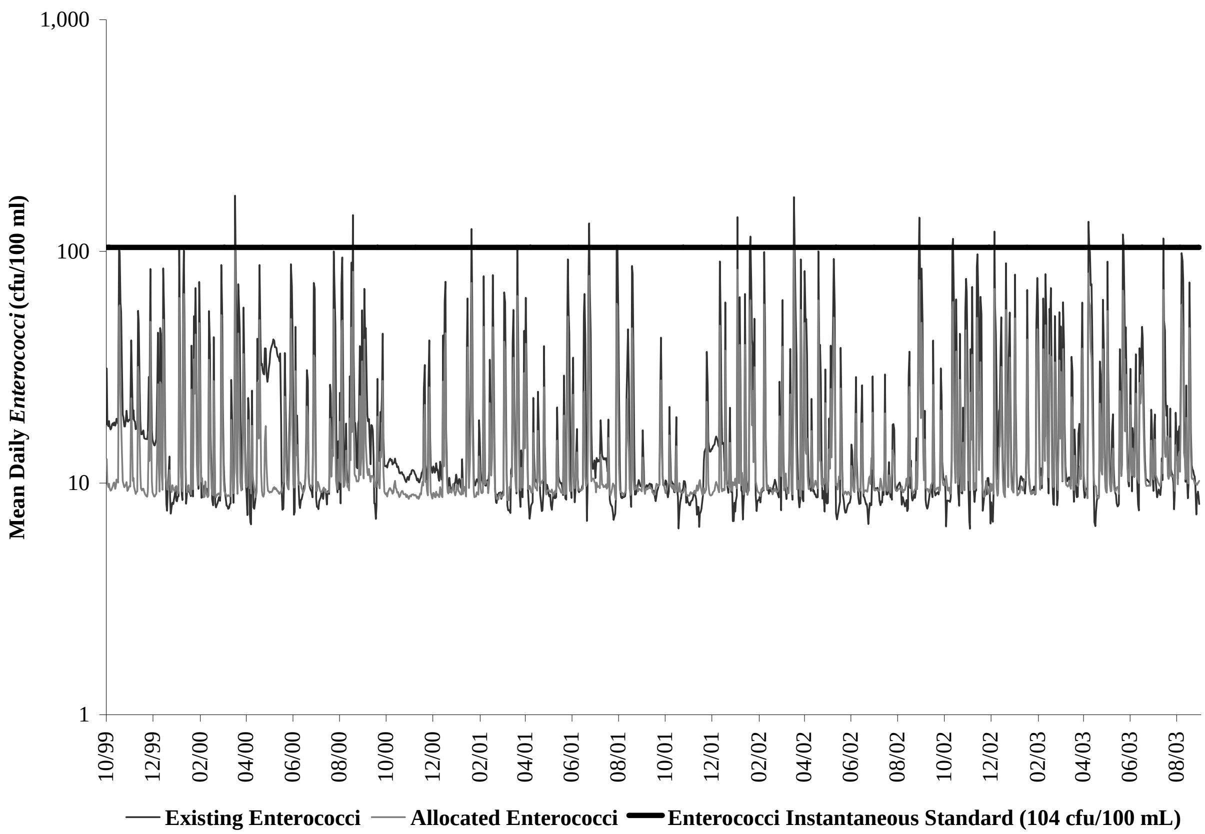


**Figure 5.3 Existing and allocated daily average in-stream *enterococci* concentrations in subwatershed 12, Deep Creek impairment outlet.**

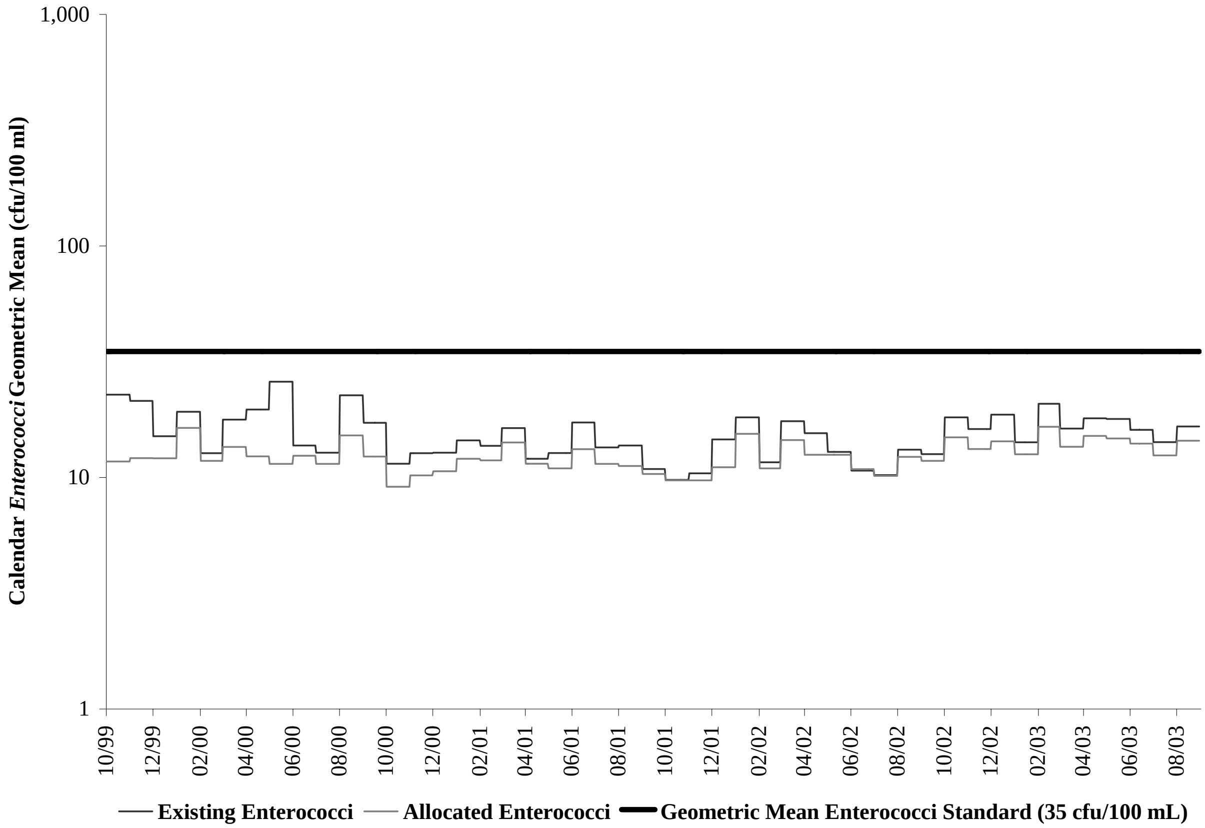


**Figure 5.4 Existing and allocated monthly geometric mean in-stream *enterococci* concentrations in subwatershed 12, Deep Creek impairment outlet.**

Table 5.7 contains estimates of existing and allocated in-stream *enterococci* loads at the Deep Creek impairment outlet reported as average annual cfu per year. These loads are distributed based on their land-based origins, as opposed to their source origins. The in-stream load estimates at the impairment outlet in Table 5.7 assume that the in-stream source distribution of *enterococci* is the same as the distribution of fecal coliform on the land. The HSPF model is calibrated to the build-up and wash-off rates by subwatershed, not by individual bacteria source or land use. Any contributing bacteria loads from downstream tidal sources are not included in this model approach. The estimates in Table 5.7 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed.

Tables C.5 through C.8 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation. The percent reductions needed to meet zero percent violations of all applicable water quality standards are given in the final column.

**Table 5.7 Estimated existing and allocated *enterococci* in-stream loads in the Deep Creek impairment.**

| Source | Total Annual Loading for Existing Run[1] (cfu/yr) | Total Annual Loading for Allocation Run[1] (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 3.29E+11 | 3.29E+11 | 0 |
| Commercial | 2.25E+11 | 2.25E+11 | 0 |
| Cropland | 2.99E+11 | 2.12E+11 | 29 |
| Forest | 3.30E+12 | 3.30E+12 | 0 |
| High Density Residential | 7.18E+11 | 7.18E+11 | 0 |
| Livestock Access | 5.89E+10 | 4.18E+10 | 29 |
| Low Density Residential | 5.15E+13 | 1.85E+13 | 64 |
| Pasture | 4.94E+11 | 3.51E+11 | 29 |
| Wetland | 2.61E+12 | 2.61E+12 | 0 |
| **Direct** | | | |
| Human | 3.23E+12 | 0.00E+00 | 100 |
| Livestock | 0.00E+00 | 0.00E+00 | 0 |
| Wildlife | 3.78E+11 | 3.78E+11 | 0 |
| Permitted Sources | 5.59E+12 | 5.59E+12 | 0 |
| **Total Loads** | 6.87E+13 | 3.23E+13 | 53 |

[1]Distribution of these in-stream loads are based on the distribution of fecal coliform deposited on the land and deposited directly in the stream as modeled in HSPF to determine the final TMDL.

Table 5.8 is the average annual TMDL table, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet existing water quality standards. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of

Newport News currently has a Municipal Separate Storm Sewer System (MS4) permit, which is partly in the Deep Creek drainage area. Therefore, the City of Newport News has a WLA load in the Deep Creek TMDL. To account for future growth of urban and residential human populations one percent of the final TMDL was set aside for future growth in the WLA portion.

**Table 5.8 Final average annual in-stream *Enterococci* bacterial loads (cfu/year) modeled after TMDL allocation in the Deep Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Deep Creek** | **5.59E+12** | **2.67E+13** | *Implicit* | **3.23E+13** |
| *Newport News MS4 VA0088641* | 5.27E+12 | | | |
| *Future Load* | *3.23E+11* | | | |

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

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily maximum in-stream loads for Deep Creek are shown in Table 5.9.

**Table 5.9 Final average daily in-stream *Enterococci* bacterial loads (cfu/day) modeled after TMDL allocation in the Deep Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL[2] |
|---|---|---|---|---|
| **Deep Creek** | **1.53E+10** | **1.05E+12** | *Implicit* | **1.07E+12** |
| *Newport News MS4 VA0088641* | 1.44E+10 | | | |
| *Future Load* | *8.84E+08* | | | |

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

[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 104 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

### 5.4.3 Warwick and James Rivers – VDH Shellfishing Use Impairment

Table 5.10 shows allocation scenarios used to determine the final TMDL for the Warwick and James River impairment. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VDH fecal coliform shellfishing use standards. The existing condition, Scenario 1, shows a 100% violations of both standards. Scenario 2 (eliminating direct human inputs), Scenario 3 (eliminating direct livestock), and Scenario 4 (a typical management scenario) all resulted in 100% violations of both standards. Scenario 5 shows 100% reductions to all anthropogenic sources meets the 90$^{th}$ percentile standard but not the geometric mean standard. This shows that reductions to wildlife loads are required to calculate the TMDL. The first 5 scenarios are explained in more detail in Section 5.4. Scenario 6 shows that a 37% reduction from direct wildlife, 36% from land-based wildlife, 100% reduction from direct livestock, 99% reductions from agricultural and residential land-based loads and correcting all straight pipes and sewer overflows meets both VDH standards.

Due to the sensitivity of the model and the relative loads from the different sources of bacteria, Scenario 7 was created and used to calculate the final average annual TMDL. During Implementation Plan Development (Chapter 6), strategies on reducing anthropogenic loads and dealing with the wildlife sources will be discussed further. The final TMDL scenario shows that a 37% reduction from direct wildlife, 36% form land-based wildlife, 86% reduction from direct livestock, 91% reduction from agricultural land-based, 99% reduction from residential land-based loads and correcting all straight pipes and sewer overflows will meet both VDH fecal coliform shellfishing use standards.

Deep Creek is also a part of this impairment. The required reductions to meet the VDH standards are more strict than those for Deep Creek to meet the swimming use standards; therefore, Deep Creek must meet the reductions in Table 5.10. As explained previously, the flood (incoming) tides from the James River must meet both the VADEQ and VDH standards before the Warwick River can meet these standards.

**Table 5.10 Allocation scenarios for reducing current bacteria loads in Warwick and James Rivers (subwatersheds 2-14).**

| | Percent Reductions to Existing Bacteria Loads | | | | | | VDH Fecal Coliform Standard violations | |
|---|---|---|---|---|---|---|---|---|
| | | Wildlife Land Based | | Agricultural Land Based | Human Direct | Human and Pet Land Based | | |
| Scenario | Wildlife Direct | Barren, Commercial, Forest, HIR, Wetlands | Livestock Direct | Cropland, Pasture, LAX | Straight Pipes | LIR | >14 Geometric Mean | >49 90th Percentile |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 100% | 100% |
| 2 | 0 | 0 | 0 | 0 | 100 | 0 | 100% | 100% |
| 3 | 0 | 0 | 100 | 0 | 100 | 0 | 100% | 100% |
| 4 | 0 | 0 | 90 | 50 | 100 | 50 | 100% | 100% |
| 5 | 0 | 0 | 100 | 100 | 100 | 100 | 100% | 0% |
| 6 | 37 | 36 | 100 | 99 | 100 | 99 | 0% | 0% |
| 7[1] | 37 | 36 | 86 | 91 | 100 | 99 | 0% | 0% |
| 8[2] | 0 | 0 | 86 | 91 | 100 | 99 | 100% | 0% |

[1]Final TMDL Scenario
[2]Stage I Implementation Scenario

Figures 5.5 and 5.6 show the existing and allocated 30-month fecal coliform geometric mean and 30-month 90th percentile fecal coliform in-stream concentrations, respectively from Warwick and James Rivers impairment outlet. These graphs show existing conditions in black, with allocated conditions overlaid in gray.

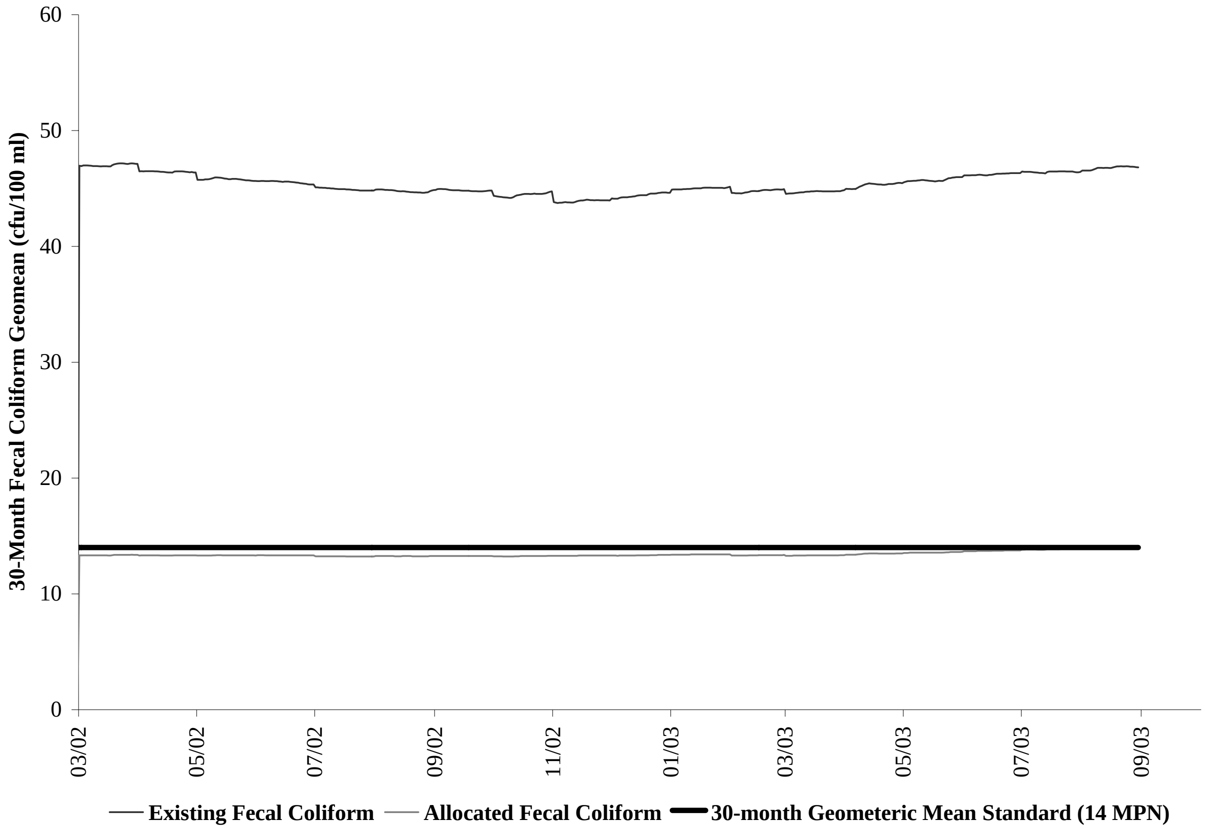


**Figure 5.5 Existing and allocated 30-month geometric mean in-stream fecal coliform concentrations in subwatershed 5, Warwick and James Rivers impairment outlet.**

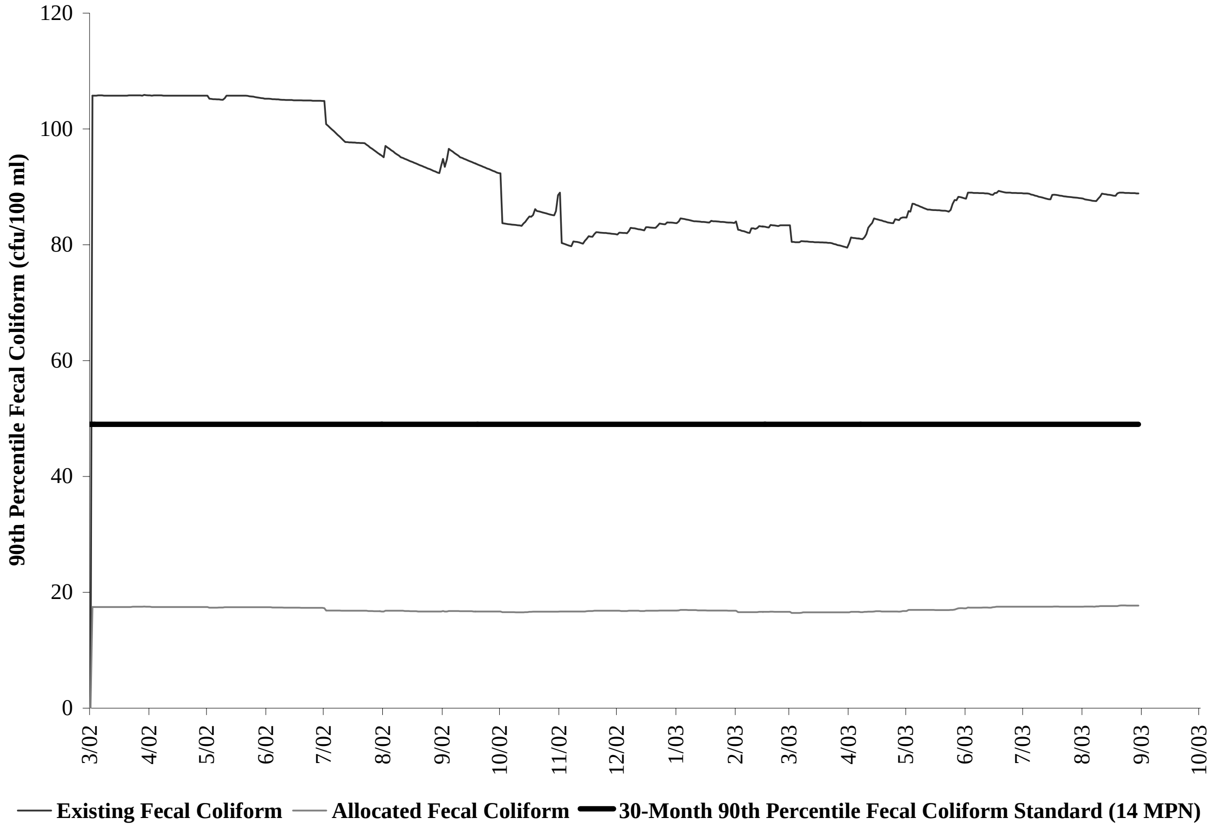


**Figure 5.6 Existing and allocated 30-month 90th percentile in-stream fecal coliform concentrations in subwatershed 5, Warwick and James Rivers impairment outlet.**

Table 5.11 contains estimates of existing and allocated in-stream fecal coliform loads at the Warwick and James Rivers impairment outlet reported as average annual cfu per year. These loads are distributed based on their land-based origins, as opposed to their source origins. The in-stream load estimates at the impairment outlet in Table 5.11 assume that the in-stream source distribution of fecal coliform is the same as the distribution of fecal coliform on the land. The HSPF model is calibrated to the build-up and wash-off rates by subwatershed, not by individual bacteria source or land use. Any contributing bacteria loads from downstream tidal sources are not included in this model approach. The estimates in Table 5.11 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed.

Tables C.9 through C.12 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation. The percent reductions needed to meet zero percent violations of all applicable water quality standards are given in the final column.

**Table 5.11 Estimated existing and allocated fecal coliform in-stream loads in the Warwick and James Rivers impairment.**

| Source | Total Annual Loading for Existing Run[1] (cfu/yr) | Total Annual Loading for Allocation Run[1] (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 1.49E+13 | 9.51E+12 | 36 |
| Commercial | 4.22E+12 | 2.70E+12 | 36 |
| Cropland | 1.12E+13 | 1.01E+12 | 91 |
| Forest | 1.56E+14 | 1.00E+14 | 36 |
| High Density Residential | 1.68E+13 | 1.08E+13 | 36 |
| Livestock Access | 2.54E+12 | 2.29E+11 | 91 |
| Low Density Residential | 1.24E+15 | 1.24E+13 | 99 |
| Pasture | 4.46E+13 | 4.01E+12 | 91 |
| Wetland | 1.66E+14 | 1.06E+14 | 36 |
| **Direct** | | | |
| Human | 1.52E+14 | 0.00E+00 | 100 |
| Livestock | 2.91E+10 | 4.08E+09 | 86 |
| Wildlife | 3.08E+13 | 1.94E+13 | 37 |
| Permitted Sources | 3.04E+12 | 3.04E+12 | 0 |
| **Total Loads** | 1.84E+15 | 2.69E+14 | 85 |

[1]Distribution of these in-stream loads are based on the distribution of fecal coliform deposited on the land and deposited directly in the stream as modeled in HSPF to determine the final TMDL.

Table 5.12 is the average annual TMDL table, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet existing water quality standards. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The City of Newport News, James City County, and Fort Eustis currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Warwick and James Rivers drainage area. Therefore, these municipalities have a WLA load in the Warwick and James Rivers TMDL. To account for future growth of urban and residential human populations one percent of the final TMDL was set aside for future growth in the WLA portion.

**Table 5.12 Final average annual in-stream fecal coliform bacterial loads (cfu/year) modeled after TMDL allocation in the Warwick And James Rivers impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **Warwick River** | **3.04E+12** | **2.66E+14** | *Implicit* | **2.69E+14** |
| *Newport News MS4 VA0088641* | *3.19E+11* | | | |
| *York County MS4 VAR040028* | *6.39E+09* | | | |
| *Fort Eustis MS4 VAR040035* | *2.52E+10* | | | |
| *Future Load* | *2.69E+12* | | | |

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

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily maximum in-stream loads for Warwick and James Rivers are shown in Table 5.13.

