E.coli TMDL Development for The Pamunkey River and Tributaries, VA

Prepared for:
Virginia Department of Environmental Quality

Draft Submitted:
January 2014

Submitted by:
MapTech, Inc.

Final Submitted:
July 2014

MapTech, Inc.
3154 State Street
Blacksburg, VA 24060
(540) 961-7864

New River-Highlands RC&D

New River Highlands RC&D
325 East Main Street, Suite E-2
Wytheville, VA 24382

This page was intentionally left blank.

ACKNOWLEDGEMENTS

Virginia Department of Environmental Quality (VADEQ), Central Office

VADEQ, Piedmont Regional Office

VADEQ, Northern Regional Office

Colonial Soil and Water Conservation District (CSWCD)

Three Rivers Soil and Water Conservation District (TRSWCD)

Hanover-Caroline Soil and Water Conservation District (HCSWCD)

Tri County/City Soil and Water Conservation District (TCCSWCD)

Thomas Jefferson Soil and Water Conservation District (TJSWCD)

Virginia Department of Health

Watershed citizens

This page was intentionally left blank.

TABLE OF CONTENTS

ACKNOWLEDGEMENTS i
FIGURES vii
TABLES xxi
EXECUTIVE SUMMARY xxvii
Background and Applicable Standards xxvii
TMDL Endpoint and Water Quality Assessment xxxi
Source Assessment xxxi
Modeling Procedures xxxi
Hydrology xxxii
Fecal Coliform xxxii
Load Allocation Scenarios xxxii
Implementation xxxvii
Public Participation xxxvii
1. INTRODUCTION 1-1
1.1 Regulations Background 1-3
1.2 Pamunkey River Watershed Characteristics 1-4
1.3 Pamunkey River Watershed Recreation Use Impairments 1-6
1.3.1 Beaverdam Creek (VAP-F11R_BDC01A12) 1-6
1.3.2 Crump Creek (VAP-F12R_CRU01A02) 1-6
1.3.3 Crump Creek Unnamed Tributary (VAP-F12R_XJC01A12) 1-7
1.3.4 Harrison Creek (VAP-F14R_HSN01A00) 1-7
1.3.5 Harrison Creek (VAP-F14E_HSN01A12) 1-7
1.3.6 Harrison Creek Unnamed Tributary (VAP-F14R_XJD01A12) 1-7
1.3.7 Jacks Creek and Tributaries (VAP-F13R_JCK01A98) 1-8
1.3.8 Kersey Creek (VAP-F12R_KER01A12) 1-8

1.3.9 Upper Little River (VAN-F10R_LTL01A02) 1-8

1.3.10 Lower Little River (VAP-F11R_LTL01B08)..... 1-8

1.3.11 Mill Creek (VAP-F09R_MLL01A12)..... 1-9

1.3.12 Pamunkey River (VAP-F12R_PMK01B08) 1-9

1.3.13 Pamunkey River (VAP-F14E_PMK02A00)..... 1-9

1.3.14 Pamunkey River (VAP-F14E_PMK03A00)..... 1-9

1.3.15 Pamunkey River (VAP-F14E_PMK04A00)..... 1-9

1.3.16 Pamunkey River (VAP-F14E_PMK01A98)..... 1-10

1.3.17 Pamunkey River Unnamed Tributary (VAP-F13R_XDW01A08)..... 1-10

1.3.18 Pamunkey River Unnamed Tributary (XDX to XDW) (VAP-F13R_XDX01A04)..... 1-10

1.3.19 Pollard Creek (VAP-F12R_PLD01A12) 1-10

1.3.20 Northeast Creek (VAN-F09R_NST01A08) 1-11

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT 2-1

2.1 Applicable Water Quality Standards 2-1

2.2 Selection of a TMDL Endpoint..... 2-3

2.3 Discussion of In-stream Water Quality..... 2-4

2.3.1 Inventory of Water Quality Monitoring Data 2-4

3. BACTERIA SOURCE ASSESSMENT 3-1

3.1 Assessment of Permitted Sources 3-3

3.2 Assessment of Nonpoint Sources..... 3-9

3.2.1 Private Residential Sewage Treatment 3-9

3.2.2 Sanitary Sewer Overflows (SSOs)..... 3-13

3.2.3 Biosolids 3-14

3.2.4 Pets..... 3-15

3.2.5 Livestock..... 3-18

3.2.6 Wildlife 3-22

4. BACTERIA MODELING PROCEDURE: LINKING THE SOURCES TO THE ENDPOINT 4-1

5. BACTERIAL ALLOCATION 5-1

5.1 Margin of Safety (MOS) 5-2

5.2 Waste Load Allocations (WLAs) 5-3

5.3 Load Allocations (LAs) 5-4

5.4 Final Total Maximum Daily Loads (TMDLs) 5-4

5.4.1 South Anna River TMDL Modification 5-5

5.4.2 Northeast Creek TMDL Watershed Unit (VAN-F09R_NST01A08, VAN-F09R_NST03A08, VAN-F09R_NST04A08 and VAN-F09R_MUS01A06) 5-14

5.4.3 Upper Little River TMDL Watershed Unit (VAP-F11R_BDC01A12, VAN-F10R_LTL01A02 and VAP-F11R_LTL01B08) 5-19

5.4.4 Upper Pamunkey/North Anna River TMDL Watershed Unit (VAP-F09R_MLL01A12 and VAP-F12R_PMK01B08) 5-24

5.4.5 Middle Pamunkey River TMDL Watershed Unit (VAP-F12R_CRU01A02, VAP-F12R_KER01A12, VAP-F12R_XJC01A12, VAP-F12R_PLD01A12, VAP-F12R_MCP03A06, VAP-F12R_XEG01A06 and VAP-F12R_MCP01A94) 5-29

5.4.6 Lower Pamunkey (Tidal) TMDL Watershed Unit (VAP-F13R_XDX01A04, VAP-F13R_XDW01A08, VAP-F13R_JCK01A98, VAP-F14R_HSN01A00, VAP-F14R_XJD 01A12, VAP-F14E_HSN01A12, VAP-F14E_PMK02A00, VAP-F14E_PMK03A00, VAP-F14E_PMK04A00, VAP-F13R_MLY01A12, VAP-F13R_MDQ01A98, VAP-F13E_PMK03A06, VAP-F13E_PMK02A98, VAP-F13E_PMK01A98 and VAP-F13R_MNQ01A98) 5-35

6. IMPLEMENTATION 6-1

6.1 Continuing Planning Process and Water Quality Management Planning .. 6-1

6.2 Staged Implementation 6-1

6.3 Implementation of Waste Load Allocations 6-2

6.3.1 Stormwater 6-2

6.3.2 TMDL Modifications for New or Expanding Discharges 6-3

6.4 Implementation of Load Allocations 6-3

6.4.1 Implementation Plan Development 6-3

6.4.2 Staged Implementation Scenarios 6-4

6.4.3 Link to Ongoing Restoration Efforts 6-5

6.4.4 Implementation Funding Sources 6-5

6.5 Follow-Up Monitoring 6-6

6.6 Attainability of Designated Uses 6-7

7. PUBLIC PARTICIPATION 7-1

REFERENCES R-1

GLOSSARY G-1

APPENDIX A: Frequency Analysis of Bacteria Data A-1

APPENDIX B: Bacteria Modeling Procedure - Linking the Sources to the Endpoint B-1

APPENDIX C: Current Conditions - Fecal Coliform Loads C-1

APPENDIX D: Pamunkey River TMDLs, 2006 ..... D-1

APPENDIX E: Public Comment and Response E-1

FIGURES

Figure 1-1 TMDL work in the current study area of the Pamunkey River watershed. 1-2

Figure 1-2 Location of the Pamunkey River watershed. 1-5

Figure 1-3 Impaired segments that are not currently addressed by a TMDL in the Pamunkey River Watershed. 1-12

Figure 2-1 Location of impairment listing VADEQ water quality monitoring stations in the Pamunkey River Watershed, and the impaired waters being addressed for the first time in this study. 2-5

Figure 3-1 Subwatersheds delineated for modeling the study area, and the impairments being addressed for the first time. (Does not include four subwatersheds for existing TMDLs or modeling changes noted in the text.) 3-5

Figure 3-2 Location of VPDES permitted point sources in the Pamunkey River watershed study area (Expected to Discharge Contaminant of Concern), and the impairments being addressed for the first time in this study. 3-7

Figure 5-1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in Northeast Creek TMDL watershed unit. 5-16

Figure 5-2 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in the Upper Little River TMDL watershed unit (Subwatershed 43). 5-21

Figure 5-3 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in Upper Pamunkey/North Anna River TMDL watershed unit. 5-26

Figure 5-4 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in the Middle Pamunkey River TMDL watershed unit (Subwatershed 51). 5-32

Figure 5-5 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations Lower Pamunkey TMDL watershed unit (Subwatershed 23). 5-38

Figure A-1 Frequency analysis of *E. coli* concentrations at station 8-ACQ001.35 in Acquinton Creek for the period from January 2011 to October 2011. ..... A-2

Figure A-2 Frequency analysis of *E. coli* concentrations at station 8-ACQ004.43 in Acquinton Creek for the period from January 2011 to October 2011. ..... A-3

Figure A-3 Frequency analysis of *E. coli* concentrations at station 8-ACQ008.01 in Acquinton Creek for the period from January 2011 to October 2011 ..... A-4

Figure A-4 Frequency analysis of *E. coli* concentrations at station 8-BDC000.05 in Beaverdam Creek for the period from February 2009 to November 2010 ..... A-5

Figure A-5 Frequency analysis of *E. coli* concentrations at station 8-BLC001.77 in Black Creek for the period from July 2003 to March 2005. ..... A-6

Figure A-6 Frequency analysis of *E. coli* concentrations at station 8-CMC005.16 in Cohoke Mill Creek for the period from February 2007 to December 2008. ..... A-7

Figure A-7 Frequency analysis of *E. coli* concentrations at station 8-CRU000.92 in Crump Creek for the period from June 2005 to December 2010. ..... A-8

Figure A-8 Frequency analysis of *E. coli* concentrations at station 8-CRU005.61 in Crump Creek for the period from January 2010 to December 2010. ..... A-9

Figure A-9 Frequency analysis of *E. coli* concentrations at station 8-CRU008.30 in Crump Creek for the period from January 2010 to December 2010. ..... A-10

Figure A-10 Frequency analysis of *E. coli* concentrations at station 8-HQT002.12 in Hornquarter Creek for the period from July 2003 to June 2004. ..... A-11

Figure A-11 Frequency analysis of *E. coli* concentrations at station 8-HSN000.92 in Harrison Creek for the period from April 2010 to March 2011. ..... A-12

Figure A-12 Frequency analysis of *E. coli* concentrations at station 8-HSN002.12 in Harrison Creek for the period from May 2005 to March 2011. ..... A-13

Figure A-13 Frequency analysis of *E. coli* concentrations at station 8-HSN002.43 in Harrison Creek for the period from April 2010 to March 2011. ..... A-14

Figure A-14 Frequency analysis of *E. coli* concentrations at station 8-HSN003.93 in Harrison Creek for the period from April 2010 to September 2011. ..... A-15

Figure A-15 Frequency analysis of *E. coli* concentrations at station 8-JKC004.15 in Jacks Creek for the period from July 2003 to October 2011. ..... A-16

Figure A-16 Frequency analysis of *E. coli* concentrations at station 8-JKC005.80 in Jacks Creek for the period from January 2011 to October 2011. A-17

Figure A-17 Frequency analysis of *E. coli* concentrations at station 8-JKC007.95 in Jacks Creek for the period from January 2011 to October 2011. A-18

Figure A-18 Frequency analysis of *E. coli* concentrations at station 8-KER001.31 in Kersey Creek for the period from January 2010 to December 2010. A-19

Figure A-19 Frequency analysis of *E. coli* concentrations at station 8-LTL002.69 in the Little River for the period from July 2003 to September 2011. A-20

Figure A-20 Frequency analysis of *E. coli* concentrations at station 8-LTL009.54 in the Little River for the period from July 2003 to October 2011. A-21

Figure A-21 Frequency analysis of *E. coli* concentrations at station 8-LTL018.80 in the Little River for the period from February 2009 to November 2010. A-22

Figure A-22 Frequency analysis of *E. coli* concentrations at station 8-LTL024.86 in the Little River for the period from June 2005 to October 2011. A-23

Figure A-23 Frequency analysis of *E. coli* concentrations at station 8-MCP002.42 in Mechumps Creek for the period from November 2002 to November 2008. A-24

Figure A-24 Frequency analysis of *E. coli* concentrations at station 8-MCP009.56 in Mechumps Creek for the period from January 2007 to September 2008. A-25

Figure A-25 Frequency analysis of *E. coli* concentrations at station 8-MCR001.64 in Mill Creek for the period from May January 2007 to November 2008. A-26

Figure A-26 Frequency analysis of *E. coli* concentrations at station 8-MDQ001.37 in Matadequin Creek for the period from November 2002 to December 2010. A-27

Figure A-27 Frequency analysis of *E. coli* concentrations at station 8-MLL001.19 in Mill Creek for the period from February 2009 to November 2010. A-28

Figure A-28 Frequency analysis of *E. coli* concentrations at station 8-MLY001.58 in Mallory Creek for the period from January 2011 to October 2011. A-29

Figure A-29 Frequency analysis of *E. coli* concentrations at station 8-MNQ004.19 in Moncuin Creek for the period from July 2003 to March 2005. ..... A-30

Figure A-30 Frequency analysis of *E. coli* concentrations at station 8-NAR005.42 in the North Anna River for the period from July 2003 to September 2011. ..... A-31

Figure A-31 Frequency analysis of *E. coli* concentrations at station 8-NFD002.26 in the Newfound River for the period from June 2005 to September 2011. ..... A-32

Figure A-32 Frequency analysis of *E. coli* concentrations at station 8-PLD001.73 in Pollard Creek for the period from January 2010 to December 2010. ..... A-33

Figure A-33 Frequency analysis of *E. coli* concentrations at station 8-PMK034.17 in the Pamunkey River for the period from July 2004 to October 2011. ..... A-34

Figure A-34 Frequency analysis of *E. coli* concentrations at station 8-PMK039.74 in the Pamunkey River for the period from July 2003 to October 2011. ..... A-35

Figure A-35 Frequency analysis of *E. coli* concentrations at station 8-PMK044.64 in the Pamunkey River for the period from January 2011 to October 2011. ..... A-36

Figure A-36 Frequency analysis of *E. coli* concentrations at station 8-PMK048.80 in the Pamunkey River for the period from August 2003 to October 2011. ..... A-37

Figure A-37 Frequency analysis of *E. coli* concentrations at station 8-PMK056.87 in the Pamunkey River for the period from August 2003 to October 2011. ..... A-38

Figure A-38 Frequency analysis of *E. coli* concentrations at station 8-PMK072.34 in the Pamunkey River for the period from July 2003 to October 2011. ..... A-39

Figure A-39 Frequency analysis of *E. coli* concentrations at station 8-PMK082.34 in the Pamunkey River for the period from December 2005 to October 2011. ..... A-40

Figure A-40 Frequency analysis of *E. coli* concentrations at station 8-SAR001.11 in the South Anna River for the period from July 2003 to September 2011. ..... A-41

Figure A-41 Frequency analysis of *E. coli* concentrations at station 8-SAR012.42 in the South Anna River for the period from July 2003 to June 2004. ..... A-42

Figure A-42 Frequency analysis of *E. coli* concentrations at station 8-SAR014.47 in the South Anna River for the period from July 2003 to March 2005. ..... A-43

Figure A-43 Frequency analysis of *E. coli* concentrations at station 8-STG001.00 in Stagg Creek for the period from June 2003 to July 2004. ..... A-44

Figure A-44 Frequency analysis of *E. coli* concentrations at station 8-STG005.46 in Stagg Creek for the period from September 2004 to July 2005. ..... A-45

Figure A-45 Frequency analysis of *E. coli* concentrations at station 8-TPT004.37 in Totopotomoy Creek for the period from August 2003 to December 2008. ..... A-46

Figure A-46 Frequency analysis of *E. coli* concentrations at station 8-XDW000.67 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009. ..... A-47

Figure A-47 Frequency analysis of *E. coli* concentrations at station 8-XDX000.38 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009. ..... A-48

Figure A-48 Frequency analysis of *E. coli* concentrations at station 8-XEG000.06 in an Unnamed Tributary to Mechumps Creek for the period from January 2007 to November 2008. ..... A-49

Figure A-49 Frequency analysis of *E. coli* concentrations at station 8-XIW000.42 in an Unnamed tributary to Jacks Creek for the period from January 2011 to October 2011. ..... A-50

Figure A-50 Frequency analysis of *E. coli* concentrations at station 8-XJC001.12 in an Unnamed tributary to Crump Creek for the period from January 2010 to December 2010. ..... A-51

Figure A-51 Frequency analysis of *E. coli* concentrations at station 8-XJD000.02 in an Unnamed tributary to Harrison Creek for the period from April 2010 to April 2011. ..... A-52

Figure A-52 Frequency analysis of *E. coli* concentrations at station 8-ARN000.73 in Arnold Creek for the period from August 2004 to July 2007. ..... A-53

Figure A-53 Frequency analysis of *E. coli* concentrations at station 8-LNG000.94 in Long Creek for the period from February 2011 to August 2012. ..... A-54

Figure A-54 Frequency analysis of *E. coli* concentrations at station 8-LTL030.55 in Little River for the period from March 2003 to July 2012. ..... A-55

Figure A-55 Frequency analysis of *E. coli* concentrations at station 8-LTL035.32 in Little River for the period from February 2011 to August 2012. ..... A-56

Figure A-56 Frequency analysis of *E. coli* concentrations at station 8-MUS000.57 in Music Branch for the period from August 2004 to July 2005. ..... A-57

Figure A-57 Frequency analysis of *E. coli* concentrations at station 8-NST000.58 in Northeast Creek for the period from August 2004 to July 2005. ..... A-58

Figure A-58 Frequency analysis of *E. coli* concentrations at station 8-NST003.46 in Northeast Creek for the period from August 2004 to August 2012. ..... A-59

Figure A-59 Frequency analysis of *E. coli* concentrations at station 8-NST007.84 in Northeast Creek for the period from August 2004 to July 2005. ..... A-60

Figure A-60 Frequency analysis of *E. coli* concentrations at station 8-NST011.60 in Northeast Creek for the period from January 2009 to December 2010. ..... A-61

Figure A-61 Frequency analysis of *E. coli* concentrations at station 8-NST011.67 in Northeast Creek for the period from August 2004 to July 2005. ..... A-62

Figure A-62 Frequency analysis of *E. coli* concentrations at station 8-XHZ000.15 in an Unnamed Tributary to Northeast Creek for the period from August 2004 to July 2005. ..... A-63

Figure A-63 Frequency analysis of *E. coli* concentrations at station 8-XIA000.89 in an unnamed tributary to Music Branch for the period from August 2004 to July 2005. ..... A-64

Figure A-64 Frequency analysis of *Enterococci* concentrations at station 8-BLC001.77 in Black Creek for the period from July 2003 to June 2004. ..... A-65

Figure A-65 Frequency analysis of *Enterococci* concentrations at station 8-HQT002.12 in Hornquarter Creek for the period from July 2003 to June 2004. ..... A-66

Figure A-66 Frequency analysis of *Enterococci* concentrations at station 8-JKC004.15 in Jacks Creek for the period from July 2003 to June 2004. ..... A-67

Figure A-67 Frequency analysis of *Enterococci* concentrations at station 8-MNQ004.19 in Moncuin Creek for the period from July 2003 to June 2004. ..... A-68

Figure A-68 Frequency analysis of *Enterococci* concentrations at station 8-SAR012.42 in the South Anna River for the period from July 2003 to June 2004. ..... A-69

Figure A-69 Frequency analysis of *Enterococci* concentrations at station 8-STG001.00 in Stagg Creek for the period from July 2003 to June 2004. ..... A-70

Figure A-70 Frequency analysis of *Enterococci* concentrations at station 8-STG005.46 in Stagg Creek for the period from September 2004 to July 2005. ..... A-71

Figure A-71 Frequency analysis of *Enterococci* concentrations at station 8-XDW000.67 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009. ..... A-72

Figure A-72 Frequency analysis of *Enterococci* concentrations at station 8-ARN000.73 in Arnold Creek for the period from August 2004 to July 2005. ..... A-73

Figure A-73 Frequency analysis of *Enterococci* concentrations at station 8-MUS000.57 in Music Branch for the period from August 2004 to July 2005. ..... A-74

Figure A-74 Frequency analysis of *Enterococci* concentrations at station 8-NST000.58 in Northeast Creek for the period from August 2004 to July 2005. ..... A-75

Figure A-75 Frequency analysis of *Enterococci* concentrations at station 8-NST007.84 in Northeast Creek for the period from August 2004 to July 2005. ..... A-76

Figure A-76 Frequency analysis of *Enterococci* concentrations at station 8-NST011.67 in Northeast Creek for the period from August 2004 to July 2005. ..... A-77

Figure A-77 Frequency analysis of *Enterococci* concentrations at station 8-XHZ000.15 in an Unnamed Tributary to Northeast Creek for the period from August 2004 to July 2005. ..... A-78

Figure A-78 Frequency analysis of Enterococci concentrations at station 8-XIA000.89 in an Unnamed Tributary to Music Branch for the period from August 2004 to July 2005. ..... A-79

Figure B-1 All subwatersheds delineated for modeling in the Pamunkey River Watershed study area. B-4

Figure B-2 Land uses in the Pamunkey River Watershed study area. B-7

Figure B-3 Stream profile representation in HSPF. B-11

Figure B-4 *E. coli* bacteria concentrations at 8-ACQ001.35 on Acquinton Creek discharge at USGS Gaging Station # 01673000. ..... B-13

Figure B-5 *E. coli* bacteria concentrations at 8-ACQ004.43 on Acquinton Creek versus discharge at USGS Gaging Station # 01673000. ..... B-13

Figure B-6 *E. coli* bacteria concentrations at 8-ACQ008.01 on Acquinton Creek versus discharge at USGS Gaging Station # 01673000. ..... B-14

Figure B-7 *E. coli* bacteria concentrations at 8-ARN000.73 on Arnolds Creek versus discharge at USGS Gaging Station # 01673000. ..... B-14

Figure B-8 *E. coli* bacteria concentrations at 8-BDC000.05 on Beaverdam Creek versus discharge at USGS Gaging Station # 01673000. ..... B-15

Figure B-9 *E. coli* bacteria concentrations at 8-BLC001.77 on Black Creek versus discharge at USGS Gaging Station # 01673000. ..... B-15

Figure B-10 *E. coli* bacteria concentrations at 8-CMC005.16 on Cohoke Mill Creek versus discharge at USGS Gaging Station # 01673000. ..... B-16

Figure B-11 *E. coli* bacteria concentrations at 8-CRU000.92 on Crump Creek versus discharge at USGS Gaging Station # 01673000. ..... B-16

Figure B-12 *E. coli* bacteria concentrations at 8-CRU005.61 on Crump Creek versus discharge at USGS Gaging Station # 01673000. ..... B-17

Figure B-13 *E. coli* bacteria concentrations at 8-CRU008.30 on Crump Creek versus discharge at USGS Gaging Station # 01673000. ..... B-17

Figure B-14 *E. coli* bacteria concentrations at 8-HQT002.12 on Hornquarter Creek versus discharge at USGS Gaging Station # 01673000. ..... B-18

Figure B-15 *E. coli* bacteria concentrations at 8-HSN000.92 on Harrison Creek versus discharge at USGS Gaging Station # 01673000. ..... B-18

Figure B-16 *E. coli* bacteria concentrations at 8-HSN002.12 on Harrison Creek versus discharge at USGS Gaging Station # 01673000. ..... B-19

Figure B-17 *E. coli* bacteria concentrations at 8-HSN002.43 on Harrison Creek versus discharge at USGS Gaging Station # 01673000. ..... B-19

Figure B-18 *E. coli* bacteria concentrations at 8-HSN003.93 on Harrison Creek versus discharge at USGS Gaging Station # 01673000. ..... B-20

Figure B-19 *E. coli* bacteria concentrations at 8-JKC004.15 on Jacks Creek versus discharge at USGS Gaging Station # 01673000. ..... B-20

Figure B-20 *E. coli* bacteria concentrations at 8-JKC005.80 on Jacks Creek versus discharge at USGS Gaging Station # 01673000. ..... B-21

Figure B-21 *E. coli* bacteria concentrations at 8-JKC007.95 on Jacks Creek versus discharge at USGS Gaging Station # 01673000. ..... B-21

Figure B-22 *E. coli* bacteria concentrations at 8-KER001.31 on Kersey Creek versus discharge at USGS Gaging Station # 01673000. ..... B-22

Figure B-23 *E. coli* bacteria concentrations at 8-LNG000.94 on Long Creek versus discharge at USGS Gaging Station # 01673000. ..... B-22

Figure B-24 *E. coli* bacteria concentrations at 8-LTL002.69 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-23

Figure B-25 *E. coli* bacteria concentrations at 8-LTL009.54 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-23

Figure B-26 *E. coli* bacteria concentrations at 8-LTL018.80 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-24

Figure B-27 *E. coli* bacteria concentrations at 8-LTL024.86 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-24

Figure B-28 *E. coli* bacteria concentrations at 8-LTL030.55 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-25

Figure B-29 *E. coli* bacteria concentrations at 8-LTL035.32 on the Little River versus discharge at USGS Gaging Station # 01673000. ..... B-25

Figure B-30 *E. coli* bacteria concentrations at 8-MCP002.42 on Mechumps Creek versus discharge at USGS Gaging Station # 01673000. ..... B-26

Figure B-31 *E. coli* bacteria concentrations at 8-MCP009.56 on Mechumps Creek versus discharge at USGS Gaging Station # 01673000. ..... B-26

Figure B-32 *E. coli* bacteria concentrations at 8-MCR001.64 on Mill Creek versus discharge at USGS Gaging Station # 01673000. ..... B-27

Figure B-33 *E. coli* bacteria concentrations at 8-MDQ001.37 on Matadequin Creek versus discharge at USGS Gaging Station # 01673000. ..... B-27

Figure B-34 *E. coli* bacteria concentrations at 8-MLL001.19 on Mill Creek versus discharge at USGS Gaging Station # 01673000. ..... B-28

Figure B-35 *E. coli* bacteria concentrations at 8-MLY001.58 on Mallory Creek versus discharge at USGS Gaging Station # 01673000. ..... B-28

Figure B-36 *E. coli* bacteria concentrations at 8-MNQ004.19 on Moncuin Creek versus discharge at USGS Gaging Station # 01673000. ..... B-29

Figure B-37 *E. coli* bacteria concentrations at 8-MUS000.57 on Music Branch versus discharge at USGS Gaging Station # 01673000. ..... B-29

Figure B-38 *E. coli* bacteria concentrations at 8-NAR005.42 on the North Anna River versus discharge at USGS Gaging Station # 01673000..... B-30

Figure B-39 *E. coli* bacteria concentrations at 8-NFD002.26 on the Newfoundland River versus discharge at USGS Gaging Station #01673000..... B-30

Figure B-40 *E. coli* bacteria concentrations at 8-NST000.58 on Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-31

Figure B-41 *E. coli* bacteria concentrations at 8-NST003.46 on Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-31

Figure B-42 *E. coli* bacteria concentrations at 8-NST007.84 on Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-32

Figure B-43 *E. coli* bacteria concentrations at 8-NST011.60 on Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-32

Figure B-44 *E. coli* bacteria concentrations at 8-NST011.67 on Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-33

Figure B-45 *E. coli* bacteria concentrations at 8-PLD001.73 on Pollard Creek versus discharge at USGS Gaging Station # 01673000. ..... B-33

Figure B-46 *E. coli* bacteria concentrations at 8-PMK034.17 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-34

Figure B-47 *E. coli* bacteria concentrations at 8-PMK039.74 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-34

Figure B-48 *E. coli* bacteria concentrations at 8-PMK044.64 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-35

Figure B-49 *E. coli* bacteria concentrations at 8-PMK048.80 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-35

Figure B-50 *E. coli* bacteria concentrations at 8-PMK056.87 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-36

Figure B-51 *E. coli* bacteria concentrations at 8-PMK072.34 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-36

Figure B-52 *E. coli* bacteria concentrations at 8-PMK082.34 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000..... B-37

Figure B-53 *E. coli* bacteria concentrations at 8-SAR001.11 on the South Anna River versus discharge at USGS Gaging Station # 01673000..... B-37

Figure B-54 *E. coli* bacteria concentrations at 8-SAR012.42 on the South Anna River versus discharge at USGS Gaging Station # 01673000..... B-38

Figure B-55 *E. coli* bacteria concentrations at 8-SAR014.47 on the South Anna River versus discharge at USGS Gaging Station # 01673000..... B-38

Figure B-56 *E. coli* bacteria concentrations at 8-STG001.00 on Stagg Creek versus discharge at USGS Gaging Station # 01673000..... B-39

Figure B-57 *E. coli* bacteria concentrations at 8-STG005.46 on Stagg Creek versus discharge at USGS Gaging Station # 01673000. ..... B-39

Figure B-58 *E. coli* bacteria concentrations at 8-TPT004.37 on Totopotomoy Creek versus discharge at USGS Gaging Station # 01673000. ..... B-40

Figure B-59 *E. coli* bacteria concentrations at 8-XDW000.67 on an unnamed tributary to the Pamunkey River versus discharge at USGS Gaging Station # 01673000. ..... B-40

Figure B-60 *E. coli* bacteria concentrations at 8-XDX000.38 on an unnamed tributary to the Pamunkey River versus discharge at USGS Gaging Station # 01673000. ..... B-41

Figure B-61 *E. coli* bacteria concentrations at 8-XEG000.06 on an unnamed tributary to Mechumps Creek versus discharge at USGS Gaging Station # 01673000. ..... B-41

Figure B-62 *E. coli* bacteria concentrations at 8-XHZ000.15 on an unnamed tributary to Northeast Creek versus discharge at USGS Gaging Station # 01673000. ..... B-42

Figure B-63 *E. coli* bacteria concentrations at 8-XIA000.89 on an unnamed tributary to Music Branch versus discharge at USGS Gaging Station # 01673000. ..... B-42

Figure B-64 *E. coli* bacteria concentrations at 8-XIW000.42 on an unnamed tributary to Jacks Creek versus discharge at USGS Gaging Station # 01673000. ..... B-43

Figure B-65 *E. coli* bacteria concentrations at 8-XJC001.12 on an unnamed tributary to Crump Creek versus discharge at USGS Gaging Station # 01673000. ..... B-43

Figure B-66 *E. coli* bacteria concentrations at 8-XJD000.02 on an unnamed tributary to Harrison Creek versus discharge at USGS Gaging Station # 01673000. ..... B-44

Figure B-67 Modeling time periods, annual historical flow (USGS Station 01673000), and precipitation (Station 447201) data..... B-45

Figure B-68 Modeling time periods, seasonal historical flow (USGS Station 01673000), and precipitation (Station 447201) data..... B-46

Figure B-69 Example of raccoon habitat layer in the Pamunkey River Watershed study area, as developed by MapTech. B-54

Figure B-70 Pamunkey River modeled flow duration versus USGS Gaging Station # 01673000 data from 10/1/2002 to 9/30/2005 (subwatershed 13). B-58

Figure B-71 Pamunkey River modeled results versus USGS Gaging Station # 01673000 data from 10/1/2002 to 9/30/2005 (subwatershed 13). B-59

Figure B-72 Pamunkey River modeled flow duration versus USGS Gaging Station # 01673000 data for validation (subwatershed 13). B-61

Figure B-73 Pamunkey River validation modeled results versus USGS Gaging Station # 01673000 data from (subwatershed 13)..... B-62

Figure B-74 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-NST003.46 in subwatershed 45 on Northeast Creek. B-64

Figure B-75 *E. coli* calibration for 10/1/2002 to 9/30/2005 for VADEQ station 8-NST000.58 in subwatershed 44 on Northeast Creek. B-65

Figure B-76 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-BDC000.05 in subwatershed 40 on Beaverdam Creek..... B-65

Figure B-77 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-LTL018.80 in subwatershed 41 on the Little River. B-66

Figure B-78 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-LTL009.54 in subwatershed 39 on the Little River. B-66

Figure B-79 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-NAR005.42 in subwatershed 17 on the North Anna River..... B-67

Figure B-80 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-MLL001.19 in subwatershed 37 on Mill Creek..... B-67

Figure B-81 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK082.34 in subwatershed 13 on the Pamunkey River..... B-68

Figure B-82 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-CRU000.92 in subwatershed 33 on Crump Creek..... B-68

Figure B-83 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-XDW000.67 in subwatershed 30 on an unnamed tributary to the Pamunkey River. B-69

Figure B-84 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-XDX000.38 in subwatershed 31 on an unnamed tributary to the Pamunkey River. B-69

Figure B-85 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK048.80 in subwatershed 8 on the Pamunkey River..... B-70

Figure B-86 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK039.74 in subwatershed 6 on the Pamunkey River..... B-70

Figure B-87 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-JKC004.15 in subwatershed 25 on Jacks Creek. B-71

Figure B-88 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-HSN000.92 in subwatershed 22 on Harrison Creek. B-71

Figure B-89 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK025.87 in subwatershed 1 on the Pamunkey River. B-72

Figure B-90 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-NST003.46 in subwatershed 45 on Northeast Creek. B-74

Figure B-91 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-LTL009.54 in subwatershed 39 on the Little River. B-75

Figure B-92 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-NAR005.42 in subwatershed 17 on the North Anna River. B-75

Figure B-93 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-PMK082.34 in subwatershed 13 on the Pamunkey River. B-76

Figure B-94 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-CRU000.92 in subwatershed 33 on Crump Creek. B-76

Figure B-95 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-PMK048.80 in subwatershed 8 on the Pamunkey River. B-77

Figure B-96 *E. coli* validation for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK039.74 in subwatershed 6 on the Pamunkey River. B-77

Figure B-97 *E. coli* validation for 10/1/2003 to 9/30/20106for VADEQ station 8-JKC004.15 in subwatershed 25 on Jacks Creek. B-78

This page was intentionally left blank.

TABLES

Table ES- 1 Impairments within the Pamunkey River Watershed addressed for the first time in this study. xxix

Table ES- 1 Impairments within the Pamunkey River Watershed addressed for the first time in this study. (cont.) xxx

Table ES- 2 TMDL equations (annual E. coli bacteria loads - cfu/year) for the Pamunkey River watershed impairments, with reference to TMDL equations from previous reports that will be superseded. xxxiii

Table ES- 2 TMDL equations (annual E. coli bacteria loads - cfu/year) for the Pamunkey River watershed impairments, with reference to TMDL equations from previous reports that will be superseded. (cont.) xxxiv

Table ES- 3 TMDL equations for the South Anna River watershed impairments (annual E. coli bacteria loads - cfu/year) that have been modified from a previous TMDL report. xxxv

Table ES- 4 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will remain unchanged. xxxvi

Table 1.1 Impairments within the Pamunkey River Watershed addressed for the first time in this study. 1-13

Table 1.1 Impairments within the Pamunkey River Watershed included in this study(cont.). 1-14

Table 1.2 Former TMDL equations (annual E. coli bacteria loads - cfu/year) that will be superseded by TMDL equations developed in this report. 1-15

Table 1.2 Former TMDL equations (annual E. coli bacteria loads - cfu/year) that will be superseded by TMDL equations developed in this report. (cont.) 1-16

Table 1.3 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will be modified in this report. 1-17

Table 1.4 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will remain unchanged. 1-18

Table 2.1 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from March 2003 – August 2012. 2-6

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.). 2-7

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.). 2-8

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.). 2-9

Table 2.3 Summary of *Enterococci* (cfu/100mL) data collected by VADEQ from March 2003 – June 2011 (cont.). 2-11

Table 3.1 Subwatersheds with their associated TMDL watershed unit. 3-1

Table 3-1 Subwatersheds with their associated TMDL watershed unit (cont.). 3-2

Table 3.2 Summary of Individual VPDES permitted point sources permitted for fecal bacteria control in the Pamunkey River Watershed study area. 3-6

Table 3.3 Domestic permits in the Pamunkey River Watershed study area. 3-8

Table 3.4 Permits for MS4s in the James River – City of Richmond study area. 3-9

Table 3.5 Human population, housing units, houses on sanitary sewer, septic systems, straight pipes, pit privies, and failing septic systems for areas contributing to impaired segments in the Pamunkey River Watershed study area. 3-12

Table 3.5 Human population, housing units, houses on sanitary sewer, septic systems, straight pipes, pit privies, and failing septic systems for areas contributing to impaired segments in the Pamunkey River Watershed study area (cont.). 3-13

Table 3.6 Volume of sanitary sewer overflows reported within the study area between June 2001 and January 2013. 3-14

Table 3.7 Application of biosolids within the Pamunkey River study area (2001 – 2012). 3-15

Table 3.8 Domestic animal population density, waste load, and fecal coliform (FC) density. 3-16

Table 3.9 Estimated domestic animal populations in areas contributing to impaired segments in the Pamunkey River Watershed study area. 3-17

Table 3.9 Estimated domestic animal populations in areas contributing to impaired segments in the Pamunkey River Watershed study area (cont.). 3-18

Table 3.10 Livestock populations in areas contributing to impaired segments in the Pamunkey River Watershed study area. 3-19

Table 3.10 Livestock populations in areas contributing to impaired segments in the Pamunkey River Watershed study area(cont.). 3-20

Table 3.11 Average fecal coliform densities and waste loads associated with livestock. 3-20

Table 3.12 Average percentage of collected livestock waste applied throughout year. 3-21

Table 3.13 Average time dry cows and replacement heifers spend in different areas per day. 3-22

Table 3.14 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day. 3-22

Table 3.15 Wildlife population densities for the Pamunkey River Watershed study area. 3-23

Table 3.16 Estimated wildlife populations in the Pamunkey River Watershed study area. 3-24

Table 3.16 Estimated wildlife populations in the Pamunkey River Watershed study area (cont.). 3-25

Table 3.17 Average fecal coliform densities for wildlife. 3-25

Table 3.18 Wildlife percentage of time spent in stream access areas and habitat. 3-26

Table 5.1. TMDLs included in the modification process. 5-6

Table 5.2 Allocation scenarios for reducing current bacteria loads in the South Anna River. 5-7

Table 5.3. Updated permitted point source details. 5-8

Table 5.4. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F01R-01) impairment. 5-9

Table 5.5. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F02R-01) impairment. 5-9

Table 5.6. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-01) impairment. 5-10

Table 5.7. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-02) impairment. 5-10

Table 5.8. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) impairment. 5-10

Table 5.9. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAN-F01R-01) impairment. 5-11

Table 5.10. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAN-F02R-01) impairment. 5-12

Table 5.11. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAP-F04R-01) impairment. 5-13

Table 5.12. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAP-F04R-02) impairment. 5-13

Table 5.13. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) impairment. 5-14

Table 5.14 Allocation scenarios for reducing current bacteria loads in Northeast Creek (Subwatersheds 44,45,46). 5-15

Table 5.15 Estimated existing and allocated *E. coli* in-stream loads in the Northeast Creek TMDL watershed unit. 5-17

Table 5.16 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Northeast Creek TMDL watershed unit. 5-18

Table 5.17 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Northeast Creek TMDL watershed unit. 5-18

Table 5.18 Allocation scenarios for reducing current bacteria loads in Upper Little River TMDL watershed unit (Subwatersheds 40,41,42,43). 5-20

Table 5.19 Estimated existing and allocated *E. coli* in-stream loads in the Upper Little River TMDL watershed unit. 5-22

Table 5.20 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Upper Little River TMDL watershed unit. 5-23

Table 5.21 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Upper Little River TMDL watershed unit. 5-23

Table 5.22 Allocation scenarios for reducing current bacteria loads in Upper Pamunkey/North Anna River TMDL watershed unit (Subwatersheds 13,15,16,17,18,19,37,38,39). 5-25

Table 5.23 Estimated existing and allocated *E. coli* in-stream loads in the Upper Pamunkey/North Anna River TMDL watershed unit. 5-27

Table 5.24 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Upper Pamunkey/North Anna River TMDL watershed unit. 5-28

Table 5.25 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Upper Pamunkey/North Anna River TMDL watershed unit. 5-29

Table 5.26 Allocation scenarios for reducing current bacteria loads in the Middle Pamunkey River TMDL watershed unit (11,12,33,34,35,36,47-51). 5-31

Table 5.27 Estimated existing and allocated *E. coli* in-stream loads in the Middle Pamunkey River TMDL watershed unit. 5-33

Table 5.28 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Middle Pamunkey River TMDL watershed unit. 5-34

Table 5.29 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Middle Pamunkey River TMDL watershed unit. 5-35

Table 5.30 Allocation scenarios for reducing current bacteria loads in the Lower Pamunkey TMDL watershed unit (Subwatersheds 1-10,21-28,30,31). 5-37

Table 5.31 Estimated existing and allocated *E. coli* in-stream loads in the Lower Pamunkey TMDL watershed unit. 5-39

Table 5.32 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Lower Pamunkey TMDL watershed unit. 5-40

Table 5.33 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Lower Pamunkey TMDL watershed unit. 5-41

Table 7.1 Public participation during TMDL development for the Pamunkey River Watershed. 7-1

Table B- 1 Impairments and subwatersheds within the Pamunkey River Watershed study area. B-5

Table B- 2 Consolidated land use categories for the Pamunkey River Watershed study area drainage area used in HSPF modeling. B-7

Table B- 3 Spatial distribution of land use types in acres in the Pamunkey River study area in acres. B-8

Table B- 4 Spatial distribution of land use types in acres in the Pamunkey River study area in acres (cont.). B-9

Table B- 5 Summary of Manning's roughness coefficients for channel cells* B-11

Table B- 6 Example of an F-Table Calculated for the HSPF model. B-12

Table B- 7 Comparison of modeled period to historical records for the Pamunkey River watershed. B-46

Table B- 8 Flow rates and bacteria loads used to model VADEQ active permits in the Pamunkey River Watershed study area. B-49

Table B- 9 Estimated failing septic systems and straight pipes for 2012 in the Pamunkey River study area. B-50

Table B- 10 Estimated failing septic systems and straight pipes for 2012 in the Pamunkey River study area (cont.). B-51

Table B- 11 Initial hydrologic parameters estimated for the Pamunkey River Watershed study area, and resulting final values after calibration. B-56

Table B- 12 Hydrology calibration model performance from 10/1/2002 through 9/30/2005 at USGS Gaging Station # 01673000 on the Pamunkey River (subwatershed 13). B-57

Table B- 13 Hydrology validation model performance from 10/1/1994 through 9/30/1997 at USGS Gaging Station # 01673000 on the Pamunkey River (subwatershed 13). B-60

Table B- 14 Model parameters utilized for water quality calibration. B-63

Table B- 15 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the calibration period. B-73

Table B- 16 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period. B-79

Table B- 17 HSPF base parameter values used to determine hydrologic model response. B-81

Table B- 18 HSPF sensitivity analysis for hydrologic model parameters. B-82

Table B- 19 Base parameter values used to determine water quality model response. B-83

Table B- 20 Percent change in average monthly *E. coli* geometric mean for water years 2003-2005 at the outlet of subwatershed 25. ..... B-84

Table C- 1 Current conditions of land applied fecal coliform load for the Pamunkey River study area by land use. C-2

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area. C-3

Table C- 3 Existing annual loads from land based sources for the Pamunkey River study area. C-9

Table C- 4 Existing annual loads from direct deposition sources for the Pamunkey River study area. C-10

EXECUTIVE SUMMARY

Background and Applicable Standards

There are twenty (20) different impaired stream segments in this study area on the following streams, Pamunkey River, Crump Creek, Crump Creek Unnamed Tributary, Beaverdam Creek, Harrison Creek, Harrison Creek Unnamed Tributary, Jacks Creek, Kersey Creek, Little River, Mill Creek Pamunkey River Unnamed Tributaries, Northeast Creek and Pollard Creek.

All twenty segments have bacterial impairments. **Table ES- 1** shows the details of these impairments. In addition the TMDLs of select impairments within the South Anna watershed were modified in August 2013 to provide for appropriate future growth. The modifications are included in this document.

The Pamunkey River watershed has multiple segments impaired for violations of the fecal bacteria standard and there have been TMDLs completed previously to address some of these issues. Specifically, a major portion of the Lake Anna watershed had both TMDLs and Implementation Plans developed to address bacteria impairments. In addition, the entire South Anna River watershed was addressed through bacteria TMDL development as well as multiple individual segments of the Pamunkey River watershed. Since the completion of those studies, additional impaired segments have been identified.

In an effort to consolidate TMDL efforts in the Pamunkey River watershed, and bring this area into conformance with the current TMDL watershed unit approach for TMDL development, this TMDL study combines the unaddressed bacteria-impaired segments with some of the previous TMDL work. The combination of previous and new TMDL development requires portions of previously completed TMDLs to be superseded. This Pamunkey TMDL project follows three main development paths, some existing TMDL equations have been updated, while others superseded completely, and still other newly addressed impairments have been modeled in consideration of the overall drainage.

In Virginia, once a water body violates a given standard, a Total Maximum Daily Load (TMDL) must be developed. The TMDL is a pollution budget that determines the

amount of pollutant the water body can receive in a given period of time and still meet the intended standard.

Table ES- 1 Impairments within the Pamunkey River Watershed addressed for the first time in this study.

Stream Name Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2012 River Miles (Sq Miles)**	**2012 Listing Violation%** [1]	**Impairment Location Description**
Beaverdam Creek VAP-F11R_BDC01A12	*E. coli*	2012	8.47	44 EC	From the headwaters to its confluence with the Little River.
Crump Creek VAP-F12R_CRU01A02	*E. coli*	2008	10.08	15 EC 25 EC 17 EC	From its headwaters to its mouth.
Crump Creek X-Trib. VAP-F12R_XJC01A12	*E. coli*	2012	1.79	42 EC	From the headwaters to its confluence with Crump Creek.
Harrison Creek VAP-F14R_HSN01A00	*E. coli*	2008	2.80	37 EC 38 EC 17 EC	Upstream of a pond at Elsing Green downstream to the nearest tributary.
Harrison Creek VAP-F14E_HSN01A12	*E. coli*	2012	(0.05)	33 EC	Tidal portion of Harrison Creek at its mouth.
Harrison Creek X-Trib. VAP-F14R_XJD01A12	*E. coli*	2012	0.16	50 EC	From its headwaters to its confluence with Harrison Creek.
Jacks Creek & Tribs. VAP-F13R_JCK01A98 VAP-F13R_MLY01A12 [2]	*E. coli*	2008	21.05	18 EC	From its headwaters downstream to its confluence with the Pamunkey River.
Kersey Creek VAP-F12R_KER01A12	*E. coli*	2012	2.76	25 EC	From its headwaters downstream to its confluence with Crump Creek.
Upper Little River VAN-F10R_LTL01A02	*E. coli*	2006	4.01	23 EC	From its confluence with Hawkins Creek downstream to its confluence with Locust Creek.
Lower Little River VAP-F11R_LTL01B08	*E. coli*	2008	10.77	25 EC	From its confluence with Locust Creek downstream to its confluence with Beaverdam Creek.
Mill Creek VAP-F09R_MLL01A12	*E. coli*	2012	4.39	54 EC	From its headwaters downstream to its confluence with the North Anna River.

1 EC - Based on the instantaneous *E. coli* standard of 235 cfu/100ml.
2 Mallory Creek in its entirety was split from Jacks and Tribs in 2012.

Table ES- 1 Impairments within the Pamunkey River Watershed addressed for the first time in this study. (cont.)

Stream Name Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2012 River Miles (Sq Miles)**	**2012 Listing Violation%** [1]	**Impairment Location Description**
Pamunkey River VAP-F12R_PMK01B08	*E. coli*	2008	12.26	16 EC	From its headwaters downstream to its confluence with Mechumps Creek.
Pamunkey River VAP-F14E_PMK02A00	*E. coli*	2010	(0.81)	13 EC	From Macon Creek downstream to river mile 34.25.
Pamunkey River VAP-F14E_PMK03A00	*E. coli*	2010	(0.38)	13 EC	A one mile radius around VADEQ monitoring station 8-PMK032.00.
Pamunkey River VAP-F14E_PMK04A00	*E. coli*	2010	(2.44)	13 EC	One mile downstream of 8-PMK032.00 and extends to the downstream extent of tidal freshwater segment at approximately river mile 23.6.
Pamunkey River VAP-F13E_PMK01A98	*E. coli*	2008	(0.30)	25 EC	From Pampatike Landing to Macon Creek.
Pamunkey River X-Trib. VAP-F13R_XDW01A08	*E. coli*	2012	5.51	25 EC	From its headwaters downstream to its confluence with the Pamunkey River.
X-Trib Pamunkey River X-Trib VAP-F13R_XDX01A04	*E. coli*	2012	3.85	25 EC	From its headwaters downstream to its confluence with Pamunkey Tributary (XDW).
Pollard Creek VAP-F12R_PLD01A12	*E. coli*	2012	4.06	17 EC	From its headwaters downstream to its confluence with Crump Creek.
Northeast Creek VAN-F09R_NST01A08	*E. coli*	2006	2.74	25 EC	From an X-Trib downstream to the North Anna River confluence.

1 EC - Based on the instantaneous *E. coli* standard of 235 cfu/100ml.

TMDL Endpoint and Water Quality Assessment

Fecal bacteria TMDLs for freshwater in the Commonwealth of Virginia are developed using the *E. coli* standard. For this TMDL development, the in-stream *E. coli* targets both a monthly geometric mean not exceeding 126-cfu/100 mL and a daily concentration that does not exceed 235 cfu/100 mL more than 10% of the time. A translator developed by VADEQ was used to convert fecal coliform values to *E. coli* values.

Source Assessment

Sources of bacteria were identified and quantified in the Pamunkey River watershed. Sources included point sources as well as non-point sources. The quantification of sources is important to determine the baseline of current conditions that is causing the impairment. Sources of bacteria included human, livestock, wildlife, pets, as well as permitted point sources.

Modeling Procedures

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

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

For the tidal segments in the study area, the Steady State Tidal Prism Model, which is used by VADEQ for modeling tidally impacted waterbodies, was implemented within the

HSPF framework to model the tidally influenced segments in conjunction with lateral free-flowing impairment creeks and input from upstream drainages. The Pamunkey River downstream of Totopotomoy Creek is tidally influenced and so are multiple creeks flowing laterally into the River between Totopotomoy Creek and the downstream end of the study area.

Hydrology

The US Geological Survey (USGS) Hydrologic Simulation Program - Fortran (HSPF) water quality model was selected as the modeling framework to model hydrology and fecal coliform loads. For purposes of modeling the Pamunkey River watershed, inputs to streamflow and in-stream fecal bacteria, the drainage area was divided into forty five (45) subwatersheds.

Fecal Coliform

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

Load Allocation Scenarios

The next step in the TMDL processes was to reduce the various source loads to levels that would result in attainment of the water quality standards or endpoints. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. The final TMDL information is shown in **Table ES- 2.** However, because of the comprehensive nature of this study in which former TMDL equations will be superseded by new equations, modified, or remain unchanged, **Table ES- 2**, **Table ES- 3**, and **Table ES- 4** outline what former TMDL equations will be superseded, modified, and remain unchanged, respectively. The final bacterial TMDLs for the Pamunkey River Watershed include 100% reductions in straight pipes and sewer overflows.

Table ES- 2 TMDL equations (annual E. coli bacteria loads - cfu/year) for the Pamunkey River watershed impairments, with reference to TMDL equations from previous reports that will be superseded.

2014 Pamunkey River Watershed TMDL (cfu/yr)						Previous TMDL Equation (cfu/yr)					
Impaired TMDL Unit	WLA	LA	MOS	TMDL	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
Northeast Creek	2.34E+12	1.15E+14	Implicit	1.17E+14	**VAN-F09R_NST01A08** VAN-F09R_NST03A08** VAN-F09R_NST04A08** VAN-F09R_MUS01A06** VAN-F09R_NST02A98***	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Northeast Creek (VAP-F09R-01)	2.30E+10	2.30E+12	Implicit	2.32E+12
Upper Little River	5.61E+12	2.75E+14	Implicit	2.81E+14	**VAP-F11R_BDC01A12** **VAN-F10R_LTL01A02** **VAP-F11R_LTL01B08**	N/A	-	-	-	'	-
Upper Pamunkey River/North Anna	3.25E+13	8.71E+14	Implicit	9.03E+14	**VAP-F12R_PMK01B08** **VAP-F09R_MLL01A12**	N/A	-	-	-	'	-
Middle Pamunkey River	2.36E+13	1.06E+15	Implicit	1.08E+15	**VAP-F12R_CRU01A02** **VAP-F12R_XJC01A12** **VAP-F12R_KER01A12** **VAP-F12R_PLD01A12** VAP-F12R_MCP03A06** VAP-F12R_XEG01A06** VAP-F12R_MCP01A94*	Bacteria TMDL for Mechumps Creek Hanover County (2004)	Mechumps Creek (VAP-F12R-02)	1.00E+12	2.98E+13	Implicit	3.08E+13

Segments in bold are impaired segments being addressed by a TMDL for the first time in this report.

* Segments with a previously completed TMDL equation, which is being superceded by the TMDL equation in this report.

** Segments were nested with a previously completed TMDL, which is superceded by the TMDL equation in this report.

*** Segments were delisted prior to this report, however they had a previously completed TMDL equation that is being superceded by the TMDL equation in this report.

Table ES- 2 TMDL equations (annual E. coli bacteria loads - cfu/year) for the Pamunkey River watershed impairments, with reference to TMDL equations from previous reports that will be superseded. (cont.)

2014 Pamunkey River Watershed TMDL (cfu/yr)						Previous TMDL Equation (cfu/yr)					
Impaired TMDL Unit	WLA	LA	MOS	TMDL	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
Lower Pamunkey River	5.38E+13	1.75E+15	Implicit	1.80E+15	VAP-F13R_MNQ01A98*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Monquin/Webb Creek (VAP-F13R-04)	8.71E+10	1.81E+11	Implicit	2.68E+11
					VAP-F13E_PMK01A98* VAP-F13E_PMK02A98* VAP-F13E_PMK03A06*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2013)	Pamunkey River (VAP-F13E-02)	2.49E+13	7.22E+14	Implicit	7.47E+14
					VAP-F13R_BLC01A00***	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Black Creek (VAP-F13R-05)	1.26E+10	1.26E+12	Implicit	1.27E+12
					VAP-F13R_MDQ01A98*	Bacteria TMDL for Matadequin Creek Hanover County, Virginia (2004)	Matadequin Creek (VAP-F13R-01)	0	3.16E+13	Implicit	3.16E+13
					VAP-F14R_XJD01A12 **VAP-F14R_HSN01A00** **VAP-F14E_HSN01A12** **VAP-F14E_PMK02A00** **VAP-F14E_PMK03A00**	**VAP-F14E_PMK04A00** **VAP-F13R_JCK01A98** **VAP-F13R_MLY01A12** **VAP-F13R_XDW01A08** **VAP-F13R_XDX01A04**	N/A				

Segments in bold are impaired segments being addressed by a TMDL for the first time in this report.

* Segments with a previously completed TMDL equation, which is being superceded by the TMDL equation in this report.

** Segments were nested with a previously completed TMDL, which is superceded by the TMDL equation in this report.

*** Segments were delisted prior to this report, however they had a previously completed TMDL equation that is being superceded by the TMDL equation in this report.

Table ES- 3 TMDL equations for the South Anna River watershed impairments (annual E. coli bacteria loads - cfu/year) that have been modified from a previous TMDL report.

2014 Pamunkey River Watershed TMDL (cfu/yr)						Previous TMDL Equation (cfu/yr)					
Watershed	WLA	LA	MOS	TMDL	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
South Anna River (VAN-F01R-01)	4.92E+12	8.98E+11	Implicit	5.82E+12	VAN-F01R_SAR02B10* VAN-F01R_SAR02A02*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	South Anna River (VAN-F01R-01)	1.64E+12	3.67E+12	Implicit	5.31E+12
South Anna River (VAN-F02R-01)	7.50E+12	1.38E+13	Implicit	2.13E+13	VAN-F02R_SAR01A00* VAN-F01R_SAR01A02** VAN-F01R_HUD01A04** VAN-F01R_WLR01B10** VAN-F01R_WLR01A04** VAN-F01R_CMP01A12** VAN-F02R_SAR02A00** VAN-F02R_XIE01A08**		South Anna River (VAN-F02R-01)	1.48E+12	7.96E+12	Implicit	9.44E+12
Taylors Creek (VAN-F03R-01)	3.66E+10	6.47E+11	Implicit	6.83E+11	VAN-F03R_TLR01A00***		Taylors Creek (VAN-F03R-01)	1.89E+09	1.89E+11	Implicit	1.91E+11
South Anna River (VAP-F04R-02)	6.02E+12	4.49E+13	Implicit	5.09E+13	VAP-F04R_SAR03A98*		South Anna River (VAP-F04R-02)	3.48E+12	3.13E+13	Implicit	3.48E+13
South Anna River (VAP-F04R-01)	7.74E+12	4.42E+13	Implicit	5.19E+13	VAP-F04R_SAR03B06* VAP-F04R_STG01A06** VAN-F03R_SAR03A06** VAN-F03R_FRK01A08** VAN-F03R_DEP01A12** VAN-F03R_CUB01A08** VAN-F03R_OWN01A04** VAN-F03R_SAR01A06**	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2008)	South Anna River (VAP-F04R-01)	1.72E+12	2.98E+13	Implicit	3.15E+13

* Segments were addressed in a previously completed TMDL report.
** Segments were nested with a previously completed TMDL report.
*** Segment was delisted prior to this report.

Table ES- 4 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will remain unchanged.

Report	Watershed	WLA	LA	MOS	TMDL	Assessment Unit IDs
Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Newfound River (VAP-F05R-01)	2.89E+10	2.89E+12	Implicit	2.92E+12	VAP-F05R_NFD01A00
Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2013)[1]	Totopotomoy Creek (VAP-F13R-02)	2.62E+10	1.61E+12	Implicit	1.64E+12	VAP-F13R_TPT01A98

1 The WLA/LA in Totopotomoy Creek was modified in 2013 to accommodate facility expansions, however there were no changes made to the equation in this report.

Implementation

The goal of the TMDL program is to establish a path that will lead to attainment of water quality standards. The first step in this process is to develop TMDLs that will result in meeting water quality standards. This report represents the first phase of that effort for the impairments in the Pamunkey River Watershed. The next step will be development of a TMDL implementation plan (IP), required by Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA). The final step is to implement the TMDL IPs and to monitor stream water quality to determine if water quality standards are being attained.

Once a TMDL IP is developed, VADEQ will take the plan to the State Water Control Board (SWCB) for approval for implementing the pollutant allocations and reductions contained in the TMDL. With successful completion of implementation plans, Virginia begins the process of restoring impaired waters and enhancing the value of this important resource.

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.

Public Participation

During development of the TMDL for the impairments in the Pamunkey River Watershed study area, public involvement was encouraged through two first public meetings on February 20, 2013 and February 21, 2013 at the Snow Branch Library in Spotsylvania, Virginia, and at the Ashland Town Hall in Ashland, Virginia, respectively.. An introduction of the agencies involved, an overview of the TMDL process, details of the

pollutant sources, and the specific approach to developing the Pamunkey River Watershed TMDLs were presented at the first of the public 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 model simulations and the TMDL load allocations were presented during the final public meetings held on February 24, 2014 and February 26, 2014. There was a 30-day public comment period after the publication of the draft document. Written comments were addressed in the final document.

1. INTRODUCTION

The Pamunkey River watershed has multiple segments impaired for violations of the fecal bacteria standard and there have been TMDLs completed previously to address some of these issues. Specifically, a major portion of the Lake Anna watershed has completed TMDLs to address bacteria impairments. In addition, the entire South Anna River watershed was addressed through bacteria TMDL development as well as multiple individual segments of the Pamunkey River watershed. Since the completion of those studies, additional impaired segments have been identified.

The Virginia Department of Environmental Quality (VADEQ) has recently moved towards a more cost effective approach to conducting TMDLs. The new approach is called a TMDL watershed unit approach, where the TMDL is developed for a larger geographic area containing the smaller sub-watershed areas with impaired segments. These large geographic units are herein called a "TMDL watershed unit" because they consist of watersheds that formerly were the basis of TMDL projects. Using this approach, TMDL watershed units are designed to provide TMDLs that are cost effective, while being scientifically defensible as well as effectively implementable.

In an effort to consolidate TMDL efforts in the Pamunkey River watershed, and bring this area into conformance with the current TMDL watershed unit approach for TMDL development, this TMDL study combines the unaddressed bacteria-impaired segments (**Table 1.1**) with some of the previous TMDL work. The combination of previous and new TMDL development requires portions of previously completed TMDLs to be superseded. This Pamunkey TMDL project follows three main development paths, some existing TMDL equations have been updated, while others superseded completely, and still other newly addressed impairments have been modeled in consideration of the overall drainage. Figure 1-1 shows the current study area, the upstream drainages that have been addressed for bacterial impairments, the impaired segments in the study area that have been addressed through previous TMDL work, and the impaired segments that are addressed for the first time by this study.

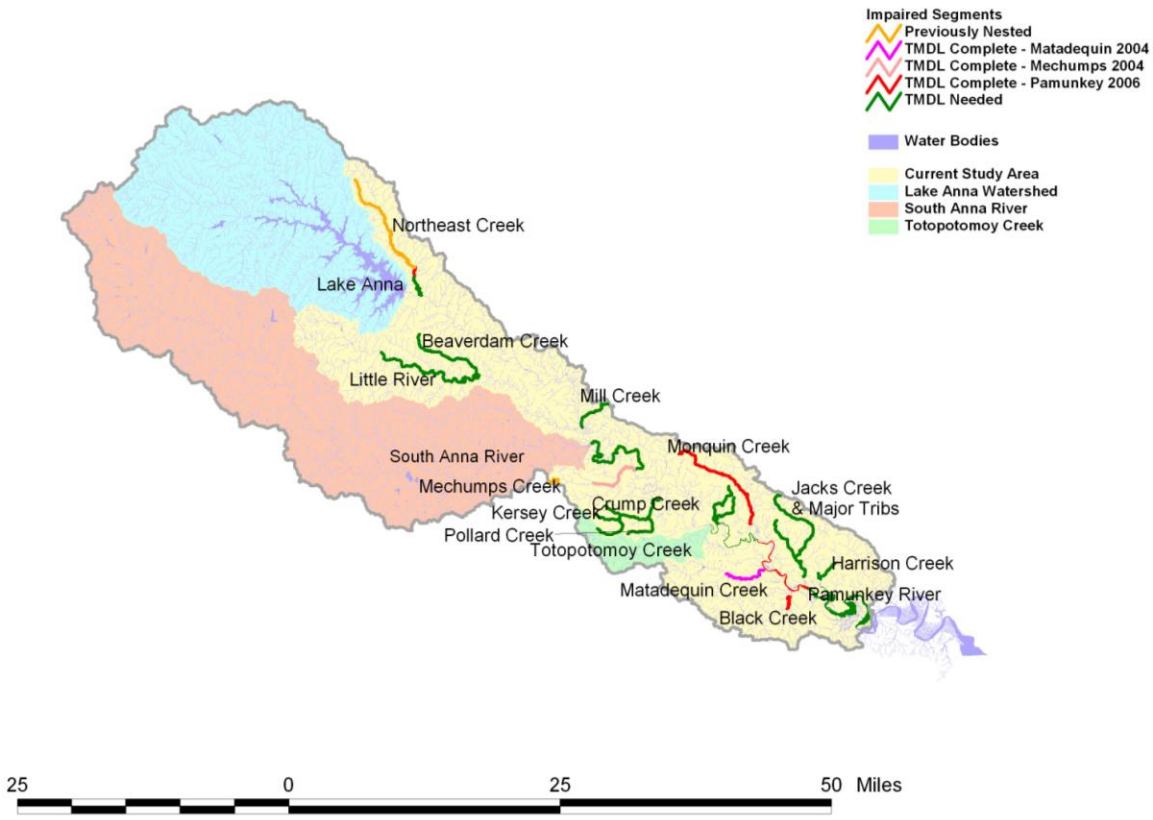

Figure 1-1 TMDL work in the current study area of the Pamunkey River watershed.

The impairments in the Lake Anna watershed were addressed in the TMDL document titled, *Bacteria TMDL for York River Basin Orange, Louisa, Spotsylvania Counties, Virginia* (VADEQ, 2005). While the flow and bacteria contributed from the Lake Anna drainage is considered in this study, the existing Lake Anna TMDLs remain unaffected. Several additional impairments were addressed in the TMDL document titled, *Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin* (DEQ, 2006). and may be reviewed in Appendix D. With the exception of Totopotomoy Creek, the impaired segments downstream of the South Anna watershed that were addressed by this document will be superseded by the current study. Since the 2006 study, the Totopotomoy Creek drainage has been significantly impacted by urban activity, as compared to the remaining study area, which has primarily rural and agricultural impacts. As such, it could not be justifiably grouped with the remaining impairments. The TMDLs of select impairments within the South Anna watershed were modified in August

2013 to provide for appropriate future growth. The details of the modification are discussed in Chapter 5.

Two additional impairments were addressed in the documents titled, *Bacteria TMDL for Matadequin Creek Hanover County, Virginia* and *Bacteria TMDL for Mechumps Creek Hanover County* (DEQ, 2004), respectively. These TMDLs were developed by DEQ using a load duration method. Incorporating these two impairments within the larger study area (as a nested unit) provided greater consistency within the overall model than incorporating the results of the previous TMDLs, as well as more accurately determining the TMDL loads than the initial load duration method could. Therefore, both of these TMDLs will be superseded by this document.

Table 1.2 shows the former TMDL equations that will be superseded by TMDL equations, associated with the impaired TMDL unit, developed in this report. **Table 1.3** shows previously developed TMDL equations and their associated assessment unit IDs that will be modified in this report. South Anna River bacteria TMDL segments were remodeled and the revised equations demonstrated use attainment for the impaired segment being addressed. **Table 1.4** shows previously developed TMDL equations associated with the Pamunkey River watershed that will remain unchanged.

1.1 Regulations 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 waters that are polluted or do not otherwise 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 six beneficial uses: recreation/swimming, aquatic life, wildlife, fish consumption, shellfish consumption, and public water supply (drinking).

When streams fail to meet standards, the stream is “listed” in the current Section 303(d) report as requiring a Total Maximum Daily Load (TMDL). 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 nonpoint source loadings are considered. A TMDL accounts for seasonal variations and must include a margin of safety (MOS).

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), which should be implemented in a staged process. Through the TMDL process, states establish water-quality based controls to reduce pollution and meet water quality standards.

1.2 *Pamunkey River Watershed Characteristics*

The Pamunkey River watershed (USGS Hydrologic Unit Code 02080106) is located in Hanover, Louisa, King William, Caroline, Spotsylvania and New Kent Counties, Virginia. This watershed is a part of the York River basin, which drains to the Chesapeake Bay. The location of the watershed is shown in **Figure 1-2**. The shaded watershed areas shown in the figure (*e.g.*, Northeast Creek) are TMDL watershed units, each of which receives a TMDL allocation. The drainage area flowing into the most downstream impairment in this project is approximately 975,000 acres.

The Pamunkey River watershed is located within the level III Piedmont (45) and Southeastern Plains (65), Level IV subsets – Northern Outer Piedmont (45f) and Rolling Coastal Plain (65m), respectively. The Piedmont ecoregion is mostly wooded and consists of irregular plains, low rolling hills and shallow valleys. The geology is mostly older metamorphic rock. The Southeastern Plains ecoregion has elevations from sea level to 300 feet. The geology is primarily newer sedimentary rock. Stream flow is very sluggish and stream bottoms are sandy. Swampy stained water is common. The Level

IV area which contains most of the Pamunkey River has a little more gradient and more defined stream flow than streams further east.

(http://www.eoearth.org/article/Ecoregions_of_Delaware%2C_Maryland%2C_Pennsylvania%2C_Virginia%2C_and_West_Virginia_%28EPA%29).

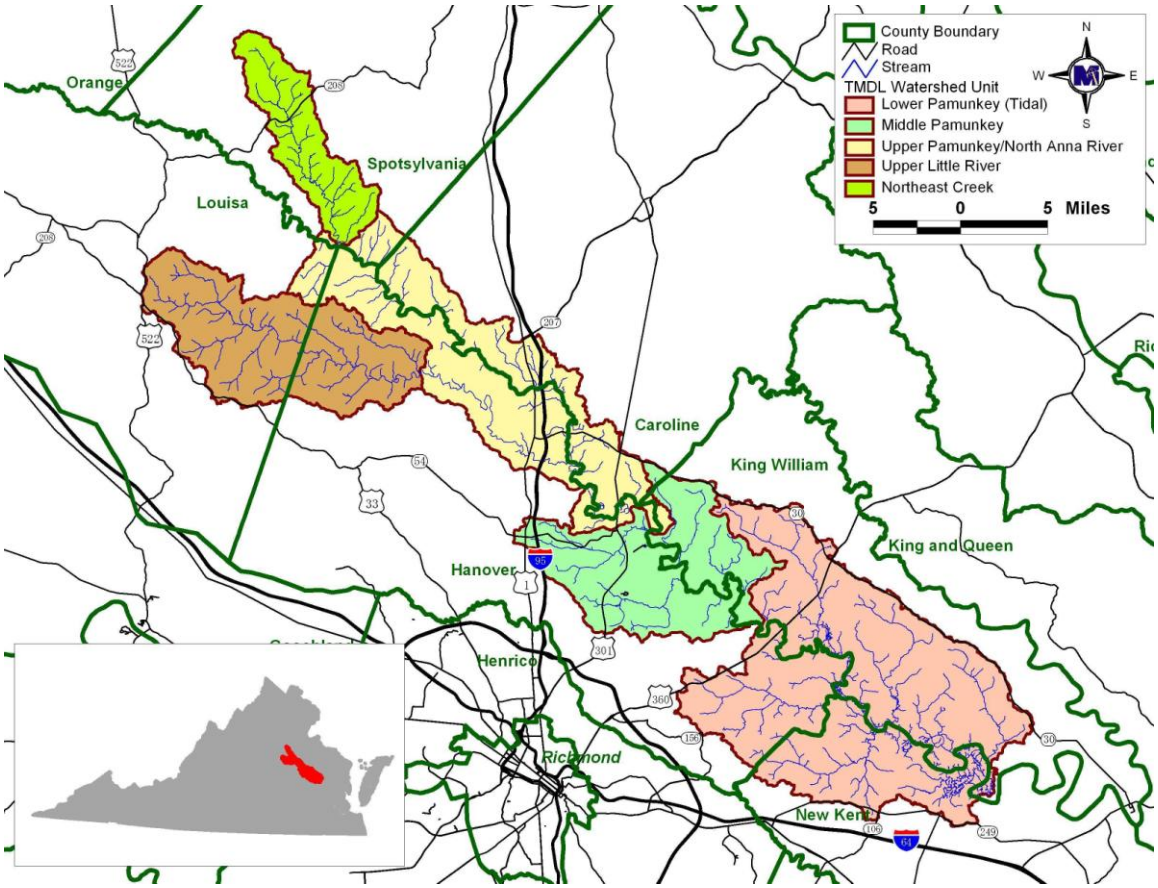

Figure 1-2 Location of the Pamunkey River watershed.

As for the climatic conditions in the Pamunkey River watershed, during the period from 1948 to 2012 Richmond International Airport, Virginia (NCDC station# 447201) received an average annual precipitation of 43.64 inches, with 56% of the precipitation occurring during the May through October growing season (SERCC, 2012). Average annual snowfall is 12.9 inches, with the highest snowfall occurring during January (SERCC, 2012). The highest average daily temperature of 88.9 ºF occurs in July, while the lowest average daily temperature of 27.8 ºF occurs in January (SERCC, 2012).

Land use in the study area was characterized using the National Land Cover Database 2006 (NLCD). The drainage area is predominantly forest with woodlands covering approximately 64% of the area. Water and wetlands account for an additional 13%, while pasture/hay and crop land covers account for roughly 8% and 11% of the drainage area, respectively. Developed, commercial, and barren land uses account for the remainder of the study area, approximately 4%.

1.3 Pamunkey River Watershed Recreation Use Impairments

There are nineteen (19) different impaired streams in this study area (**Figure 1-3** and **Table 1.1**) including impairments on the Pamunkey River, Beaverdam Creek, Crump Creek, Harrison Creek, Jacks Creek and Tributaries (including Mallory Creek, which was split from Jacks and Tributaries in 2012), Kersey Creek, Little River, Northeast Creek, and Pollard Creek. The sections below describe all impairments. There are several existing TMDLs that have been completed in the Pamunkey River watershed that will be superceded by the TMDLs in this project. These segments are listed in **Table 1.2**.

1.3.1 Beaverdam Creek (VAP-F11R_BDC01A12)

Beaverdam Creek in Hanover County, VA flows southeast into the Little River.

Beaverdam Creek is listed as impaired from its headwaters to its confluence with the Little River (8.47 miles). It was initially listed in 2012 as impaired for not supporting the recreation/swimming use. VADEQ monitoring at station 8-BDC000.05 showed a 44% bacteria standard violation rate in the 2012 assessment.

1.3.2 Crump Creek (VAP-F12R_CRU01A02)

Crump Creek, in Hanover County, flows east before its confluence with the Pamunkey River.

Crump Creek from its headwaters to its mouth (10.08 miles) was listed as impaired on the 2012 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring stations 8-CRU000.92, 8-CRU005.61 and 8-CRU008.30 had violation rates of 15% 25% and 17% respectively in the 2012 assessment.

1.3.3 Crump Creek Unnamed Tributary (VAP-F12R_XJC01A12)

Crump Creek Unnamed Tributary, in Hanover County, flows southeast before its confluence with the Crump Creek.

Crump Creek Unnamed Tributary from its headwaters to its confluence with Crump Creek (1.79 miles) was listed as impaired on the 2008 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 8-XJC001.12 had a 42% violation rate in the 2012 assessment.

1.3.4 Harrison Creek (VAP-F14R_HSN01A00)

Harrison Creek in King William County, VA flows south before its confluence with the Pamunkey River.

This impaired segment extends upstream of a pond at Elsing Green downstream to the nearest tributary (2.80 stream miles). VADEQ monitoring stations 8-HSN002.12, 8-HSN002.43 and 8-HSN003.93 had a bacteria standard violation rates of 37%, 38% and 17% respectively in the 2012 assessment.

1.3.5 Harrison Creek (VAP-F14E_HSN01A12)

The tidal portion of Harrison Creek in King William County, flows southeast before its confluence with the Pamunkey River.

The tidal portion of Harrison Creek is 0.05 square miles and is located at the mouth of the creek. It was listed as impaired on the 2012 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 8-HSN000.92 had a 33% bacteria standard violation rate in the 2012 assessment.

1.3.6 Harrison Creek Unnamed Tributary (VAP-F14R_XJD01A12)

Harrison Creek Unnamed Tributary in King William County, VA flows east before its confluence with Harrison Creek.

This impaired segment extends from its headwaters downstream to its confluence with Harrison Creek (0.16 stream miles). VADEQ monitoring station 8-XJD000.02 had a bacteria standard violation rate of 50% in the 2012 assessment.

1.3.7 Jacks Creek and Tributaries (VAP-F13R_JCK01A98)

Jacks Creek in King William County, VA flows south before its confluence with the Pamunkey River.

This impaired segment extends from its headwaters downstream to its confluence with the Pamunkey River including major tribuatries (21.05 stream miles). VADEQ monitoring station 8-JKC004.15 had a bacteria standard violation rate of 18% in the 2012 assessment. The drainage for this segment includes Mallory Creek (VAP-F13R_MLY01A12), which was split from Jacks and Tributaries in 2012.

1.3.8 Kersey Creek (VAP-F12R_KER01A12)

Kersey Creek in Hanover County, VA flows east before its confluence with the Crump Creek.

This impaired segment extends from its headwaters downstream to its confluence with Crump Creek (2.76 stream miles). VADEQ monitoring station 8-KER001.31 had a bacteria standard violation rate of 25% in the 2012 assessment.

1.3.9 Upper Little River (VAN-F10R_LTL01A02)

Little River in Louisa County, VA flows southeast before its confluence with the North Anna River.

This impaired segment extends from its confluence with Hawkins Creek downstream to its confluence with Locust Creek (4.01 stream miles). VADEQ monitoring station 8-LTL030.55 had a bacteria standard violation rate of 23% in the 2012 assessment.

1.3.10 Lower Little River (VAP-F11R_LTL01B08)

This impaired segment extends from its confluence with Locust Creek downstream to its confluence with Beaverdam Creek (10.77 stream miles). VADEQ monitoring station 8-LTL024.86 had a bacteria standard violation rate of 22% in the 2012 assessment.

1.3.11 Mill Creek (VAP-F09R_MLL01A12)

Mill Creek in Caroline County, VA flows southwest before its confluence with the North Anna River.

This impaired segment extends from its headwaters downstream to its confluence with the North Anna River (4.39 stream miles). VADEQ monitoring station 8-MLL001.19 had a bacteria standard violation rate of 54% in the 2012 assessment.

1.3.12 Pamunkey River (VAP-F12R_PMK01B08)

Pamunkey River in Caroline, Hanover, King William and New Kent Counties, VA flows southeast before its confluence with the York River.

This impaired segment extends from its headwaters downstream to its confluence with Mechumps Creek (12.26 stream miles). VADEQ monitoring station 8-PMK082.34 had a bacteria standard violation rate of 16% in the 2012 assessment.

1.3.13 Pamunkey River (VAP-F14E_PMK02A00)

This impaired segment extends from Macon Creek downstream to river mile 34.25 (0.81 square miles). VADEQ monitoring station 8-PMK034.17 had a bacteria standard violation rate of 13% in the 2012 assessment.

1.3.14 Pamunkey River (VAP-F14E_PMK03A00)

This impaired segment consists of a mile radius around monitoring station 8-PMK032.00 (0.38 square miles). VADEQ monitoring station 8-PMK034.17 had a bacteria standard violation rate of 13% in the 2012 assessment.

1.3.15 Pamunkey River (VAP-F14E_PMK04A00)

This impaired segment is one mile downstream of 8-PMK032.00 and extends to the downstream extent of tidal freshwater segment at approximately river mile 23.6 (2.44 square miles). VADEQ monitoring station 8-PMK034.17 had a bacteria standard violation rate of 13% in the 2012 assessment.

1.3.16 Pamunkey River (VAP-F14E_PMK01A98)

From Pampatike Landing to Macon Creek (0.30 square miles). VADEQ monitoring station 8-PMK056.87 had a bacteria standard violation rate of 25% in the 2012 assessment.

1.3.17 Pamunkey River Unnamed Tributary (VAP-F13R_XDW01A08)

Pamunkey River Unnamed Tributary in King William County, VA flows southwest before its confluence with the Pamunkey River.

This impaired segment extends from its headwaters downstream to its confluence with the Pamunkey River (5.51 stream miles). VADEQ monitoring station 8-XDW000.67 had a bacteria standard violation rate of 25% in the 2012 assessment.

1.3.18 Pamunkey River Unnamed Tributary (XDX to XDW) (VAP-F13R_XDX01A04)

Pamunkey River Unnamed Tributary (XDX) to (XDW) in King William County, VA flows southwest before its confluence with an unnamed Pamunkey River Tributary (XDW).

This impaired segment extends from its headwaters downstream to its confluence with a Pamunkey River Tributary (XDW) (3.85 stream miles). VADEQ monitoring station 8-XDX000.38 had a bacteria standard violation rate of 25% in the 2012 assessment.

1.3.19 Pollard Creek (VAP-F12R_PLD01A12)

Pollard Creek in Hanover County, VA flows northeast before its confluence with the Crump Creek.

This impaired segment extends from its headwaters downstream to its confluence with Crump Creek (4.06 stream miles). VADEQ monitoring station 8-PLD001.73 had a bacteria standard violation rate of 17% in the 2012 assessment.

1.3.20 Northeast Creek (VAN-F09R_NST01A08)

Northeast Creek in Spotsylvania County, VA flows south-southeast before its confluence with the North Anna River.

The impaired segment begins at an Unnamed Tributary and continues downstream until its confluence with the North Anna River (2.74 stream miles). VADEQ monitoring station 8-NST000.58 had a bacteria standard violation rate of 25% in the 2012 assessment to list it as impaired on the 2012 303(d) list.

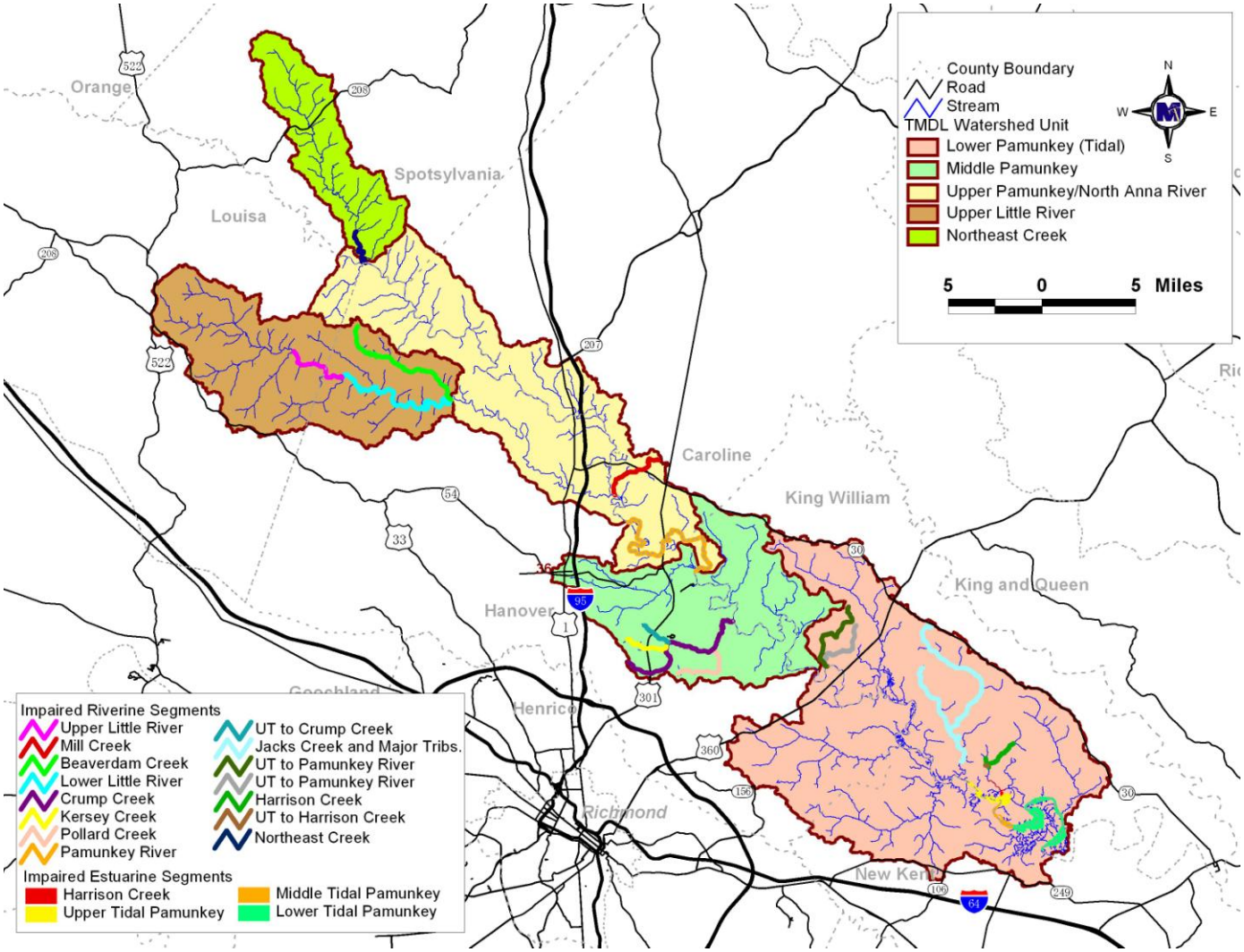

Figure 1-3 Impaired segments that are not currently addressed by a TMDL in the Pamunkey River Watershed.

Table 1.1 Impairments within the Pamunkey River Watershed addressed for the first time in this study.

Stream Name Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2012 River Miles (Sq Miles)**	**2012 Listing Violation%** [1]	**Impairment Location Description**
Beaverdam Creek VAP-F11R_BDC01A12	*E. coli*	2012	8.47	44 EC	From the headwaters to its confluence with the Little River.
Crump Creek VAP-F12R_CRU01A02	*E. coli*	2008	10.08	15 EC 25 EC 17 EC	From its headwaters to its mouth.
Crump Creek X-Trib. VAP-F12R_XJC01A12	*E. coli*	2012	1.79	42 EC	From the headwaters to its confluence with Crump Creek.
Harrison Creek VAP-F14R_HSN01A00	*E. coli*	2008	2.80	37 EC 38 EC 17 EC	Upstream of a pond at Elsing Green downstream to the nearest tributary.
Harrison Creek VAP-F14E_HSN01A12	*E. coli*	2012	(0.05)	33 EC	Tidal portion of Harrison Creek at its mouth.
Harrison Creek X-Trib. VAP-F14R_XJD01A12	*E. coli*	2012	0.16	50 EC	From its headwaters to its confluence with Harrison Creek.
Jacks Creek & Tribs. VAP-F13R_JCK01A98 VAP-F13R_MLY01A12 [2]	*E. coli*	2008	21.05	18 EC	From its headwaters downstream to its confluence with the Pamunkey River.
Kersey Creek VAP-F12R_KER01A12	*E. coli*	2012	2.76	25 EC	From its headwaters downstream to its confluence with Crump Creek.
Upper Little River VAN-F10R_LTL01A02	*E. coli*	2006	4.01	23 EC	From its confluence with Hawkins Creek downstream to its confluence with Locust Creek.
Lower Little River VAP-F11R_LTL01B08	*E. coli*	2008	10.77	25 EC	From its confluence with Locust Creek downstream to its confluence with Beaverdam Creek.
Mill Creek VAP-F09R_MLL01A12	*E. coli*	2012	4.39	54 EC	From its headwaters downstream to its confluence with the North Anna River.

1 EC - Based on the instantaneous *E. coli* standard of 235 cfu/100ml.
2 Mallory Creek in its entirety was split from Jacks and Tribs in 2012

Table 1.1 Impairments within the Pamunkey River Watershed included in this study(cont.).

Stream Name Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2012 River Miles (Sq Miles)**	**2012 Listing Violation%**	**Impairment Location Description**
Pamunkey River VAP-F12R_PMK01B08	*E. coli*	2008	12.26	16 EC	From its headwaters downstream to its confluence with Mechumps Creek.
Pamunkey River VAP-F14E_PMK02A00	*E. coli*	2010	(0.81)	13 EC	From Macon Creek downstream to river mile 34.25.
Pamunkey River VAP-F14E_PMK03A00	*E. coli*	2010	(0.38)	13 EC	A one mile radius around VADEQ monitoring station 8-PMK032.00.
Pamunkey River VAP-F14E_PMK04A00	*E. coli*	2010	(2.44)	13 EC	One mile downstream of 8-PMK032.00 and extends to the downstream extent of tidal freshwater segment at approximately river mile 23.6.
Pamunkey River VAP-F13E_PMK01A98	*E. coli*	2008	(0.30)	25 EC	From Pampatike Landing to Macon Creek.
Pamunkey River X-Trib. VAP-F13R_XDW01A08	*E. coli*	2012	5.51	25 EC	From its headwaters downstream to its confluence with the Pamunkey River.
X-Trib Pamunkey River X-Trib VAP-F13R_XDX01A04	*E. coli*	2012	3.85	25 EC	From its headwaters downstream to its confluence with Pamunkey Tributary (XDW).
Pollard Creek VAP-F12R_PLD01A12	*E. coli*	2012	4.06	17 EC	From its headwaters downstream to its confluence with Crump Creek.
Northeast Creek VAN-F09R_NST01A08	*E. coli*	2006	2.74	25 EC	From an X-Trib downstream to the North Anna River confluence.

EC - Based on the instantaneous *E. coli* standard of 235 cfu/100ml.

Table 1.2 Former TMDL equations (annual E. coli bacteria loads - cfu/year) that will be superseded by TMDL equations developed in this report.

2014 Pamunkey River Watershed TMDL		Previous TMDL Equation (cfu/yr)					
Impaired TMDL Unit	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
Northeast Creek	**VAN-F09R_NST01A08** VAN-F09R_NST03A08** VAN-F09R_NST04A08** VAN-F09R_MUS01A06** VAN-F09R_NST02A98***	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Northeast Creek (VAP-F09R-01)	2.30E+10	2.30E+12	Implicit	2.32E+12
Upper Little River	**VAP-F11R_BDC01A12** **VAN-F10R_LTL01A02** **VAP-F11R_LTL01B08**	N/A	-	-	-	-	-
Upper Pamunkey River/North Anna	**VAP-F12R_PMK01B08** **VAP-F09R_MLL01A12**	N/A	-	-	-	-	-
Middle Pamunkey River	**VAP-F12R_CRU01A02** **VAP-F12R_XJC01A12** **VAP-F12R_KER01A12** **VAP-F12R_PLD01A12** VAP-F12R_MCP03A06** VAP-F12R_XEG01A06** VAP-F12R_MCP01A94*	Bacteria TMDL for Mechumps Creek Hanover County (2004)	Mechumps Creek (VAP-F12R-02)	1.00E+12	2.98E+13	Implicit	3.08E+13

Segments in bold are impaired segments being addressed by a TMDL for the first time in this report.

* Segments with a previously completed TMDL equation, which is being superceded by the TMDL equation in this report.

** Segments were nested with a previously completed TMDL, which is superceded by the TMDL equation in this report.

*** Segments were delisted prior to this report, however they had a previously completed TMDL equation that is being superceded by the TMDL equation in this report.

Table 1.2 Former TMDL equations (annual E. coli bacteria loads - cfu/year) that will be superseded by TMDL equations developed in this report. (cont.)

2014 Pamunkey River Watershed TMDL		Previous TMDL Equation (cfu/yr)					
Impaired TMDL Unit	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
Lower Pamunkey River	VAP-F13R_MNQ01A98*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Monquin/Webb Creek (VAP-F13R-04)	8.71E+10	1.81E+11	Implicit	2.68E+11
	VAP-F13E_PMK01A98* VAP-F13E_PMK02A98* VAP-F13E_PMK03A06*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2013)	Pamunkey River (VAP-F13E-02)	2.49E+13	7.22E+14	Implicit	7.47E+14
	VAP-F13R_BLC01A00***	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Black Creek (VAP-F13R-05)	1.26E+10	1.26E+12	Implicit	1.27E+12
	VAP-F13R_MDQ01A98*	Bacteria TMDL for Matadequin Creek Hanover County, Virginia (2004)	Matadequin Creek (VAP-F13R-01)	0	3.16E+13	Implicit	3.16E+13
	VAP-F14R_XJD01A12 **VAP-F14R_HSN01A00** **VAP-F14E_HSN01A12** **VAP-F14E_PMK02A00** **VAP-F14E_PMK03A00**	**VAP-F14E_PMK04A00** **VAP-F13R_JCK01A98** **VAP-F13R_MLY01A12** **VAP-F13R_XDW01A08** **VAP-F13R_XDX01A04**	N/A				

Segments in bold are impaired segments being addressed by a TMDL for the first time in this report.

* Segments with a previously completed TMDL equation, which is being superceded by the TMDL equation in this report.

** Segments were nested with a previously completed TMDL, which is superceded by the TMDL equation in this report.

*** Segments were delisted prior to this report, however they had a previously completed TMDL equation that is being superceded by the TMDL equation in this report.

Table 1.3 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will be modified in this report.

2014 Pamunkey River Watershed TMDL		Previous TMDL Equation (cfu/yr)					
Watershed	Assessment Unit IDs addressed by 2014 TMDL	Report	Watershed	WLA	LA	MOS	TMDL
South Anna River (VAN-F01R-01)	VAN-F01R_SAR02B10* VAN-F01R_SAR02A02*	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	South Anna River (VAN-F01R-01)	1.64E+12	3.67E+12	Implicit	5.31E+12
South Anna River (VAN-F02R-01)	VAN-F02R_SAR01A00* VAN-F01R_SAR01A02** VAN-F01R_HUD01A04** VAN-F01R_WLR01B10** VAN-F01R_WLR01A04** VAN-F01R_CMP01A12** VAN-F02R_SAR02A00** VAN-F02R_XIE01A08**		South Anna River (VAN-F02R-01)	1.48E+12	7.96E+12	Implicit	9.44E+12
Taylors Creek (VAN-F03R-01)	VAN-F03R_TLR01A00***		Taylors Creek (VAN-F03R-01)	1.89E+09	1.89E+11	Implicit	1.91E+11
South Anna River (VAP-F04R-02)	VAP-F04R_SAR03A98*		South Anna River (VAP-F04R-02)	3.48E+12	3.13E+13	Implicit	3.48E+13
South Anna River (VAP-F04R-01)	VAP-F04R_SAR03B06* VAP-F04R_STG01A06** VAN-F03R_SAR03A06** VAN-F03R_FRK01A08** VAN-F03R_DEP01A12** VAN-F03R_CUB01A08** VAN-F03R_OWN01A04** VAN-F03R_SAR01A06**	Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2008)	South Anna River (VAP-F04R-01)	1.72E+12	2.98E+13	Implicit	3.15E+13

* Segments were addressed in a previously completed TMDL report.
** Segments were nested with a previously completed TMDL report.
*** Segment was delisted prior to this report.

Table 1.4 TMDL equations (annual E. coli bacteria loads (cfu/year)) from a previous TMDL report that will remain unchanged.

Report	Watershed	WLA	LA	MOS	TMDL	Assessment Unit IDs
Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006)	Newfound River (VAP-F05R-01)	2.89E+10	2.89E+12	Implicit	2.92E+12	VAP-F05R_NFD01A00
Bacteria Total Maximum Daily Load Development for the Pamunkey River Basin (2006, modified 2013)[1]	Totopotomoy Creek (VAP-F13R-02)	2.62E+10	1.61E+12	Implicit	1.64E+12	VAP-F13R_TPT01A98

1 The WLA/LA in Totopotomoy Creek was modified in 2013 to accommodate facility expansions, however there were no changes made to the equation in this report.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to Virginia Water Quality Standard 9 VAC 25-260-5, 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".

Virginia state law 9 VAC 25-260-10 (Designation of uses) states:

> 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.*
>
> ◆
>
> E. *At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§ 301(b)(1)(A) and (B) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*
>
> ◆
>
> H. *The [State Water Quality Control] Board may remove a designated use which is not an existing use, or establish subcategories of a use, if the board can demonstrate that attaining the designated use is not feasible because:*
>
> 1. *Naturally occurring pollutant concentrations prevent the attainment of the use;*
>
> 2. *Natural, ephemeral, intermittent or low flow conditions or water levels prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation requirements to enable uses to be met;*

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 water body to its original condition or to operate such modification in a way that would result in the attainment of the use;*

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

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

I. The board may not remove designated uses if:

1. *They are existing uses, unless a use requiring more stringent criteria is added; or*

2. *Such uses will be attained by implementing effluent limits required under §§ 301(b)(1)(A) and (B) and 306 of the Clean Water Act and by implementing cost-effective and reasonable best management practices for nonpoint source control.*

Virginia's current bacterial standard uses *E. coli* and *enterococci* as bacterial indicators. *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. Prior to January 2003, Virginia's water quality standard in fresh water for swimming/recreational use was based on fecal coliform rather than *E. coli*. The change was based on EPA's recommendation that all states adopt an *E. coli* or *enterococci* standard for fresh water and *enterococci* criteria for marine waters by 2003. The EPA pursued the states' adoption of these standards because there is a stronger correlation between the concentration of these organisms (*E. coli* and *enterococci*) and the incidence of gastrointestinal illness than with fecal coliform.

Virginia's current criteria are outlined in Section 9 VAC 25-260-170 and read as follows:

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

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

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

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

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

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

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

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

2.2 Selection of a TMDL Endpoint

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

For the purpose of this TMDL, VADEQ interprets the bacteria standard as requiring compliance with both the geometric-mean (monthly) criterion and the single-sample (instantaneous) criterion. Since all of the water bodies in question are fresh water, the in-

stream *E. coli* targets for the TMDLs in this study were both monthly geometric means not exceeding 126 cfu/100 ml and no more than 10% exceedance of the 235 cfu/100 mL single-sample criterion.

2.3 Discussion of In-stream Water Quality

This section provides an inventory and analysis of available observed in-stream fecal bacteria monitoring data in the Pamunkey River Watershed. An examination of data from water quality stations used in the 303(d) assessment was performed. Sources of data and pertinent results are discussed.

2.3.1 Inventory of Water Quality Monitoring Data

The primary source of available water quality information was bacteria enumerations from seventy nine (79) VADEQ in-stream monitoring stations with data from March 2003 to August 2012.

2.3.1.1 VADEQ Water Quality Monitoring for TMDL Assessment

Data from in-stream water samples, collected at VADEQ monitoring stations from March 2003 to August 2012, were analyzed for *E.coli* (**Table 2.1**) and *Enterococci* (**Table 2.2**). Samples were taken for the express purpose of determining compliance with the state instantaneous bacteria standards. Information in the tables is arranged in alphabetical order by stream name then from downstream to upstream station location. VADEQ water quality monitoring stations used for listing the impaired segments are shown in **Figure 2-1**.

Table 2.2 is shown for informational purposes only because the impaired segments are were all listed for *E. coli*.

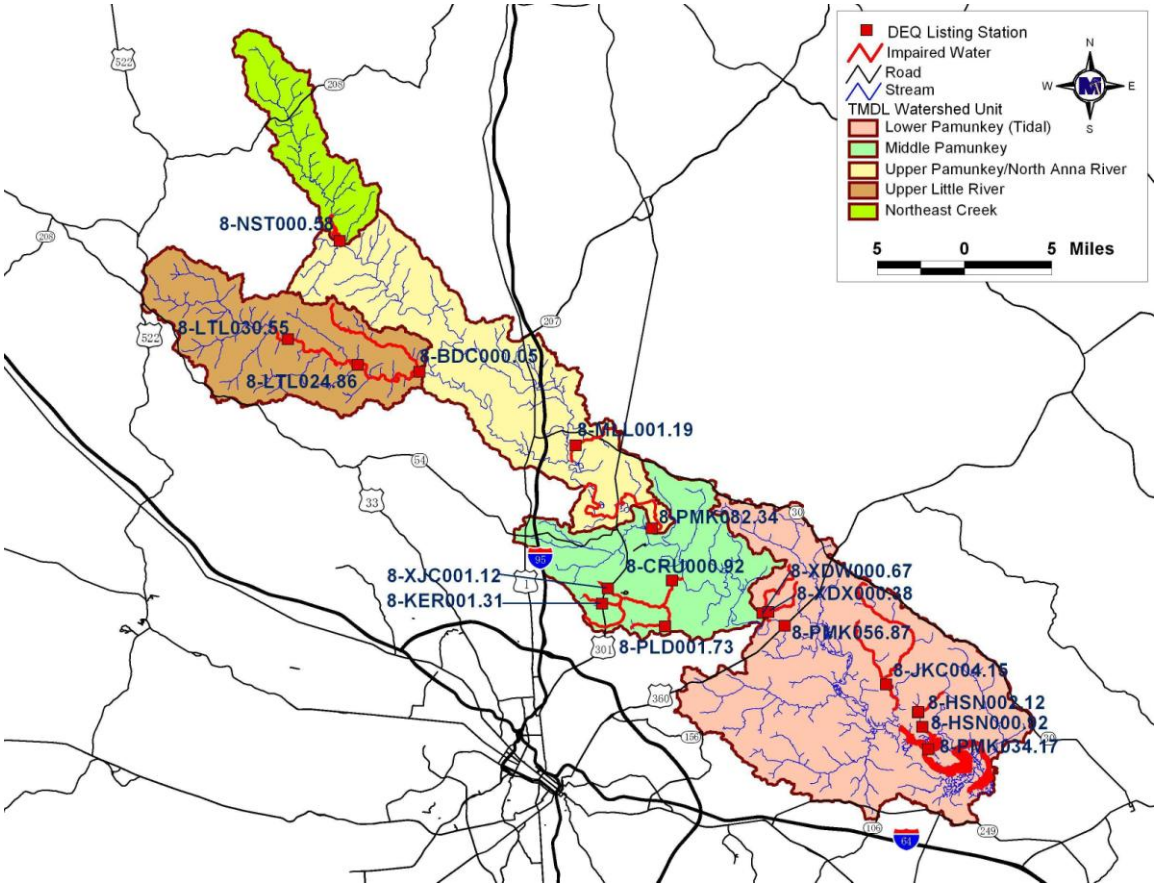

Figure 2-1 Location of impairment listing VADEQ water quality monitoring stations in the Pamunkey River Watershed, and the impaired waters being addressed for the first time in this study.

Table 2.1 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from March 2003 – August 2012.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Acquinton Creek	8-ACQ001.35	1/11 - 10/11	10	100	300	160	100	96.61	30.00%
Acquinton Creek	8-ACQ004.43	1/11 - 10/11	9	100	200	111	100	33.33	0.00%
Acquinton Creek	8-ACQ008.01	1/11 - 10/11	9	100	400	133	100	100	11.10%
Arnolds Creek	8-ARN000.73	8/04 - 7/05	12	10	260	47	25	69.98	8.3%
Beaverdam Creek	8-BDC000.05*	2/09 - 11/10	9	50	2,000	472	200	641.34	44.40%
Black Creek	8-BLC001.77	7/03 - 3/05	23	10	370	69	50	78.34	4.30%
Black Creek	8-BLC005.54	4/09	1	10	10	10	NA	NA	0.00%
Cohoke Mill Creek	8-CMC005.16	2/07 - 12/08	12	23	800	139	100	210.74	8.30%
Crump Creek	8-CRU000.92*	6/05 - 12/10	33	13	8,000	369	100	1,379.28	15.20%
Crump Creek	8-CRU005.61	1/10 - 12/10	12	25	2,000	290	120	549.25	25.00%
Crump Creek	8-CRU008.30	1/05 - 12/10	12	25	2,000	264	75	559.53	16.70%
Harrison Creek	8-HSN000.92*	4/10 - 3/11	12	100	800	225	100	226.13	25.00%
Harrison Creek	8-HSN002.12*	5/05 - 3/11	22	25	1,400	306	100	414.36	31.80%
Harrison Creek	8-HSN002.43	4/10 - 3/11	12	100	1,300	250	100	345.1	25.00%
Harrison Creek	8-HSN003.93	4/10 - 9/11	15	100	400	180	100	126.49	26.70%
Hornquarter Creek	8-HQT002.12	7/03 - 6/04	12	10	180	54	35	57.44	0.00%
Jacks Creek	8-JKC004.15*	7/03 - 10/11	32	20	1,200	165	100	233.43	21.90%
Jacks Creek	8-JKC005.80	1/11 - 10/11	9	100	1,200	256	100	367.8	22.20%
Jacks Creek	8-JKC007.95	1/11 - 10/11	10	100	200	120	100	42.16	0.00%
Kersey Creek	8-KER001.31*	1/10 - 12/10	12	25	550	177	110	191.68	25.00%
Little River	8-LTL002.69	7/03 - 9/11	16	25	700	105	25	178	12.50%
Little River	8-LTL009.54	7/03 - 10/11	113	3	1,200	116	50	202.41	8.80%
Little River	8-LTL018.80	2/09 - 11/10	12	25	950	184	100	266.73	25.00%
Little River	8-LTL024.86*	6/05 - 10/11	24	25	650	141	50	188.04	20.80%

[*] Listing station shown in Figure 2.1.
[1] Based on the current instantaneous *E. coli* standard of 235 cfu/100mL. NA – Not Applicable

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Little River	8-LTL030.55*	3/03 - 7/12	50	25	2,000	218	63	449.75	30.0%
Locust Creek	8-LOC002.00	3/07	1	10	10	10	NA	NA	0.00%
Long Creek	8-LNG000.94	2/11 - 8/12	10	25	1,750	370	175	540.81	40.0%
Mallory Creek	8-MLY001.58	1/11 - 10/11	10	100	500	190	100	137.03	30.00%
Matadequin Creek	8-MDQ001.37	11/02 - 12/10	14	1	4,100	655	110	1,212.03	35.70%
Mechumps Creek	8-MCP002.42	11/02 - 11/08	14	1	2,400	306	100	613.72	35.70%
Mechumps Creek	8-MCP009.56	1/07 - 9/08	11	8	500	170	100	174.56	27.30%
Mehixen Creek	8-MHX000.27	5/10	1	140	140	140	NA	NA	0.00%
Mill Creek	8-MCR001.64	1/07 - 11/08	12	3	100	77	100	42.57	0.00%
Mill Creek	8-MLL001.19*	2/09 - 11/10	13	25	3,400	915	500	1,016.50	53.80%
Moncuin Creek	8-MNQ004.19	7/03 - 3/05	23	10	400	119	75	113.2	17.40%
Music Branch	8-MUS000.57	8/04 - 7/05	12	10	360	101	55	110.82	16.7%
Newfound River	8-NFD002.26	6/05 - 9/11	15	25	750	208	100	219.91	40.00%
North Anna River	8-NAR005.42	7/03 - 9/11	62	8	950	95	25	151.9	9.70%
North Anna River	8-NAR025.28	4/05	1	10	10	10	NA	NA	0.00%
Northeast Creek	8-NST000.58*	8/04 - 7/05	12	10	510	139	40	182.73	25.0%
Northeast Creek	8-NST003.46	8/04 - 8/12	40	10	520	94	48	112.52	12.5%
Northeast Creek	8-NST007.84	8/04 - 7/05	12	10	340	93	55	113.80	16.7%
Northeast Creek	8-NST011.60	1/09 - 12/10	11	25	1,100	211	50	344.80	27.3%
Northeast Creek	8-NST011.67	8/04 - 7/05	12	10	380	83	40	111.04	8.3%
Pamunkey River	8-PMK034.17*	7/04 - 10/11	86	25	900	105	75	140.88	10.50%
Pamunkey River	8-PMK034.37	7/08	1	10	10	10	NA	NA	0.00%
Pamunkey River	8-PMK039.74	7/03 - 10/11	23	25	850	92	50	170.61	4.30%
Pamunkey River	8-PMK044.64	1/11 - 10/11	10	25	100	45	25	30.73	0.00%

[*] Listing station shown in Figure 2.1.
[1] Based on the current instantaneous *E. coli* standard of 235 cfu/100mL. NA – Not Applicable

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Pamunkey River	8-PMK048.80	8/03 - 10/11	47	10	1,900	183	75	329.87	17.00%
Pamunkey River	8-PMK056.87*	8/03 - 10/11	51	10	2,000	206	100	347.73	19.60%
Pamunkey River	8-PMK072.34	7/03 - 10/11	21	25	250	65	50	51.52	4.80%
Pamunkey River	8-PMK077.53	3/06	1	20	20	20	NA	NA	0.00%
Pamunkey River	8-PMK082.34*	12/05 - 10/11	35	14	650	103	50	126.67	14.30%
Pamunkey River	8-PMK092.12	6/10	1	60	60	60	NA	NA	0.00%
Pollard Creek	8-PLD001.73*	1/10 - 12/10	12	25	2,000	279	110	555.09	16.70%
South Anna River	8-SAR001.11	7/03 - 9/11	51	8	3,600	244	100	582.3	17.60%
South Anna River	8-SAR012.42	7/03 - 6/04	12	10	300	100	40	108.04	25.00%
South Anna River	8-SAR014.47	7/03 - 3/05	11	25	100	52	50	28.4	0.00%
South Anna River	8-SAR021.22	11/03 - 9/11	6	25	625	276	241	233.36	50.00%
Southern Branch	8-SOB000.15	4/05	1	50	50	50	NA	NA	0.00%
Stagg Creek	8-STG000.73	3/09	1	20	20	20	NA	NA	0.00%
Stagg Creek	8-STG001.00	7/03 - 6/04	12	10	800	273	150	279.17	41.70%
Stagg Creek	8-STG005.46	9/04 - 7/05	11	10	550	240	270	220.95	54.50%
Stone Horse Creek	8-SHC001.59	3/10	1	310	310	310	NA	NA	100.00%
Totopotomoy Creek	8-TPT004.37	8/03 - 12/08	13	18	5,600	544	100	1,524.01	15.40%
Unnamed tributary to Crump Creek	8-XJC001.12*	1/10 - 12/10	12	25	2,000	356	220	539.7	41.70%
Unnamed tributary to Harrison Creek	8-XJD000.02*	4/10 - 4/11	12	100	1,300	342	100	391.87	33.30%
Unnamed tributary to Jacks Creek	8-XIW000.42	1/11 - 10/11	9	100	1,000	244	100	300.46	22.20%

[*] Listing station shown in Figure 2.1.
[1] Based on the current instantaneous *E. coli* standard of 235 cfu/100mL. NA – Not Applicable

Table 2.1 Summary of E. coli (cfu/100mL) data collected by VADEQ from March 2003 – August 2012 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Unnamed Tributary to Locust Creek	8-XJE000.48	4/11	1	10	10	10	NA	NA	0.0%
Unnamed Tributary to Mechumps Creek	8-XEG000.06	1/07 - 11/08	12	2	5,900	656	100	1,660.62	33.30%
Unnamed Tributary to Music Branch	8-XIA000.89	8/04 - 7/05	12	10	420	53	10	116.57	8.3%
Unnamed Tributary to Northeast Creek	8-XHZ000.15	8/04 - 7/05	12	10	220	63	45	63.44	0.0%
Unnamed Tributary to Northeast Creek	8-XJF000.27	6/11	1	20	20	20	NA	NA	0.0%
Unnamed tributary to the North Anna River	8-XIM000.53	3/08	1	20	20	20	NA	NA	0.00%
Unnamed tributary to the Pamunkey River	8-XDW000.67*	1/09 - 12/09	12	100	400	150	100	100	16.70%
Unnamed tributary to the Pamunkey River	8-XDX000.38*	1/09 - 12/09	12	100	500	217	200	146.68	25.00%

[*] Listing station shown in Figure 2.1.
[1] Based on the current instantaneous *E. coli* standard of 235 cfu/100mL. NA – Not Applicable

Table 2.2 Summary of *Enterococci* (cfu/100mL) data collected by VADEQ from March 2003 – June 2011.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation
Arnolds Creek	8-ARN000.73	8/04 - 7/05	12	10	640	211	170	199.66
Black Creek	8-BLC001.77	7/03 - 6/04	12	10	280	110	90	83.88
Harrison Creek	8-HSN000.92*	4/10 - 5/10	2	25	25	25	NA	0
Hornquarter Creek	8-HQT002.12	7/03 - 6/04	12	10	710	173	130	191.42
Jacks Creek	8-JKC004.15	7/03 - 6/04	12	10	800	258	75	302.23
Little River	8-LTL009.54	7/03 - 5/04	6	30	270	115	80	89.39
Little River	8-LTL030.55	3/03 - 5/03	2	250	590	420	NA	240.42
Little Rocky Creek	8-LRK000.11	4/08	1	800	800	800	NA	NA
Locust Creek	8-BLC005.54	4/09	1	10	10	10	NA	NA
Locust Creek	8-LOC001.31	4/04	1	50	50	50	NA	NA
Locust Creek	8-LOC002.00	3/07	1	60	60	60	NA	NA
Mehixen Creek	8-MHX000.27	5/10	1	290	290	290	NA	NA
Moncuin Creek	8-MNQ004.19	7/03 - 6/04	12	10	800	309	175	317.22
Music Branch	8-MUS000.57	8/04 - 7/05	12	10	800	311	165	300.98
North Anna River	8-NAR005.42	7/03 - 5/04	6	10	460	118	50	171.16
North Anna River	8-NAR025.28	4/05	1	10	10	10	NA	NA
Northeast Creek	8-NST003.46	2/05 - 5/05	4	50	160	88	70	51.88
Northeast Creek	8-NST007.84	8/04 - 7/05	12	30	790	310	235	266.97
Northeast Creek	8-NST011.67	8/04 - 7/05	12	10	800	283	140	294.62
Pamunkey River	8-PMK034.37	7/08	1	40	40	40	NA	NA
Pamunkey River	8-PMK048.80	8/03 - 6/04	6	10	150	77	65	57.15
Pamunkey River	8-PMK056.87*	8/03 - 6/04	6	20	200	87	75	68.02
Pamunkey River	8-PMK077.53	3/06	1	10	10	10	NA	NA
Pamunkey River	8-PMK092.12	6/10	1	60	60	60	NA	NA
South Anna River	8-SAR001.11	7/03 - 5/04	6	30	340	157	130	127.07

Table shown for informational purposes only. NA – Not Applicable

Table 2.3 Summary of *Enterococci* (cfu/100mL) data collected by VADEQ from March 2003 – June 2011 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation
South Anna River	8-SAR012.42	7/03 - 6/04	12	10	800	438	425	317.2
Southern Branch	8-SOB000.15	4/06	1	30	30	30	NA	NA
Stagg Creek	8-STG000.73	3/09	1	60	60	60	NA	NA
Stagg Creek	8-STG001.00	7/03 - 6/04	12	10	800	405	340	299.2
Stagg Creek	8-STG005.46	9/04 - 7/05	11	10	800	434	310	331.19
Stone Horse Creek	8-SHC001.59	3/10	1	180	180	180	NA	NA
Unnamed Tributary to Locust Creek	8-XJE000.48	4/11	1	10	10	10	NA	NA
Unnamed Tributary to Music Branch	8-XIA000.89	8/04 - 7/05	12	20	800	242	145	283.80
Unnamed Tributary to Northeast Creek	8-XHZ000.15	8/04 - 7/05	12	20	550	186	130	186.23
Unnamed Tributary to Northeast Creek	8-XJF000.27	6/11	1	290	290	290	NA	NA
Unnamed tributary to the North Anna River	8-XIM000.53	3/08	1	10	10	10	NA	NA
Unnamed tributary to the Pamunkey River	8-XDW000.67	1/09 - 12/09	12	25	1,300	350	200	430.87

Table shown for informational purposes only. NA – Not Applicable

This page was intentionally left blank.

3. BACTERIA SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal bacteria in the Pamunkey River and tributaries watershed study area. 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 and citizen 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 Appendix B. To adequately represent the spatial variation in the watershed, the Pamunkey River Watershed drainage area was divided into forty seven (47) subwatersheds (**Figure 3-1**). The subwatersheds are numbered from 1 to 51, however, four numbers are skipped-over, leaving a total of 47 subwatersheds assessed in this study for sources of bacteria. The four numbers skipped were 14, 20, 29, and 32. Three of these numbers represented the Lake Anna, South Anna, and Totopotomoy subwatersheds, which were not re-modeled for this study. Additionally, subwatershed 29 was merged with subwatershed 9 during the model development process and no longer exists (**Table 3.1**). Source assessment is conducted on subwatershed level where estimates of all potential pollutants are generated for each individual subwatershed.

Table 3.1 Subwatersheds with their associated TMDL watershed unit.

Subwatershed #	TMDL Watershed Unit	Notes
1	Lower Pamunkey River	
2	Lower Pamunkey River	
3	Lower Pamunkey River	
4	Lower Pamunkey River	
5	Lower Pamunkey River	
6	Lower Pamunkey River	
7	Lower Pamunkey River	
8	Lower Pamunkey River	
9	Lower Pamunkey River	
10	Lower Pamunkey River	
11	Middle Pamunkey River	
12	Middle Pamunkey River	

Table 3-1 Subwatersheds with their associated TMDL watershed unit (cont.).

Subwatershed #	TMDL Watershed Unit	Notes
13	Upper Pamunkey River/ North Anna River	
14	South Anna River	Existing TMDL
15	Upper Pamunkey River/ North Anna River	
16	Upper Pamunkey River/ North Anna River	
17	Upper Pamunkey River/ North Anna River	
18	Upper Pamunkey River/ North Anna River	
19	Upper Pamunkey River/ North Anna River	
20	Lake Anna	Existing TMDL
21	Lower Pamunkey River	
22	Lower Pamunkey River	
23	Lower Pamunkey River	
24	Lower Pamunkey River	
25	Lower Pamunkey River	
26	Lower Pamunkey River	
27	Lower Pamunkey River	
28	Lower Pamunkey River	
29		combined with subwatershed 9 for modeling
30	Lower Pamunkey River	
31	Lower Pamunkey River	
32	Totopotomoy Creek	Existing TMDL
33	Middle Pamunkey River	
34	Middle Pamunkey River	
35	Middle Pamunkey River	
36	Middle Pamunkey River	
37	Upper Pamunkey River/ North Anna River	
38	Upper Pamunkey River/ North Anna River	
39	Upper Pamunkey River/ North Anna River	
40	Upper Little River	
41	Upper Little River	
42	Upper Little River	
43	Upper Little River	
44	Northeast Creek	
45	Northeast Creek	
46	Northeast Creek	
47	Middle Pamunkey River	
48	Middle Pamunkey River	
49	Middle Pamunkey River	
50	Middle Pamunkey River	
51	Middle Pamunkey River	

3.1 Assessment of Permitted Sources

Table 3.2 lists permitted point sources that discharge to surface water bodies in the Pamunkey River and Tributaries watershed study area. Point sources are permitted to discharge fecal bacteria to surface water bodies in the Pamunkey River Watershed study area through the Virginia Pollutant Discharge Elimination System (VPDES). The use of "UT" in this table refers to unnamed tributaries. There may be other industrial process water and/or stormwater dischargers in the watershed that are authorized to discharge under the VPDES program. These facilities are not expected to discharge the pollutant of concern (bacteria). However, there may be incidental, insignificant levels of bacteria found in these discharges; these discharges are not considered to have a reasonable potential to cause or contribute to exceedances of the Virginia Water Quality Standards and the observed stream impairments. Any inadvertent bacteria discharge would be insignificant, and thus they are not considered in this TMDL. Should any of these permits have large enough associated flows to impact the hydrology of the watershed, even without directly impacting the bacterial load, they would have been included; however, no additional permits of significant size were identified in this watershed.

Permitted point discharges that may contain pathogens associated with fecal matter are required to maintain an *E. coli* concentration below 126 cfu/100mL, the current riverine primary contact standard. Chlorine is added to the discharge stream at levels intended to kill pathogens. The monitoring method for ensuring the goal is to measure the concentration of total residual chlorine (TRC) in the effluent. Typically, if minimum TRC levels are met, bacteria concentrations are reduced to levels well below the standard. All of Hanover County's facilities use UV Disinfection rather than chlorine for disinfection. VPDES Discharge Monitoring Reports (DMRs) are reviewed by the contractor for flow, bacteria and residual chlorine information. The location of permitted dischargers is shown in **Figure 3-2**.

Table 3.3 shows Domestic discharges within the Pamunkey River Watershed study area. These permits allow treated residential wastewater to be discharged to surface waters. These facilities discharge water and bacteria to surface water.

There are no Animal Feeding Operations (AFOs) or Virginia Pollution Abatement (VPA) facilities in the study area.

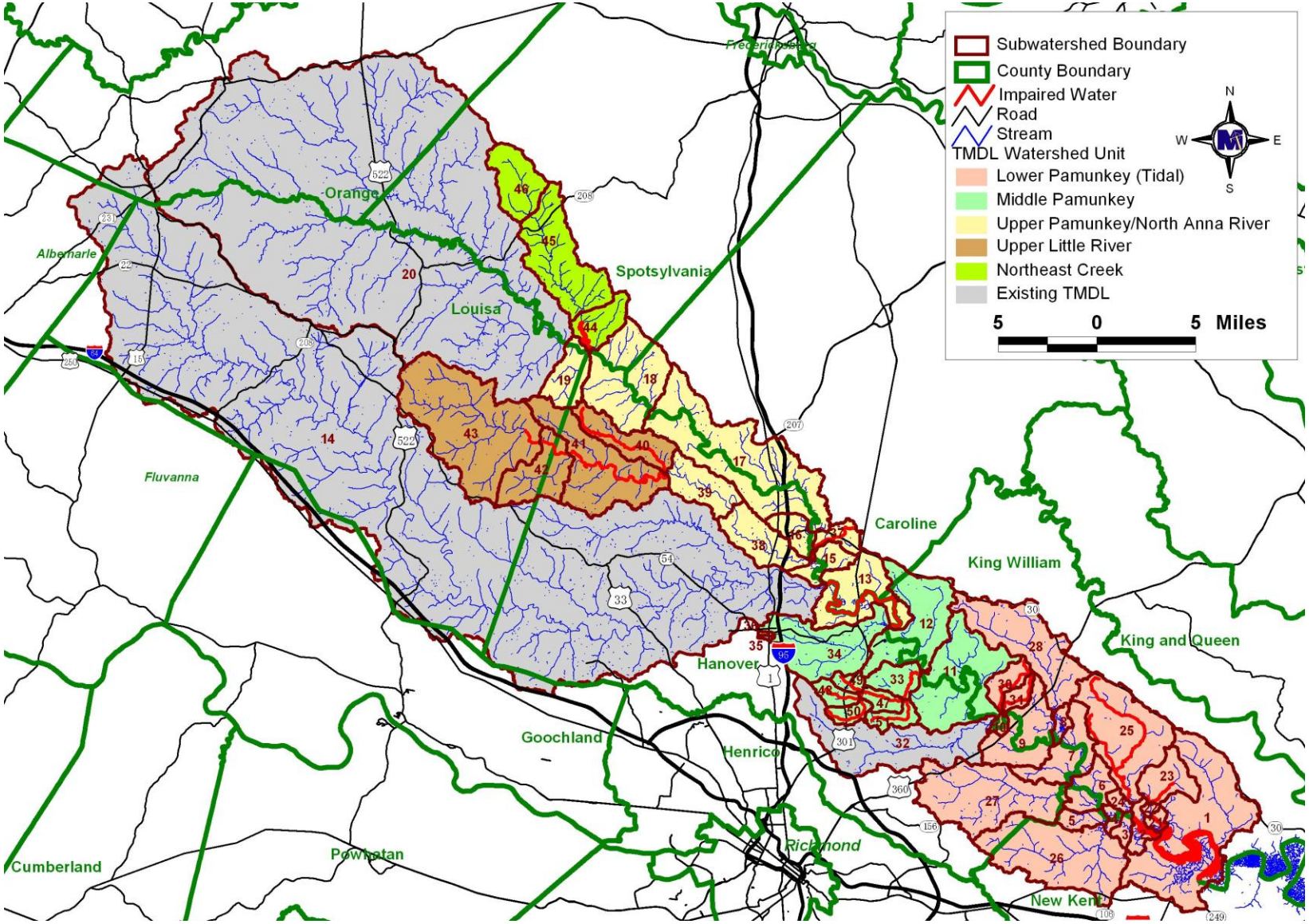

Figure 3-1 **Subwatersheds delineated for modeling the study area, and the impairments being addressed for the first time. (Does not include four subwatersheds for existing TMDLs or modeling changes noted in the text.)**

Table 3.2 Summary of Individual VPDES permitted point sources permitted for fecal bacteria control in the Pamunkey River Watershed study area.

Permit	Facility Name	Receiving Stream(s)	Permitted for *E. coli* Control	Design Flow (MGD)
VA0020630	DJJ Barrett Juvenile Correctional Center	Crump Creek	YES	0.019
VA0020664	DJJ Hanover Juvenile Correctional Center	Pamunkey River	YES	0.0347
VA0023914	Hamilton Holmes Wastewater Treatment Plant	Acquinton Creek, UT	YES	0.02
VA0029521	Hanover County Doswell WWTP	North Anna River	YES	6.34
VA0062154	Hanover Courthouse WWTP	Pamunkey R.	YES	0.08
VA0067121	Cumberland Hospital for Children and Adolescents	Pamunkey R.	YES	0.03
VA0068314	Rhapsody Industrial Park - Purgo (CIRCAM, INC)	North Anna R. UT	YES	0.005
VA0088102	HRSD King William County Sewage Treatment Plant	Moncuin Creek	YES	0.1
VA0089915	Hanover County Totopotomoy WWTP	Pamunkey River	YES	10
VA0091537	Mount Olive Wastewater Treatment Facility	Mallory Creek	YES	0.008

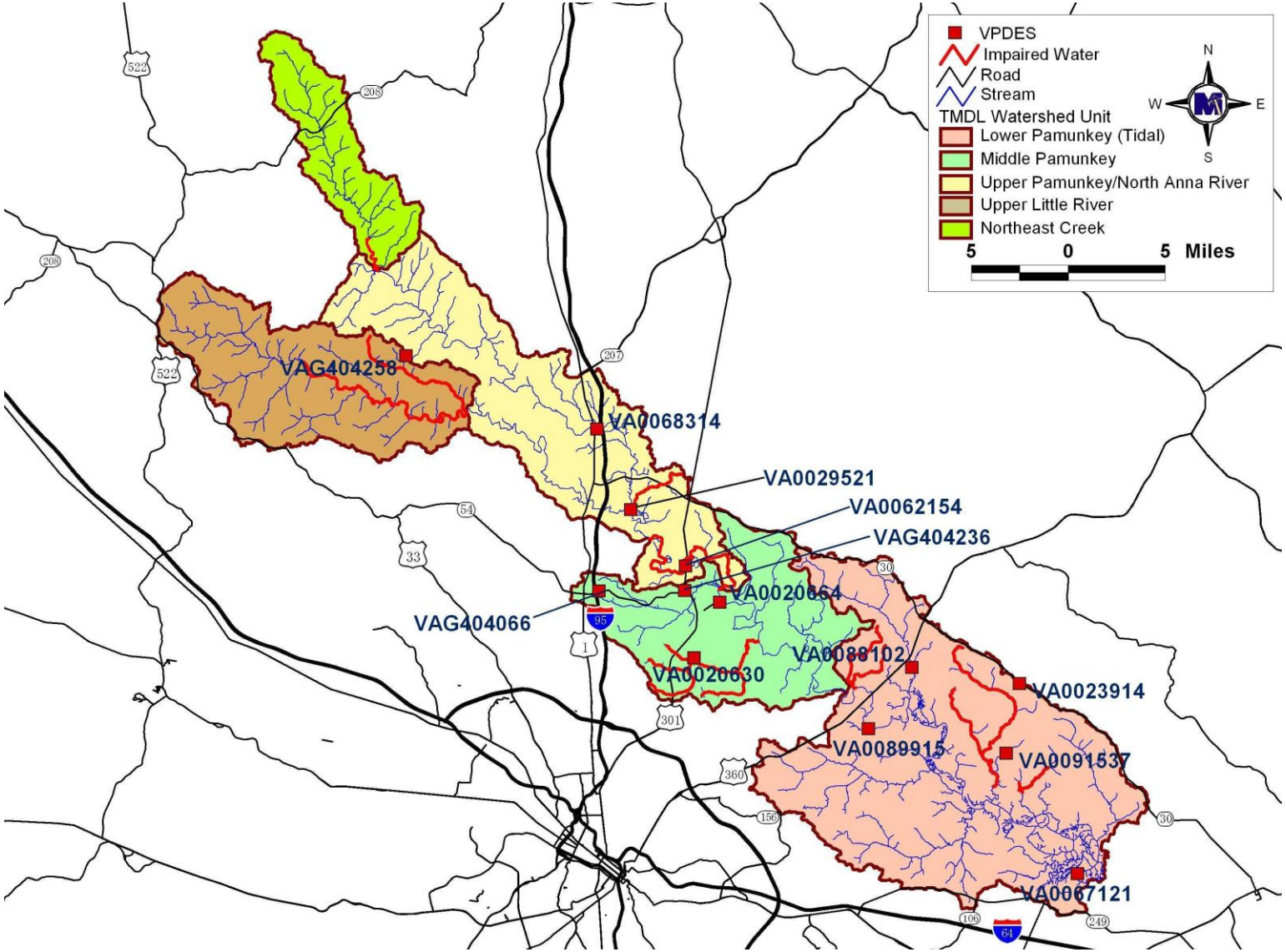

Figure 3-2 **Location of VPDES permitted point sources in the Pamunkey River watershed study area (Expected to Discharge Contaminant of Concern), and the impairments being addressed for the first time in this study.**

Table 3.3 Domestic permits in the Pamunkey River Watershed study area.

Permit	Receiving Stream	Facility Type
VAG404066	Mechumps Creek UT	Domestic
VAG404236	UT Mechumps Creek	Domestic
VAG404258	UT Beaverdam Creek	Domestic

The WLAs for these facilities will be met through compliance with existing permit limits.

In addition to permits issued under the VPDES program, there are currently three Municipal Separate Storm Sewer System (MS4) permits issued to cities, counties and other facilities within the TMDL watersheds. These permits are detailed in **Table 3.4**. For these Phase II Permits all land-based loadings from developed land use categories (high, medium, and low intensity developed land uses) within the most recent United States Census-defined urban areas of the permit boundaries were allocated to the MS4s. The most recent United States decennial census with defined urban areas is the 2010 Census. This approach for developing MS4 allocations is a land-use based approach.

One disadvantage to the land-use based approach is that it is not able to distinguish between urban areas that drain to regulated MS4s and those that drain to other unregulated pervious areas or directly to surface waters. At the time of TMDL development, detailed information regarding the portion of each watershed that drains to a MS4 system was not available, so a conservative, land-use based approach was used. It is important to note that the actual areas within the TMDL watersheds that are subject to a MS4 WLA are those areas that are specifically regulated under the MS4 permit. This TMDL study does not attempt or intend to define the MS4 regulatory area. Rather, the areas used to develop loadings associated with the MS4 permits in this TMDL (developed and Census defined urban areas) are only surrogates for establishing WLAs, estimating a reasonable pollutant loading that is expected to be contributed by these permitted sources. The WLAs for MS4 permittees can be revised in the future, as necessary, if additional information regarding the MS4 drainage areas becomes available or if adaptive management indicates that related loading(s) or reduction strategies would be impacted to a significant degree.

Due to the spatial overlap between MS4 entities and the resulting uncertainty of the appropriate operator of the system, the MS4 loads are aggregated by jurisdiction (Town of Ashland, and Hanover County) in the TMDL. In most cases, the boundaries of MS4 areas are not available in enough geospatial detail to disaggregate the MS4 loads and assign individual Waste Load Allocations. EPA, DEQ, and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation for the implementation of appropriate BMPs to address reductions required by the TMDL.

Table 3.4 Permits for MS4s in the James River – City of Richmond study area.

Permit	Phase	Facility Name	Bacteria Contribution
VAR040012	Phase II	Hanover County	Yes
VAR040011	Phase II	Town of Ashland	Yes
VAR040115	Phase II	VDOT	Yes

3.2 Assessment of Nonpoint Sources

In the Pamunkey River and Tributaries watershed study area, both developed and agricultural nonpoint sources of fecal bacteria were considered. Sources include residential sewage disposal systems, illicit straight pipes, sewer overflows, land application of waste (livestock), livestock, wildlife, and pets. Sources were identified and enumerated. Where appropriate, spatial distribution of sources was also determined utilizing the subwatersheds.

3.2.1 Private Residential Sewage Treatment

Population, housing units, and type of sewage treatment from U.S. Census Bureau (USCB, 1990, 2010) were calculated using GIS (**Table 3.5**). 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 were assumed to be disposing of sewage

via a straight pipes (direct stream outfall) or pit privies. The breakdown between pit privies and straight pipes was based on agencies response or assuming that 90% of the houses under "Other Means" category were using pit privies and the remainder 10% were disposing sewage via straight pipes.

The number of houses with septic systems was estimated by subwatershed. The accuracy of the initial estimates was enhanced by obtaining geographic information from counties detailing the locations of septic systems. Adjustments were made to initial estimates of number of houses with septic systems based on the more up-to-date county data. For instance, Caroline County provided information regarding homes in the community of Dawn that were provided sewage treatment services. The number of houses with failing septic systems was estimated based on the assumption that each septic systems fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with regions' Health Departments and feedback was obtained and used in adjusting numbers. Comments from multiple health districts were incorporated. The estimates shown in **Table 3.5** are given by subwatershed which correspond to geographic illustration shown in **Figure 3-1**.

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

A septic failure occurs when a drain field has inadequate drainage or a "break", 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, previously performed by MapTech (MapTech, 1999), showed that failures were more likely to occur in the winter-spring months than in the summer-fall months, and that a higher percentage of system failures were reported because of a back-up to the household than because of a failure noticed in the yard.

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

Table 3.5 Human population, housing units, houses on sanitary sewer, septic systems, straight pipes, pit privies, and failing septic systems for areas contributing to impaired segments in the Pamunkey River Watershed study area.

Sub-watershed	Human Population	Housing Units	Homes with Sewer	Homes with Septic	Estimated Homes with Straight Pipes	Estimated Homes with Pit Privies	Estimated Homes with Failing Septic Systems
1	1,129	451	3	434	1	13	9
2	34	19	0	18	0	1	0
3	9	4	0	4	0	0	0
4	6	3	0	3	0	0	0
5	113	60	0	59	0	1	2
6	100	49	0	47	0	2	1
7	394	164	3	158	0	3	4
8	24	8	0	8	0	0	0
9	625	263	7	250	1	5	8
10	4	3	0	3	0	0	0
11	1,615	628	7	611	1	9	14
12	871	209	1	200	1	7	4
13	525	265	175	70	2	18	3
15	129	53	18	28	1	6	1
16	308	140	4	125	1	10	4
17	2,643	1,087	50	973	6	58	32
18	1,446	552	46	483	2	21	16
19	396	173	0	165	1	7	3
21	2	2	0	2	0	0	0
22	0	0	0	0	0	0	0
23	153	61	0	57	0	4	2
24	8	3	0	3	0	0	0
25	848	361	2	346	1	12	12
26	3,695	1,421	291	1,120	1	9	37
27	4,345	1,737	36	1,685	2	14	56
28	2,588	1,027	15	975	4	33	32
30	202	78	1	76	0	1	3
31	121	44	0	43	0	1	1
33	195	98	0	96	0	2	3
34	6,502	2,242	1,262	903	8	69	30
35	966	439	438	1	0	0	0
36	631	371	369	1	0	1	0
37	320	130	7	105	2	16	4
38	749	311	2	295	1	13	10
39	473	181	1	177	0	3	6
40	545	218	12	192	1	13	6
41	1,501	613	5	576	3	29	18
42	816	345	2	322	2	19	8
43	2,639	1,114	0	1,036	8	70	21
44	531	189	1	180	1	7	6
45	1,688	627	5	602	2	18	20

Table 3.5 Human population, housing units, houses on sanitary sewer, septic systems, straight pipes, pit privies, and failing septic systems for areas contributing to impaired segments in the Pamunkey River Watershed study area (cont.).

Sub-watershed	Human Population	Housing Units	Homes with Sewer	Homes with Septic	Estimated Homes with Straight Pipes	Estimated Homes with Pit Privies	Estimated Homes with Failing Septic Systems
46	595	231	0	222	1	8	7
47	667	271	0	267	0	4	9
48	1,415	571	110	417	4	40	14
49	330	132	2	128	0	2	4
50	1,093	441	50	389	0	2	13
51	699	281	5	273	0	3	9
Total	**44,688**	**17,670**	**2,930**	**14,128**	**58**	**554**	**432**

3.2.2 Sanitary Sewer Overflows (SSOs)

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 or the capacity is reduced by a blockage, 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, or due to infrastructure failure. Failures are typically addressed by counties/municipalities when they occur and programs exist that intend to repair damaged sewer lines and resolve high maintenance problems. **Table 3.6** details the volume of overflows reported between June, 2001 and January, 2013.

Table 3.6 Volume of sanitary sewer overflows reported within the study area between June 2001 and January 2013.

Subwatershed	Volume (Gallon)
12	2,400
14	34,175
16	1,695
34	16,875
36	600
50	200
Total	**66,945**

3.2.3 Biosolids

Biosolids data was collected by MapTech where it was available (Biosolids data were not available in Caroline, Spotsylvania and Louisa Counties). Between 2001 and 2012 biosolids were applied to fields within the Pamunkey River and Tributaries study area (**Table 3.7**). The total amount of biosolids applied was 16,425 dry tons. The task of regulating biosolids applications is the responsibility of the Virginia Department of Environmental Quality. Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. All applications are done so in accordance with an approved Nutrient Management Plan. Class B biosolids may not have a fecal coliform density greater than 1,995,262 cfu/g (total solids) however; actual applications may have densities far less than this amount. Application rates must be limited to a maximum of 15 dry tons/acre per three-year period.

Table 3.7 Application of biosolids within the Pamunkey River study area (2001 – 2012).

Subwatershed	Application Year	Applied amount (dry tons)
1	2006	35
7	2001	67
	2006	55
9	2001	1,474
	2006	657
10	2001	959
	2006	504
11	2002	2,516
	2010	215
	2011	1,694
12	2006	911
	2010	449
13	2002	417
	2005	98
	2006	189
17	2005	14
23	2004	1,172
	2006	841
25	2001	995
	2006	608
26	2012	215
28	2010	821
	2011	276
	2012	356
33	2002	282
	2004	279
38	2005	165
41	2006	161
Total		**16,425**

3.2.4 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Pamunkey River and Tributaries watershed and were the only pets considered in this analysis. Cat and dog populations were derived from American Veterinary Medical Association Center for Information Management demographics collected in 1997. Dog waste load was reported by Weiskel et al. (1996), while cat waste load was previously measured by MapTech (MapTech, 1999). Fecal coliform density for dogs and cats was

previously measured from samples collected by MapTech (MapTech, 1999). A summary of the data collected is given in **Table 3.8**. **Table 3.9** lists the domestic animal populations for impairments in the study area by subwatershed.

Table 3.8 Domestic animal population density, waste load, and fecal coliform (FC) density.

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

* animals per house
** grams per animal per day

Table 3.9 Estimated domestic animal populations in areas contributing to impaired segments in the Pamunkey River Watershed study area.

Sub-watershed	Housing Units	Dogs	Cats
1	451	241	270
2	19	10	11
3	4	2	2
4	3	2	2
5	60	32	36
6	49	26	30
7	164	93	105
8	8	4	5
9	263	150	168
10	3	2	2
11	628	355	398
12	209	116	130
13	265	145	163
15	53	28	32
16	140	82	92
17	1,087	594	665
18	552	306	343
19	173	95	106
21	2	1	2
22	0	0	0
23	61	33	37
24	3	2	2
25	361	193	216
26	1,421	771	864
27	1,737	1,020	1,143
28	1,027	547	613
30	78	42	47
31	44	24	26
33	98	58	65
34	2,242	1,317	1,475
35	439	258	289
36	371	218	244
37	130	69	78
38	311	183	205
39	181	107	120
40	218	128	143
41	613	357	399
42	345	189	212

Table 3.9 Estimated domestic animal populations in areas contributing to impaired segments in the Pamunkey River Watershed study area (cont.).

Sub-watershed	Housing Units	Dogs	Cats
43	1,114	595	666
44	189	101	113
45	627	335	375
46	231	123	138
47	271	159	178
48	571	335	376
49	132	78	87
50	441	259	290
51	281	166	185
Total	**17,670**	**9,951**	**11,148**

3.2.5 Livestock

The predominant type of livestock in the Pamunkey River and Tributaries watershed study area is beef cattle, horses, and dairy, although other types of livestock identified were considered in modeling the watershed. The estimates shown in **Table 3.10** are given by subwatershed which correspond to geographic illustration shown in **Figure 3-1**. Animal populations were based on communication with VADEQ, Colonial Soil and Water Conservation District, Three Rivers Soil and Water Conservation District, Hanover-Caroline Soil and Water Conservation District, Thomas Jefferson Soil and Water Conservation District, Culpepper Soil and Water Conservation District, Tri-County/City Soil and Water Conservation District, extension agents, watershed visits, and communication with citizens at the first public meeting and afterwards.

Table 3.10 Livestock populations in areas contributing to impaired segments in the Pamunkey River Watershed study area.

Subshed ID	Beef Cattle	Beef Calves	Dairy Milkers	Dairy Heifers	Dairy Calves	Sheep	Horses	Chickens	Goats
1	47	54	7	3	3	0	34		67
2	6	7	1	0	0	0	5		8
3	3	3	0	0	0	0	4		3
4	3	3	0	0	0	0	4		3
5	11	11	0	0	0	0	15		12
6	39	39	1	0	0	0	49		43
7	97	0	103	52	52	7	43		38
8	10	10	1	1	1	0	5		9
9	165	127	156	78	78	12	74		72
10	18	15	0	0	0	2	8		3
11	194	31	162	81	81	12	88		119
12	80	87	9	5	5	4	40		82
13	69	62	1	1	1	8	30		32
15	30	24	0	0	0	4	13		8
16	47	38	0	0	0	5	20		10
17	173	140	0	0	0	21	74		46
18	223	203	4	2	2	16	63		34
19	61	49	0	0	0	4	15		10
21	10	13	2	1	1	0	5		16
22	4	5	1	0	0	0	2		7
23	5	6	1	0	0	0	2		8
24	0	0	0	0	0	0	0		0
25	38	46	8	4	4	0	20		60
26	42	41	0	0	0	1	50		39
27	164	134	0	0	0	14	75		33
28	43	52	9	4	4	0	22		68
30	12	14	2	1	1	0	6		18
31	3	4	1	0	0	0	2		5
33	25	20	0	0	0	2	11		4
34	154	125	0	0	0	14	67		27
35	0	0	0	0	0	0	0		0
36	0	0	0	0	0	0	0		0
37	23	19	0	0	0	5	9		11
38	42	34	0	0	0	4	18		7
39	71	58	0	0	0	6	31		13
40	175	142	0	0	0	16	75		31
41	304	170	132	66	66	28	135		56
42	120	97	0	0	0	10	44		23
43	293	196	0	0	0	20	64	60,800	58
44	111	119	0	0	0	2	23		5

Table 3.10 Livestock populations in areas contributing to impaired segments in the Pamunkey River Watershed study area(cont.).

Subshed ID	Beef Cattle	Beef Calves	Dairy Milkers	Dairy Heifers	Dairy Calves	Sheep	Horses	Chickens	Goats
45	190	170	0	0	0	5	52		11
46	54	58	0	0	0	1	11		2
47	14	11	0	0	0	1	6		2
48	24	20	0	0	0	2	11		4
49	19	16	0	0	0	2	8		3
50	25	20	0	0	0	2	11		4
51	24	20	0	0	0	2	10		4
Total	**3,265**	**2,513**	**601**	**299**	**299**	**232**	**1,354**	**60,800**	**1,118**

Values of fecal coliform density and waste storage die-off of livestock sources were based on sampling previously performed by MapTech (MapTech, 1999). Reported manure production rates for livestock were taken from American Society of Agricultural Engineers (1998). A summary of fecal coliform density values and manure production rates is presented in **Table 3.11.**

Table 3.11 Average fecal coliform densities and waste loads associated with livestock.

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)
Beef stocker (850 lb)	51.0	101,000
Beef calf (350 lb)	21.0	101,000
Dairy milker (1,400 lb)	120.4	271,329
Dairy heifer (850 lb)	70.0	271,329
Dairy calf (350 lb)	29.0	271,329
Hog (135 lb)	11.3	400,000
Horse (1,000 lb)	51.0	94,000
Sheep (60 lb)	2.4	43,000
Goat (140 lb)	5.7	15,000
Poultry		
Broiler	0.17	586,000
Layer	0.26	586,000

Fecal bacteria produced by livestock can enter surface waters through four pathways. First, waste produced by animals in confinement is typically collected, stored, and applied to the landscape (*e.g.*, pasture and cropland), where it is available for wash-off during a runoff-producing rainfall event. **Table 3.12** shows the average percentage of

collected livestock waste that is applied throughout the year. Second, grazing livestock deposit manure directly on the land where it is available for wash-off during a runoff-producing rainfall event. Third, livestock with access to streams occasionally deposit manure directly in streams. Fourth, some animal confinement facilities may have drainage systems that divert wash-water and waste directly to drainage ways or streams.

Table 3.12 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total		Land use
	Dairy	Beef	
January	2.00	4.00	Cropland
February	2.00	4.00	Cropland
March	20.00	12.00	Cropland
April	20.00	12.00	Cropland
May	5.00	12.00	Cropland
June	2.00	8.00	Pasture
July	2.00	8.00	Pasture
August	2.00	8.00	Pasture
September	21.00	12.00	Cropland
October	20.00	12.00	Cropland
November	2.00	4.00	Cropland
December	2.00	4.00	Cropland

Some livestock were expected to deposit a portion of waste on land areas. The percentage of time spent on pasture for dairy and beef cattle was estimated based on projects in other areas of Virginia. Horses and sheep were assumed to be in pasture 100% of the time.

It was assumed that beef cattle with access to flowing water contribute bacteria to the environment through direct deposition. For areas where direct deposition by cattle is assumed, the average amount of time spent by dairy and beef cattle in stream access areas for each month is given in **Table 3.13** and **Table 3.14**.

Table 3.13 Average time dry cows and replacement heifers spend in different areas per day.

Month	Pasture (hr)	Stream Access (hr)	Loafing Lot (hr)
January	23.3	0.7	0
February	23.3	0.7	0
March	22.6	1.4	0
April	21.8	2.2	0
May	21.8	2.2	0
June	21.1	2.9	0
July	21.1	2.9	0
August	21.1	2.9	0
September	21.8	2.2	0
October	22.6	1.4	0
November	22.6	1.4	0
December	23.3	0.7	0

Table 3.14 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day.

Month	Pasture (hr)	Stream Access (hr)
January	23.3	0.7
February	23.3	0.7
March	23.0	1.0
April	22.6	1.4
May	22.6	1.4
June	22.3	1.7
July	22.3	1.7
August	22.3	1.7
September	22.6	1.4
October	23.0	1.0
November	23.0	1.0
December	23.3	0.7

3.2.6 Wildlife

The predominant wildlife species in the Pamunkey River and Tributaries watershed study area 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 other state and local officials. Population densities were calculated from data provided by VDGIF and FWS, and are listed in **Table 3.15** (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987; Mayhorn, 2005).

Table 3.15 Wildlife population densities for the Pamunkey River Watershed study area.

Deer (an/ac of habitat)	Turkey (an/ac of habitat)	Goose (an/ac of habitat)	Duck (an/ac of habitat)	Muskrat (an/ac of habitat)	Raccoon (an/ac of habitat)	Beaver (an/mi of stream)
0.0344	0.00907	0.0189	0.0333	0.3125	0.0703	4.8

The numbers of animals estimated to be in the study area are reported in **Table 3.16.** Habitat and seasonal food preferences were determined based on information obtained from The Fire Effects Information System (1999) and VDGIF (Costanzo, 2003; Norman, 2003; Rose and Cranford, 1987; and VDGIF, 1999). Waste loads were comprised from literature values and discussion with VDGIF personnel (ASAE, 1998; Bidrowski, 2003; Costanzo, 2003; Weiskel et al., 1996, and Yagow, 1999).

Table 3.16 Estimated wildlife populations in the Pamunkey River Watershed study area.

Subshed ID	Raccoon	Muskrat	Duck	Goose	Deer	Turkey	Beaver
1	1,839	1,715	183	104	898	227	462
2	130	175	19	11	63	16	50
3	74	82	9	5	36	9	19
4	56	107	11	6	27	7	27
5	139	138	15	8	68	17	31
6	291	279	30	17	142	37	70
7	499	407	43	25	244	63	105
8	82	135	14	8	40	10	44
9	655	395	42	24	320	81	82
10	49	49	5	3	24	6	10
11	1,205	702	75	42	589	149	142
12	971	516	55	31	474	122	105
13	805	554	59	33	392	99	113
15	235	182	19	11	115	29	42
16	221	109	12	7	97	20	23
17	1,973	1,236	132	75	956	239	248
18	1,127	751	80	45	550	140	155
19	379	239	25	14	185	48	49
21	62	78	8	5	30	8	19
22	29	25	3	2	14	4	5
23	354	179	19	11	173	44	31
24	64	57	6	3	31	8	12
25	1,176	615	65	37	574	146	132
26	1,424	811	86	49	695	177	166
27	1,312	697	74	42	640	161	135
28	1,099	608	65	37	531	132	114
30	201	96	10	6	98	25	21
31	110	50	5	3	54	14	10
33	249	132	14	8	121	28	26
34	954	518	55	31	454	106	107
35	10	1	0	0	4	0	25
36	10	0	0	0	3	0	57
37	176	125	13	8	86	20	54
38	515	275	29	17	250	61	58
39	456	291	31	18	218	57	151
40	480	285	30	17	233	60	70
41	1,189	742	79	45	581	148	248
42	581	336	36	20	283	72	50
43	2,072	1,191	127	72	1,010	258	158
44	332	232	25	14	162	42	44
45	1,053	718	77	43	513	130	0
46	508	206	22	12	248	62	0
47	131	69	7	4	63	15	14
48	140	74	8	4	68	16	15
49	92	49	5	3	45	10	10

Table 3.16 Estimated wildlife populations in the Pamunkey River Watershed study area (cont.).

Subshed ID	Raccoon	Muskrat	Duck	Goose	Deer	Turkey	Beaver
50	129	68	7	4	63	15	13
51	162	85	9	5	78	18	17
Total	**25,800**	**16,384**	**1,743**	**989**	**12,543**	**3,156**	**3,539**

Fecal coliform densities and fecal production information are reported in **Table 3.17**. Where available, fecal coliform densities were based on sampling of wildlife scat performed by MapTech (MapTech, 1999). The only value that was not obtained from MapTech sampling in the watershed was for beaver.

Table 3.17 Average fecal coliform densities for wildlife.

Animal Type	Waste Load (g/an-day)	Fecal Coliform Density (cfu/g)
Raccoon	450	2,100,000
Muskrat	100	1,900,000
Beaver[1]	200	1,000
Deer	772	380,000
Turkey[2]	320	1,332
Goose[3]	225	250,000
Duck	150	3,500

[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)

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. **Table 3.18** summarizes the wildlife habitat and estimated percentages of time spent in stream access areas (*i.e.*, within 100 feet of stream).

Table 3.18 Wildlife percentage of time spent in stream access areas and habitat.

Animal	Portion of Day in Stream Access Areas (%)	Habitat
Raccoon	5	**Primary** = region within 600 ft of perennial streams **Secondary** = region between 601 and 7,920 ft from perennial streams **Infrequent/Seldom** = rest of watershed area including waterbodies (lakes, ponds)
Muskrat	90	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Beaver	100	**Primary** = Perennial streams. Generally flat slope regions (slow moving water), food sources nearby (corn, forest, younger trees) **Infrequent/Seldom** = rest of the watershed area
Deer	5	**Primary** = forested, harvested forest land, orchards, grazed woodland, urban grassland, cropland, pasture, wetlands, transitional land **Secondary** = low density residential, medium density residential **Infrequent/Seldom** = remaining land use areas
Turkey	5	**Primary** = forested, harvested forest land, grazed woodland, orchards, wetlands, transitional land **Secondar**y = cropland, pasture **Infrequent/Seldom** = remaining land use areas
Goose	50	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area
Mallard (Duck)	75	**Primary** = waterbodies, and land area within 66 ft from the edge of perennial streams, and waterbodies **Secondary** = region between 67 and 308 ft from perennial streams, and waterbodies **Infrequent/Seldom** = rest of the watershed area

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

This chapter represents a brief description of the modeling procedures. Complete description is presented in Appendix B. Computer modeling is used in this study as a tool that allows simulating the interaction between the land surface and subsurface and the quantities of various bacteria sources by location. The model allows the climatological factors and in particular, precipitation, to drive this interaction. By modeling the watershed conditions and bacteria sources, the model allows quantifying the relationship between sources as they exist throughout the watershed to bacteria concentrations within the watershed. Two modeling approaches were used in the analysis. For the free flowing tributaries, the model used was the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources.

For the tidal segments in the study area, the Steady State Tidal Prism Model, which is used by VADEQ for modeling tidally impacted waterbodies, was implemented within the HSPF framework to model the tidally influenced segments in conjunction with lateral free-flowing streams and input from upstream drainages. The Pamunkey River downstream of Totopotomoy Creek is tidally influenced and so are multiple creeks flowing laterally into the River between Totopotomoy Creek and the downstream end of the study area.

To adequately represent the spatial variation in the watershed parameters and pollutant quantification, the drainage area was divided into forty seven (47) subwatersheds (**Figure 3-1**). Hydrologic parameters collected for the watershed were adjusted based on previously conducted hydrologic calibration in nearby projects where flow was calibrated by comparing model output to observed flow. Flow was calibrated by comparing model output to observed flow within the Pamunkey River and making the proper adjustments to obtain the best match between simulated and observed flow. Once the flow component was built, the bacteria concentration was calibrated by comparing model

simulations of bacteria to observed bacteria values collected by VADEQ at two locations. Finally the bacteria concentration was validated using a different time period from the calibration period.

Existing conditions of bacteria were then entered into the model to simulate the baseline conditions. This stage gives an indication of the current, predicted, violation rates of the geometric mean standard. The model was then used in the allocations process where reductions are simulated for various sources until the bacteria geometric mean standard was met. A complete description of the modeling approach is presented in Appendix B.

5. BACTERIAL ALLOCATION

Total Maximum Daily Loads (TMDLs) consist of waste load allocations (WLAs, permitted direct sources) and load allocations (LAs, non-permitted sources and diffuse 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:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS}$$

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 (cfu).

Allocation scenarios were modeled using HSPF. The first change made to existing conditions was adjusting the flood tides (incoming) 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 Pamunkey River watershed were based on the Virginia State standard for *E. coli*. As detailed in **Section 2.1**, the DEQ riverine primary contact recreational use *E. coli* standard states that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml, or that a maximum single sample concentration of *E. coli* shall not exceed 235 cfu/100 ml more than 10% of the time.

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* through the use of the following equation (developed from a data set containing 493 paired data points):

$$\log_2(C_{ec}) = -0.0172 + 0.91905 \cdot \log_2(C_{fc})$$

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

Pollutant concentrations were modeled over the entire duration of a representative modeling period and pollutant loads were adjusted until the standards were met. For the purpose of this TMDL, VADEQ interprets the bacteria standard as requiring compliance with both the geometric-mean (monthly) criterion and the single-sample (instantaneous) criterion. Since all of the water bodies in question are fresh water, the in-stream *E. coli* targets for the TMDLs in this study were both monthly geometric means not exceeding 126 cfu/100 ml and no more than 10% exceedance of the 235 cfu/100 mL single-sample criterion. The South Anna River, Lake Anna, and Totopotomoy Creek watersheds were set to their allocated load for the modeling runs because of the previously approved bacteria TMDLs in these areas. 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 (both geometric mean and single sample).

5.1 Margin of Safety (MOS)

In order to account for uncertainty in modeled output, a Margin of Safety (MOS) was incorporated into the TMDL development process. Individual errors in model inputs, such as data used for developing model parameters or data used for calibration, may affect the load allocations in a positive or a negative way. A MOS can be incorporated implicitly in the model through the use of conservative estimates of model parameters, or explicitly as an additional load reduction requirement. The intention of an MOS in the development of bacteria TMDLs 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)

There are several VPDES point sources currently permitted to discharge into the Pamunkey River study area. The allocation for these discharges is equivalent to their current permit levels (design discharge and 126 cfu/100 ml). Future growth was accounted for by setting aside 2% of the TMDL for growth in the permitted discharge or creation of new discharges or expansion of existing discharges.

In addition to permits issued under the VPDES program, there are currently three Municipal Separate Storm Sewer System (MS4) permits issued to cities, counties and other facilities within the TMDL watersheds. These permits are detailed in **Table 3.4**. For these Phase II Permits all land-based loadings from developed land use categories (high, medium, and low intensity developed land uses) within the most recent United States Census-defined urban areas of the permit boundaries were allocated to the MS4s. The most recent United States decennial census with defined urban areas is the 2010 Census. This approach for developing MS4 allocations is a land-use based approach.

One disadvantage to the land-use based approach is that it is not able to distinguish between urban areas that drain to regulated MS4s and those that drain to other unregulated pervious areas or directly to surface waters. At the time of TMDL development, detailed information regarding the portion of each watershed that drains to a MS4 system was not available, so a conservative, land-use based approach was used. It is important to note that the actual areas within the TMDL watersheds that are subject to a MS4 WLA are those areas that are specifically regulated under the MS4 permit. This TMDL study does not attempt or intend to define the MS4 regulatory area. Rather, the areas used to develop loadings associated with the MS4 permits in this TMDL (developed and Census defined urban areas) are only surrogates for establishing WLAs, estimating a reasonable pollutant loading that is expected to be contributed by these permitted sources. The WLAs for MS4 permittees can be revised in the future, as necessary, if additional information regarding the MS4 drainage areas becomes available

or if adaptive management indicates that related loading(s) or reduction strategies would be impacted to a significant degree.

Due to the spatial overlap between MS4 entities and the resulting uncertainty of the appropriate operator of the system, the MS4 loads are aggregated by jurisdiction (Town of Ashland, and Hanover County) in the TMDL. In most cases, the boundaries of MS4 areas are not available in enough geospatial detail to disaggregate the MS4 loads and assign individual Waste Load Allocations. EPA, DEQ, and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation for the implementation of appropriate BMPs to address reductions required by the TMDL.

5.3 Load Allocations (LAs)

Load allocations to nonpoint sources are divided into land-based loadings from land uses (nonpoint source, NPS) and directly applied loads in the stream (livestock, wildlife, straight pipes, and sewer overflows). Source reductions include those that are affected by both high and low flow conditions. Land-based NPS loads most significantly impact bacteria concentrations during high-flow conditions, while direct deposition NPS most significantly impact low flow bacteria concentrations. Nonpoint source load reductions were performed by land use, as opposed to reducing sources, as it is considered that the majority of BMPs will be implemented by land use. Appendix C shows tables of the breakdown of the annual fecal coliform per animal per land use for contributing subwatersheds in the study area.

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 the scenarios developed to determine the TMDLs. The first scenario was 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, a scenario reflects the impact of eliminating direct human sources from straight pipes and sewer overflows. 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 graphs in the following sections depict the existing and allocated 30-day geometric mean in-stream bacteria concentrations.

The second table in each of the following sections shows the existing and allocated *E. coli* loads that are output from the 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 and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. 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 TMDL watershed unit outlet or the most limiting subwatershed within the TMDL watershed unit.

5.4.1 South Anna River TMDL Modification

Prior to assessing the downstream TMDLs in the study area, a modification was incorporated into the South Anna River TMDL model. The rationale behind the South Anna River TMDL modification is that in the original TMDLs, the waste load allocation did not include the future growth portion, although it was indicated in the original TMDL that future growth scenarios were modeled and met water quality standards. In the modification, the future growth was set to varying amounts based on existing permitted load or total TMDL load. In addition, a small portion of the future growth load was transferred from the South Anna River, upstream to Taylors Creek to accommodate the possibility of a small number of single-family home or similar discharges. TMDLs included in the modification along with future load estimation method are shown here in **Table 5.1**.

Table 5.1. TMDLs included in the modification process.

TMDL segment	Pollutant	Future Growth Load Estimation Method
South Anna River (VAN-F01R-01)	*E. coli*	Two times the load from all permitted point sources within the area of interest
South Anna River (VAN-F02R-01)	*E. coli*	Four times the load from all permitted point sources within the area of interest
South Anna River (VAP-F04R-01)	*E. coli*	Four times the load from all permitted point sources within the area of interest
South Anna River (VAP-F04R-02)	*E. coli*	5% of the total TMDL load at the impairment outlet
Taylors Creek (VAN-F03R-01)	*E. coli*	Equivalent to load from 20 Single Family Home permits

The modification involved updating the permitted sources information to conform with current (2013) status. This updating included changes to design flows, addition, and removal of certain permitted sources from the model and the TMDL tables.

The following measures were taken to ensure a sound outcome of the modification process.

- Verified that the existing model is hydrologically linked, with TMDLs being inclusive of upstream loads.
- Started with the original future-growth model that included future growth loads in each impaired segment based on an additional 4-times the load from all dischargers (4x) or 1% of the TMDL where no significant dischargers were in the watershed (such as the case of Taylors Creek).
- Updated permitted sources to correspond with the current (2013) VADEQ information.
- Moved a portion of the downstream South Anna River (VAP-F04R-02) future growth load (*i.e.*, equivalent of 20 single family home general permit loads) to the outlet subwatershed of Taylors Creek.
- Because the proposed method from the original TMDL (4x) resulted in a very large WLA for segments VAN- F01R-01 and VAN- F04R-02, based on local input the future-growth load in these segments was reduced to 2-times the load from all

permitted discharges (2x) and 5% of the TMDL, respectively. It should be kept in mind that in the old modeling files and TMDL document, there was no mention of the 4x. The old modeling files included 5x but no individual entry for existing permits at the time resulting in effective future growth load being 4x because 1x was taken to represent the actual existing permits.

- The future growth, in each case, was conservatively modeled by placing the load at the mouth subwatershed of each segment.
- Verified that the existing reductions still meet the standard in each impaired segment.
- Calculated new TMDL tables for each impairment.
- As in the original document, only the permits that directly impact each segment (not the permits in upstream impairments) were included in the TMDL tables. However, all loads from the upstream TMDLs were included in the model for the downstream TMDLs.

Table 5.2, below, is excerpted from the original TMDL and indicates the reductions to loads that were allocated in the original TMDL. These same reductions were used in this modification.

Table 5.2 Allocation scenarios for reducing current bacteria loads in the South Anna River.