**Table 5.13 Final Average daily in-stream fecal coliform bacterial loads (cfu/day) modeled after TMDL allocation in the Warwick and James Rivers impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL[2] |
|---|---|---|---|---|
| **Warwick River** | **8.32E+09** | **1.94E+12** | Implicit | **1.95E+12** |
| *Newport News MS4 VA0088641* | *8.74E+08* | | | |
| *York County MS4 VAR040028* | *1.75E+07* | | | |
| *Fort Eustis MS4 VAR040035* | *6.91E+07* | | | |
| *Future Load* | *7.36E+09* | | | |

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 14 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

With the completion and implementation of this TMDL, the Warwick and James Rivers shellfishing impairment, condemnation area 34A, will be closer to meeting the water quality standards and may eventually be de-listed. However, due to the HRSD- James River Sewage Treatment Plant (VA0081272) outfall to the James and Warwick River confluence, the condemnation area 34B, will always be closed to shellfishing. This is an administrative closure designed to prohibit shellfish harvesting and consumption due to the potential presence of viruses or non-bacterial pathogens, which may survive the chlorination disinfection process. This effectively removes the shellfish use from this segment of the water body and in the view of the EPA and VADEQ it is no longer considered a shellfish use water for TMDL purposes. This area will retain the restriction: "as to area B, it shall be unlawful for any person, firm or corporation to take shellfish from this area, for any purpose". Condemnation area 34B is shown in Figure 5.7.

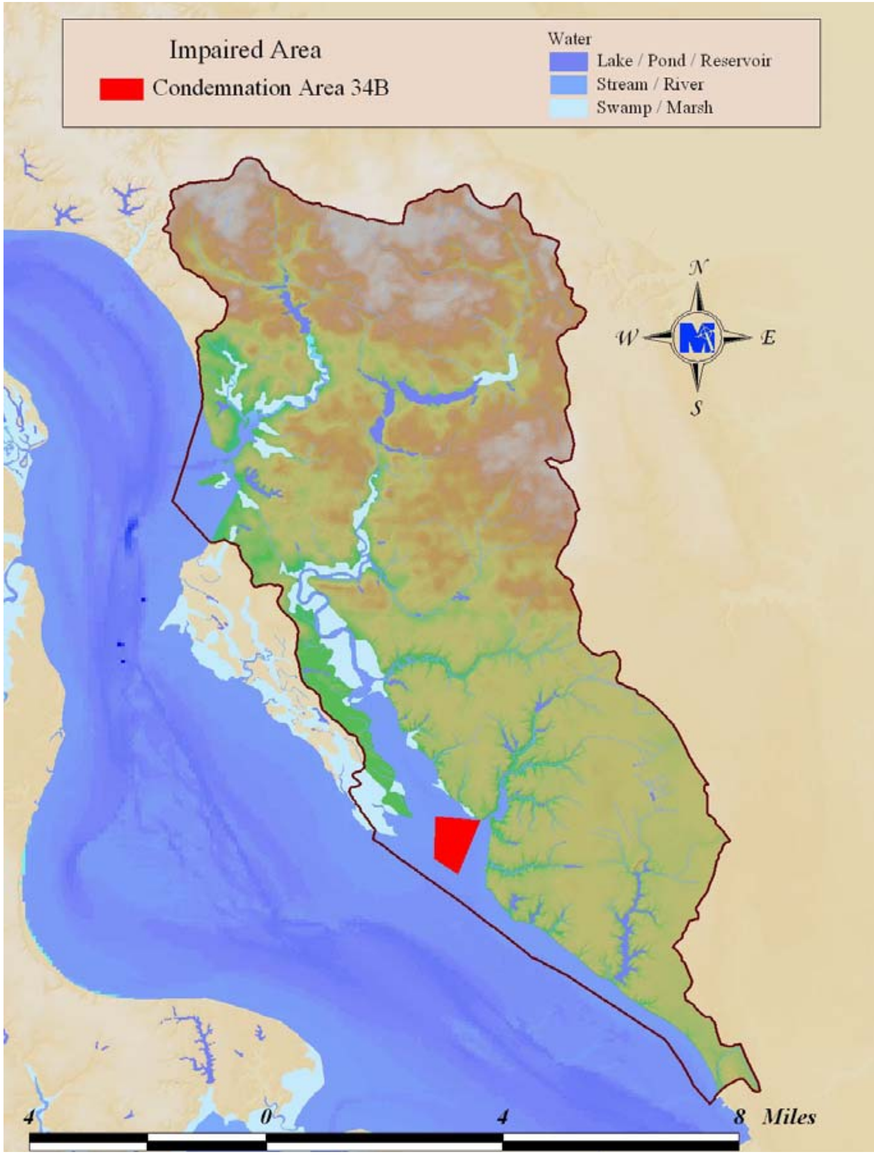


**Figure 5.7** **VDH condemnation area 34B, no shellfishing is allowed in this area, even after the TMDL is completed and implemented.**

### 5.4.4 James River – Opposite Fort Eustis & Skiffes Creek – VDH Shellfishing Use Impairment

Table 5.14 shows allocation scenarios used to determine the final TMDL for the Skiffes Creek impairment. Because Virginia's standards do not permit any exceedances, modeling was conducted for a target value of 0% exceedance of the VDH fecal coliform shellfishing use standards. The existing condition, Scenario 1, shows a 100% violations of the geometric mean standard. Scenario 2 (eliminating direct human inputs), Scenario 3 (eliminating direct livestock), Scenario 4 (a typical management scenario), and Scenario 5 (100% reductions to all anthropogenic sources) all resulted in 100% violations of the geometric mean standard. This shows that reductions to wildlife loads are required to calculate the TMDL. The first 5 scenarios are explained in more detail in Section 5.4. Scenario 6 shows that a 91% reduction from direct wildlife, 85% from land-based wildlife, 100% reduction from direct livestock, 99% reductions from agricultural and residential land-based loads and correcting all straight pipes and sewer overflows meets both VDH standards.

Due to the sensitivity of the model and the relative loads from the different sources of bacteria, Scenario 7 was created and used to calculate the final average annual TMDL. During Implementation Plan Development (Chapter 6), strategies on reducing anthropogenic loads and dealing with the wildlife sources will be discussed further. The final TMDL scenario shows that a 91% reduction from direct wildlife, 85% form land-based wildlife, 96% reduction from direct livestock, 96% reduction from agricultural land-based, 99% reduction from residential land-based loads and correcting all straight pipes and sewer overflows will meet both VDH fecal coliform shellfishing use standards. As explained previously, the flood (incoming) tides from the James River must meet both the VADEQ and VDH standards before the Warwick River can meet these standards.

**Table 5.14 Allocation scenarios for reducing current bacteria loads in Skiffes Creek (subwatersheds 15 and 16).**

| | Percent Reductions to Existing Bacteria Loads | | | | | | VDH Fecal Coliform Standard violations | |
|---|---|---|---|---|---|---|---|---|
| | | Wildlife Land Based | | Agricultural Land Based | Human Direct | Human and Pet Land Based | | |
| Scenario | Wildlife Direct | Barren, Commercial, Forest, HIR, Wetlands | Livestock Direct | Cropland, Pasture, LAX | Straight Pipes | LIR | >14 Geometric Mean | >49 90th Percentile |
| 1 | 0 | 0 | 0 | 0 | 0 | 0 | 100% | 0% |
| 2 | 0 | 0 | 0 | 0 | 100 | 0 | 100% | 0% |
| 3 | 0 | 0 | 100 | 0 | 100 | 0 | 100% | 0% |
| 4 | 0 | 0 | 90 | 50 | 100 | 50 | 100% | 0% |
| 5 | 0 | 0 | 100 | 100 | 100 | 100 | 100% | 0% |
| 6 | 91 | 85 | 100 | 99 | 100 | 99 | 0% | 0% |
| 7[1] | 91 | 85 | 96 | 96 | 100 | 99 | 0% | 0% |
| 8[2] | 0 | 0 | 96 | 96 | 100 | 99 | 100% | 0% |

[1]Final TMDL Scenario
[2]Stage I Implementation Scenario

Figures 5.8 and 5.9 show the existing and allocated 30-month fecal coliform geometric mean and 30-month 90th percentile fecal coliform in-stream concentrations, respectively from the Skiffes Creek impairment outlet. These graphs show existing conditions in black, with allocated conditions overlaid in gray.

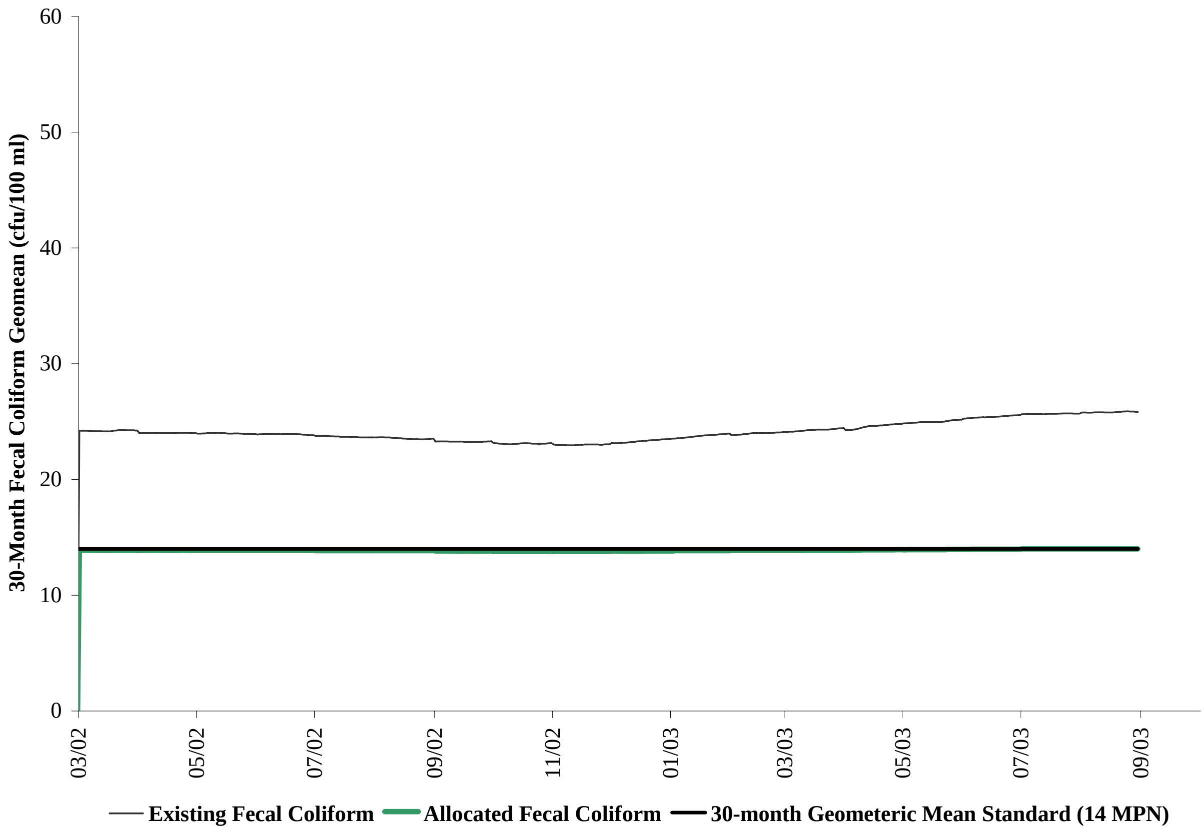


**Figure 5.8 Existing and allocated 30-month geometric mean in-stream fecal coliform concentrations in subwatershed 16, Skiffes Creek impairment outlet.**

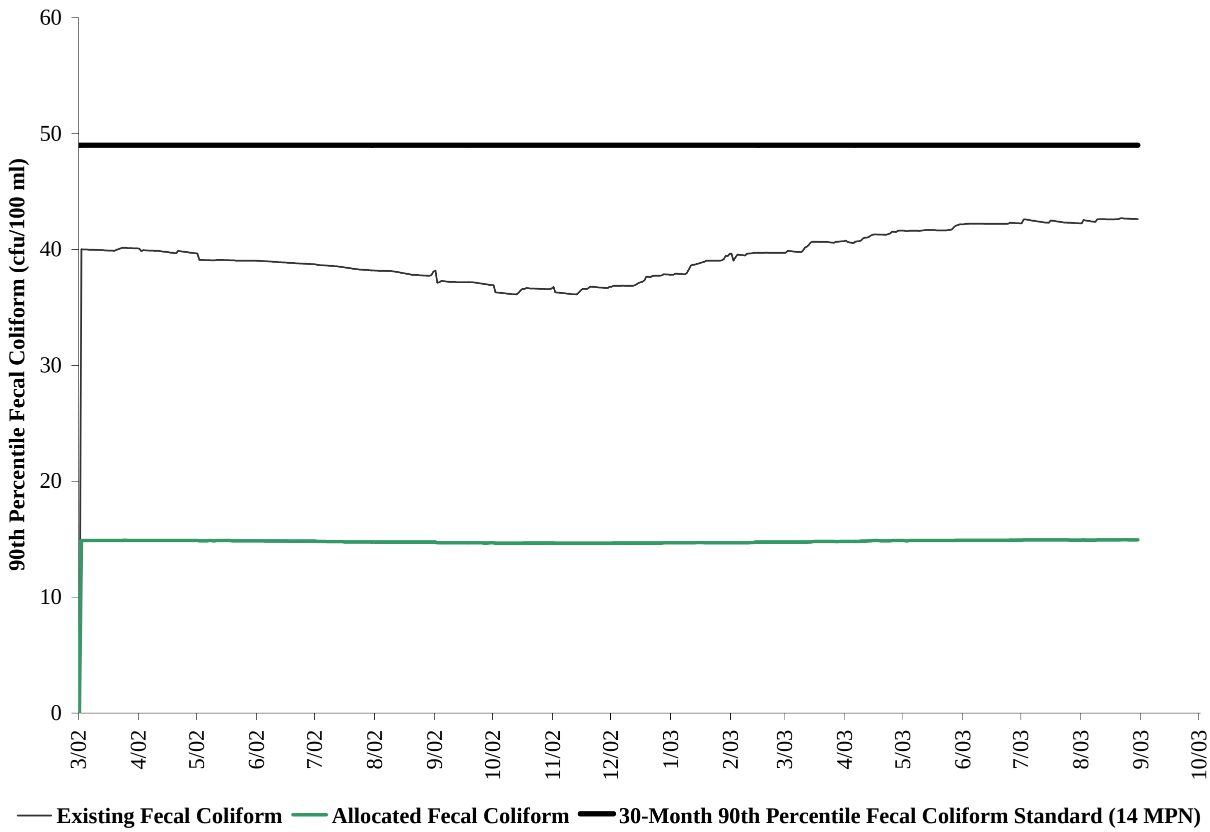


**Figure 5.9 Existing and allocated 30-month 90th percentile in-stream fecal coliform concentrations in subwatershed 16, Skiffes Creek impairment outlet.**

Table 5.15 contains estimates of existing and allocated in-stream fecal coliform loads at the Skiffes Creek impairment outlet reported as average annual cfu per year. These loads are distributed based on their land-based origins, as opposed to their source origins. The in-stream load estimates at the impairment outlet in Table 5.15 assume that the in-stream source distribution of fecal coliform is the same as the distribution of fecal coliform on the land. The HSPF model is calibrated to the build-up and wash-off rates by subwatershed, not by individual bacteria source or land use. Any contributing bacteria loads from downstream tidal sources are not included in this model approach. The estimates in Table 5.15 are generated from available data, and these values are specific to the impairment outlet for the allocation rainfall for the current land use distribution in the watershed.

Tables C.13 through C.16 include the land-based fecal coliform load distributions and offer more details for specific implementation development and source assessment evaluation. The percent reductions needed to meet zero percent violations of all applicable water quality standards are given in the final column.

**Table 5.15 Estimated existing and allocated fecal coliform in-stream loads in the Skiffes Creek impairment.**

| Source | Total Annual Loading for Existing Run[1] (cfu/yr) | Total Annual Loading for Allocation Run[1] (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 3.51E+13 | 5.26E+12 | 85 |
| Commercial | 9.89E+12 | 1.48E+12 | 85 |
| Cropland | 2.17E+14 | 8.70E+12 | 96 |
| Forest | 6.80E+14 | 1.02E+14 | 85 |
| High Density Residential | 2.24E+13 | 3.35E+12 | 85 |
| Livestock Access | 4.36E+12 | 1.74E+11 | 96 |
| Low Density Residential | 1.00E+15 | 1.00E+13 | 99 |
| Pasture | 1.35E+14 | 5.41E+12 | 96 |
| Wetland | 5.96E+14 | 8.94E+13 | 85 |
| **Direct** | | | |
| Human | 1.70E+14 | 0.00E+00 | 100 |
| Livestock | 2.43E+11 | 9.73E+09 | 96 |
| Wildlife | 1.13E+14 | 1.02E+13 | 91 |
| Permitted Sources | 2.46E+12 | 2.46E+12 | 0 |
| **Total Loads** | 2.99E+15 | 2.38E+14 | 92 |

[1]Distribution of these in-stream loads are based on the distribution of fecal coliform deposited on the land and deposited directly in the stream as modeled in HSPF to determine the final TMDL.

Table 5.16 is the average annual TMDL table, which gives the average amount of bacteria that can be present in the stream in a given year, and still meet existing water quality standards. These values are output from the HSPF model and incorporate in-stream die-off, tidal mixing, and other hydrological and environmental processes involved in runoff and stream routing techniques within the HSPF model framework. The City of Newport News, James City County, York County, and Fort Eustis currently have Municipal Separate Storm Sewer System (MS4) permits, which are partly in the Skiffes Creek drainage area. Therefore, these municipalities have a WLA load in the

Skiffes Creek TMDL. To account for future growth of urban and residential human populations one percent of the final TMDL was set aside for future growth in the WLA portion.

**Table 5.16 Final average annual in-stream bacterial loads (cfu/year) modeled after TMDL allocation in the James River – Opposite Fort Eustis & Skiffes Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL |
|---|---|---|---|---|
| **James River – Opposite Fort Eustis & Skiffes Creek** | **2.46E+12** | **2.36E+14** | *Implicit* | **2.38E+14** |
| Newport News MS4 VA0088641 | 4.24E+10 | | | |
| Fort Eustis MS4 VAR040035 | 1.05E+10 | | | |
| York County MS4 VAR040028 | 7.11E+09 | | | |
| James City Co MS4 VAR040037 | 3.33E+10 | | | |
| Future Load | 2.38E+12 | | | |

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

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily maximum in-stream loads for Skiffes Creek are shown in Table 5.17.

**Table 5.17 Final average daily in-stream fecal coliform bacterial loads (cfu/day) modeled after TMDL allocation in the James River – Opposite Fort Eustis & Skiffes Creek impairment.**

| Impairment | WLA[1] | LA | MOS | TMDL[2] |
|---|---|---|---|---|
| **James River – Opposite Fort Eustis & Skiffes Creek** | **6.79E+09** | **1.11E+12** | *Implicit* | **1.12E+12** |
| Newport News MS4 VA0088641 | 1.16E+08 | | | |
| Fort Eustis MS4 VAR040035 | 2.87E+07 | | | |
| York County MS4 VAR040028 | 1.95E+07 | | | |
| James City Co MS4 VAR040037 | 9.11E+07 | | | |
| Future Load | *6.53E+09* | | | |

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 14 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.

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

VADEQ staff will also request that the SWCB adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia Water Quality Standards, such as in the case for bacteria. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on VADEQ'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 Reasonable Assurance for Implementation

#### 6.4.1 Stormwater

Part of the Warwick River watershed is covered by The City of Newport News (VA0088641), York County (VAR040028), James City County (VAR040037), and Fort Eustis (VAR040035) small municipal separate storm sewer systems (MS4s) owned by the each of these municipalities.

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

For MS4/VSMP permits, the Commonwealth expects the permittee to specifically address the TMDL waste load allocations for stormwater through the iterative implementation of programmatic BMPs. BMP effectiveness would be determined through permittee implementation of an individual control strategy that includes a monitoring program that is sufficient to determine its BMP effectiveness. As stated in EPA's *Memorandum on TMDLs and Stormwater Permits*, dated November 22, 2002, "The NPDES permits must require the monitoring necessary to assure compliance under the permit limits." Ambient in-stream monitoring would not be an appropriate means of determining permit compliance. Ambient monitoring would be appropriate to determine if the entire TMDL is being met by all attributed sources. This is in accordance with recent EPA guidance. If future monitoring indicates no improvement in the quality of the regulated discharge, the permit could require the MS4 to expand or better tailor its stormwater management program to achieve the TMDL waste load allocation. However, only failing to implement the programmatic BMPs identified in the modified stormwater management program would be considered a violation of the permit. Any changes to the TMDL resulting from water quality standards changes on the Pagan River would be reflected in the permit.

Waste load allocations for stormwater discharges from storm sewer systems covered by a MS4 permit will be addressed as a condition of the MS4 permit. An implementation plan will identify types of corrective actions and strategies to obtain the load allocation for the pollutant causing the water quality impairment. Permittees will be required to participate in the development of TMDL implementation plans since recommendations from the process may result in modifications to the stormwater management plan in order to meet the TMDL. For example, MS4 permittees regulate erosion and sediment control programs that affect discharges that are not regulated by the MS4 permit.

Additional information on Virginia's Stormwater Program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm.

### 6.4.2 TMDL Modifications for New or Expanding Dischargers

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

## *6.5 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.

### 6.5.1 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 VADEQ and VADCR 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 VADEQ, VADCR, 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.

### 6.5.2 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 (Tables 6.1 through 6.4). Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

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 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 6.6.

**Table 6.1 Fecal coliform land-based loads deposited on all land uses and direct loads in the Baptist Run watershed for existing conditions and for the Stage I scenario.**

| Source | Total Annual Loading for Existing Run (cfu/yr) | Total Annual Loading for Allocation Run (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 2.10E+10 | 2.10E+10 | 0 |
| Commercial | 3.60E+10 | 3.60E+10 | 0 |
| Cropland | 4.25E+11 | 4.25E+10 | 90 |
| Forest | 2.14E+13 | 2.14E+13 | 0 |
| High Density Residential | 5.55E+10 | 5.55E+10 | 0 |
| LAX | 8.98E+10 | 8.98E+09 | 90 |
| Low Density Residential | 1.45E+13 | 8.70E+11 | 94 |
| Pasture | 5.18E+11 | 5.18E+10 | 90 |
| Wetland | 1.30E+12 | 1.30E+12 | 0 |
| **Direct** | | | |
| Human | 1.14E+12 | 0.00E+00 | 100 |
| Livestock | 0.00E+00 | 0.00E+00 | 0 |
| Wildlife | 6.34E+11 | 6.34E+11 | 0 |

**Table 6.2 Fecal coliform land-based loads deposited on all land uses and direct loads in the Deep Creek watershed for existing conditions and for the Stage I scenario.**

| Source | Total Annual Loading for Existing Run (cfu/yr) | Total Annual Loading for Allocation Run (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 2.87E+12 | 2.87E+12 | 0 |
| Commercial | 1.96E+12 | 1.96E+12 | 0 |
| Cropland | 2.61E+12 | 2.61E+12 | 0 |
| Forest | 2.88E+13 | 2.88E+13 | 0 |
| High Density Residential | 6.26E+12 | 6.26E+12 | 0 |
| LAX | 5.14E+11 | 5.14E+11 | 0 |
| Low Density Residential | 4.49E+14 | 4.49E+14 | 0 |
| Pasture | 4.31E+12 | 4.31E+12 | 0 |
| Wetland | 2.28E+13 | 2.28E+13 | 0 |
| **Direct** | | | |
| Human | 2.82E+13 | 0.00E+00 | 100 |
| Livestock | 0.00E+00 | 0.00E+00 | 0 |
| Wildlife | 3.30E+12 | 3.30E+12 | 0 |

**Table 6.3 Fecal coliform land-based loads deposited on all land uses and direct loads in the Warwick and James Rivers watershed for existing conditions and for the Stage I scenario.**

| Source | Total Annual Loading for Existing Run (cfu/yr) | Total Annual Loading for Allocation Run (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 4.61E+12 | 4.61E+12 | 0 |
| Commercial | 1.30E+12 | 1.30E+12 | 0 |
| Cropland | 2.86E+13 | 1.14E+12 | 96 |
| Forest | 8.94E+13 | 8.94E+13 | 0 |
| High Density Residential | 2.94E+12 | 2.94E+12 | 0 |
| LAX | 5.73E+11 | 2.29E+10 | 96 |
| Low Density Residential | 1.32E+14 | 1.32E+12 | 99 |
| Pasture | 1.78E+13 | 7.12E+11 | 96 |
| Wetland | 7.84E+13 | 7.84E+13 | 0 |
| **Direct** | | | |
| Human | 2.24E+13 | 0.00E+00 | 100 |
| Livestock | 3.20E+10 | 1.28E+09 | 96 |
| Wildlife | 1.49E+13 | 1.49E+13 | 0 |

**Table 6.4 Fecal coliform land-based loads deposited on all land uses and direct loads in the James River – Opposite Fort Eustis & Skiffes Creek watershed for existing conditions and for the Stage I scenario.**

| Source | Total Annual Loading for Existing Run (cfu/yr) | Total Annual Loading for Allocation Run (cfu/yr) | Percent Reduction |
|---|---|---|---|
| **Land Based** | | | |
| Barren | 2.91E+13 | 2.91E+13 | 0 |
| Commercial | 8.27E+12 | 8.27E+12 | 0 |
| Cropland | 2.20E+13 | 1.98E+12 | 91 |
| Forest | 3.06E+14 | 3.06E+14 | 0 |
| High Density Residential | 3.29E+13 | 3.29E+13 | 0 |
| LAX | 4.97E+12 | 4.47E+11 | 91 |
| Low Density Residential | 2.43E+15 | 2.43E+13 | 99 |
| Pasture | 8.73E+13 | 7.86E+12 | 91 |
| Wetland | 3.24E+14 | 3.24E+14 | 0 |
| **Direct** | | | |
| Human | 2.98E+14 | 0.00E+00 | 100 |
| Livestock | 5.70E+10 | 7.98E+09 | 86 |
| Wildlife | 6.02E+13 | 6.02E+13 | 0 |

### 6.5.3 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.

### 6.5.4 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 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.

### 6.6 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient and biological monitoring programs. VADEQ'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 the VADEQ *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. Since there may be a lag time of one-to-several years before any improvement in the benthic community will be evident, follow-up biological monitoring may not have to occur in the fiscal year immediately following the implementation of control measures.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the VADEQ staff, in cooperation with VADCR 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 VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year.