Impairment	Percent Reduction in Fecal Coliform Loading from Existing Conditions						
	Straight Pipes	Residential	Livestock DD	Cropland	Pasture	Wildlife DD	Forest
South Anna River (VAN-F01R-01)	100	100	99	97	97	90	0
South Anna River (VAN-F02R-01)	100	100	100	99	99	92	0
South Anna River (VAP-F04R-01)	100	100	98	95	95	41	0
South Anna River (VAP-F04R-02)	100	100	94	94	94	94	0
Taylors Creek (VAN-F03R-01)	100	100	97	99	100	97	0

The updated permitted point source details are shown in **Table 5.3**.

Table 5.3. Updated permitted point source details.

Permit Number	Facility Name	Impaired segment	Design Flow (mgd)	Receiving Stream
VA0021105	Gordonsville Sewage Treatment Plant	VAN-F01R-01	0.94	UT to South Anna River
VAG406073	Residence - Delmer Watson	VAN-F01R-01	0.001	South Anna River
VAG406049	Annandale Land Trust	VAN-F01R-01	0.001	UT to South Anna River
VAG406484	Haney Residence	VAN-F02R-01	0.001	UT to Bowles Creek
VA0088706	South Creek - Zion Crossroads	VAN-F02R-01	0.0395	UT to Central Branch
VA0076678	Shenandoah Crossing	VAN-F02R-01	0.1	Lickinghole Creek
VA0088421	Twin Oaks Community STP	VAN-F02R-01	0.01	Polecat Creek
VA0090743	Zion Crossroads WWTP	VAN-F02R-01	0.7	South Anna River
VAG406402	Dove – Residence	VAN-F02R-01	0.001	UT to Fosters Creek
VAG406455	George Seymour Residence	VAN-F02R-01	0.001	UT South Anna River
VAG406457	Crickenberger Stephanie Residence	VAN-F02R-01	0.001	UT to Harris Creek
VAG406462	Barrett Grove - Lot 10	VAN-F02R-01	0.001	UT to Harris Creek
VAG406463	Barrett Grove - Lot 11	VAN-F02R-01	0.001	UT to Harris Creek
VAG406464	Barrett Grove - Lot 20	VAN-F02R-01	0.001	UT to Harris Creek
VAG406474	East End Farm	VAN-F02R-01	0.001	UT to Hudson Creek
VAG406491	Thomas Thompson Propery	VAN-F02R-01	0.001	UT to South Anna River
VAG406492	Michael Kennan Residence	VAN-F02R-01	0.001	Reedy Creek
VAG406496	Nolting Elisabeth Aiken Residence	VAN-F02R-01	0.001	UT to Fielding Creek
VAG406527	CFS Resources	VAN-F02R-01	0.001	UT to Fosters Creek
VAG404137	Hanover Community Center	VAN-F03R-01	0.001	UT to Wolf Swamp
VA0090140	Six O Five Village M H P STP	VAP-F04R-01	0.04	UT to South Anna River
VA0067954	Louisa Regional Sewage	VAP-F04R-01	0.8	Beaver Creek
VA0067105	Missionary Learning Center	VAP-F04R-01	0.04	South Anna River
VAG404205	Resident (Clifford and Taran Main)	VAP-F04R-01	0.001	UT to Stone Horse Creek
VAG404210	Resident (Chalres and Margaret Francis)	VAP-F04R-01	0.001	UT to South Anna River
VAG404217	Resident (K&M Investments, LLC)	VAP-F04R-01	0.001	UT to Stone Horse Creek
VAG404222	Resident (Thomas Waller)	VAP-F04R-01	0.001	UT to South Anna River
VAG406370	William A Cooke Inc – Residence	VAP-F04R-01	0.001	UT to Beaver Creek
VAG406424	Hale and White Offices	VAP-F04R-01	0.001	Beaver Creek
VAG406501	Jordan Residence – Domestic	VAP-F04R-01	0.001	Desper Creek
VAG404261	Thomas And Julie Rao (SFGP)	VAP-F04R-01	0.001	UT to South Anna River
VAG404259	Roy and Annie Carter (SFGP)	VAP-F04R-01	0.001	UT to Turkey Creek
VAG404251	Wilbert D. And Mary T. Adams (SFGP)	VAP-F04R-01	0.001	Cedar Creek
VA0024899	Ashland WWTP	VAP-F04R-02	2	South Anna River

The modification process resulted in the following TMDL tables (**Table 5.4 through 5-8**).

Table 5.4. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F01R-01) impairment.

Impairment	WLA	LA	MOS	TMDL
South Anna River VAN-F01R-01	4.92E+12	8.98E+11	*Implicit*	5.82E+12
VA0021105	*1.64E+12*			
VAG406073	*1.74E+09*			
VAG406049	*1.74E+09*			
Future Growth	*3.28E+12*			

Table 5.5. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAN-F02R-01) impairment.

Impairment	WLA	LA	MOS	TMDL
South Anna River VAN-F02R-01	7.50E+12	1.38E+13	*Implicit*	2.13E+13
VAG406484	1.74E+09			
VA0088706	6.88E+10			
VA0076678	1.74E+11			
VA0088421	1.74E+10			
VA0090743	1.22E+12			
VAG406402	1.74E+09			
VAG406455	1.74E+09			
VAG406457	1.74E+09			
VAG406462	1.74E+09			
VAG406463	1.74E+09			
VAG406464	1.74E+09			
VAG406474	1.74E+09			
VAG406491	1.74E+09			
VAG406492	1.74E+09			
VAG406496	1.74E+09			
VAG406527	1.74E+09			
Future Growth	6.00E+12			

Table 5.6. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-01) impairment.

Impairment	WLA	LA	MOS	TMDL
South Anna River VAP-F04R-01	7.74E+12	4.42E+13	*Implicit*	5.19E+13
VA0090140	6.97E+10			
VA0067954	1.39E+12			
VA0067105	6.97E+10			
VAG404205	1.74E+09			
VAG404210	1.74E+09			
VAG404217	1.74E+09			
VAG404222	1.74E+09			
VAG406370	1.74E+09			
VAG406424	1.74E+09			
VAG406501	1.74E+09			
VAG404261	1.74E+09			
VAG404259	1.74E+09			
VAG404251	1.74E+09			
Future Growth	6.19E+12			

Table 5.7. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in South Anna River (VAP-F04R-02) impairment.

Impairment	WLA	LA	MOS	TMDL
South Anna River VAP-F04R-02	6.02E+12	4.49E+13	*Implicit*	5.09E+13
VA0024899	*3.48E+12*			
Future Growth	*2.54E+12*			

Table 5.8. Annual *E. coli* bacteria loads (cfu/yr) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) impairment.

Impairment	WLA	LA	MOS	TMDL
Taylors Creek VAN-F03R-01	3.66E+10	6.47E+11	*Implicit*	6.83E+11
VAG404137	1.74E+09			
Future Growth	*3.48E+10*			

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 average in-stream loads for the South Anna River impairments are shown in **Table 5.4** through **Table 5.13**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.9. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAN-F01R-01) impairment.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
South Anna River VAN-F01R-01	1.35E+10	4.49E+11	*Implicit*	4.63E+11
VA0021105	4.48E+09			
VAG406073	4.77E+06			
VAG406049	4.77E+06			
Future Growth	8.99E+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 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.

Table 5.10. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAN-F02R-01) impairment.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
South Anna River VAN-F02R-01	2.05E+10	8.49E+12		8.51E+12
VAG406484	4.77E+06			
VA0088706	1.88E+08			
VA0076678	4.77E+08			
VA0088421	4.77E+07			
VA0090743	3.34E+09			
VAG406402	4.77E+06			
VAG406455	4.77E+06		*Implicit*	
VAG406457	4.77E+06			
VAG406462	4.77E+06			
VAG406463	4.77E+06			
VAG406464	4.77E+06			
VAG406474	4.77E+06			
VAG406491	4.77E+06			
VAG406492	4.77E+06			
VAG406496	4.77E+06			
VAG406527	4.77E+06			
Future Growth	1.64E+10			

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

Table 5.11. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAP-F04R-01) impairment.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
South Anna River VAP-F04R-01	2.12E+10	1.61E+13	*Implicit*	1.61E+13
VA0090140	1.91E+08			
VA0067954	3.82E+09			
VA0067105	1.91E+08			
VAG404205	4.77E+06			
VAG404210	4.77E+06			
VAG404217	4.77E+06			
VAG404222	4.77E+06			
VAG406370	4.77E+06			
VAG406424	4.77E+06			
VAG406501	4.77E+06			
VAG404261	4.77E+06			
VAG404259	4.77E+06			
VAG404251	4.77E+06			
Future Growth	1.70E+10			

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

Table 5.12. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in South Anna River (VAP-F04R-02) impairment.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
South Anna River VAP-F04R-02	1.65E+10	1.65E+13	*Implicit*	1.65E+13
VA0024899	9.54E+09			
Future Growth	6.96E+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 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.

Table 5.13. Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in Taylors Creek (VAN-F03R-01) impairment.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Taylors Creek VAN-F03R-01	1.00E+08	1.57E+12	*Implicit*	1.57E+12
VAG404137	4.77E+06			
Future Growth	9.54E+07			

[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 Northeast Creek TMDL Watershed Unit (VAN-F09R_NST01A08, VAN-F09R_NST03A08, VAN-F09R_NST04A08 and VAN-F09R_MUS01A06)

Table 5.14 shows allocation scenarios used to determine the final TMDL for the Northeast Creek TMDL watershed unit. Because all of the waters in this TMDL watershed unit are riverine (freshwater), the bacterial indicator assessed was *E. coli.* Modeling was conducted for a target goal of meeting both primary contact recreational use (swimming) criteria: 0% exceedance of 126 cfu/100mL *E. coli* for the monthly geometric mean and less than 10% exceedance of 235 cfu/100 mL *E. coli* for single samples. The existing condition, Scenario 1, shows 20.8% violations of the geometric mean standard. Scenario 2 (eliminating straight pipe inputs) showed some improvement, with a violation rate of 6.3%. Scenario 3 showed that eliminating straight pipes and direct inputs from livestock would achieve 0% violations of the monthly geometric-mean criterion, however an additional 80% reduction of land-based loads from both agricultural and residential lands was needed to achieve less than 10% violations of the single-sample criterion (Scenario 4). This scenario will be the target goal during the implementation of best management practices (BMPs).

Table 5.14 Allocation scenarios for reducing current bacteria loads in Northeast Creek (Subwatersheds 44,45,46).

	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[1], Commercial, Forest**	**Livestock Direct**	**Cropland, Pasture, LAX[2]**	**Straight Pipes**	**Residential**	**% > GM[3]**	**%>Inst. Std.[3]**
1	0	0	0	0	0	0	20.8	18.0
2	0	0	0	0	100	0	6.3	14.7
3	0	0	100	0	100	0	0.0	14.2
4[4]	0	0	100	80	100	80	0.0	9.4

[1] Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2] LAX - livestock pasture access near flowing streams.
[3] Percent violations of the monthly Geometric Mean (GM) criterion (126 cfu/100mL *E. coli*) or the instantaneous standard (Inst. Std.) (235 cfu/100mL *E. coli*) in the "worst case" segment.
[4] Final TMDL Scenario.

Figure 5-1 shows the existing and allocated monthly geometric mean *E. coli* concentrations, from the Northeast Creek TMDL watershed unit outlet. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

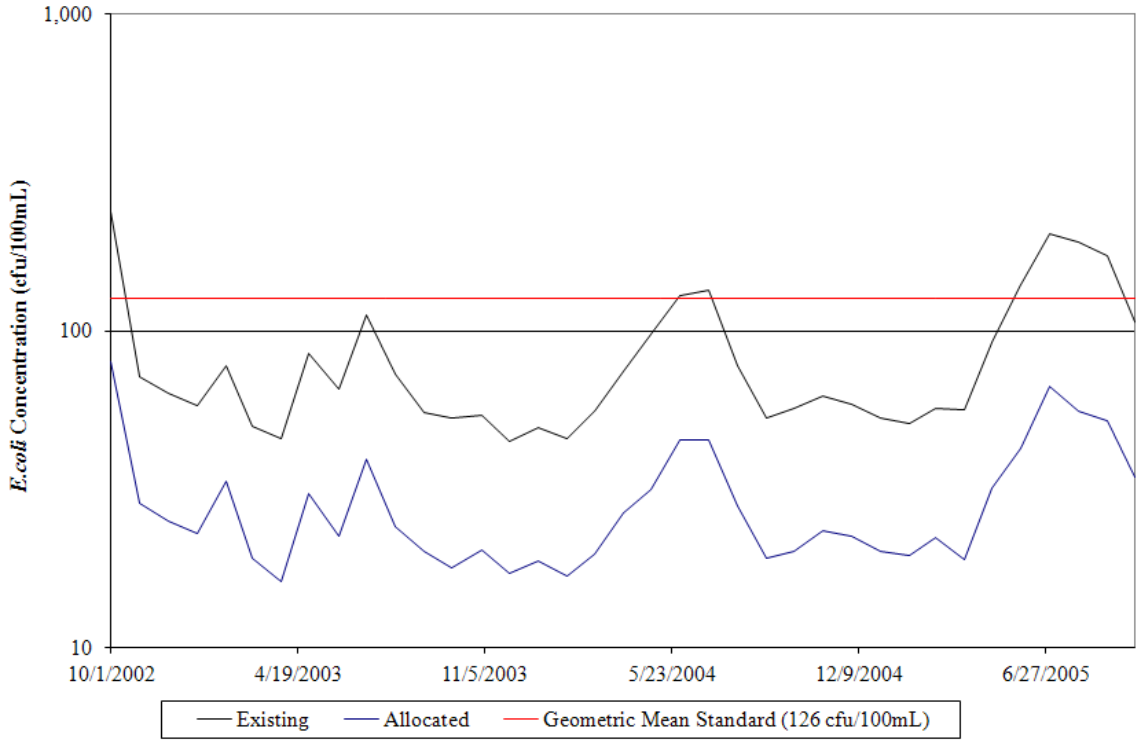

Figure 5-1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in Northeast Creek TMDL watershed unit.

Table 5.15 contains estimates of existing and allocated in-stream *E. coli* loads at the Northeast Creek TMDL watershed unit outlet reported as average annual cfu per year. 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. The percent reductions needed to meet zero percent violations of both water quality criteria for *E. coli* are given in the final column.

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

Table 5.15 Estimated existing and allocated *E. coli* in-stream loads in the Northeast Creek TMDL watershed unit.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Developed	5.38E+12	1.08E+12	80
Commercial	2.93E+10	2.93E+10	0
Barren*	1.55E+11	1.55E+11	0
Forest	7.28E+13	7.28E+13	0
Pasture	9.48E+13	1.90E+13	80
Cropland	6.90E+12	1.38E+12	80
Wetland	1.75E+13	1.75E+13	0
LAX**	5.06E+12	1.01E+12	80
Direct			
Human	3.77E+12	0	100
Livestock	8.63E+11	0	100
Wildlife	1.83E+12	1.83E+12	0
Permitted Sources	na	na	na
Future Growth	na	2.34E+12	na
Total Loads	**2.09E+14**	**1.17E+14**	**44.01**

* Barren – Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

** LAX – livestock pasture access near flowing streams.

Table 5.16 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 the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.16 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Northeast Creek TMDL watershed unit.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL[2] (cfu/yr)
Northeast Creek	2.34E+12	1.15E+14	*Implicit*	1.17E+14
Future Growth	*2.34E+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.
[2] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value may be different from the tables providing nonpoint source load (**Table 5.15**) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Northeast Creek impairments are shown in **Table 5.17**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.17 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Northeast Creek TMDL watershed unit.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Northeast Creek	6.41E+9	5.41E+12	*Implicit*	5.42E+12
Future Growth	6.41E+9			

[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.

5.4.3 Upper Little River TMDL Watershed Unit (VAP-F11R_BDC01A12, VAN-F10R_LTL01A02 and VAP-F11R_LTL01B08)

Table 5.18 shows allocation scenarios used to determine the final TMDL for the Upper Little River TMDL watershed unit (VAP-F11R_BDC01A12, VAN-F10R_LTL01A02 and VAP-F11R_LTL01B08). Because all of the waters in this TMDL watershed unit are riverine (freshwater), the bacterial indicator assessed was *E. coli.* Modeling was conducted for a target goal of meeting both primary contact recreational use (swimming) criteria: 0% exceedance of 126 cfu/100mL *E. coli* for the monthly geometric mean and less than 10% exceedance of 235 cfu/100 mL *E. coli* for single samples. The existing condition, Scenario 1, shows 31.3% violations of the geometric mean standard. Scenario 2 (eliminating straight pipe inputs) showed additional improvement (violation rate 8.3%). Scenario 3 showed that eliminating straight pipes and direct inputs from livestock would provide additional water quality benefits. Scenario number 5 showed that elimination of all anthropogenic sources provided considerable water quality improvement but exceedances persisted. Scenario 7 requires a 25% reduction to direct and indirect wildlife sources in addition to reductions in all anthropogenic categories. This scenario meets the geometric mean standard of 126 cfu/100mL, and reduces single-sample violations to approximately 10%. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.18 Allocation scenarios for reducing current bacteria loads in Upper Little River TMDL watershed unit (Subwatersheds 40,41,42,43).

	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[1], Commercial, Forest	Livestock Direct	Cropland, Pasture, LAX[2]	Straight Pipes	Residential	% > GM[3]	%>Inst. Std.[3]
1	0	0	0	0	0	0	31.30	23.8
2	0	0	0	0	100	0	8.30	17.5
3	0	0	100	0	100	0	2.10	16.2
5	0	0	100	100	100	100	2.10	5.7
6	25	25	100	99	100	99	0.00	2.7
7[4]	25	25	100	70	100	70	0.00	10.3

[1] Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2] LAX - livestock pasture access near flowing streams.
[3] Percent violations of the monthly Geometric Mean (GM) criterion (126 cfu/100mL *E. coli*) or the instantaneous standard (Inst. Std.) (235 cfu/100mL *E. coli*) in the "worst case" segment.
[4] Final TMDL Scenario.

Figure 5-2 shows the existing and allocated monthly geometric mean *E. coli* concentrations in the Upper Little River TMDL watershed unit (subwatershed 43). Subwatershed 43 is shown because it was the most limiting subwatershed in this TMDL watershed unit. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

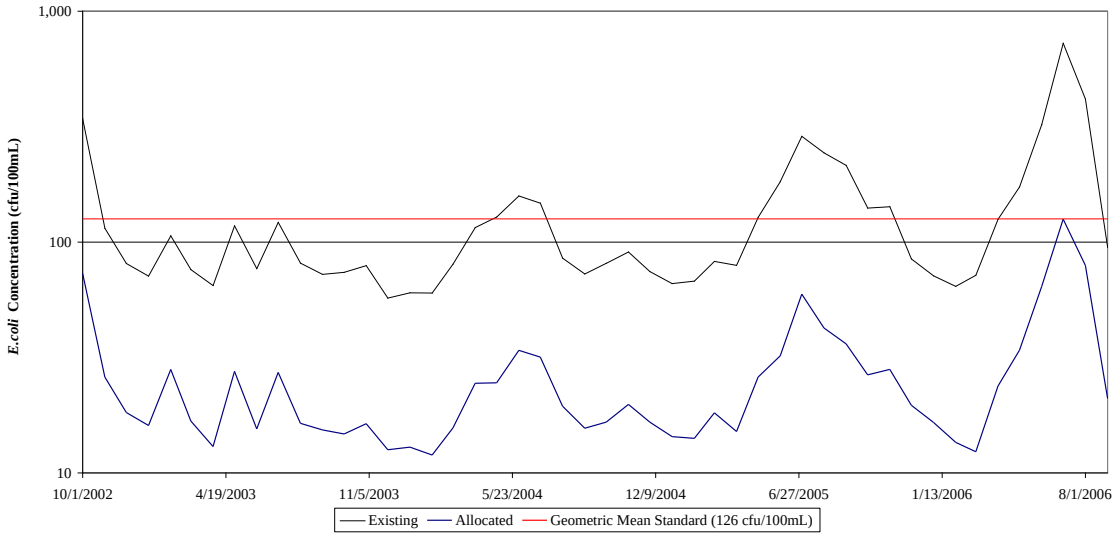

Figure 5-2 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in the Upper Little River TMDL watershed unit (Subwatershed 43).

Table 5.19 contains estimates of existing and allocated in-stream *E. coli* loads at the Upper Little River TMDL watershed unit outlet reported as average annual cfu per year. The estimates in **Table 5.19** 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. The percent reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column.

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

Table 5.19 Estimated existing and allocated *E. coli* in-stream loads in the Upper Little River TMDL watershed unit.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Developed	8.38E+12	2.61E+12	70
Commercial	1.42E+11	1.07E+11	25
Barren*	3.96E+11	2.97E+11	25
Forest	1.25E+14	9.35E+13	25
Pasture	2.18E+14	6.53E+13	70
Cropland	2.84E+14	8.52E+13	70
Wetland	2.81E+13	2.10E+13	25
LAX**	1.05E+13	3.14E+12	70
Direct			
Human	1.29E+13	0	100
Livestock	2.00E+12	0	100
Wildlife	4.65E+12	3.49E+12	25
Permitted Sources	1.74E+09	1.74E+09	0
Future Growth	na	5.61E+12	na
Total Loads	**6.93E+14**	**2.80E+14**	**59.58**

* Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.

** LAX - livestock pasture access near flowing streams.

Table 5.20 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 the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.20 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Upper Little River TMDL watershed unit.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL[2] (cfu/yr)
Upper Little River	5.61E+12	2.75E+14	*Implicit*	2.81E+14
VAG404258	*1.74E+09*			
Future Growth	*5.61E+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.
[2] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value may be different from the tables providing nonpoint source load (**Table 5.19**) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Little River and Beaverdam Creek impairment are shown in **Table 5.21**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.21 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Upper Little River TMDL watershed unit.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Upper Little River	1.53E+10	1.29E+12	*Implicit*	1.31E+12
VAG404258	*4.77E+06*			
Future Growth	*1.53E+10*			

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

5.4.4 Upper Pamunkey/North Anna River TMDL Watershed Unit (VAP-F09R_MLL01A12 and VAP-F12R_PMK01B08)

Table 5.22 shows allocation scenarios used to determine the final TMDL for the Upper Pamunkey/North Anna River TMDL watershed unit. Because all of the waters in this TMDL watershed unit are riverine (freshwater), the bacterial indicator assessed was *E. coli.* Modeling was conducted for a target goal of meeting both primary contact recreational use (swimming) criteria: 0% exceedance of 126 cfu/100mL *E. coli* for the monthly geometric mean and less than 10% exceedance of 235 cfu/100 mL *E. coli* for single samples. The existing condition, Scenario 1, shows 45.8% violations of the geometric mean standard. Scenario 2 (eliminating straight pipe inputs) showed some improvement (violation rate 10.4%. Scenario 3 showed that eliminating straight pipes and direct inputs from livestock would provide additional water quality benefits. Scenario number 5 showed that elimination of all anthropogenic sources provided no additional water quality improvement, in terms of the water quality violation rate. Scenario 7 requires a 25% reduction to both direct and indirect wildlife sources in addition to reductions in all anthropogenic categories. This scenario achieves both 0% violations of the monthly geometric-mean criterion and less than 10% violations of the single-sample criterion. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.22 Allocation scenarios for reducing current bacteria loads in Upper Pamunkey/North Anna River TMDL watershed unit (Subwatersheds 13,15,16,17,18,19,37,38,39).

	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[1], Commercial, Forest	Livestock Direct	Cropland, Pasture, LAX[2]	Straight Pipes	Residential	% > GM[3]	%>Inst. Std.[3]
1	0	0	0	0	0	0	45.8	14.9
2	0	0	0	0	100	0	10.4	14.2
3	0	0	100	0	100	0	2.1	14.2
5	0	0	100	100	100	100	2.1	9.3
6[4]	25	25	100	99	100	99	0.00	8.5

[1] Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2] LAX - livestock pasture access near flowing streams.
[3] Percent violations of the monthly Geometric Mean (GM) criterion (126 cfu/100mL *E. coli*) or the instantaneous standard (Inst. Std.) (235 cfu/100mL *E. coli*) in the "worst case" segment.
[4] Final TMDL Scenario.

Figure 5-3 shows the existing and allocated monthly geometric mean *E. coli* concentrations in the Upper Pamunkey/North Anna River TMDL watershed unit (subwatershed 37). Subwatershed 37 is shown because it was the most limiting subwatershed in the TMDL watershed. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

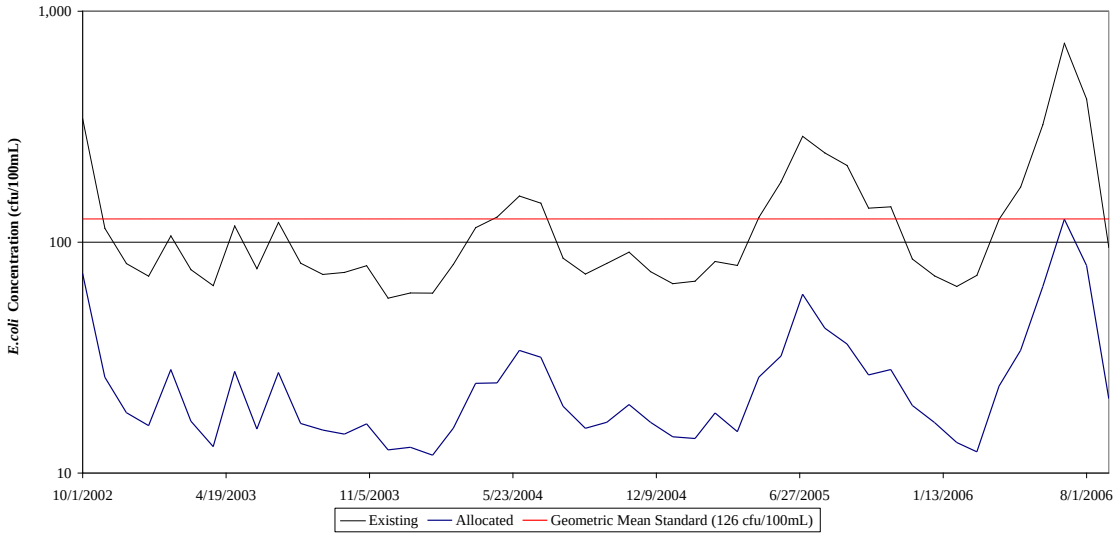

Figure 5-3 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in Upper Pamunkey/North Anna River TMDL watershed unit.

Table 5.23 contains estimates of existing and allocated in-stream *E. coli* loads at the Upper Pamunkey/North Anna River TMDL watershed unit outlet reported as average annual cfu per year. The estimates in **Table 5.23** 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. The percent reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column.

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

Table 5.23 Estimated existing and allocated *E. coli* in-stream loads in the Upper Pamunkey/North Anna River TMDL watershed unit.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Developed*	5.38E+13	5.38E+11	99
Commercial*	2.71E+12	2.03E+12	25
Barren**	3.57E+12	2.68E+12	25
Forest	4.87E+14	3.65E+14	25
Pasture	5.41E+14	5.41E+12	99
Cropland	2.00E+14	2.00E+12	99
Wetland	1.05E+14	7.85E+13	25
LAX***	1.54E+13	1.54E+11	99
Direct			
Human	4.70E+13	0	100
Livestock	5.10E+12	0	100
Wildlife	2.15E+13	1.61E+13	25
Permitted Sources	1.44E+13	1.44E+13	0
Upstream Load	9.02E+14	3.97E+14	55.97
Future Growth	Na	1.81E+13	na
Total Loads	**2.40E+15**	**9.03E+14**	**62.33**

*Outside of MS4 areas
** Barren – Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX – livestock pasture access near flowing streams.

Table 5.24 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 the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Multiple Municipal Separate Storm Sewer System (MS4) permits Storm Sewer System (MS4) permits exist within the study area. In most cases, MS4 areas are overlapping or

intertwined and there is currently no standardized technology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ, and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDLs.

Table 5.24 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Upper Pamunkey/North Anna River TMDL watershed unit.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL[3] (cfu/yr)
Upper Pamunkey/North Anna River	3.24E+13	8.71E+14	*Implicit*	9.03E+14
VA0062154	*1.39E+11*			
VA0029521	*1.10E+13*			
VA0068314	*8.71E+09*			
MS4 Hanover County (VAR040012)	} [2] *3.20E+12*			
MS4 VDOT in Hanover County (VAR040115)				
Future Growth	*1.81E+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.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value may be different from the tables providing nonpoint source load (**Table 5.23**) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Upper Pamunkey/North Anna River TMDL watershed unit are shown in **Table 5.25**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.25 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Upper Pamunkey/North Anna River TMDL watershed unit.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Upper Pamunkey/North Anna River	8.89E+10	5.43E+13	*Implicit*	5.44E+13
VA0062154	*3.82E+08*			
VA0029521	*3.02E+10*			
VA0068314	*2.38E+07*			
MS4 Hanover County (VAR040012) *MS4 VDOT in Hanover County (VAR040115)* } [3]	*8.75E+09*			
Future Growth	*4.95E+10*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.

5.4.5 Middle Pamunkey River TMDL Watershed Unit (VAP-F12R_CRU01A02, VAP-F12R_KER01A12, VAP-F12R_XJC01A12, VAP-F12R_PLD01A12, VAP-F12R_MCP03A06, VAP-F12R_XEG01A06 and VAP-F12R_MCP01A94)

Table 5.26 shows allocation scenarios used to determine the final TMDL for the Middle Pamunkey River TMDL watershed unit. Because all of the waters in this TMDL watershed unit are riverine (freshwater), the bacterial indicator assessed was *E. coli*. Modeling was conducted for a target goal of meeting both primary contact recreational use (swimming) criteria: 0% exceedance of 126 cfu/100mL *E. coli* for the monthly geometric mean and less than 10% exceedance of 235 cfu/100 mL *E. coli* for single samples. The existing condition, Scenario 1, shows 41.7% violations of the geometric mean standard. Scenario 2 (eliminating straight pipe inputs) showed some improvement (violation rate 20.8%). Scenario 3 showed that eliminating straight pipes and direct inputs from livestock would provide additional water quality benefits. Scenario number 5 showed that elimination of all anthropogenic sources provided considerable water quality improvement but there were still exceedances. Scenario 7 requires a 20%

reduction to direct and indirect wildlife sources in addition to reductions in all anthropogenic categories. This scenario achieves both 0% violations of the monthly geometric-mean criterion and less than 10% violations of the single-sample criterion. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.26 Allocation scenarios for reducing current bacteria loads in the Middle Pamunkey River TMDL watershed unit (11,12,33,34,35,36,47-51).

	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[1], Commercial, Forest	Livestock Direct	Cropland, Pasture, LAX[2]	Straight Pipes	Residential	% > GM[3]	%>Inst. Std.[3]
1	0	0	0	0	0	0	41.7	12.8
2	0	0	0	0	100	0	20.8	12.6
3	0	0	100	0	100	0	12.5	12.5
5	0	0	100	100	100	100	6.3	5.4
6	25	25	100	99	100	99	0.0	5.1
7[4]	20	20	100	99	100	99	0.0	5.1

[1] Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2] LAX - livestock pasture access near flowing streams.
[3] Percent violations of the monthly Geometric Mean (GM) criterion (126 cfu/100mL *E. coli*) or the instantaneous standard (Inst. Std.) (235 cfu/100mL *E. coli*) in the "worst case" segment.
[4] Final TMDL Scenario.

Figure 5-4 shows the existing and allocated monthly geometric mean *E. coli* concentrations in the Middle Pamunkey River TMDL watershed unit (subwatershed 51). Subwatershed 51 is shown because it was the most limiting subwatershed in the TMDL watershed unit. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

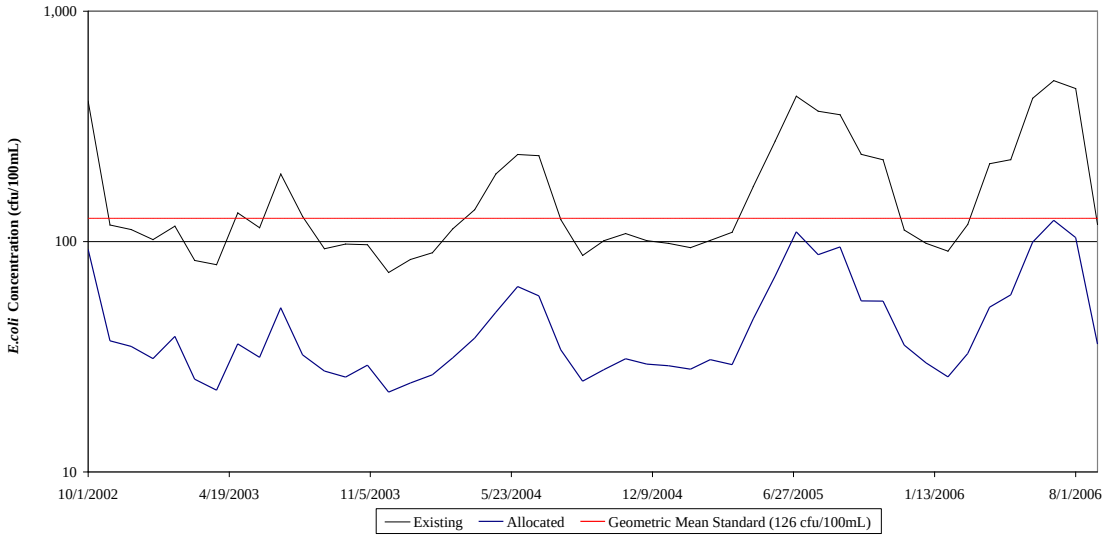

Figure 5-4 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in the Middle Pamunkey River TMDL watershed unit (Subwatershed 51).

Table 5.27 contains estimates of existing and allocated in-stream *E. coli* loads at the Middle Pamunkey River TMDL watershed unit outlet reported as average annual cfu per year. The estimates in **Table 5.27** 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. The percent reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column.

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

Table 5.27 Estimated existing and allocated *E. coli* in-stream loads in the Middle Pamunkey River TMDL watershed unit.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Developed*	4.31E+12	4.31E+10	99
Commercial*	8.94E+11	7.16E+11	20
Barren	7.76E+11	6.21E+11	20
Forest	1.08E+14	8.65E+13	20
Pasture	2.75E+14	2.75E+12	99
Cropland	3.11E+14	3.11E+12	99
Wetland	6.49E+13	5.19E+13	20
LAX**	2.45E+12	2.45E+10	99
Direct			
Human	2.23E+13	0.00E+00	100
Livestock	3.16E+12	0.00E+00	100
Wildlife	1.25E+13	1.00E+13	20
Permitted Sources	1.92E+12	1.92E+12	0
Upstream Load	2.40E+15	9.03E+14	62.67
Future Growth	na	2.17E+13	na
Total Loads	**3.21E+15**	**1.08E+15**	**66.23**

*Outside of MS4 areas
** Barren – Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX – livestock pasture access near flowing streams.

Table 5.28 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 the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Multiple Municipal Separate Storm Sewer System (MS4) permits exist within the study area. In most cases, MS4 areas are overlapping or intertwined and there is currently no

standardized technology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ, and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDLs.

Table 5.28 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Middle Pamunkey River TMDL watershed unit.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL[3] (cfu/yr)
Middle Pamunkey River	2.36E+13	1.06E+15	*Implicit*	1.08E+15
VA0020664	*6.05E+10*			
VA0020630	*3.31E+10*			
VAG404066	*1.74E+09*			
VAG404236	*1.74E+09*			
MS4 Hanover County (VAR040012) *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County (VAR040115)*	} [2] *1.83E+12*			
Future Growth	*2.17E+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.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value may be different from the tables providing nonpoint source load (**Table 5.27**) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Middle Pamunkey River TMDL watershed unit are shown in **Table 5.29**. The daily TMDL was calculated using the 99th percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.29 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Middle Pamunkey River TMDL watershed unit.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Middle Pamunkey River	6.45E+10	5.98E+13	*Implicit*	5.99E+13
VA0020664	*1.66E+08*			
VA0020630	*9.06E+07*			
VAG404066	*4.77E+06*			
VAG404236	*4.77E+06*			
MS4 Hanover County (VAR040012) *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County (VAR040115)*	} [3] *5.00E+09*			
Future Growth	*5.93E+10*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.

5.4.6 Lower Pamunkey (Tidal) TMDL Watershed Unit (VAP-F13R_XDX01A04, VAP-F13R_XDW01A08, VAP-F13R_JCK01A98, VAP-F14R_HSN01A00, VAP-F14R_XJD 01A12, VAP-F14E_HSN01A12, VAP-F14E_PMK02A00, VAP-F14E_PMK03A00, VAP-F14E_PMK04A00, VAP-F13R_MLY01A12, VAP-F13R_MDQ01A98, VAP-F13E_PMK03A06, VAP-F13E_PMK02A98, VAP-F13E_PMK01A98 and VAP-F13R_MNQ01A98)

Table 5.30 shows allocation scenarios used to determine the final TMDL for the Lower Pamunkey River TMDL watershed unit. Because all of the waters in this TMDL watershed unit are riverine (freshwater) or freshwater estuarine, the bacterial indicator assessed was *E. coli*. Modeling was conducted for a target goal of meeting both primary contact recreational use (swimming) criteria: 0% exceedance of 126 cfu/100mL *E. coli* for the monthly geometric mean and less than 10% exceedance of 235 cfu/100 mL *E. coli* for single samples. The existing condition, Scenario 1, shows 20.8% violations of the

geometric mean standard. Scenario 2 (eliminating straight pipe inputs) showed some improvement (violation rate 14.6%). Scenario 3 showed that eliminating straight pipes and direct inputs from livestock would provide additional water quality benefits. Scenario number 5 showed that elimination of all anthropogenic sources provided considerable water quality improvement but exceedances persisted. Scenario 7 requires a 30% reduction to direct and indirect wildlife sources in addition to reductions in all anthropogenic categories. This scenario achieves both 0% violations of the monthly geometric-mean criterion and less than 10% violations of the single-sample criterion. Scenario 7 will be the target goal during the implementation of best management practices (BMPs).

Table 5.30 Allocation scenarios for reducing current bacteria loads in the Lower Pamunkey TMDL watershed unit (Subwatersheds 1-10,21-28,30,31).

	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[1], Commercial, Forest**	**Livestock Direct**	**Cropland, Pasture, LAX[2]**	**Straight Pipes**	**Residential**	**% > GM[3]**	**%>Inst. Std.[3]**
1	0	0	0	0	0	0	20.8	16.4
2	0	0	0	0	100	0	14.6	15.7
3	0	0	100	0	100	0	14.6	15.7
5	0	0	100	100	100	100	4.2	11.6
6	25	25	100	99	100	99	4.2	10.1
7[4]	30	30	100	99	100	99	0.0	9.7

[1] Barren - Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
[2] LAX - livestock pasture access near flowing streams.
[3] Percent violations of the monthly Geometric Mean (GM) criterion (126 cfu/100mL *E. coli*) or the instantaneous standard (Inst. Std.) (235 cfu/100mL *E. coli*) in the "worst case" segment.
[4] Final TMDL Scenario.

Figure 5-5 shows the existing and allocated monthly geometric mean *E. coli* concentrations in the Lower Pamunkey TMDL watershed unit (subwatershed 23). Subwatershed 23 is shown because it was the most limiting subwatershed in the TMDL watershed unit. The graph shows existing conditions in black, with allocated conditions overlaid in blue.

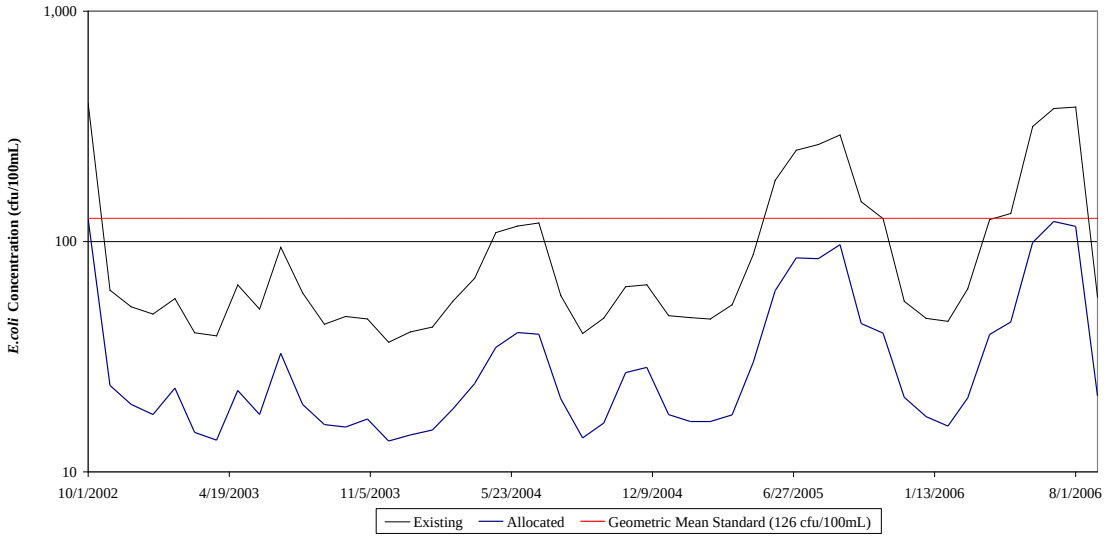

Figure 5-5 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations Lower Pamunkey TMDL watershed unit (Subwatershed 23).

Table 5.31 contains estimates of existing and allocated in-stream *E. coli* loads at the Lower Pamunkey TMDL watershed unit outlet reported as average annual cfu per year. The estimates in **Table 5.31** 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. The percent reductions needed to meet zero percent violations of the monthly geometric mean criteria are given in the final column.

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

Table 5.31 Estimated existing and allocated *E. coli* in-stream loads in the Lower Pamunkey TMDL watershed unit.

Source	Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based			
Developed*	7.09E+13	7.09E+11	99
Commercial*	4.35E+11	3.05E+11	30
Barren**	7.61E+11	5.33E+11	30
Forest	3.93E+14	3.14E+14	20
Pasture	5.13E+14	5.13E+12	99
Cropland	8.41E+14	8.41E+12	99
Wetland	3.34E+14	2.34E+14	30
LAX***	1.19E+13	1.19E+11	99
Direct			
Human	7.82E+13	0	100
Livestock	1.65E+13	0	100
Wildlife	1.56E+14	1.09E+14	30
Permitted Sources	5.03E+12	5.03E+12	0
Upstream Load	3.21E+15	1.08E+15	66.46
Future Growth	na	3.60E+13	na
Total Loads	**5.63E+15**	**1.79E+15**	**68.00**

*Outside of MS4 areas
** Barren – Areas of bedrock, strip mines, gravel pits, and other accumulations of earthen material. Generally, vegetation accounts for less than 15% of total cover.
*** LAX – livestock pasture access near flowing streams.

Table 5.32 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 the water quality standard. These values are output from the HSPF model and incorporate in-stream die-off and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Multiple Municipal Separate Storm Sewer System (MS4) permits exist within the study area. In most cases, MS4 areas are overlapping or intertwined and there is currently no standardized technology for disaggregating the MS4 loads to assign individual Waste Load Allocations. EPA, DEQ, and DCR support the aggregation of MS4 WLAs for this reason. Additionally, aggregation encourages stakeholder cooperation and speeds the implementation of appropriate BMPs to address reductions required by the TMDLs. To account for future growth of urban and residential human populations, two percent of the final TMDL was set aside for future growth in the WLA portion.

Table 5.32 Final average annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation in the Lower Pamunkey TMDL watershed unit.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL[3] (cfu/yr)
Lower Pamunkey River	5.38E+13	1.75E+15	*Implicit*	1.80E+15
VA0067121	*5.23E+10*			
VA0089915	*1.74E+13*			
VA0023914	*3.48E+10*			
VA0091537	*1.39E+10*			
VA0088102	*1.74E+11*			
MS4 Hanover County (VAR040012) / *MS4 VDOT in Hanover County (VAR040115)*	[2] *1.10E+11*			
Future Growth	*3.60E+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.
[2] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.
[3] The Load Allocation is the remaining loading allowed after the MOS and WLA are subtracted from the TMDL as determined for the downstream end of the impaired segment, the watershed outlet. This value may be different from the tables providing nonpoint source load (**Table 5.31**) because of factors such as bacteria die off that occur between the point of deposition and the modeled watershed outlet.

Starting in 2007, the USEPA has mandated that TMDL studies include a daily load as well as the average annual load previously shown. The approach to developing a daily maximum load was similar to the USEPA approved approach to developing load duration bacterial TMDLs. The daily average in-stream loads for the Lower Pamunkey TMDL watershed unit are shown in **Table 5.33**. The daily TMDL was calculated using the 99th

percentile daily flow condition during the allocation time period at the numeric water quality criterion of 235 cfu/100ml *E. coli*. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.33 Final average daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation in the Lower Pamunkey TMDL watershed unit.

Impairment	WLA[1] (cfu/day)	LA (cfu/day)	MOS	TMDL[2] (cfu/day)
Lower Pamunkey River	1.47E+11	9.65E+13	*Implicit*	9.67E+13
VA0067121	*1.43E+08*			
VA0089915	*4.77E+10*			
VA0023914	*9.54E+07*			
VA0091537	*3.82E+07*			
VA0088102	*4.77E+08*			
MS4 Hanover County (VAR040012) *MS4 VDOT in Hanover County (VAR040115)*	} [3] *3.00E+08*			
Future Growth	*9.86E+10*			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 235 cfu/100ml. The TMDL is variable depending on flow conditions. The numeric water quality criterion will be used to assess progress toward TMDL goals.
[3] Each of the municipality MS4 loads has been aggregated with a portion of the adjacent VDOT MS4 load, due to the continuity of the system. For MS4/VSMP permits, the permittee may address the TMDL WLAs for stormwater through the iterative implementation of programmatic BMPs.

6. IMPLEMENTATION

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

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

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 the VADEQ web site under www.deq.state.va.us/export/sites/default/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.

6.3.1 Stormwater

Prior to July 1, 2013, VADEQ and VADCR coordinated separate state permitting programs that regulated the management of pollutants carried by stormwater runoff. Since July 1, VADEQ regulates both stormwater discharges associated with industrial activities through its VPDES program, and stormwater discharges from construction sites and from Municipal Separate Storm Sewer Systems (MS4s) through its VSMP program. As with non-stormwater permits, all new or revised stormwater permits must be consistent with the assumptions and requirements of any applicable TMDL WLA. If a WLA is based on conditions specified in existing permits, and the permit conditions are being met, no additional actions may be needed. If a WLA is based on reduced pollutant loads, additional pollutant control actions will need to be implemented. More information regarding these programs can be found at http://www.deq.virginia.gov/Programs/Water/StormwaterManagement.aspx.

6.3.2 TMDL Modifications for New or Expanding Discharges

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

6.4 Implementation of Load Allocations

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

6.4.1 Implementation Plan Development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses at a minimum the requirements specified in the Code of Virginia, Section 62.1-44.19:7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters". The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments". EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process". The listed elements include implementation actions/management measures, timelines, legal or regulatory controls,

time required to attain water quality standards, monitoring plans and milestones for attaining water quality standards.

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

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

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

6.4.2 Staged Implementation Scenarios

6.4.2.1 Bacteria

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. Among the most efficient bacterial BMPs for urban or rural watersheds are stream side fencing to prevent livestock access to streams, pet waste clean-up programs, and government or assistance grant programs available to homeowners with failing septic systems and installation of treatment systems for homeowners currently using straight pipes.

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

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

6.4.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Pamunkey River Watershed.

6.4.4 Implementation Funding Sources

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

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

With additional appropriations for the Water Quality Improvement Fund during the last two legislative sessions, the Fund has become a significant funding source for

agricultural BMPs and wastewater treatment plants. Additionally, funding is being made available to address urban and residential water quality problems. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/Programs/Water/CleanWaterFinancingAssistance/WaterQualityImprovementFund.aspx.

6.5 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired streams in accordance with its ambient monitoring programs. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, monthly for one year of a six-year cycle. In accordance with *DEQ Guidance Memo No. 04-2005* (http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/042005b.pdf), during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The details of the follow-up ambient monitoring will be outlined in the Annual Water Monitoring Plan prepared by each VADEQ Regional Office.

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

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plans. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An

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

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

6.6 Attainability of Designated Uses

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

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

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

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

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

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

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

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

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

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

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

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

and BMPs can be identified, a UAA may then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

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

This page was intentionally left blank.

7. PUBLIC PARTICIPATION

Public participation during TMDL development for the Pamunkey River Watershed was encouraged; a summary of the meetings is presented in Table 7.1. The first public meetings were repeated at 2 locations in the watershed. The two sets of meetings took place on February 20, 2013 and February 21, 2013 at the Snow Branch Library in Spotsylvania, Virginia, and at the Ashland Town Hall in Ashland, Virginia, respectively. A total of 42 stakeholders attended these meetings. The second set of public meetings was held on February 24, 2014 and February 26, 2014. A total of 17 people attended the meetings. The meetings were publicized by placing notices in the Virginia Register, signs in the watershed, and emailing notices to local stakeholders and representatives.

Table 7.1 Public participation during TMDL development for the Pamunkey River Watershed.

Date	Location	Attendance[1]	Type
2/20/2013	Snow Branch Library in Spotsylvania, VA	10	1st public
2/21/2013	Ashland Town Hall in Ashland, VA	32	1st public
2/24/2014	Ashland Public Library in Ashland, VA	9	2nd public
2/26/2014	Snow Branch Library in Spotsylvania, VA	8	2nd public

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

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

This page was intentionally left blank.

REFERENCES

American Veterinary Medical Association – Center for Information Management. 1997 U.S. Pet Ownership and Demographics Sourcebook.

ASAE Standards, 45th Edition. 1998. D384.1 DEC93. Manure Production and Characteristics. St. Joseph, Mich.: ASAE.

Bidrowski, T. 2003, Virginia Department of Game and Inland Fisheries. Personal telecommunication, 01/29/03.

Bidrowski, T. 2004. Virginia Department of Game and Inland Fisheries. Personal telecommunication. July 16, 2004 and August 9, 2004.

Costanzo, G. 2003, Virginia Department of Game and Inland Fisheries. Personal telecommunication, 01/29/03.

Farrar, R. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication.

Fies, M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. 08/11/04, 08/12/04, and 08/24/04.

Geldreich, E. E. 1978. Bacterial Populations and Indicator Concepts in Feces, Sewage, Stormwater, and Solid Wastes. In Indicators of Viruses in Water and Food, ed. G. Berg. Ann Arbor, Mich.: Ann Arbor Science Publishers, Inc.

Knox, W. M. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. August 03, 2004, August 05, 2004, and August 25, 2004.

MapTech. 1999. Unpublished source sampling data. Blackwater River TMDL Study.

MapTech. 2002. Modeling Cattle Stream Access. Submitted to: VADCR, in cooperation with Biological Systems Engineering Department, Virginia Tech.

Mayhorn, R. 2005. Buchanan County Bird Club. Personal Communication. 08/17/05.

Norman, G. 2004. Virginia Department of Game & Inland Fisheries. Personal telecommunication. July 12, 2004.

Norman, G.W. 2003. Virginia Department of Game and Inland Fisheries. Personal telecommunication.

NRCS. 2012. Regional Hydraulic Geometry Curves. http://wmc.ar.nrcs.usda.gov/technical/HHSWR/Geomorphic/

Raftovich, R. V. 2004. Atlantic Flyway Breeding Waterfowl Plot Survey: Breeding Pair and Population Size Estimates 2004. U.S. Fish and Wildlife Service. Division of

Migratory Bird Management. July 28, 2004.Reneau, R.B., Jr. 2000. Department of Crop and Soil Environmental Sciences, Virginia Tech. Personal communication. January 7, 2000.

Rose, R.K., Cranford, J.A. 1987. Handbook of Virginia Mammals. Final Report, Project No. 567460. VA Dept. Game & Inland Fisheries, Richmond, VA: 121.

SERCC. 2011. Southeast Regional Climate Center. http://www.sercc.com/

USCB, 1990. *1990 Census*. United States Census Bureau. Washington D.C.

USCB, 2010. *2010 Census*. United States Census Bureau. Washington D.C.

USEPA, 2007. Options for Expressing Daily Loads in TMDLs.

VADCR and VADEQ. 2003. Guidance Manual for Total Maximum Daily Load Implementation Plans. http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf.

VADEQ. 2002. Section 303(d) Water Quality Assessment Integrated Report.

VADEQ. 2003a. Guidance Memo No. 03-2012. HSPF Model Calibration and Verification for Bacteria TMDLs. Memo from Larry G. Lawson to Regional Directors. September 3, 2003.

VADEQ. 2003b. Guidance Memo No. 03-2004. Managing Water Monitoring Programs While Under Reduced Resources. Memo from Larry G. Lawson to Regional Directors of the VADEQ. February 10, 2003. Accessible at: http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/042005b.pdf

VADEQ. 2004. Section 303(d) Water Quality Assessment Integrated Report.

VADEQ. 2006. Section 303(d) Water Quality Assessment Integrated Report.

VADEQ. 2008. Section 303(d) Water Quality Assessment Integrated Report.

VADEQ. 2010. Final 2010 305(B)/303(D) Water Quality Assessment Integrated Report. Chapter 2.4. http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityAssessments/2010305b303dIntegratedReport.aspx.

VASS. 1999. Virginia Agricultural Statistics Bulletin 1997. Virginia Agricultural Statistics Service. Richmond, VA.

VASS. 2005. Virginia Agricultural Statistics Bulletin 2001. Virginia Agricultural Statistics Service. Richmond, VA.

VDEQ. August 2005. Bacteria TMDLs for York River Basin - Orange, Louisa, Spotsylvania Counties, Virginia. Virginia Department of Environmental Quality, Richmond, VA.

VDGIF. 1999. www.dgif.state.va.us. Virginia Fish and Wildlife Information Service.

Weiskel. P. A., B. L. Howes, and G. R. Heufelder. 1996. Coliform contamination of a coastal embayment: sources and transport pathways. Environ. Sci. Technol. 30:1872-1881.

Yagow, E. 1999. Unpublished monitoring data. Mountain Run TMDL Study.

This page was intentionally left blank.

GLOSSARY

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

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

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

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

Antidegradation Policies*. Policies that are part of each states water quality standards. These policies are designed to protect water quality and provide a method of assessing activities that might affect the integrity of waterbodies.*

Aquatic ecosystem. *Complex of biotic and abiotic components of natural waters. The aquatic ecosystem is an ecological unit that includes the physical characteristics (such as flow or velocity and depth), the biological community of the water column and benthos, and the chemical characteristics such as dissolved solids, dissolved oxygen, and nutrients. Both living and nonliving components of the aquatic ecosystem interact and influence the properties and status of each component.*

Assimilative capacity*. The amount of contaminant load that can be discharged to a specific waterbody without exceeding water quality standards or criteria. Assimilative capacity is used to define the ability of a waterbody to naturally absorb and use a discharged substance without impairing water quality or harming aquatic life.*

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

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

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

Benthic. *Refers to material, especially sediment, at the bottom of an aquatic ecosystem. It can be used to describe the organisms that live on, or in, the bottom of a waterbody.*

Benthic organisms. *Organisms living in, or on, bottom substrates in aquatic ecosystems.*

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

Bioassessment. Evaluation of the condition of an ecosystem that uses biological surveys and other direct measurements of the resident biota.

Biochemical Oxygen Demand (BOD). Represents the amount of oxygen consumed by bacteria as they break down organic matter in the water.

Biological Integrity. A water body's ability to support and maintain a balanced, integrated adaptive assemblage of organisms with species composition, diversity, and functional organization comparable to that of similar natural, or non-impacted habitat.

Biometric. (Biological Metric) The study of biological phenomena by measurements and statistics.

Box and whisker plot. A graphical representation of the mean, lower quartile, upper quartile, upper limit, lower limit, and outliers of a data set.

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

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).*

Concentration-based limit. *A limit based on the relative strength of a pollutant in a waste stream, usually expressed in milligrams per liter (mg/L).*

Concentration-response model. A quantitative (usually statistical) model of the relationship between the concentration of a chemical to which a population or community of organisms is exposed and the frequency or magnitude of a biological response. (2)

Conductivity. An indirect measure of the presence of dissolved substances within water.

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

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

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

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

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

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

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

Critical condition. *The critical condition can be thought of as the "worst case" scenario of environmental conditions in the waterbody in which the loading expressed in the TMDL for the pollutant of concern will continue to meet water quality standards. Critical conditions are the combination of environmental factors (e.g., flow, temperature, etc.) that results in attaining and maintaining the water quality criterion and has an acceptably low frequency of occurrence.*

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

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

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

Dilution. *The addition of some quantity of less-concentrated liquid (water) that results in a decrease in the original concentration.*

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

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

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

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

Dispersion. *The spreading of chemical or biological constituents, including pollutants, in various directions at varying velocities depending on the differential in-stream flow characteristics.*

Dissolved Oxygen (DO). The amount of oxygen in water. DO is a measure of the amount of oxygen available for biochemical activity in a waterbody.

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

DNA. Deoxyribonucleic acid. The genetic material of cells and some viruses.

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

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

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

Dynamic simulation. *Modeling of the behavior of physical, chemical, and/or biological phenomena and their variations over time.*

Ecoregion. A region defined in part by its shared characteristics. These include meteorological factors, elevation, plant and animal speciation, landscape position, and soils.

Ecosystem. *An interactive system that includes the organisms of a natural community association together with their abiotic physical, chemical, and geochemical environment.*

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

Effluent guidelines. *The national effluent guidelines and standards specify the achievable effluent pollutant reduction that is attainable based upon the performance of treatment technologies employed within an industrial category. The National Effluent Guidelines Program was established with a phased approach whereby industry would first be required to meet interim limitations based on best practicable control technology currently available for existing sources (BPT). The second level of effluent limitations to be attained by industry was referred to as best available technology economically achievable (BAT), which was established primarily for the control of toxic pollutants.*

Effluent limitation. *Restrictions established by a state or EPA on quantities, rates, and concentrations in pollutant discharges.*

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

Enhancement. *In the context of restoration ecology, any improvement of a structural or functional attribute.*

Erosion. The detachment and transport of soil particles by water and wind. Sediment resulting from soil erosion represents the single largest source of nonpoint pollution in the United States.

Eutrophication. The process of enrichment of water bodies by nutrients. Waters receiving excessive nutrients may become eutrophic, are often undesirable for recreation, and may not support normal fish populations.

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

Fate of pollutants*. Physical, chemical, and biological transformation in the nature and changes of the amount of a pollutant in an environmental system. Transformation processes are pollutant-specific. Because they have comparable kinetics, different formulations for each pollutant are not required.*

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

Flux. *Movement and transport of mass of any water quality constituent over a given period of time. Units of mass flux are mass per unit time.*

General Standard. A narrative standard that ensures the general health of state waters. All state waters, including wetlands, shall be free from substances attributable to sewage, industrial waste, or other waste in concentrations, amounts, or combinations which contravene established standards or interfere directly or indirectly with designated uses of such water or which are inimical or harmful to human, animal, plant, or aquatic life (9VAC25-260-20). (4)

GIS. Geographic Information System. A system of hardware, software, data, people, organizations and institutional arrangements for collecting, storing, analyzing and disseminating information about areas of the earth. (Dueker and Kjerne, 1989)

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

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

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

Hydrologic cycle*. The circuit of water movement from the atmosphere to the earth and its return to the atmosphere through various stages or processes, such as precipitation, interception, runoff, infiltration, storage, evaporation, and transpiration.*

Hydrology*. The study of the distribution, properties, and effects of water on the earth's surface, in the soil and underlying rocks, and in the atmosphere.*

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

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

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

Indicator organism. *An organism used to indicate the potential presence of other (usually pathogenic) organisms. Indicator organisms are usually associated with the other organisms, but are usually more easily sampled and measured.*

Indirect causation. The induction of effects through a series of cause-effect relationships, so that the impaired resource may not even be exposed to the initial cause.

Indirect effects. Changes in a resource that are due to a series of cause-effect relationships rather than to direct exposure to a contaminant or other stressor.

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

In situ. *In place; in situ measurements consist of measurements of components or processes in a full-scale system or a field, rather than in a laboratory.*

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

Leachate. *Water that collects contaminants as it trickles through wastes, pesticides, or fertilizers. Leaching can occur in farming areas, feedlots, and landfills and can result in hazardous substances entering surface water, ground water, or soil.*

Limits (upper and lower). The lower limit equals the lower quartile – 1.5x(upper quartile – lower quartile), and the upper limit equals the upper quartile + 1.5x(upper quartile – lower quartile). Values outside these limits are referred to as outliers.

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

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

Loading capacity (LC). *The greatest amount of loading a water can receive without violating water quality standards.*

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

conservative assumptions, additional MOS can be added as a separate component of the TMDL (in this case, quantitatively, a TMDL = LC = WLA + LA + MOS).

Mass balance. *An equation that accounts for the flux of mass going into a defined area and the flux of mass leaving the defined area. The flux in must equal the flux out.*

Mass loading. *The quantity of a pollutant transported to a waterbody.*

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

Metric ton (Mg or t). A unit of mass equivalent to 1,000 kilograms. An annual load of a pollutant is typically reported in metric tons per year (t/yr).

Metrics. Indices or parameters used to measure some aspect or characteristic of a water body's biological integrity. The metric changes in some predictable way with changes in water quality or habitat condition.

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

Mitigation. *Actions taken to avoid, reduce, or compensate for the effects of environmental damage. Among the broad spectrum of possible actions are those that restore, enhance, create, or replace damaged ecosystems.*

Model. Mathematical representation of hydrologic and water quality processes. Effects of 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.

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

Narrative criteria. *Nonquantitative guidelines that describe the desired water quality goals.*

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

Natural waters. *Flowing water within a physical system that has developed without human intervention, in which natural processes continue to take place.*

Nitrogen. An essential nutrient to the growth of organisms. Excessive amounts of nitrogen in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

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

Non-Stressor(s): Those stressors with data indicating normal conditions, without water quality standard violations, or without the observable impacts usually associated with a specific stressor, were eliminated as possible stressors.

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

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

Nutrient. An element or compound essential to life, including carbon, oxygen, nitrogen, phosphorus, and many others: as a pollutant, any element or compound, such as phosphorus or nitrogen, that in excessive amounts contributes to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

Organic matter. *The organic fraction that includes plant and animal residue at various stages of decomposition, cells and tissues of soil organisms, and substances synthesized by the soil population. Commonly determined as the amount of organic material contained in a soil or water sample.*

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

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

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

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

Permit Compliance System (PCS). *Computerized management information system that contains data on NPDES permit-holding facilities. PCS keeps extensive records on more*

than 65,000 active water-discharge permits on sites located throughout the nation. PCS tracks permit, compliance, and enforcement status of NPDES facilities.

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

Phosphorus. An essential nutrient to the growth of organisms. Excessive amounts of phosphorus in water can contribute to abnormally high growth of algae, reducing light and oxygen in aquatic ecosystems.

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

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

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

Polycyclic aromatic hydrocarbons (**PAH**s) are chemical compounds that consist of fused aromatic rings and do not contain heteroatoms or carry substituents. PAHs occur in oil, coal, and tar deposits, and are produced as byproducts of fuel burning (whether fossil fuel or biomass). As a pollutant, they are of concern because some compounds have been identified as carcinogenic, mutagenic, and teratogenic.

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

Postaudit. *A subsequent examination and verification of a model's predictive performance following implementation of an environmental control program.*

Privately owned treatment works. *Any device or system that is (a) used to treat wastes from any facility whose operator is not the operator of the treatment works and (b) not a publicly owned treatment works.*

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

Publicly owned treatment works (POTW). *Any device or system used in the treatment (including recycling and reclamation) of municipal sewage or industrial wastes of a liquid nature that is owned by a state or municipality. This definition includes sewers, pipes, or other conveyances only if they convey wastewater to a POTW providing treatment.*

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

Rapid Bioassessment Protocol II (RBP II). A suite of measurements based on a quantitative assessment of benthic macroinvertebrates and a qualitative assessment of their habitat. RBP II scores are compared to a reference condition or conditions to determine to what degree a water body may be biologically impaired.

Reach. Segment of a stream or river.

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

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

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

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

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

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

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

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

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

Seasonal Kendall test. A statistical tool used to test for trends in data, which is unaffected by seasonal cycles. (Gilbert, 1987)

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

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

Sewer. *A channel or conduit that carries wastewater and 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.

Spatial segmentation*. A numerical discretization of the spatial component of a system into one or more dimensions; forms the basis for application of numerical simulation models.*

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

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

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

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

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

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

Steady-state model. *Mathematical model of fate and transport that uses constant values of input variables to predict constant values of receiving water quality concentrations. Model variables are treated as not changing with respect to time.*

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.*

Stressor. Any physical, chemical, or biological entity that can induce an adverse response. [2]

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

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

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

Suspended Solids. Usually fine sediments and organic matter. Suspended solids limit sunlight penetration into the water, inhibit oxygen uptake by fish, and alter aquatic habitat.

Technology-based standards. *Effluent limitations applicable to direct and indirect sources that are developed on a category-by-category basis using statutory factors, not including water quality effects.*

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

Ton (T). A unit of measure of mass equivalent to 2,200 English lbs.

Topography. *The physical features of a geographic surface area including relative elevations and the positions of natural and man-made features.*

Total Dissolved Solids (TDS). A measure of the concentration of dissolved inorganic chemicals in water.

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

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

Transport of pollutants (in water). *Transport of pollutants in water involves two main processes: (1) advection, resulting from the flow of water, and (2) dispersion, or transport due to turbulence in the water.*

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

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

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

Variance. A measure of the variability of a data set. The sum of the squared deviations (observation – mean) divided by (number of observations) – 1.

VADACS. Virginia Department of Agriculture and Consumer Services.

VADCR. Virginia Department of Conservation and Recreation.

VADEQ. Virginia Department of Environmental Quality.

VDH. Virginia Department of Health.

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

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

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

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

Water quality-based permit*. A permit with an effluent limit more stringent than one based on technology performance. Such limits might be necessary to protect the designated use of receiving waters (e.g., recreation, irrigation, industry, or water supply).*

Water quality criteria*. Levels of water quality expected to render a body of water suitable for its designated use, composed of numeric and narrative criteria. Numeric criteria are scientifically derived ambient concentrations developed by the 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.

This page was intentionally left blank.

APPENDIX A: FREQUENCY ANALYSIS OF BACTERIA DATA

Legend for Appendix A figures:

- Samples meeting standard
- Samples violating standard

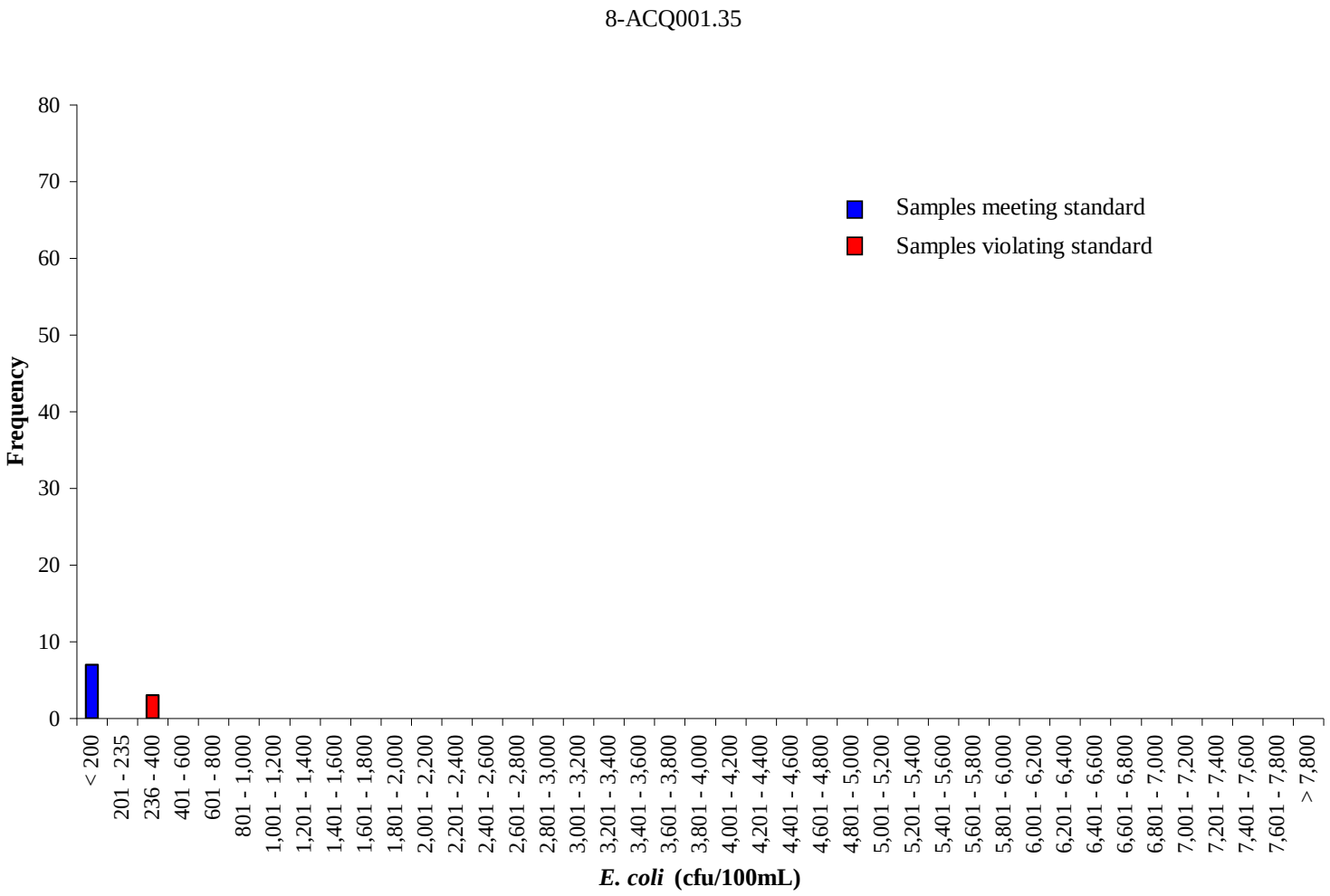

Figure A-1 Frequency analysis of *E. coli* concentrations at station 8-ACQ001.35 in Acquinton Creek for the period from January 2011 to October 2011.

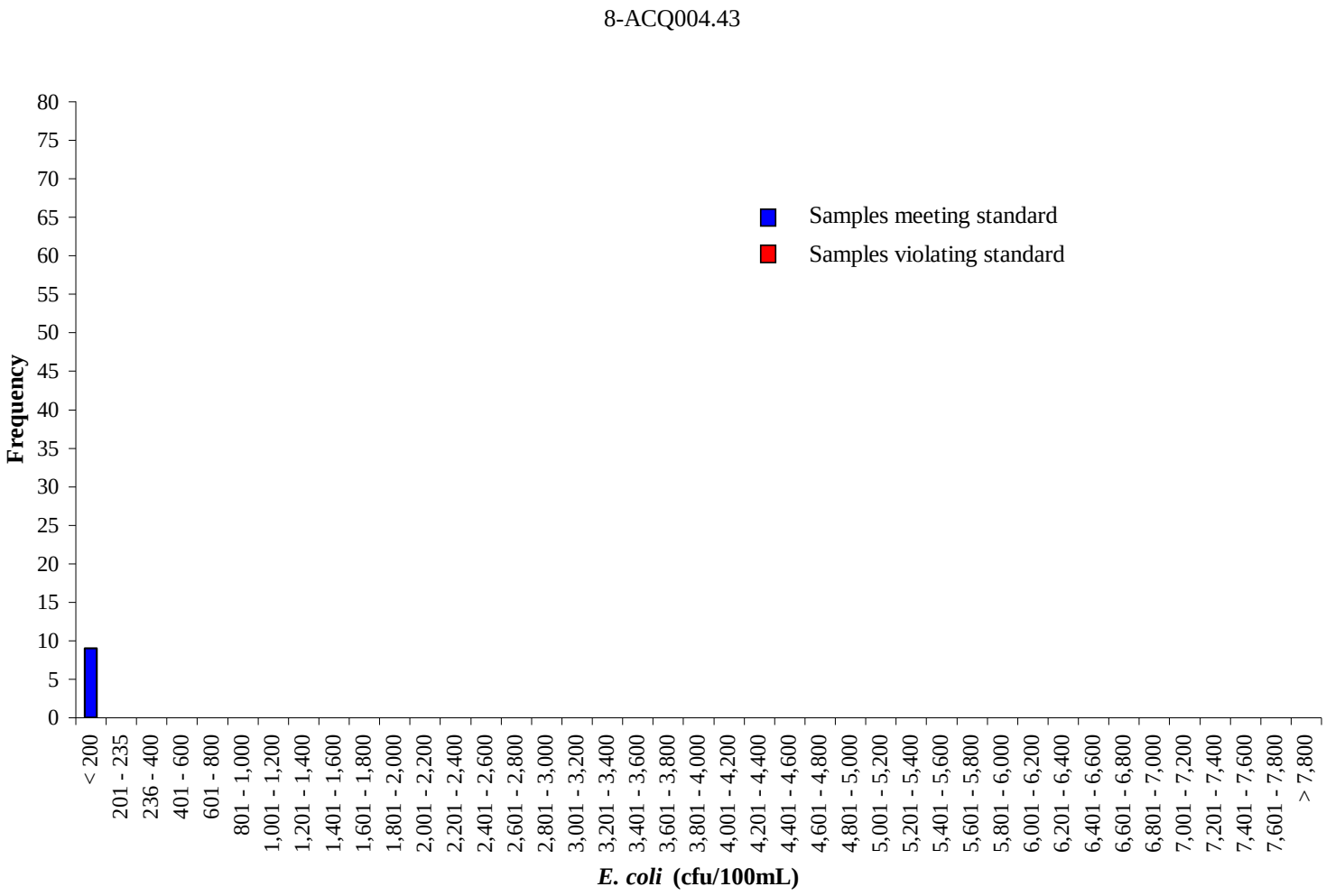

Figure A-2 Frequency analysis of *E. coli* concentrations at station 8-ACQ004.43 in Acquinton Creek for the period from January 2011 to October 2011.

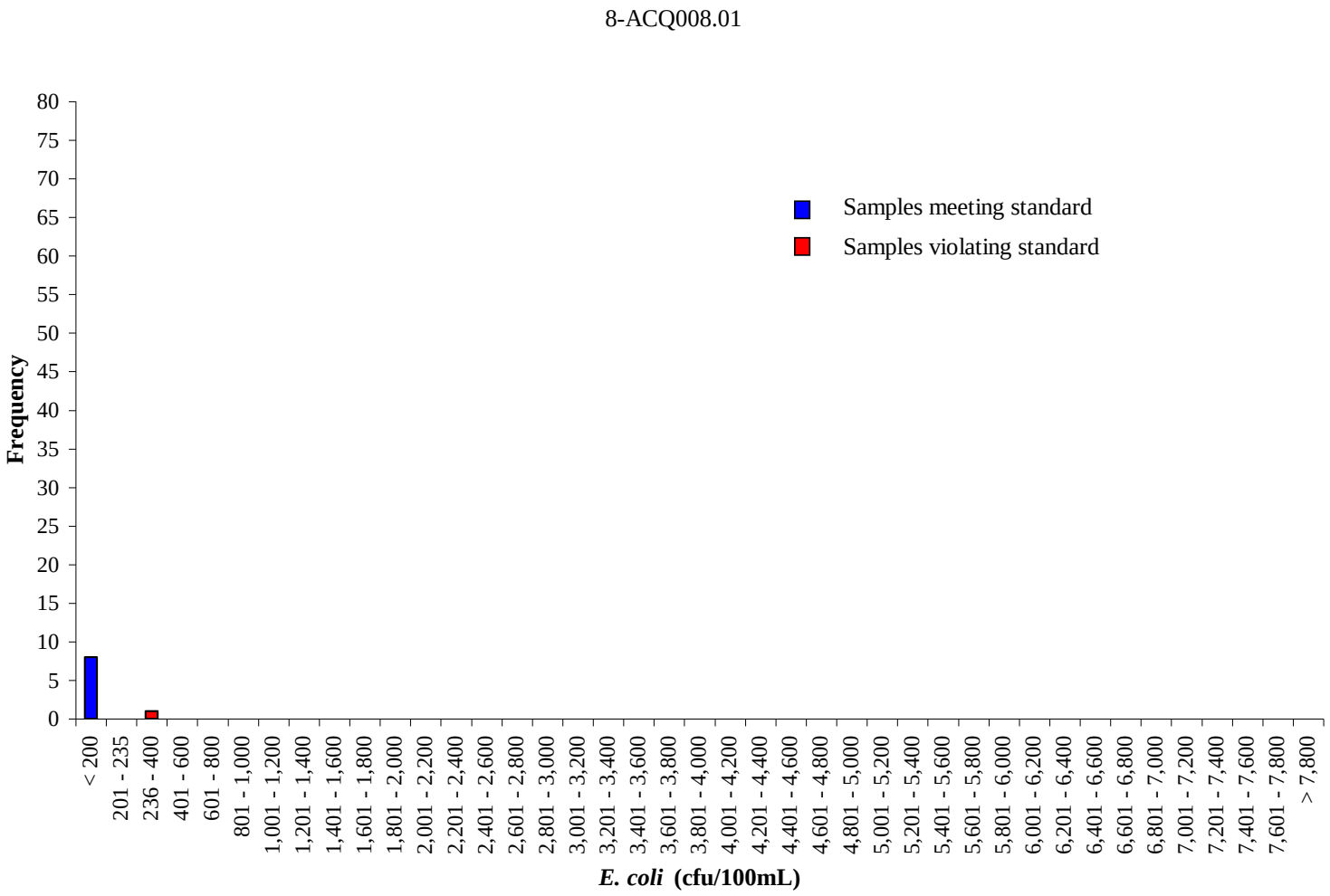

Figure A-3 Frequency analysis of *E. coli* concentrations at station 8-ACQ008.01 in Acquinton Creek for the period from January 2011 to October 2011.

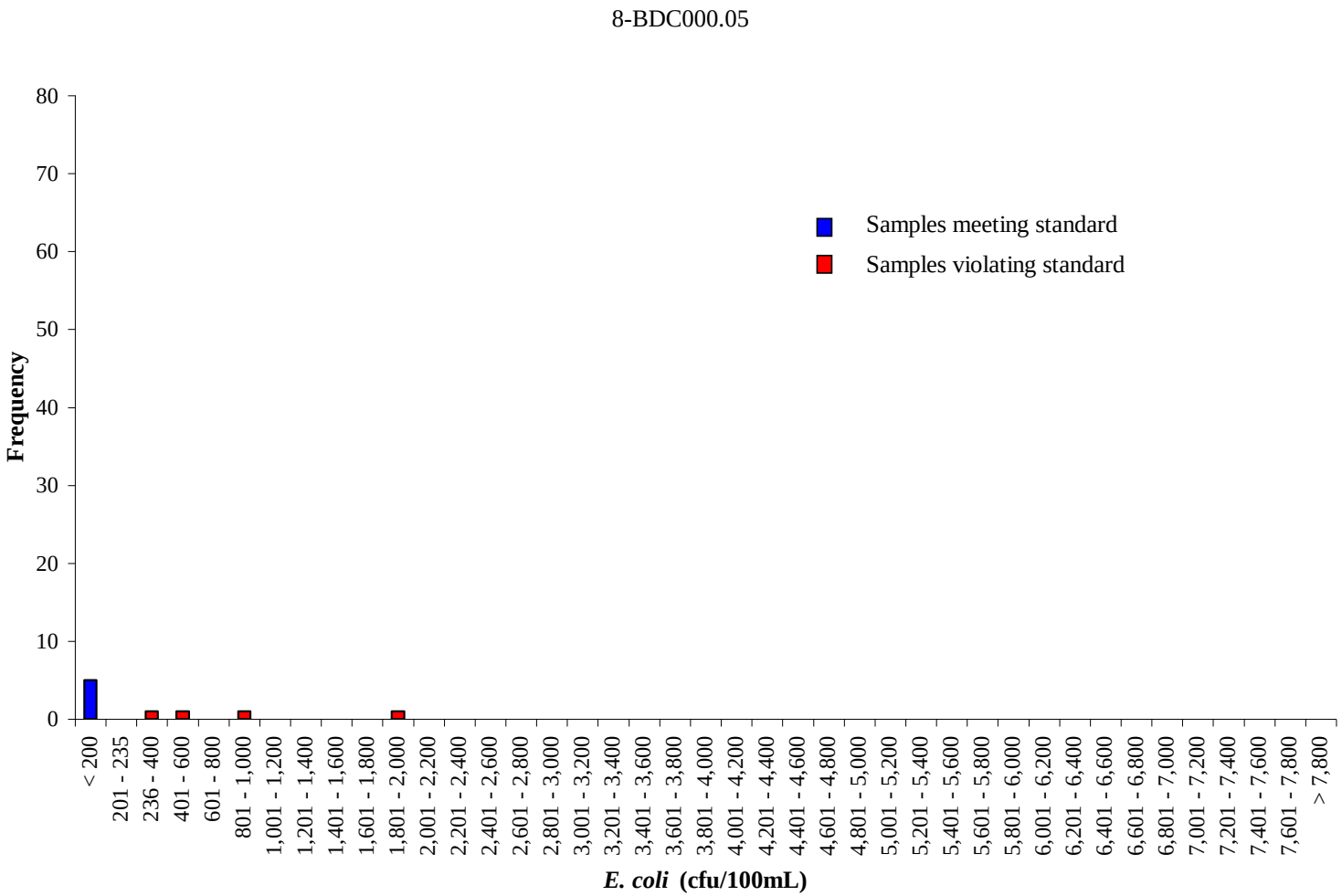

Figure A-4 Frequency analysis of *E. coli* concentrations at station 8-BDC000.05 in Beaverdam Creek for the period from February 2009 to November 2010.

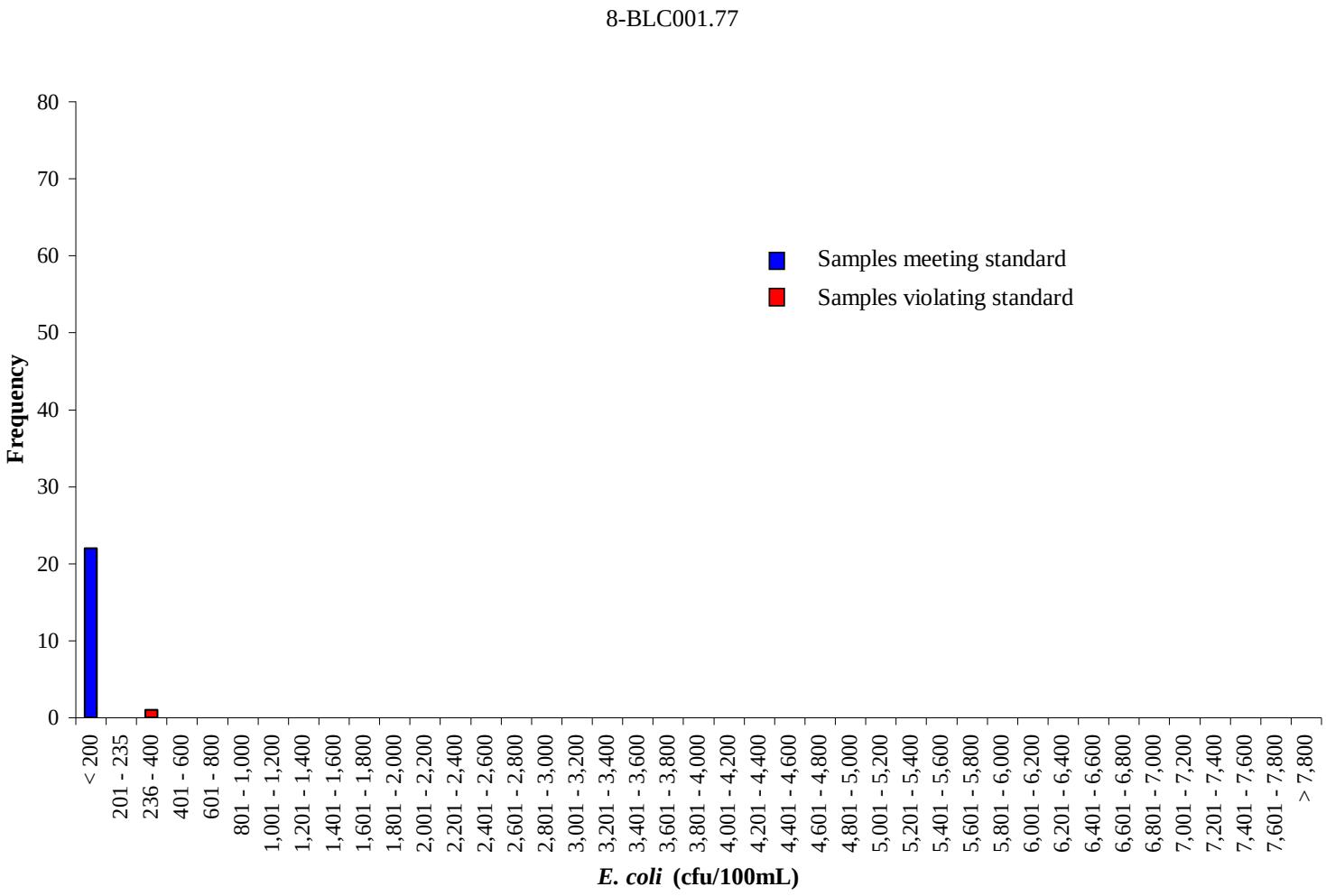

Figure A-5 Frequency analysis of *E. coli* concentrations at station 8-BLC001.77 in Black Creek for the period from July 2003 to March 2005.

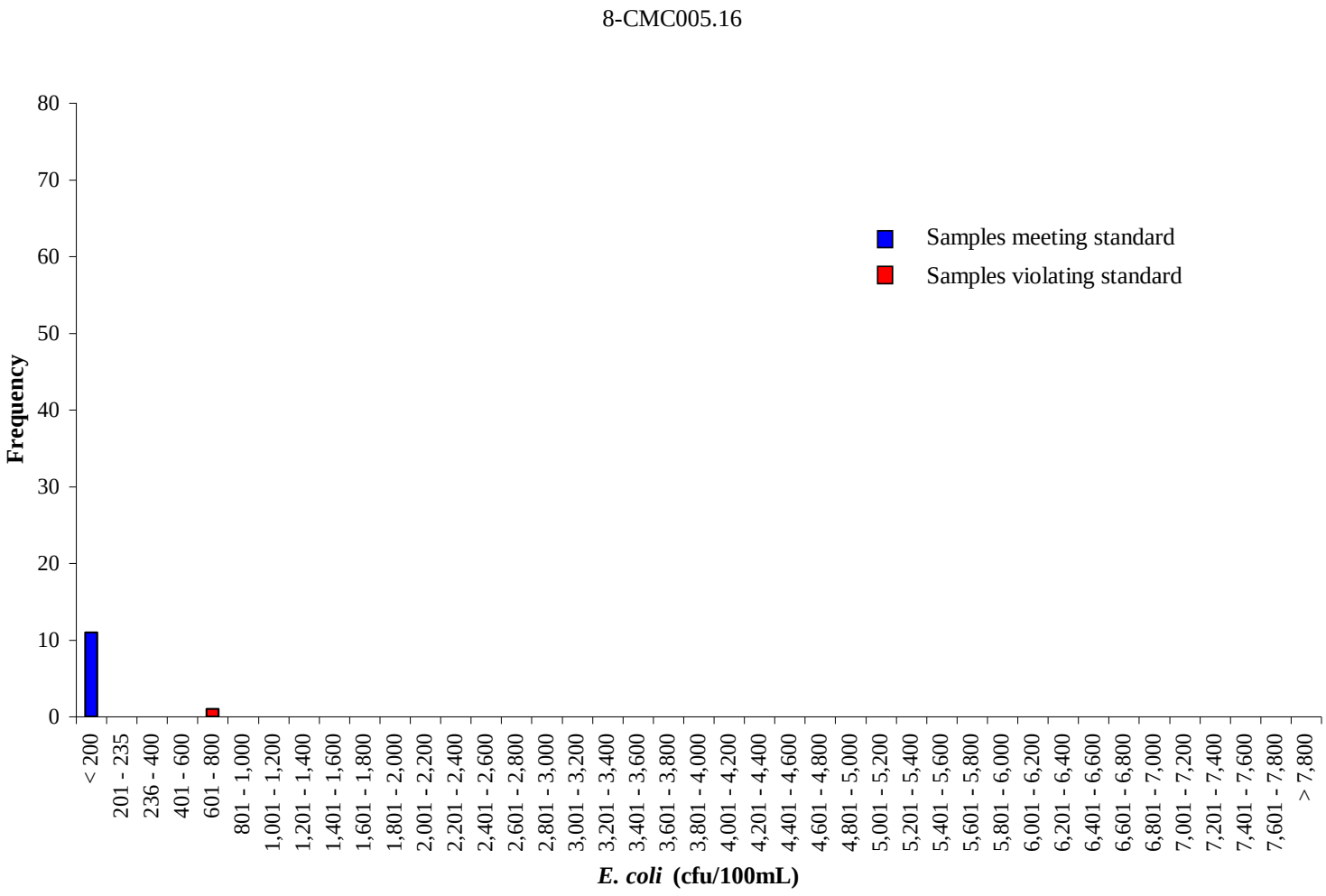

Figure A-6 Frequency analysis of *E. coli* concentrations at station 8-CMC005.16 in Cohoke Mill Creek for the period from February 2007 to December 2008.

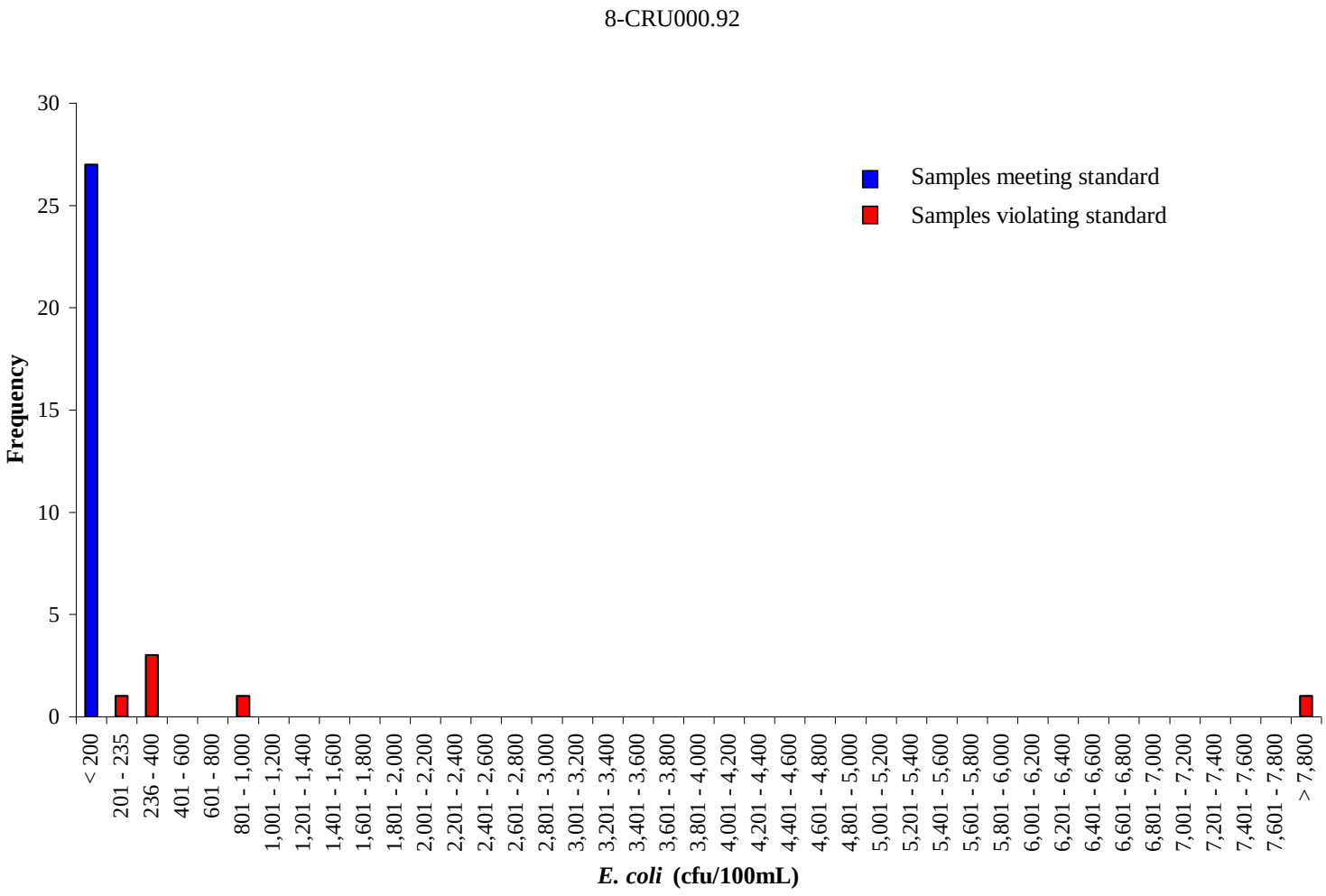

Figure A-7 Frequency analysis of *E. coli* concentrations at station 8-CRU000.92 in Crump Creek for the period from June 2005 to December 2010.

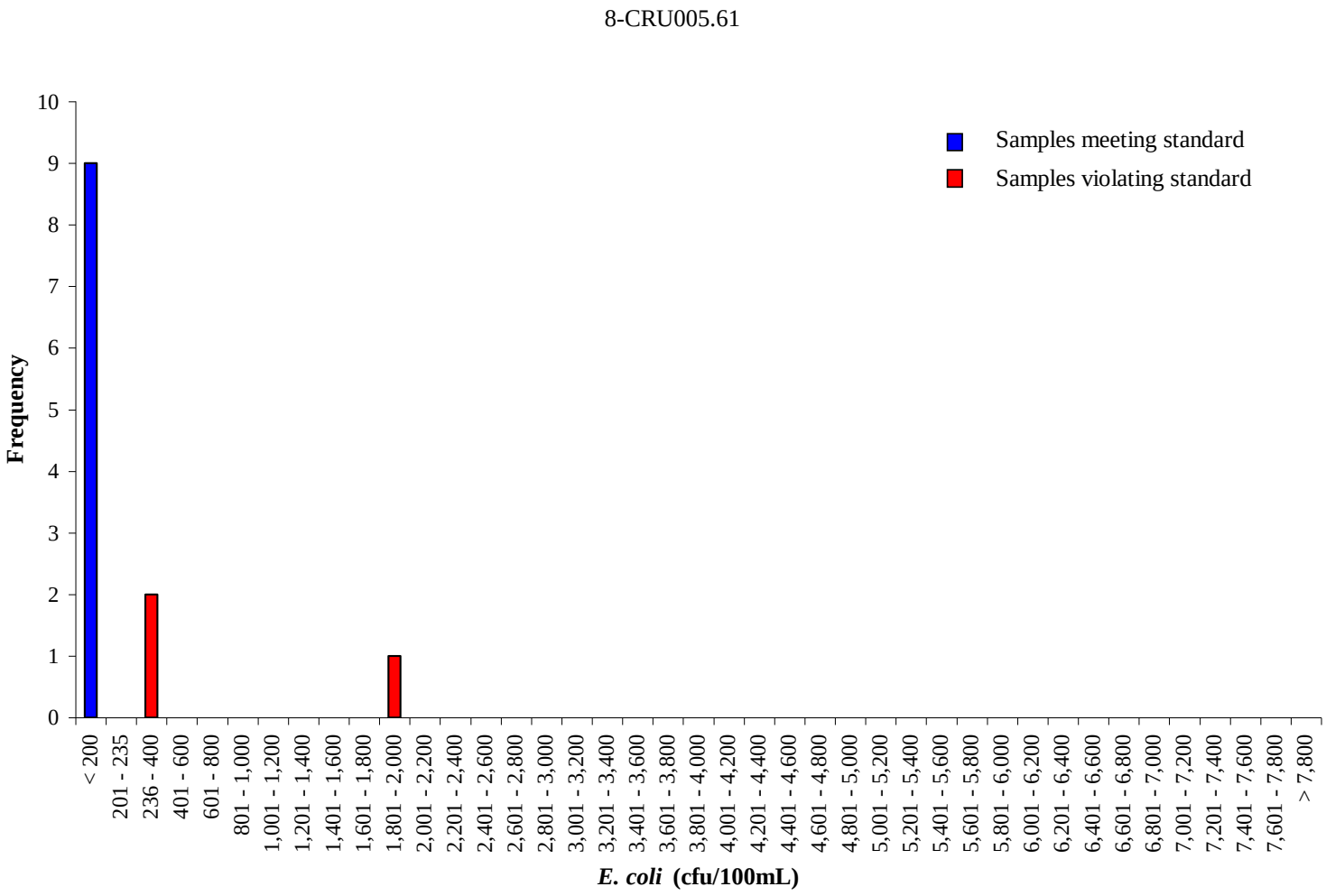

Figure A-8 Frequency analysis of *E. coli* concentrations at station 8-CRU005.61 in Crump Creek for the period from January 2010 to December 2010.

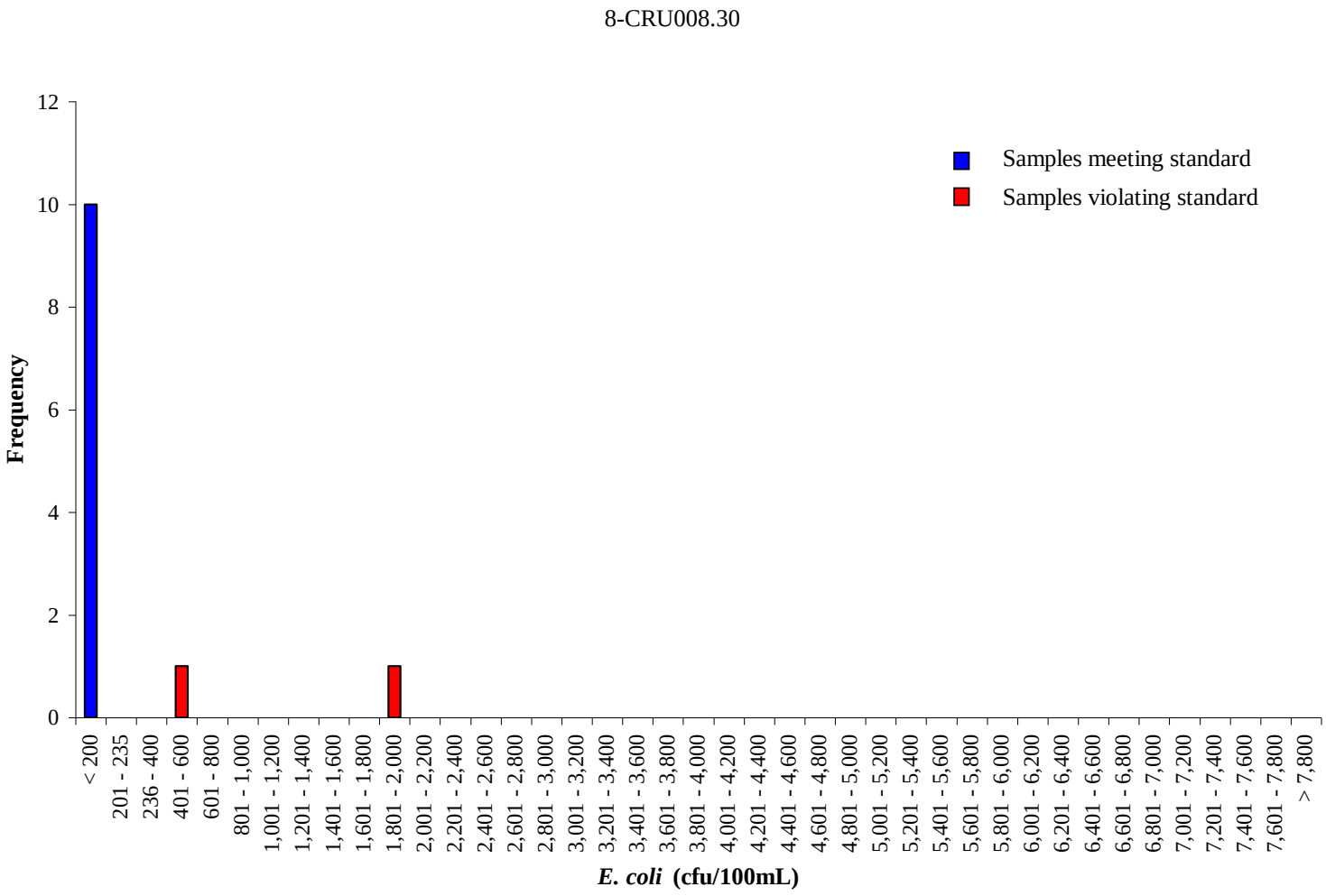

Figure A-9 Frequency analysis of *E. coli* concentrations at station 8-CRU008.30 in Crump Creek for the period from January 2010 to December 2010.

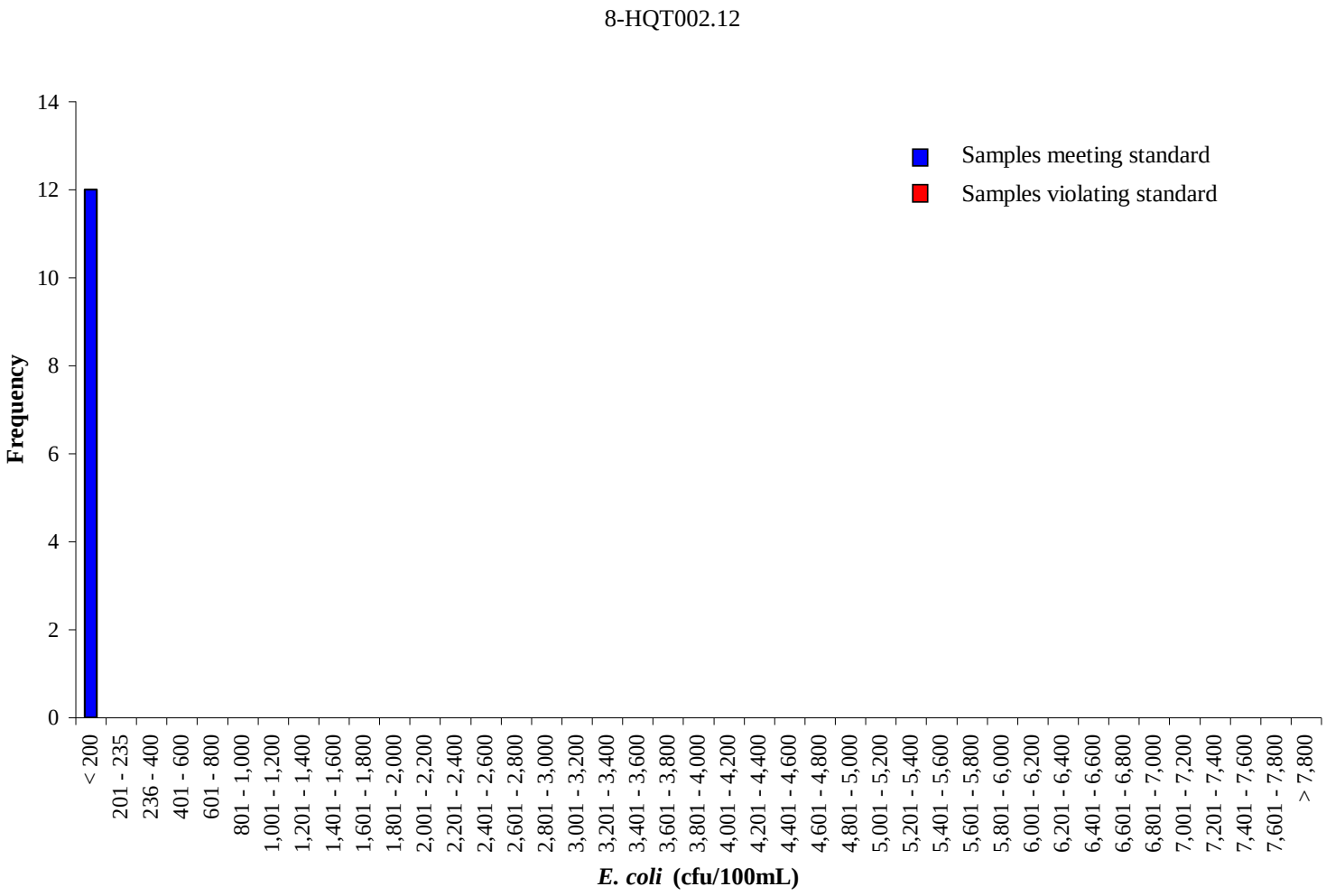

Figure A-10 Frequency analysis of *E. coli* concentrations at station 8-HQT002.12 in Hornquarter Creek for the period from July 2003 to June 2004.

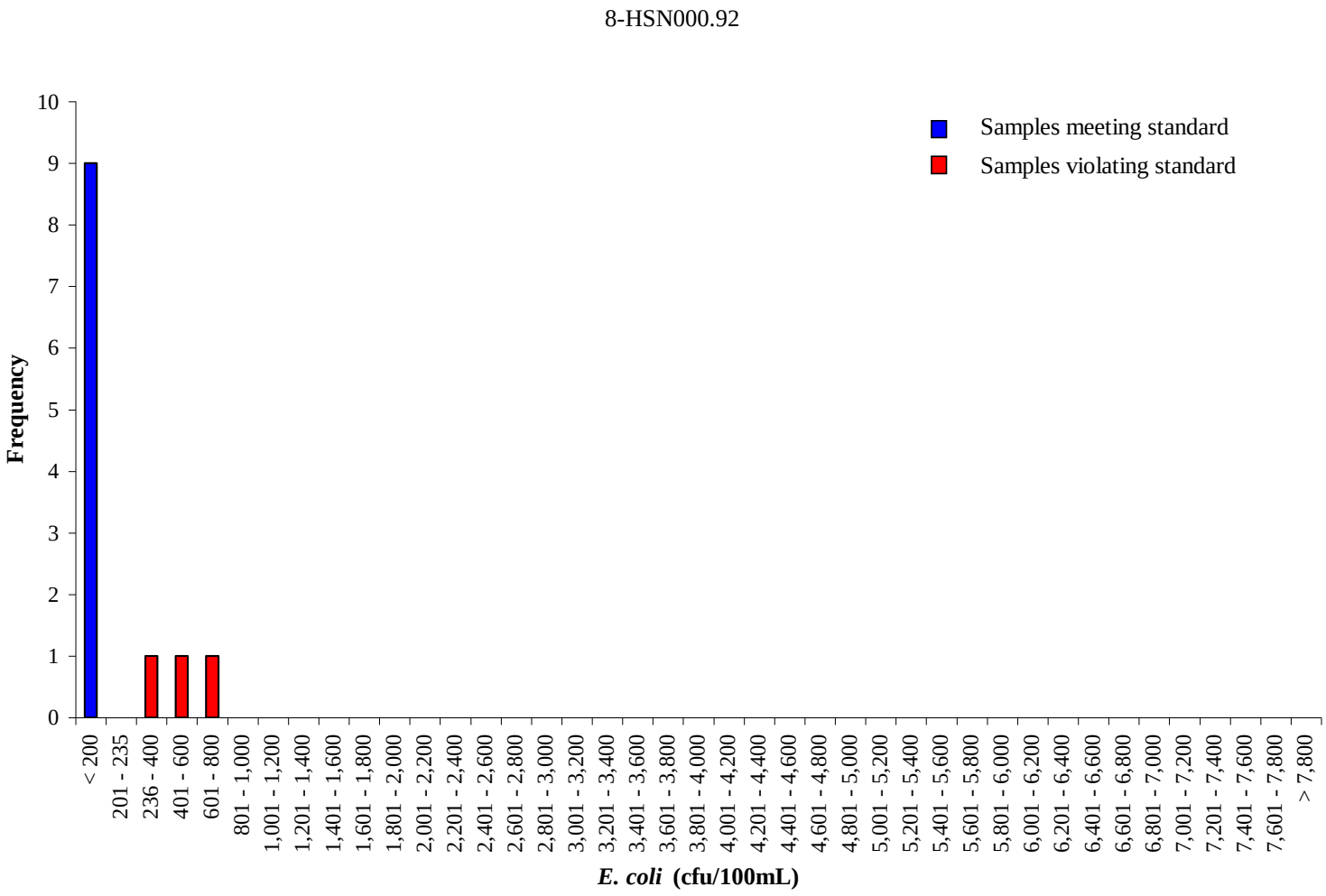

Figure A-11 Frequency analysis of *E. coli* concentrations at station 8-HSN000.92 in Harrison Creek for the period from April 2010 to March 2011.

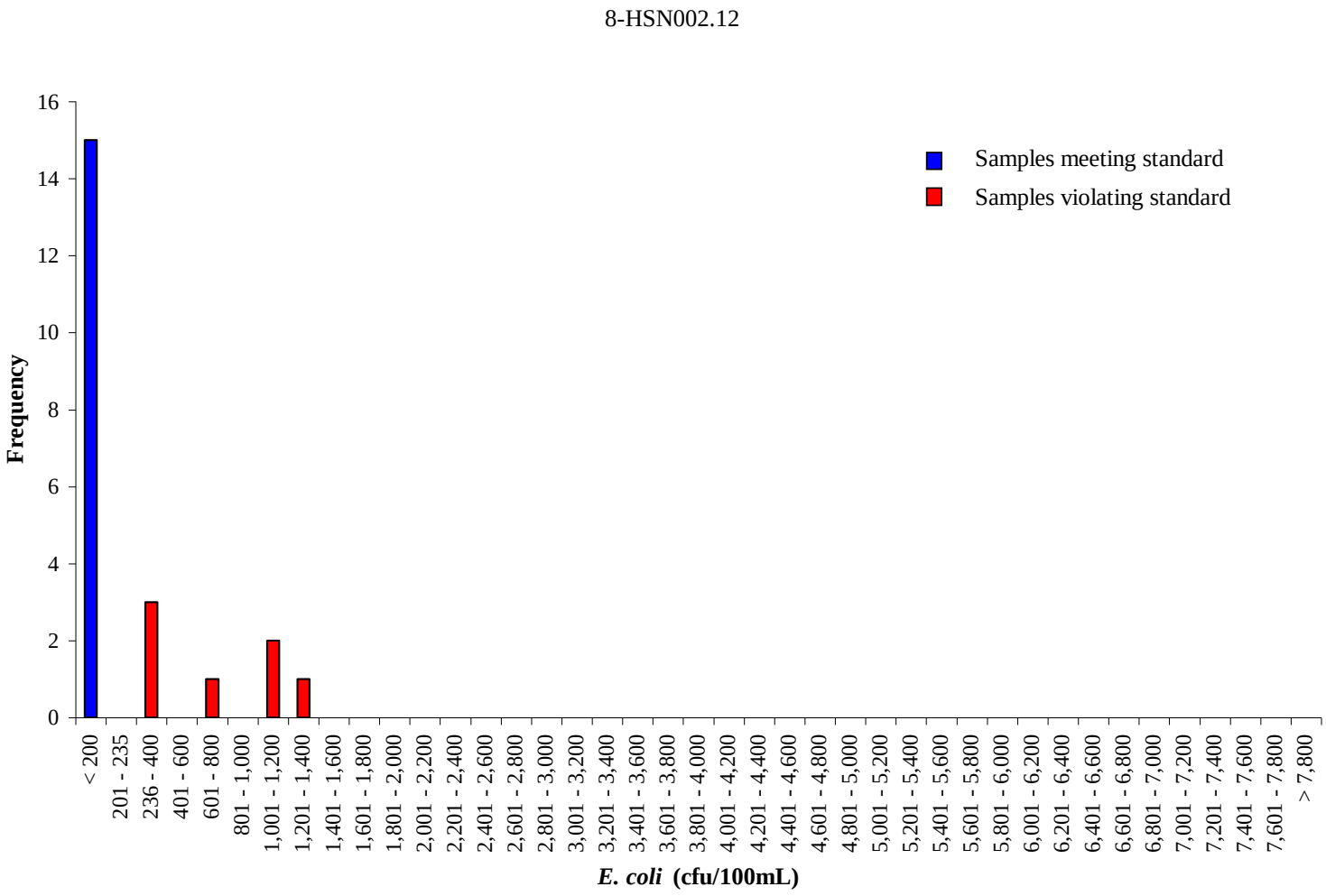

Figure A-12 Frequency analysis of *E. coli* concentrations at station 8-HSN002.12 in Harrison Creek for the period from May 2005 to March 2011.

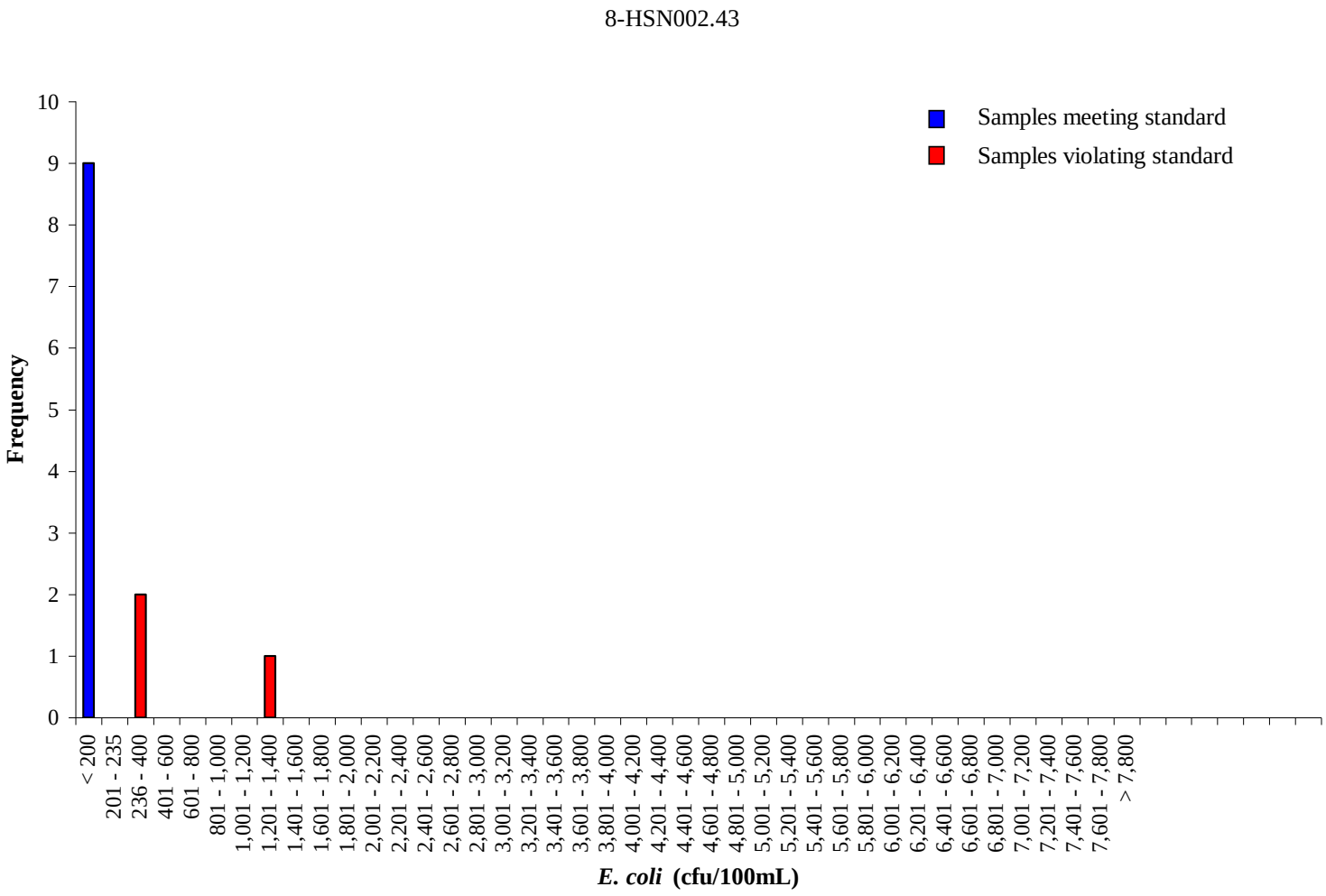

Figure A-13 Frequency analysis of *E. coli* concentrations at station 8-HSN002.43 in Harrison Creek for the period from April 2010 to March 2011.

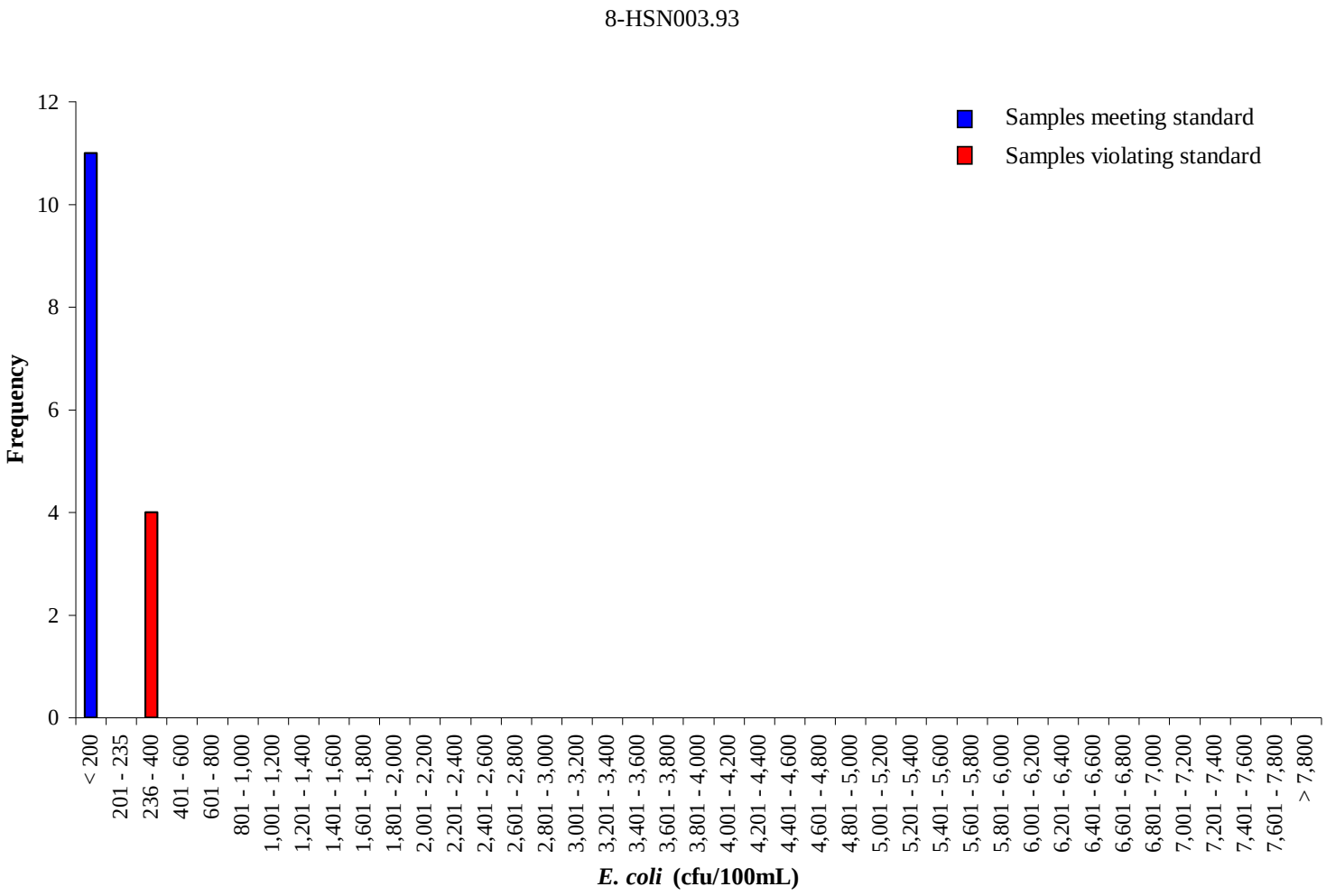

Figure A-14 Frequency analysis of *E. coli* concentrations at station 8-HSN003.93 in Harrison Creek for the period from April 2010 to September 2011.

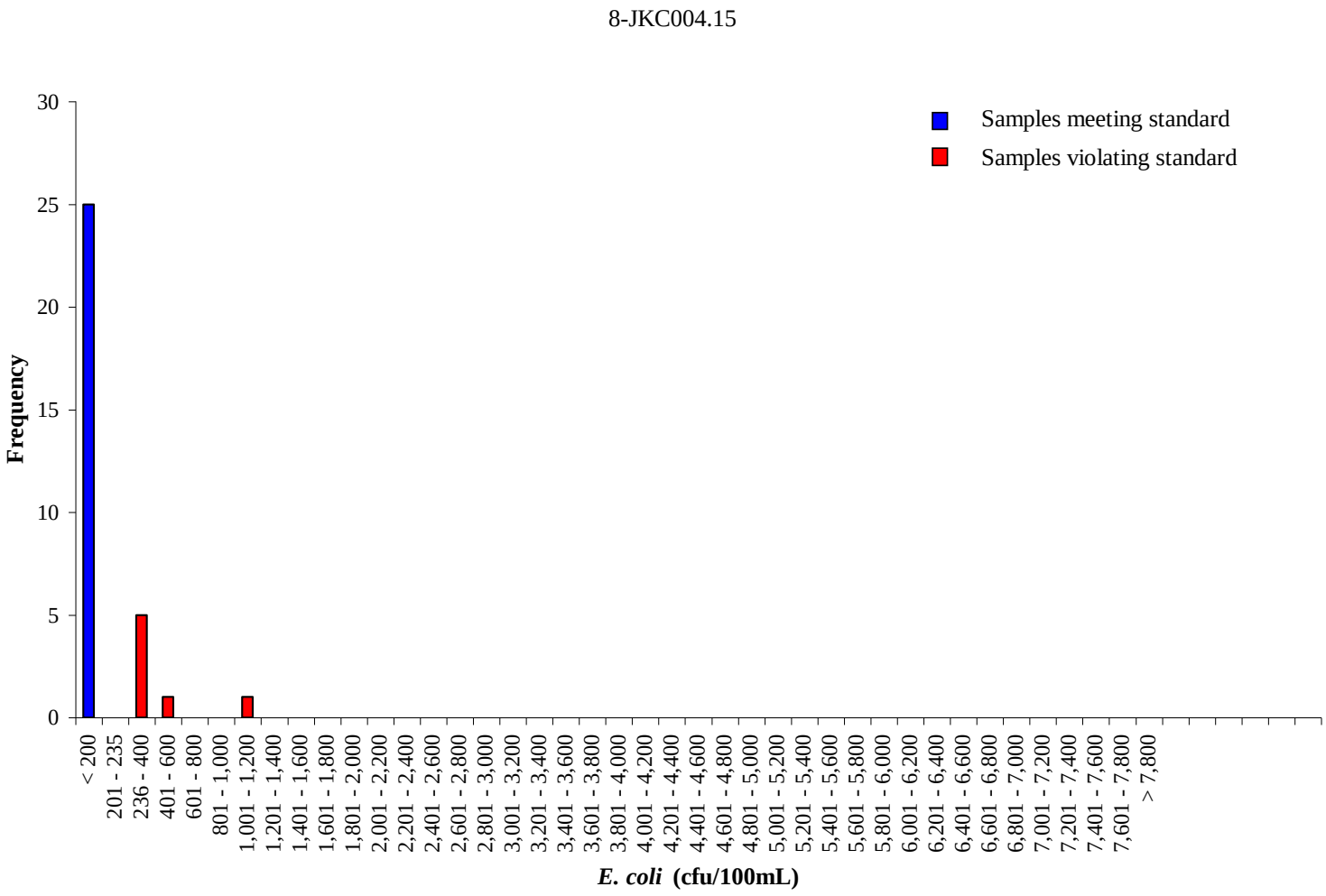

Figure A-15 Frequency analysis of *E. coli* concentrations at station 8-JKC004.15 in Jacks Creek for the period from July 2003 to October 2011.

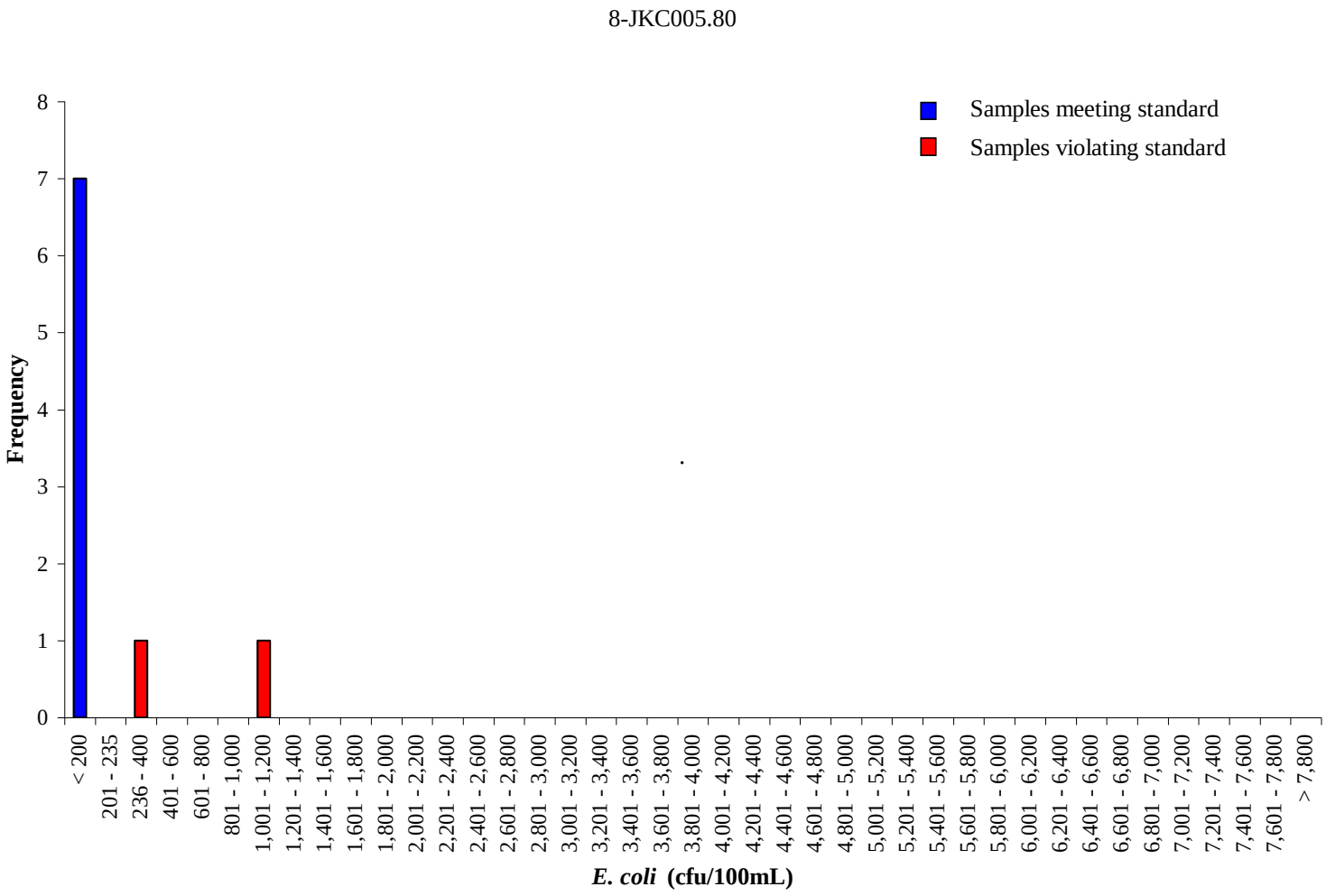

Figure A-16 Frequency analysis of *E. coli* concentrations at station 8-JKC005.80 in Jacks Creek for the period from January 2011 to October 2011.

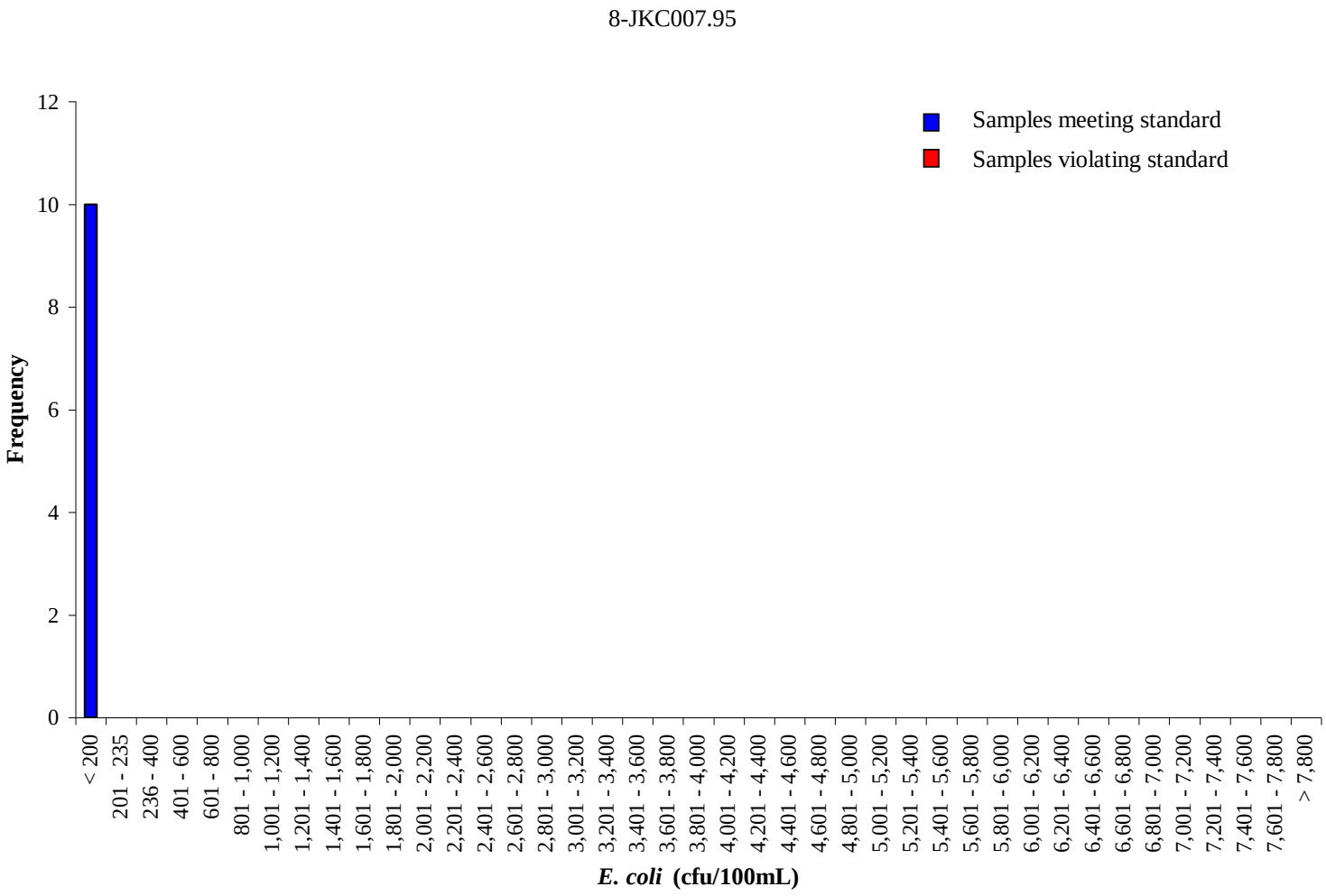

Figure A-17 Frequency analysis of *E. coli* concentrations at station 8-JKC007.95 in Jacks Creek for the period from January 2011 to October 2011.

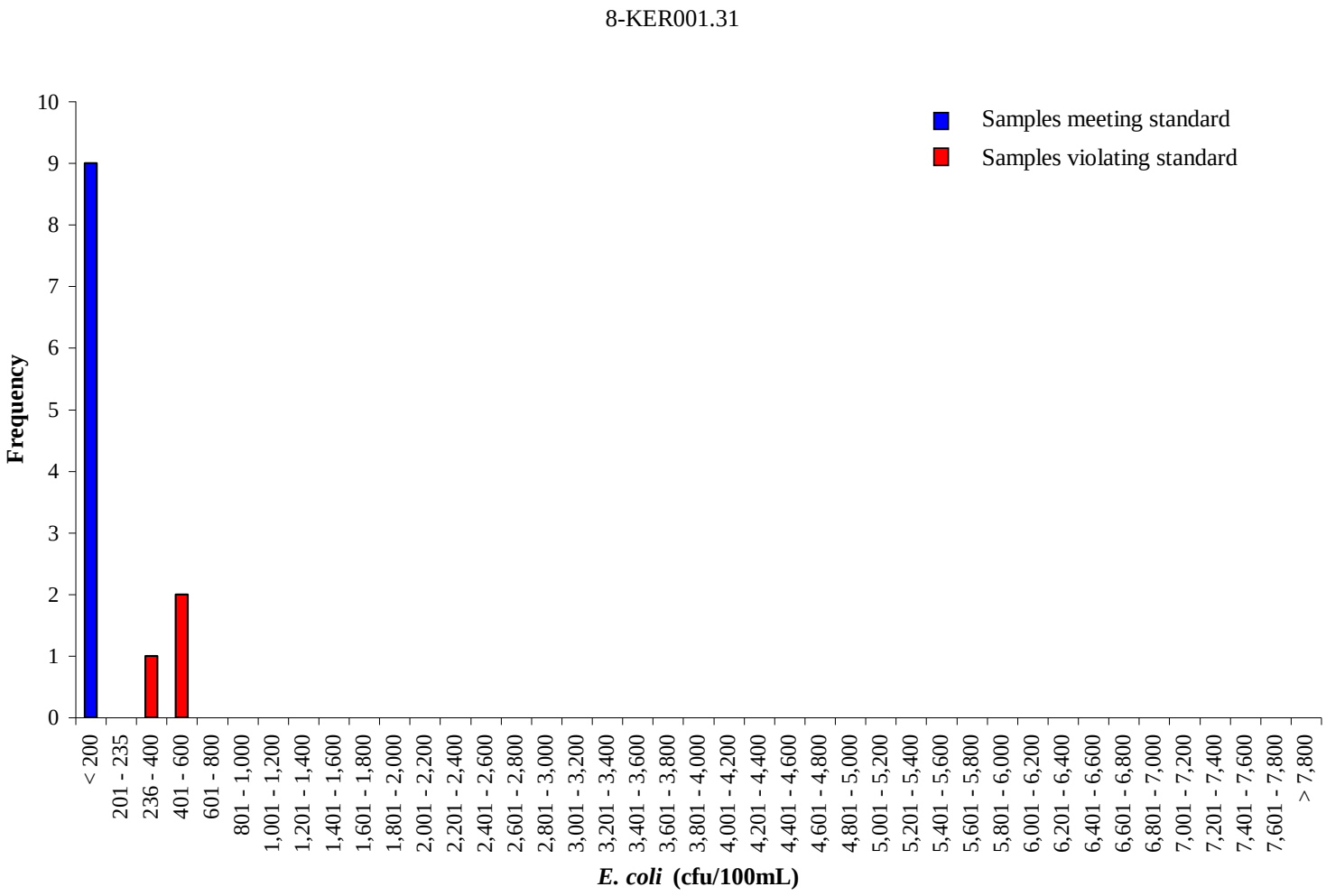

Figure A-18 Frequency analysis of *E. coli* concentrations at station 8-KER001.31 in Kersey Creek for the period from January 2010 to December 2010.

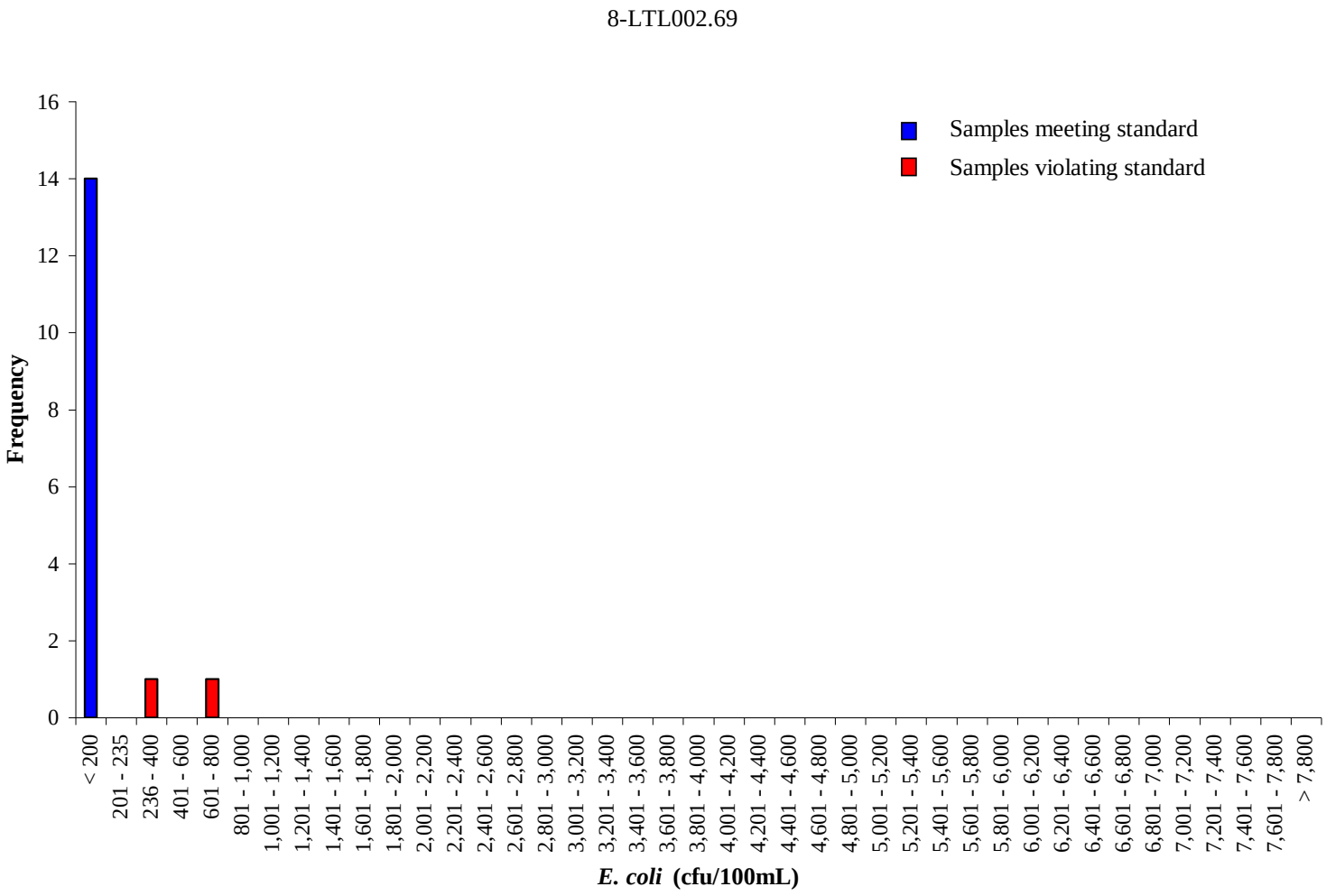

Figure A-19 Frequency analysis of *E. coli* concentrations at station 8-LTL002.69 in the Little River for the period from July 2003 to September 2011.

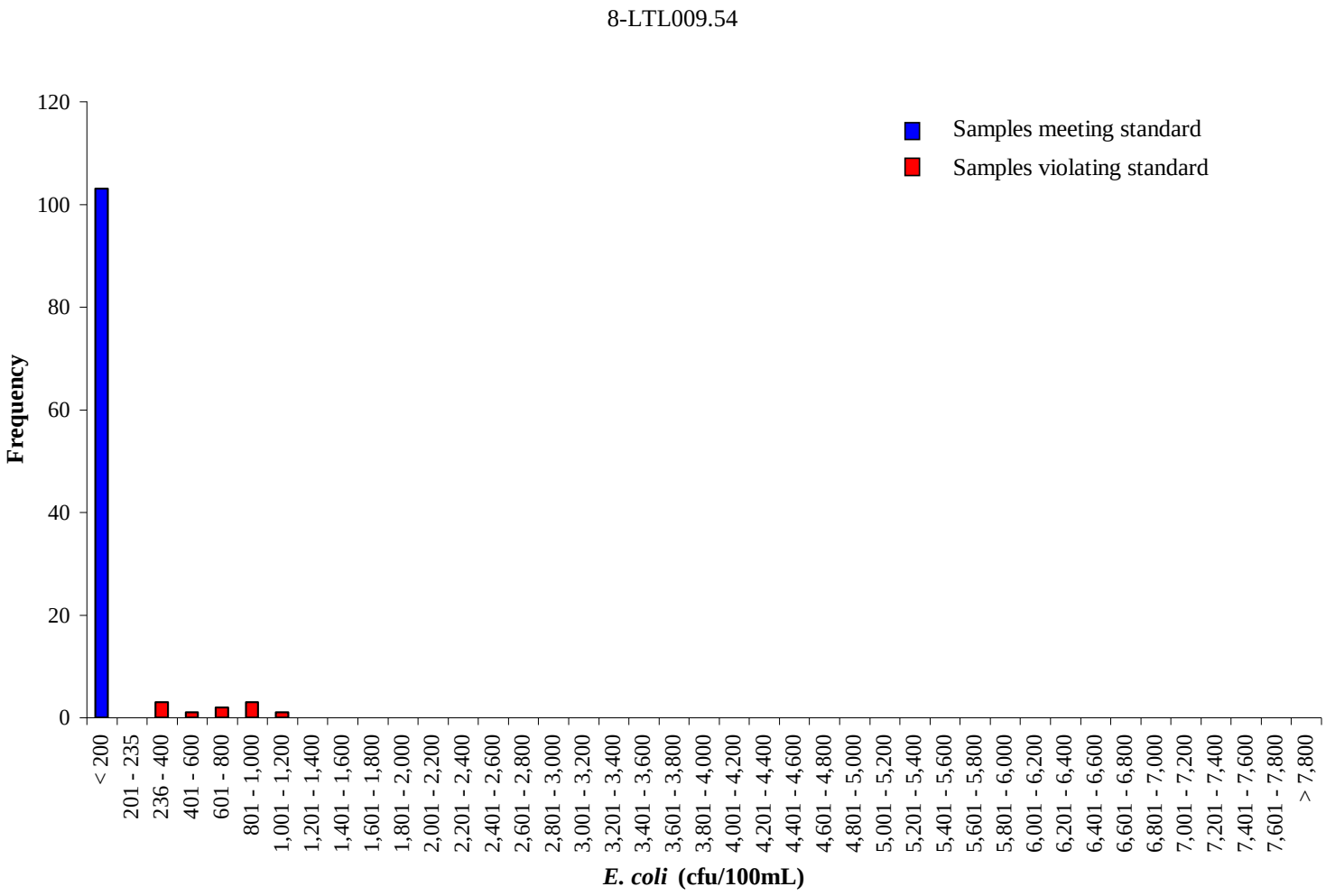

Figure A-20 Frequency analysis of *E. coli* concentrations at station 8-LTL009.54 in the Little River for the period from July 2003 to October 2011.

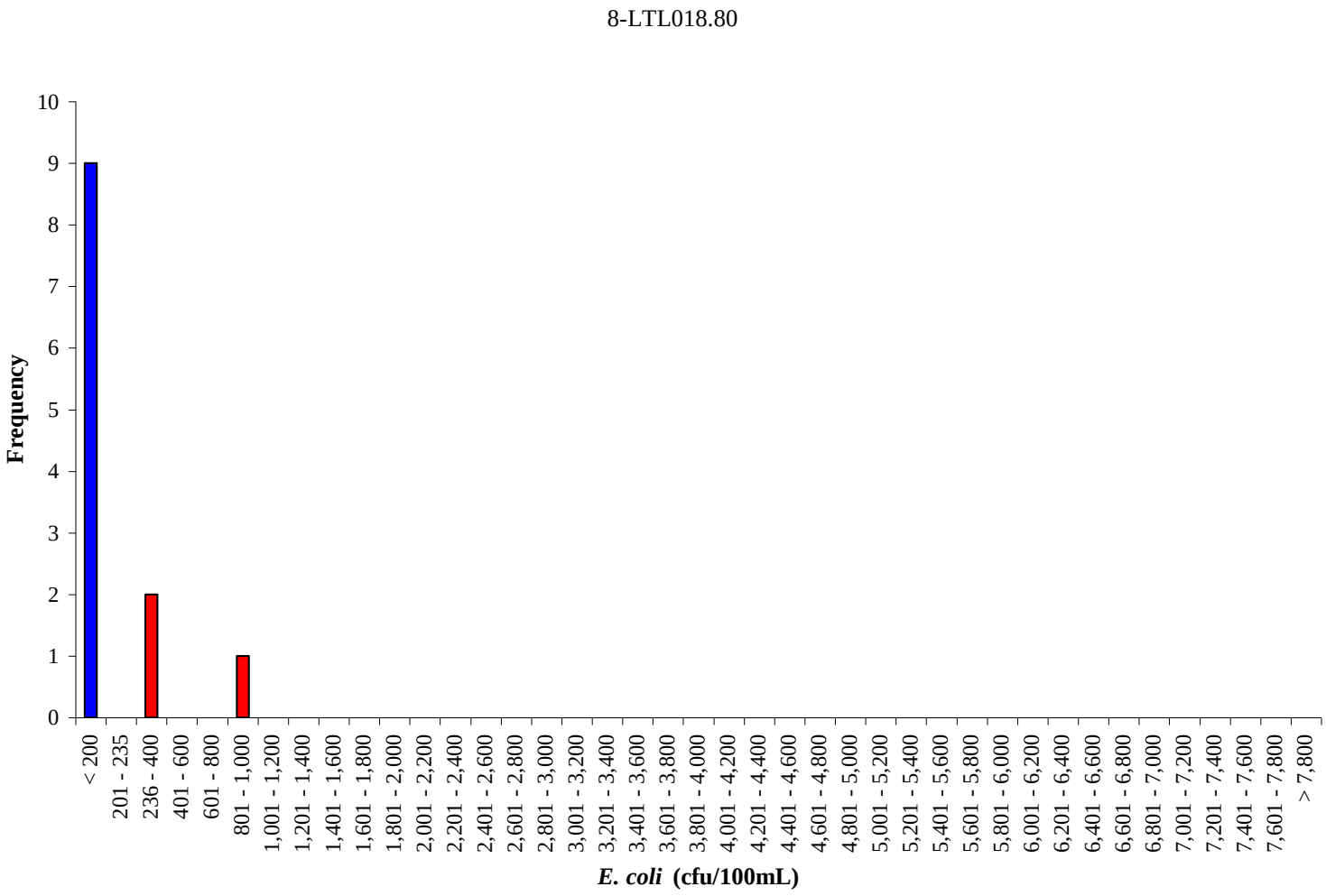

Figure A-21 Frequency analysis of *E. coli* concentrations at station 8-LTL018.80 in the Little River for the period from February 2009 to November 2010.

Figure A-22 Frequency analysis of *E. coli* concentrations at station 8-LTL024.86 in the Little River for the period from June 2005 to October 2011.

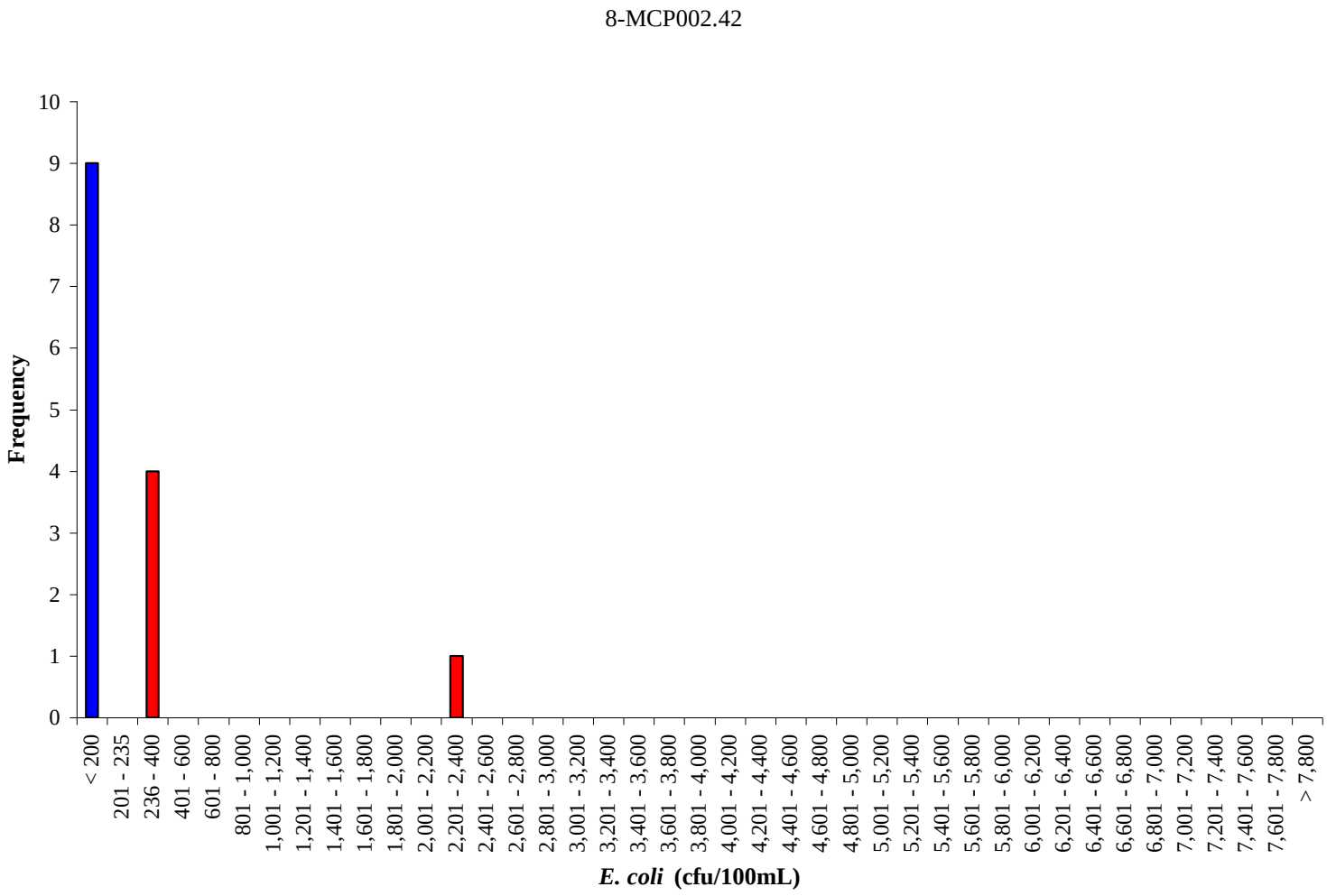

Figure A-23 Frequency analysis of *E. coli* concentrations at station 8-MCP002.42 in Mechumps Creek for the period from November 2002 to November 2008.

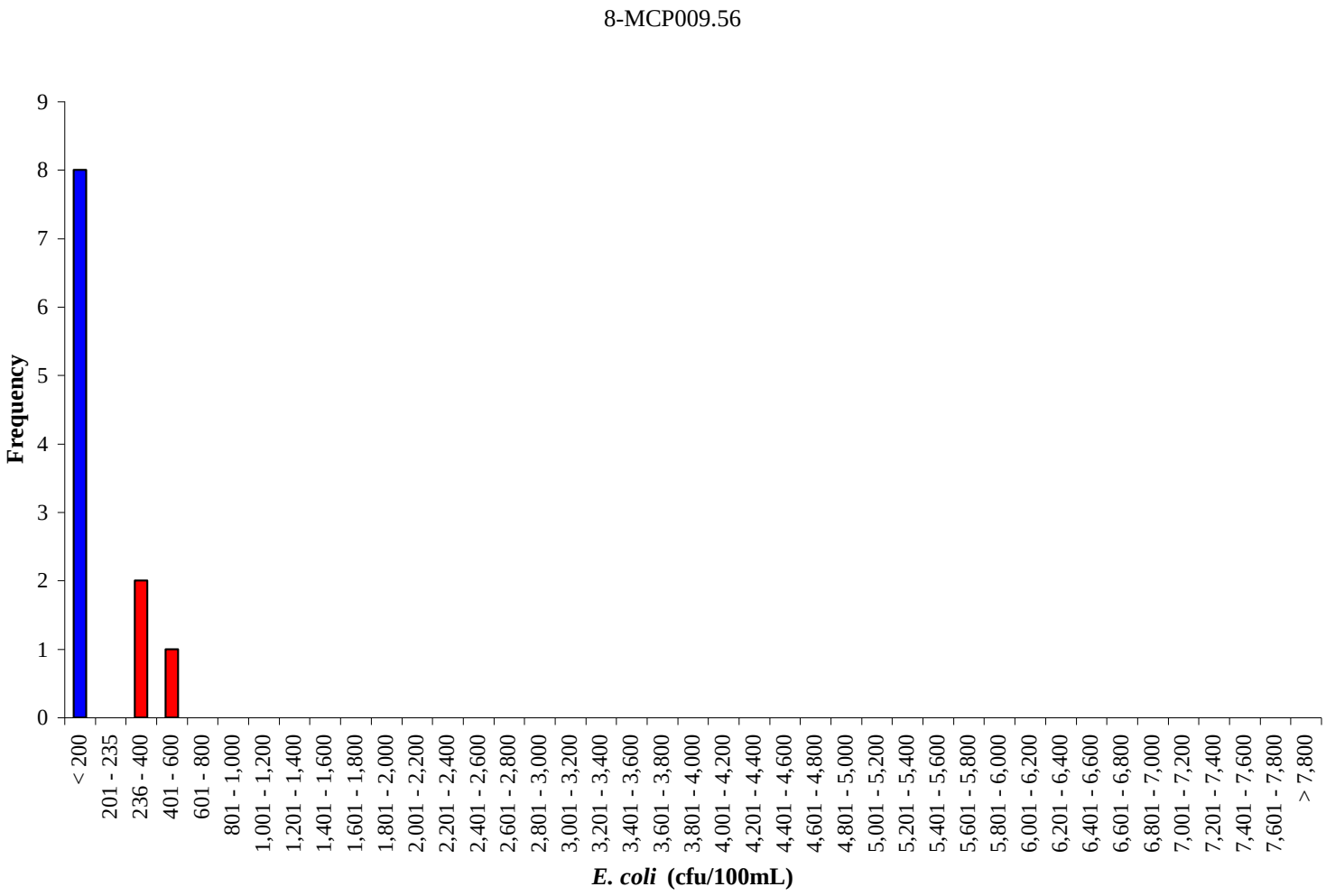

Figure A-24 Frequency analysis of *E. coli* concentrations at station 8-MCP009.56 in Mechumps Creek for the period from January 2007 to September 2008.

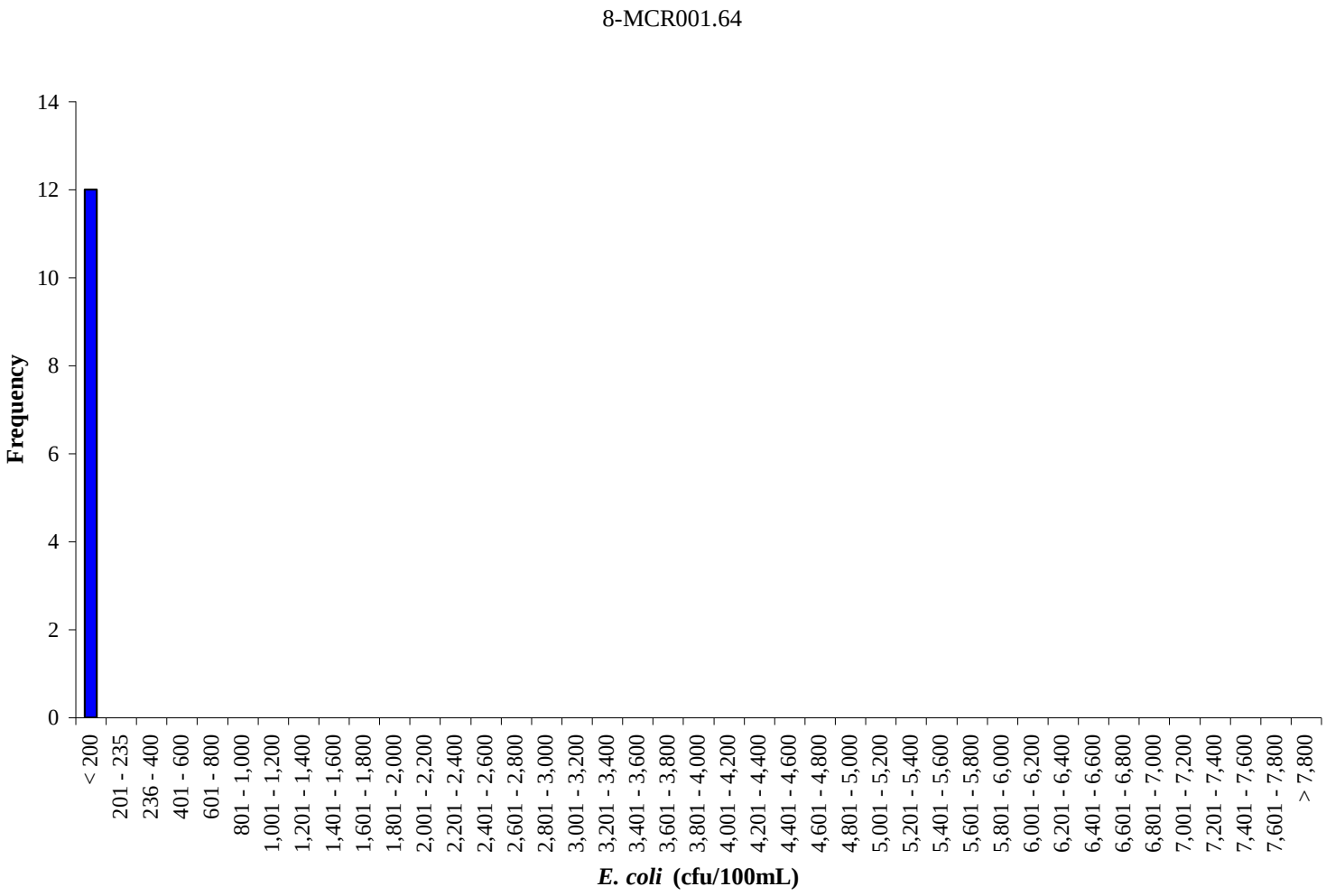

Figure A-25 Frequency analysis of *E. coli* concentrations at station 8-MCR001.64 in Mill Creek for the period from May January 2007 to November 2008.

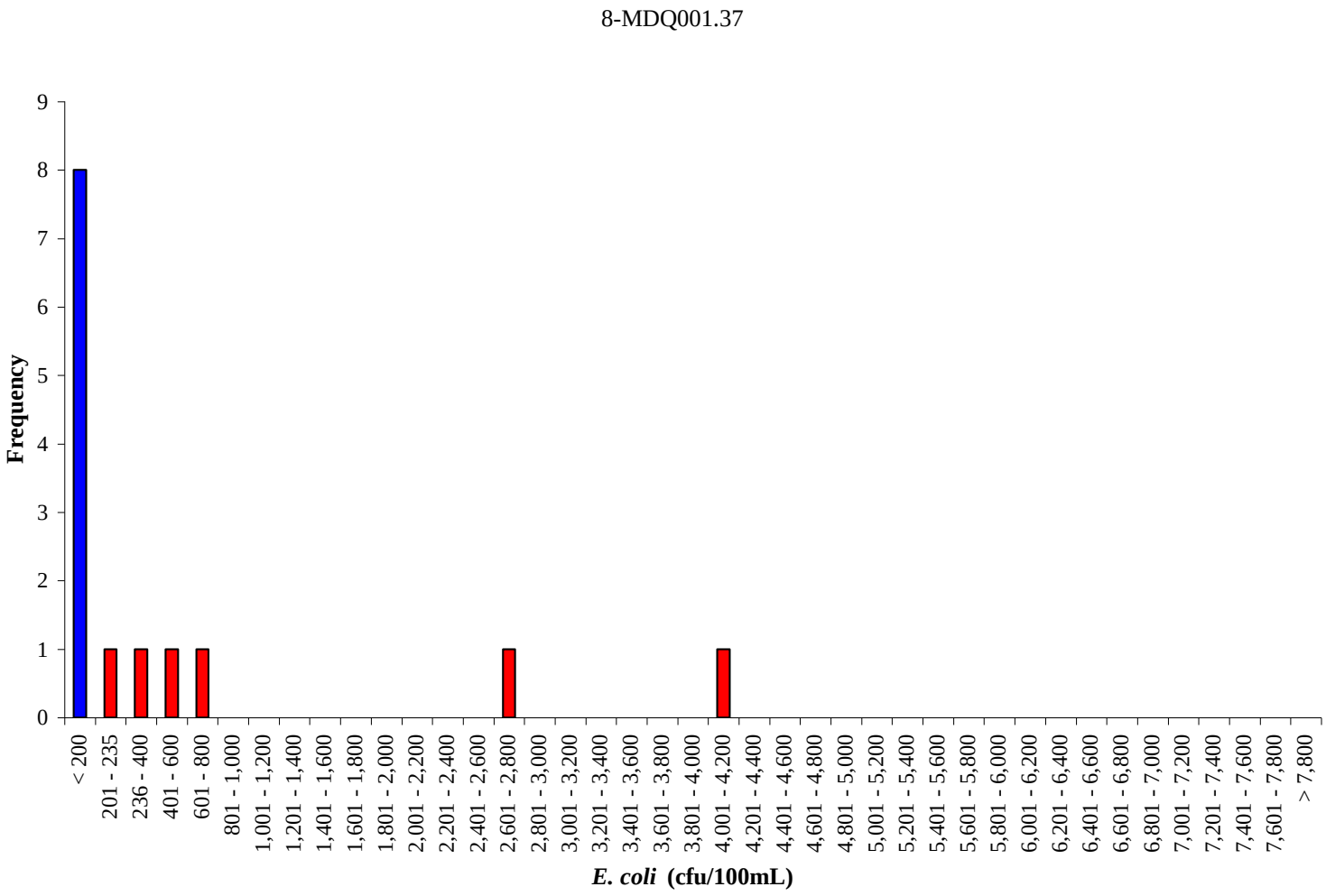

Figure A-26 Frequency analysis of *E. coli* concentrations at station 8-MDQ001.37 in Matadequin Creek for the period from November 2002 to December 2010.