VADEQ staff, in cooperation with VADCR 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 VADEQ'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 VADEQ 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 bimonthly 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), VADEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, dissolved oxygen, etc) is bimonthly monitoring for two consecutive years.

## 6.7 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. VADEQ 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, "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed."

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# 7. PUBLIC PARTICIPATION

The public was invited to participate in the development of the Warwick River TMDL. Table 7.1 details the public participation throughout the project. The first public meeting was held at the Grissom Library in Newport News, Virginia on September 21, 2006; eight people attended, including two VADEQ agents, one VADCR representative, two government officials, one representative each from the Hampton Roads Planning District Commission (HRPDC) and the Hampton Roads Sanitation District (HRSD), and one consultant. The meeting was publicized with notices in the *Virginia Register* and the *Daily Press*, a local newspaper. Information about the MS4 was disseminated and the watershed management plan for Skiffes Creek was discussed.

**Table 7.1 Public participation during TMDL development for the Warwick River watershed.**

| Date | Location | Attendance[1] | Type | Format |
|---|---|---|---|---|
| 9/21/2006 | Grissom Library Newport News, VA | 8 | 1st public | Open to public at large |
| 4/18/2007 | Grissom Library Newport News, VA | 8 | TAC | Invited |
| 5/9/2007 | Grissom Library Newport News, VA | 8 | 2nd public | Open to public at large |

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

Participation continued through the technical advisory committee (TAC) and the final public meeting. The TAC meeting on April 18, 2007 included representatives from VADEQ, MapTech, York County, HRPDC, HRSD, Newport News planning, Newport News stormwater, and James City County. The presentation for the final public meeting was discussed and adjusted during this meeting. Eight people representing VADEQ, MapTech, York County, HRPDC, HRSD, and Newport News planning and stormwater divisions attended the final public meeting, held on May 10, 2007. There was a 30-day public comment period beginning when the TMDL was available to the public on the VADEQ website and two letters with written comments were received, answered and incorporated into this final document.

Public participation is critical to promote reasonable assurances that the implementation activities will occur. A stakeholders' committee will have the express purpose of formulating the TMDL Implementation Plan. The major stakeholders were identified during the development of this TMDL. The committee should consist of, but not be limited to, representatives from VADEQ, VADCR, HRPDC, HRSD, and local governments. This committee will have the responsibility for identifying corrective actions that are founded in practicality, establishing a time line to insure expeditious implementation, and setting measurable goals and milestones for attaining water quality standards.

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## GLOSSARY

Note: Entries in italics are taken from http://www.deq.virginia.gov/tmdl/glossary.html

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

***Critical condition.*** *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.)*

*that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

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

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

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

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

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

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

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

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

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

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

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

**E. coli (Escherichia coli) –** one of the groups of fecal coliform bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

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

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

**Enterococci –** a subgroup of fecal streptococcal bacteria associated with the digestive tract of warm-blooded animals used as indicator organisms (organisms indicating presence of pathogens) to detect the presence of pathogenic bacteria in the water.

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

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

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

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

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

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

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

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

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

***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.*

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

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

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

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

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

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

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

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

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

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

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

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

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

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

***Nonpoint source.*** *Pollution that originates from diffuse sources over a relatively large area. Nonpoint sources can be divided into source activities related to either land or water use including failing septic tanks, improper animal-keeping practices, forest practices, and urban and rural runoff.*

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

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

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

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

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

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

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

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

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

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

***Pollution.*** *Generally, the presence of matter or energy whose nature, location, or quantity produces undesired environmental effects. Under the Clean Water Act, for example, the term is defined as the man-made or man-induced alteration of the physical, biological, chemical, and radiological integrity of water.*

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

**Raw sewage.** Untreated municipal sewage.

**Reach.** Segment of a stream or river.

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

**Stream Reach**. A straight portion of a stream.

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

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

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

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

**Tidal Prism Model –** a steady state model that uses mass balance equations to calculate the volume of water in a tidal water system and the associated pollutant load (*e.g.*, fecal coliform concentration).

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

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

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

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

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

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

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

**VADACS.** Virginia Department of Agriculture and Consumer Services.

**VADCR.** Virginia Department of Conservation and Recreation.

**VADEQ.** Virginia Department of Environmental Quality.

**VDH.** Virginia Department of Health.

***Wasteload allocation (WLA).*** *The portion of a receiving waters' loading capacity that is allocated to one of its existing or future point sources of pollution. WLAs constitute a type of water quality-based effluent limitation (40 CFR 130.2(h)).*

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

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

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

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

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

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

**WQIA.** Water Quality Improvement Act.

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# APPENDIX A

## Frequency Analyses of Water Quality Sampling Data

### *Description of Graphs*

The following graphs are shown because the station has 10 or greater samples taken with a 10% or greater violation rate of any applicable water quality standard. All data used in these graphs is also represented in tables in Section 2.3.1.1 and 2.3.1.2 in this document.

In the VADEQ fecal coliform graphs (A.1 through A.11) blue indicates samples not violating any standards and red indicates samples violating the VADEQ instantaneous swimming standard (400 cfu/100mL).

In the VADEQ *enterococci* graphs (A.12 through A.22) blue indicates samples not violating any standards, orange indicates samples violating the current VADEQ geometric mean swimming standard (35 cfu/100mL), and red indicates samples violating both VADEQ swimming standards (35 and 104 cfu/100mL).

In the VDH fecal coliform graphs (A.21 through A.24) blue indicates samples not violating any standards, orange indicates samples violating the VDH shellfishing use geometric mean standard (14 cfu/100mL), and red indicates samples violating both VDH shellfishing use standards (14 and 49 cfu/100mL).

### *VADEQ – Fecal Coliform*

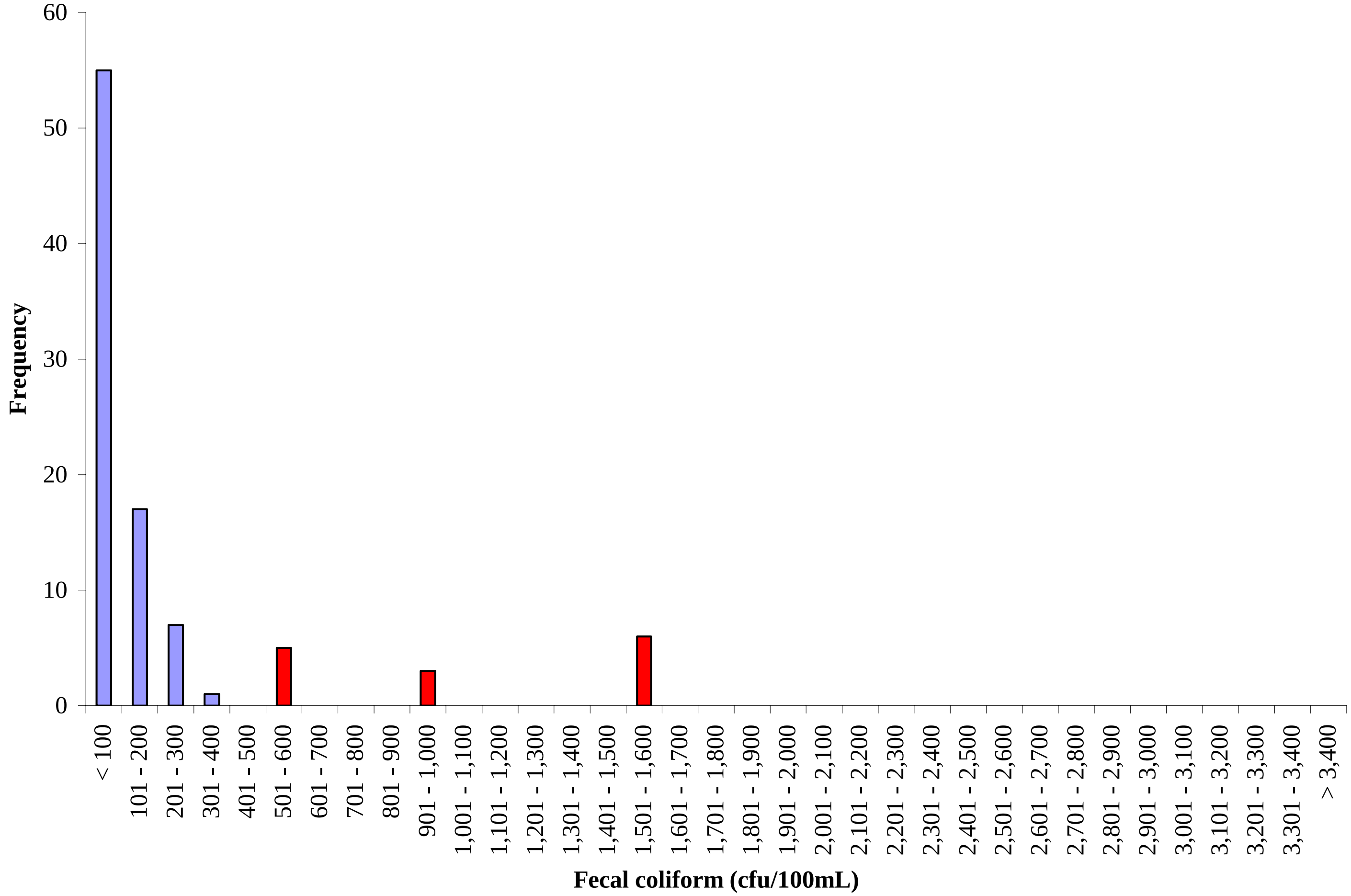


**Figure A.1 Frequency analysis of fecal coliform concentrations at station 2-WWK003.98 in the Warwick River for the period January 1980 to November 2005.**

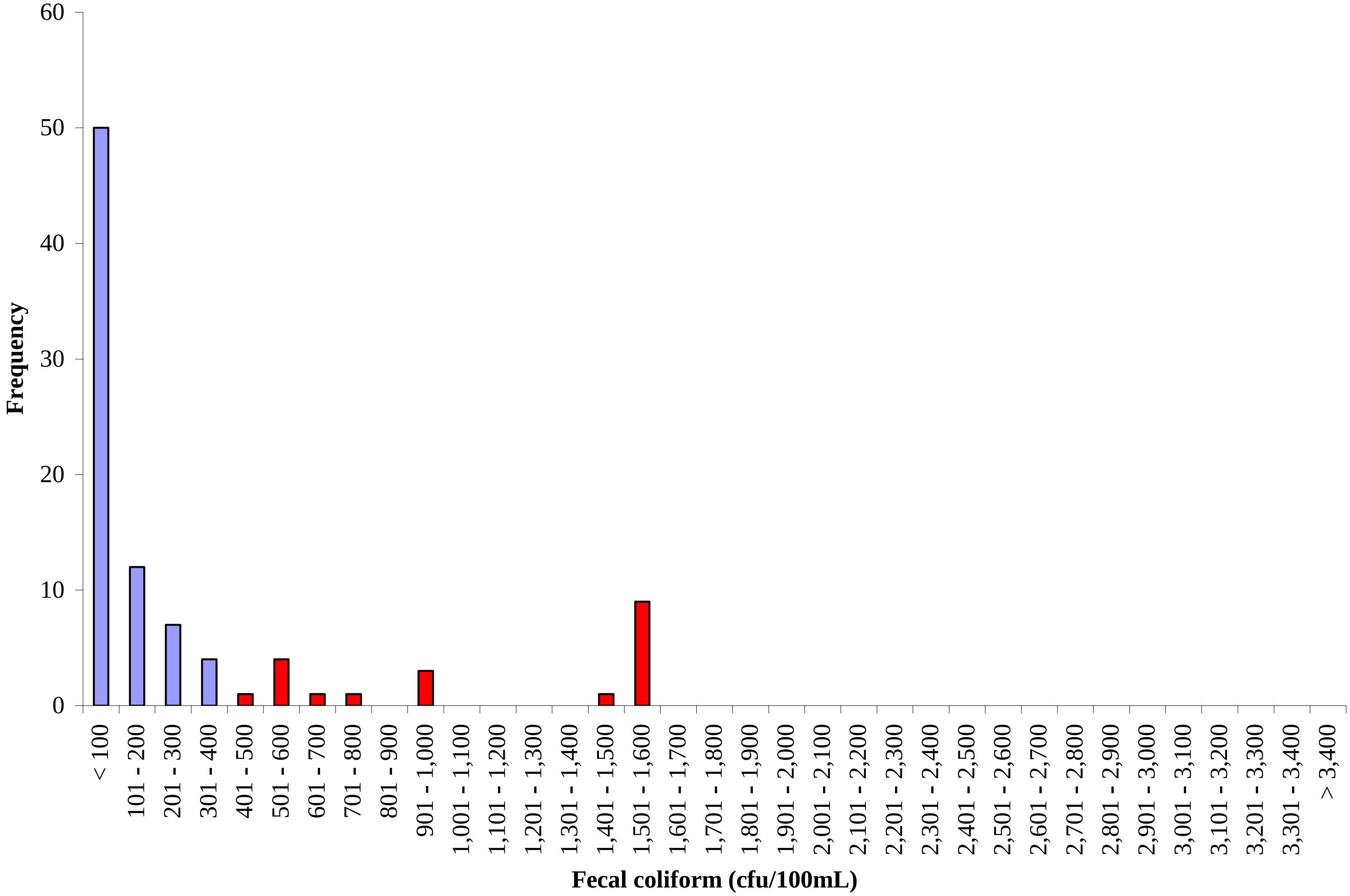


**Figure A.2** **Frequency analysis of fecal coliform concentrations at station 2-DEP000.26 in Deep Creek for the period January 1980 to November 2005.**

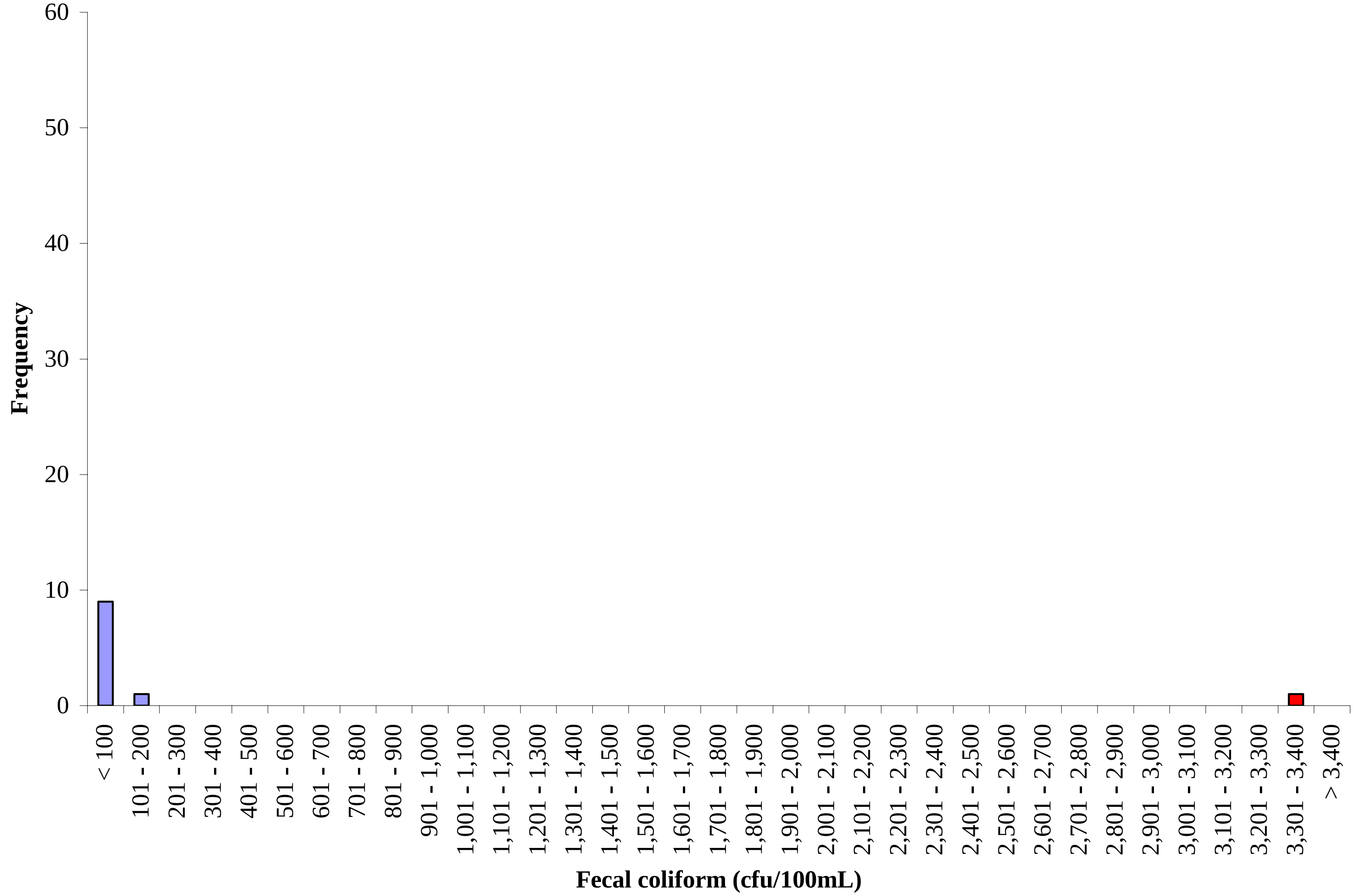


**Figure A.3 Frequency analysis of fecal coliform concentrations at station 2-LHR002.56 in the Lee Hall Reservoir for the period January 1980 to November 2005.**

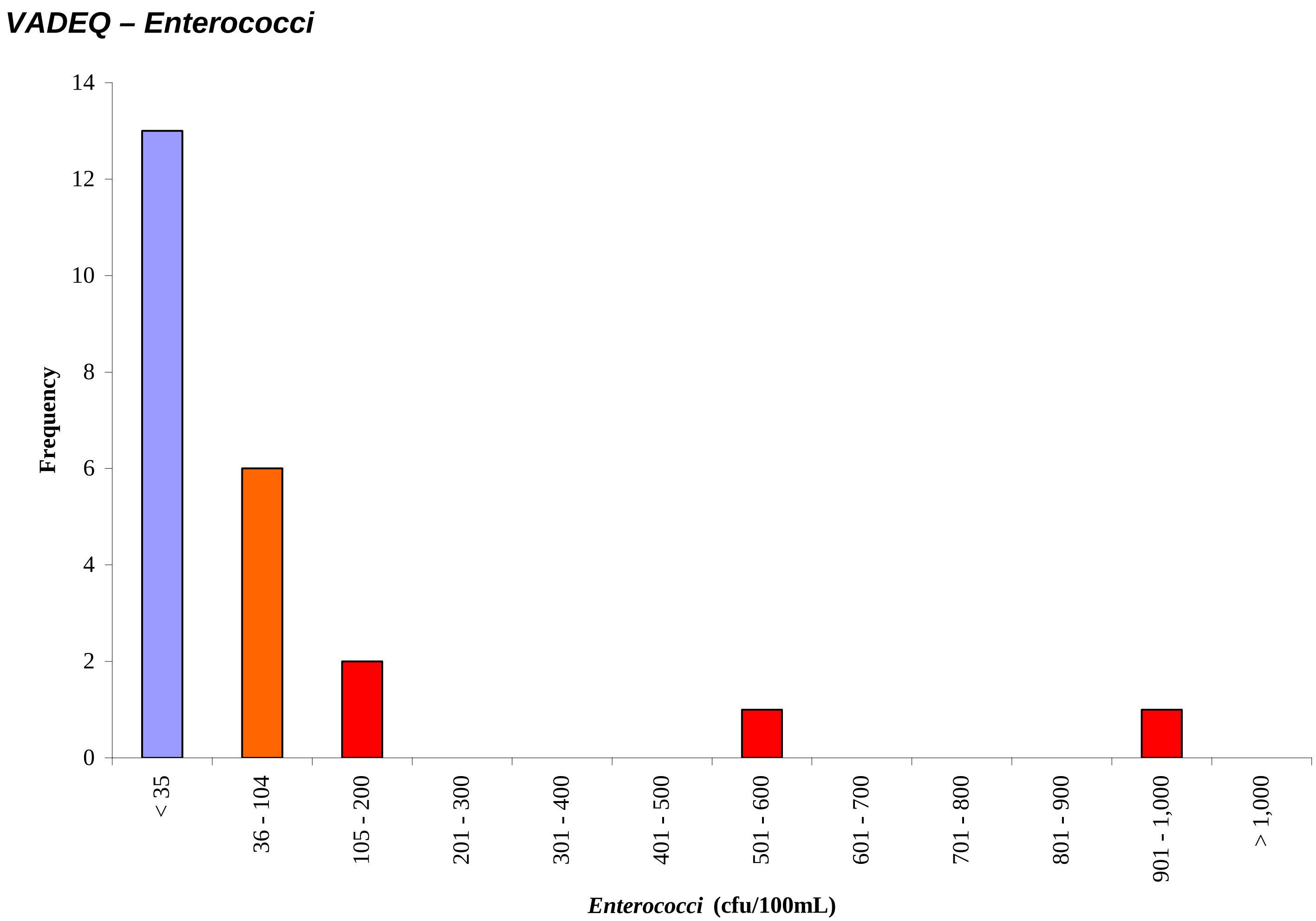


**Figure A.4 Frequency analysis of *enterococci* concentrations at station 2-WWK003.98 in the Warwick River for the period March 2000 to December 2005.**