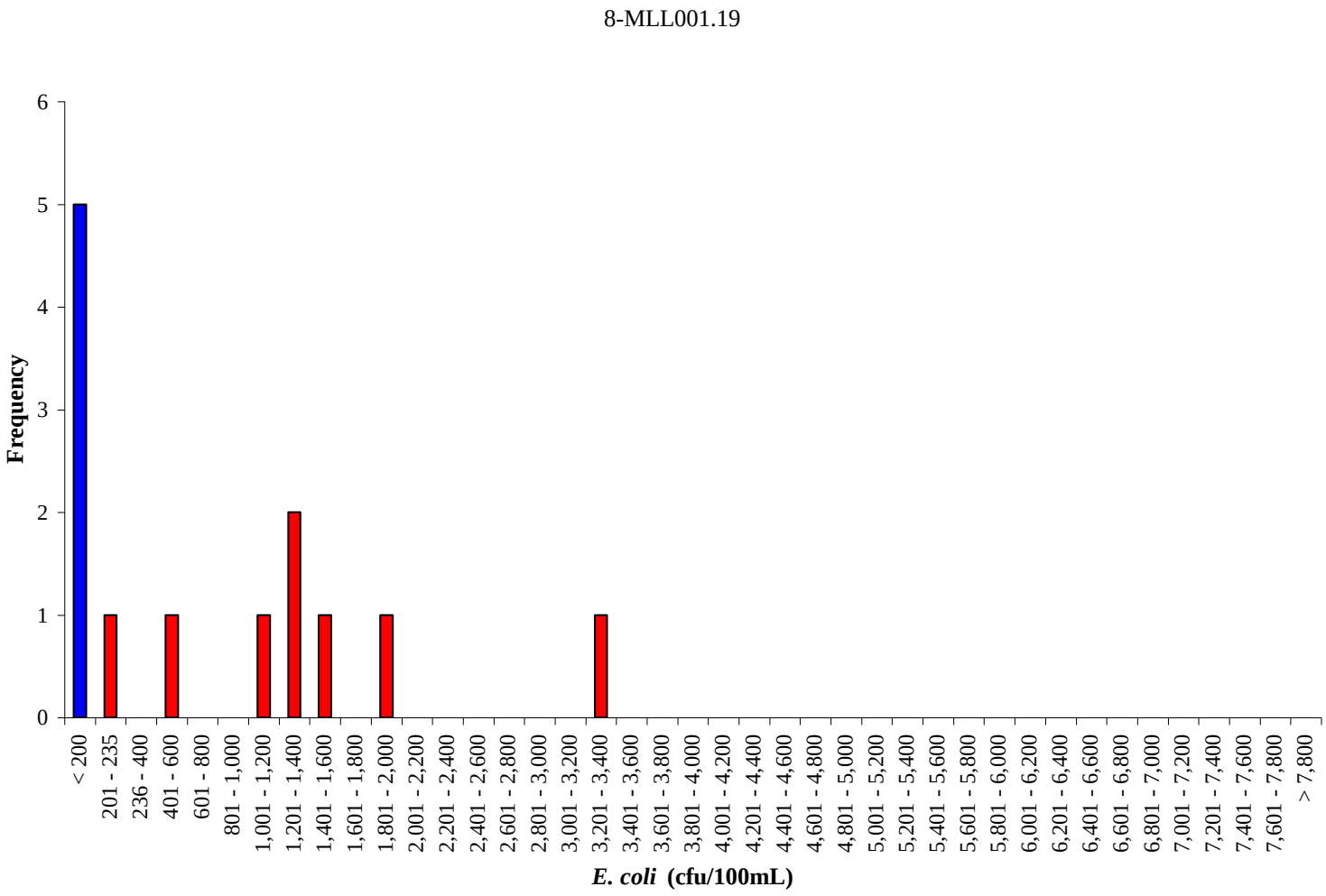

Figure A-27 Frequency analysis of *E. coli* concentrations at station 8-MLL001.19 in Mill Creek for the period from February 2009 to November 2010.

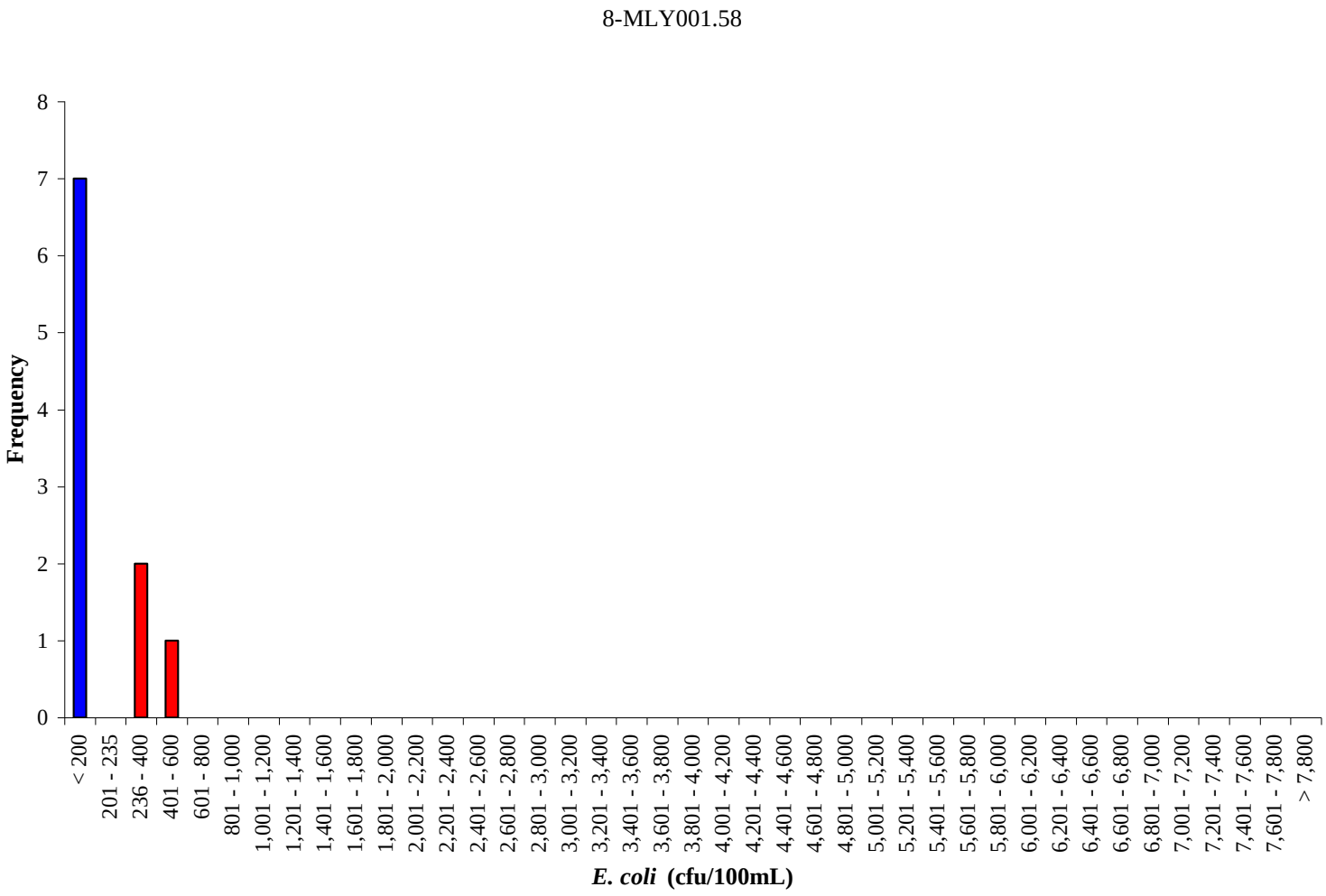

Figure A-28 Frequency analysis of *E. coli* concentrations at station 8-MLY001.58 in Mallory Creek for the period from January 2011 to October 2011.

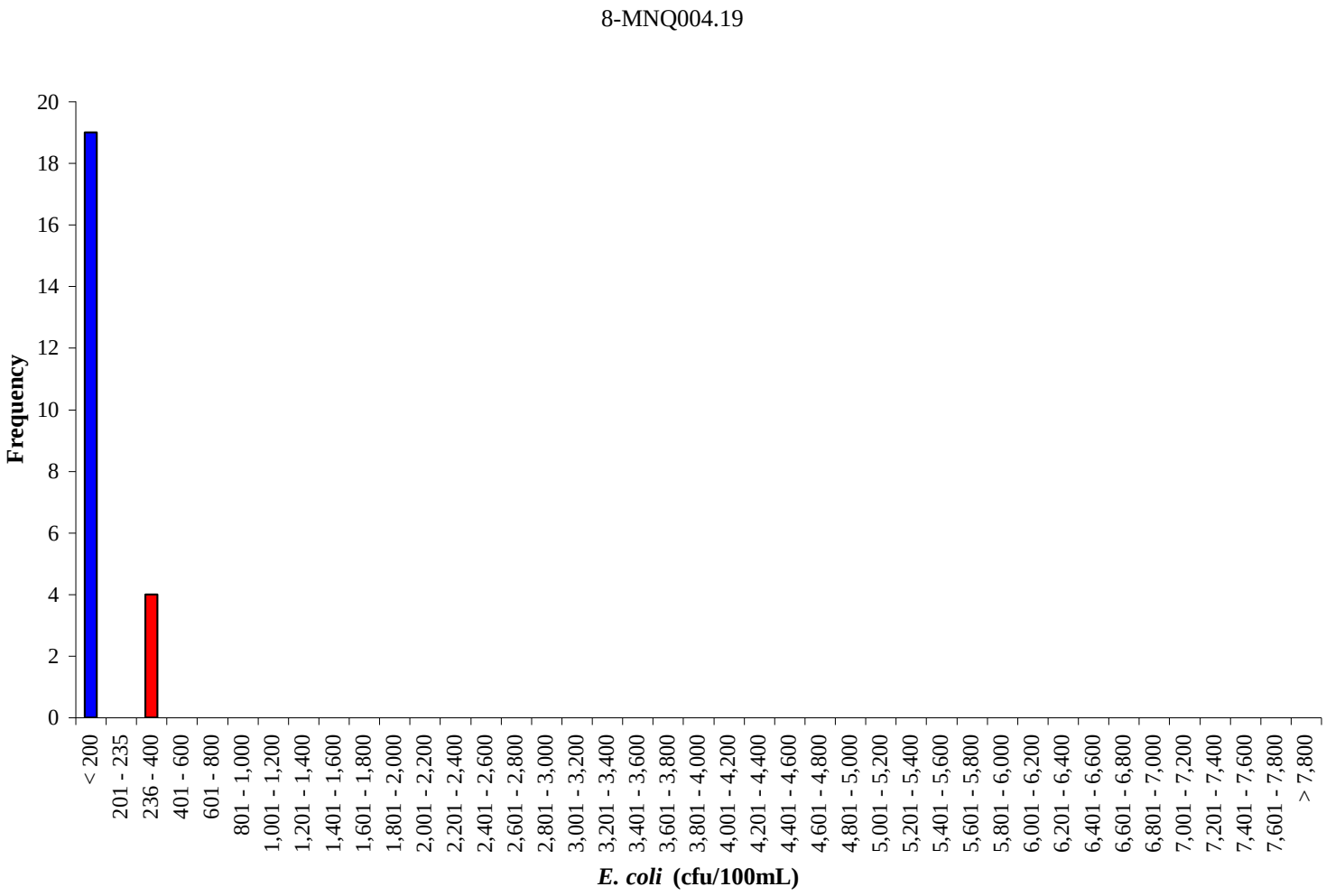

Figure A-29 Frequency analysis of *E. coli* concentrations at station 8-MNQ004.19 in Moncuin Creek for the period from July 2003 to March 2005.

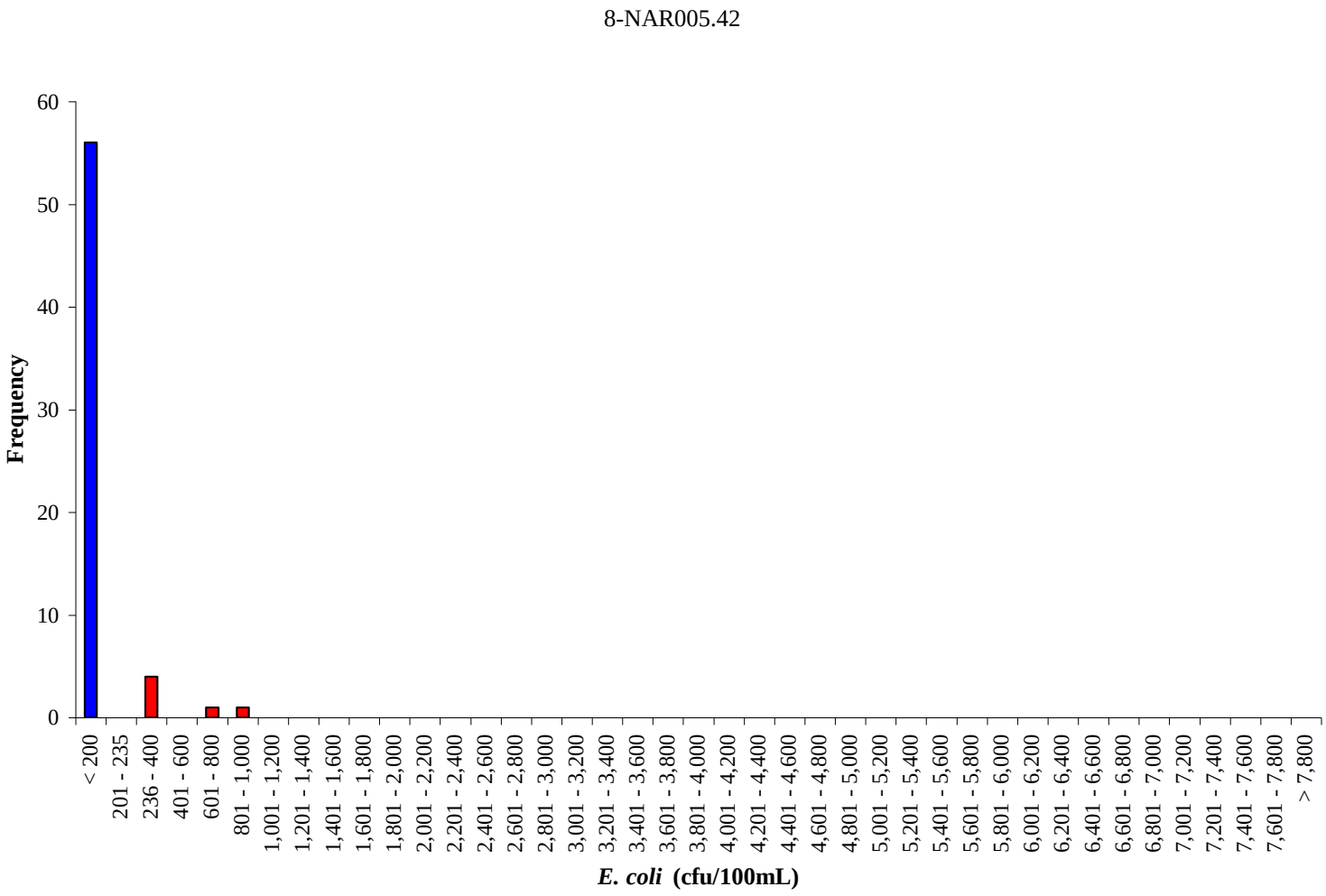

Figure A-30 Frequency analysis of *E. coli* concentrations at station 8-NAR005.42 in the North Anna River for the period from July 2003 to September 2011.

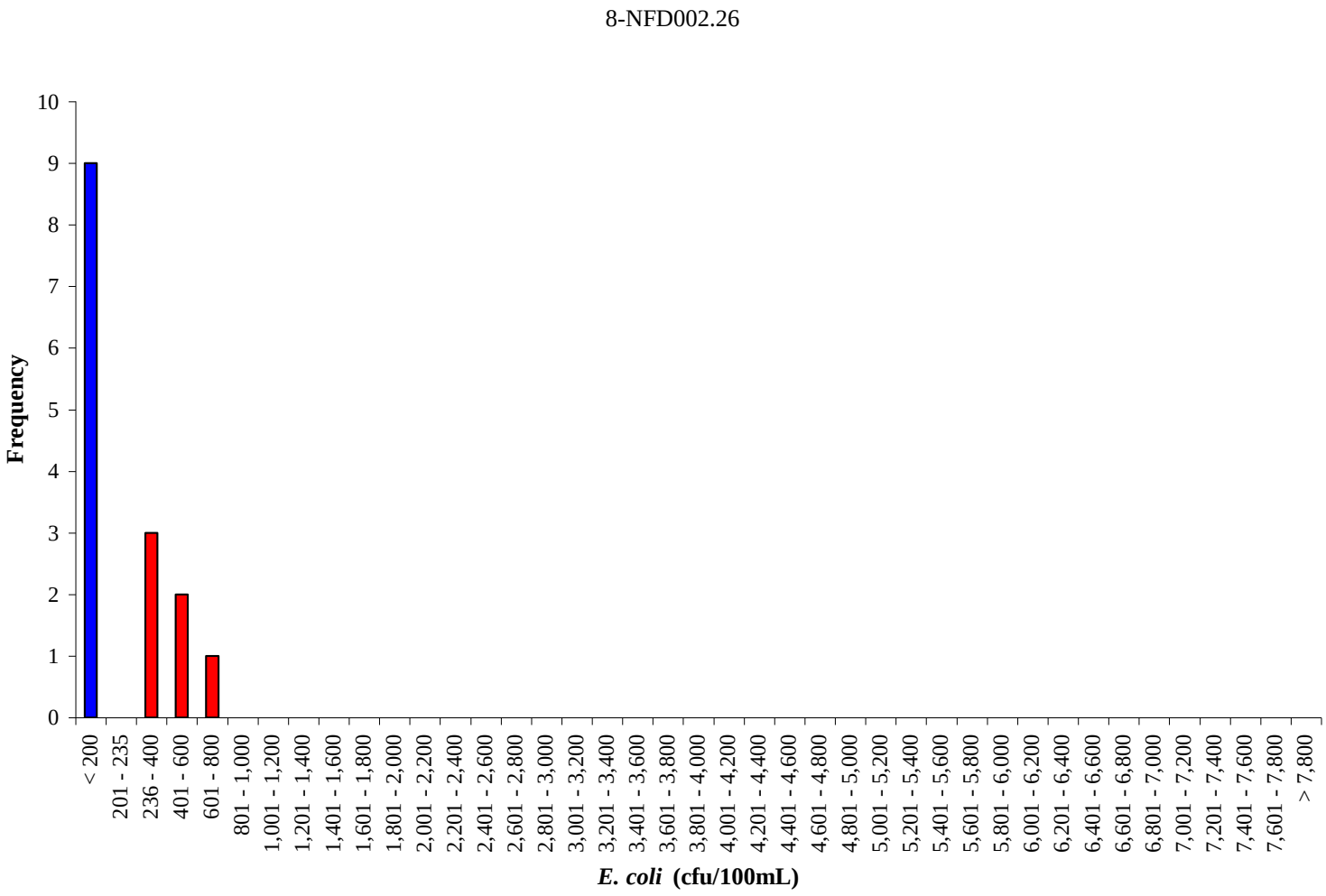

Figure A-31 Frequency analysis of *E. coli* concentrations at station 8-NFD002.26 in the Newfound River for the period from June 2005 to September 2011.

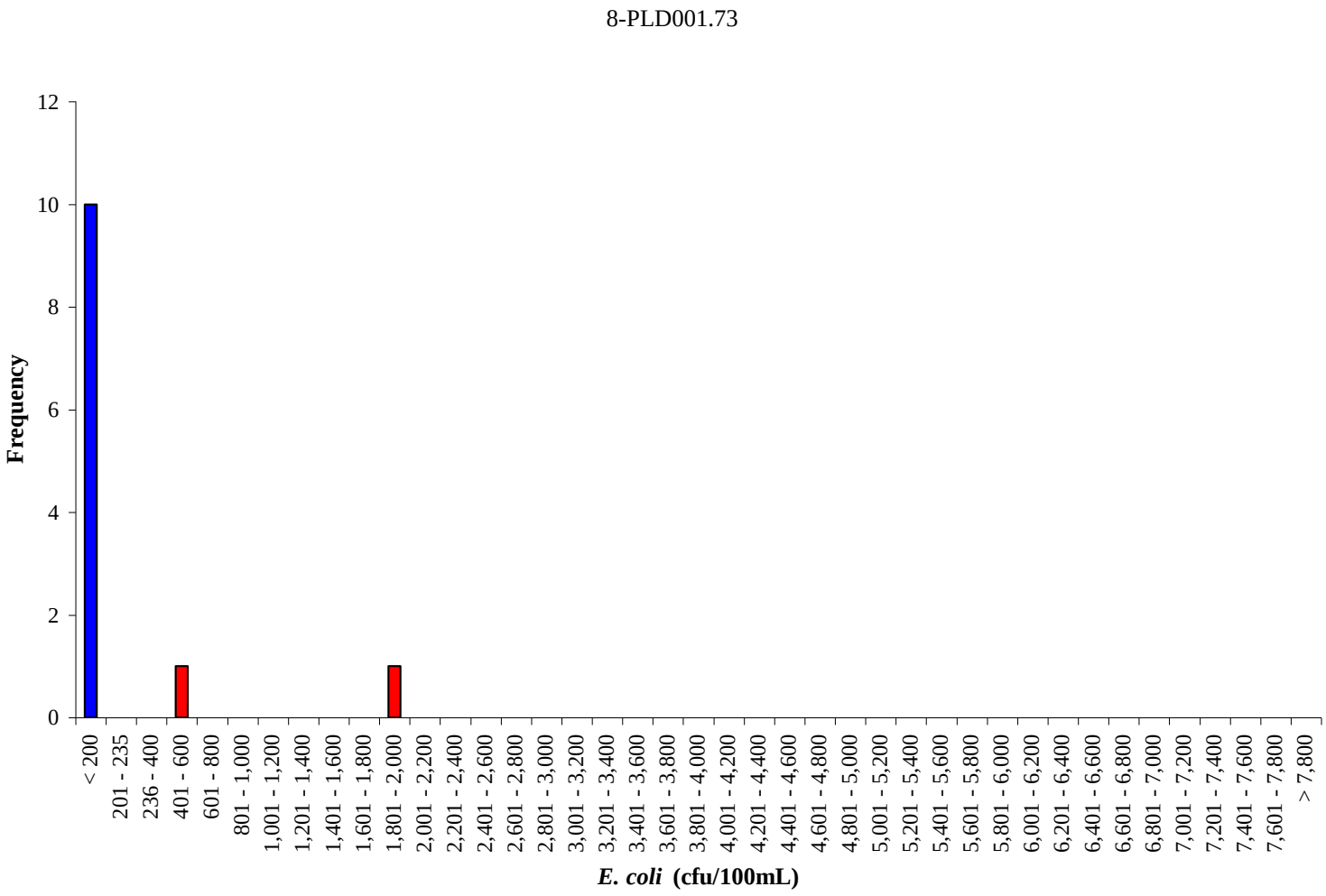

Figure A-32 Frequency analysis of *E. coli* concentrations at station 8-PLD001.73 in Pollard Creek for the period from January 2010 to December 2010.

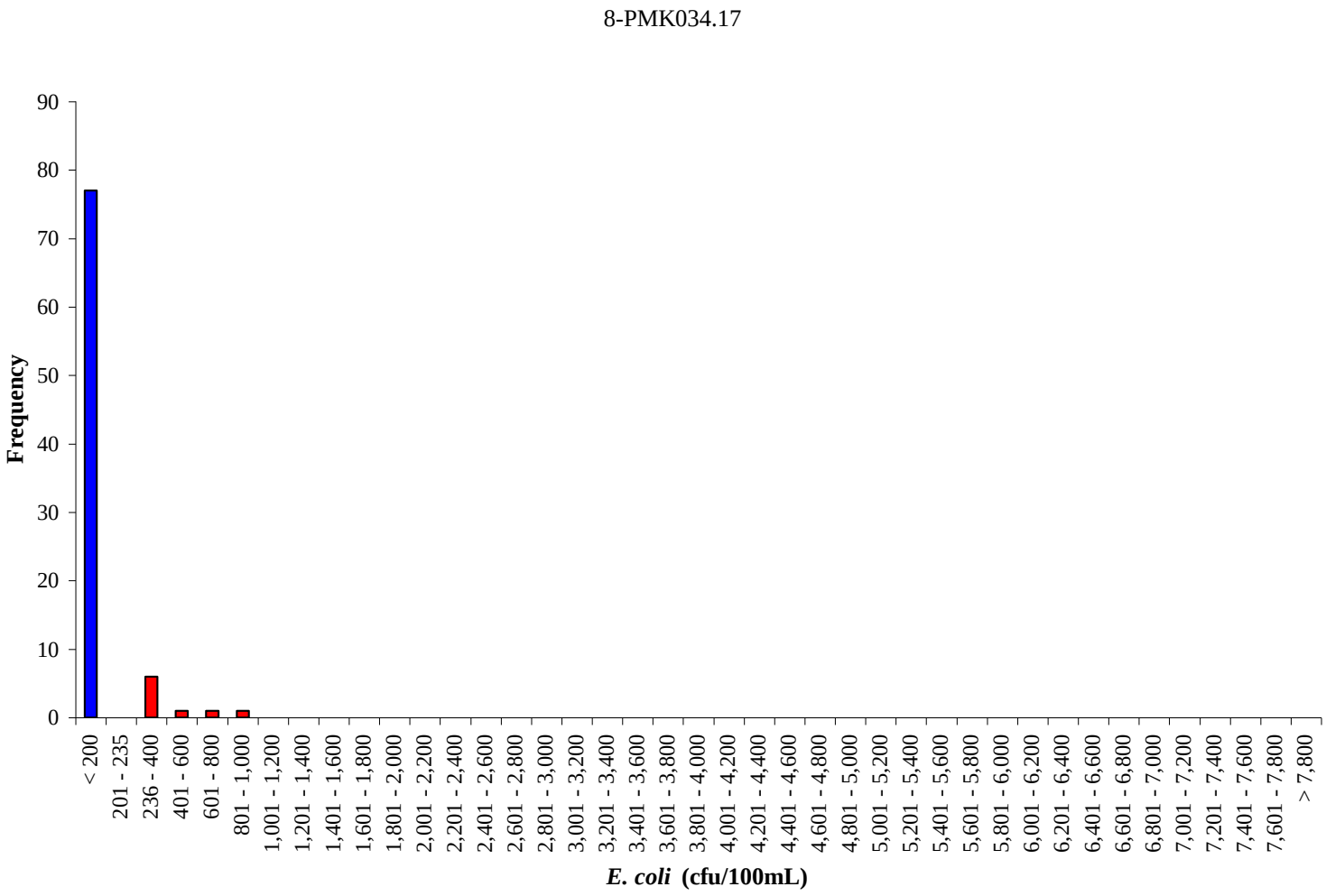

Figure A-33 Frequency analysis of *E. coli* concentrations at station 8-PMK034.17 in the Pamunkey River for the period from July 2004 to October 2011.

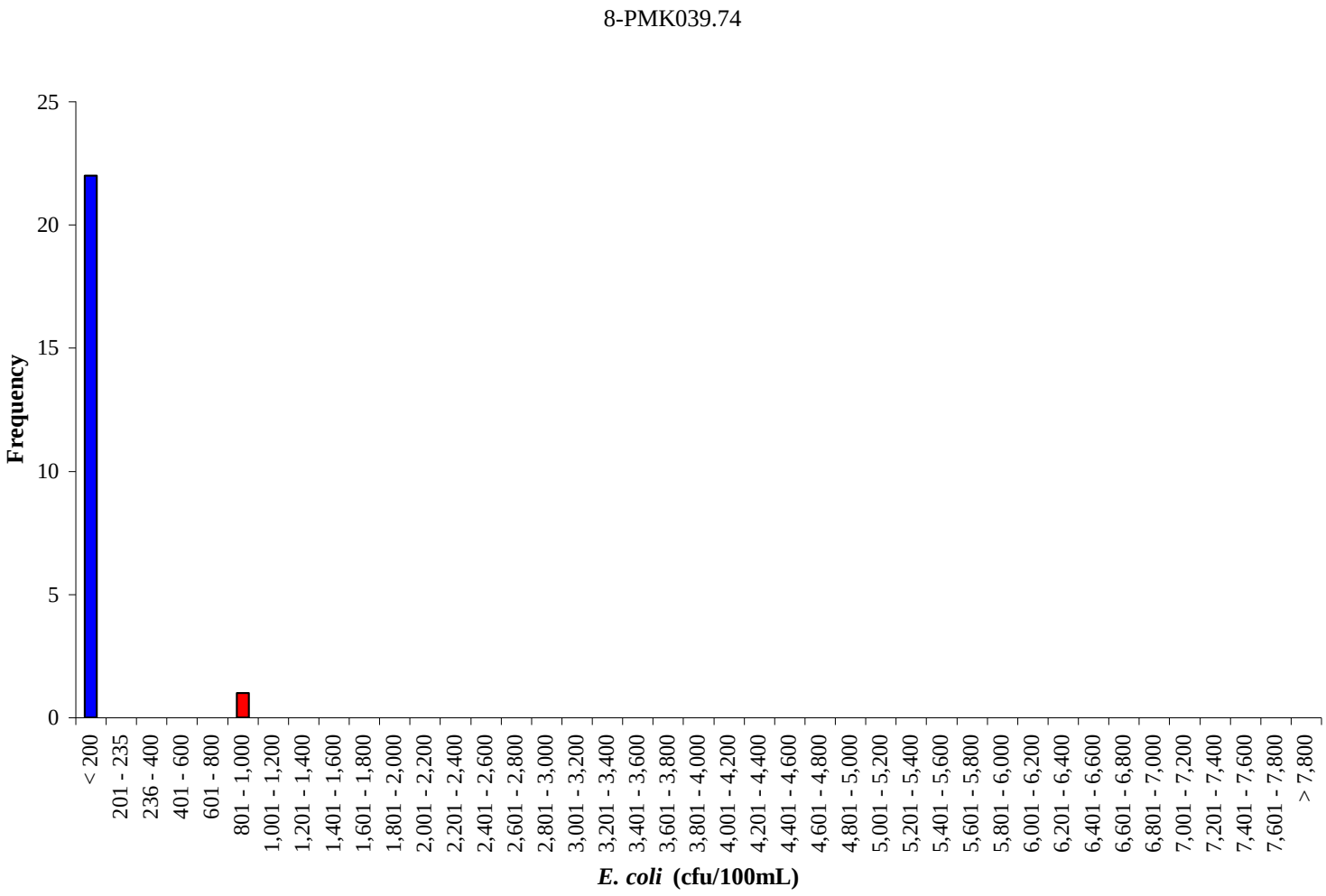

Figure A-34 Frequency analysis of *E. coli* concentrations at station 8-PMK039.74 in the Pamunkey River for the period from July 2003 to October 2011.

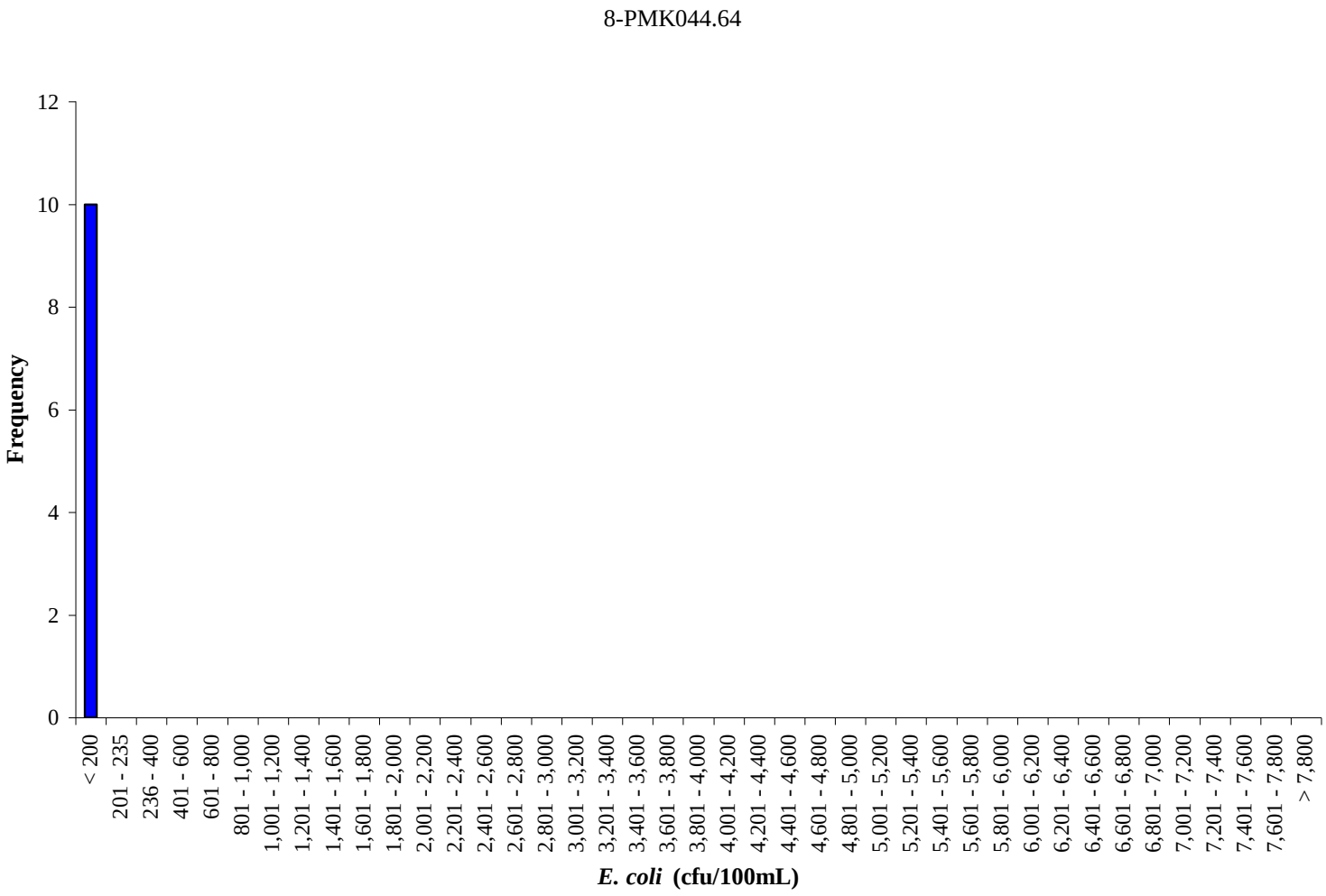

Figure A-35 Frequency analysis of *E. coli* concentrations at station 8-PMK044.64 in the Pamunkey River for the period from January 2011 to October 2011.

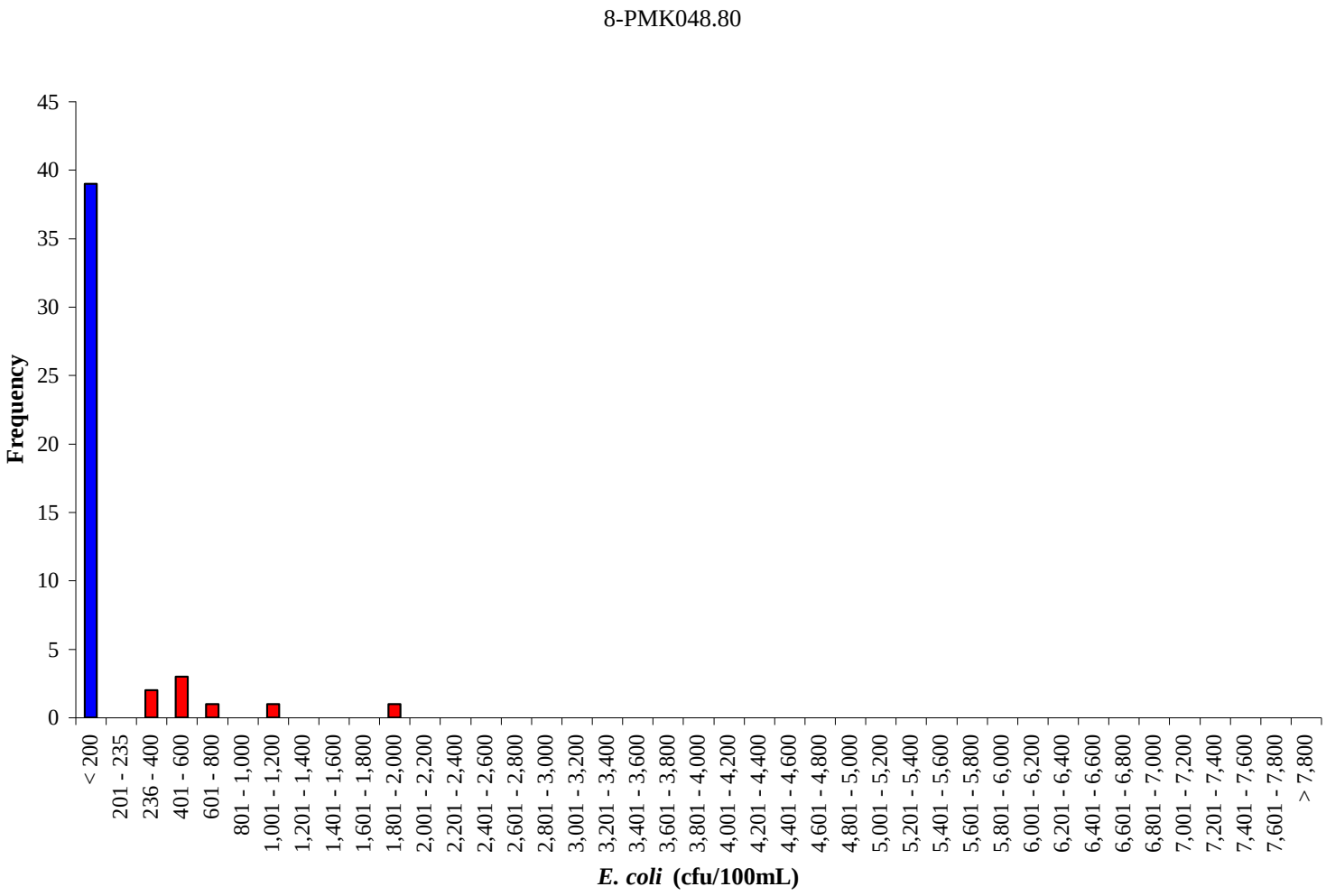

Figure A-36 Frequency analysis of *E. coli* concentrations at station 8-PMK048.80 in the Pamunkey River for the period from August 2003 to October 2011.

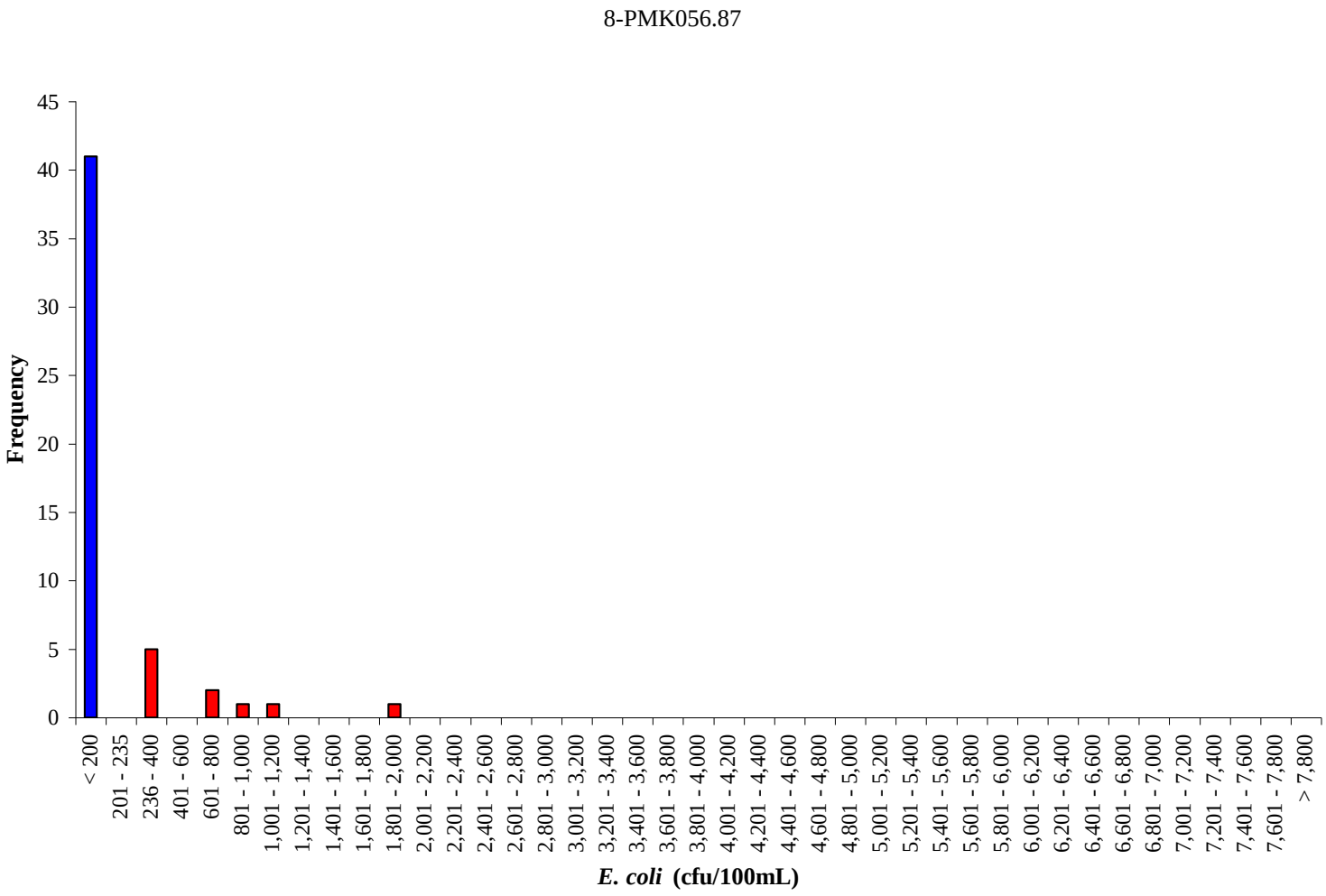

Figure A-37 Frequency analysis of *E. coli* concentrations at station 8-PMK056.87 in the Pamunkey River for the period from August 2003 to October 2011.

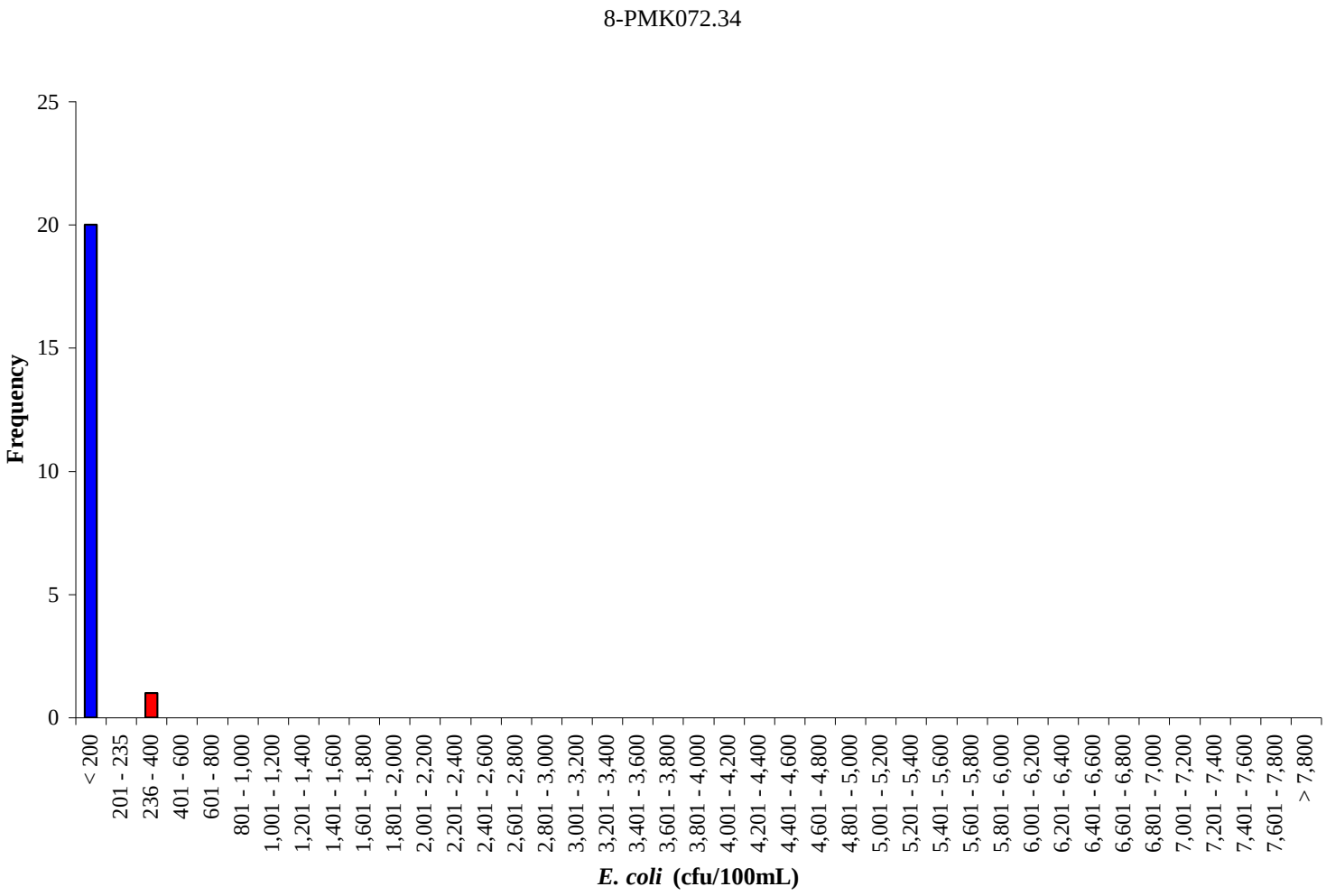

Figure A-38 Frequency analysis of *E. coli* concentrations at station 8-PMK072.34 in the Pamunkey River for the period from July 2003 to October 2011.

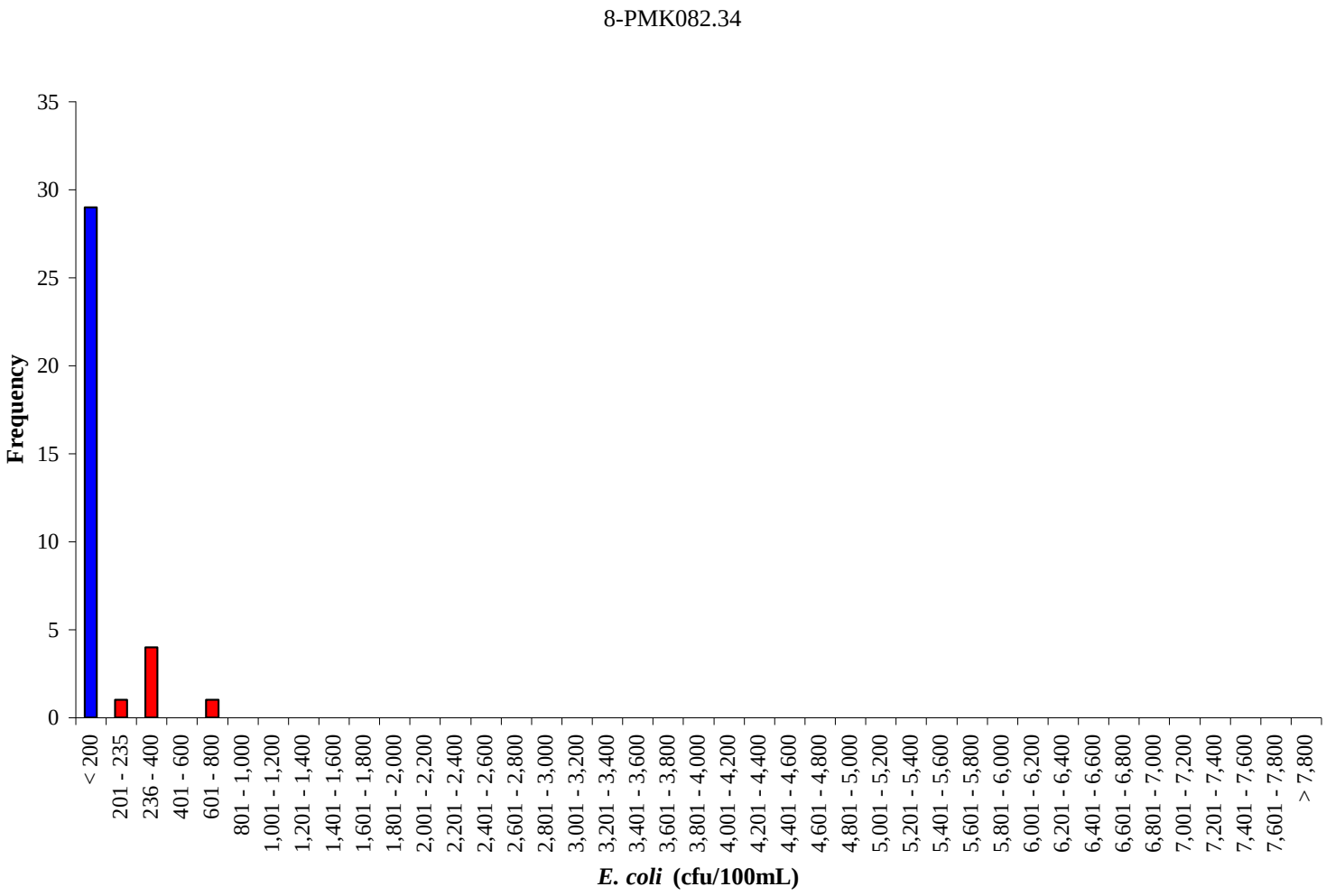

Figure A-39 Frequency analysis of *E. coli* concentrations at station 8-PMK082.34 in the Pamunkey River for the period from December 2005 to October 2011.

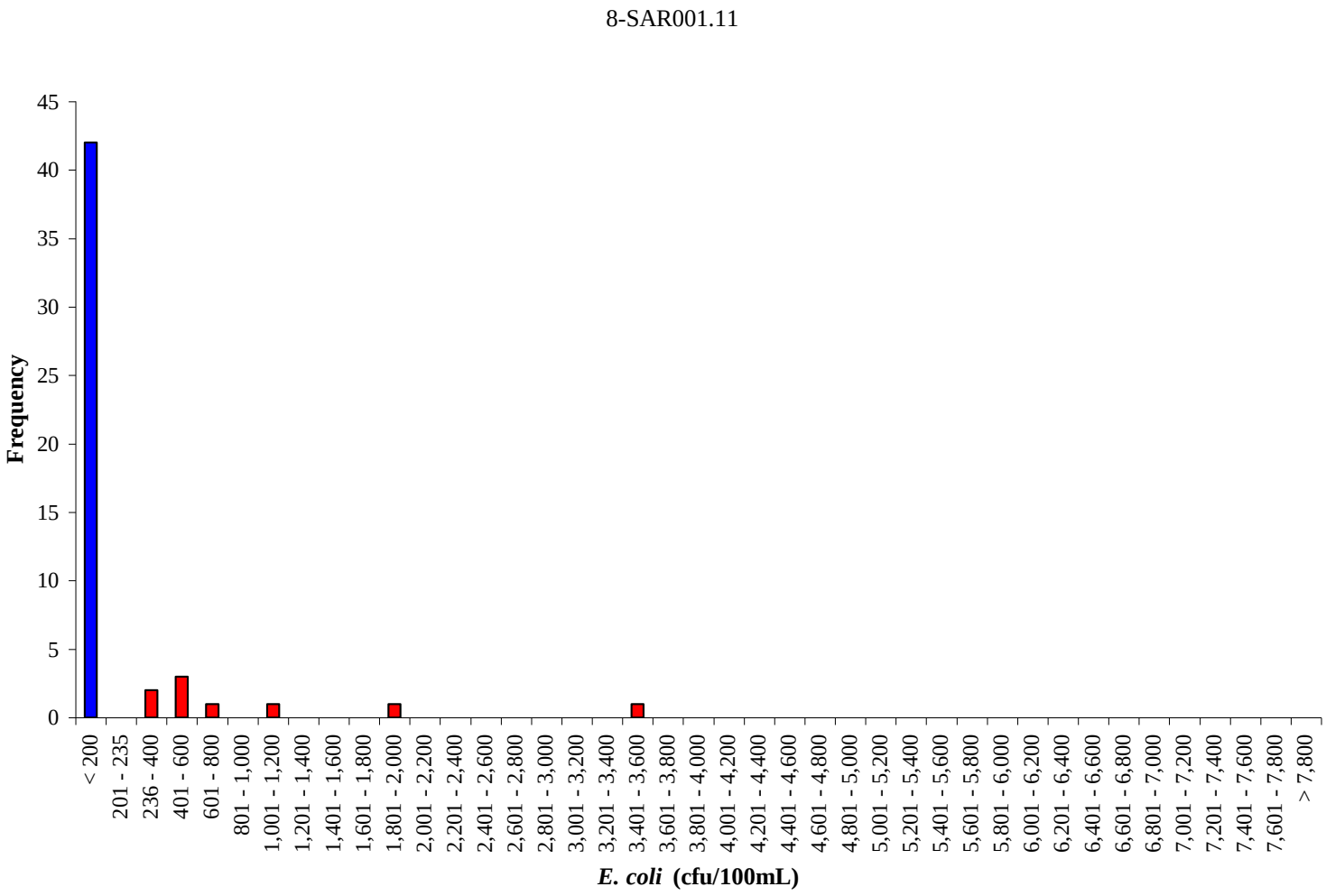

Figure A-40 Frequency analysis of *E. coli* concentrations at station 8-SAR001.11 in the South Anna River for the period from July 2003 to September 2011.

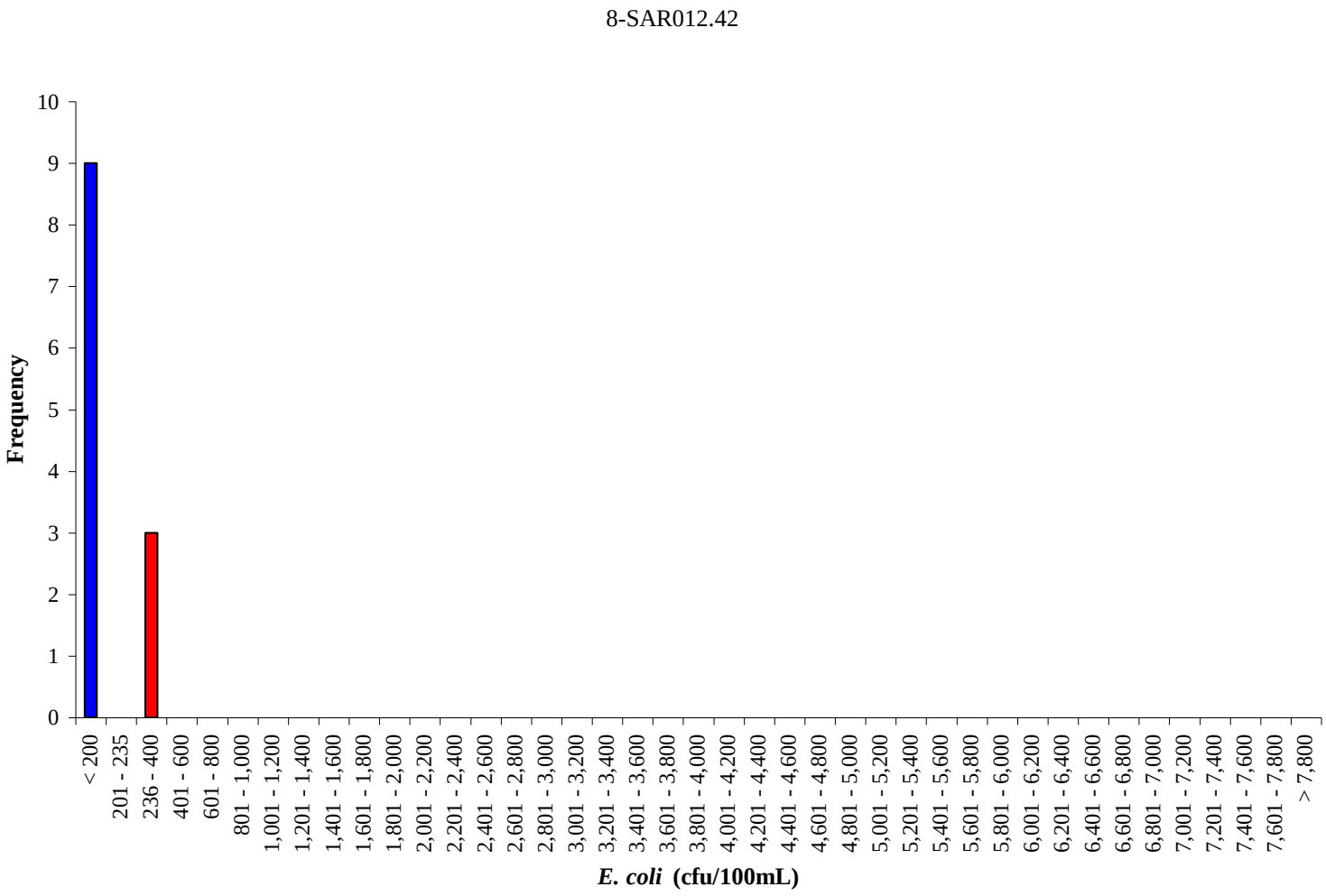

Figure A-41 Frequency analysis of *E. coli* concentrations at station 8-SAR012.42 in the South Anna River for the period from July 2003 to June 2004.

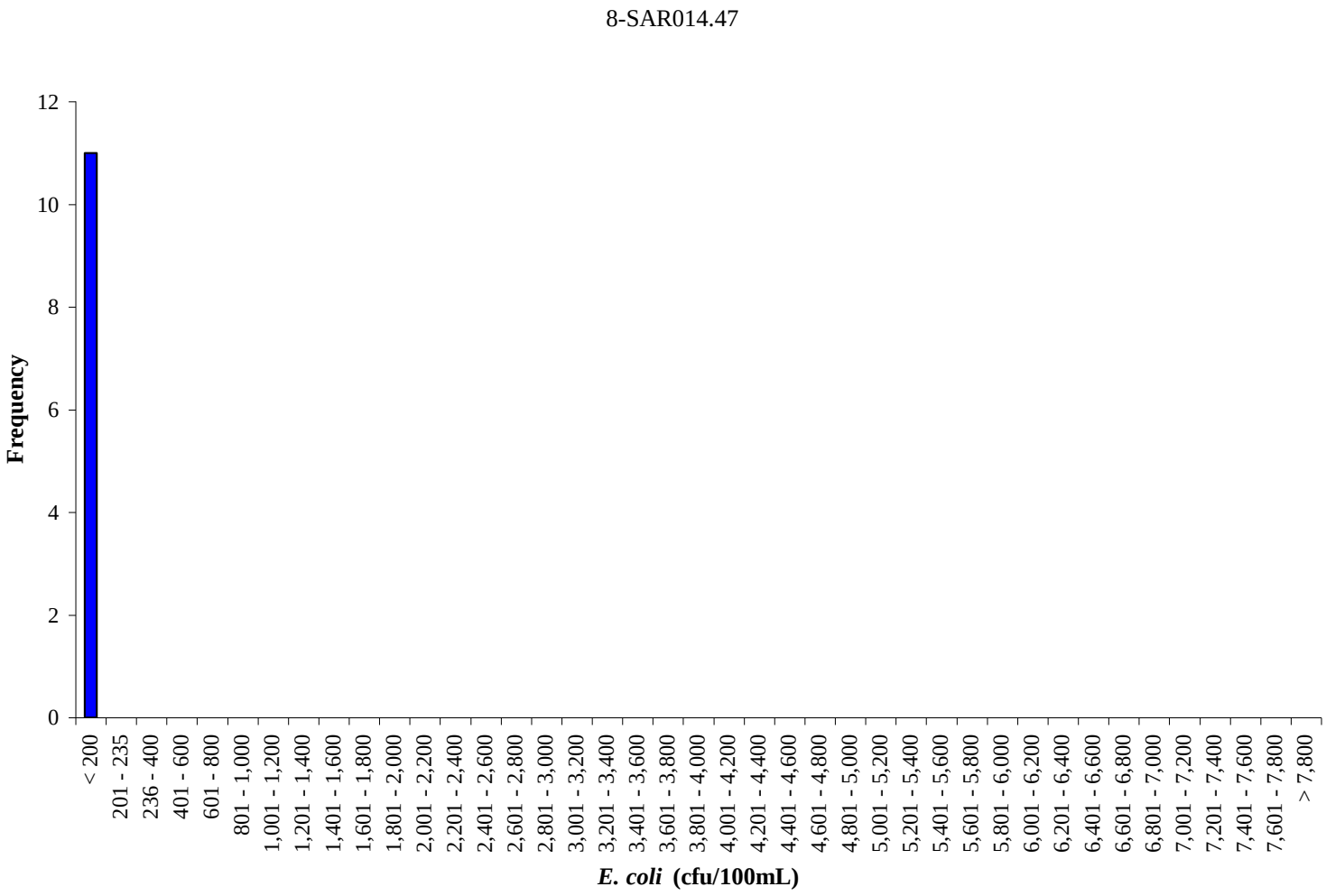

Figure A-42 Frequency analysis of *E. coli* concentrations at station 8-SAR014.47 in the South Anna River for the period from July 2003 to March 2005.

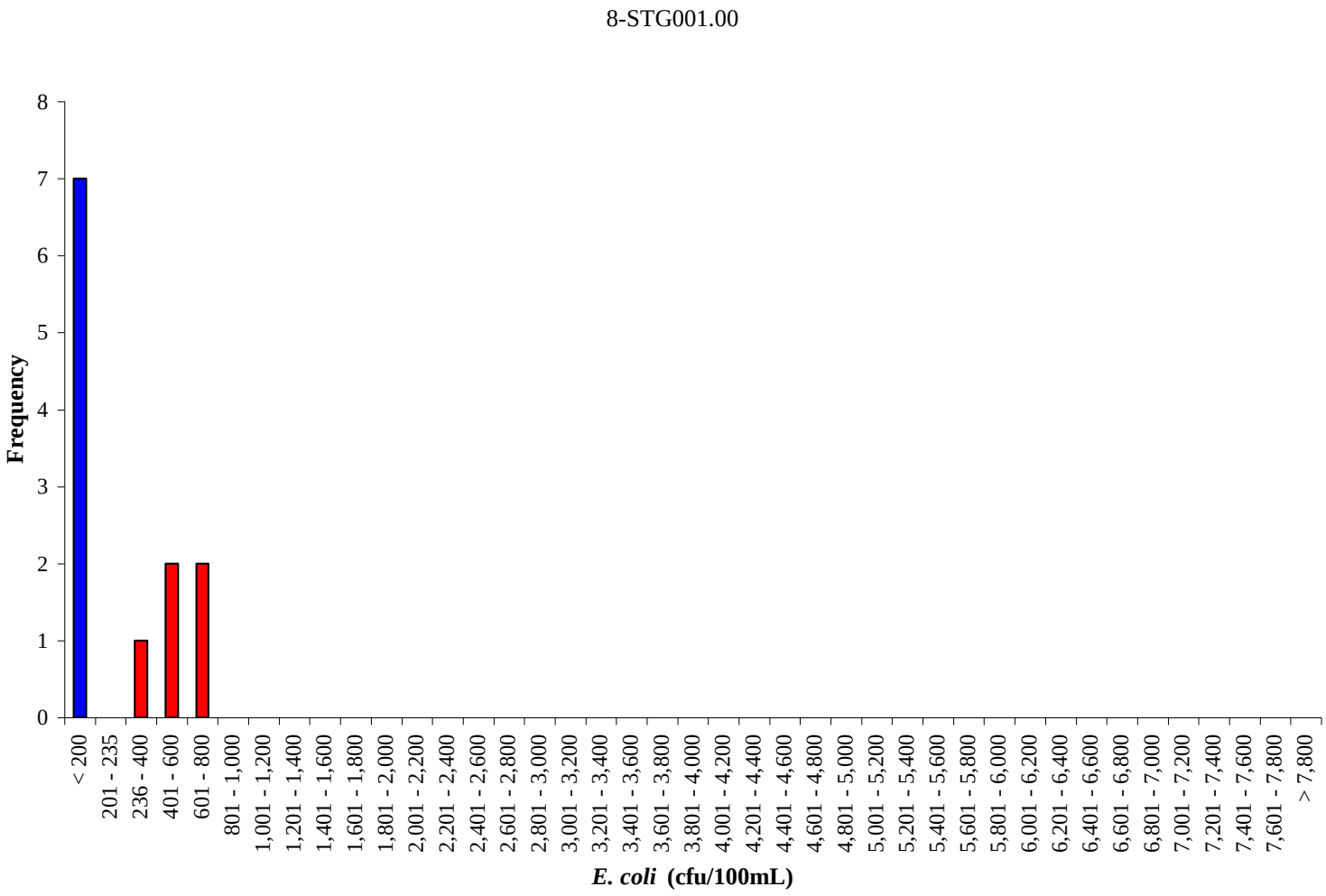

Figure A-43 Frequency analysis of *E. coli* concentrations at station 8-STG001.00 in Stagg Creek for the period from June 2003 to July 2004.

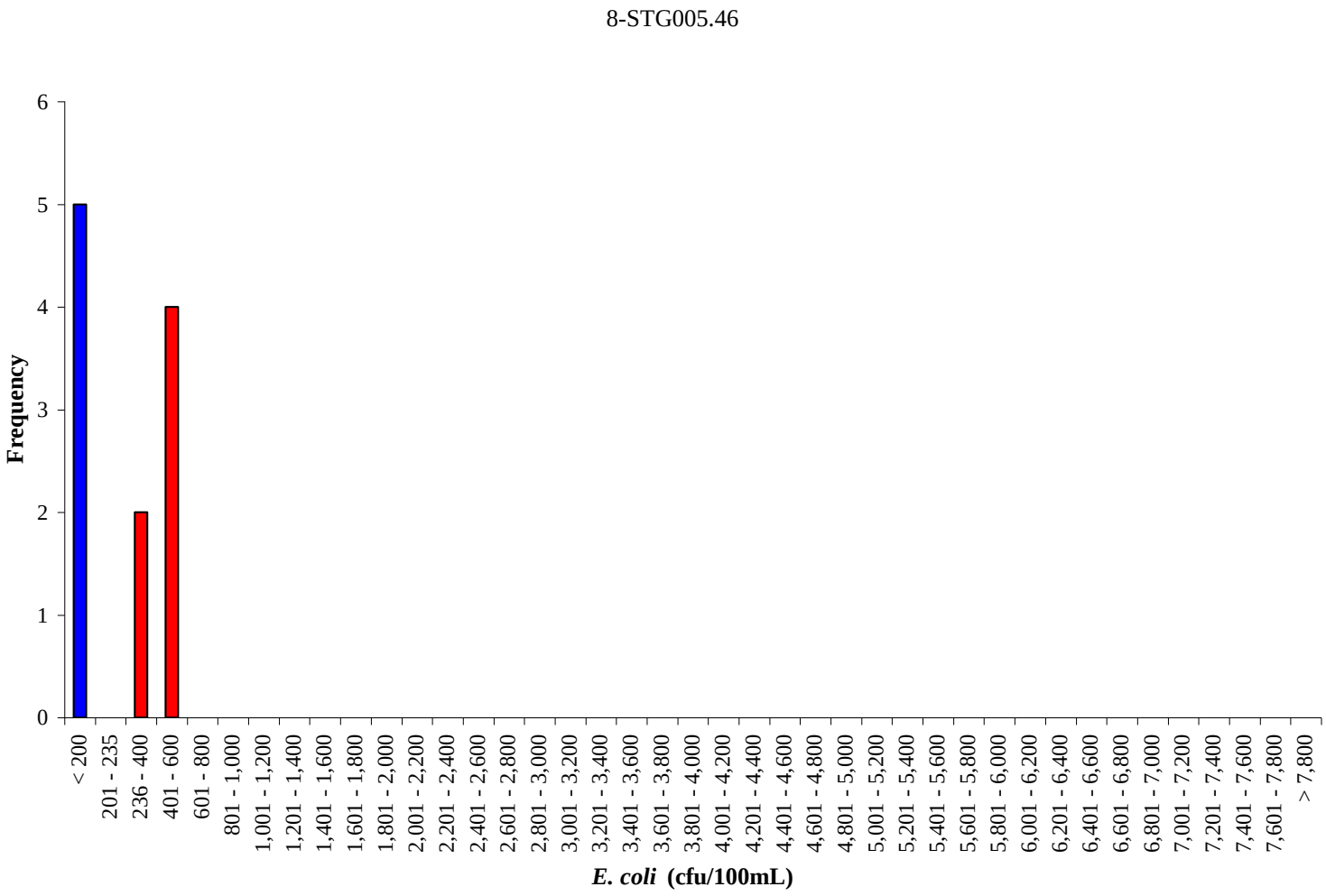

Figure A-44 Frequency analysis of *E. coli* concentrations at station 8-STG005.46 in Stagg Creek for the period from September 2004 to July 2005.

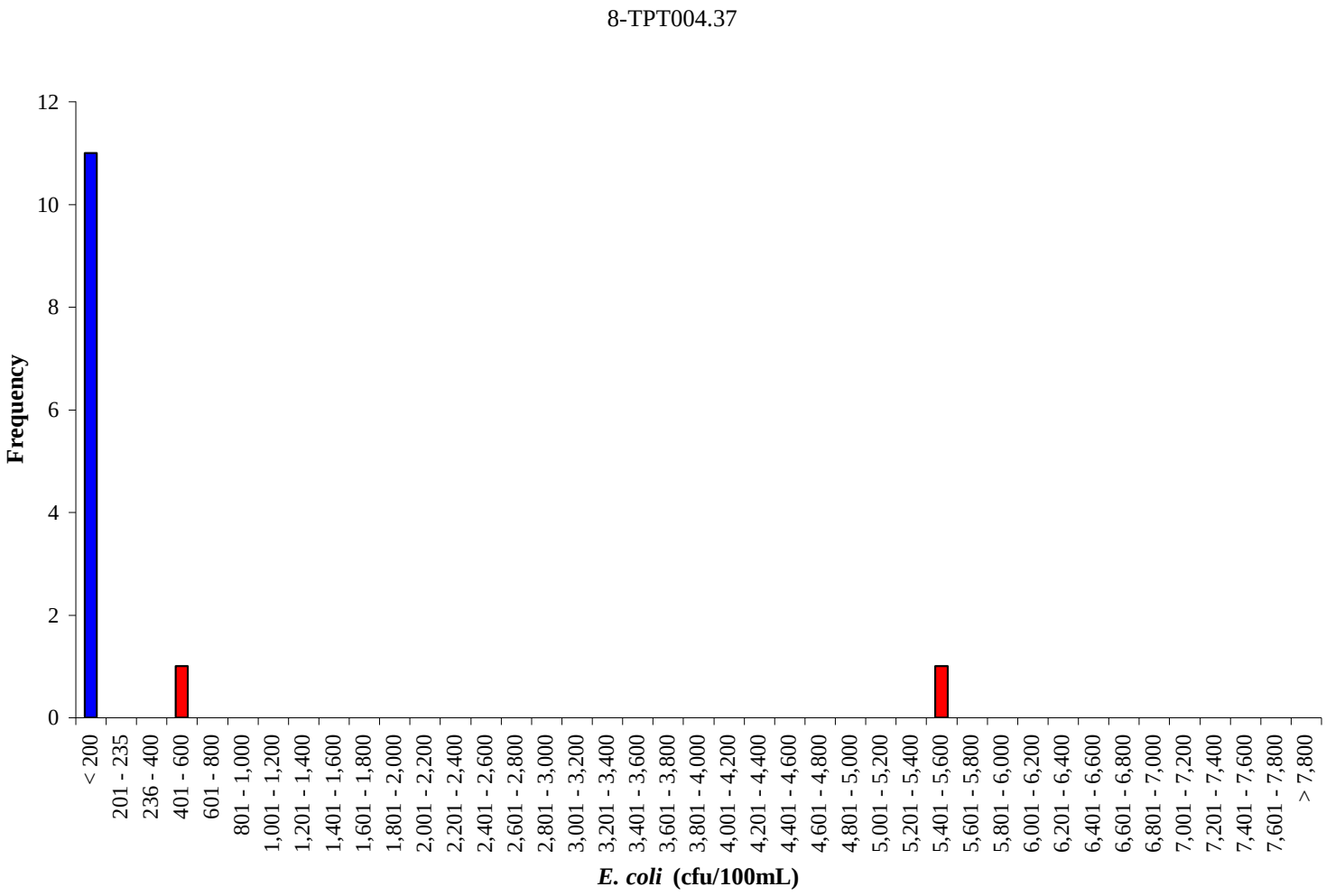

Figure A-45 Frequency analysis of *E. coli* concentrations at station 8-TPT004.37 in Totopotomoy Creek for the period from August 2003 to December 2008.

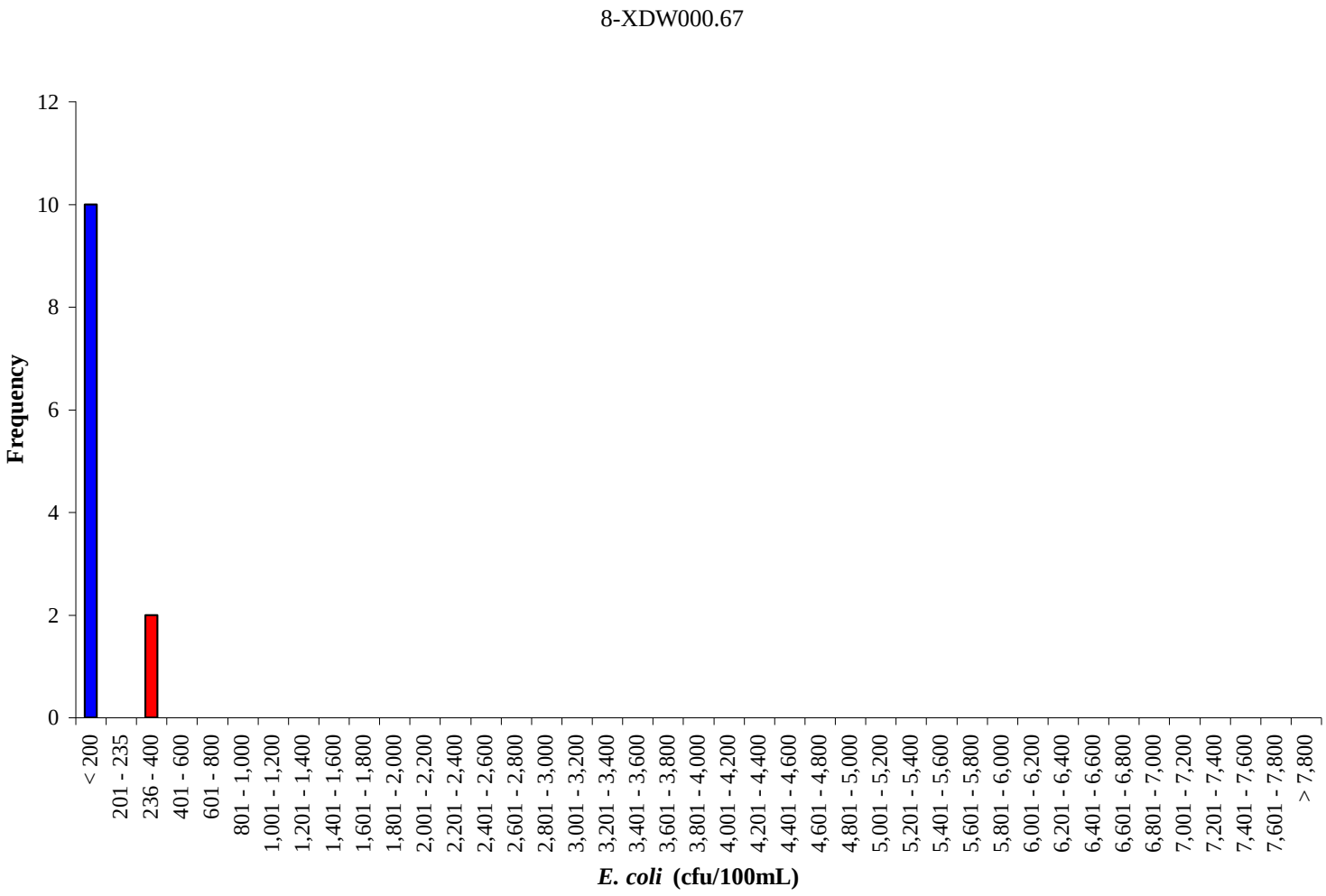

Figure A-46 Frequency analysis of *E. coli* concentrations at station 8-XDW000.67 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009.

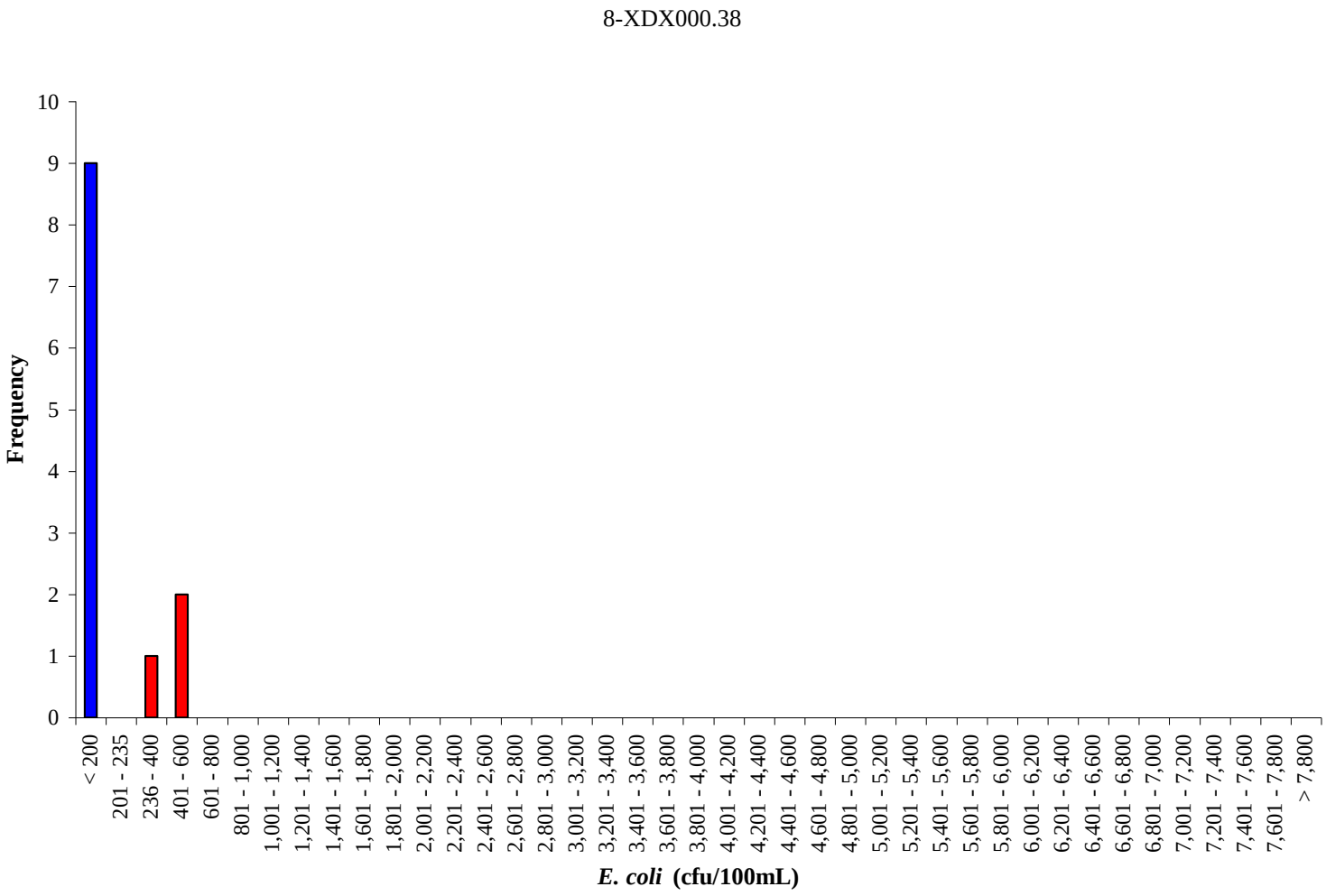

Figure A-47 Frequency analysis of *E. coli* concentrations at station 8-XDX000.38 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009.