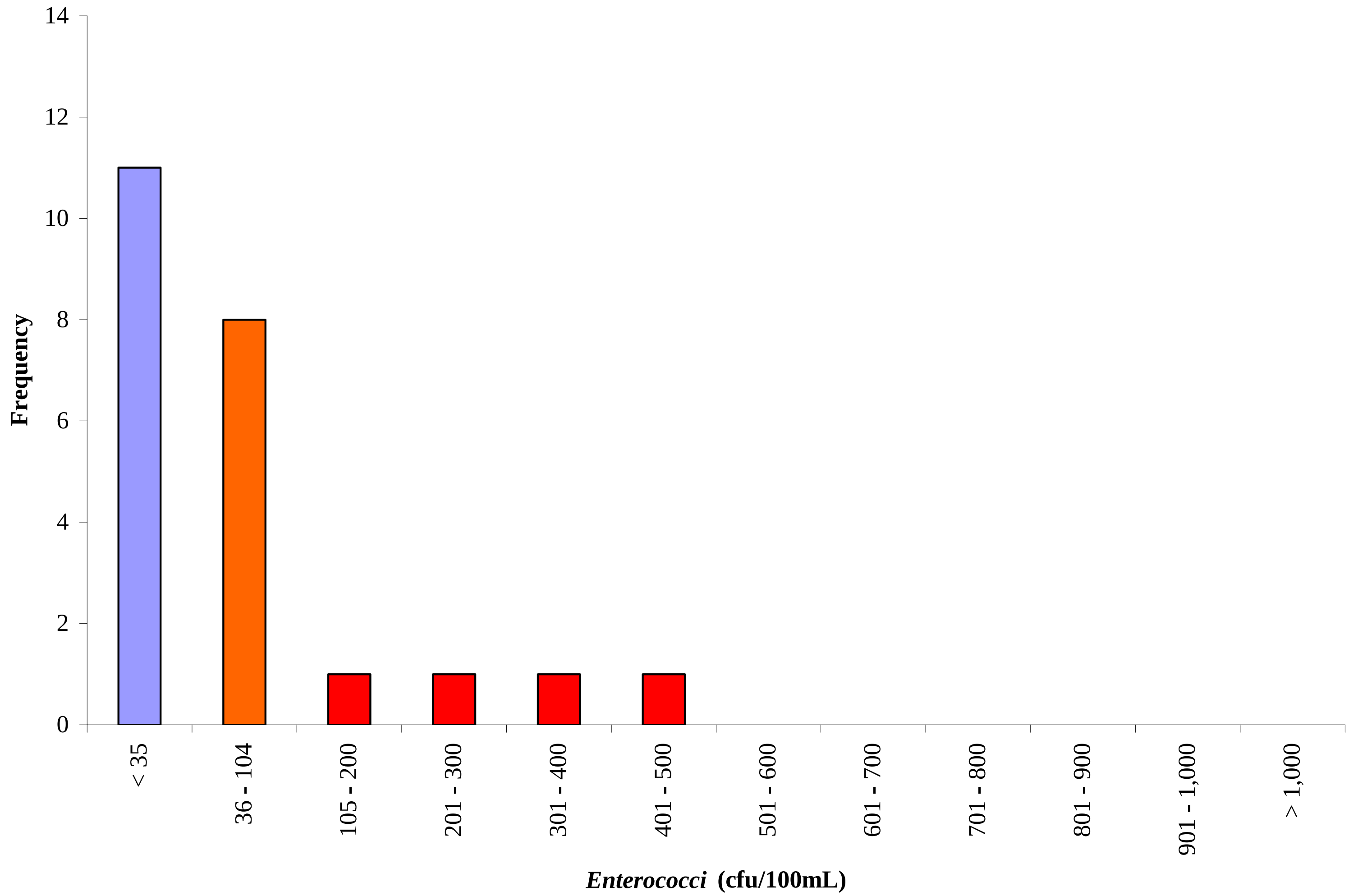


**Figure A.5 Frequency analysis of *enterococci* concentrations at station 2-DEP000.26 in the Warwick River for the period March 2000 to December 2005.**

***VDH – Fecal Coliform***

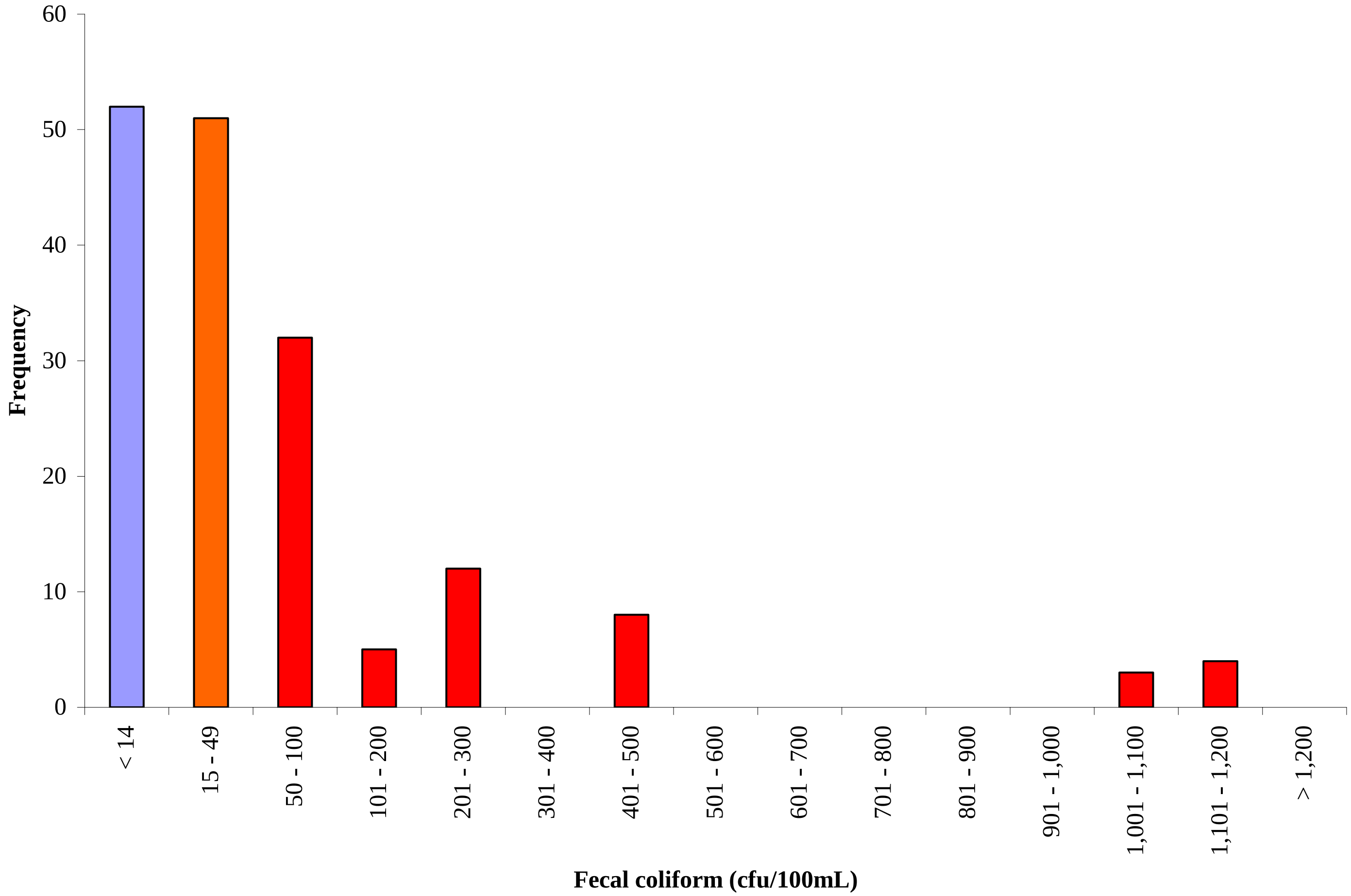


**Figure A.6 Frequency analysis of fecal coliform concentrations in subwatershed 5 (VDH station 58-13) in the Warwick River for the period December 1984 through January 2006.**

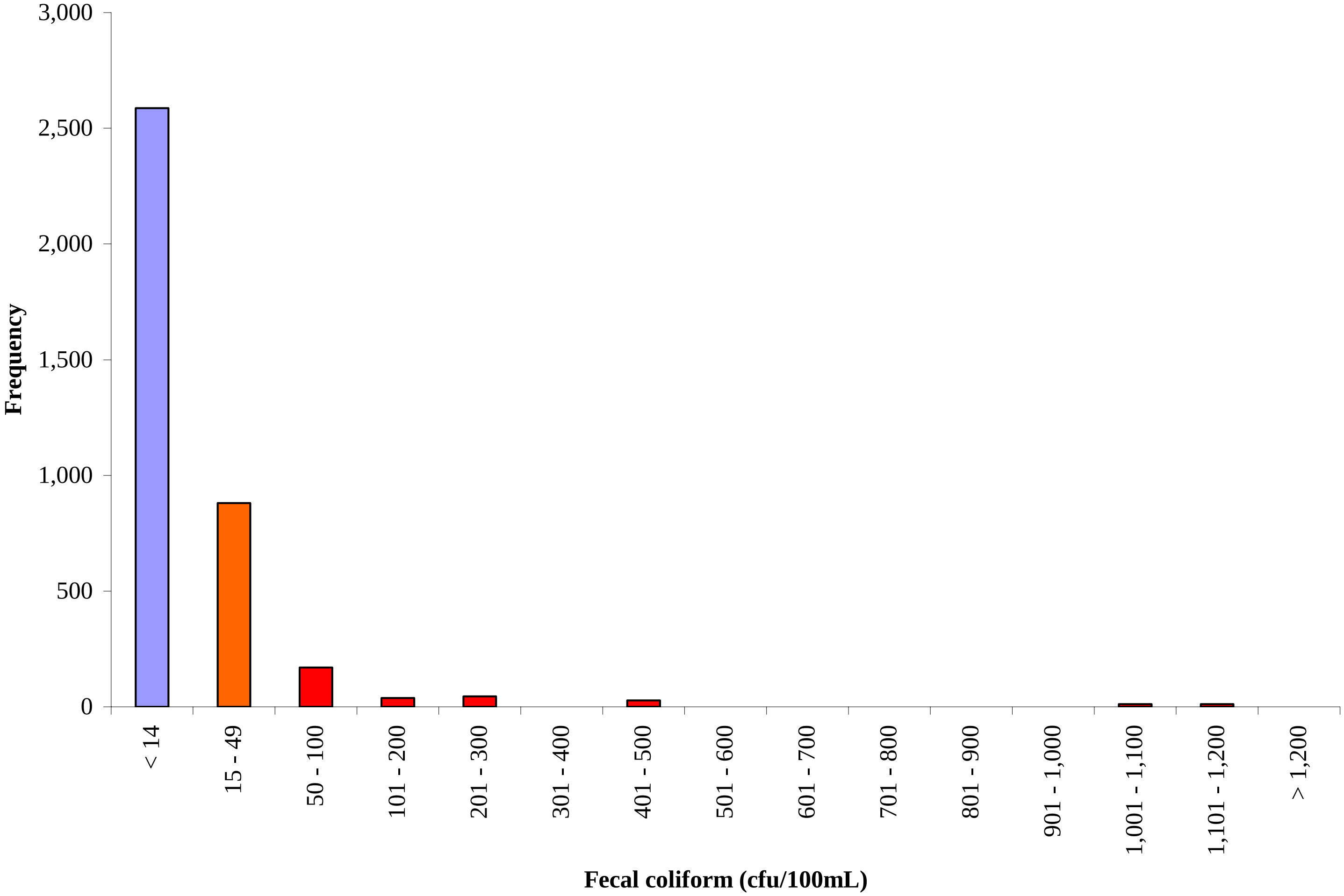


**Figure A.7** **Frequency analysis of fecal coliform concentrations in subwatershed 6 (VDH stations 57-E57, 58-0.5, 58-0.5Y, 58-0.5Z, 58-1.5A, 58-10, 58-11, 58-12, 58-1A, 58-1Z, 58-2.5A, 58-5, 58-6, 58-7, 58-8, 58-9, 58-A62, 58-65A, 58-B64, 58-B65, 58-C67, 58-JRSTP) in the Warwick River for the period December 1984 through January 2006.**

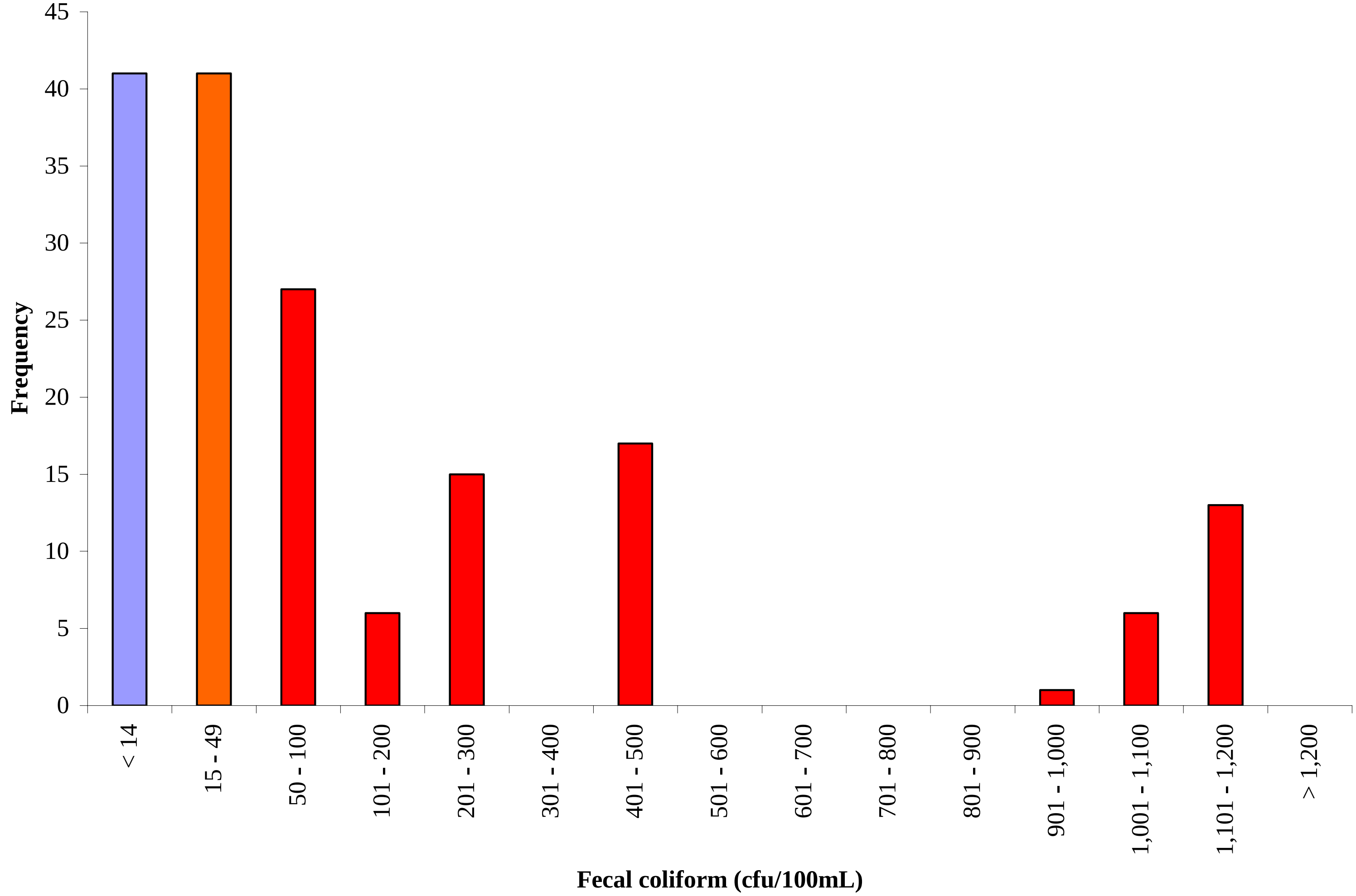


**Figure A.8 Frequency analysis of fecal coliform concentrations in subwatershed 9 (VDH station 58-13A) in Lucas Creek for the period December 1984 through January 2006.**

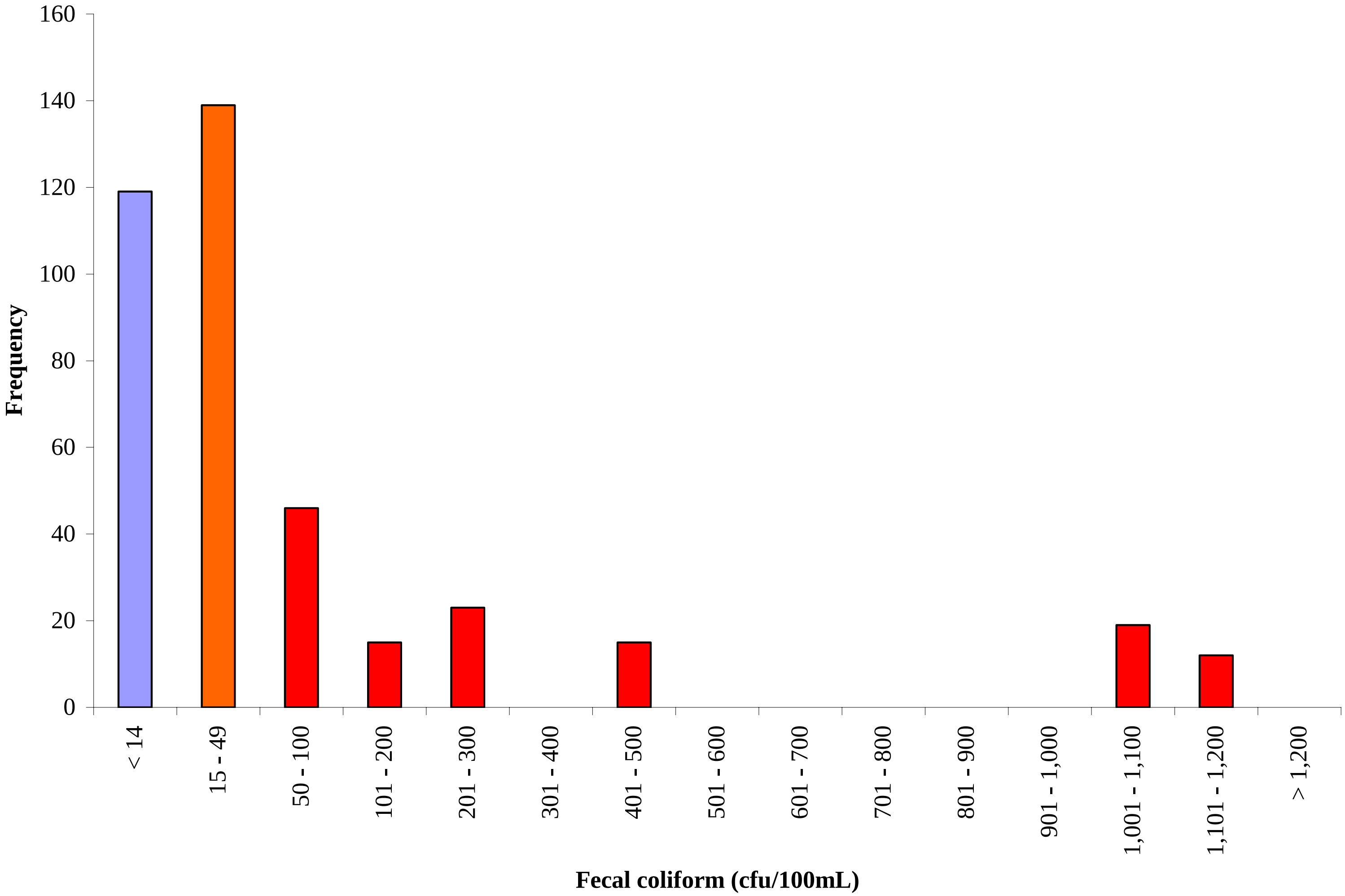


**Figure A.9** **Frequency analysis of fecal coliform concentrations in subwatershed 12 (VDH stations 58-3 and 58-4) in Deep Creek for the period December 1984 through January 2006.**

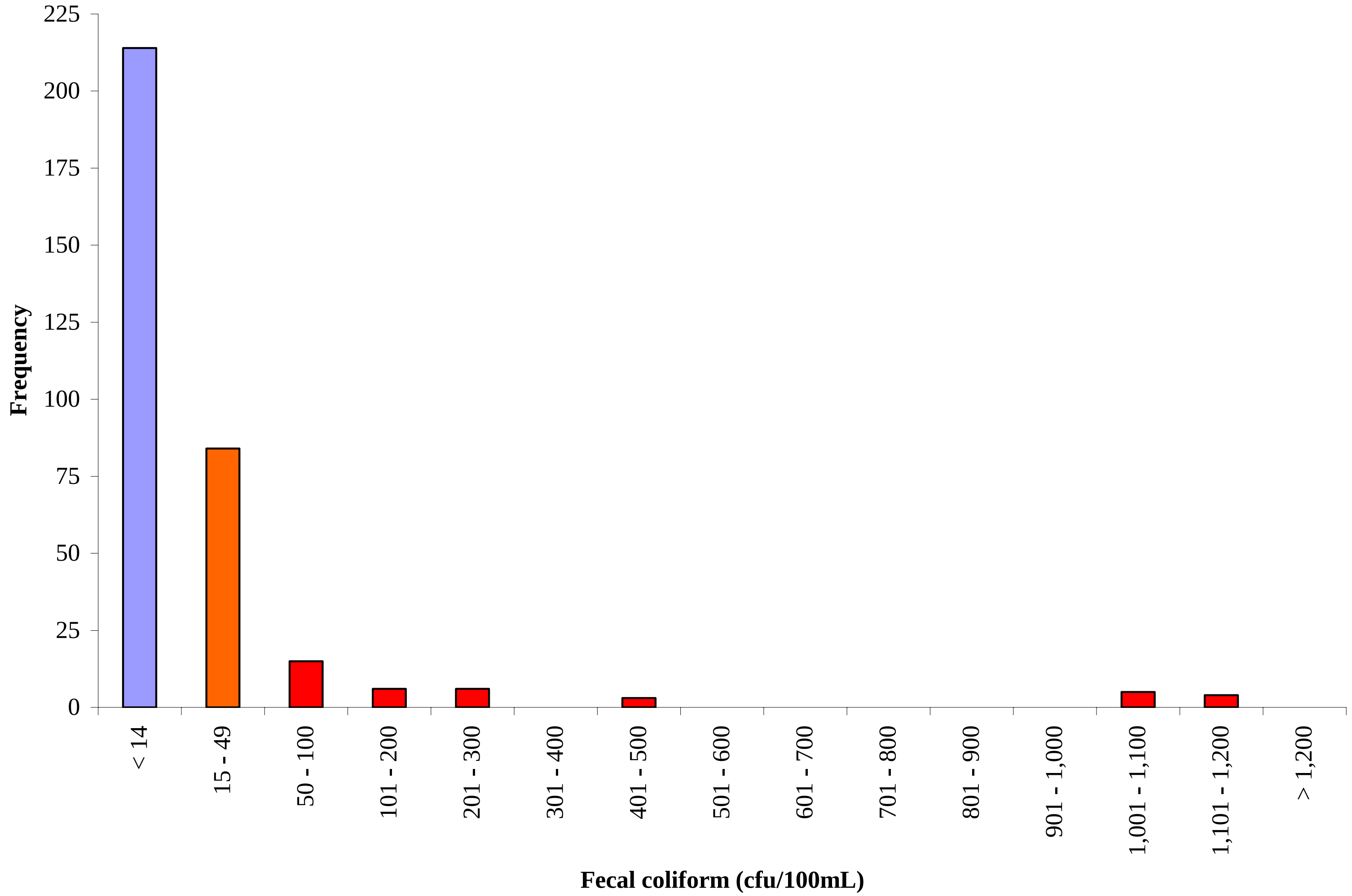


**Figure A.10 Frequency analysis of fecal coliform concentrations in subwatershed 16 (VDH stations 59-AA78, 59-BB77, 59-X79, 59-X81, AND 59-Z79) in Skiffes Creek for the period December 1984 through January 2006.**