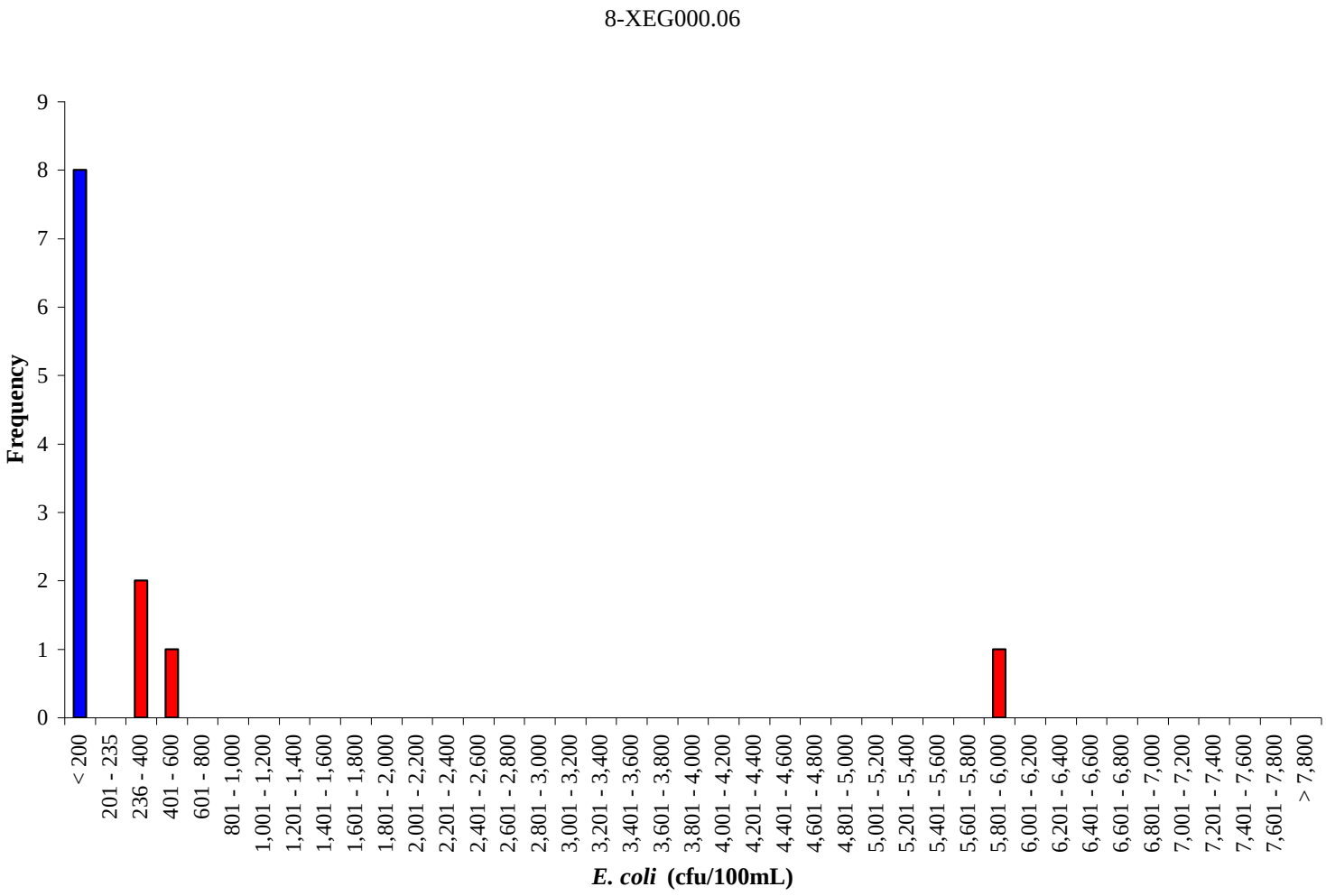

Figure A-48 Frequency analysis of *E. coli* concentrations at station 8-XEG000.06 in an Unnamed Tributary to Mechumps Creek for the period from January 2007 to November 2008.

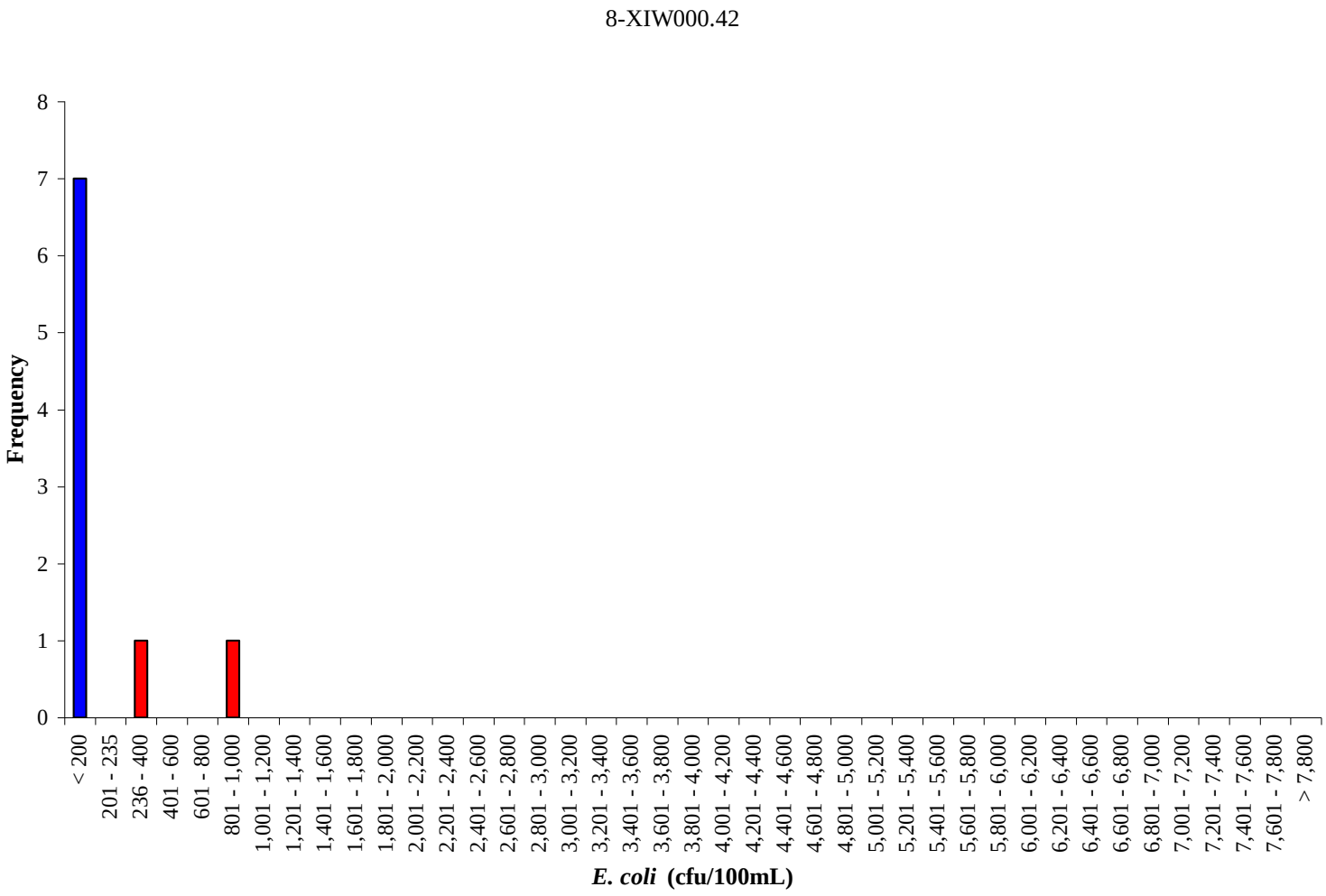

Figure A-49 Frequency analysis of *E. coli* concentrations at station 8-XIW000.42 in an Unnamed tributary to Jacks Creek for the period from January 2011 to October 2011.

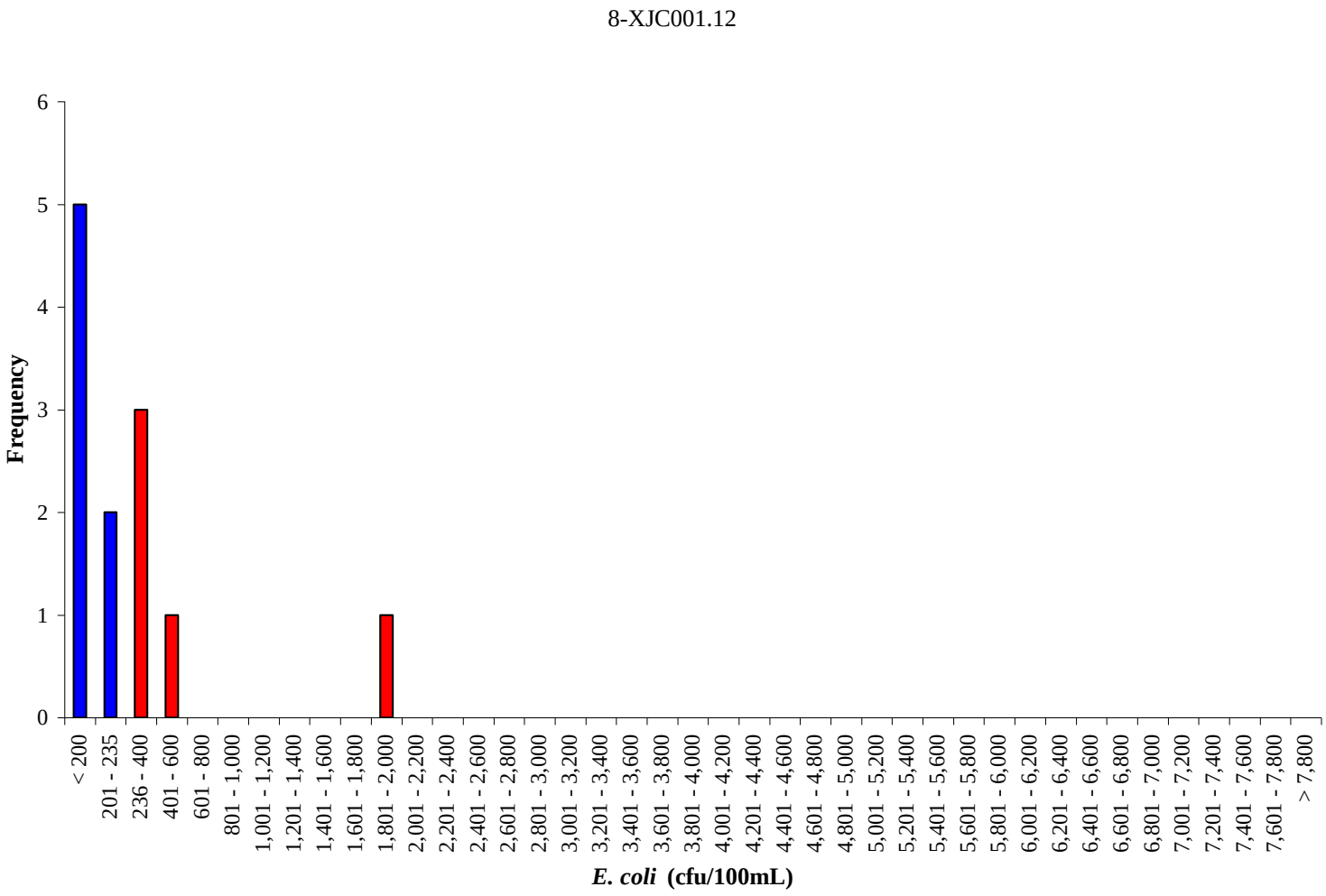

Figure A-50 Frequency analysis of *E. coli* concentrations at station 8-XJC001.12 in an Unnamed tributary to Crump Creek for the period from January 2010 to December 2010.

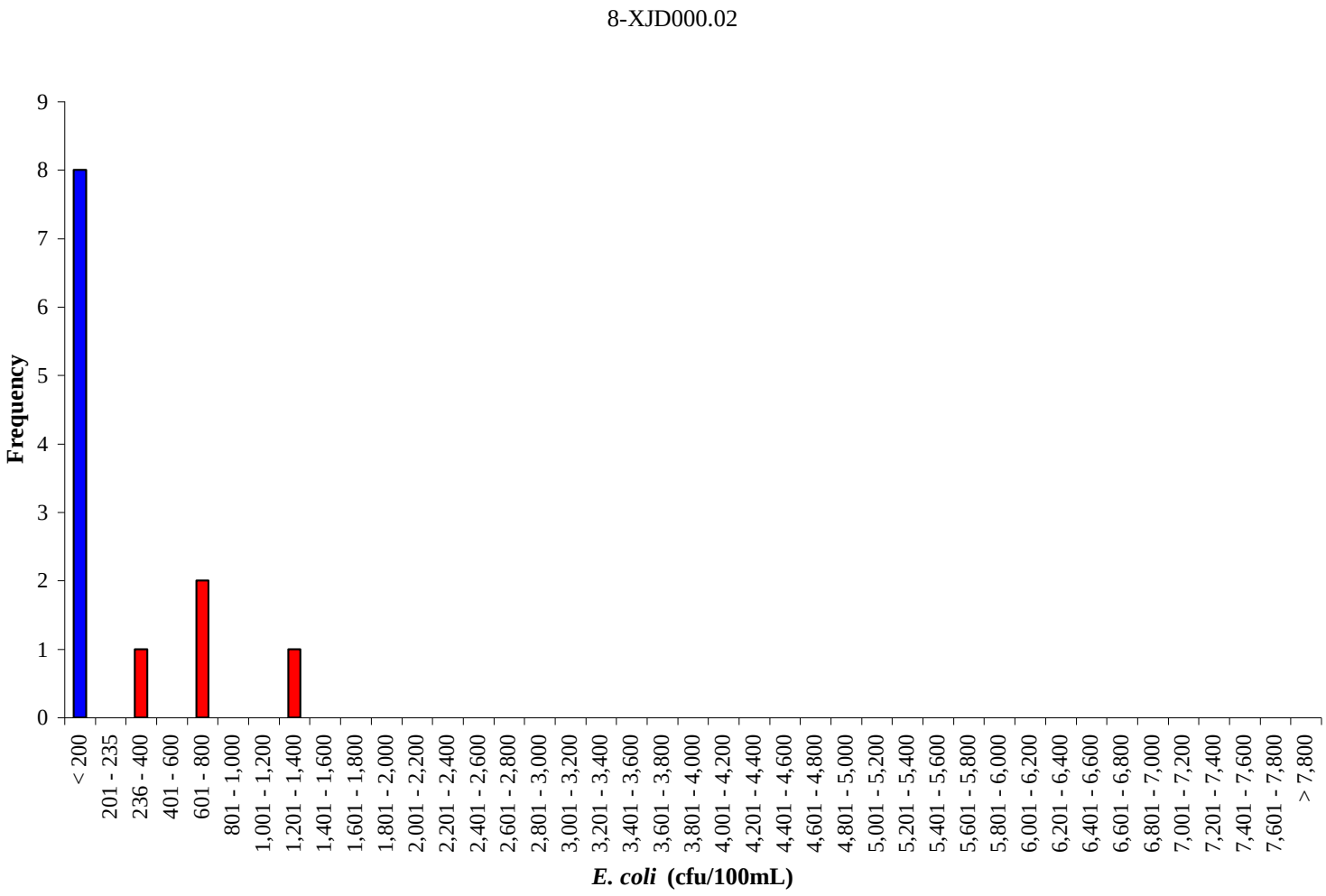

Figure A-51 Frequency analysis of *E. coli* concentrations at station 8-XJD000.02 in an Unnamed tributary to Harrison Creek for the period from April 2010 to April 2011.

Figure A-52 Frequency analysis of *E. coli* concentrations at station 8-ARN000.73 in Arnold Creek for the period from August 2004 to July 2007.

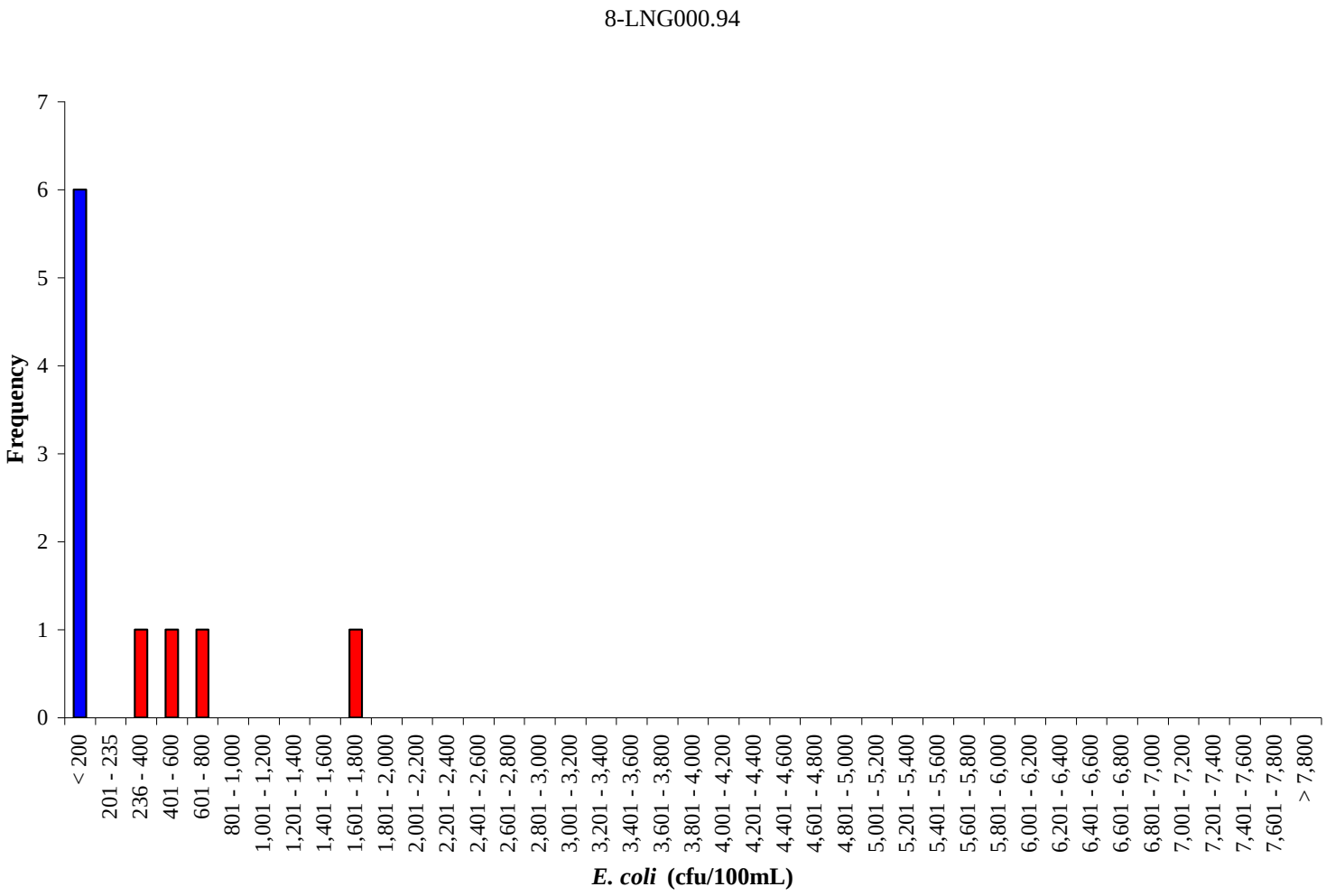

Figure A-53 Frequency analysis of *E. coli* concentrations at station 8-LNG000.94 in Long Creek for the period from February 2011 to August 2012.

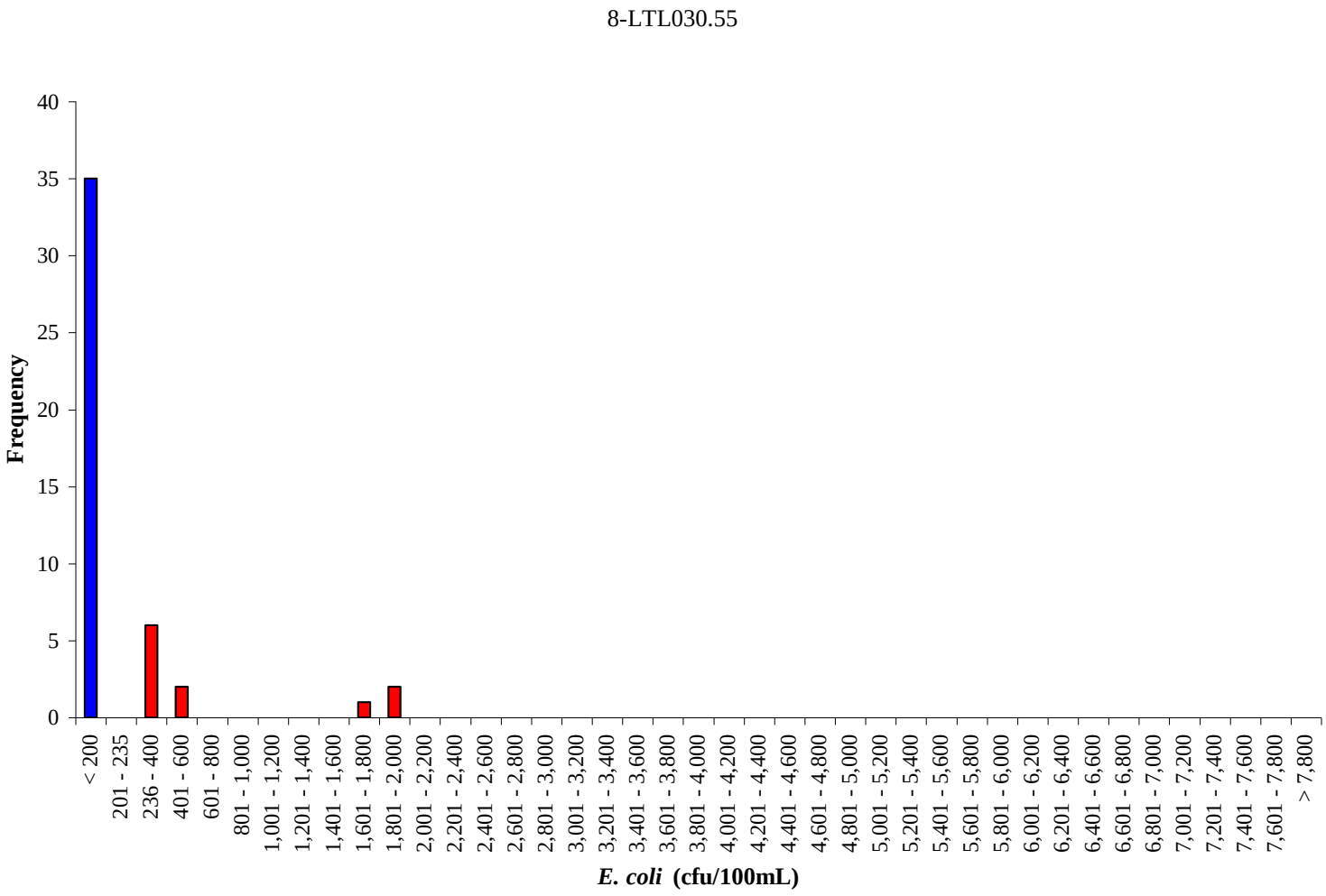

Figure A-54 Frequency analysis of *E. coli* concentrations at station 8-LTL030.55 in Little River for the period from March 2003 to July 2012.

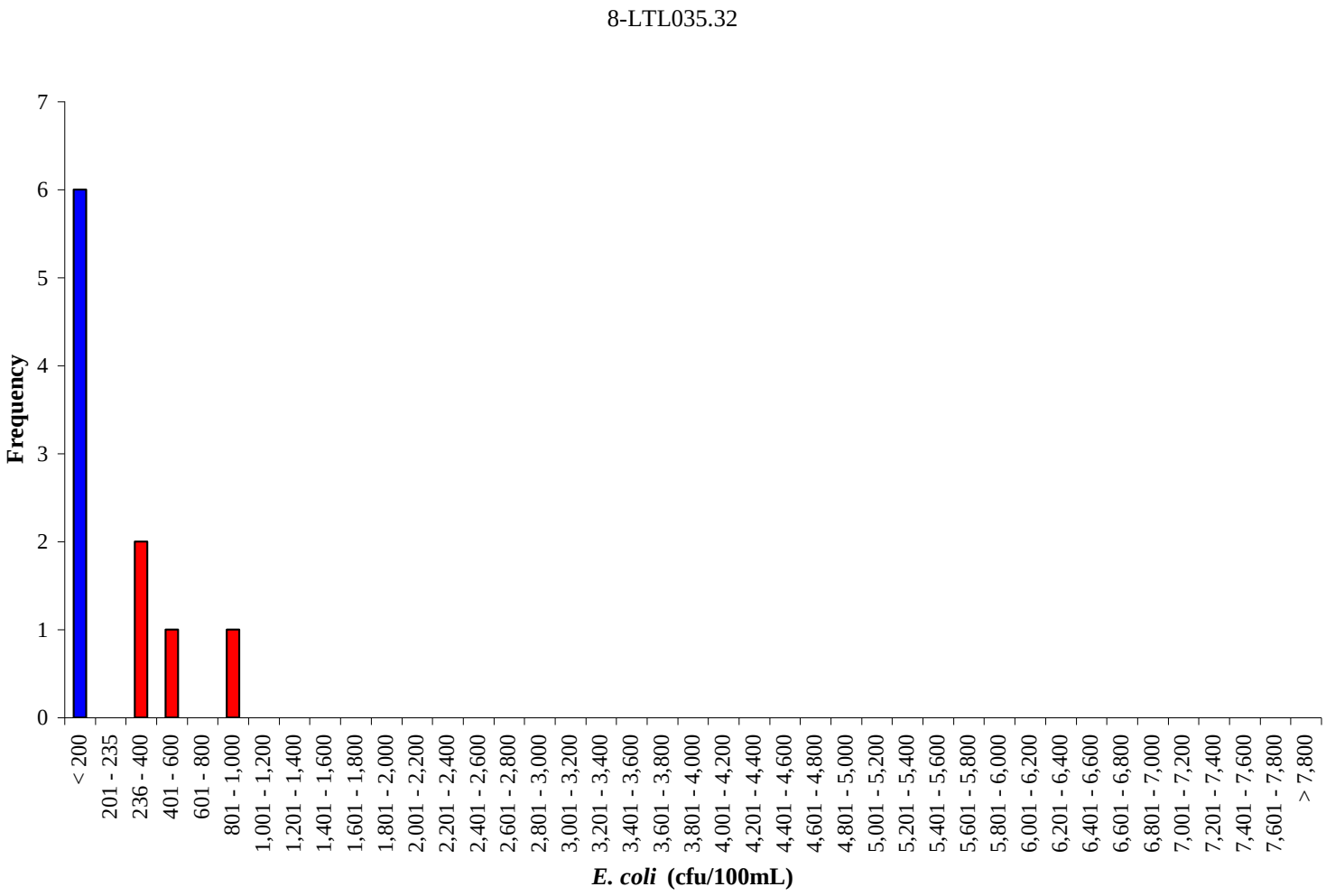

Figure A-55 Frequency analysis of *E. coli* concentrations at station 8-LTL035.32 in Little River for the period from February 2011 to August 2012.

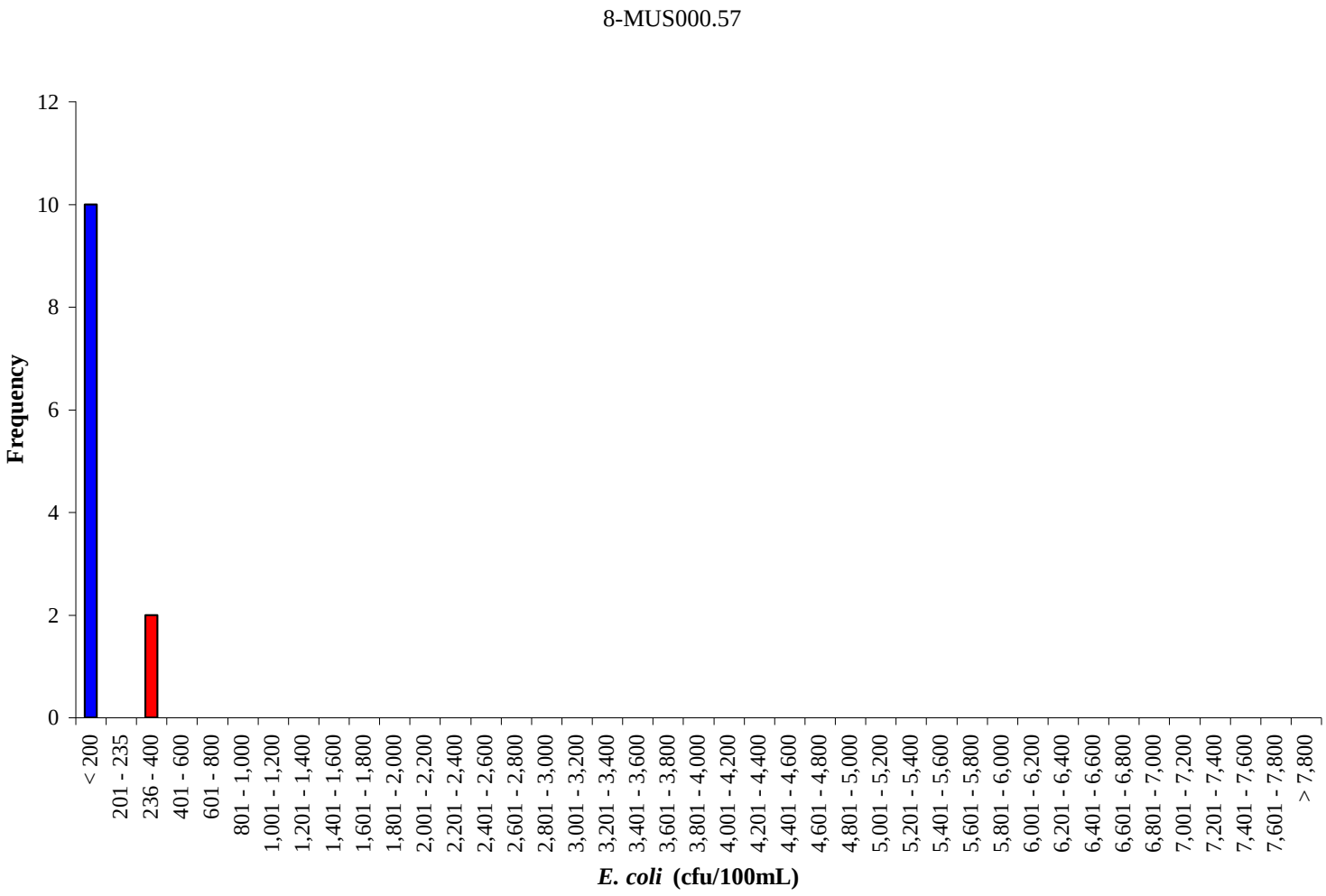

Figure A-56 Frequency analysis of *E. coli* concentrations at station 8-MUS000.57 in Music Branch for the period from August 2004 to July 2005.

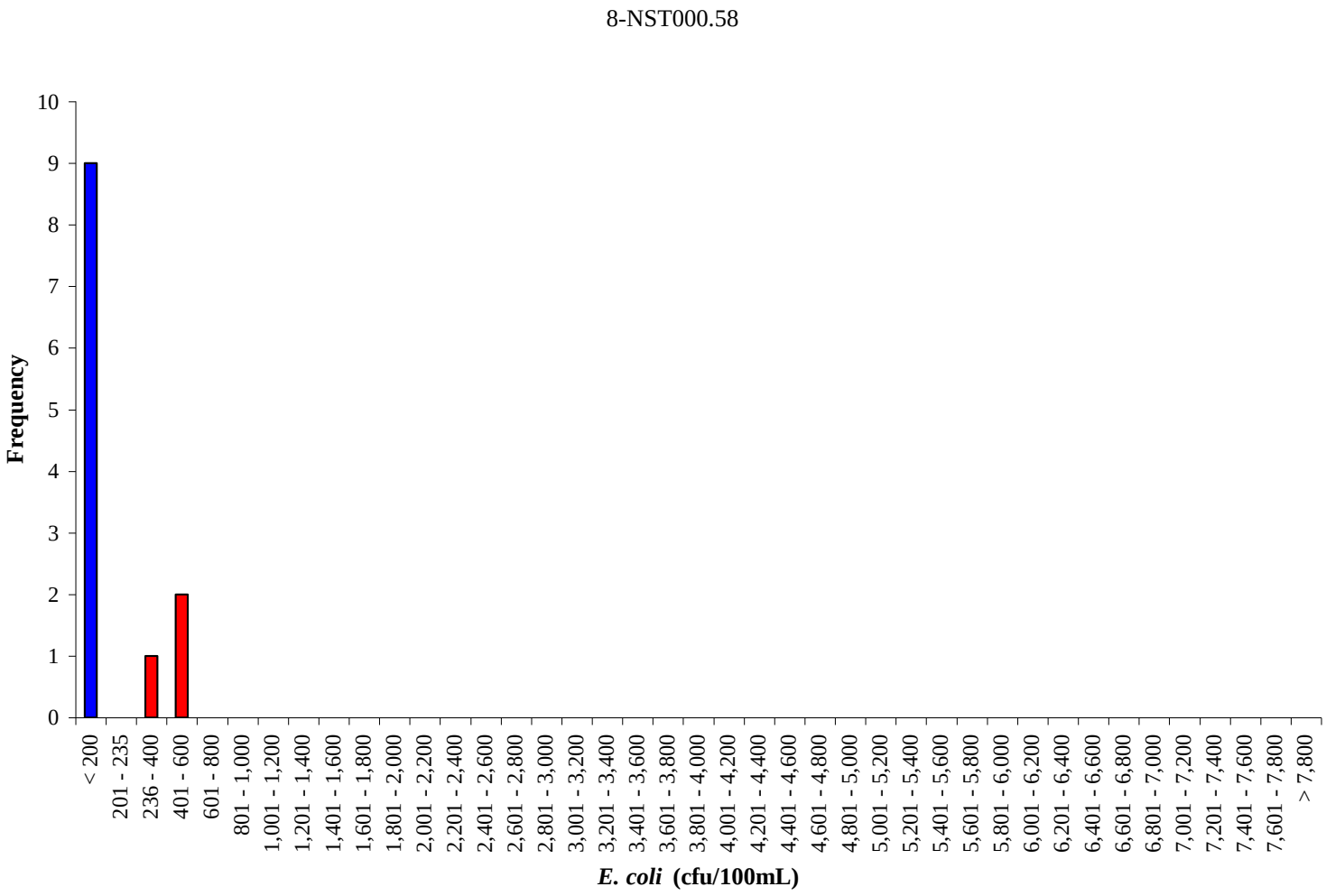

Figure A-57 Frequency analysis of *E. coli* concentrations at station 8-NST000.58 in Northeast Creek for the period from August 2004 to July 2005.

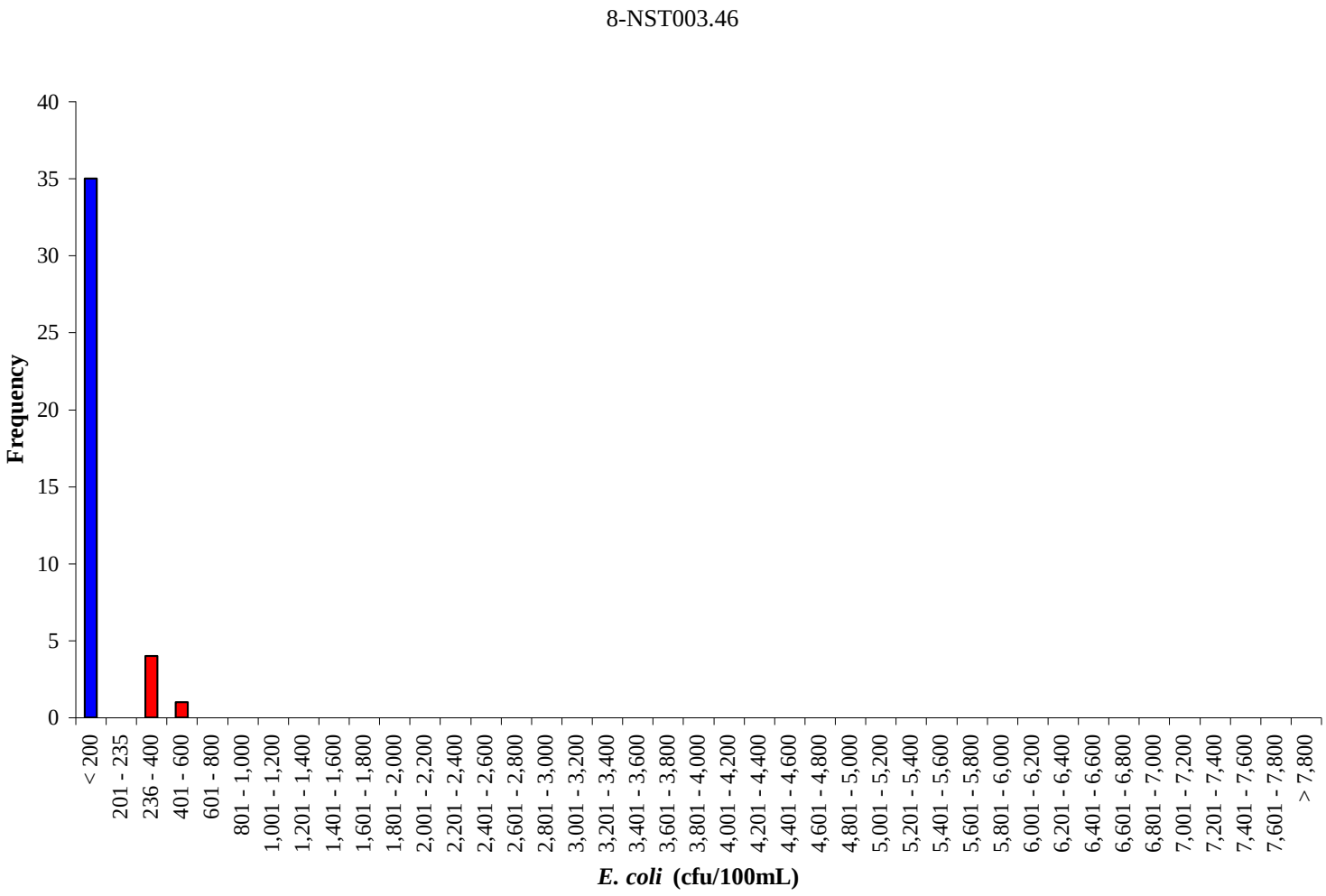

Figure A-58 Frequency analysis of *E. coli* concentrations at station 8-NST003.46 in Northeast Creek for the period from August 2004 to August 2012.

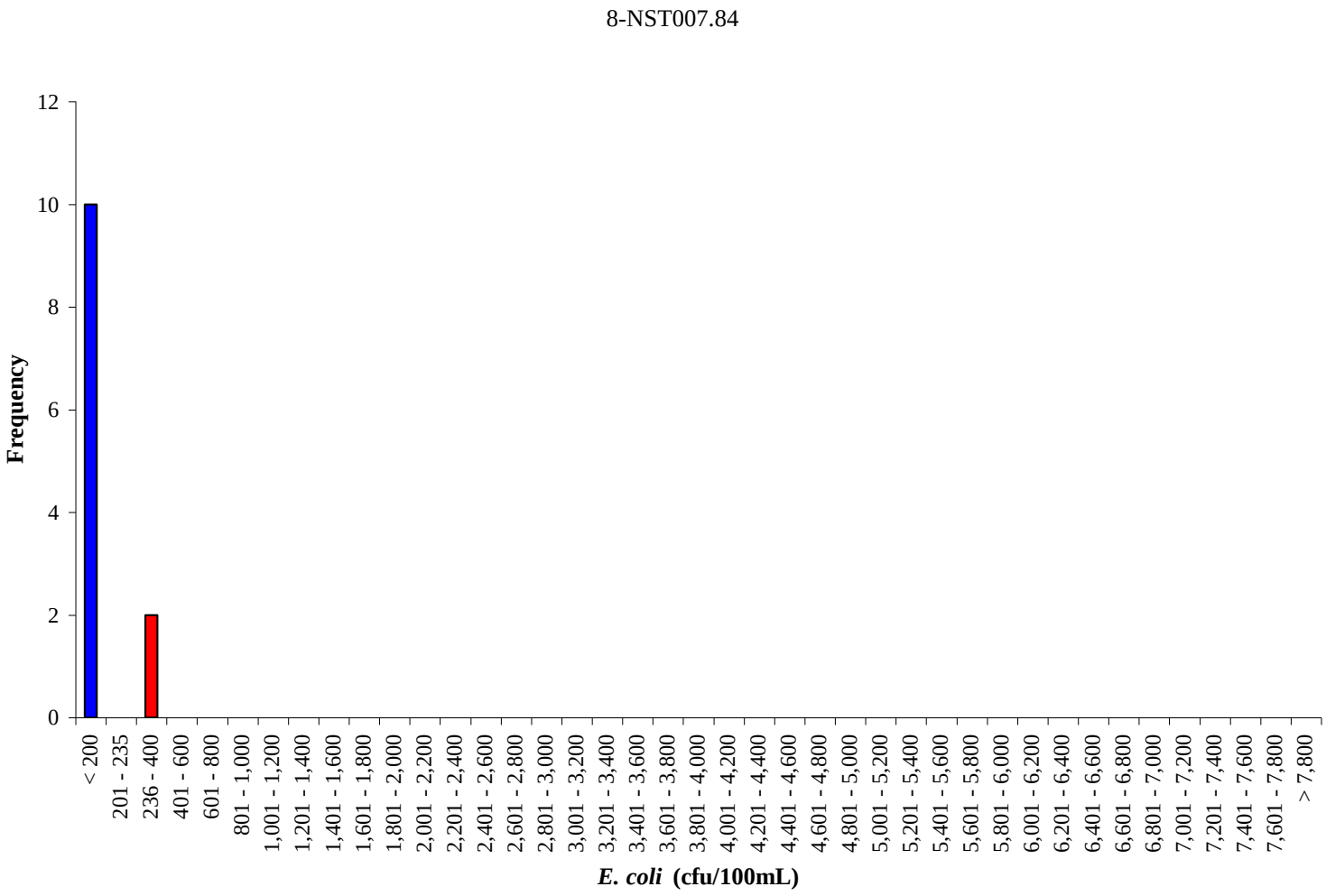

Figure A-59 Frequency analysis of *E. coli* concentrations at station 8-NST007.84 in Northeast Creek for the period from August 2004 to July 2005.

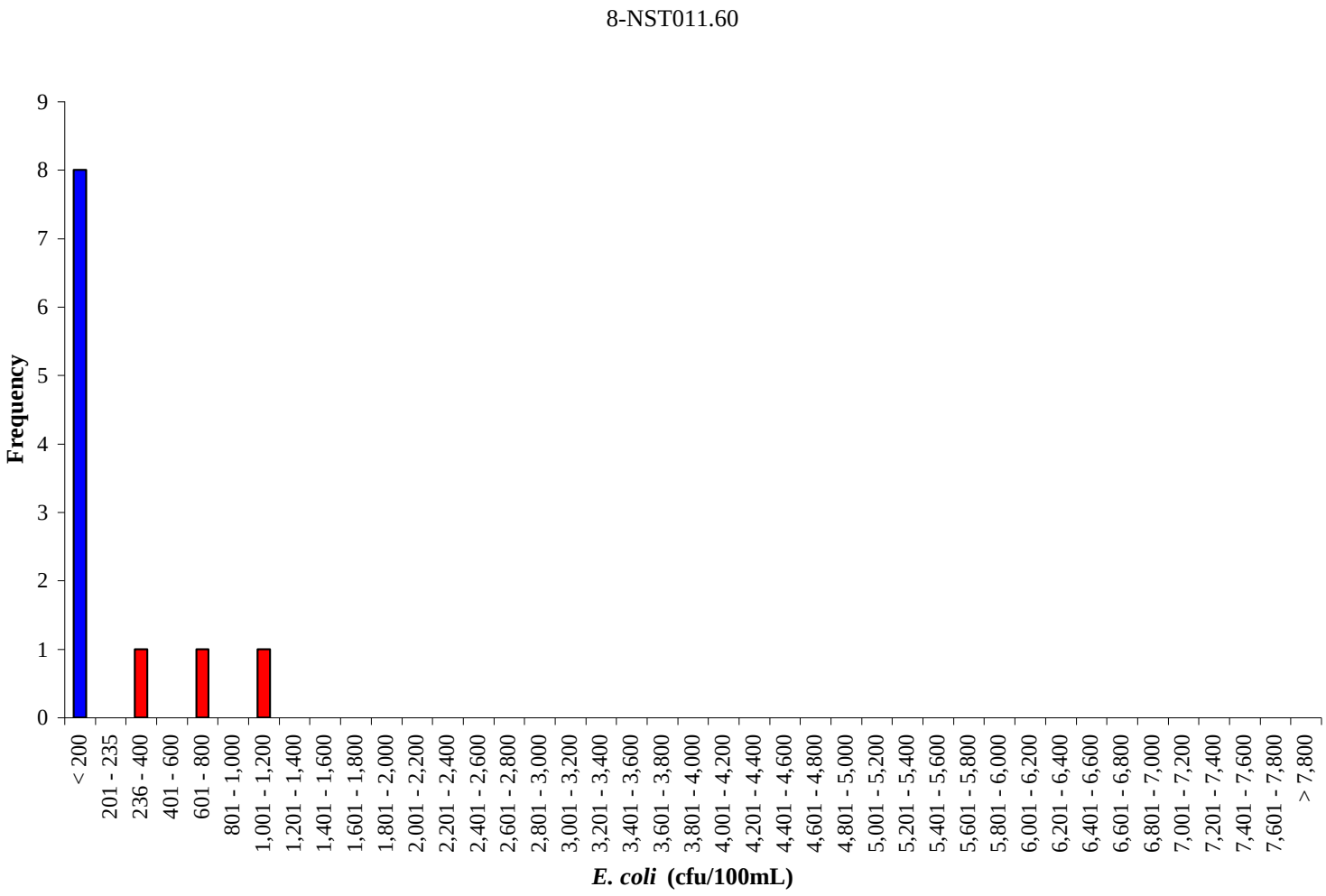

Figure A-60 Frequency analysis of *E. coli* concentrations at station 8-NST011.60 in Northeast Creek for the period from January 2009 to December 2010.

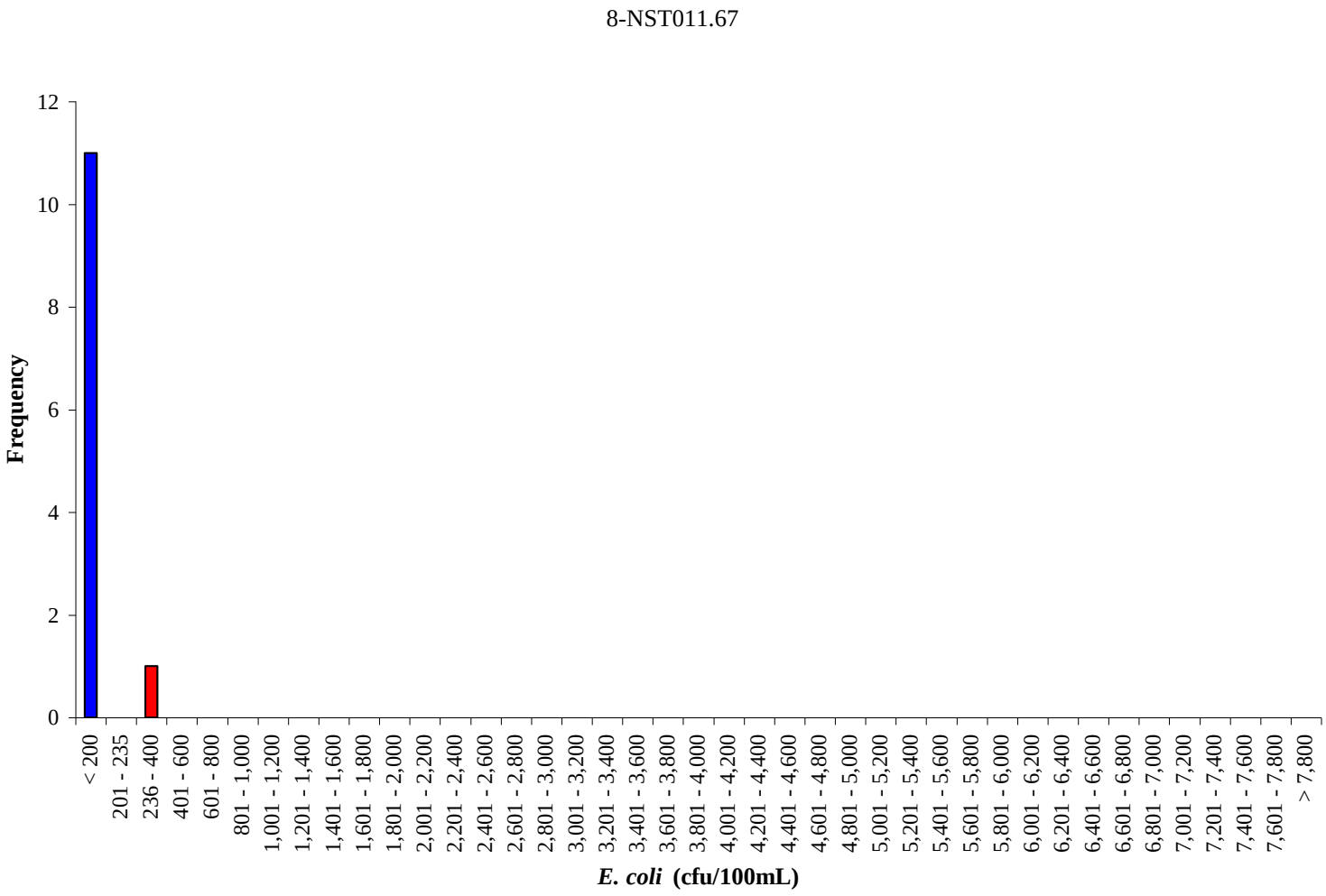

Figure A-61 Frequency analysis of *E. coli* concentrations at station 8-NST011.67 in Northeast Creek for the period from August 2004 to July 2005.

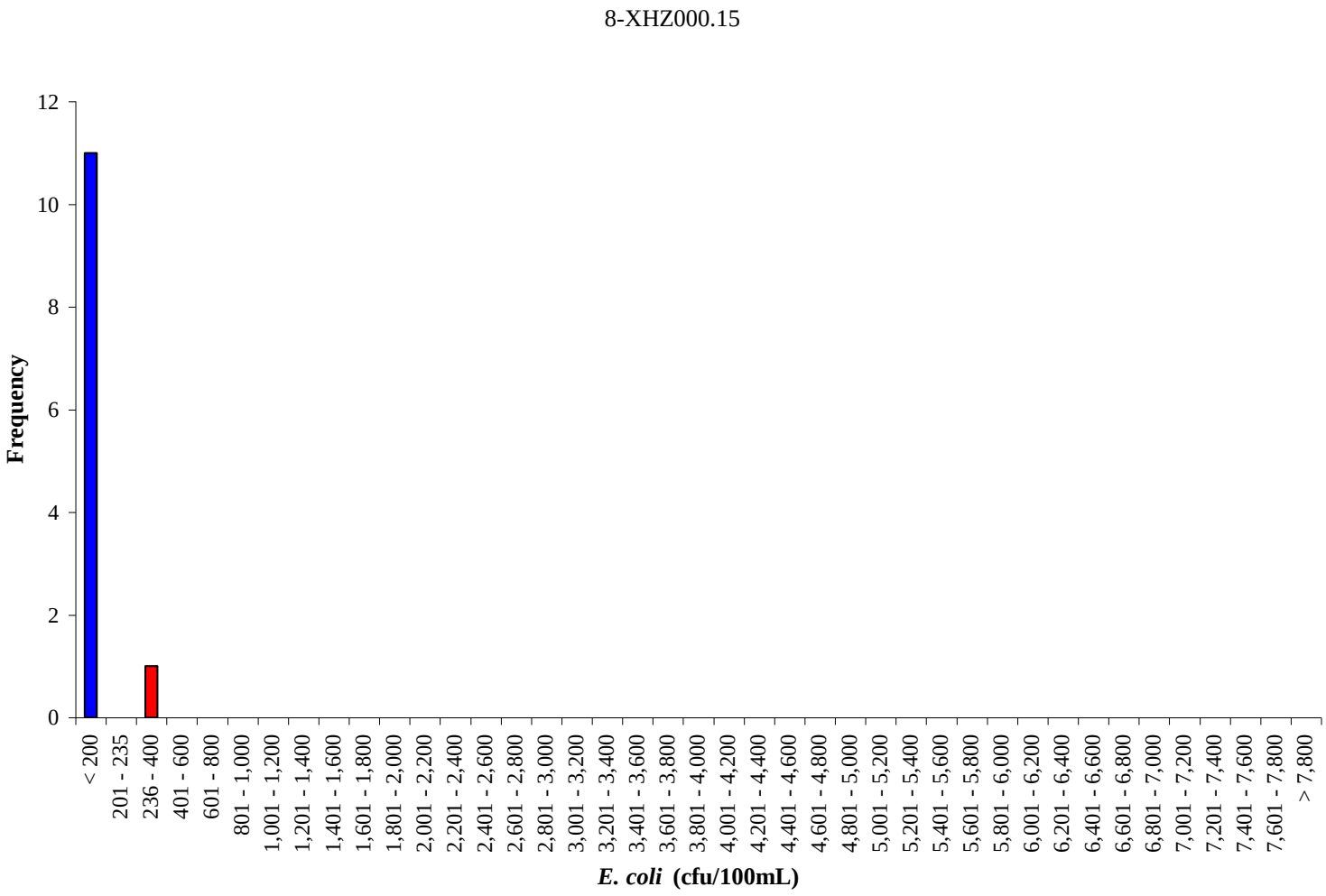

Figure A-62 Frequency analysis of *E. coli* concentrations at station 8-XHZ000.15 in an Unnamed Tributary to Northeast Creek for the period from August 2004 to July 2005.

Figure A-63 Frequency analysis of *E. coli* concentrations at station 8-XIA000.89 in an unnamed tributary to Music Branch for the period from August 2004 to July 2005.

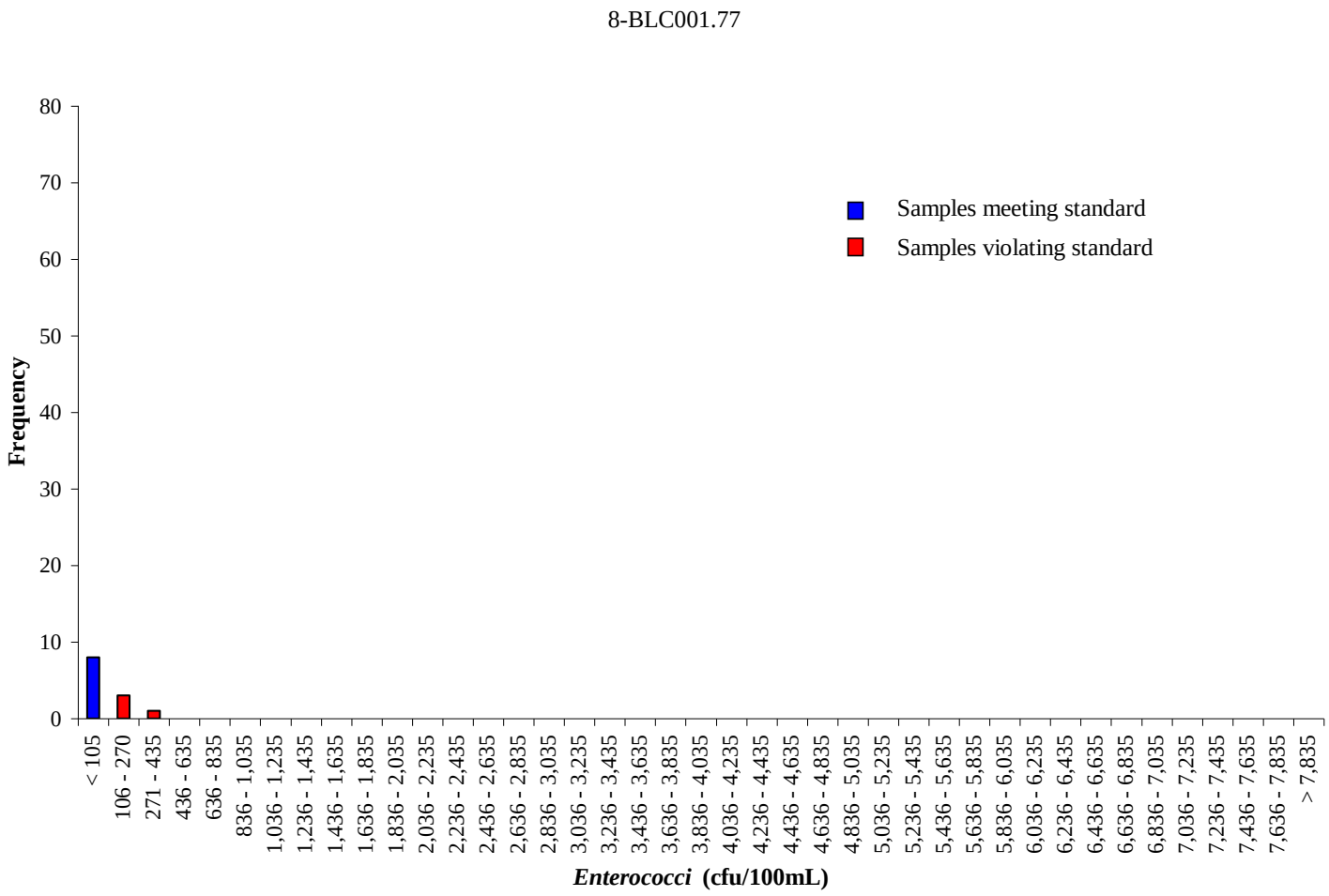

Figure A-64 Frequency analysis of *Enterococci* concentrations at station 8-BLC001.77 in Black Creek for the period from July 2003 to June 2004.

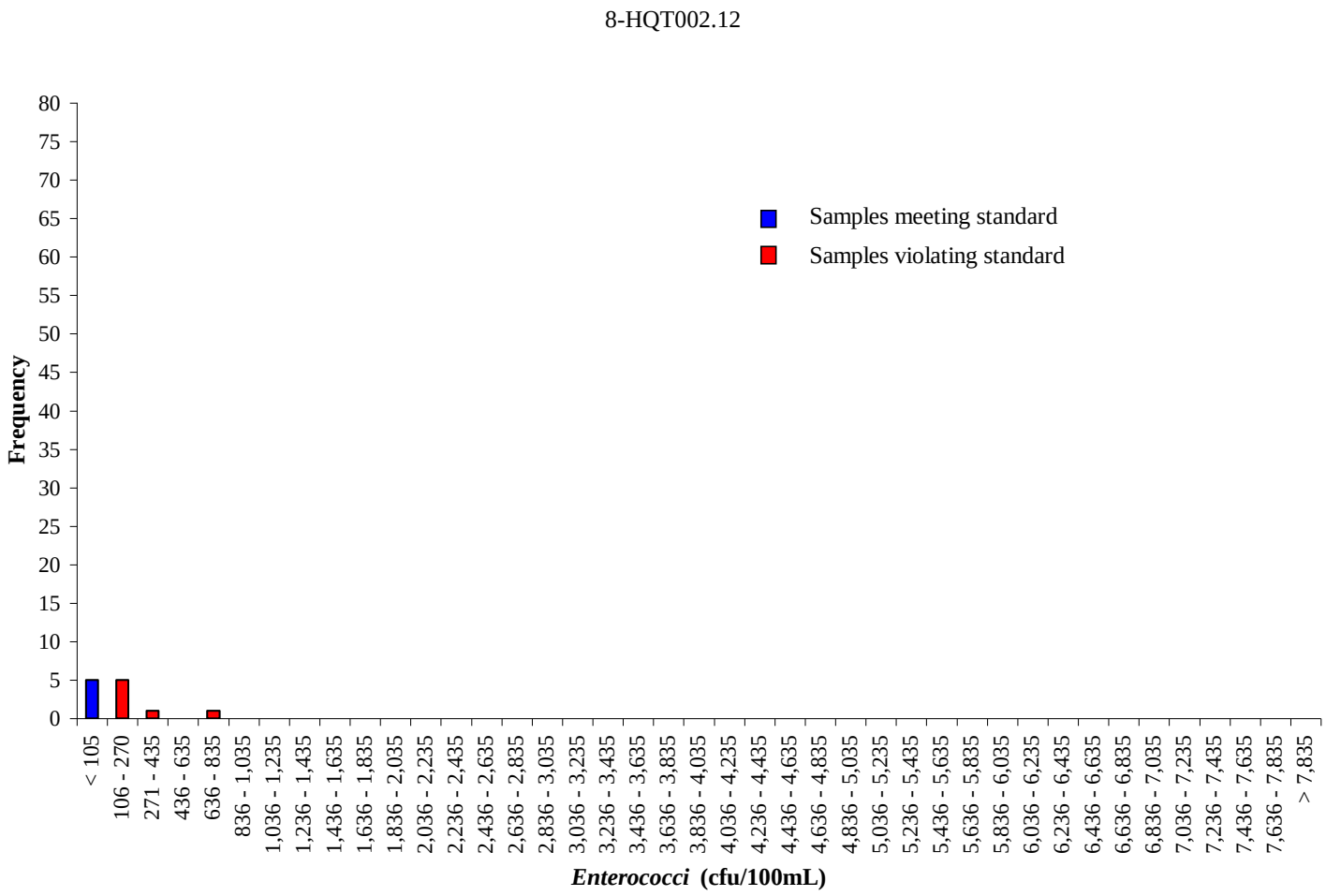

Figure A-65 Frequency analysis of *Enterococci* concentrations at station 8-HQT002.12 in Hornquarter Creek for the period from July 2003 to June 2004.

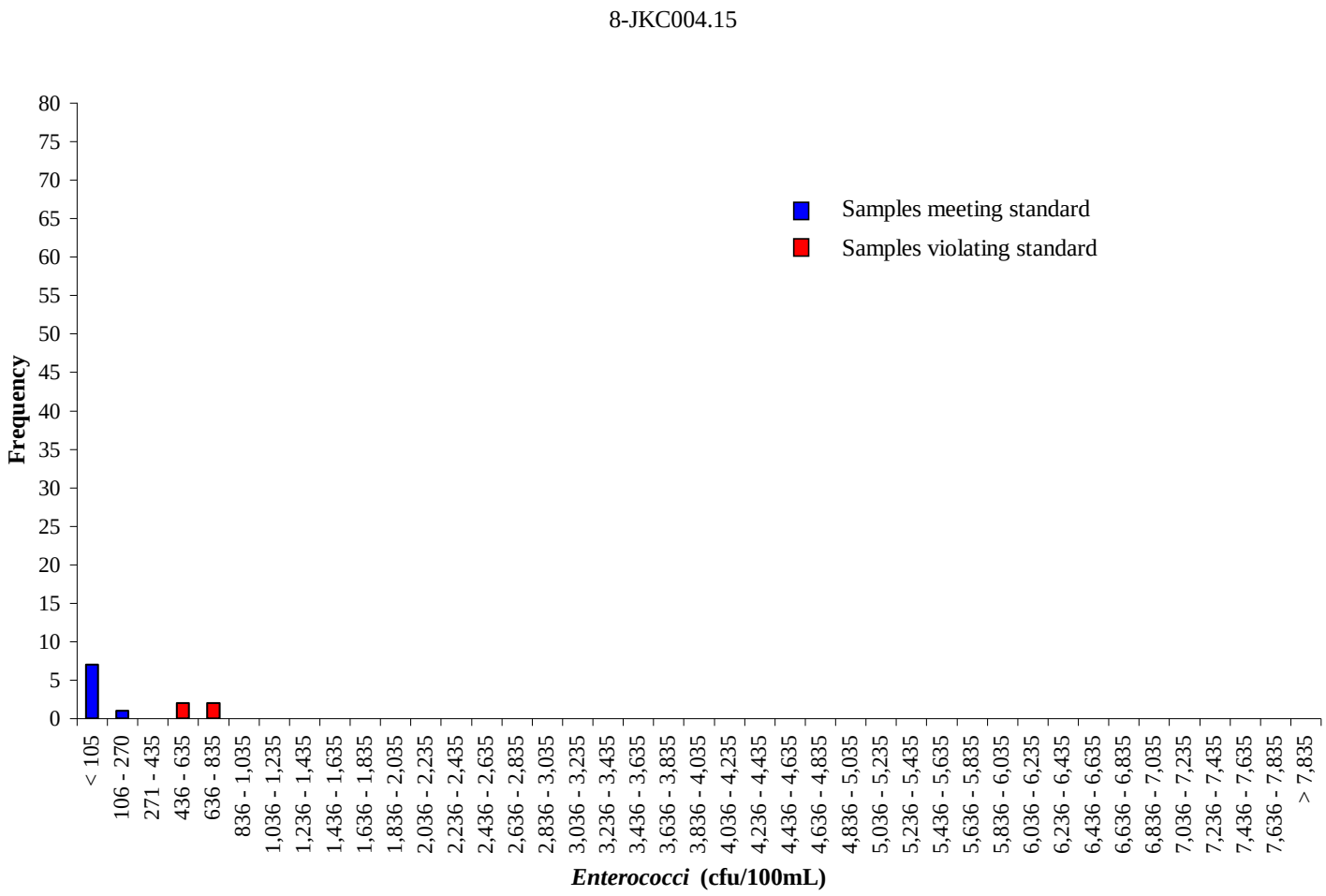

Figure A-66 Frequency analysis of *Enterococci* concentrations at station 8-JKC004.15 in Jacks Creek for the period from July 2003 to June 2004.

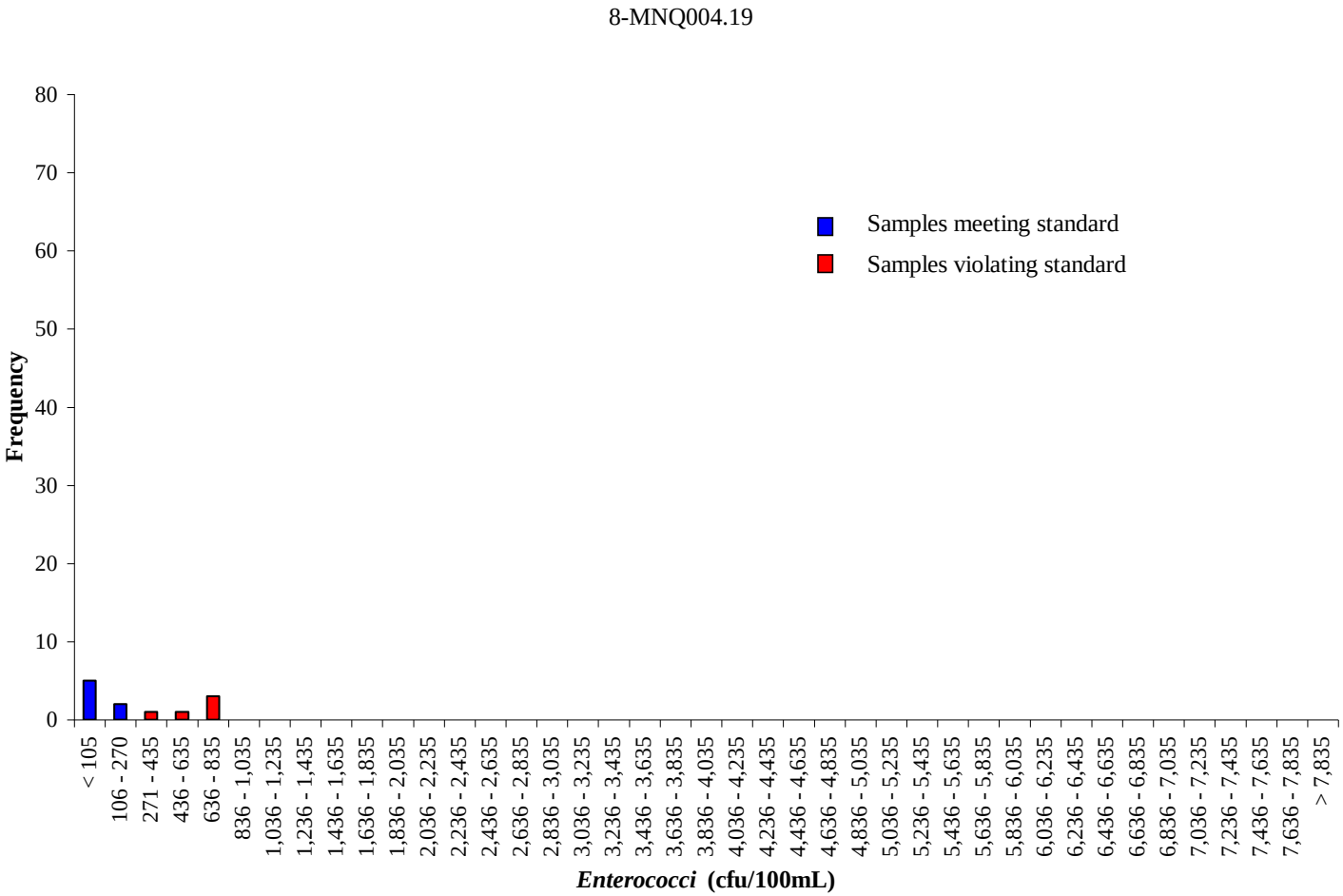

Figure A-67 Frequency analysis of *Enterococci* concentrations at station 8-MNQ004.19 in Moncuin Creek for the period from July 2003 to June 2004.

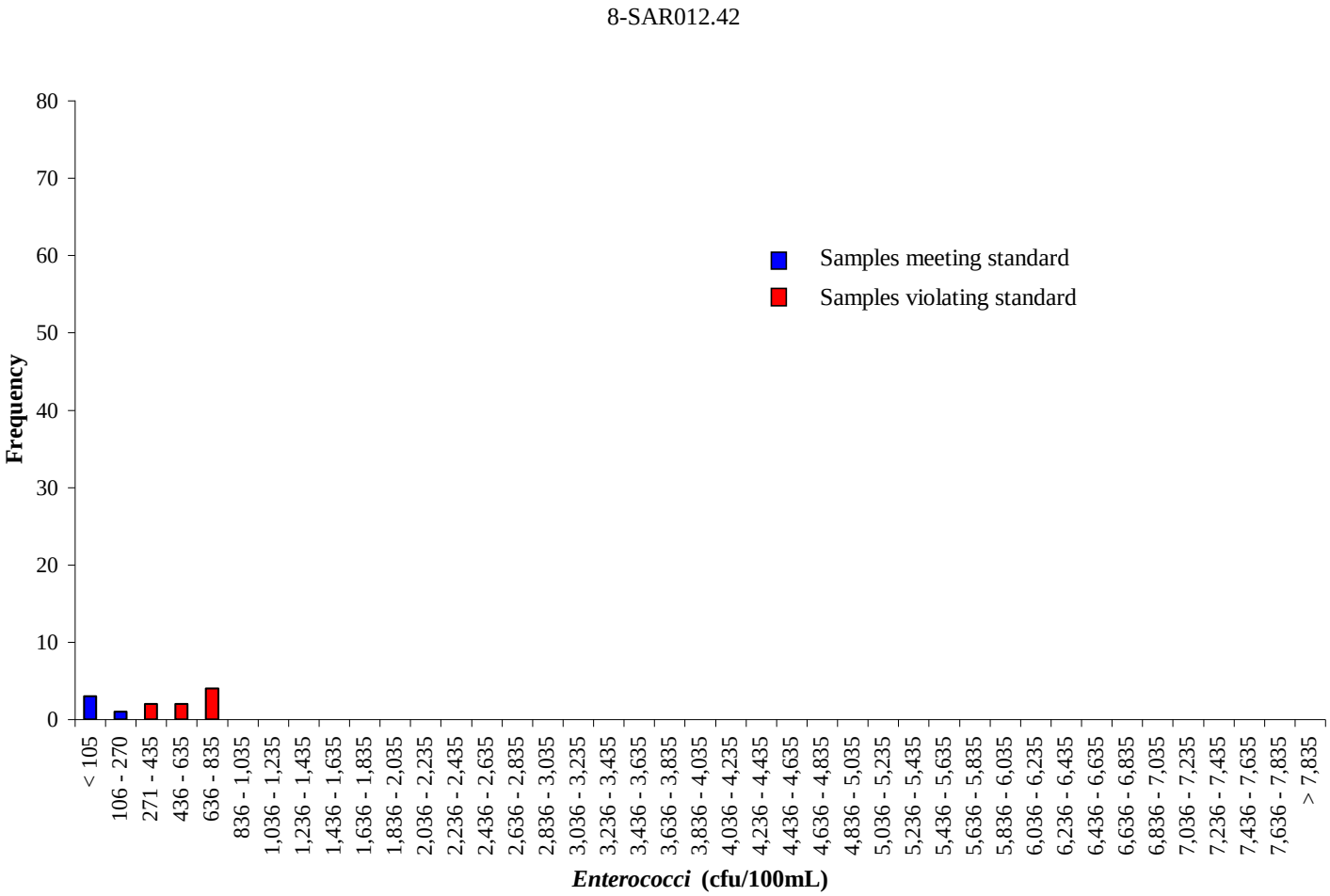

Figure A-68 Frequency analysis of *Enterococci* concentrations at station 8-SAR012.42 in the South Anna River for the period from July 2003 to June 2004.

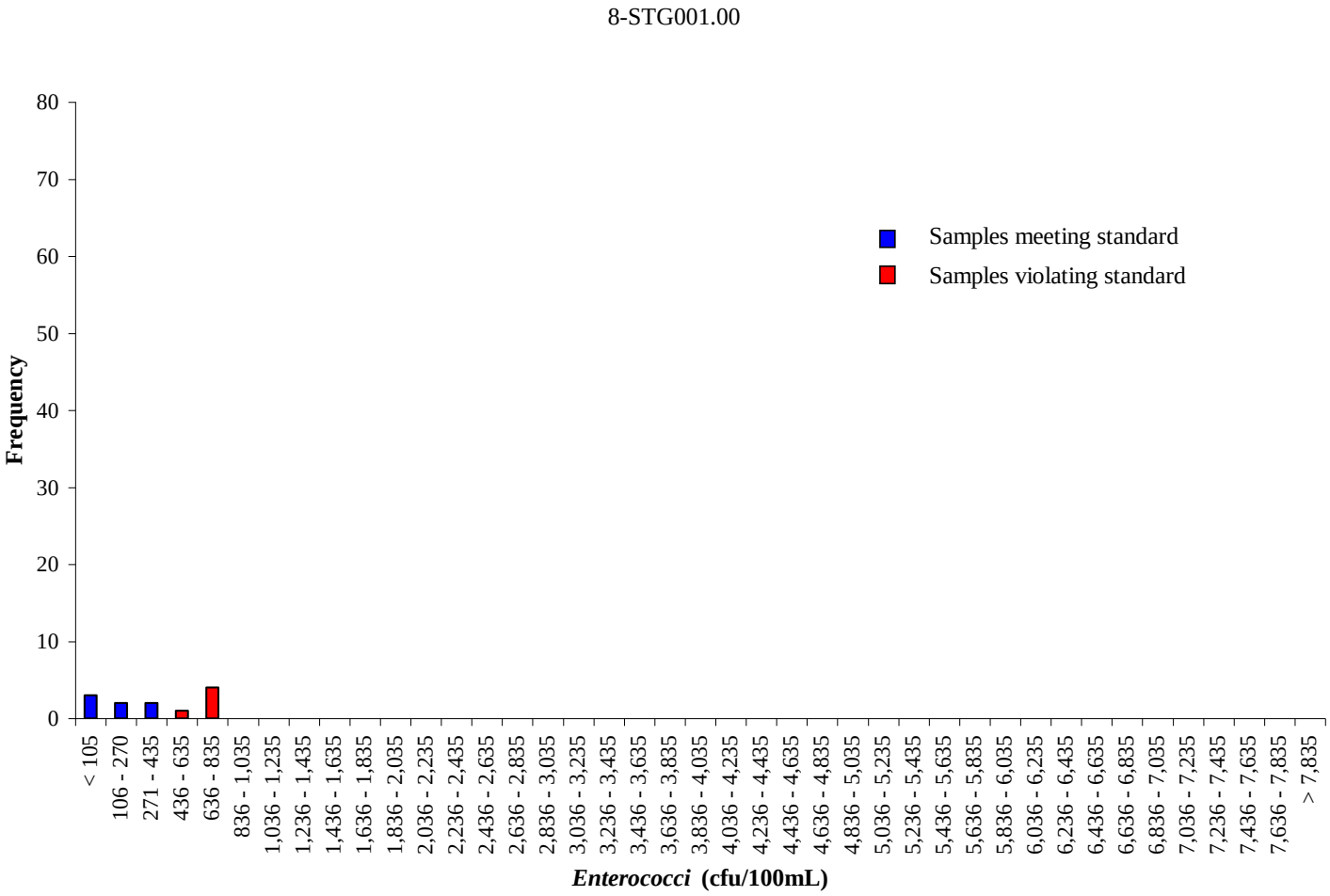

Figure A-69 Frequency analysis of *Enterococci* concentrations at station 8-STG001.00 in Stagg Creek for the period from July 2003 to June 2004.