# APPENDIX B

Critical Period Analyses: Concentration versus Duration Graphs

Trends and Seasonal Analyses

### *Critical Period Analyses: Concentration versus Duration Graphs:*

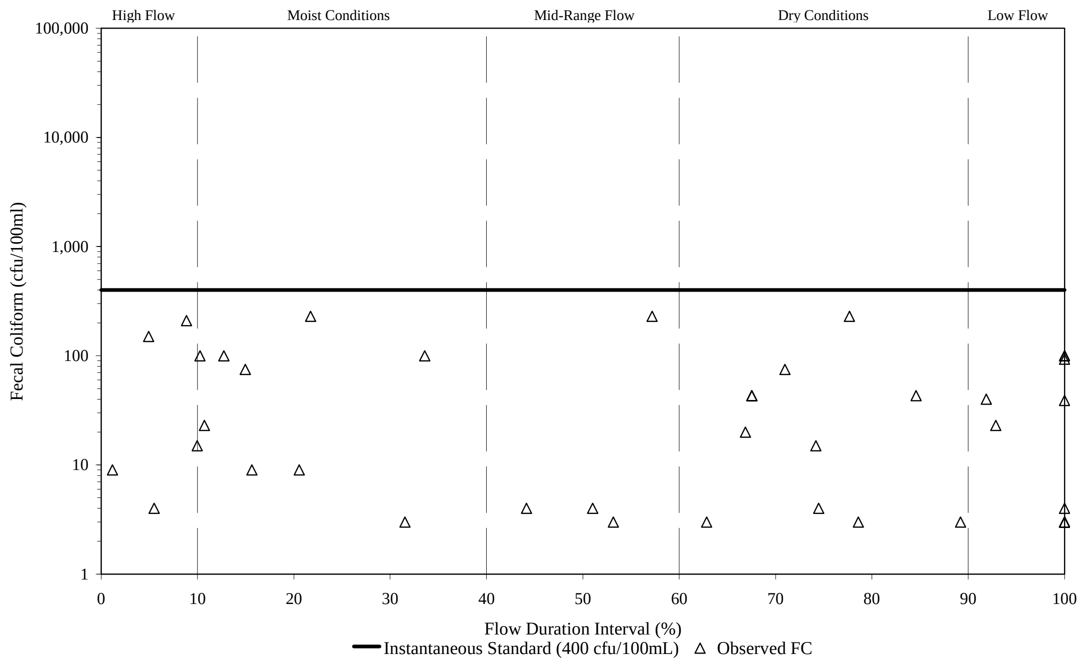


**Figure B. 1 Relationship between fecal coliform concentrations (VADEQ Station 2-SFF000.17) and discharge (USGS Station #02047500) for Skiffes Creek.**

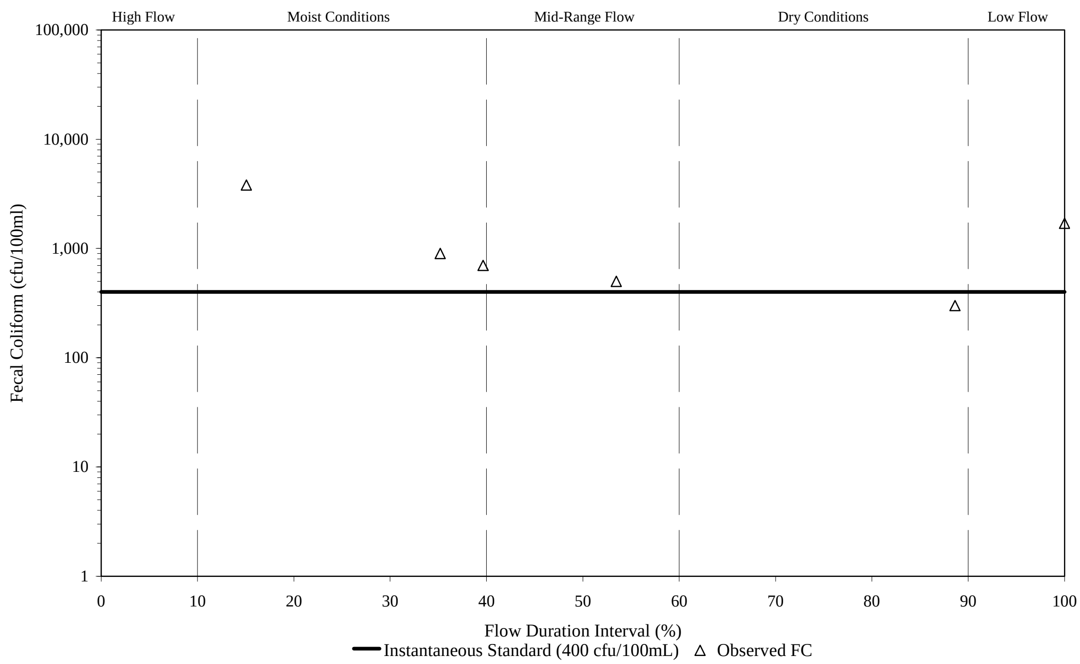


**Figure B. 2 Relationship between fecal coliform concentrations (VADEQ Station 2-BAP000.80) and discharge (USGS Station #02047500) for Baptist Run.**

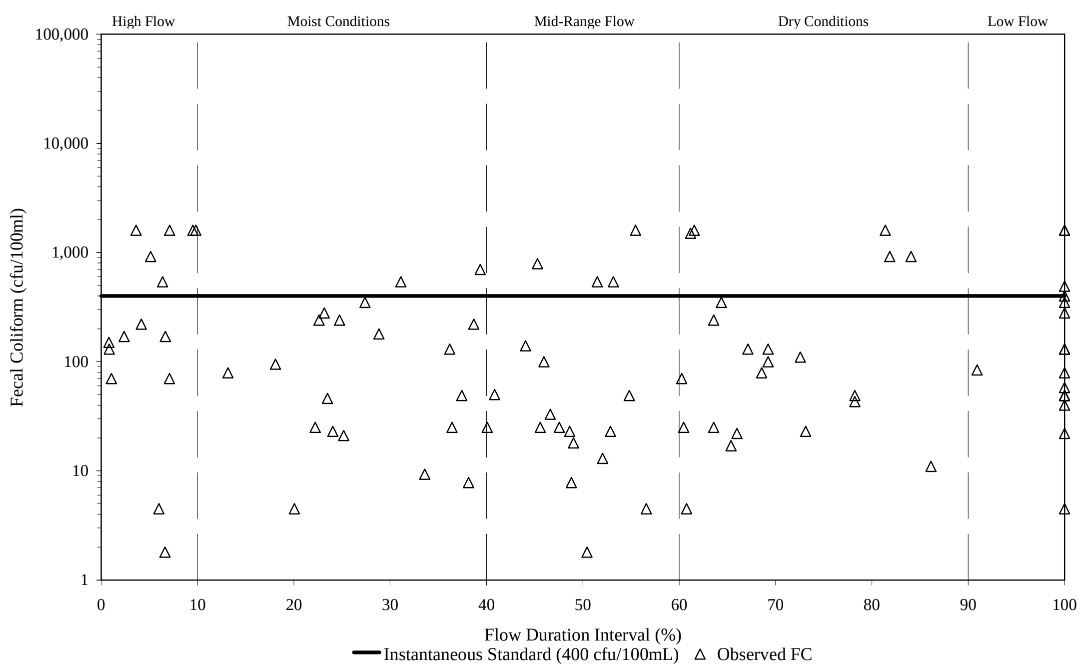


**Figure B. 3 Relationship between fecal coliform concentrations (VADEQ Station 2-DEP000.26) and discharge (USGS Station #02047500) for Deep Creek.**

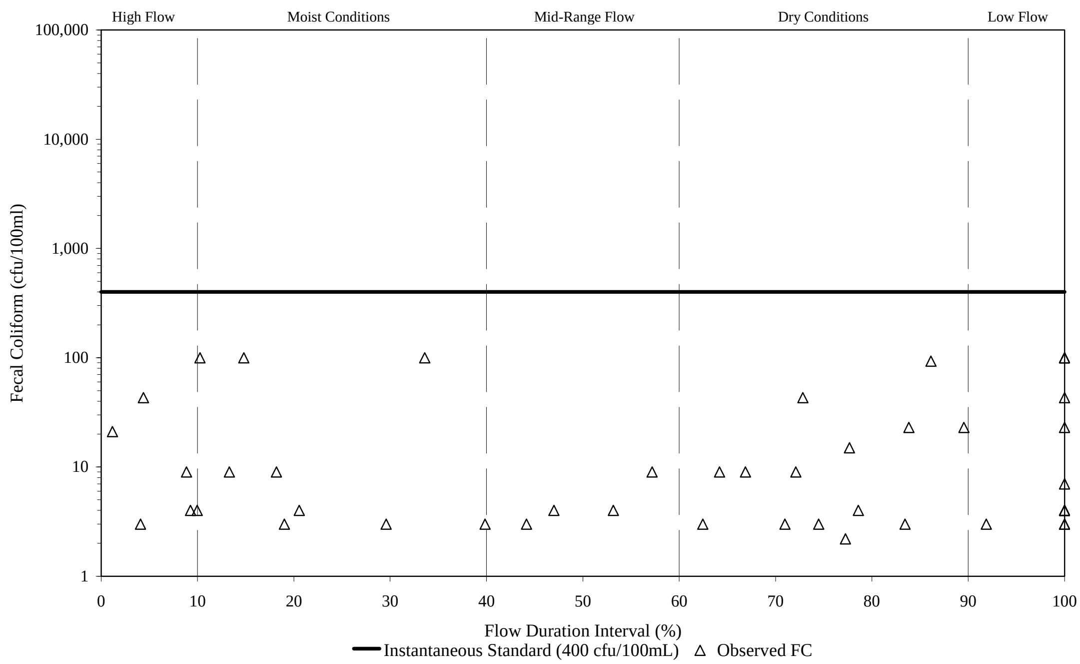


**Figure B. 4 Relationship between fecal coliform concentrations (VADEQ Station 2-WWK000.00) and discharge (USGS Station #02047500) for the Warwick River.**

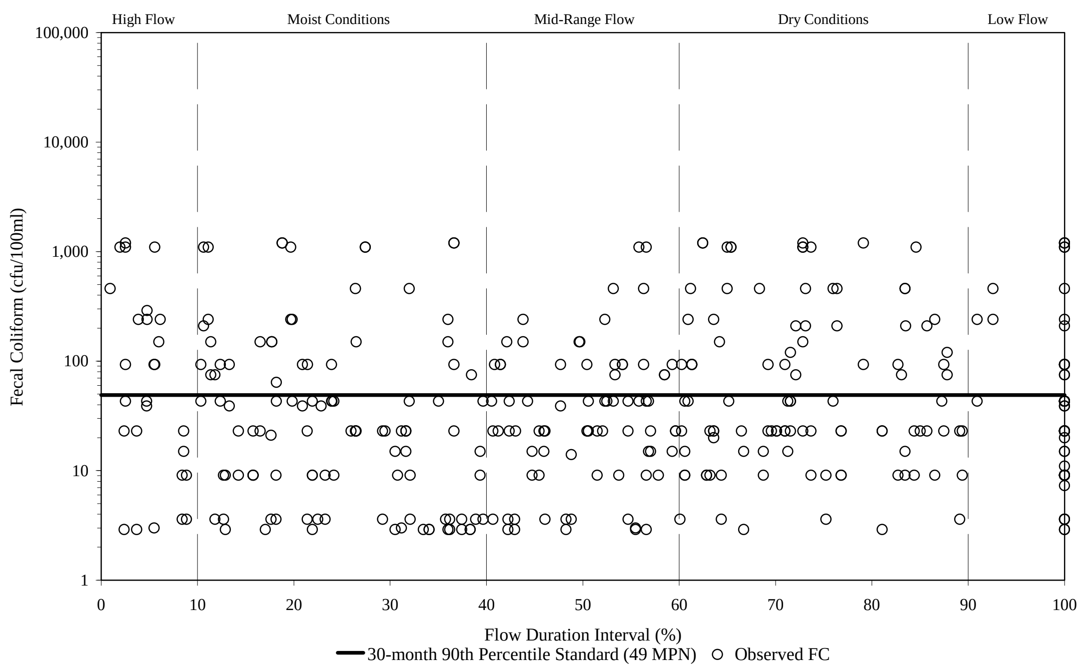


**Figure B. 5 Relationship between fecal coliform concentrations in subwatershed 16 (VDH Stations 59-AA78, 59-BB77, 59-X79, 59-X81, and 59-Z79) and discharge (USGS Station #02047500) for Skiffes Creek.**

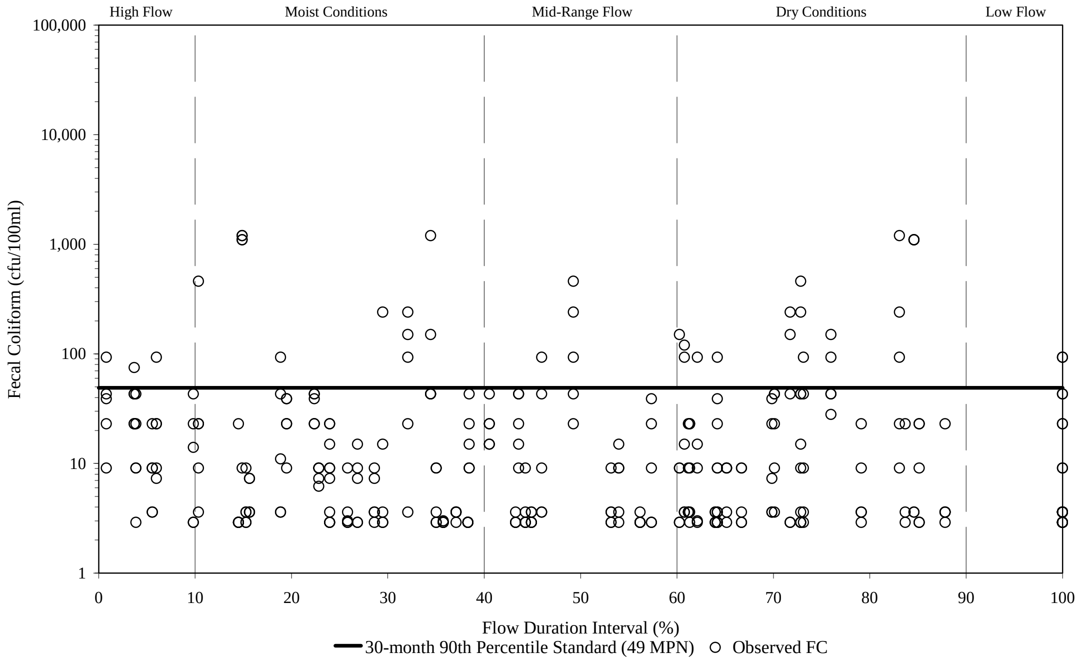


**Figure B. 6 Relationship between fecal coliform concentrations in subwatershed 12 (VDH Stations 58-3 and 58-4) and discharge (USGS Station #02047500) for Deep Creek.**

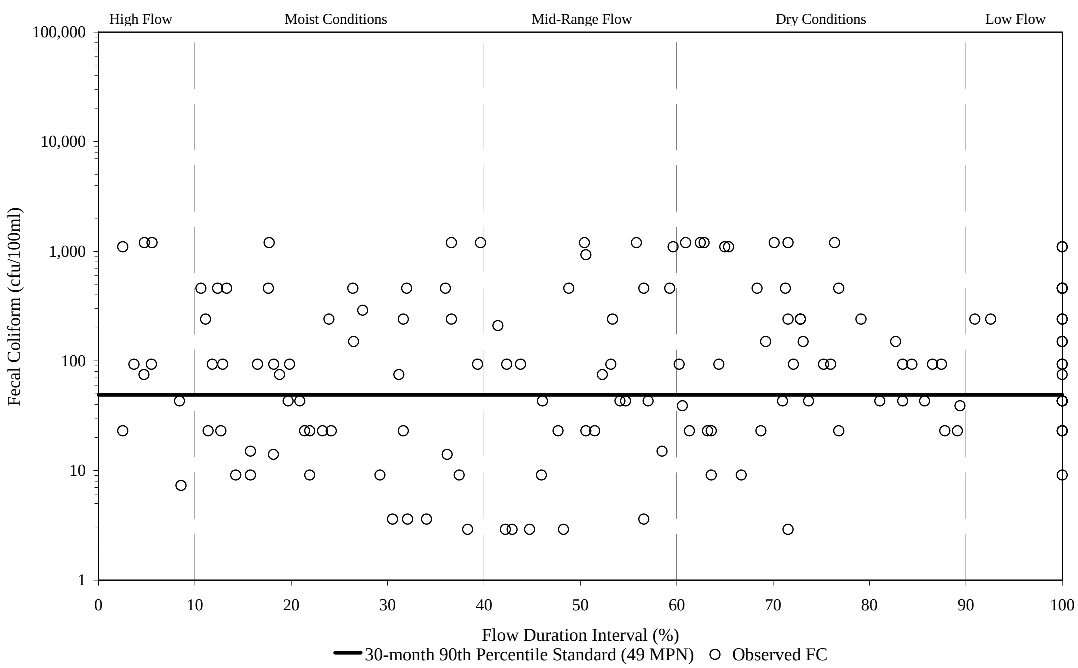


**Figure B. 7 Relationship between fecal coliform concentrations in subwatershed 9 (VDH Station 58-13A) and discharge (USGS Station #02047500) for Warwick River tributary, Lucas Creek.**

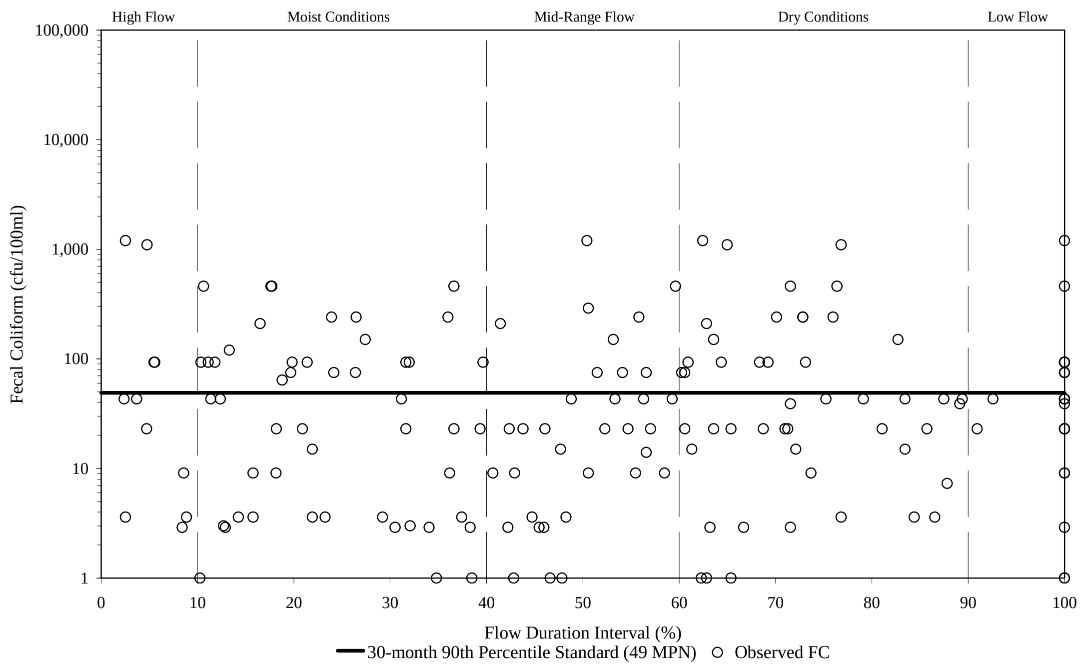


**Figure B. 8 Relationship between fecal coliform concentrations in subwatershed 5 (VDH Station 58-13) and discharge (USGS Station #02047500) for the Warwick River (Upper).**

## *Trends and Seasonality*

**Table B. 1 Summary of trend analysis on precipitation (inches).**

| Station | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| 446054 | 3.79 | 3.42 | 16.25 | 0.18 | 2.19 | 696 | No Trend |
| 444720 | 3.63 | 3.21 | 31.52 | 0.04 | 2.33 | 1,143 | No Trend |
| 447864 | 4.05 | 3.40 | 23.06 | 0.02 | 2.63 | 573 | No Trend |

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

**Table B. 2 Summary of the Mood's Median Test on mean monthly precipitation at NCDC station #446054 Newport News (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 3.39 | 0.46 | 6.35 | | B | |
| February | 3.56 | 0.39 | 9.21 | | B | C |
| March | 3.94 | 0.58 | 9.46 | | B | C |
| April | 2.98 | 0.32 | 6.36 | A | B | |
| May | 3.86 | 0.63 | 11.79 | | B | C |
| June | 4.15 | 0.25 | 9.72 | | B | C |
| July | 5.36 | 1.58 | 16.25 | | | C |
| August | 5.37 | 1.28 | 12.54 | | | C |
| September | 3.83 | 0.30 | 13.61 | A | B | C |
| October | 3.09 | 0.20 | 10.35 | A | B | |
| November | 2.66 | 0.20 | 6.39 | A | | |
| December | 3.43 | 0.80 | 7.02 | | B | C |

**Table B. 3 Summary of the Mood's Median Test on mean monthly precipitation at NCDC station #444720 Langley Air Force Base (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 3.36 | 0.72 | 10.48 | | B | C |
| February | 3.39 | 0.78 | 10.58 | | B | C |
| March | 3.85 | 1.05 | 10.94 | | | C |
| April | 3.01 | 0.31 | 8.38 | A | B | C |
| May | 3.55 | 0.25 | 13.00 | | B | C |
| June | 3.67 | 0.36 | 10.26 | | B | C |
| July | 4.82 | 0.58 | 12.52 | | | C |
| August | 4.78 | 0.60 | 12.03 | | | C |
| September | 3.97 | 0.16 | 19.36 | | B | C |
| October | 2.84 | 0.04 | 7.59 | A | B | |
| November | 3.12 | 0.22 | 31.52 | A | | |
| December | 3.12 | 0.45 | 8.14 | | B | |

**Table B. 4 Summary of the Mood's Median Test on mean monthly precipitation at NCDC station #447864 Smithfield (p=0.010).**

| Month | Mean (in) | Minimum (in) | Maximum (in) | Median Groups | |
|---|---|---|---|---|---|
| January | 3.66 | 1.34 | 11.86 | A | B |
| February | 3.69 | 0.75 | 10.70 | A | B |
| March | 4.10 | 0.93 | 11.38 | A | B |
| April | 3.35 | 0.64 | 13.26 | A | |
| May | 3.85 | 0.30 | 13.04 | A | B |
| June | 4.04 | 0.47 | 10.13 | A | B |
| July | 5.13 | 1.05 | 10.78 | | B |
| August | 5.83 | 1.87 | 19.22 | | B |
| September | 4.87 | 0.51 | 23.06 | A | B |
| October | 3.31 | 0.02 | 9.88 | A | B |
| November | 3.27 | 0.25 | 13.74 | A | B |
| December | 3.38 | 0.52 | 11.30 | A | B |

**Table B. 5 Summary of fecal coliform data trends at VADEQ stations (cfu/100mL).**

| Station | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|
| 2-DEP000.26 | 320 | 90 | 1,600 | 2 | 494 | 92 | No Trend |
| 2-SFF000.17 | 297 | 43 | 11,000 | 3 | 69 | 74 | No Trend |
| 2-WWK000.00 | 41 | 9 | 430 | 2 | 33 | 83 | No Trend |
| 2-WWK000.95 | 25 | 25 | 25 | 25 | -- | 1 | -- |
| 2-WWK003.98 | 235 | 79 | 1,600 | 2 | 407 | 93 | No Trend |
| 2-BAP000.80 | 1,317 | 800 | 3,800 | 300 | 1,307 | 6 | -- |
| 2-LHR000.96 | 36 | 25 | 100 | 25 | 28.35 | 7 | -- |
| 2-LHR001.76 | 29 | 25 | 50 | 25 | 9.45 | 7 | -- |
| 2-LHR002.56 | 390 | 25 | 3,400 | 25 | 26.73 | 10 | -- |

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

**Table B. 6 Summary of fecal coliform data trends at VDH stations (MPN).**

| Stream | Station | Mean | Median | Max | Min | SD[1] | N[2] | Significant Trend[3] |
|---|---|---|---|---|---|---|---|---|
| James River | 57-E57 | 36.14 | 3.6 | 1,200 | 2.9 | 136.12 | 178 | 0.001 |
| James River | 57-E61 | 8.09 | 3.6 | 93 | 2.9 | 12.23 | 182 | No Trend |
| James River | 57-F58 | 9.45 | 3 | 150 | 2.9 | 18.16 | 210 | No Trend |
| James River | 57-I54 | 18.19 | 3.6 | 1,100 | 2.9 | 89.00 | 182 | No Trend |
| James River | 57-M53 | 15.61 | 3 | 1,100 | 2.9 | 84.04 | 182 | No Trend |
| James River | 57-O50 | 10.73 | 3.6 | 240 | 2.9 | 22.66 | 182 | 0.001 |
| James River | 58-A62 | 22.01 | 3.6 | 1,200 | 2.9 | 91.87 | 163 | No Trend |
| James River | 58- -A65 | 11.47 | 3.6 | 240 | 2.9 | 27.64 | 164 | No Trend |
| James River | 58- -B64 | 14.14 | 3.6 | 240 | 2.9 | 28.72 | 155 | No Trend |
| James River | 58- -B65 | 11.07 | 3.6 | 240 | 2.9 | 25.51 | 155 | No Trend |
| James River | 58- -C67 | 7.14 | 2.9 | 75 | 2.9 | 10.58 | 164 | No Trend |
| James River | 58- -E70 | 11.47 | 3.6 | 150 | 2.9 | 20.65 | 164 | 0.001 |
| Warwick River | 58-1.5A | 33.46 | 9.1 | 1,200 | 2.9 | 106.39 | 161 | 0.001 |
| Warwick River | 58-1Z | 11.93 | 3.6 | 240 | 2.9 | 29.22 | 163 | No Trend |
| Warwick River | 58-2A | 49.43 | 9.1 | 1,200 | 2.9 | 155.26 | 160 | -0.064 |
| Warwick River | 58-4 | 187 | 43 | 1,200 | 2.9 | 335.80 | 194 | No Trend |
| Warwick River | 58-5 | 19.5 | 3.6 | 460 | 2.9 | 46.80 | 164 | No Trend |
| Warwick River | 58-6 | 23.37 | 3.6 | 1,200 | 2.9 | 93.78 | 164 | No Trend |
| Warwick River | 58-7 | 24.79 | 7.3 | 1,200 | 2.9 | 98.71 | 155 | No Trend |
| Warwick River | 58-8 | 41.82 | 9.1 | 1,100 | 2.9 | 145.49 | 164 | No Trend |
| Warwick River | 58-9 | 52.29 | 9.1 | 1,200 | 2.9 | 185.07 | 155 | No Trend |
| Warwick River | 58-10 | 44.2 | 9.1 | 1,200 | 2.9 | 108.98 | 164 | No Trend |
| Warwick River | 58-11 | 72.78 | 23 | 1,200 | 2.9 | 158.33 | 155 | No Trend |
| Warwick River | 58-12 | 84.13 | 23 | 1,200 | 2.9 | 192.88 | 155 | No Trend |
| Warwick River | 58-13 | 126.98 | 43 | 1,200 | 2.9 | 249.67 | 155 | No Trend |
| Warwick River | 58-13A | 263.5 | 93 | 1,200 | 2.9 | 378.64 | 147 | No Trend |
| Warwick River | 58-JRSTP | 27.68 | 9.1 | 1,200 | 2.9 | 101.31 | 164 | 0.001 |
| Warwick/ James conf. | 58-1A | 27.91 | 9.1 | 460 | 2.9 | 57.87 | 153 | No Trend |
| Warwick/ James conf. | 58-0.5 | 14.56 | 3.6 | 460 | 2.9 | 39.03 | 164 | No Trend |
| Warwick/ James conf. | 58-.5Y | 6.99 | 3.6 | 43 | 2.9 | 9.32 | 164 | No Trend |
| Warwick/ James conf. | 58-0.5Z | 12.17 | 3.6 | 210 | 2.9 | 24.97 | 155 | 0.001 |
| Deep Creek | 58-3 | 122.8 | 23 | 1,200 | 2.9 | 281.28 | 164 | No Trend |
| Deep Creek/ Warwick conf. | 58-2.5 | 56.7 | 9.1 | 1,200 | 2.9 | 169.98 | 155 | No Trend |
| Skiffes Creek | 59- -BB77 | 90.79 | 23 | 1,200 | 2.9 | 212.20 | 65 | No Trend |
| Skiffes Creek/ James conf. | 59- -AA78 | 81.41 | 15 | 1,200 | 2.9 | 241.57 | 65 | No Trend |
| James River | 59- -V81 | 11.66 | 3.6 | 240 | 2.9 | 26.50 | 210 | No Trend |
| James River | 59- -X79 | 32.33 | 3.6 | 1,100 | 2.9 | 135.19 | 69 | No Trend |
| James River | 59- -X81 | 7.33 | 3.6 | 43 | 2.9 | 9.56 | 69 | No Trend |
| James River | 59- -Z79 | 72.07 | 9.1 | 1,200 | 2.9 | 238.50 | 69 | No Trend |

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

Interpretation of box and whisker plots is illustrated in Figure B.9, in which the data range for a given metric is displayed as four quartiles. The "box" of two colors shows the two inner quartiles with the dividing line between the colors representing the median value. The "whiskers" above and below each box show the outer quartiles with the upper quartile extending above the box and the lower quartile extending below the box. Finally, the mean value is displayed as a square within one of the two inner-quartile boxes.

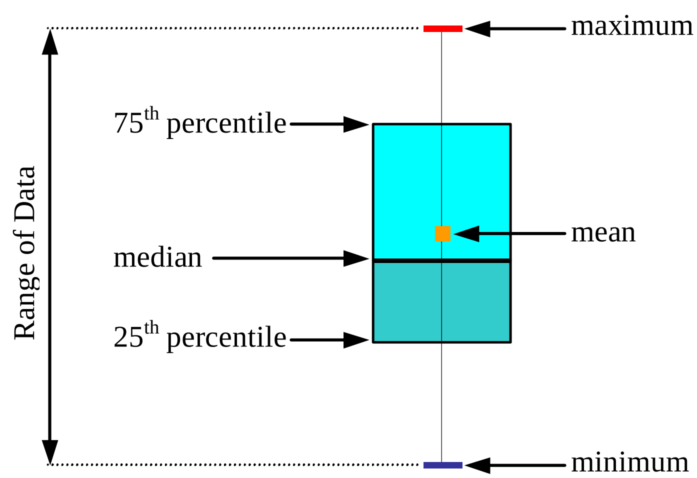


**Figure B. 9 Interpretation of Box and Whisker plots.**

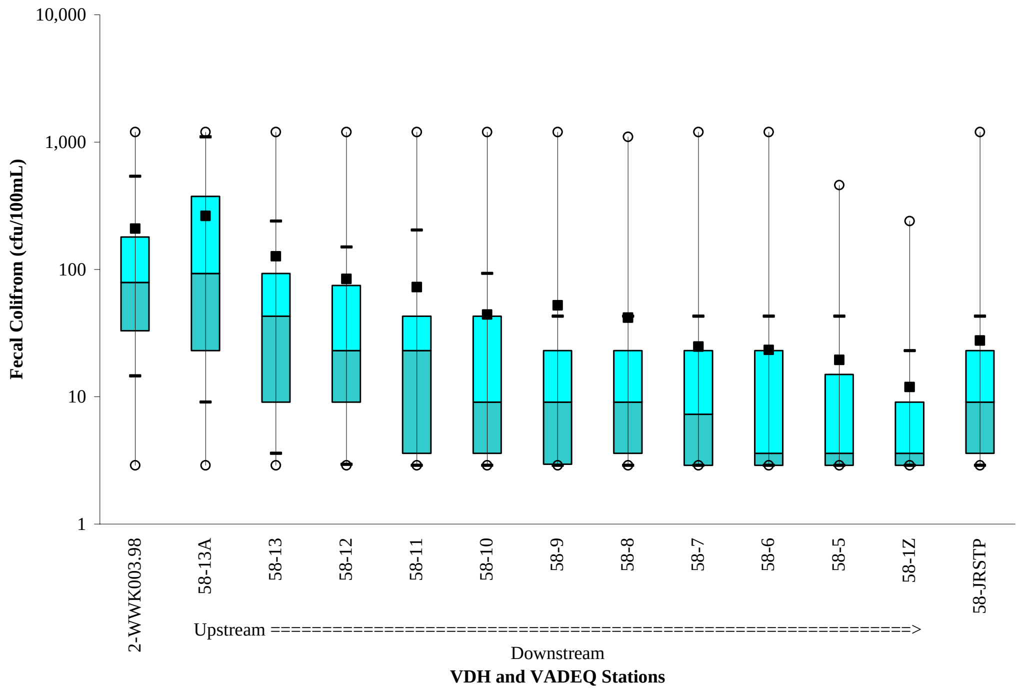


**Figure B. 10 Fecal coliform data from stations on the Warwick River arranged upstream to downstream.**

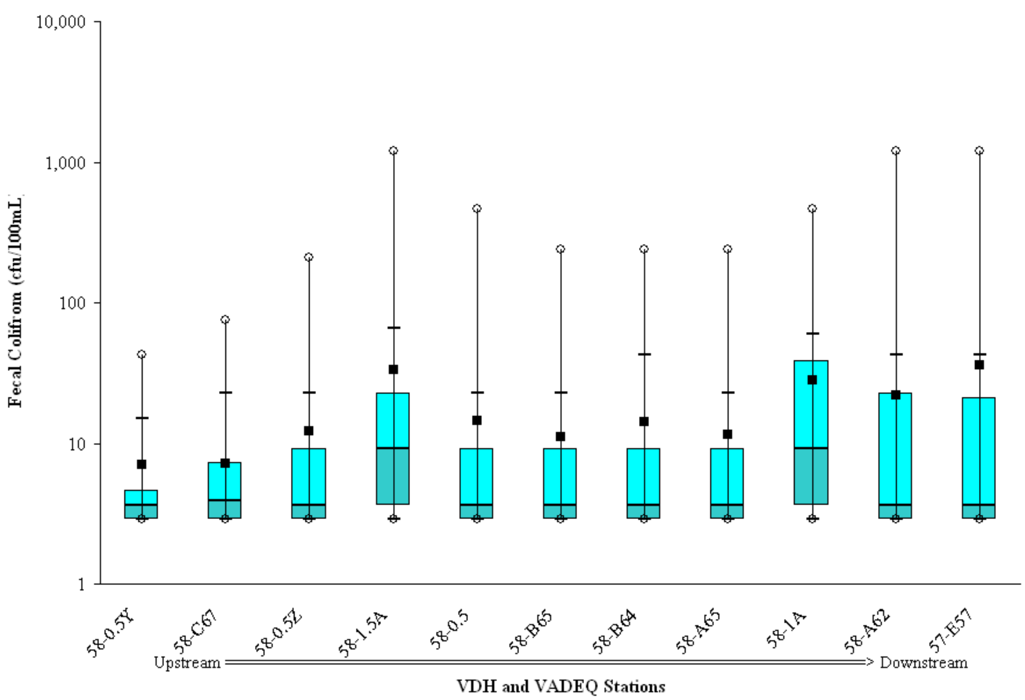


**Figure B. 11 Fecal coliform data from stations on the James River arranged upstream to downstream.**

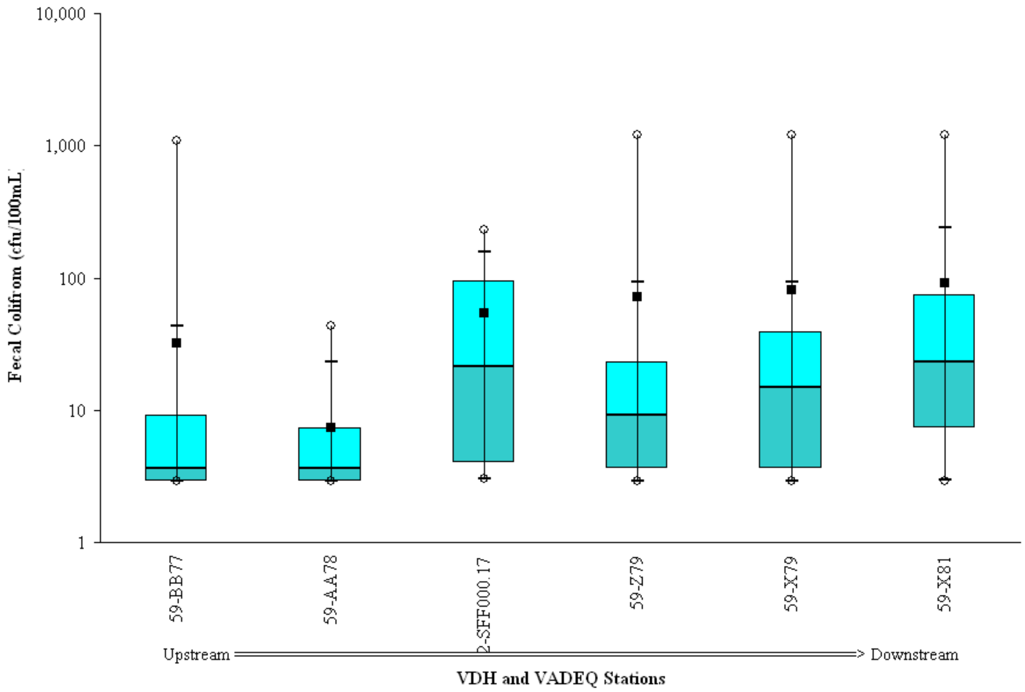


**Figure B. 12 Fecal coliform data from stations on the Skiffes Creek arranged upstream to downstream.**

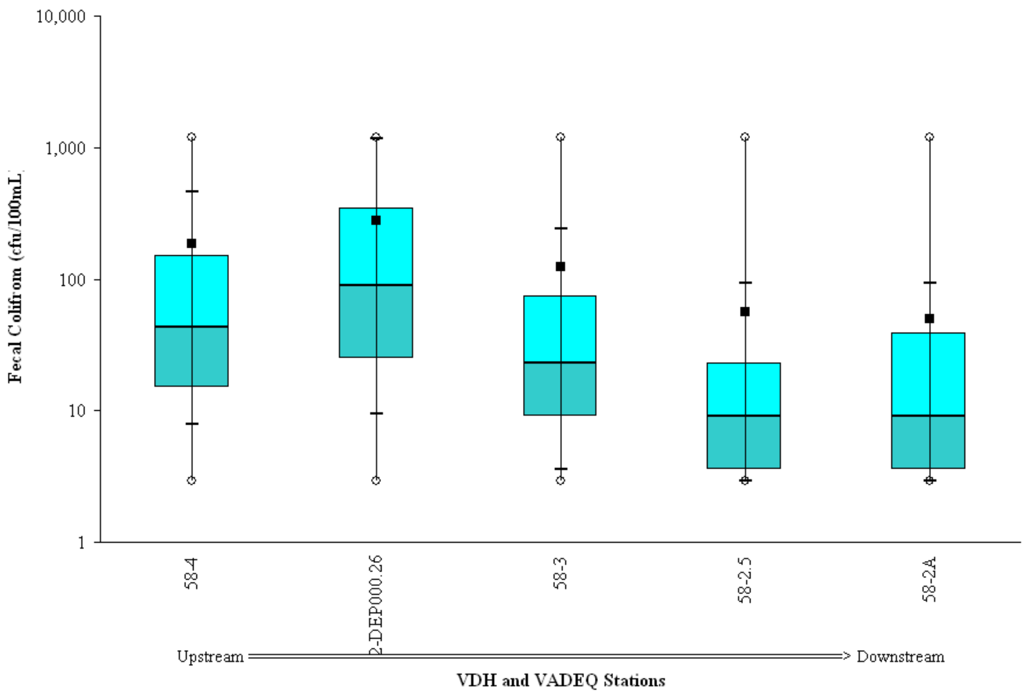


**Figure B. 13 Fecal coliform data from stations on the Deep Creek arranged upstream to downstream.**

**Table B. 7 Summary of the Mood's Median Test on fecal coliform at VDH station 57-E61 (p=0.006).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 5.93 | 2.9 | 15.0 | | B |
| February | 8.17 | 2.9 | 43.0 | | B |
| March | 6.91 | 2.9 | 23.0 | | B |
| April | 6.83 | 2.9 | 43.0 | | B |
| May | 7.91 | 2.9 | 39.0 | | B |
| June | 3.51 | 2.9 | 9.1 | | B |
| July | 3.03 | 2.9 | 3.6 | A | |
| August | 4.24 | 2.9 | 23.0 | A | |
| September | 7.43 | 2.9 | 23.0 | | B |
| October | 17.55 | 2.9 | 93.0 | | B |
| November | 20.07 | 2.9 | 75.0 | | B |
| December | 6.62 | 2.9 | 15.0 | | B |

**Table B. 8 Summary of the Mood's Median Test on fecal coliform at VDH station 57-F58 (p=0.002).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 9.13 | 2.9 | 93.0 | | B |
| February | 4.31 | 2.9 | 15.0 | | B |
| March | 10.15 | 2.9 | 75.0 | | B |
| April | 13.42 | 2.9 | 150.0 | | B |
| May | 5.90 | 2.9 | 23.0 | | B |
| June | 5.75 | 2.9 | 23.0 | | B |
| July | 3.74 | 2.9 | 15.0 | A | |
| August | 7.29 | 2.9 | 75.0 | A | |
| September | 11.99 | 2.9 | 93.0 | | B |
| October | 14.48 | 2.9 | 75.0 | | B |
| November | 19.68 | 2.9 | 93.0 | | B |
| December | 8.54 | 2.9 | 43.0 | | B |

**Table B. 9 Summary of the Mood's Median Test on fecal coliform at VDH station 57-I54 (p=0.001).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 7.28 | 2.9 | 43.0 | | B |
| February | 7.70 | 2.9 | 23.0 | | B |
| March | 8.73 | 2.9 | 43.0 | | B |
| April | 73.81 | 2.9 | 1,100.0 | | B |
| May | 8.07 | 2.9 | 43.0 | | B |
| June | 6.27 | 2.9 | 43.0 | | B |
| July | 3.38 | 2.9 | 9.1 | A | |
| August | 34.44 | 2.9 | 460.0 | | B |
| September | 14.11 | 2.9 | 150.0 | | B |
| October | 22.71 | 2.9 | 93.0 | | B |
| November | 17.59 | 2.9 | 93.0 | | B |
| December | 10.14 | 2.9 | 39.0 | | B |

**Table B. 10 Summary of the Mood's Median Test on fecal coliform at VDH station 58-4 (p=0.004).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | | |
|---|---|---|---|---|---|---|
| January | 22.05 | 2.9 | 93.0 | A | | |
| February | 26.89 | 2.9 | 150.0 | A | | |
| March | 160.73 | 3.6 | 1,200.0 | A | B | |
| April | 241.93 | 3.6 | 1,200.0 | | B | C |
| May | 438.50 | 15 | 1,200.0 | | | C |
| June | 173.24 | 9.1 | 1,200.0 | | B | C |
| July | 219.54 | 9.1 | 1,200.0 | | B | C |
| August | 251.66 | 3.6 | 1,100.0 | | B | C |
| September | 265.08 | 9.1 | 1,200.0 | | B | C |
| October | 183.17 | 3.6 | 1,200.0 | | B | C |
| November | 102.01 | 2.9 | 460.0 | A | B | C |
| December | 125.78 | 3.6 | 1,100.0 | | B | |

**Table B. 11 Summary of the Mood's Median Test on fecal coliform at VDH station 58-1Z (p=0.002).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 17.66 | 2.9 | 240.0 | | B | |
| February | 3.44 | 2.9 | 9.1 | A | | |
| March | 3.97 | 2.9 | 9.1 | | B | |
| April | 13.14 | 2.9 | 43.0 | | | C |
| May | 23.72 | 2.9 | 150.0 | | | C |
| June | 20.84 | 2.9 | 240.0 | | B | C |
| July | 6.66 | 2.9 | 43.0 | | B | C |
| August | 6.14 | 2.9 | 23.0 | | B | |
| September | 6.62 | 2.9 | 23.0 | | B | C |
| October | 22.21 | 2.9 | 93.0 | | B | C |
| November | 7.75 | 2.9 | 43.0 | | B | |
| December | 8.54 | 2.9 | 43.0 | | B | C |

**Table B. 12 Summary of the Mood's Median Test on fecal coliform at VDH station 58-2A (p=0.002).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 5.93 | 2.9 | 23.0 | A | B |
| February | 7.45 | 2.9 | 43.0 | A | |
| March | 84.53 | 2.9 | 1,100.0 | A | B |
| April | 123.71 | 3.6 | 1,100.0 | | B |
| May | 30.47 | 2.9 | 93.0 | | B |
| June | 34.86 | 2.9 | 93.0 | | B |
| July | 116.93 | 2.9 | 1,200.0 | | B |
| August | 37.03 | 2.9 | 240.0 | | B |
| September | 20.13 | 2.9 | 93.0 | | B |
| October | 69.98 | 2.9 | 460.0 | | B |
| November | 28.69 | 2.9 | 150.0 | | B |
| December | 30.81 | 2.9 | 240.0 | | B |

**Table B. 13 Summary of the Mood's Median Test on fecal coliform at VDH station 58-3 (p=0.007).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 13.99 | 2.9 | 43.0 | A | |
| February | 14.77 | 2.9 | 75.0 | A | B |
| March | 165.31 | 2.9 | 1,200.0 | A | B |
| April | 171.99 | 3.6 | 1,200.0 | | B |
| May | 120.78 | 3.6 | 1,100.0 | | B |
| June | 120.66 | 3.6 | 1,100.0 | A | B |
| July | 208.01 | 9.1 | 1,200.0 | | B |
| August | 199.92 | 3.6 | 1,200.0 | | B |
| September | 48.79 | 2.9 | 240.0 | A | B |
| October | 152.99 | 3.6 | 1,100.0 | A | B |
| November | 107.77 | 2.9 | 1,100.0 | A | B |
| December | 144.74 | 2.9 | 1,100.0 | A | B |

**Table B. 14 Summary of the Mood's Median Test on fecal coliform at VDH station 58-6 (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 4.95 | 2.9 | 23.0 | A | |
| February | 5.92 | 2.9 | 43.0 | A | |
| March | 7.31 | 2.9 | 23.0 | A | B |
| April | 38.44 | 2.9 | 240.0 | | B |
| May | 21.33 | 2.9 | 93.0 | | B |
| June | 11.58 | 2.9 | 43.0 | A | B |
| July | 83.14 | 2.9 | 1,200.0 | A | |
| August | 18.13 | 2.9 | 43.0 | A | B |
| September | 17.15 | 2.9 | 43.0 | | B |
| October | 36.29 | 3.6 | 290.0 | | B |
| November | 14.01 | 2.9 | 43.0 | A | B |
| December | 19.82 | 2.9 | 150.0 | A | B |

**Table B. 15 Summary of the Mood's Median Test on fecal coliform at VDH station 58-8 (p=0.001).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 5.34 | 2.9 | 23.0 | A | |
| February | 6.46 | 2.9 | 43.0 | A | |
| March | 10.78 | 2.9 | 23.0 | | B |
| April | 97.45 | 2.9 | 1,100.0 | | B |
| May | 44.85 | 3.6 | 210.0 | | B |
| June | 20.13 | 2.9 | 43.0 | | B |
| July | 14.79 | 2.9 | 43.0 | | B |
| August | 123.39 | 2.9 | 1,100.0 | A | B |
| September | 26.59 | 2.9 | 120.0 | | B |
| October | 99.84 | 2.9 | 1,100.0 | | B |
| November | 31.43 | 2.9 | 240.0 | | B |
| December | 25.54 | 2.9 | 210.0 | A | B |

**Table B. 16 Summary of the Mood's Median Test on fecal coliform at VDH station 58-10 (p=0.001).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 6.48 | 2.9 | 23.0 | A | |
| February | 8.53 | 2.9 | 39.0 | A | |
| March | 17.22 | 2.9 | 150.0 | A | |
| April | 77.55 | 3.6 | 240.0 | | B |
| May | 58.01 | 9.1 | 460.0 | | B |
| June | 33.55 | 3.6 | 93.0 | A | B |
| July | 111.94 | 2.9 | 1,200.0 | | B |
| August | 55.07 | 2.9 | 240.0 | | B |
| September | 18.49 | 2.9 | 43.0 | | B |
| October | 33.44 | 2.9 | 150.0 | A | B |
| November | 45.43 | 2.9 | 240.0 | A | B |
| December | 61.78 | 2.9 | 460.0 | A | B |