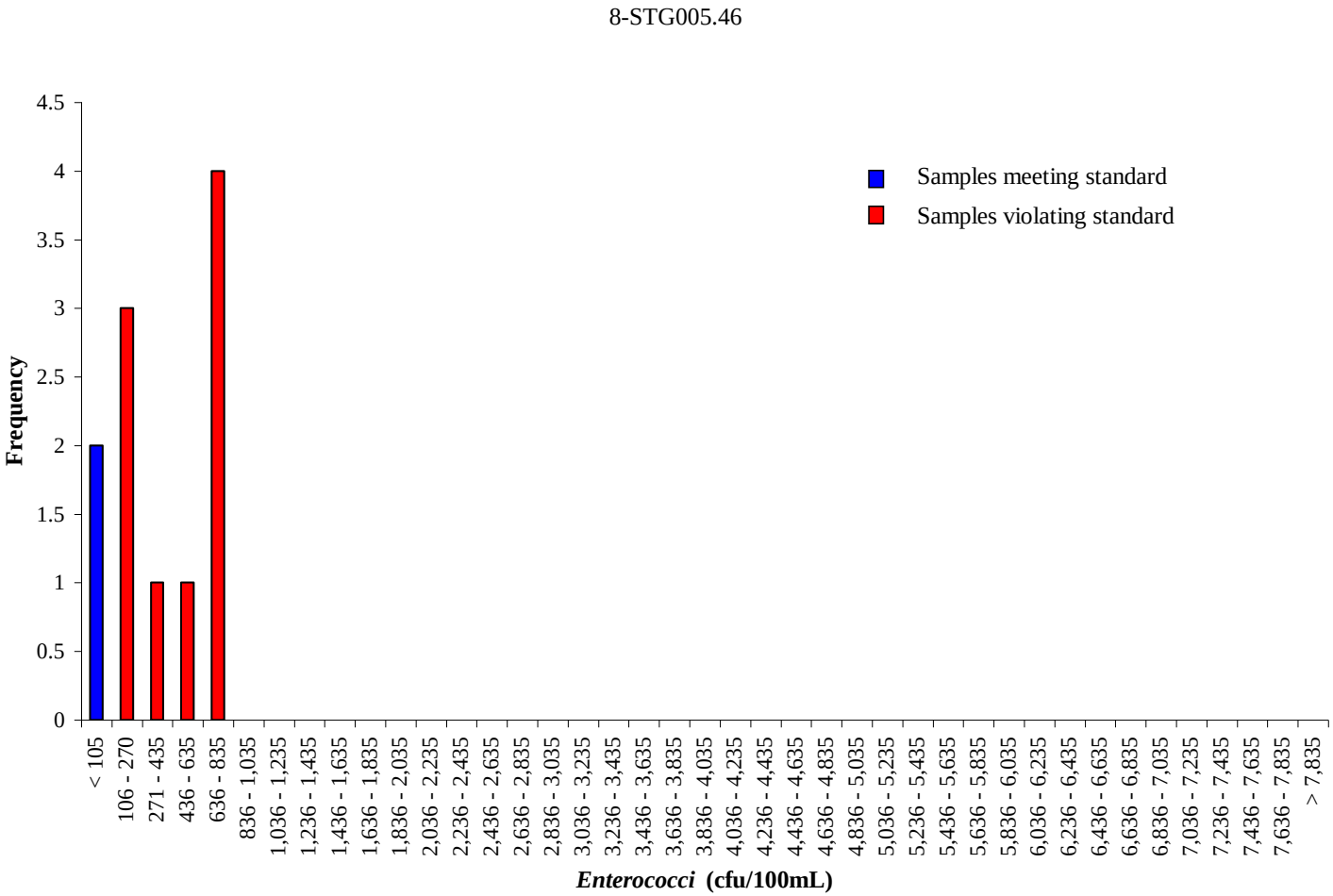

Figure A-70 Frequency analysis of *Enterococci* concentrations at station 8-STG005.46 in Stagg Creek for the period from September 2004 to July 2005.

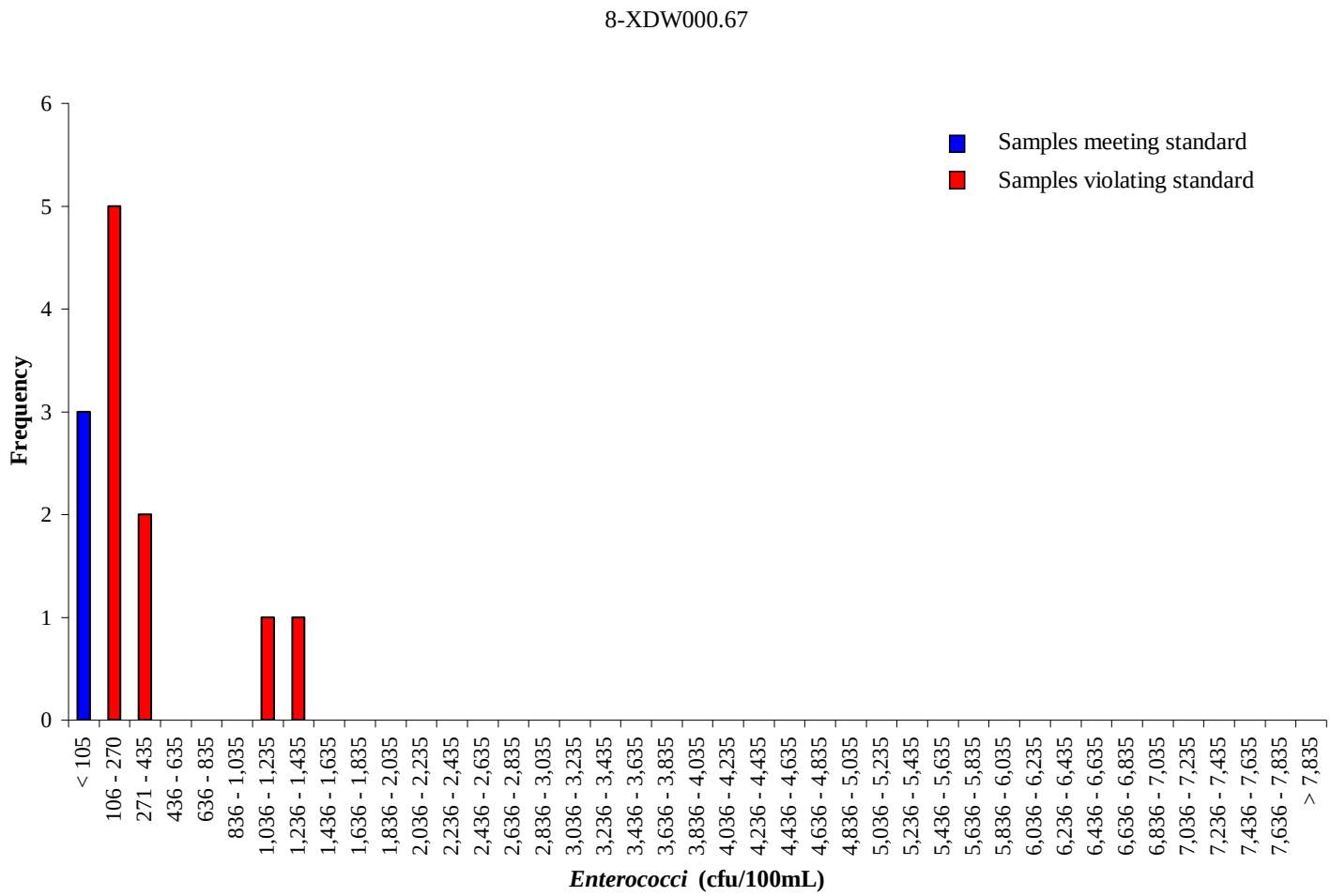

Figure A-71 Frequency analysis of *Enterococci* concentrations at station 8-XDW000.67 in an Unnamed tributary to the Pamunkey River for the period from January 2009 to December 2009.

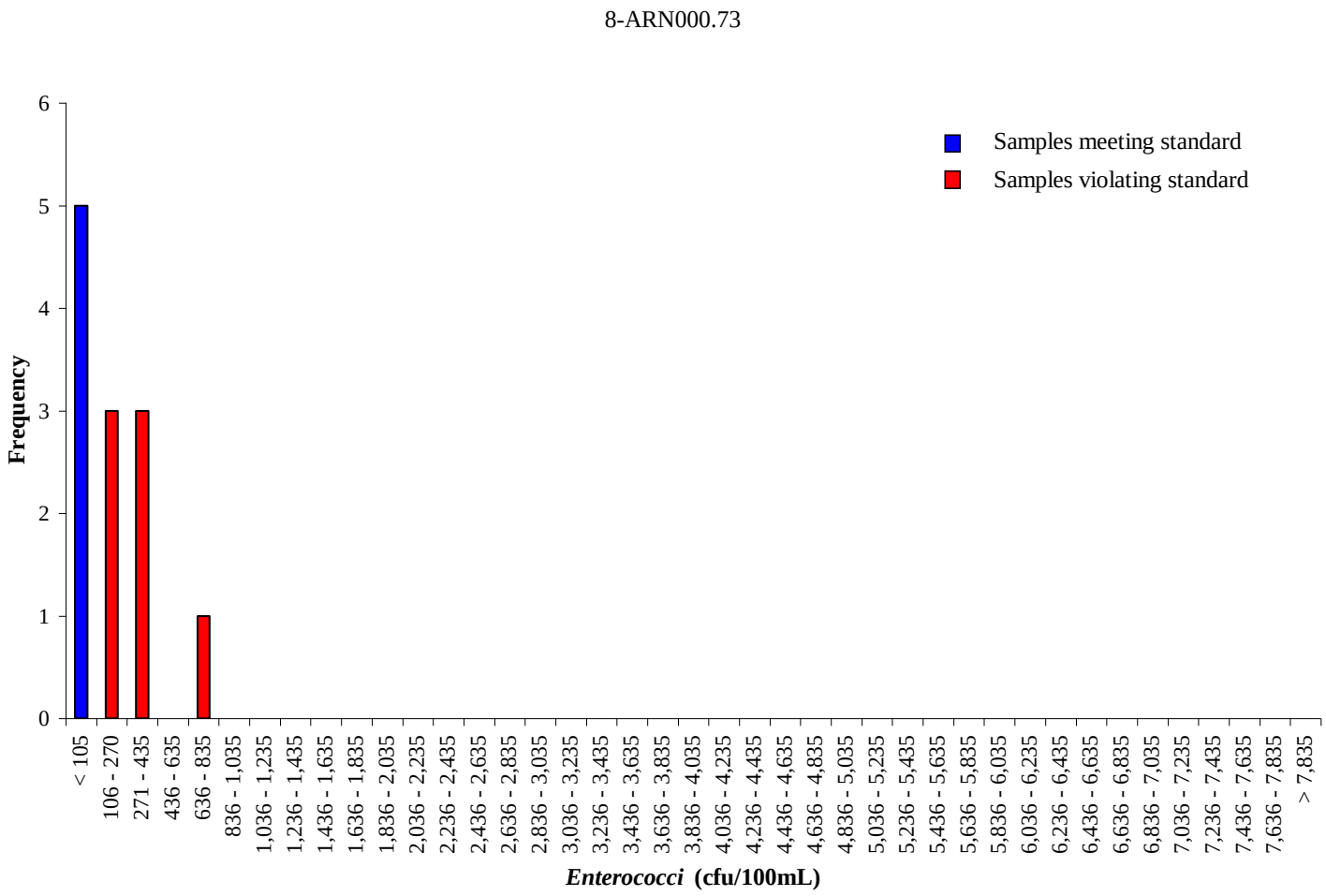

Figure A-72 Frequency analysis of *Enterococci* concentrations at station 8-ARN000.73 in Arnold Creek for the period from August 2004 to July 2005.

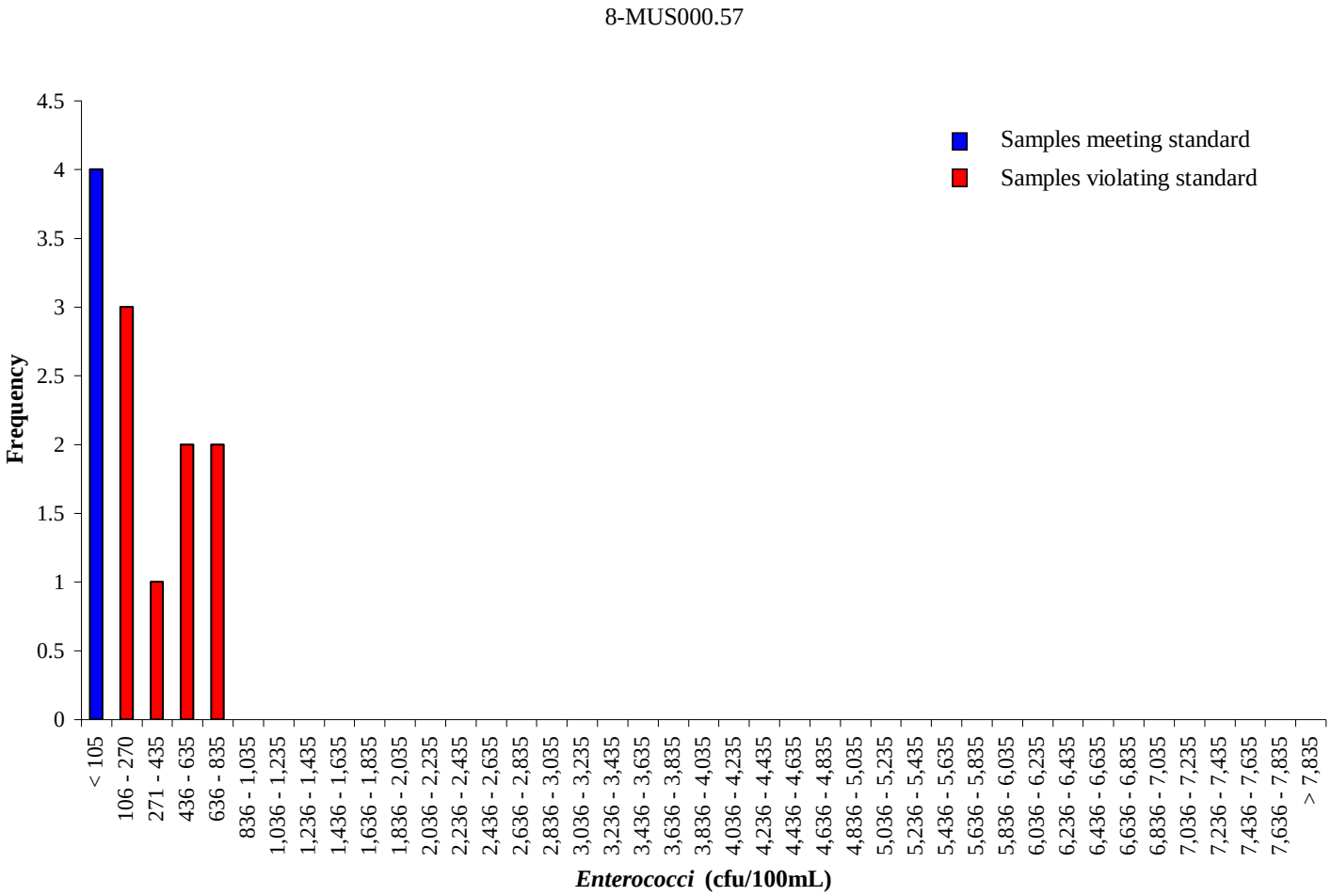

Figure A-73 Frequency analysis of *Enterococci* concentrations at station 8-MUS000.57 in Music Branch for the period from August 2004 to July 2005.

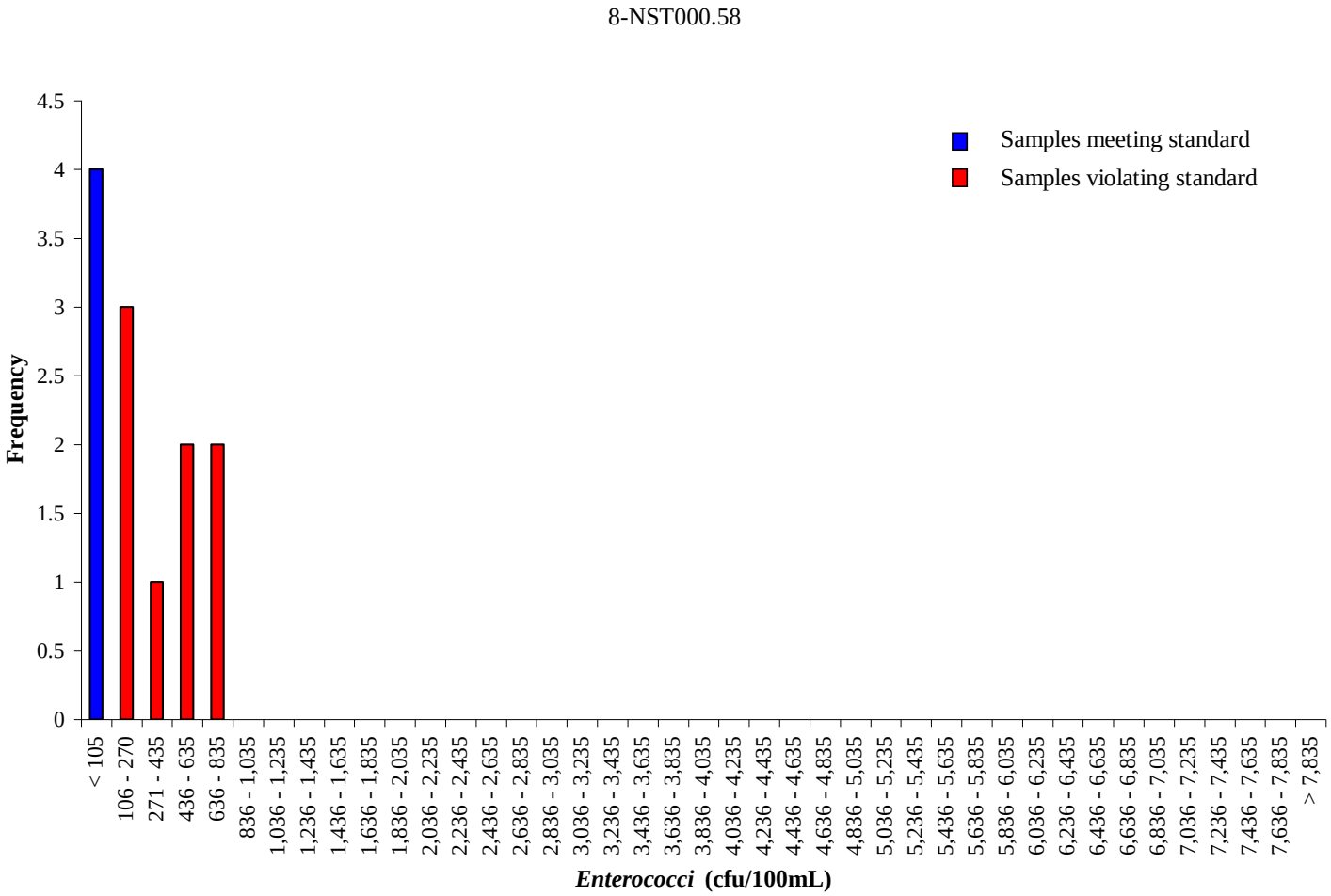

Figure A-74 Frequency analysis of *Enterococci* concentrations at station 8-NST000.58 in Northeast Creek for the period from August 2004 to July 2005.

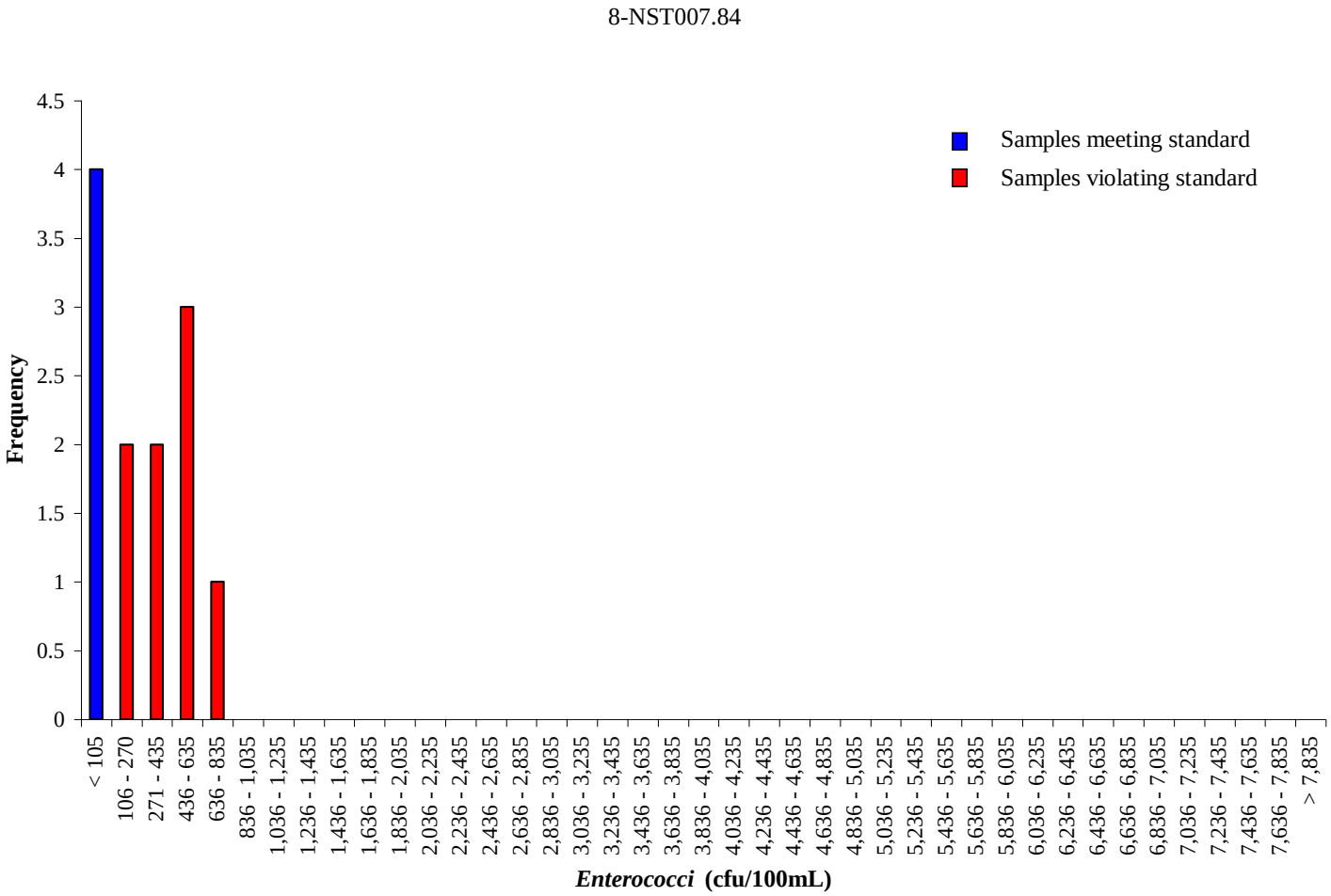

Figure A-75 Frequency analysis of *Enterococci* concentrations at station 8-NST007.84 in Northeast Creek for the period from August 2004 to July 2005.

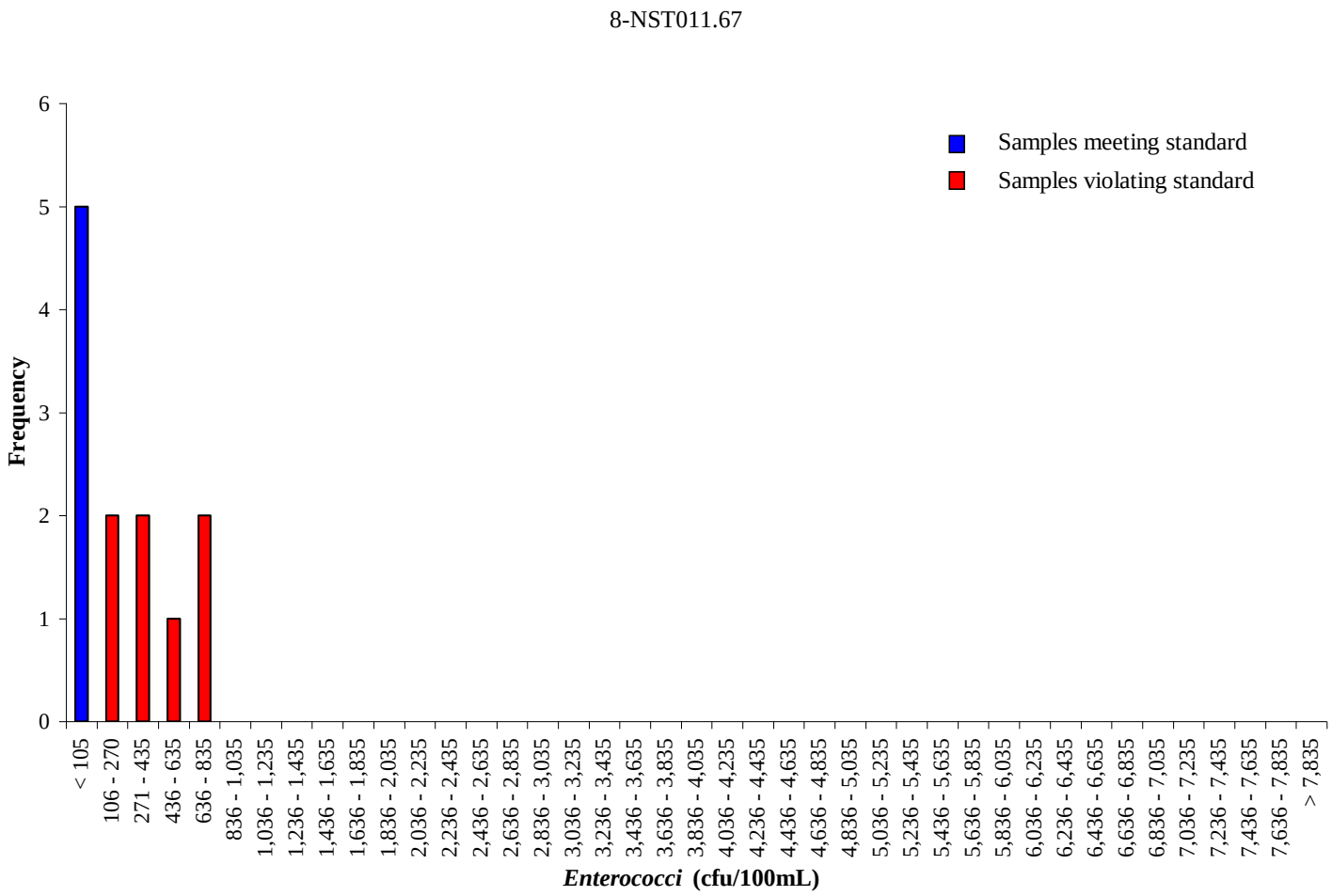

Figure A-76 Frequency analysis of *Enterococci* concentrations at station 8-NST011.67 in Northeast Creek for the period from August 2004 to July 2005.

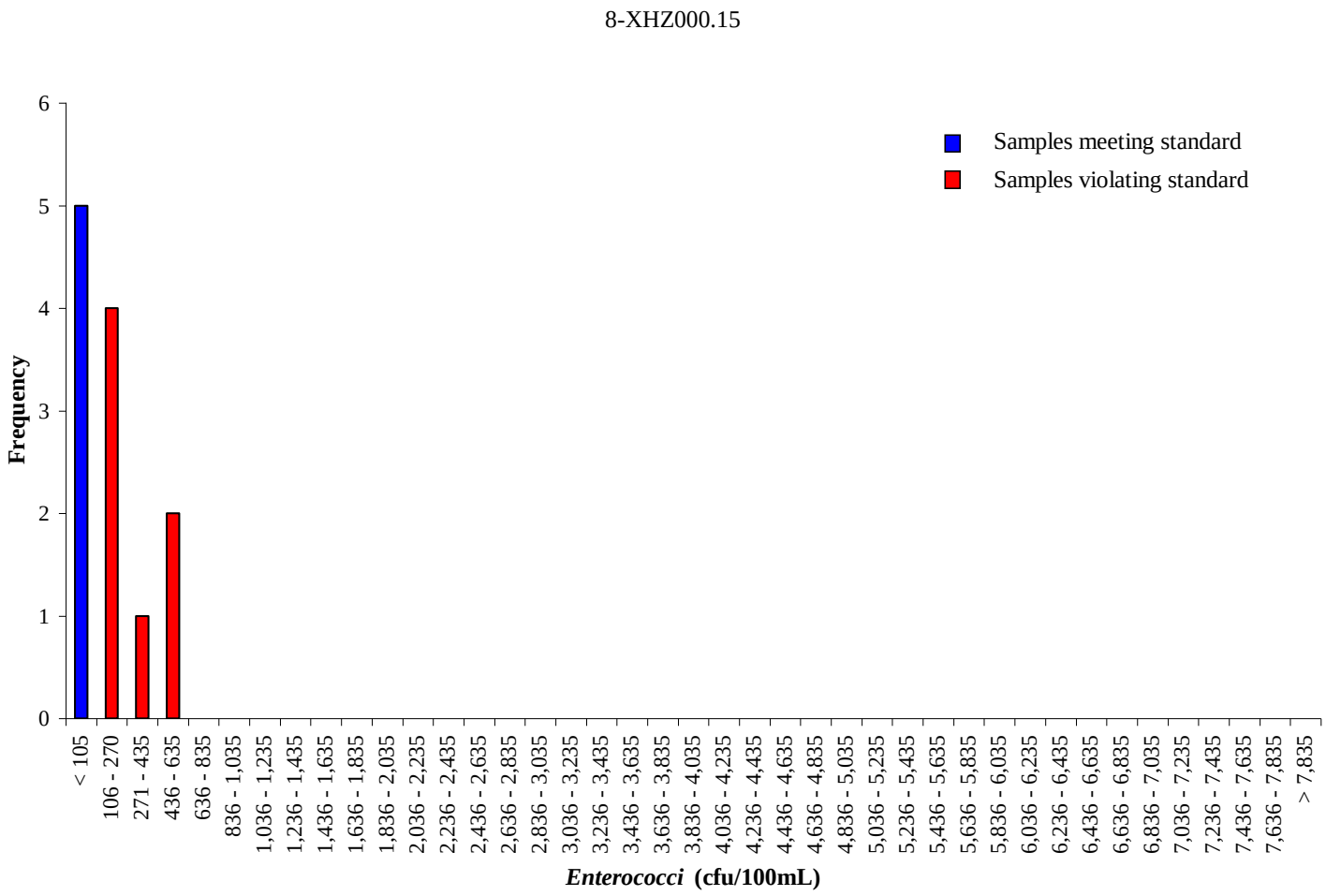

Figure A-77 Frequency analysis of *Enterococci* concentrations at station 8-XHZ000.15 in an Unnamed Tributary to Northeast Creek for the period from August 2004 to July 2005.

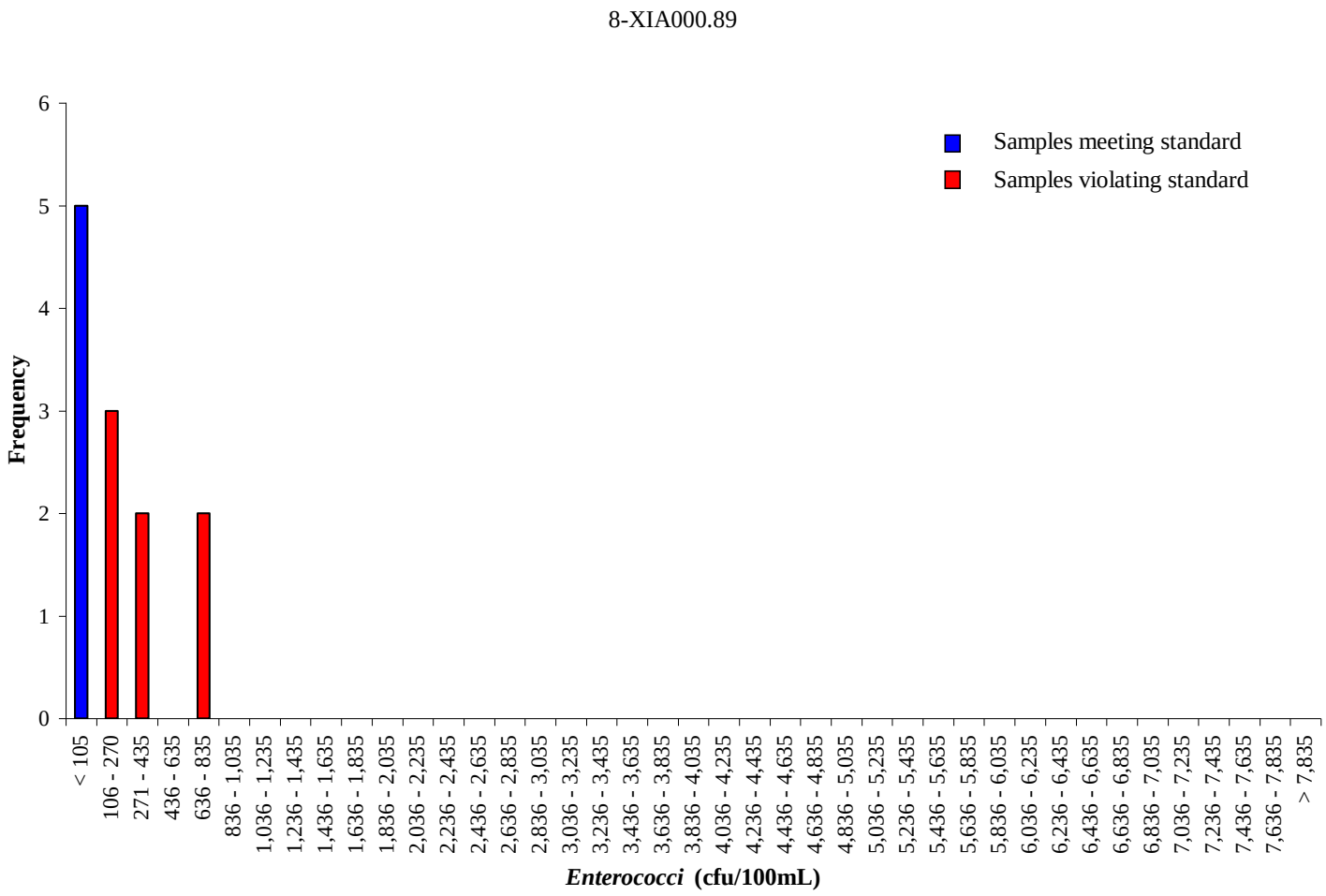

Figure A-78 Frequency analysis of Enterococci concentrations at station 8-XIA000.89 in an Unnamed Tributary to Music Branch for the period from August 2004 to July 2005.

This page was intentionally left blank.

APPENDIX B: BACTERIA MODELING PROCEDURE - LINKING THE SOURCES TO THE ENDPOINT

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

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

Modeling Framework Selection

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

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

The HSPF model is a continuous simulation model that can account for nonpoint source (NPS) pollutants in runoff, as well as pollutants entering the flow channel from point sources. In establishing the existing and allocation conditions, seasonal variations in hydrology, climatic conditions, and watershed activities were explicitly accounted for in the model. The use of HSPF allowed consideration of seasonal aspects of precipitation patterns within the watershed.

Model Setup

Daily precipitation data was available at the Richmond International Airport NCDC station #USW00013740. The final filled daily precipitation was disaggregated using the hourly station data available at the Richmond International Airport NCDC Coop station #447201.

To adequately represent the spatial variation in the watershed, the Pamunkey River Watershed study area drainage area was divided into fifty (50) subwatersheds (**Figure B-1**). The subwatersheds are numbered from 1 to 51, however, subwatershed 29 was merged with subwatershed 9 during the model development process and no longer exists. The rationale for choosing these subwatersheds was based on the availability of water quality data, the stream network configuration, and the limitations of the HSPF model.

Sixteen of these subwatersheds were used in hydrologic calibration since they were upstream of the flow gage with observed data (outlet of subwatershed 13). The entire set of 50 subwatersheds was used in the bacteria calibration. **Figure B-1** shows all subwatersheds, which were used to achieve the unified model (three subwatersheds represent existing TMDLs). **Table B- 1** notes the subwatersheds contained within each impairment, the impaired stream segments, and the outlet subwatershed for each impairment.

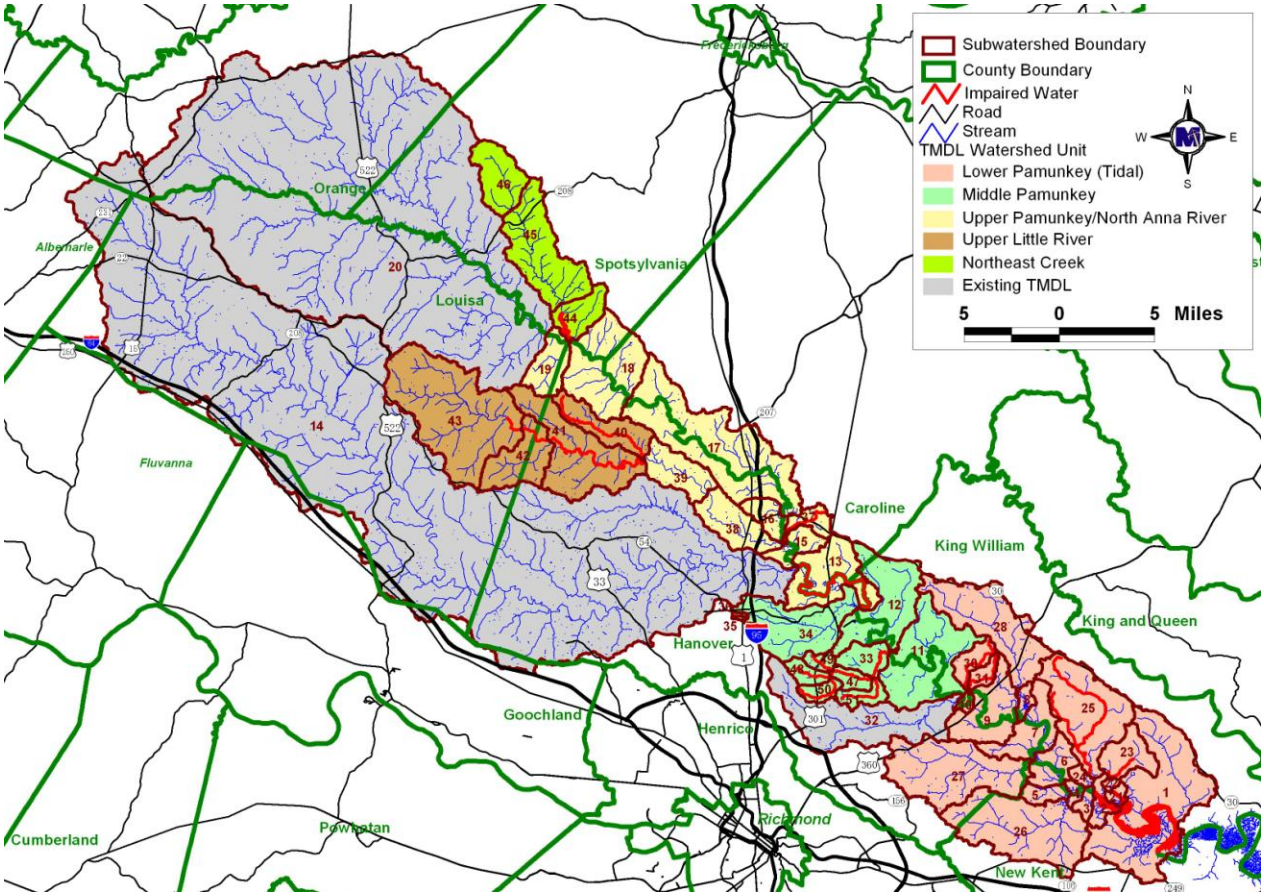

Figure B-1 All subwatersheds delineated for modeling in the Pamunkey River Watershed study area.

Table B- 1 Impairments and subwatersheds within the Pamunkey River Watershed study area.

Impairment	NTU	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds
Beaverdam Creek (VAP-F11R_BDC01A12)	299	40	40	40
Crump Creek (VAP-F12R_CRU01A02)	74	33,47,50	33	33,47,48,49,50,51
Crump Creek Unnamed Tributary (VAP-F12R_XJC01A12)	74	49	49	49
Harrison Creek (VAP-F14R_HSN01A00)	73	23	23	23
Harrison Creek (VAP-F14E_HSN01A12)	73	21	21	21,22,23
Harrison Creek Unnamed Tributary (VAP-F14R_XJD01A12)	73	23	23	23
Jacks Creek and Tributaries (VAP-F13R_JCK01A98)	73	25	25	25
Kersey Creek (VAP-F12R_KER01A12)	74	48	48	48
Upper Little River (VAN-F10R_LTL01A12)	299	42,43	42	42,43
Lower Little River (VAP-F11R_LTL01B08)	299	41	41	41,42,43
Mill Creek (VAP-F09R_MLL01A12)	75	37	37	37
Pamunkey River (VAP-F12R_PMK01B08)	75	13	13	13,15-19,37-46
Pamunkey River (VAP-F14E_PMK02A00)	73	2	2	2-13,15-19,21-51
Pamunkey River (VAP-F14E_PMK03A00)	73	1	1	1-13,15-19,21-51
Pamunkey River (VAP-F14E_PMK04A00)	73	1	1	1-13,15-19,21-51
Pamunkey River Unnamed Tributary (VAP-F13R_XDW01A08)	73	30	30	30,31
Pamunkey River Unnamed Tributary (VAP-F13R_XDX01A04)	73	31	31	31
Pollard Creek (VAP-F12R_PLD01A012)	74	51	51	51
Northeast Creek (VAN-F09R_NST01A08)	341	44,45	44	44,45,46

In an effort to standardize modeling procedures across the state, VADEQ has required that fecal bacteria models be run at a 1-hour time-step. The HSPF model requires that the

time of concentration in any subwatershed be greater than the time-step being used for the model. These modeling constraints as well as the desire to maintain a spatial distribution of watershed characteristics and associated parameters were considered in the delineation of subwatersheds. The spatial division of the watersheds allowed for a more refined representation of pollutant sources, and a more realistic description of hydrologic factors in the watersheds.

Nine land uses were identified in the watershed. These land uses were obtained by merging different sources including the MRLC land use grid, and aerial photography of the region. The nine land use types are given in **Table B- 2**. Within each subwatershed, up to the nine land use types were represented. Each land use in each subwatershed has hydrologic parameters (*e.g.,* average slope length) and pollutant behavior parameters (*e.g., E. coli* accumulation rate) associated with it. These land use types are represented in HSPF as pervious land segments (PERLNDs) and impervious land segments (IMPLNDs). Impervious areas in the watershed are represented in 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 the season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Figure B-2 shows the land uses used in modeling the Pamunkey River Watershed study area. **Table B- 3** and **Table B- 4** show the breakdown of land uses within the drainage area of each impairment. These acreages represent only what is within the boundaries of the Pamunkey River Watershed study area.

Table B- 2 Consolidated land use categories for the Pamunkey River Watershed study area drainage area used in HSPF modeling.

TMDL Land use Categories	Pervious / Impervious (%)
Barren	Pervious (100%)
Cropland	Pervious (100%)
Commercial	Pervious (35%) Impervious (65%)
Developed	Pervious (92.5%) Impervious (7.5%)
Forest	Pervious (100%)
Livestock Access	Pervious (100%)
Pasture	Pervious (100%)
Wetland	Pervious (100%)
Water	Pervious (100%)

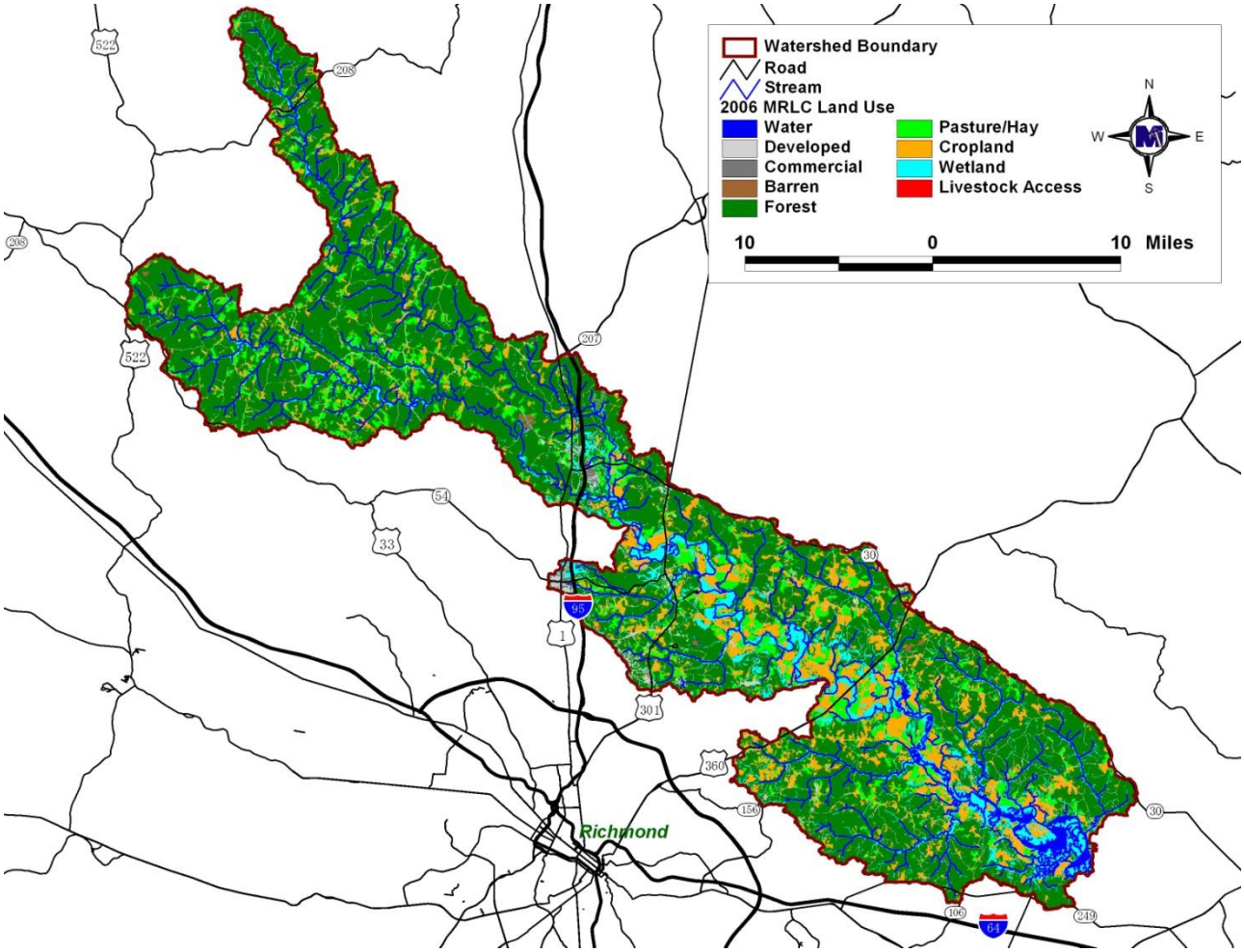

Figure B-2 Land uses in the Pamunkey River Watershed study area.

Table B- 3 Spatial distribution of land use types in acres in the Pamunkey River study area in acres.

Sub-water-shed	Water	Developed	Commercial	Barren	Forest	Pasture	Cropland	Wetland	LAX	Total
1	2694.8	1079.4	2.51		14976	926.83	3302	5819.4	4.04	28805
2	332.04	102.46			475.28	109.78	432	720.3	2.63	2174.5
3	120.44	52.83			304.33	42.21	224.8	425.7	0.11	1170.4
4	87.93	24.04			62.99	39.3	210.9	457.68	0.03	882.88
5	82.01	69.53			1135.39	143.33	320.2	302.63	0.74	2053.8
6	292.37	84.13			933.96	534.85	1574	1007.5	5.8	4432.6
7	290.91	148.8			2901.85	926.19	1851	1256.8	9.06	7385
8	74.51	19.15			233.81	150.03	208.9	549.13	1.38	1236.9
9	105.34	337.97		5.33	2210.66	1654.9	2968	2130.8	9.35	9422.5
10	8.95	21.43			33.83	131.78	273.6	229.36	0.22	699.15
11	114.68	727.91			7103.91	2318.4	3873	3108.8	4.9	17251
12	108.38	372.66	7.34		7484.24	1347.1	2453	2123.3	7.65	13903
13	97.31	509.36	10.39	34.4	5495.54	762.46	2076	2547.2	3.57	11536
15	22.02	99.31	3.44		1985.91	269.13	384.6	594.9	0.11	3359.4
16	16.63	597.85	311.3	5.21	1091.91	380.7	108.7	645.52	1.84	3159.7
17	405.11	1432.8	100.4	124	22041.1	1543.2	1636	1120.9	15.92	28420
18	114.13	545.46	3.86	3.79	12962.4	1409.6	639.5	442.39	8.95	16130
19	33.18	133.86	3.92		4344.12	471.36	353.8	69.43	8.77	5418.5
21	30.96	35.2			198.58	231.11	74.38	344.24	0.67	915.14
22	19.97	19.67			223.24	97.53		74.81		435.22
23	57.97	216.78			4181.55	106.54	155.5	375.43	0.54	5094.3
24	14.77	34.6			471.61		138.1	266.97		926
25	81	611.43	13.01	9.82	11793.9	852.72	1814	1607.9	3.3	16787
26	151.45	720.89	1.33		15998.6	517.73	1519	1460.4	6.27	20375

LAX is livestock access to a stream.

Table B- 4 Spatial distribution of land use types in acres in the Pamunkey River study area in acres (cont.).

Sub-water-shed	Water	Developed	Commercial	Barren	Forest	Pasture	Cropland	Wetland	LAX	Total
27	131.89	846.96	28.08		12345.2	1248.6	2872	1298	2.29	18774
28	124.33	848.61	26.34	128	10179.3	951.36	2307	1159.8	6.43	15731
30	11.32	75.24			1403.96	255.88	631.6	492.88	0.14	2871
31	6.94	53.8			796.03	74.18	271.8	368.51	0.61	1571.9
33	31.18	139.42		38	2057.85	185.12	659.1	458.41	0.7	3569.8
34	85.08	1453.6	320.1	43.7	7336.65	1155.6	1373	1867.8	2.94	13638
35		91.4	31.45		20	1.13				143.98
36		74.17	59.56		3.41					137.14
37	39.04	260.35	3.5		1641.03	296.52	141.9	150.24	5.67	2538.2
38	38.24	567.78	55.21	3.59	5323.71	316.59	305.5	751.87	0.61	7363.1
39	58.44	94.1	21.07	137	5176.43	523.43	271.7	256.34	6.04	6544.1
40	46.69	212.28	5.11	31.6	4443.88	1257.3	526.7	315.72	28.57	6867.8
41	108	544.61	4.5	4.57	11885.3	2341.8	1116	986.34	20.07	17011
42	50.6	246.22		25.8	6132.84	1001	467.8	378.99	10.74	8314
43	236.8	958	25.15	48.6	23022.7	2719.8	1409	1226.5	43.11	29690
44	28.33	124.95	2.44		3519.08	507.9	373.6	172.65	10.09	4739.1
45	88.53	523.45	5.54	32.8	11127.5	1152.1	1146	952.88	11.67	15041
46	23.25	350.28			6029.38	254.8	57.81	520.4	1.21	7237.1
47	10.82	133.52	1.51		1365.18	104.64	75.29	183.77	0.19	1874.9
48	28.99	390.82	4.49		1173.67	181.56	142.1	87.63	0.92	2010.2
49	11.63	183.06	2.7		725.11	145.56	226.7	21.28	0.89	1316.9
50	8.46	355.28	42.69		1037.73	187.31	136.2	82.52	0.4	1850.6
51	28.91	160.31	1.11		1654.14	180.34	174.2	120.81	0.56	2320.4
Total	**6554.4**	**16686**	**1098**	**676**	**237045**	**30009**	**41276**	**39535**	**249.7**	**373129**

LAX is livestock access to a stream.

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

Stream Characteristics

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

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2008), Digital Elevation Models (DEM), nautical charts, and bathymetry data was used. The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the Pamunkey River Watershed study area. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each subwatershed outlet. A profile perpendicular to the channel was generated showing the stream profile height with

distance for each subwatershed outlet (**Figure B-3**). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile.

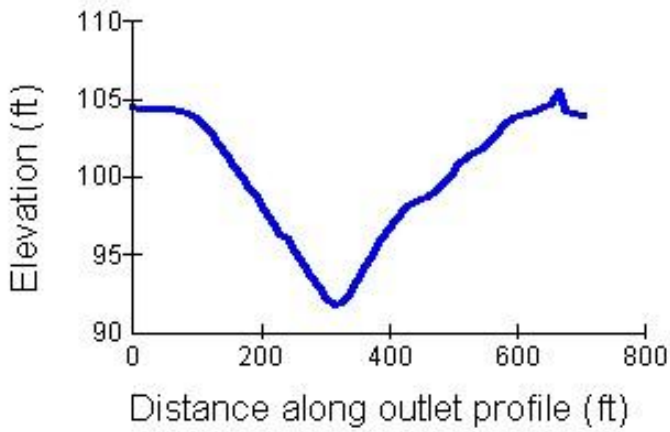

Figure B-3 Stream profile representation in HSPF.

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 B- 5**. 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 B- 6**.

Table B- 5 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 greater	0.05

*Brater and King (1976)

Table B- 6 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

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

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

A description of the data used in these analyses is shown in Table 2.1 in Chapter 2. Graphical analyses of fecal bacteria concentrations and flow duration intervals showed that water quality standard violations occurred at nearly every flow interval at four (4) VADEQ monitoring stations in the Pamunkey River Watershed study area (**Figure B-4** to **Figure B-66**). This demonstrates that this stream should have all flow regimes represented in the allocation modeling time period.

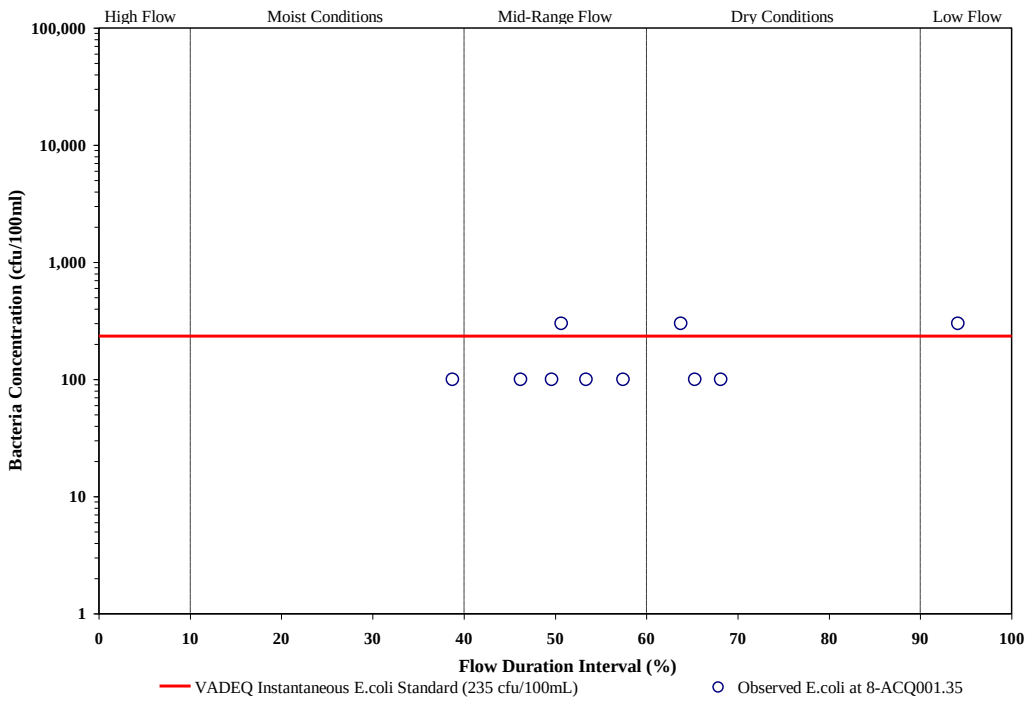

Figure B-4 ***E. coli*** **bacteria concentrations at 8-ACQ001.35 on Acquinton Creek discharge at USGS Gaging Station # 01673000.**

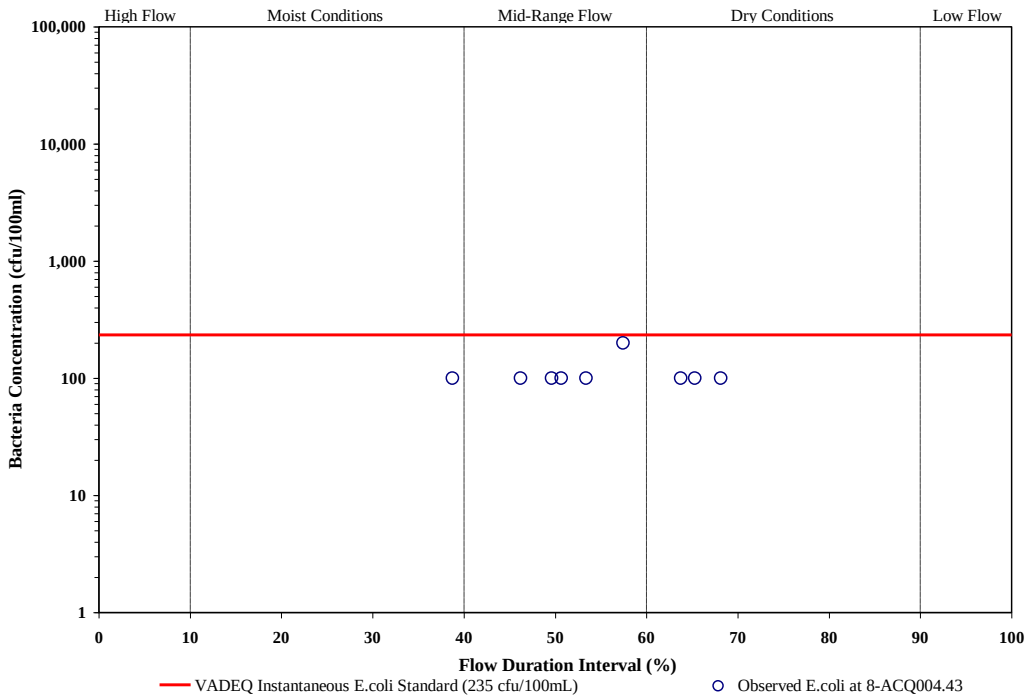

Figure B-5 ***E. coli*** **bacteria concentrations at 8-ACQ004.43 on Acquinton Creek versus discharge at USGS Gaging Station # 01673000.**

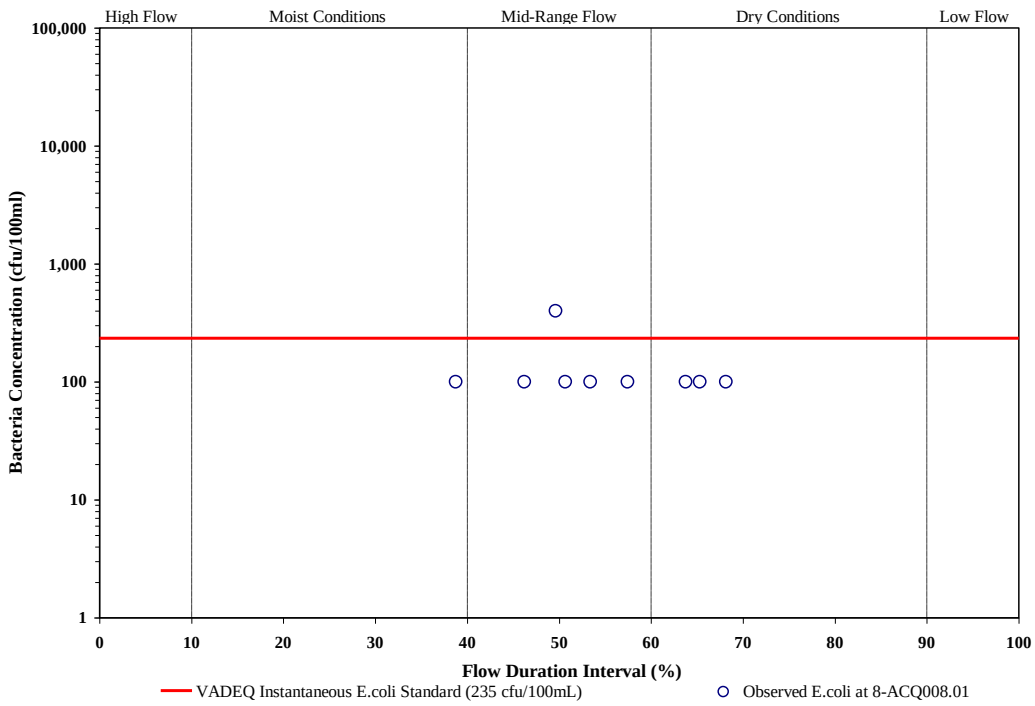

Figure B-6 ***E. coli*** **bacteria concentrations at 8-ACQ008.01 on Acquinton Creek versus discharge at USGS Gaging Station # 01673000.**

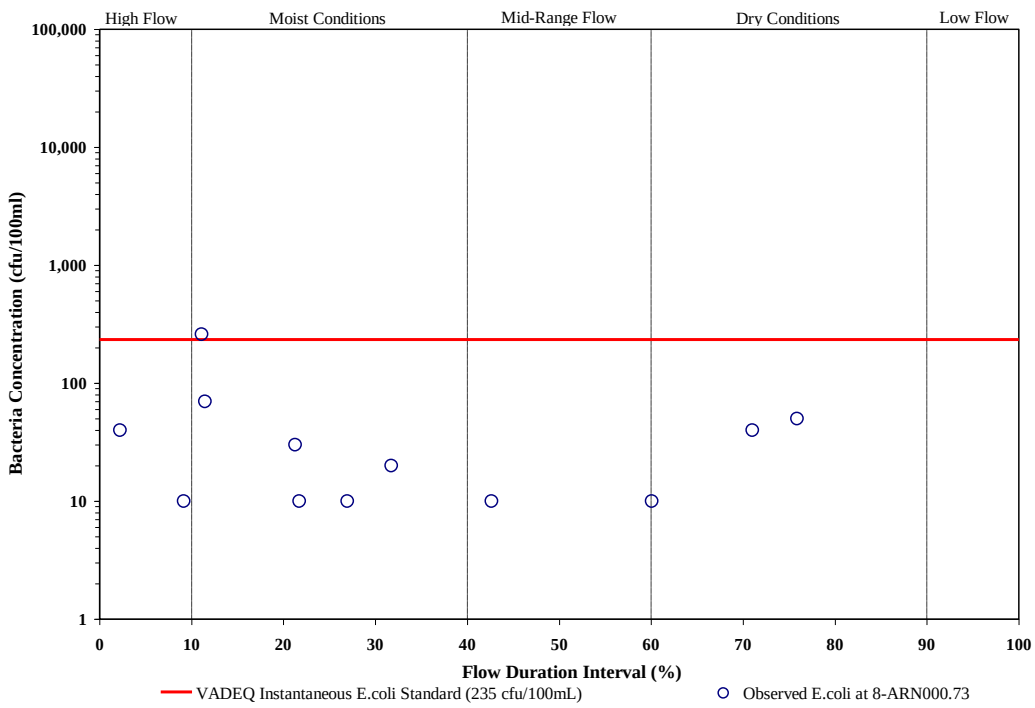

Figure B-7 ***E. coli*** **bacteria concentrations at 8-ARN000.73 on Arnolds Creek versus discharge at USGS Gaging Station # 01673000.**

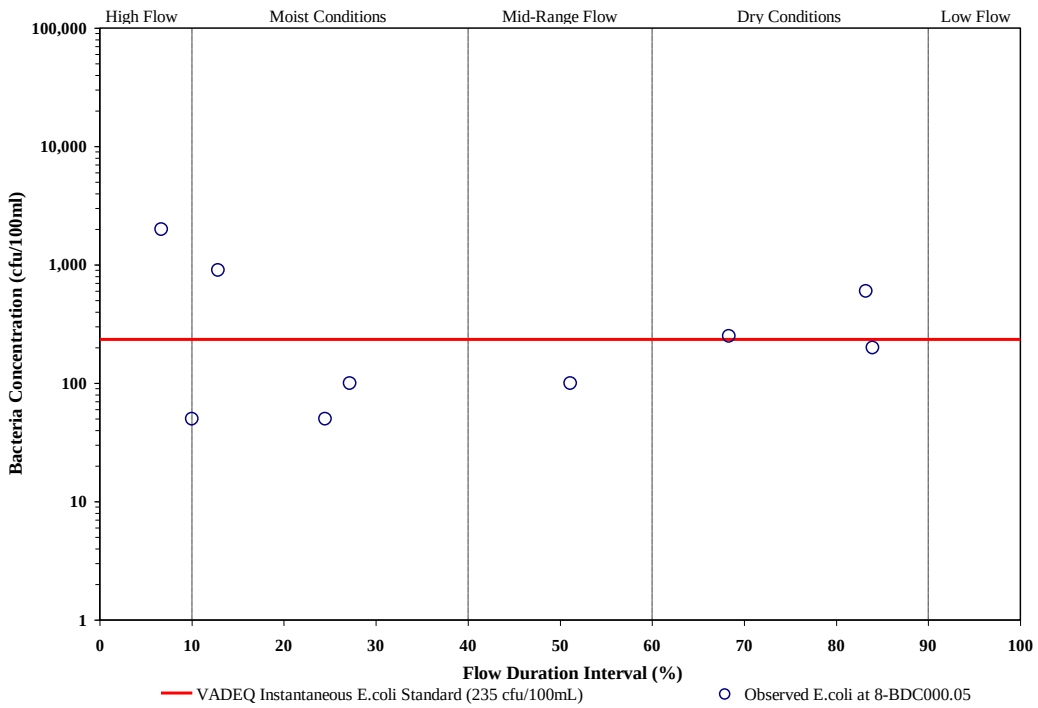

Figure B-8 ***E. coli*** **bacteria concentrations at 8-BDC000.05 on Beaverdam Creek versus discharge at USGS Gaging Station # 01673000.**

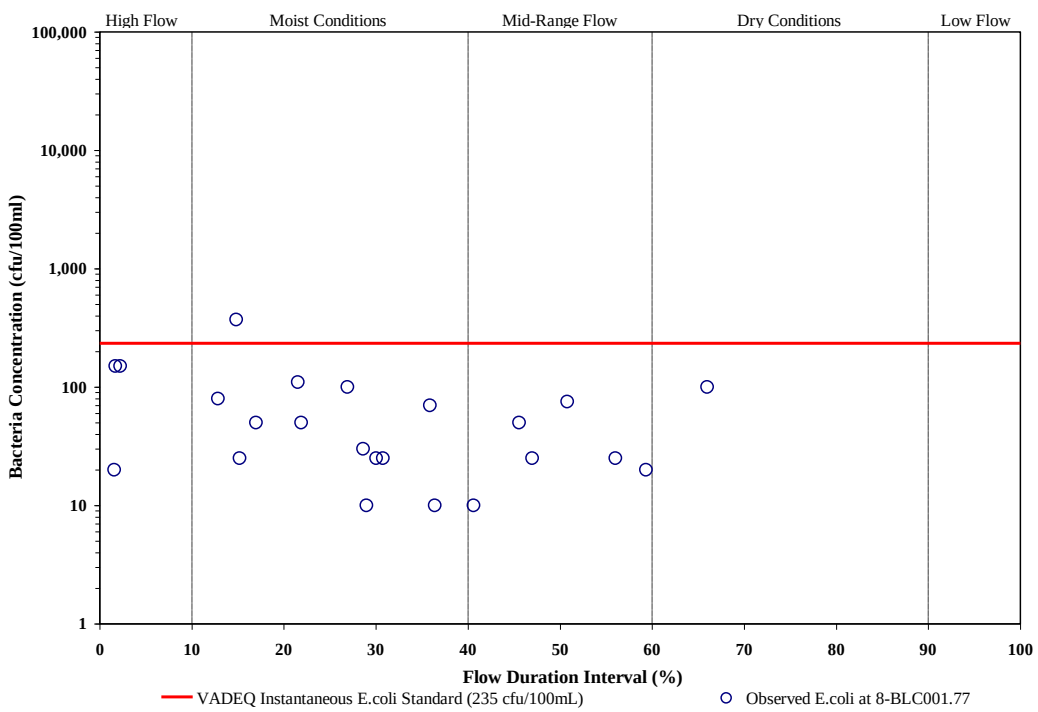

Figure B-9 ***E. coli*** **bacteria concentrations at 8-BLC001.77 on Black Creek versus discharge at USGS Gaging Station # 01673000.**

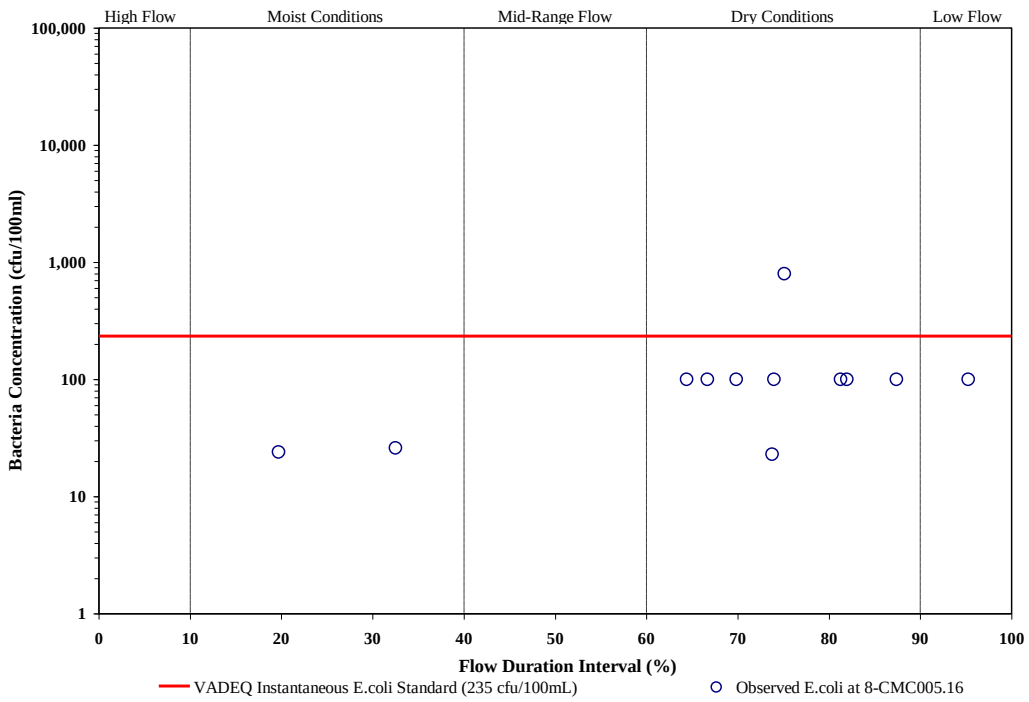

Figure B-10 ***E. coli*** **bacteria concentrations at 8-CMC005.16 on Cohoke Mill Creek versus discharge at USGS Gaging Station # 01673000.**

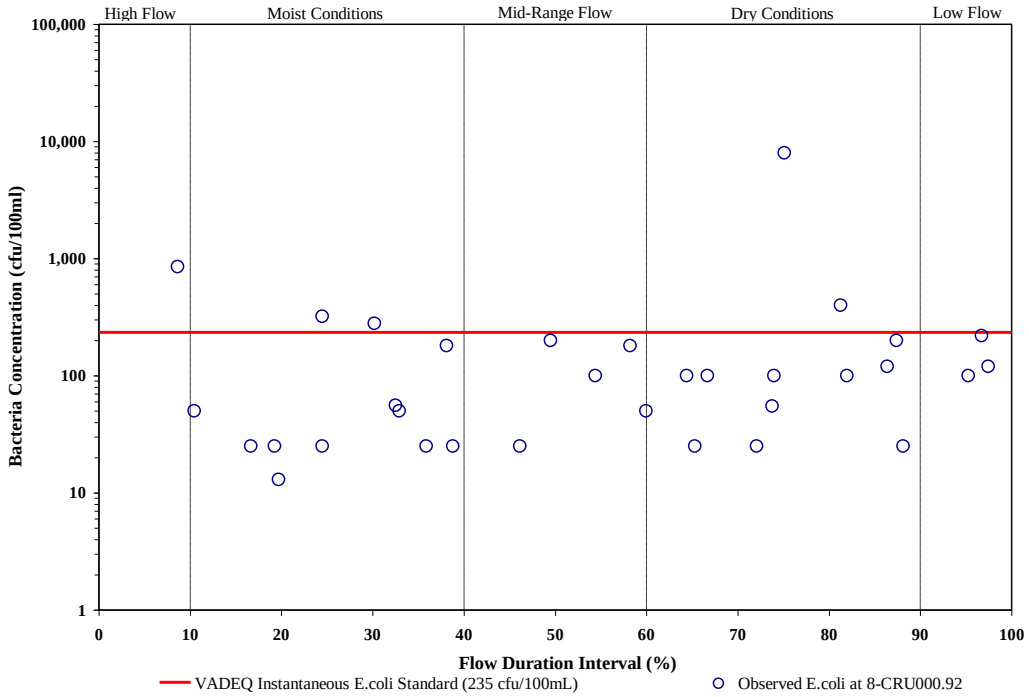

Figure B-11 ***E. coli*** **bacteria concentrations at 8-CRU000.92 on Crump Creek versus discharge at USGS Gaging Station # 01673000.**

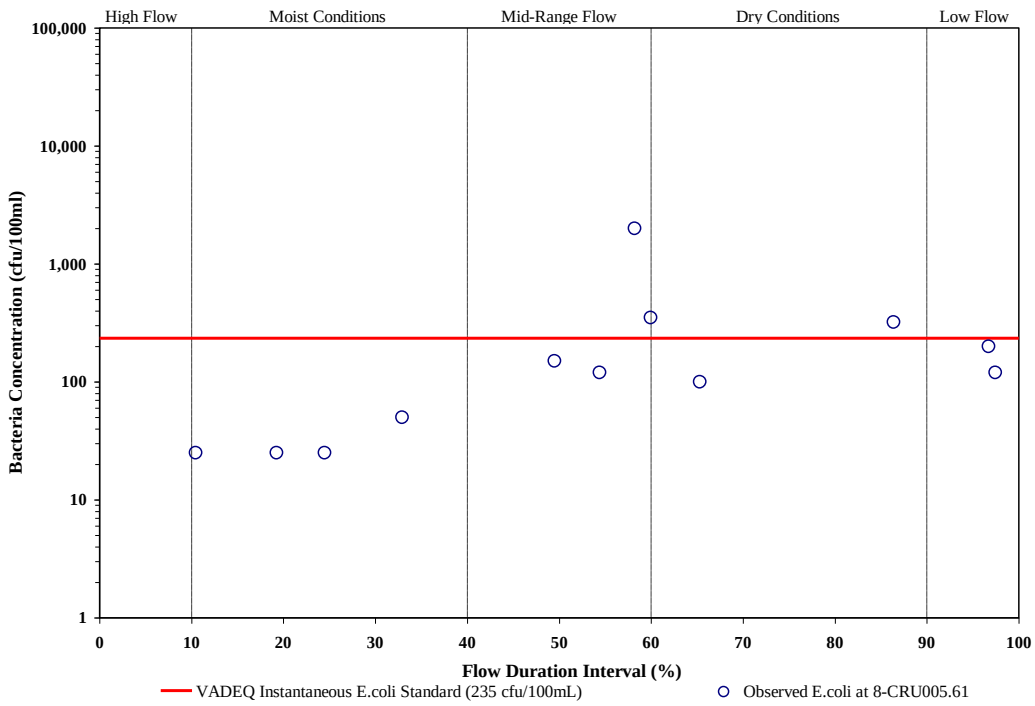

Figure B-12 ***E. coli*** **bacteria concentrations at 8-CRU005.61 on Crump Creek versus discharge at USGS Gaging Station # 01673000.**

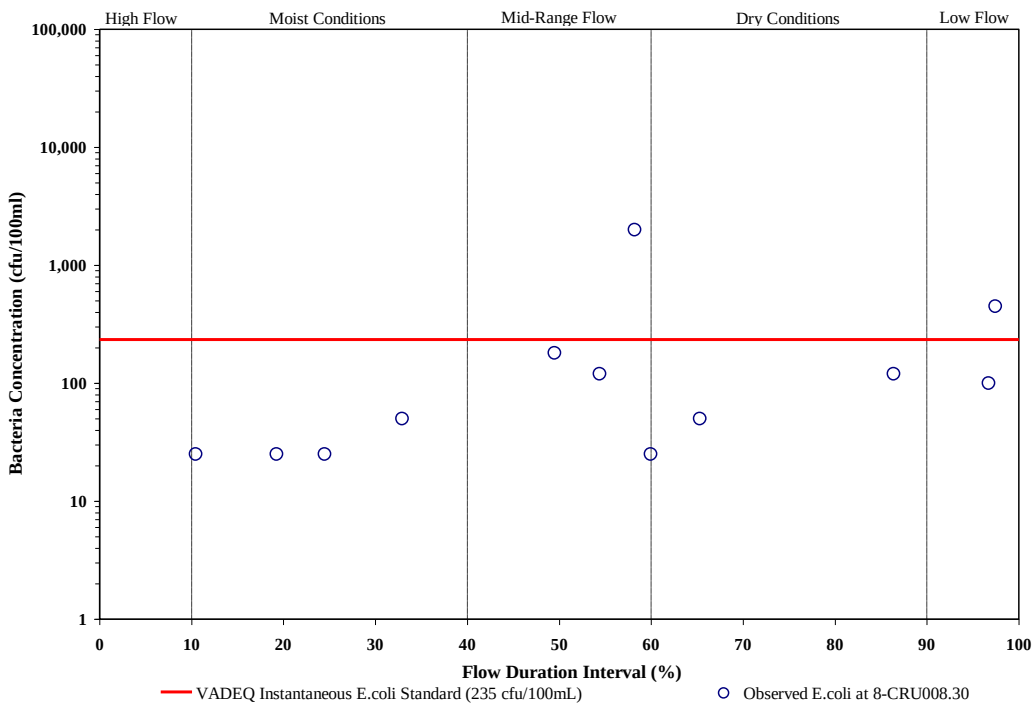

Figure B-13 ***E. coli*** **bacteria concentrations at 8-CRU008.30 on Crump Creek versus discharge at USGS Gaging Station # 01673000.**

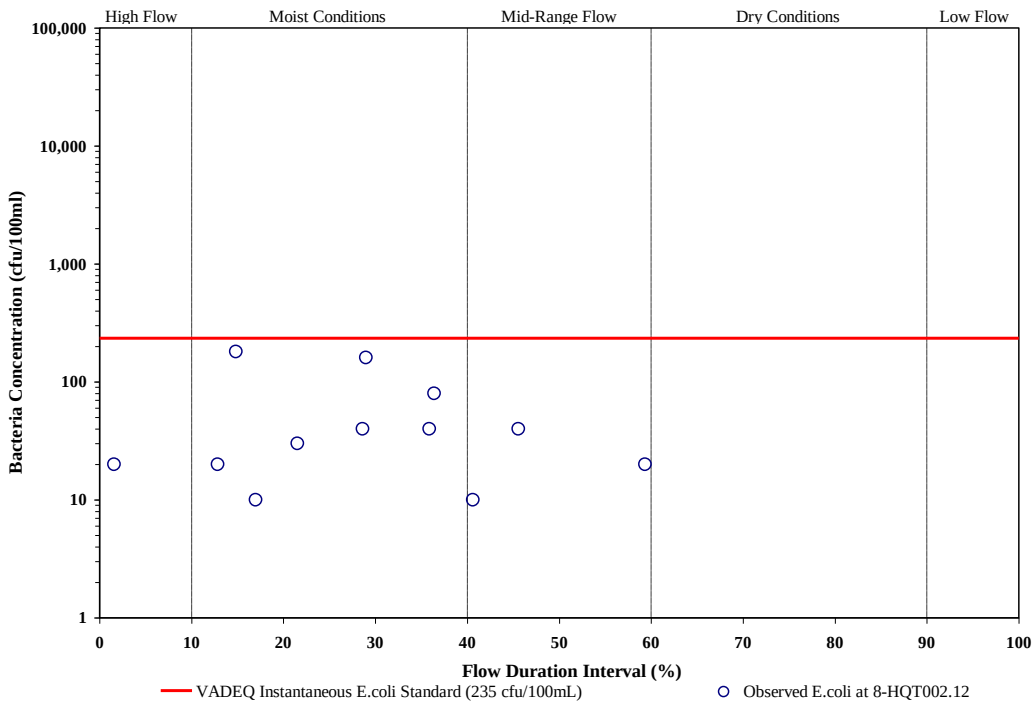

Figure B-14 ***E. coli*** **bacteria concentrations at 8-HQT002.12 on Hornquarter Creek versus discharge at USGS Gaging Station # 01673000.**

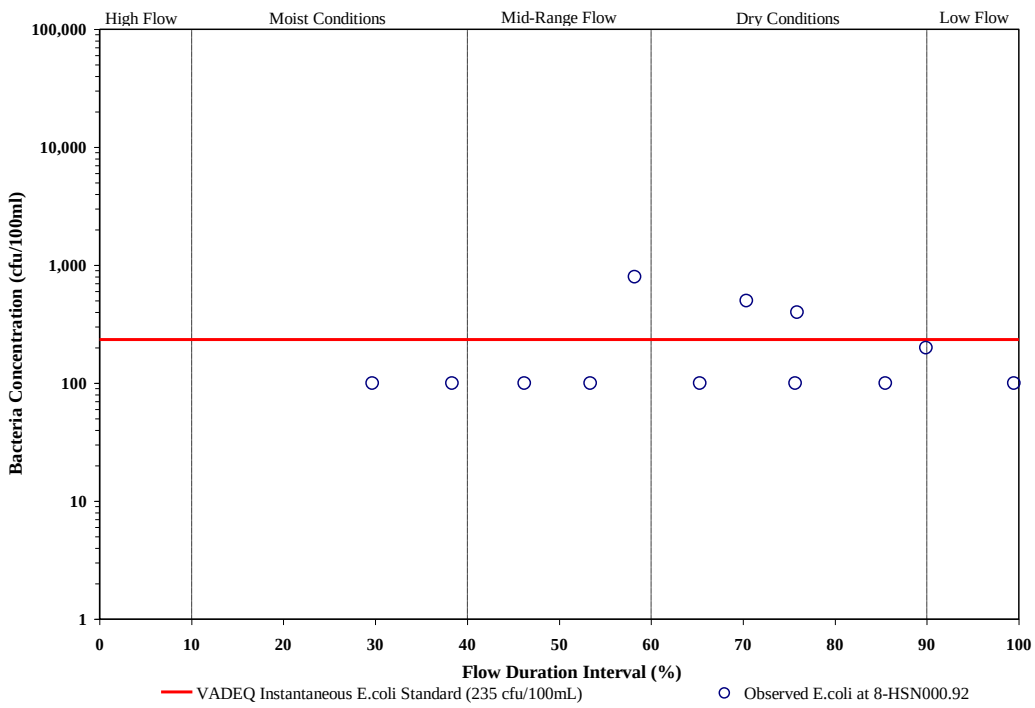

Figure B-15 ***E. coli*** **bacteria concentrations at 8-HSN000.92 on Harrison Creek versus discharge at USGS Gaging Station # 01673000.**

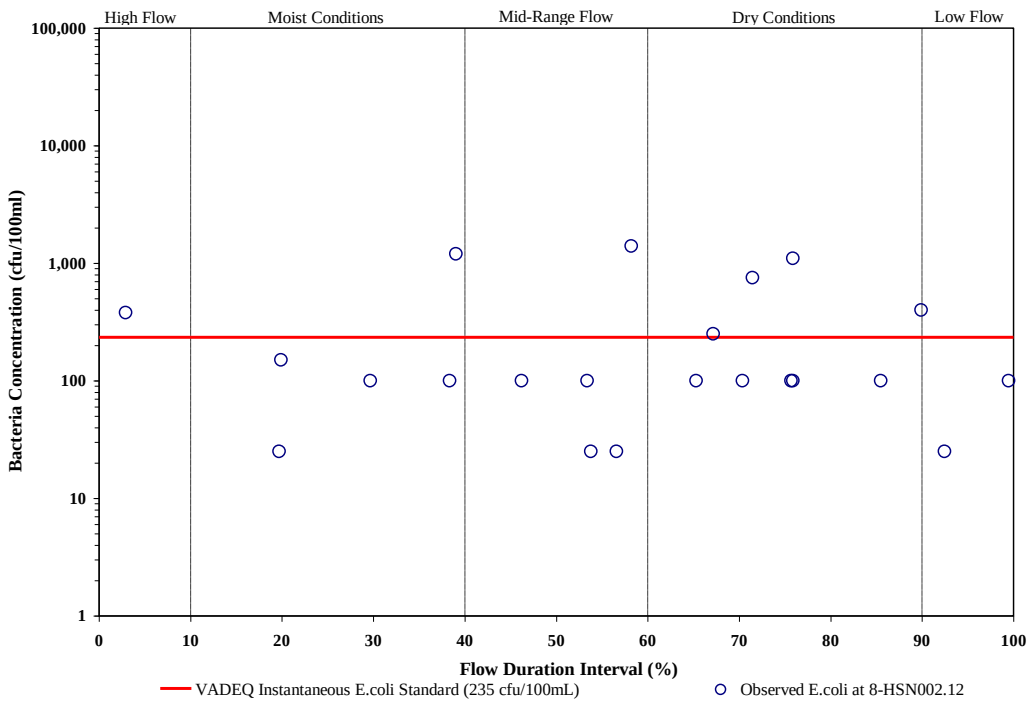

Figure B-16 *E. coli* bacteria concentrations at 8-HSN002.12 on Harrison Creek versus discharge at USGS Gaging Station # 01673000.