**Table B. 17 Summary of the Mood's Median Test on fecal coliform at VDH station 58-A62 (p=0.020).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | | |
|---|---|---|---|---|---|---|
| January | 6.77 | 2.9 | 23.0 | A | B | |
| February | 6.36 | 2.9 | 43.0 | A | | |
| March | 11.78 | 2.9 | 43.0 | A | B | C |
| April | 11.65 | 2.9 | 43.0 | | B | C |
| May | 22.34 | 2.9 | 75.0 | | | C |
| June | 17.08 | 2.9 | 93.0 | | B | C |
| July | 90.26 | 2.9 | 1,200.0 | A | B | C |
| August | 16.58 | 2.9 | 93.0 | A | B | C |
| September | 10.92 | 2.9 | 43.0 | | B | |
| October | 40.37 | 2.9 | 240.0 | | B | C |
| November | 17.34 | 2.9 | 93.0 | A | B | C |
| December | 7.81 | 2.9 | 43.0 | A | | |

**Table B. 18 Summary of the Mood's Median Test on fecal coliform at VDH station 58-A65 (p=0.038).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 7.24 | 2.9 | 23.0 | A | B |
| February | 9.43 | 2.9 | 75.0 | A | B |
| March | 6.04 | 2.9 | 23.0 | A | |
| April | 13.87 | 2.9 | 93.0 | | B |
| May | 15.36 | 2.9 | 43.0 | | B |
| June | 6.01 | 2.9 | 43.0 | A | |
| July | 7.00 | 2.9 | 43.0 | A | |
| August | 8.14 | 2.9 | 23.0 | A | B |
| September | 21.29 | 2.9 | 240.0 | A | |
| October | 26.01 | 2.9 | 240.0 | A | B |
| November | 11.21 | 2.9 | 93.0 | A | B |
| December | 7.85 | 2.9 | 39.0 | A | B |

**Table B. 19 Summary of the Mood's Median Test on fecal coliform at VDH station 58-C67 (p=0.001).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 17.22 | 2.9 | 75.0 | | B |
| February | 7.79 | 2.9 | 43.0 | | B |
| March | 4.11 | 2.9 | 9.1 | | B |
| April | 11.40 | 2.9 | 43.0 | | B |
| May | 6.69 | 2.9 | 23.0 | | B |
| June | 4.24 | 2.9 | 23.0 | A | |
| July | 4.54 | 2.9 | 9.1 | | B |
| August | 2.95 | 2.9 | 3.6 | A | B |
| September | 3.49 | 2.9 | 9.1 | | B |
| October | 9.88 | 2.9 | 43.0 | | B |
| November | 4.85 | 2.9 | 23.0 | | B |
| December | 7.31 | 2.9 | 23.0 | | B |

**Table B. 20 Summary of the Mood's Median Test on fecal coliform at VDH station 58-E70 (p=0.021).**

| **Month** | **Mean** (mg/L) | **Minimum** (mg/L) | **Maximum** (mg/L) | **Median Groups** | |
|---|---|---|---|---|---|
| January | 12.28 | 2.9 | 120.0 | A | B |
| February | 6.01 | 2.9 | 43.0 | A | |
| March | 6.42 | 2.9 | 43.0 | A | |
| April | 24.57 | 2.9 | 120.0 | | B |
| May | 27.87 | 2.9 | 93.0 | | B |
| June | 5.75 | 2.9 | 23.0 | A | B |
| July | 15.40 | 2.9 | 150.0 | A | B |
| August | 4.97 | 2.9 | 23.0 | A | |
| September | 6.51 | 2.9 | 23.0 | A | |
| October | 12.57 | 2.9 | 43.0 | | B |
| November | 8.09 | 2.9 | 23.0 | A | B |
| December | 6.55 | 2.9 | 23.0 | A | B |

**Table B. 21 Summary of the Mood's Median Test on fecal coliform at VDH station 58-0.5Z (p=0.003).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 17.49 | 2.9 | 93.0 | | B |
| February | 12.17 | 2.9 | 93.0 | | B |
| March | 4.84 | 2.9 | 23.0 | A | |
| April | 22.21 | 2.9 | 120.0 | | B |
| May | 22.54 | 2.9 | 93.0 | | B |
| June | 6.77 | 2.9 | 43.0 | | B |
| July | 9.86 | 2.9 | 93.0 | | B |
| August | 6.05 | 2.9 | 23.0 | A | |
| September | 6.30 | 2.9 | 23.0 | | B |
| October | 24.78 | 2.9 | 210.0 | | B |
| November | 6.37 | 2.9 | 23.0 | | B |
| December | 5.44 | 2.9 | 23.0 | | B |

**Table B. 22 Summary of the Mood's Median Test on fecal coliform at VDH station 58-11 (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 4.87 | 2.9 | 9.1 | A | |
| February | 9.08 | 2.9 | 43.0 | A | |
| March | 38.85 | 2.9 | 240.0 | A | B |
| April | 177.78 | 9.1 | 1,100.0 | | B |
| May | 136.07 | 2.9 | 460.0 | | B |
| June | 53.58 | 2.9 | 240.0 | | B |
| July | 133.49 | 3.6 | 1,200.0 | | B |
| August | 79.55 | 2.9 | 460.0 | | B |
| September | 46.98 | 2.9 | 240.0 | | B |
| October | 80.21 | 3.6 | 460.0 | | B |
| November | 65.83 | 2.9 | 460.0 | | B |
| December | 39.12 | 2.9 | 240.0 | A | B |

**Table B. 23 Summary of the Mood's Median Test on fecal coliform at VDH station 58-12 (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 11.16 | 2.9 | 43.0 | A | | |
| February | 9.13 | 2.9 | 43.0 | A | | |
| March | 25.01 | 2.9 | 93.0 | | B | |
| April | 187.98 | 3.6 | 1,100.0 | | B | C |
| May | 218.24 | 9.1 | 1,100.0 | | | C |
| June | 54.10 | 9.1 | 240.0 | | B | C |
| July | 212.34 | 3.6 | 1,200.0 | | B | C |
| August | 69.25 | 3.6 | 240.0 | | B | C |
| September | 31.59 | 2.9 | 93.0 | | B | |
| October | 71.80 | 3.0 | 290.0 | | B | C |
| November | 33.05 | 2.9 | 93.0 | | B | |
| December | 69.09 | 2.9 | 460.0 | | B | C |

**Table B. 24 Summary of the Mood's Median Test on fecal coliform at VDH station 58-13 (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 10.05 | 2.9 | 75.0 | A | | |
| February | 14.50 | 2.9 | 43.0 | | B | |
| March | 36.60 | 2.9 | 150.0 | | B | |
| April | 248.31 | 15 | 1,100.0 | | | C |
| May | 133.08 | 15 | 240.0 | | B | C |
| June | 145.51 | 2.9 | 460.0 | | B | C |
| July | 394.79 | 9.1 | 1,200.0 | | B | C |
| August | 90.48 | 3.6 | 460.0 | | B | C |
| September | 45.70 | 7.3 | 93.0 | | B | C |
| October | 182.47 | 9.1 | 1,200.0 | | B | C |
| November | 37.38 | 2.9 | 93.0 | | B | |
| December | 151.97 | 2.9 | 1,100.0 | | B | C |

**Table B. 25 Summary of the Mood's Median Test on fecal coliform at VDH station 58-13A (p=0.007).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 17.35 | 2.9 | 93.0 | A | |
| February | 51.15 | 3.6 | 460.0 | A | |
| March | 91.17 | 14.0 | 290.0 | | B |
| April | 372.92 | 23.0 | 1,200.0 | | B |
| May | 443.67 | 43.0 | 1,200.0 | | B |
| June | 354.14 | 23.0 | 1,200.0 | | B |
| July | 455.21 | 23.0 | 1,200.0 | | B |
| August | 371.77 | 23.0 | 1,200.0 | | B |
| September | 170.26 | 9.1 | 1,100.0 | | B |
| October | 378.69 | 23.0 | 1,200.0 | | B |
| November | 148.30 | 2.9 | 460.0 | | B |
| December | 189.45 | 2.9 | 1,100.0 | A | B |

**Table B. 26 Summary of the Mood's Median Test on fecal coliform at VDH station 58-1A (p=0.001).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 8.65 | 2.9 | 43.0 | A | B |
| February | 6.94 | 2.9 | 23.0 | A | |
| March | 41.25 | 2.9 | 460.0 | A | B |
| April | 62.87 | 2.9 | 460.0 | | B |
| May | 36.65 | 7.3 | 120.0 | | B |
| June | 29.47 | 2.9 | 150.0 | | B |
| July | 27.98 | 2.9 | 93.0 | A | B |
| August | 19.17 | 2.9 | 93.0 | A | B |
| September | 20.91 | 2.9 | 93.0 | A | B |
| October | 43.59 | 2.9 | 150.0 | A | B |
| November | 15.63 | 2.9 | 93.0 | A | B |
| December | 16.91 | 2.9 | 93.0 | A | |

**Table B. 27 Summary of the Mood's Median Test on fecal coliform at VDH station 58-2.5 (p=0.008).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 5.31 | 2.9 | 15.0 | A | |
| February | 6.67 | 2.9 | 23.0 | A | |
| March | 38.56 | 2.9 | 240.0 | | B |
| April | 180.46 | 2.9 | 1,100.0 | | B |
| May | 40.82 | 2.9 | 210.0 | | B |
| June | 65.08 | 2.9 | 460.0 | | B |
| July | 136.64 | 2.9 | 1,200.0 | | B |
| August | 18.48 | 2.9 | 93.0 | A | B |
| September | 17.53 | 2.9 | 93.0 | | B |
| October | 121.30 | 2.9 | 1,100.0 | | B |
| November | 17.46 | 2.9 | 43.0 | A | B |
| December | 16.28 | 2.9 | 93.0 | A | B |

**Table B. 28 Summary of the Mood's Median Test on fecal coliform at VDH station 58-7 (p=0.043).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | |
|---|---|---|---|---|---|
| January | 5.43 | 2.9 | 23.0 | A | |
| February | 4.12 | 2.9 | 9.1 | A | |
| March | 7.53 | 2.9 | 23.0 | A | B |
| April | 30.62 | 3.6 | 150.0 | | B |
| May | 21.81 | 2.9 | 93.0 | | B |
| June | 20.89 | 2.9 | 150.0 | A | B |
| July | 17.65 | 2.9 | 43.0 | | B |
| August | 13.22 | 2.9 | 43.0 | A | B |
| September | 18.13 | 2.9 | 93.0 | | B |
| October | 118.57 | 2.9 | 1,200.0 | | B |
| November | 20.98 | 2.9 | 93.0 | | B |
| December | 17.92 | 2.9 | 93.0 | A | B |

**Table B. 29 Summary of the Mood's Median Test on fecal coliform at VDH station 58-9 (p=0.002).**

| Month | Mean (mg/L) | Minimum (mg/L) | Maximum (mg/L) | Median Groups | | |
|---|---|---|---|---|---|---|
| January | 6.68 | 2.9 | 23.0 | | B | |
| February | 3.32 | 2.9 | 7.2 | A | | |
| March | 12.14 | 2.9 | 43.0 | | B | C |
| April | 194.88 | 2.9 | 1,100.0 | | | C |
| May | 43.17 | 2.9 | 240.0 | | | C |
| June | 27.51 | 2.9 | 93.0 | | B | C |
| July | 107.32 | 2.9 | 1,200.0 | | | C |
| August | 20.68 | 2.9 | 43.0 | | B | C |
| September | 17.11 | 2.9 | 43.0 | | B | C |
| October | 108.31 | 3.6 | 1,200.0 | | B | C |
| November | 64.23 | 2.9 | 460.0 | | B | C |
| December | 14.91 | 2.9 | 93.0 | | B | C |

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# APPENDIX C

**Fecal Coliform Loads for Existing Conditions**

## *Baptist Run*

**Table C.1 Current conditions of land applied fecal coliform load for Baptist Run by land use (subwatershed 1):**

| Land use | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Barren** | 1.78E+09 | 1.61E+09 | 1.78E+09 | 1.72E+09 | 1.78E+09 | 1.72E+09 | 1.78E+09 | 1.78E+09 | 1.72E+09 | 1.78E+09 | 1.72E+09 | 1.78E+09 | 2.10E+10 |
| **Commercial** | 3.06E+09 | 2.76E+09 | 3.06E+09 | 2.96E+09 | 3.06E+09 | 2.96E+09 | 3.06E+09 | 3.06E+09 | 2.96E+09 | 3.06E+09 | 2.96E+09 | 3.06E+09 | 3.60E+10 |
| **Cropland** | 3.61E+10 | 3.26E+10 | 3.61E+10 | 3.49E+10 | 3.61E+10 | 3.49E+10 | 3.61E+10 | 3.61E+10 | 3.49E+10 | 3.61E+10 | 3.49E+10 | 3.61E+10 | 4.25E+11 |
| **Forest** | 1.82E+12 | 1.64E+12 | 1.82E+12 | 1.76E+12 | 1.82E+12 | 1.76E+12 | 1.82E+12 | 1.82E+12 | 1.76E+12 | 1.82E+12 | 1.76E+12 | 1.82E+12 | 2.14E+13 |
| **High Density** | 4.71E+09 | 4.26E+09 | 4.71E+09 | 4.56E+09 | 4.71E+09 | 4.56E+09 | 4.71E+09 | 4.71E+09 | 4.56E+09 | 4.71E+09 | 4.56E+09 | 4.71E+09 | 5.55E+10 |
| **LAX** | 7.49E+09 | 6.77E+09 | 7.56E+09 | 7.45E+09 | 7.69E+09 | 7.51E+09 | 7.76E+09 | 7.76E+09 | 7.45E+09 | 7.56E+09 | 7.32E+09 | 7.49E+09 | 8.98E+10 |
| **Low Density** | 1.35E+12 | 1.20E+12 | 1.28E+12 | 1.22E+12 | 1.24E+12 | 1.18E+12 | 1.18E+12 | 1.18E+12 | 1.14E+12 | 1.15E+12 | 1.14E+12 | 1.26E+12 | 1.45E+13 |
| **Pasture** | 4.41E+10 | 3.99E+10 | 4.41E+10 | 4.25E+10 | 4.39E+10 | 4.24E+10 | 4.39E+10 | 4.39E+10 | 4.25E+10 | 4.41E+10 | 4.26E+10 | 4.41E+10 | 5.18E+11 |
| **Wetland** | 1.10E+11 | 9.97E+10 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.30E+12 |

**Table C.2 Monthly, directly deposited fecal coliform loads in Baptist Run (reach 1):**

| Source Type | Reach ID | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Human/Pet** | 1 | 9.70E+10 | 8.76E+10 | 9.70E+10 | 9.39E+10 | 9.70E+10 | 9.39E+10 | 9.70E+10 | 9.70E+10 | 9.39E+10 | 9.70E+10 | 9.39E+10 | 9.70E+10 | 1.14E+12 |
| **Livestock** | 1 | 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 | 0.00E+00 |
| **Wildlife** | 1 | 5.38E+10 | 4.86E+10 | 5.38E+10 | 5.21E+10 | 5.38E+10 | 5.21E+10 | 5.38E+10 | 5.38E+10 | 5.21E+10 | 5.38E+10 | 5.21E+10 | 5.38E+10 | 6.34E+11 |

**Table C.3 Existing annual loads from land-based sources for Baptist Run (subwatershed 1):**

| Source | Barren | Commercial | Cropland | Forest | High Density | LAX | Low Density | Pasture | Water | Wetland |
|---|---|---|---|---|---|---|---|---|---|---|
| **Beef** | 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 |
| **Beef Calf** | 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 |
| **Cats** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.43E+06 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Dairy** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Dairy Calf** | 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 |
| **Dairy Dry** | 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 |
| **Deer** | 0.00E+00 | 0.00E+00 | 7.76E+10 | 2.77E+12 | 0.00E+00 | 2.74E+09 | 6.50E+10 | 1.05E+11 | 0.00E+00 | 6.68E+10 |
| **Dogs** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.21E+12 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Duck** | 0.00E+00 | 2.47E+05 | 8.08E+06 | 5.23E+08 | 7.64E+05 | 3.53E+06 | 3.01E+07 | 5.70E+06 | 0.00E+00 | 4.80E+07 |
| **Goose** | 0.00E+00 | 1.05E+07 | 3.44E+08 | 2.23E+10 | 3.25E+07 | 1.50E+08 | 1.28E+09 | 2.43E+08 | 0.00E+00 | 2.04E+09 |
| **Hogs** | 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 |
| **Horse** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.98E+09 | 0.00E+00 | 7.54E+10 | 0.00E+00 | 0.00E+00 |
| **Muskrat** | 0.00E+00 | 5.13E+09 | 1.68E+11 | 1.09E+13 | 1.59E+10 | 7.33E+10 | 6.26E+11 | 1.19E+11 | 0.00E+00 | 9.98E+11 |
| **People w/Septic Failures** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.82E+12 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Raccoon** | 2.10E+10 | 3.09E+10 | 1.79E+11 | 7.78E+12 | 3.96E+10 | 9.64E+09 | 7.98E+11 | 2.19E+11 | 0.00E+00 | 2.32E+11 |
| **Sheep** | 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 |
| **Turkey** | 0.00E+00 | 0.00E+00 | 3.49E+06 | 4.98E+08 | 0.00E+00 | 1.23E+05 | 0.00E+00 | 4.72E+06 | 0.00E+00 | 1.20E+07 |

**Table C.4 Existing annual loads from direct-deposition sources for Baptist Run (reach 1):**

| Source | Annual Total Loads (cfu/yr) |
|---|---|
| **Beaver** | 1.74E+09 |
| **Beef** | 0.00E+00 |
| **Beef Calf** | 0.00E+00 |
| **Dairy** | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 |
| **Deer** | 1.55E+09 |
| **Duck** | 2.41E+07 |
| **Goose** | 6.76E+08 |
| **Hogs** | 0.00E+00 |
| **Horse** | 0.00E+00 |
| **Muskrat** | 6.07E+11 |
| **People w/Straight Pipes** | 1.14E+12 |
| **Raccoon** | 2.33E+10 |
| **Sheep** | 0.00E+00 |
| **Turkey** | 2.59E+05 |
| **Beaver** | 1.74E+09 |

***Deep Creek***

**Table C.5 Current conditions of land applied fecal coliform load for Deep Creek by land use (subwatersheds 10,11,12):**

| Land use | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Barren** | 2.44E+11 | 2.21E+11 | 2.44E+11 | 2.36E+11 | 2.44E+11 | 2.36E+11 | 2.44E+11 | 2.44E+11 | 2.36E+11 | 2.44E+11 | 2.36E+11 | 2.44E+11 | 2.87E+12 |
| **Commercial** | 1.66E+11 | 1.50E+11 | 1.66E+11 | 1.61E+11 | 1.66E+11 | 1.61E+11 | 1.66E+11 | 1.66E+11 | 1.61E+11 | 1.66E+11 | 1.61E+11 | 1.66E+11 | 1.96E+12 |
| **Cropland** | 2.22E+11 | 2.00E+11 | 2.22E+11 | 2.15E+11 | 2.22E+11 | 2.15E+11 | 2.22E+11 | 2.22E+11 | 2.15E+11 | 2.22E+11 | 2.15E+11 | 2.22E+11 | 2.61E+12 |
| **Forest** | 2.45E+12 | 2.21E+12 | 2.45E+12 | 2.37E+12 | 2.45E+12 | 2.37E+12 | 2.45E+12 | 2.45E+12 | 2.37E+12 | 2.45E+12 | 2.37E+12 | 2.45E+12 | 2.88E+13 |
| **High Density** | 5.32E+11 | 4.80E+11 | 5.32E+11 | 5.14E+11 | 5.32E+11 | 5.14E+11 | 5.32E+11 | 5.32E+11 | 5.14E+11 | 5.32E+11 | 5.14E+11 | 5.32E+11 | 6.26E+12 |
| **LAX** | 4.36E+10 | 3.94E+10 | 4.36E+10 | 4.22E+10 | 4.36E+10 | 4.22E+10 | 4.36E+10 | 4.36E+10 | 4.22E+10 | 4.36E+10 | 4.22E+10 | 4.36E+10 | 5.14E+11 |
| **Low Density** | 3.89E+13 | 3.50E+13 | 3.85E+13 | 3.71E+13 | 3.82E+13 | 3.68E+13 | 3.77E+13 | 3.77E+13 | 3.65E+13 | 3.76E+13 | 3.65E+13 | 3.83E+13 | 4.49E+14 |
| **Pasture** | 3.66E+11 | 3.31E+11 | 3.66E+11 | 3.55E+11 | 3.66E+11 | 3.55E+11 | 3.66E+11 | 3.66E+11 | 3.55E+11 | 3.66E+11 | 3.55E+11 | 3.66E+11 | 4.31E+12 |
| **Wetland** | 1.94E+12 | 1.75E+12 | 1.94E+12 | 1.88E+12 | 1.94E+12 | 1.88E+12 | 1.94E+12 | 1.94E+12 | 1.88E+12 | 1.94E+12 | 1.88E+12 | 1.94E+12 | 2.28E+13 |

**Table C.6 Monthly, directly deposited fecal coliform loads in Deep Creek (reaches 10,11,12):**

| Source Type | Reach ID | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Human/Pet** | 10 | 2.16E+12 | 1.95E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.54E+13 |
| **Livestock** | 10 | 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 | 0.00E+00 |
| **Wildlife** | 10 | 6.16E+10 | 5.57E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 7.26E+11 |
| **Human/Pet** | 11 | 2.39E+11 | 2.16E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.81E+12 |
| **Livestock** | 11 | 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 | 0.00E+00 |
| **Wildlife** | 11 | 4.62E+10 | 4.17E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 5.44E+11 |
| **Human/Pet** | 12 | 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 | 0.00E+00 |
| **Livestock** | 12 | 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 | 0.00E+00 |
| **Wildlife** | 12 | 1.72E+11 | 1.56E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 2.03E+12 |

**Table C.7 Existing annual loads from land-based sources for Deep Creek (subwatersheds 10,11,12):**

| Source | Barren | Commercial | Cropland | Forest | High Density | LAX | Low Density | Pasture | Water | Wetland |
|---|---|---|---|---|---|---|---|---|---|---|
| **Beef** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.76E+09 | 0.00E+00 |
| **Beef Calf** | 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 |
| **Cats** | 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 |
| **Dairy** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.54E+08 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Dairy Calf** | 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 |
| **Dairy Dry** | 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 |
| **Deer** | 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 |
| **Dogs** | 0.00E+00 | 0.00E+00 | 3.60E+11 | 3.28E+12 | 0.00E+00 | 2.69E+10 | 1.14E+12 | 7.35E+11 | 0.00E+00 | 5.66E+11 |
| **Duck** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.91E+14 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Goose** | 1.03E+08 | 2.37E+07 | 5.60E+07 | 7.28E+08 | 1.33E+08 | 1.97E+07 | 6.11E+08 | 8.13E+07 | 0.00E+00 | 9.43E+08 |
| **Hogs** | 4.37E+09 | 1.01E+09 | 2.38E+09 | 3.10E+10 | 5.67E+09 | 8.38E+08 | 2.60E+10 | 3.46E+09 | 0.00E+00 | 4.01E+10 |
| **Horse** | 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 |
| **Muskrat** | 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 |
| **People w/Septic Failures** | 2.14E+12 | 4.93E+11 | 1.16E+12 | 1.51E+13 | 2.77E+12 | 4.10E+11 | 1.27E+13 | 1.69E+12 | 0.00E+00 | 1.96E+13 |
| **Raccoon** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.25E+13 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Sheep** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.54E+13 | 0.00E+00 |
| **Turkey** | 7.35E+11 | 1.46E+12 | 1.09E+12 | 1.04E+13 | 3.48E+12 | 7.65E+10 | 1.15E+13 | 1.89E+12 | 0.00E+00 | 2.61E+12 |

**Table C.8 Existing annual loads from direct-deposition sources for Deep Creek (reaches 10,11,12):**

| Source | Annual Total Loads (cfu/yr) |
|---|---|
| **Beaver** | 7.61E+09 |
| **Beef** | 0.00E+00 |
| **Beef Calf** | 0.00E+00 |
| **Dairy** | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 |
| **Deer** | 3.06E+09 |
| **Duck** | 1.27E+08 |
| **Goose** | 3.56E+09 |
| **Hogs** | 0.00E+00 |
| **Horse** | 0.00E+00 |
| **Muskrat** | 3.20E+12 |
| **People w/Straight Pipes** | 2.82E+13 |
| **Raccoon** | 8.32E+10 |
| **Sheep** | 0.00E+00 |
| **Turkey** | 3.72E+05 |
| **Beaver** | 7.61E+09 |

***Warwick and James Rivers***

**Table C.9 Current conditions of land applied fecal coliform load for Warwick and James Rivers by land use (subwatersheds 2-14):**

| Land use | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Barren** | 2.47E+12 | 2.24E+12 | 2.47E+12 | 2.40E+12 | 2.47E+12 | 2.40E+12 | 2.47E+12 | 2.47E+12 | 2.40E+12 | 2.47E+12 | 2.40E+12 | 2.47E+12 | 2.91E+13 |
| **Commercial** | 7.02E+11 | 6.34E+11 | 7.02E+11 | 6.79E+11 | 7.02E+11 | 6.79E+11 | 7.02E+11 | 7.02E+11 | 6.79E+11 | 7.02E+11 | 6.79E+11 | 7.02E+11 | 8.27E+12 |
| **Cropland** | 1.87E+12 | 1.69E+12 | 1.87E+12 | 1.81E+12 | 1.87E+12 | 1.81E+12 | 1.87E+12 | 1.87E+12 | 1.81E+12 | 1.87E+12 | 1.81E+12 | 1.87E+12 | 2.20E+13 |
| **Forest** | 2.60E+13 | 2.35E+13 | 2.60E+13 | 2.51E+13 | 2.60E+13 | 2.51E+13 | 2.60E+13 | 2.60E+13 | 2.51E+13 | 2.60E+13 | 2.51E+13 | 2.60E+13 | 3.06E+14 |
| **High Density** | 2.79E+12 | 2.52E+12 | 2.79E+12 | 2.70E+12 | 2.79E+12 | 2.70E+12 | 2.79E+12 | 2.79E+12 | 2.70E+12 | 2.79E+12 | 2.70E+12 | 2.79E+12 | 3.29E+13 |
| **LAX** | 3.98E+11 | 3.60E+11 | 4.10E+11 | 4.20E+11 | 4.34E+11 | 4.32E+11 | 4.46E+11 | 4.46E+11 | 4.20E+11 | 4.10E+11 | 3.97E+11 | 3.98E+11 | 4.97E+12 |
| **Low Density** | 2.09E+14 | 1.88E+14 | 2.07E+14 | 2.00E+14 | 2.06E+14 | 1.99E+14 | 2.05E+14 | 2.05E+14 | 1.98E+14 | 2.05E+14 | 1.98E+14 | 2.07E+14 | 2.43E+15 |
| **Pasture** | 7.47E+12 | 6.75E+12 | 7.44E+12 | 7.14E+12 | 7.38E+12 | 7.12E+12 | 7.35E+12 | 7.35E+12 | 7.14E+12 | 7.44E+12 | 7.20E+12 | 7.47E+12 | 8.73E+13 |
| **Wetland** | 2.75E+13 | 2.49E+13 | 2.75E+13 | 2.67E+13 | 2.75E+13 | 2.67E+13 | 2.75E+13 | 2.75E+13 | 2.67E+13 | 2.75E+13 | 2.67E+13 | 2.75E+13 | 3.24E+14 |

**Table C.10 Monthly, directly deposited fecal coliform loads in Warwick and James Rivers (reaches 2-14):**

| Source Type | Reach ID | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Human/Pet** | 2 | 2.38E+10 | 2.15E+10 | 2.38E+10 | 2.30E+10 | 2.38E+10 | 2.30E+10 | 2.38E+10 | 2.38E+10 | 2.30E+10 | 2.38E+10 | 2.30E+10 | 2.38E+10 | 2.80E+11 |
| **Livestock** | 2 | 3.17E+08 | 2.86E+08 | 3.17E+08 | 3.07E+08 | 3.17E+08 | 3.07E+08 | 3.17E+08 | 3.17E+08 | 3.07E+08 | 3.17E+08 | 3.07E+08 | 3.17E+08 | 3.73E+09 |
| **Wildlife** | 2 | 2.07E+11 | 1.87E+11 | 2.07E+11 | 2.00E+11 | 2.07E+11 | 2.00E+11 | 2.07E+11 | 2.07E+11 | 2.00E+11 | 2.07E+11 | 2.00E+11 | 2.07E+11 | 2.44E+12 |
| **Human/Pet** | 3 | 1.68E+12 | 1.52E+12 | 1.68E+12 | 1.63E+12 | 1.68E+12 | 1.63E+12 | 1.68E+12 | 1.68E+12 | 1.63E+12 | 1.68E+12 | 1.63E+12 | 1.68E+12 | 1.98E+13 |
| **Livestock** | 3 | 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 | 0.00E+00 |
| **Wildlife** | 3 | 3.31E+11 | 2.99E+11 | 3.31E+11 | 3.20E+11 | 3.31E+11 | 3.20E+11 | 3.31E+11 | 3.31E+11 | 3.20E+11 | 3.31E+11 | 3.20E+11 | 3.31E+11 | 3.90E+12 |
| **Human/Pet** | 4 | 1.43E+12 | 1.29E+12 | 1.43E+12 | 1.39E+12 | 1.43E+12 | 1.39E+12 | 1.43E+12 | 1.43E+12 | 1.39E+12 | 1.43E+12 | 1.39E+12 | 1.43E+12 | 1.69E+13 |
| **Livestock** | 4 | 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 | 0.00E+00 |
| **Wildlife** | 4 | 3.56E+11 | 3.21E+11 | 3.56E+11 | 3.44E+11 | 3.56E+11 | 3.44E+11 | 3.56E+11 | 3.56E+11 | 3.44E+11 | 3.56E+11 | 3.44E+11 | 3.56E+11 | 4.19E+12 |
| **Human/Pet** | 5 | 1.12E+12 | 1.02E+12 | 1.12E+12 | 1.09E+12 | 1.12E+12 | 1.09E+12 | 1.12E+12 | 1.12E+12 | 1.09E+12 | 1.12E+12 | 1.09E+12 | 1.12E+12 | 1.32E+13 |
| **Livestock** | 5 | 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 | 0.00E+00 |
| **Wildlife** | 5 | 5.48E+11 | 4.95E+11 | 5.48E+11 | 5.31E+11 | 5.48E+11 | 5.31E+11 | 5.48E+11 | 5.48E+11 | 5.31E+11 | 5.48E+11 | 5.31E+11 | 5.48E+11 | 6.45E+12 |
| **Human/Pet** | 6 | 1.22E+12 | 1.10E+12 | 1.22E+12 | 1.18E+12 | 1.22E+12 | 1.18E+12 | 1.22E+12 | 1.22E+12 | 1.18E+12 | 1.22E+12 | 1.18E+12 | 1.22E+12 | 1.44E+13 |
| **Livestock** | 6 | 4.53E+09 | 4.09E+09 | 4.53E+09 | 4.38E+09 | 4.53E+09 | 4.38E+09 | 4.53E+09 | 4.53E+09 | 4.38E+09 | 4.53E+09 | 4.38E+09 | 4.53E+09 | 5.33E+10 |
| **Wildlife** | 6 | 2.74E+12 | 2.47E+12 | 2.74E+12 | 2.65E+12 | 2.74E+12 | 2.65E+12 | 2.74E+12 | 2.74E+12 | 2.65E+12 | 2.74E+12 | 2.65E+12 | 2.74E+12 | 3.22E+13 |
| **Human/Pet** | 7 | 9.34E+12 | 8.44E+12 | 9.34E+12 | 9.04E+12 | 9.34E+12 | 9.04E+12 | 9.34E+12 | 9.34E+12 | 9.04E+12 | 9.34E+12 | 9.04E+12 | 9.34E+12 | 1.10E+14 |
| **Livestock** | 7 | 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 | 0.00E+00 |
| **Wildlife** | 7 | 1.67E+11 | 1.51E+11 | 1.67E+11 | 1.62E+11 | 1.67E+11 | 1.62E+11 | 1.67E+11 | 1.67E+11 | 1.62E+11 | 1.67E+11 | 1.62E+11 | 1.67E+11 | 1.97E+12 |
| **Human/Pet** | 8 | 1.21E+12 | 1.09E+12 | 1.21E+12 | 1.17E+12 | 1.21E+12 | 1.17E+12 | 1.21E+12 | 1.21E+12 | 1.17E+12 | 1.21E+12 | 1.17E+12 | 1.21E+12 | 1.43E+13 |
| **Livestock** | 8 | 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 | 0.00E+00 |
| **Wildlife** | 8 | 3.01E+10 | 2.72E+10 | 3.01E+10 | 2.92E+10 | 3.01E+10 | 2.92E+10 | 3.01E+10 | 3.01E+10 | 2.92E+10 | 3.01E+10 | 2.92E+10 | 3.01E+10 | 3.55E+11 |
| **Human/Pet** | 9 | 3.62E+11 | 3.27E+11 | 3.62E+11 | 3.51E+11 | 3.62E+11 | 3.51E+11 | 3.62E+11 | 3.62E+11 | 3.51E+11 | 3.62E+11 | 3.51E+11 | 3.62E+11 | 4.27E+12 |
| **Livestock** | 9 | 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 | 0.00E+00 |
| **Wildlife** | 9 | 9.50E+10 | 8.58E+10 | 9.50E+10 | 9.20E+10 | 9.50E+10 | 9.20E+10 | 9.50E+10 | 9.50E+10 | 9.20E+10 | 9.50E+10 | 9.20E+10 | 9.50E+10 | 1.12E+12 |
| **Human/Pet** | 10 | 2.16E+12 | 1.95E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.09E+12 | 2.16E+12 | 2.54E+13 |
| **Livestock** | 10 | 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 | 0.00E+00 |

| | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Wildlife** | 10 | 6.16E+10 | 5.57E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 5.97E+10 | 6.16E+10 | 7.26E+11 |
| **Human/Pet** | 11 | 2.39E+11 | 2.16E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.31E+11 | 2.39E+11 | 2.81E+12 |
| **Livestock** | 11 | 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 | 0.00E+00 |
| **Wildlife** | 11 | 4.62E+10 | 4.17E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 4.47E+10 | 4.62E+10 | 5.44E+11 |
| **Human/Pet** | 12 | 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 | 0.00E+00 |
| **Livestock** | 12 | 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 | 0.00E+00 |
| **Wildlife** | 12 | 1.72E+11 | 1.56E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 1.67E+11 | 1.72E+11 | 2.03E+12 |
| **Human/Pet** | 13 | 3.41E+12 | 3.08E+12 | 3.41E+12 | 3.30E+12 | 3.41E+12 | 3.30E+12 | 3.41E+12 | 3.41E+12 | 3.30E+12 | 3.41E+12 | 3.30E+12 | 3.41E+12 | 4.01E+13 |
| **Livestock** | 13 | 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 | 0.00E+00 |
| **Wildlife** | 13 | 9.96E+10 | 9.00E+10 | 9.96E+10 | 9.64E+10 | 9.96E+10 | 9.64E+10 | 9.96E+10 | 9.96E+10 | 9.64E+10 | 9.96E+10 | 9.64E+10 | 9.96E+10 | 1.17E+12 |
| **Human/Pet** | 14 | 3.07E+12 | 2.77E+12 | 3.07E+12 | 2.97E+12 | 3.07E+12 | 2.97E+12 | 3.07E+12 | 3.07E+12 | 2.97E+12 | 3.07E+12 | 2.97E+12 | 3.07E+12 | 3.61E+13 |
| **Livestock** | 14 | 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 | 0.00E+00 |
| **Wildlife** | 14 | 2.63E+11 | 2.38E+11 | 2.63E+11 | 2.55E+11 | 2.63E+11 | 2.55E+11 | 2.63E+11 | 2.63E+11 | 2.55E+11 | 2.63E+11 | 2.55E+11 | 2.63E+11 | 3.10E+12 |

**Table C.11 Existing annual loads from land-based sources for Warwick and James Rivers (subwatersheds 2-14):**

| Source | Barren | Commercial | Cropland | Forest | High Density | LAX | Low Density | Pasture | Water | Wetland |
|---|---|---|---|---|---|---|---|---|---|---|
| **Beef** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 5.25E+10 | 0.00E+00 |
| **Beef Calf** | 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 |
| **Cats** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.33E+11 | 0.00E+00 | 8.93E+12 | 5.70E+10 | 0.00E+00 |
| **Dairy** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 4.21E+11 | 0.00E+00 | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.53E+12 | 0.00E+00 | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.94E+09 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Deer** | 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 |
| **Dogs** | 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 |
| **Duck** | 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 |
| **Goose** | 0.00E+00 | 0.00E+00 | 2.80E+12 | 3.35E+13 | 0.00E+00 | 1.33E+11 | 7.09E+12 | 5.47E+12 | 0.00E+00 | 6.83E+12 |
| **Hogs** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.15E+15 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Horse** | 1.15E+09 | 1.13E+08 | 5.46E+08 | 8.19E+09 | 6.69E+08 | 1.69E+08 | 4.62E+09 | 8.11E+08 | 0.00E+00 | 1.37E+10 |
| **Muskrat** | 4.87E+10 | 4.82E+09 | 2.32E+10 | 3.48E+11 | 2.85E+10 | 7.17E+09 | 1.97E+11 | 3.45E+10 | 0.00E+00 | 5.81E+11 |
| **People w/Septic Failures** | 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 |
| **Raccoon** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.04E+11 | 0.00E+00 | 3.29E+13 | 0.00E+00 | 0.00E+00 |
| **Sheep** | 2.38E+13 | 2.35E+12 | 1.14E+13 | 1.70E+14 | 1.39E+13 | 3.50E+12 | 9.61E+13 | 1.69E+13 | 0.00E+00 | 2.84E+14 |
| **Turkey** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.03E+14 | 0.00E+00 | 0.00E+00 | 0.00E+00 |

**Table C.12 Existing annual loads from direct-deposition sources for Warwick and James Rivers (reaches 2-14):**

| Source | Annual Total Loads (cfu/yr) |
|---|---|
| **Beaver** | 5.44E+10 |
| **Beef** | 5.70E+10 |
| **Beef Calf** | 0.00E+00 |
| **Dairy** | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 |
| **Deer** | 0.00E+00 |
| **Duck** | 2.79E+10 |
| **Goose** | 2.36E+09 |
| **Hogs** | 6.62E+10 |
| **Horse** | 0.00E+00 |
| **Muskrat** | 0.00E+00 |
| **People w/Straight Pipes** | 5.94E+13 |
| **Raccoon** | 2.98E+14 |
| **Sheep** | 6.53E+11 |
| **Turkey** | 0.00E+00 |
| **Beaver** | 3.81E+06 |

## *James River – Opposite Fort Eustis & Skiffes Creek*

**Table C.13 Current conditions of land applied fecal coliform load for James River – Opposite Fort Eustis & Skiffes Creek by land use (subwatersheds 15,16):**

| Land use | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Barren** | 3.92E+11 | 3.54E+11 | 3.92E+11 | 3.79E+11 | 3.92E+11 | 3.79E+11 | 3.92E+11 | 3.92E+11 | 3.79E+11 | 3.92E+11 | 3.79E+11 | 3.92E+11 | 4.61E+12 |
| **Commercial** | 1.10E+11 | 9.98E+10 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.07E+11 | 1.10E+11 | 1.30E+12 |
| **Cropland** | 1.23E+12 | 1.18E+12 | 4.06E+12 | 4.03E+12 | 4.06E+12 | 9.27E+11 | 9.58E+11 | 9.58E+11 | 1.83E+12 | 4.06E+12 | 4.03E+12 | 1.23E+12 | 2.86E+13 |
| **Forest** | 7.59E+12 | 6.86E+12 | 7.59E+12 | 7.35E+12 | 7.59E+12 | 7.35E+12 | 7.59E+12 | 7.59E+12 | 7.35E+12 | 7.59E+12 | 7.35E+12 | 7.59E+12 | 8.94E+13 |
| **High Density** | 2.49E+11 | 2.25E+11 | 2.49E+11 | 2.41E+11 | 2.49E+11 | 2.41E+11 | 2.49E+11 | 2.49E+11 | 2.41E+11 | 2.49E+11 | 2.41E+11 | 2.49E+11 | 2.94E+12 |
| **LAX** | 4.12E+10 | 3.72E+10 | 4.49E+10 | 5.06E+10 | 5.23E+10 | 5.42E+10 | 5.60E+10 | 5.60E+10 | 5.06E+10 | 4.49E+10 | 4.35E+10 | 4.12E+10 | 5.73E+11 |
| **Low Density** | 1.15E+13 | 1.03E+13 | 1.13E+13 | 1.09E+13 | 1.13E+13 | 1.09E+13 | 1.11E+13 | 1.11E+13 | 1.08E+13 | 1.11E+13 | 1.08E+13 | 1.13E+13 | 1.32E+14 |
| **Pasture** | 1.43E+12 | 1.30E+12 | 1.45E+12 | 1.40E+12 | 1.44E+12 | 1.69E+12 | 1.74E+12 | 1.74E+12 | 1.38E+12 | 1.45E+12 | 1.40E+12 | 1.43E+12 | 1.78E+13 |
| **Wetland** | 6.66E+12 | 6.01E+12 | 6.66E+12 | 6.44E+12 | 6.66E+12 | 6.44E+12 | 6.66E+12 | 6.66E+12 | 6.44E+12 | 6.66E+12 | 6.44E+12 | 6.66E+12 | 7.84E+13 |

**Table C.14 Monthly, directly deposited fecal coliform loads in James River – Opposite Fort Eustis & Skiffes Creek (reaches 15,16):**

| Source Type | Reach ID | January | February | March | April | May | June | July | August | September | October | November | December | Annual Total Loads (cfu/yr) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Human/Pet** | 15 | 1.35E+12 | 1.22E+12 | 1.35E+12 | 1.30E+12 | 1.35E+12 | 1.30E+12 | 1.35E+12 | 1.35E+12 | 1.30E+12 | 1.35E+12 | 1.30E+12 | 1.35E+12 | 1.59E+13 |
| **Livestock** | 15 | 1.90E+09 | 1.72E+09 | 1.90E+09 | 1.84E+09 | 1.90E+09 | 1.84E+09 | 1.90E+09 | 1.90E+09 | 1.84E+09 | 1.90E+09 | 1.84E+09 | 1.90E+09 | 2.24E+10 |
| **Wildlife** | 15 | 2.02E+11 | 1.83E+11 | 2.02E+11 | 1.96E+11 | 2.02E+11 | 1.96E+11 | 2.02E+11 | 2.02E+11 | 1.96E+11 | 2.02E+11 | 1.96E+11 | 2.02E+11 | 2.38E+12 |
| **Human/Pet** | 16 | 5.50E+11 | 4.97E+11 | 5.50E+11 | 5.32E+11 | 5.50E+11 | 5.32E+11 | 5.50E+11 | 5.50E+11 | 5.32E+11 | 5.50E+11 | 5.32E+11 | 5.50E+11 | 6.48E+12 |
| **Livestock** | 16 | 8.15E+08 | 7.36E+08 | 8.15E+08 | 7.89E+08 | 8.15E+08 | 7.89E+08 | 8.15E+08 | 8.15E+08 | 7.89E+08 | 8.15E+08 | 7.89E+08 | 8.15E+08 | 9.59E+09 |
| **Wildlife** | 16 | 1.06E+12 | 9.59E+11 | 1.06E+12 | 1.03E+12 | 1.06E+12 | 1.03E+12 | 1.06E+12 | 1.06E+12 | 1.03E+12 | 1.06E+12 | 1.03E+12 | 1.06E+12 | 1.25E+13 |

**Table C.15 Existing annual loads from land-based sources for James River – Opposite Fort Eustis & Skiffes Creek (subwatersheds 15,16):**

| Source | Barren | Commercial | Cropland | Forest | High Density | LAX | Low Density | Pasture | Water | Wetland |
|---|---|---|---|---|---|---|---|---|---|---|
| **Beef** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.42E+10 | 0.00E+00 |
| **Beef Calf** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.46E+10 | 0.00E+00 | 5.01E+12 | 3.20E+10 | 0.00E+00 |
| **Cats** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 3.51E+11 | 0.00E+00 | 0.00E+00 |
| **Dairy** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 9.46E+07 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 | 0.00E+00 | 1.46E+13 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.09E+11 | 0.00E+00 | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 | 0.00E+00 | 1.17E+12 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 6.50E+10 | 0.00E+00 | 0.00E+00 |
| **Deer** | 0.00E+00 | 0.00E+00 | 1.42E+12 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 7.84E+10 | 0.00E+00 | 0.00E+00 |
| **Dogs** | 0.00E+00 | 0.00E+00 | 1.81E+12 | 9.69E+12 | 0.00E+00 | 1.19E+10 | 7.59E+11 | 1.88E+12 | 0.00E+00 | 1.77E+12 |
| **Duck** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 1.04E+14 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Goose** | 1.75E+08 | 3.99E+07 | 2.36E+08 | 2.38E+09 | 7.24E+07 | 1.08E+07 | 5.03E+08 | 7.20E+07 | 0.00E+00 | 3.29E+09 |
| **Hogs** | 7.43E+09 | 1.70E+09 | 1.00E+10 | 1.01E+11 | 3.08E+09 | 4.61E+08 | 2.14E+10 | 3.06E+09 | 0.00E+00 | 1.40E+11 |
| **Horse** | 0.00E+00 | 0.00E+00 | 8.98E+10 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.98E+10 | 0.00E+00 | 0.00E+00 |
| **Muskrat** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.19E+11 | 0.00E+00 | 4.15E+12 | 0.00E+00 | 0.00E+00 |
| **People w/Septic Failures** | 3.63E+12 | 8.28E+11 | 4.90E+12 | 4.94E+13 | 1.51E+12 | 2.25E+11 | 1.04E+13 | 1.49E+12 | 0.00E+00 | 6.83E+13 |
| **Raccoon** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 8.99E+12 | 0.00E+00 | 0.00E+00 | 0.00E+00 |
| **Sheep** | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 0.00E+00 | 2.23E+13 | 0.00E+00 |
| **Turkey** | 9.79E+11 | 4.71E+11 | 4.55E+12 | 3.02E+13 | 1.43E+12 | 4.19E+10 | 7.65E+12 | 3.92E+12 | 0.00E+00 | 8.18E+12 |

**Table C.16 Existing annual loads from direct-deposition sources for James River – Opposite Fort Eustis & Skiffes Creek (reaches 15,16):**

| Source | Annual Total Loads (cfu/yr) |
|---|---|
| **Beaver** | 1.42E+10 |
| **Beef** | 3.20E+10 |
| **Beef Calf** | 0.00E+00 |
| **Dairy** | 0.00E+00 |
| **Dairy Calf** | 0.00E+00 |
| **Dairy Dry** | 0.00E+00 |
| **Deer** | 7.97E+09 |
| **Duck** | 5.85E+08 |
| **Goose** | 1.64E+10 |
| **Hogs** | 0.00E+00 |
| **Horse** | 0.00E+00 |
| **Muskrat** | 1.47E+13 |
| **People w/Straight Pipes** | 2.23E+13 |
| **Raccoon** | 1.44E+11 |
| **Sheep** | 0.00E+00 |
| **Turkey** | 1.11E+06 |
| **Beaver** | 1.42E+10 |