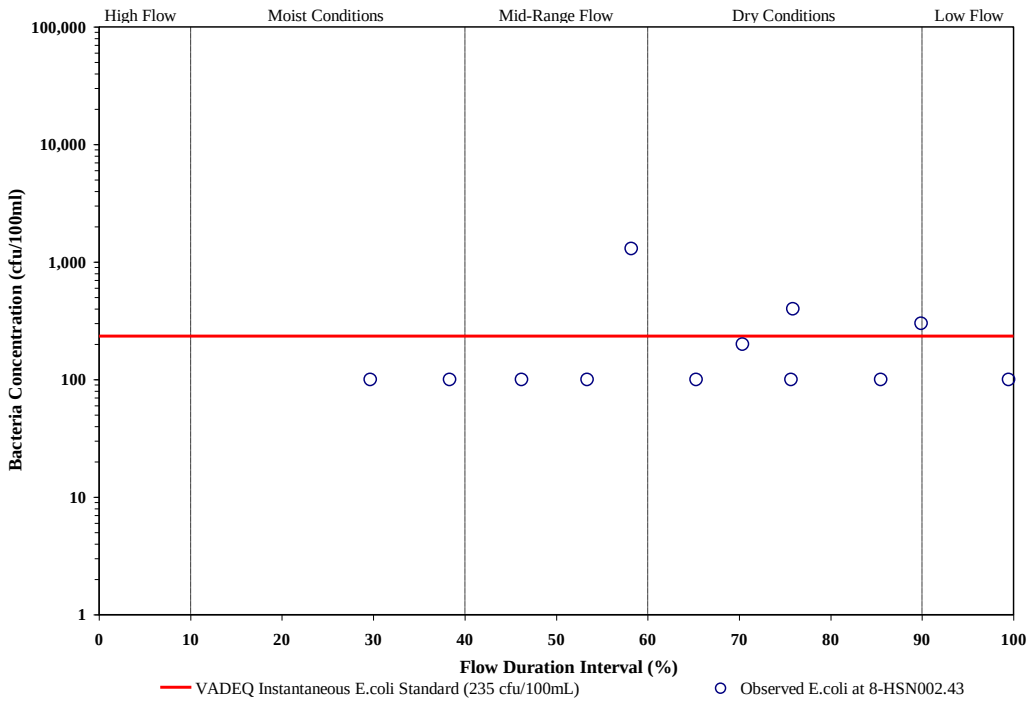

Figure B-17 *E. coli* bacteria concentrations at 8-HSN002.43 on Harrison Creek versus discharge at USGS Gaging Station # 01673000.

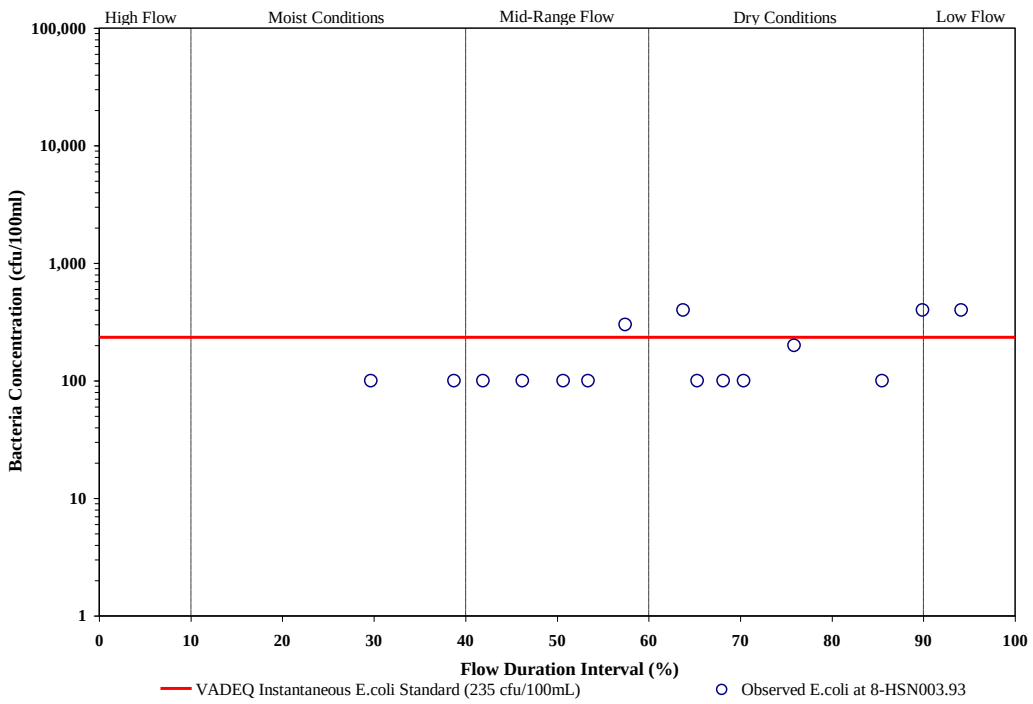

Figure B-18 ***E. coli*** **bacteria concentrations at 8-HSN003.93 on Harrison Creek versus discharge at USGS Gaging Station # 01673000.**

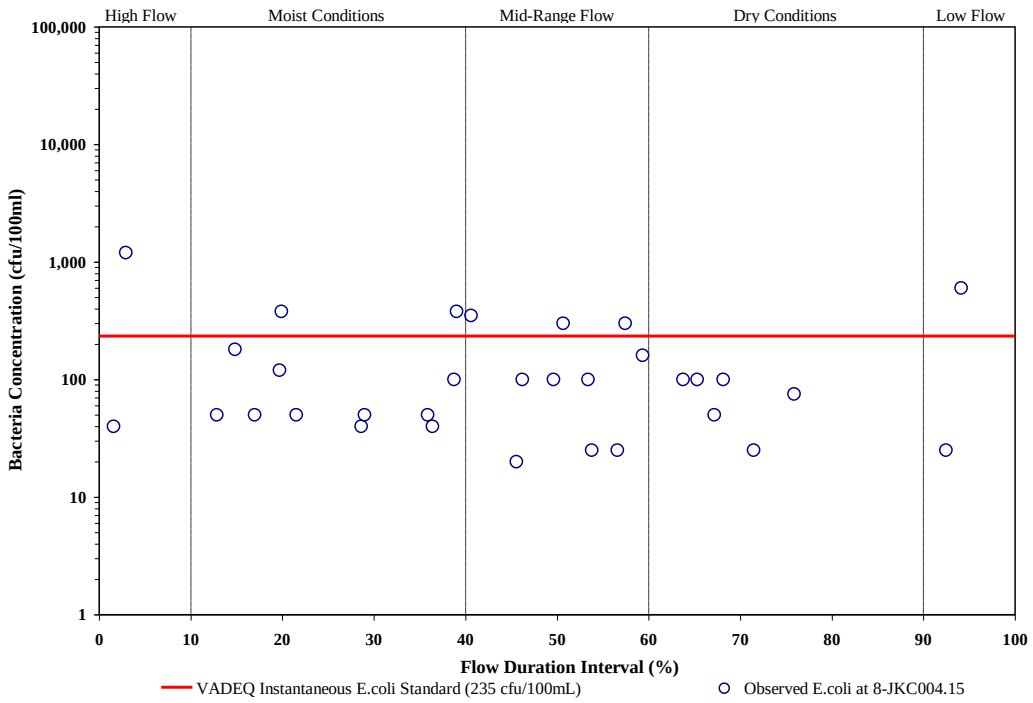

Figure B-19 ***E. coli*** **bacteria concentrations at 8-JKC004.15 on Jacks Creek versus discharge at USGS Gaging Station # 01673000.**

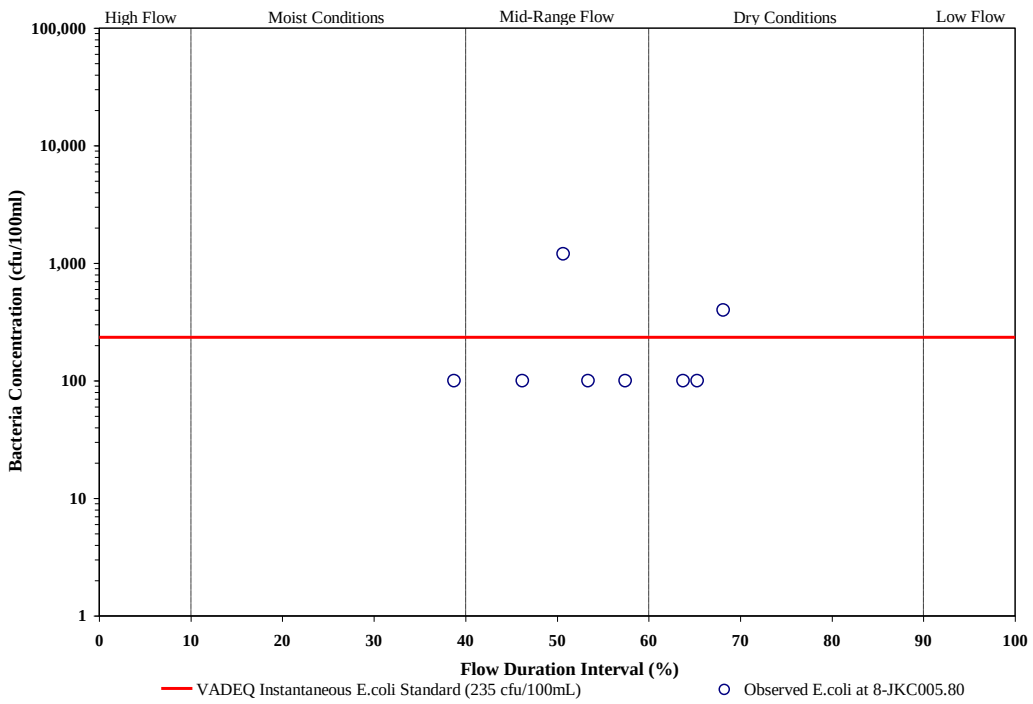

Figure B-20 ***E. coli*** **bacteria concentrations at 8-JKC005.80 on Jacks Creek versus discharge at USGS Gaging Station # 01673000.**

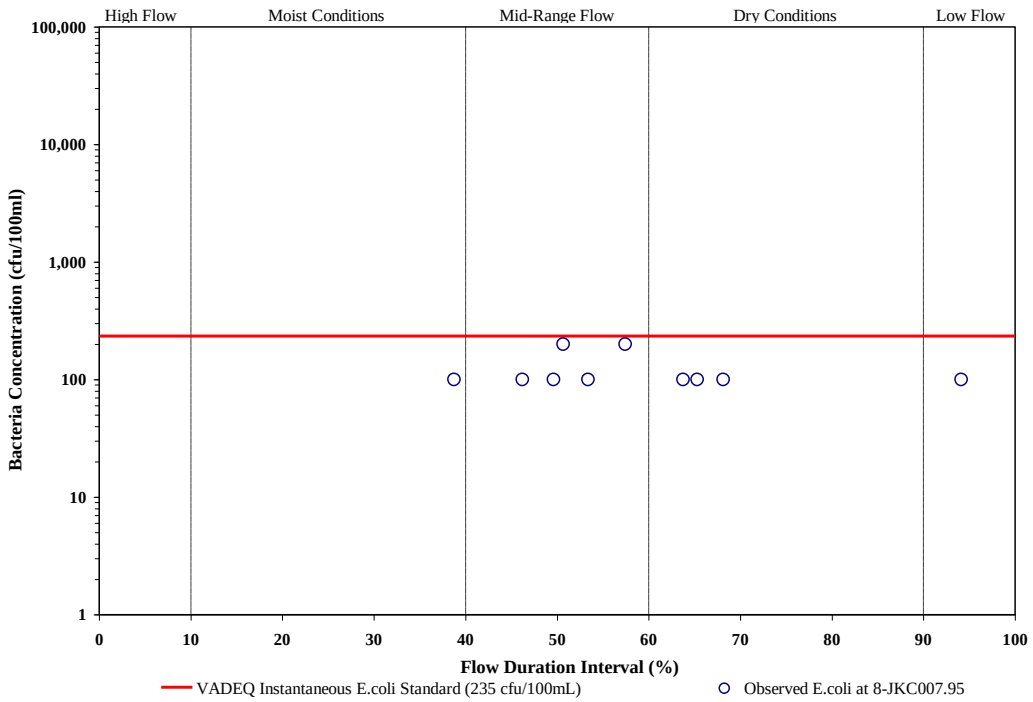

Figure B-21 ***E. coli*** **bacteria concentrations at 8-JKC007.95 on Jacks Creek versus discharge at USGS Gaging Station # 01673000.**

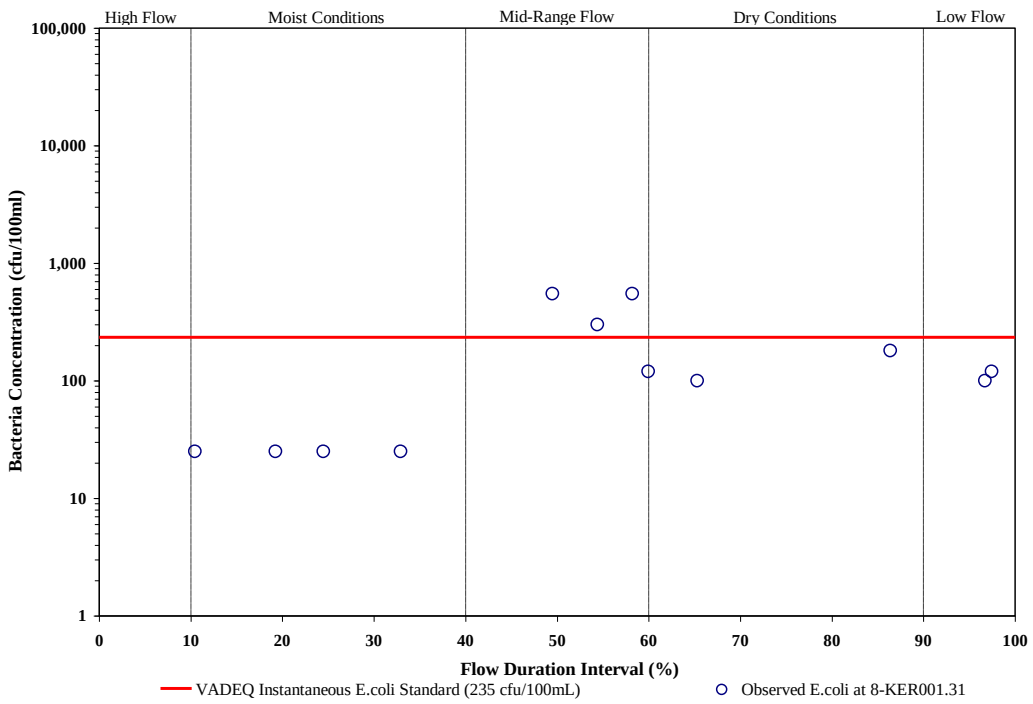

Figure B-22 ***E. coli*** **bacteria concentrations at 8-KER001.31 on Kersey Creek versus discharge at USGS Gaging Station # 01673000.**

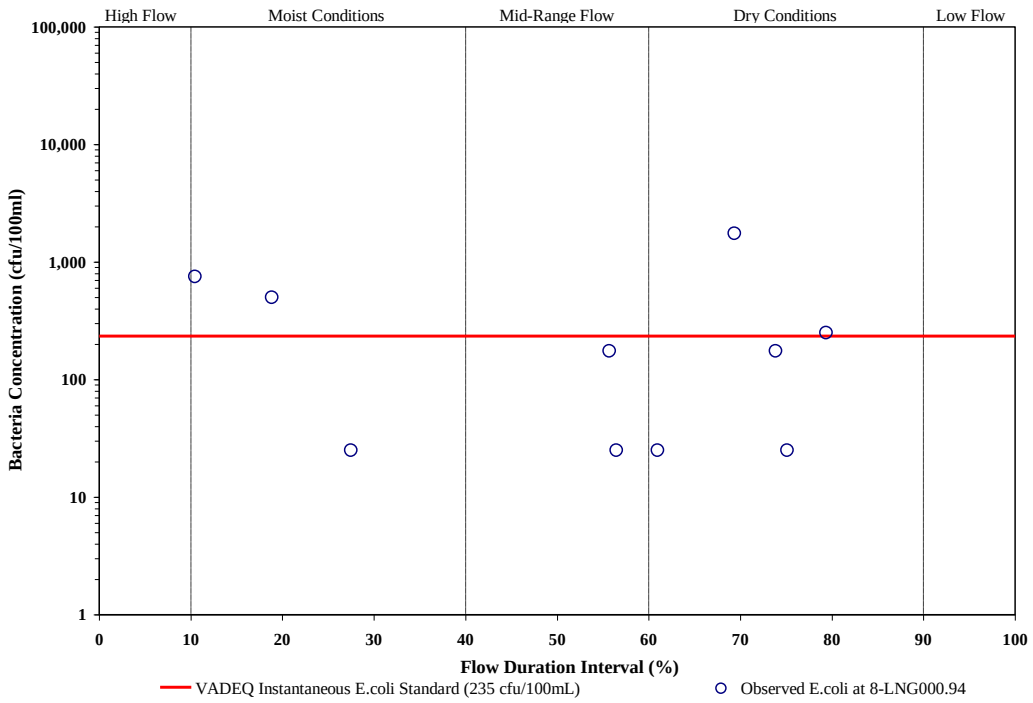

Figure B-23 ***E. coli*** **bacteria concentrations at 8-LNG000.94 on Long Creek versus discharge at USGS Gaging Station # 01673000.**

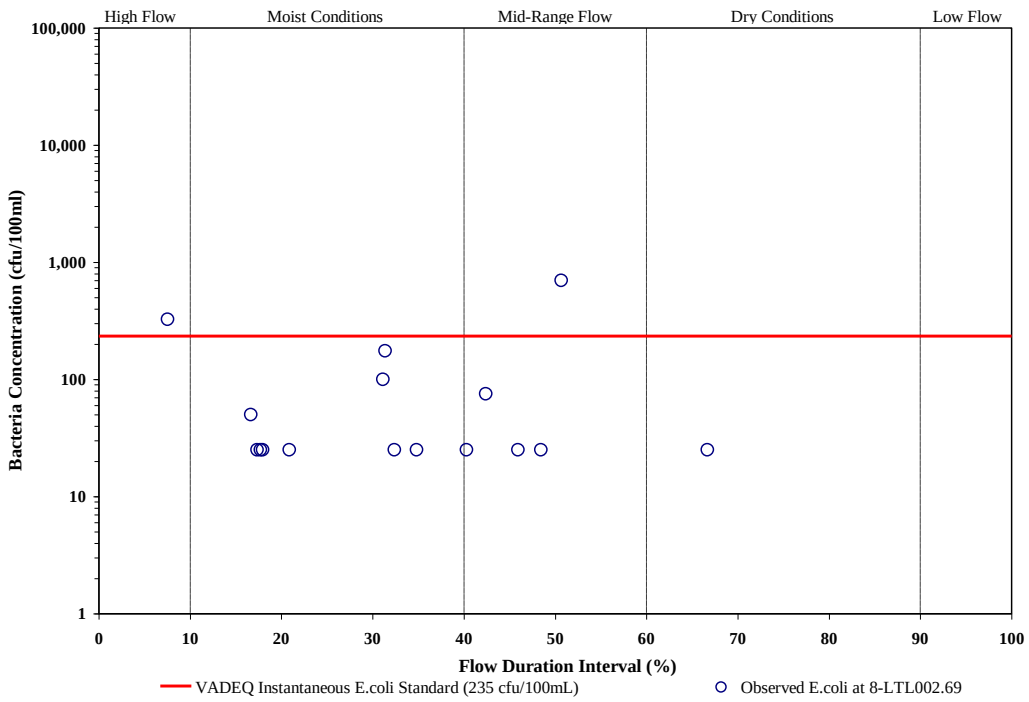

Figure B-24 *E. coli* bacteria concentrations at 8-LTL002.69 on the Little River versus discharge at USGS Gaging Station # 01673000.

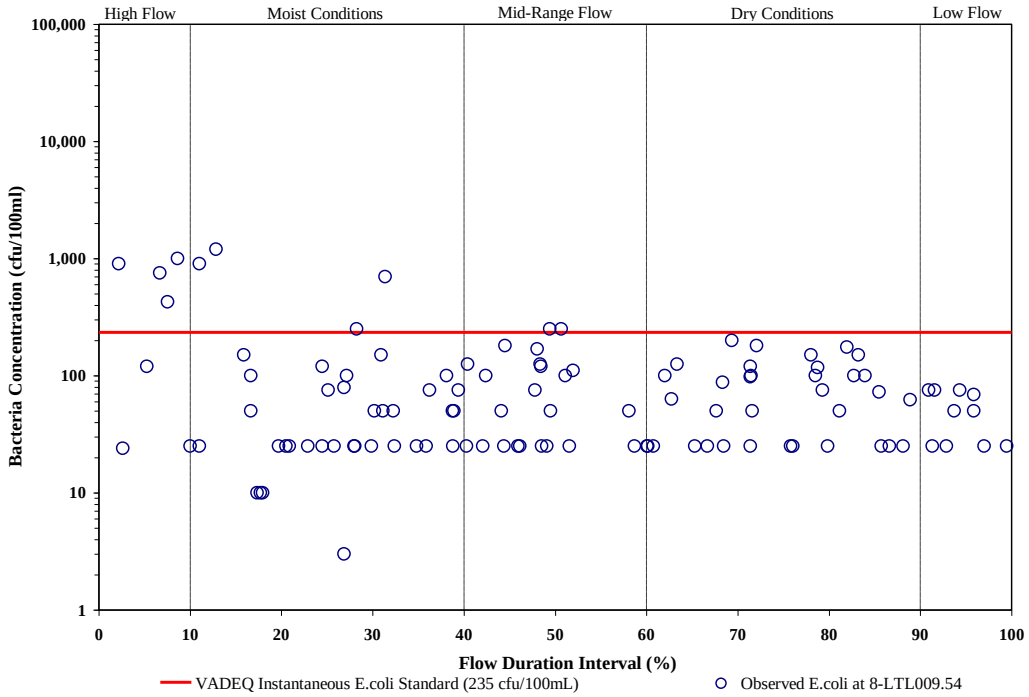

Figure B-25 *E. coli* bacteria concentrations at 8-LTL009.54 on the Little River versus discharge at USGS Gaging Station # 01673000.

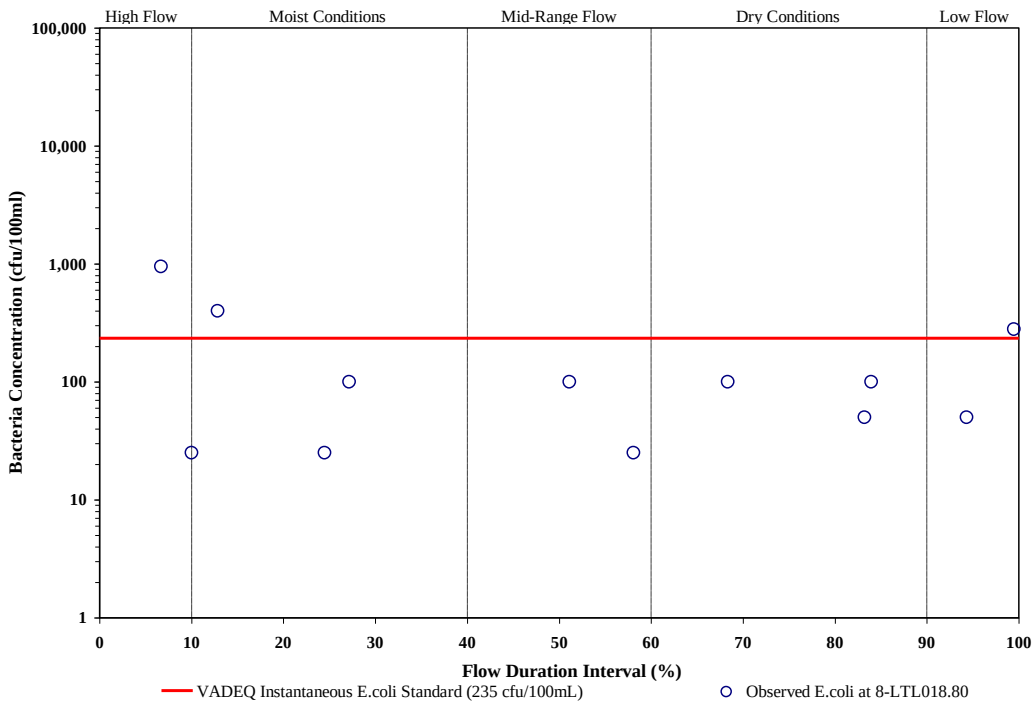

Figure B-26 ***E. coli*** **bacteria concentrations at 8-LTL018.80 on the Little River versus discharge at USGS Gaging Station # 01673000.**

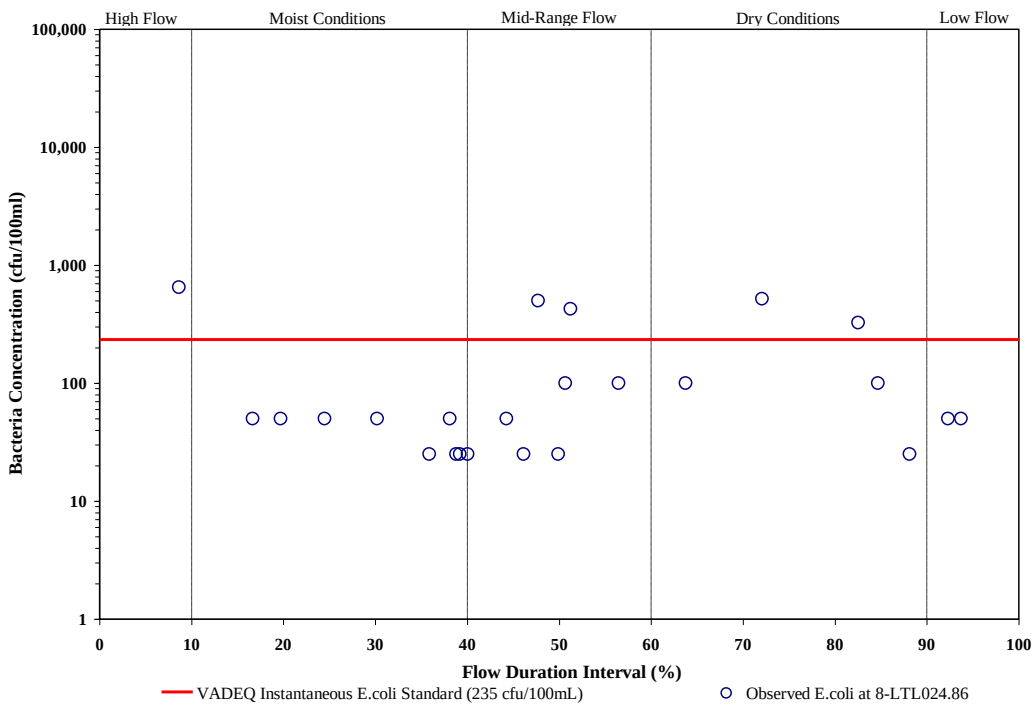

Figure B-27 ***E. coli*** **bacteria concentrations at 8-LTL024.86 on the Little River versus discharge at USGS Gaging Station # 01673000.**

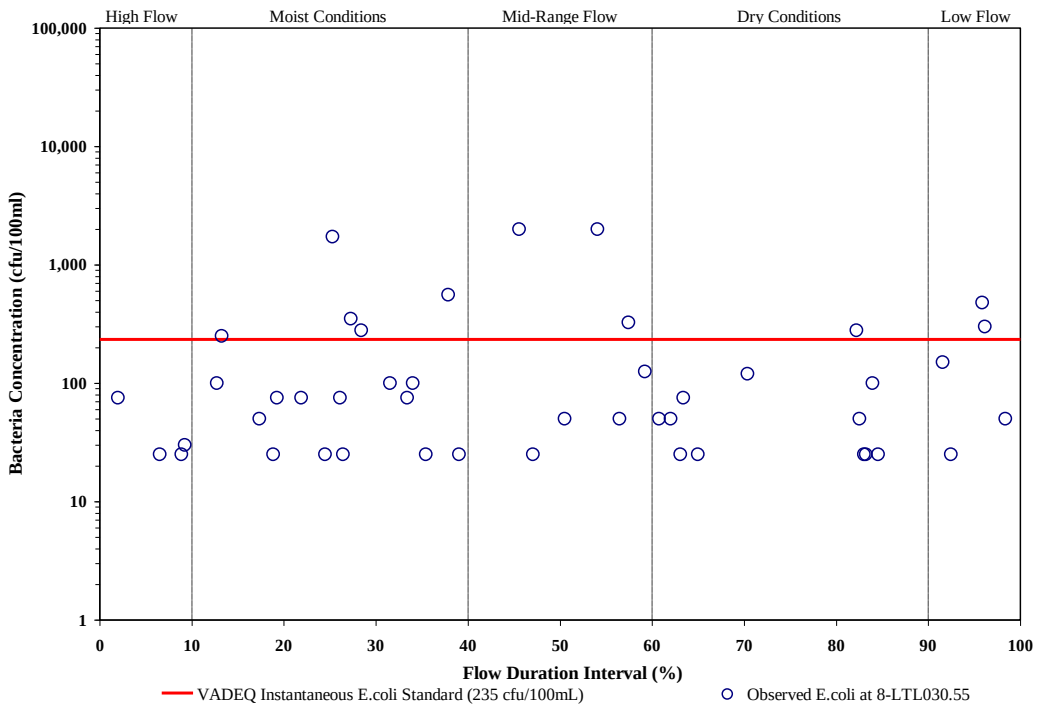

Figure B-28 *E. coli* bacteria concentrations at 8-LTL030.55 on the Little River versus discharge at USGS Gaging Station # 01673000.

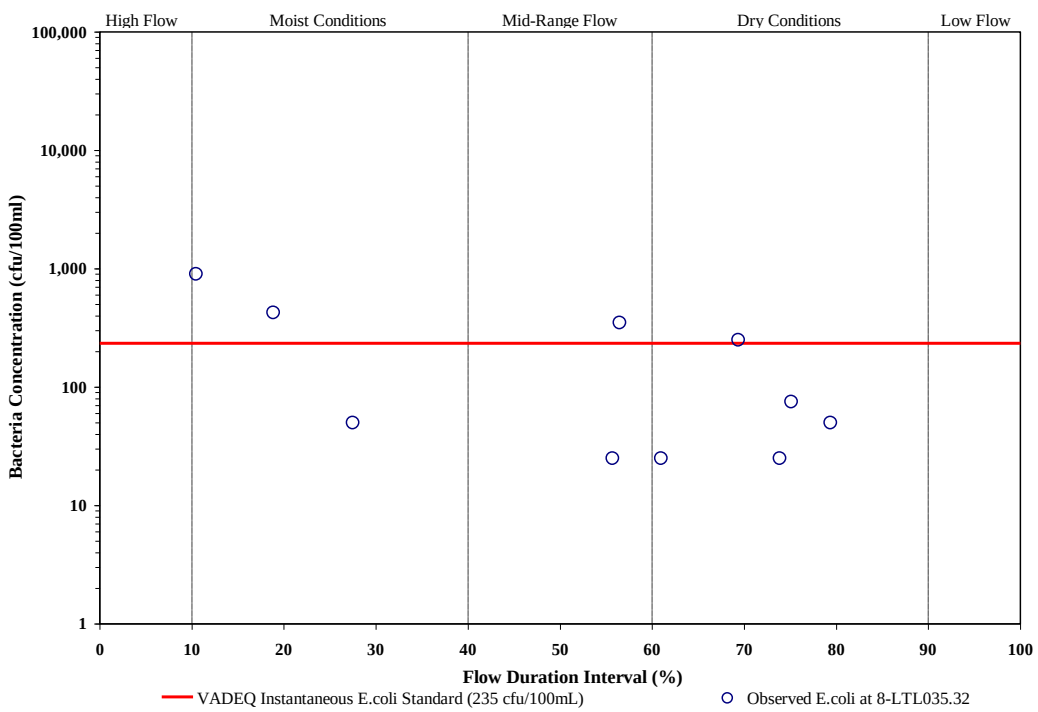

Figure B-29 *E. coli* bacteria concentrations at 8-LTL035.32 on the Little River versus discharge at USGS Gaging Station # 01673000.

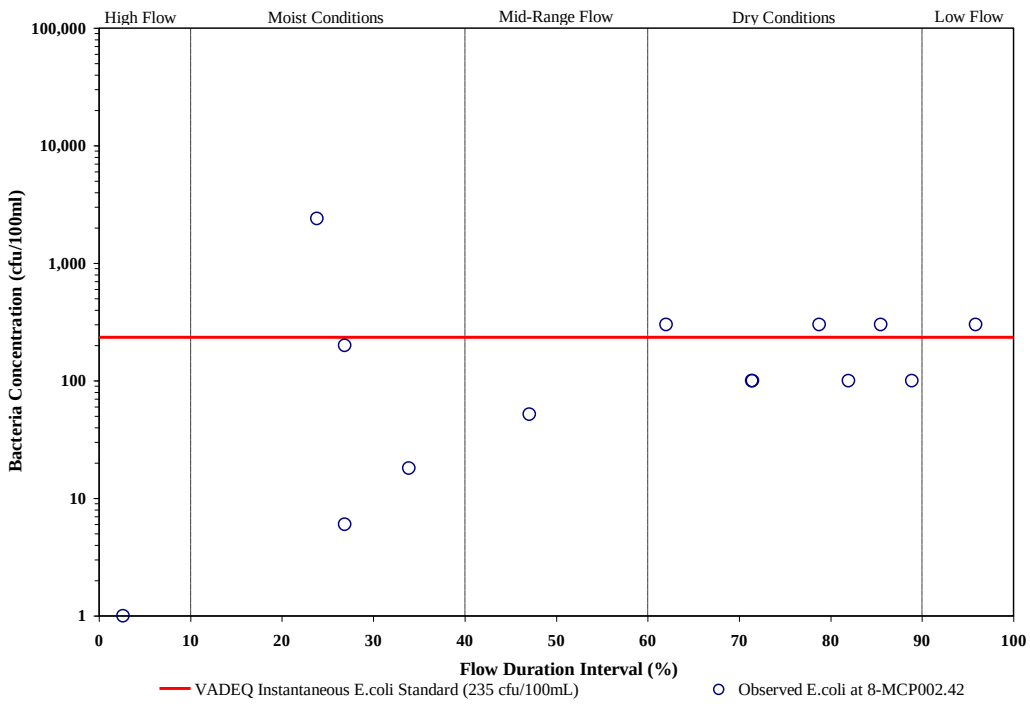

Figure B-30 ***E. coli*** **bacteria concentrations at 8-MCP002.42 on Mechumps Creek versus discharge at USGS Gaging Station # 01673000.**

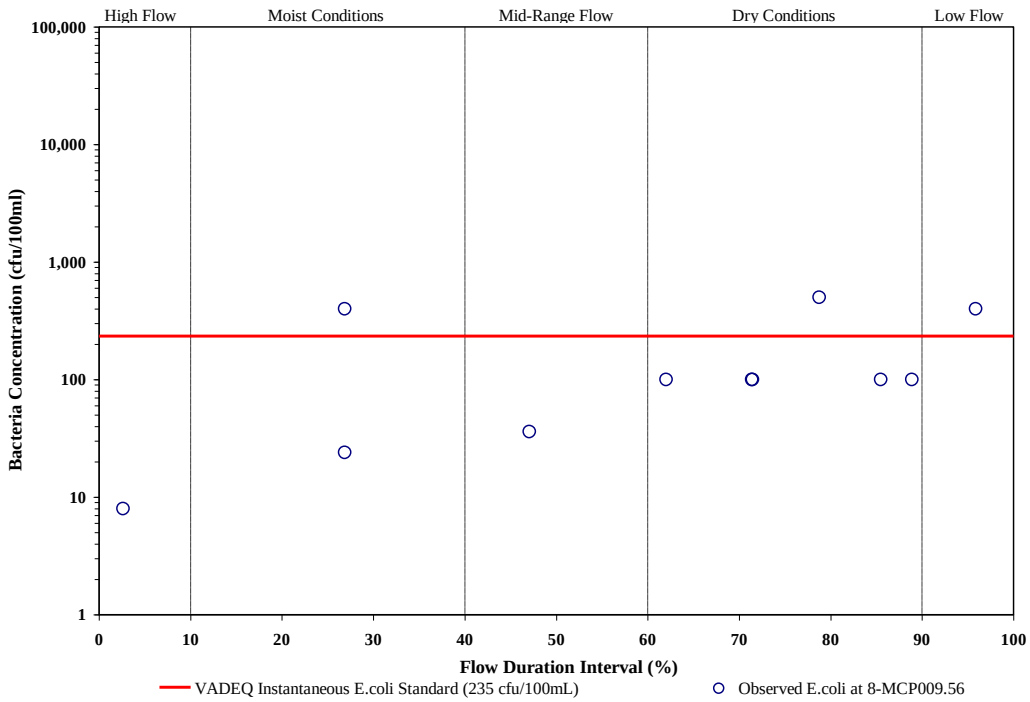

Figure B-31 ***E. coli*** **bacteria concentrations at 8-MCP009.56 on Mechumps Creek versus discharge at USGS Gaging Station # 01673000.**

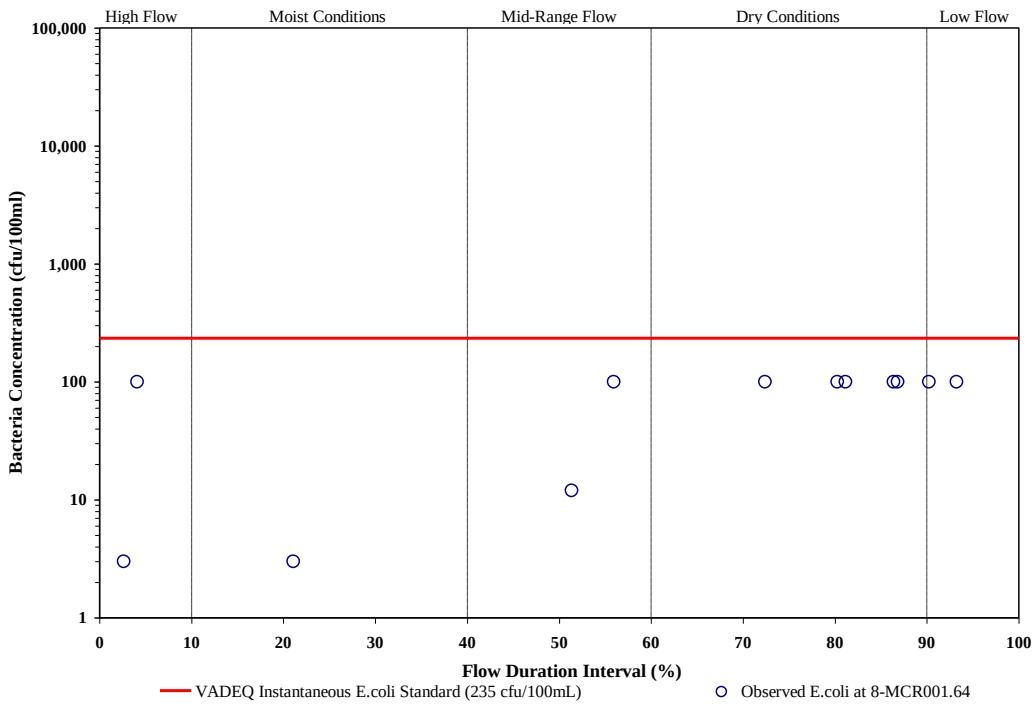

Figure B-32 ***E. coli*** **bacteria concentrations at 8-MCR001.64 on Mill Creek versus discharge at USGS Gaging Station # 01673000.**

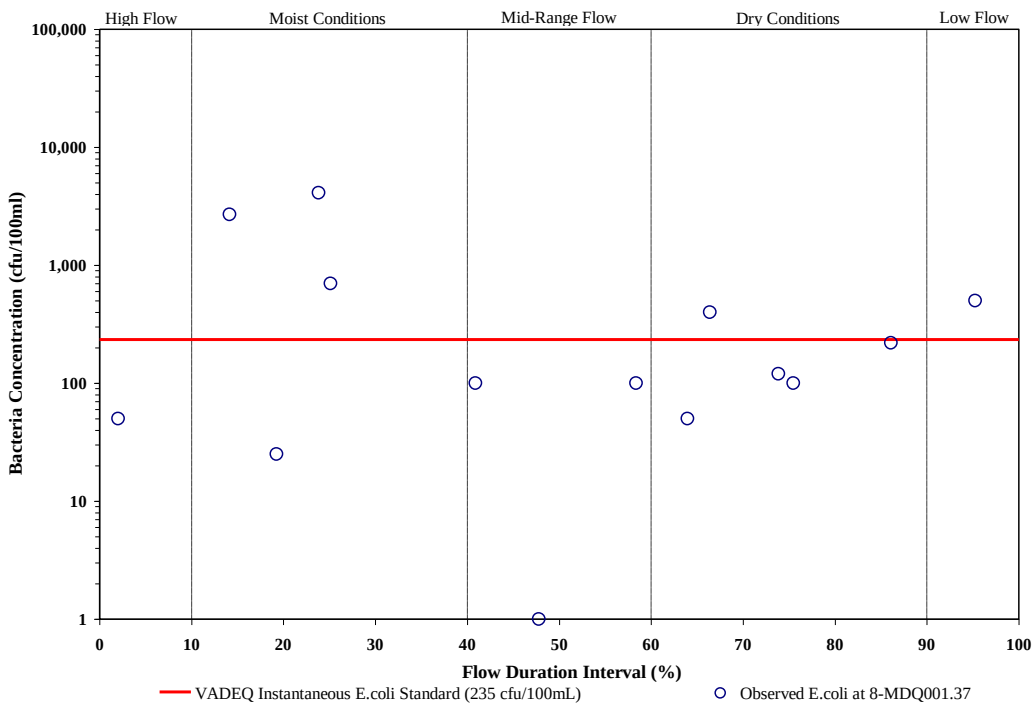

Figure B-33 ***E. coli*** **bacteria concentrations at 8-MDQ001.37 on Matadequin Creek versus discharge at USGS Gaging Station # 01673000.**

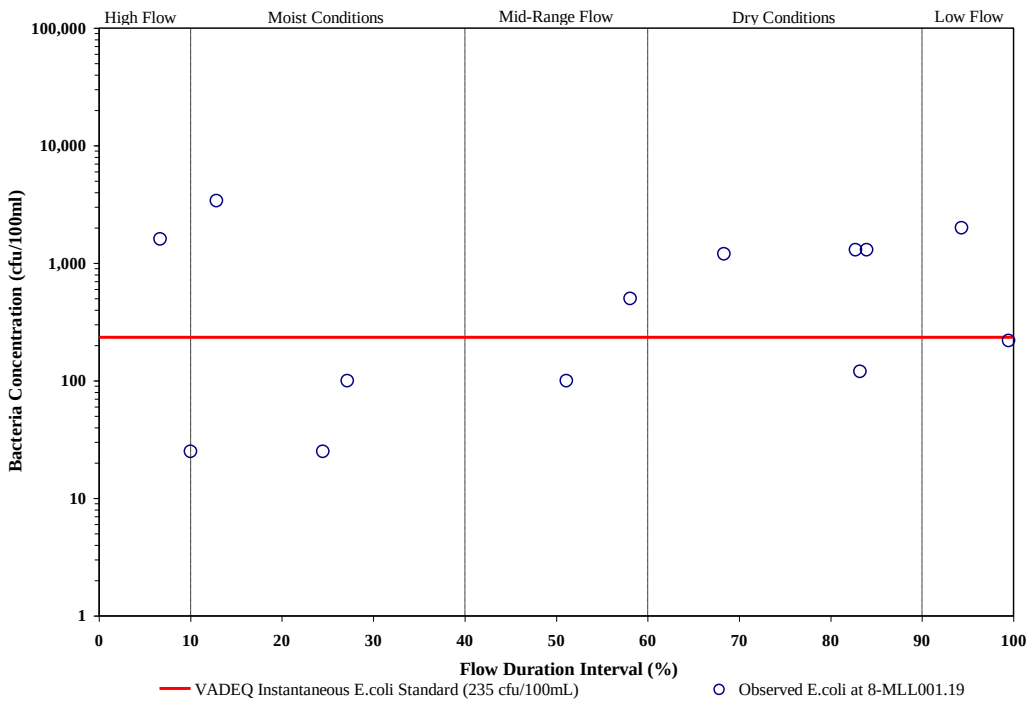

Figure B-34 ***E. coli*** **bacteria concentrations at 8-MLL001.19 on Mill Creek versus discharge at USGS Gaging Station # 01673000.**

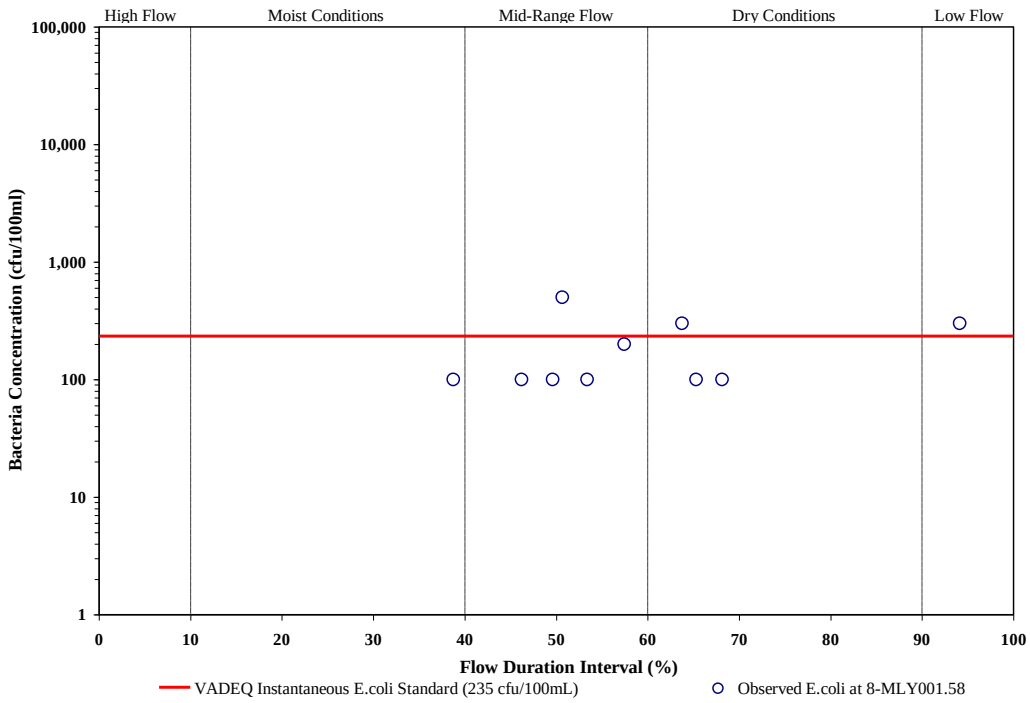

Figure B-35 ***E. coli*** **bacteria concentrations at 8-MLY001.58 on Mallory Creek versus discharge at USGS Gaging Station # 01673000.**

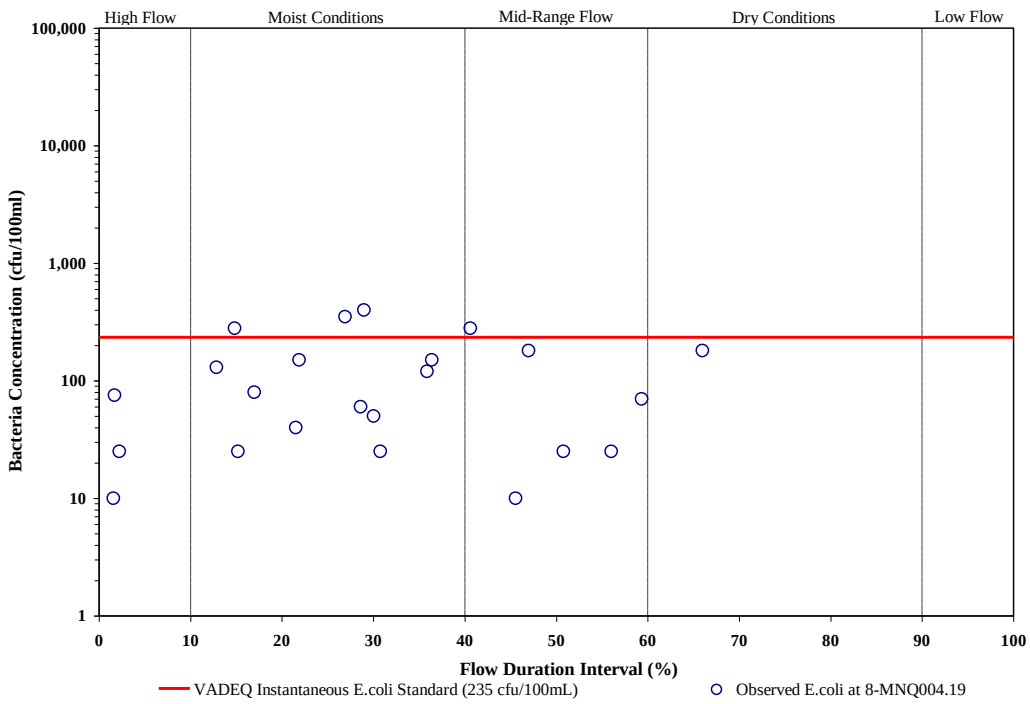

Figure B-36 *E. coli* bacteria concentrations at 8-MNQ004.19 on Moncuin Creek versus discharge at USGS Gaging Station # 01673000.

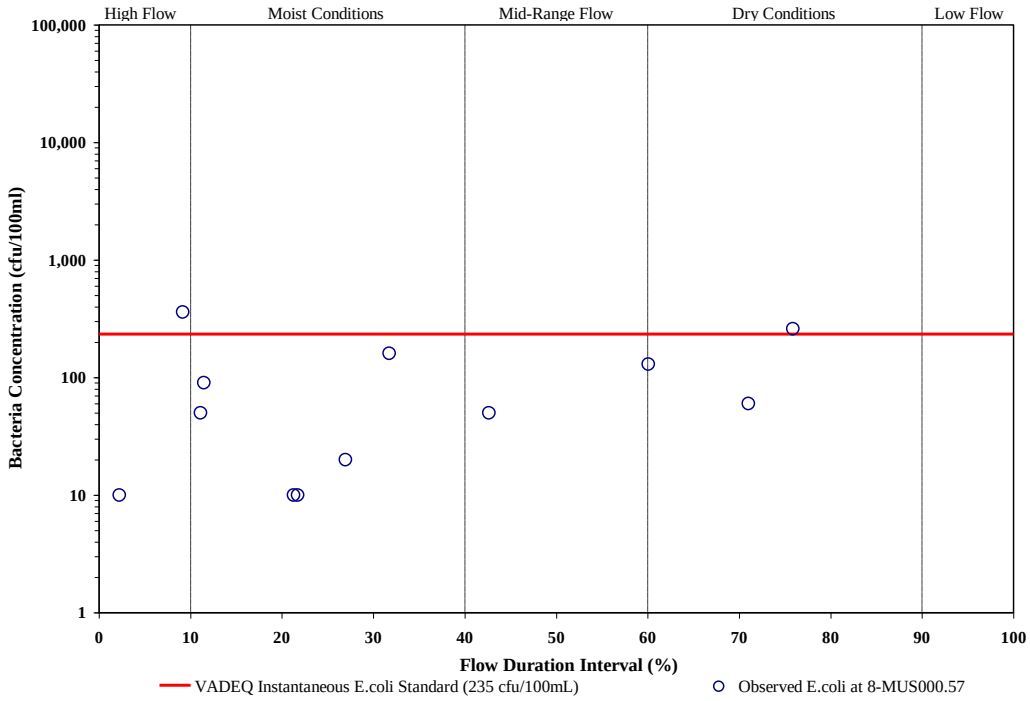

Figure B-37 *E. coli* bacteria concentrations at 8-MUS000.57 on Music Branch versus discharge at USGS Gaging Station # 01673000.

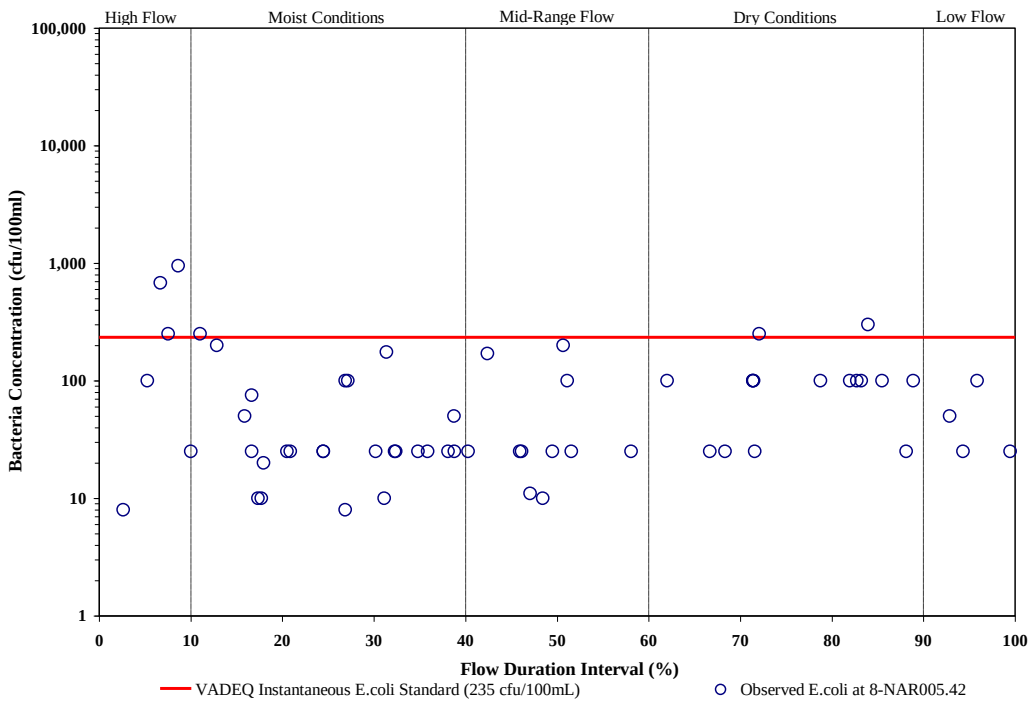

Figure B-38 ***E. coli*** **bacteria concentrations at 8-NAR005.42 on the North Anna River versus discharge at USGS Gaging Station # 01673000.**

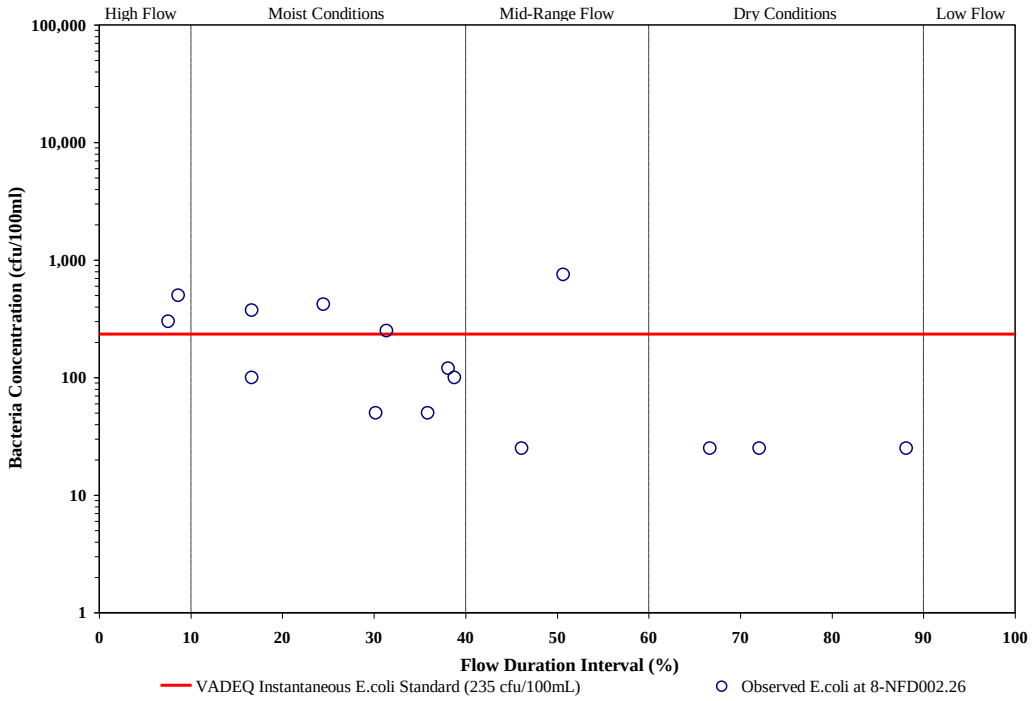

Figure B-39 ***E. coli*** **bacteria concentrations at 8-NFD002.26 on the Newfoundland River versus discharge at USGS Gaging Station #01673000.**

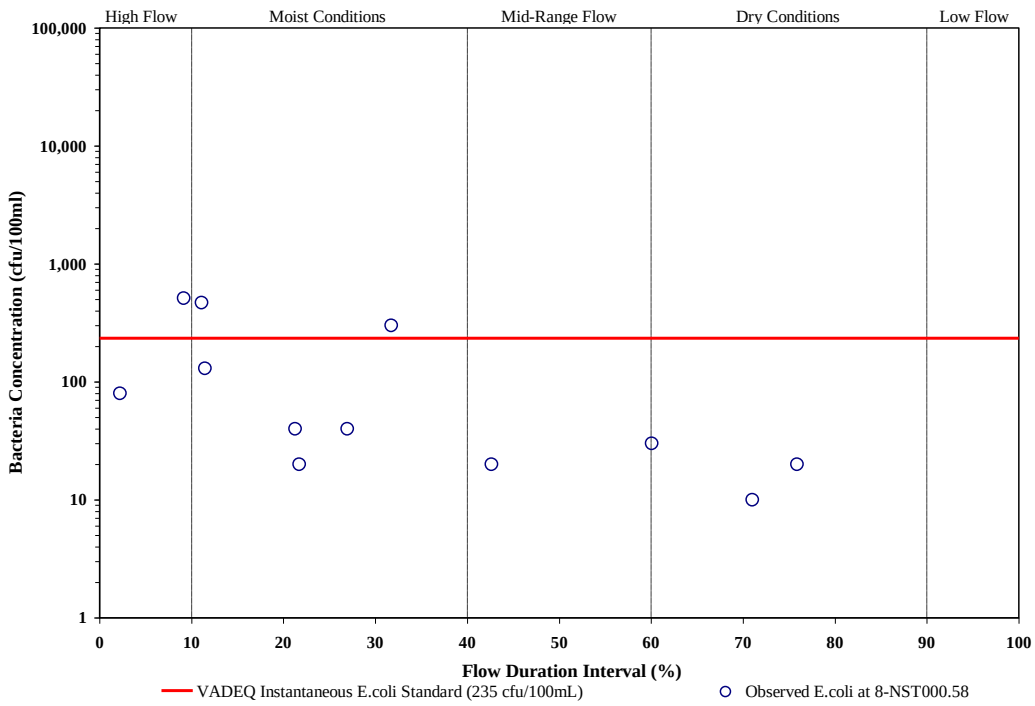

Figure B-40 ***E. coli*** **bacteria concentrations at 8-NST000.58 on Northeast Creek versus discharge at USGS Gaging Station # 01673000.**

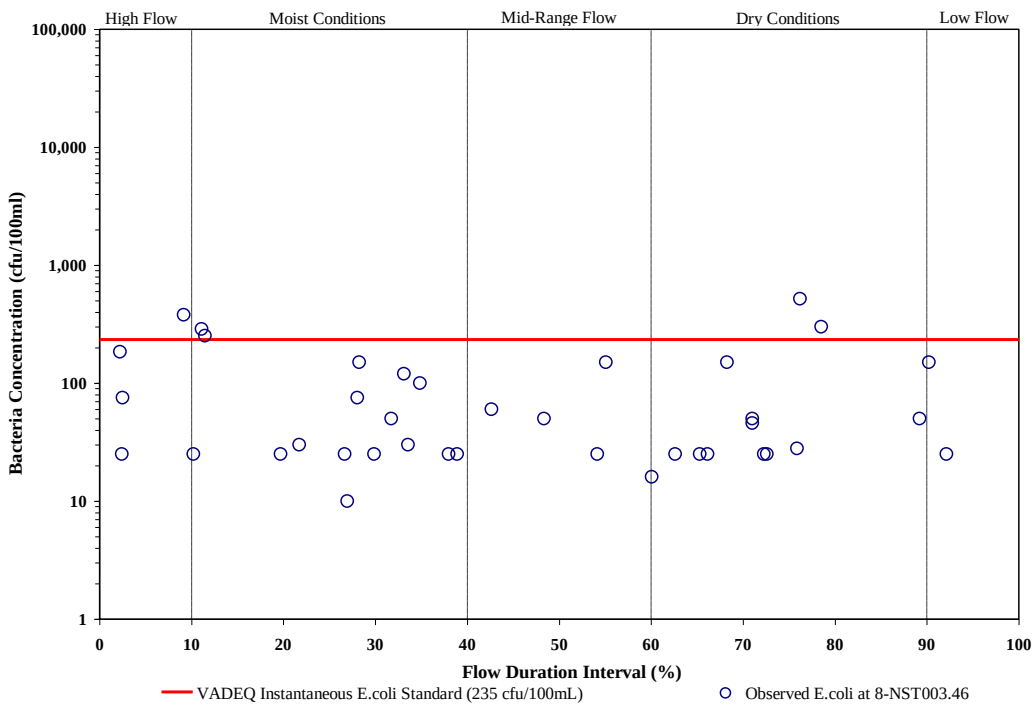

Figure B-41 ***E. coli*** **bacteria concentrations at 8-NST003.46 on Northeast Creek versus discharge at USGS Gaging Station # 01673000.**

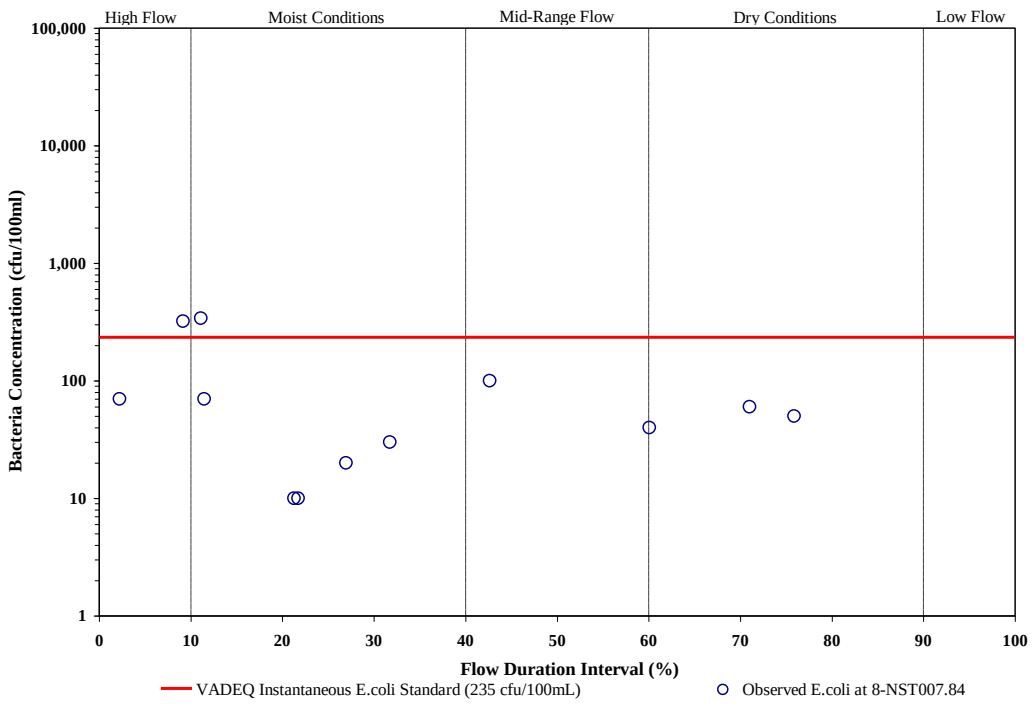

Figure B-42 ***E. coli*** **bacteria concentrations at 8-NST007.84 on Northeast Creek versus discharge at USGS Gaging Station # 01673000.**

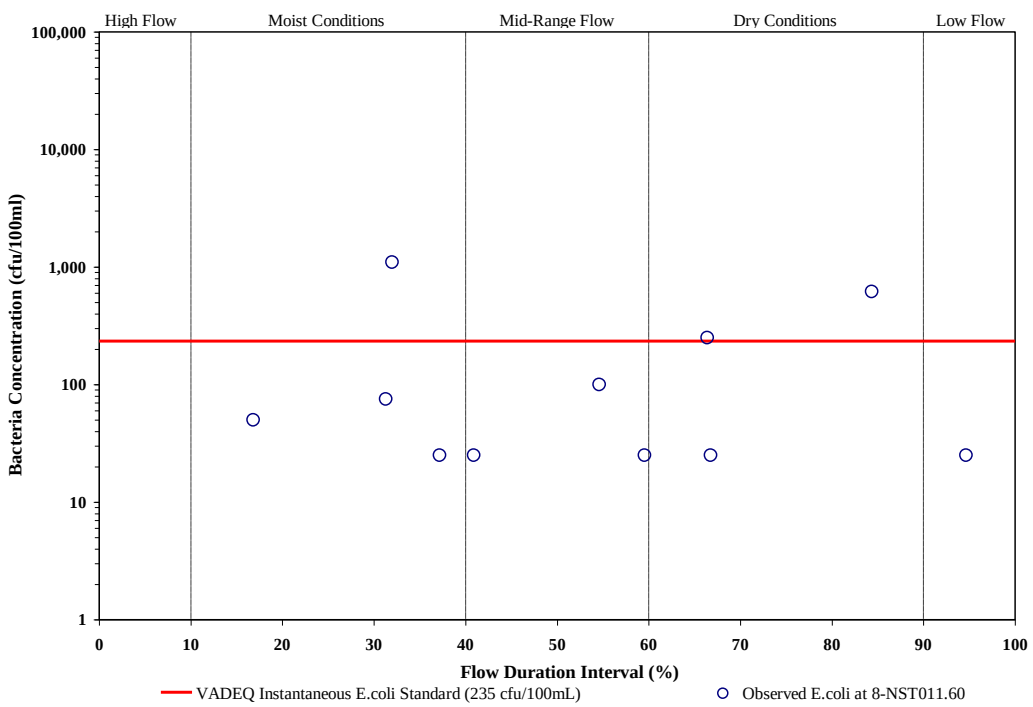

Figure B-43 ***E. coli*** **bacteria concentrations at 8-NST011.60 on Northeast Creek versus discharge at USGS Gaging Station # 01673000.**

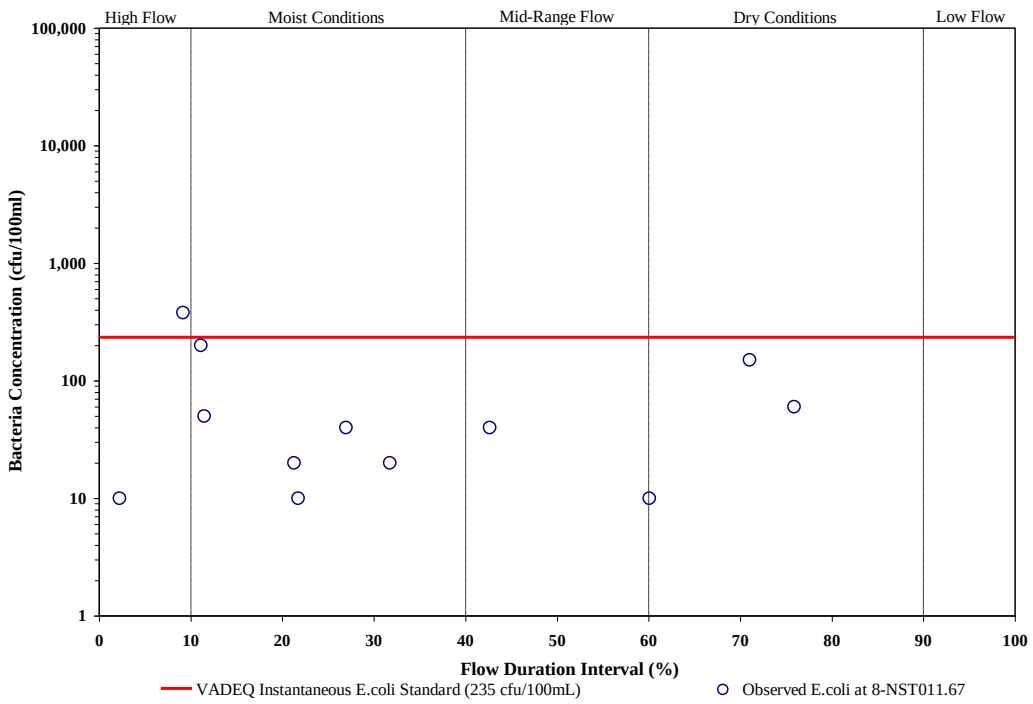

Figure B-44 *E. coli* bacteria concentrations at 8-NST011.67 on Northeast Creek versus discharge at USGS Gaging Station # 01673000.

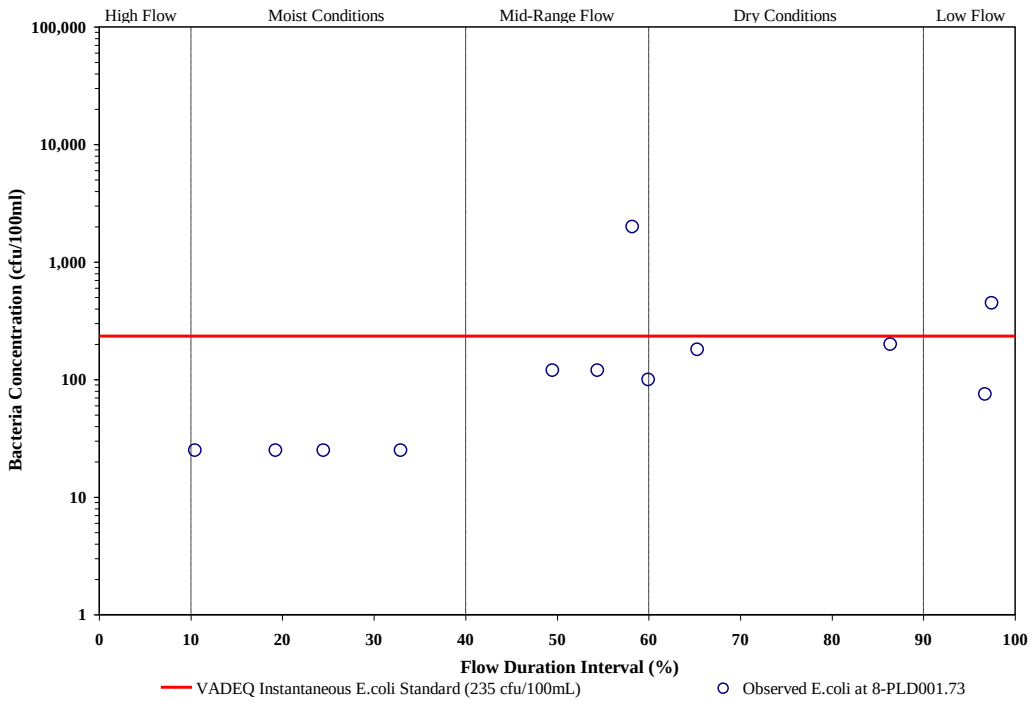

Figure B-45 *E. coli* bacteria concentrations at 8-PLD001.73 on Pollard Creek versus discharge at USGS Gaging Station # 01673000.

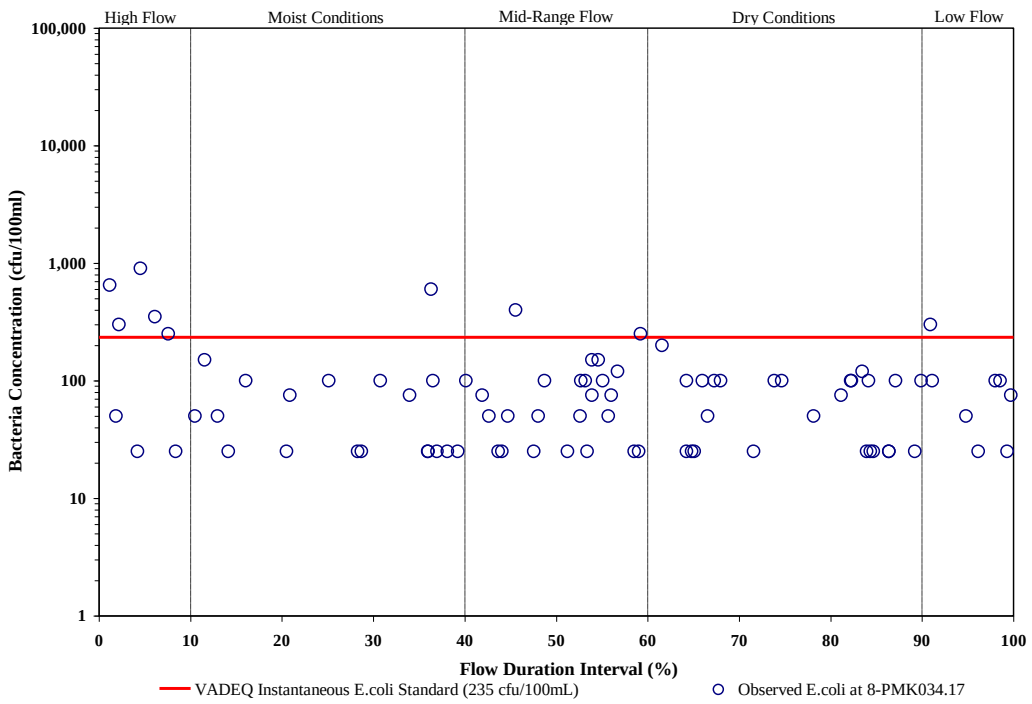

Figure B-46 ***E. coli*** **bacteria concentrations at 8-PMK034.17 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

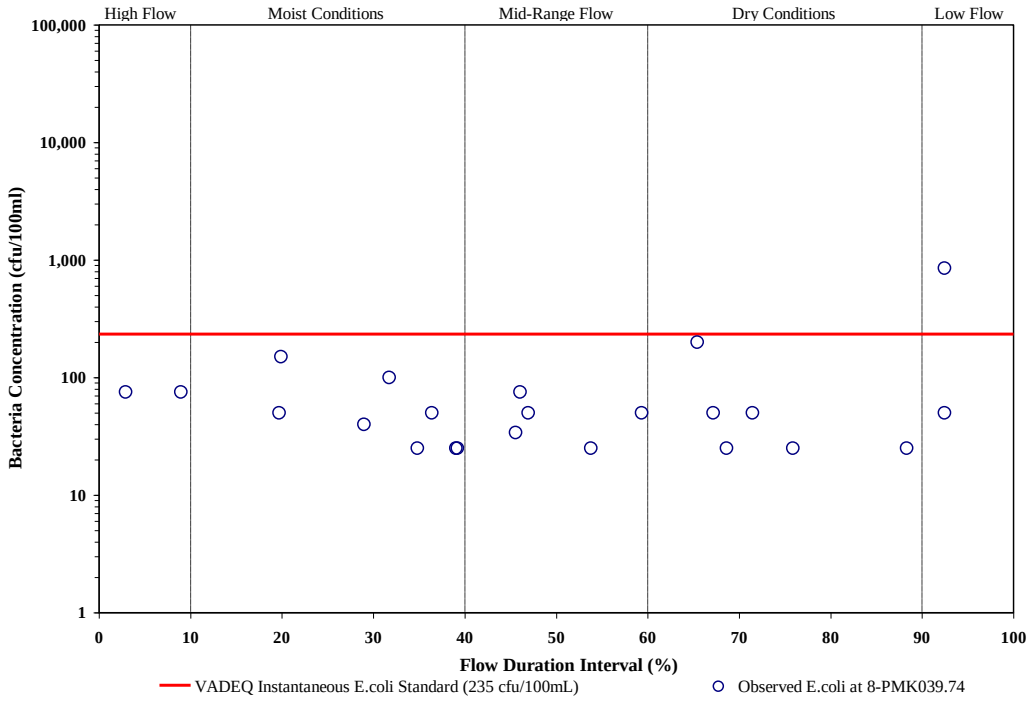

Figure B-47 ***E. coli*** **bacteria concentrations at 8-PMK039.74 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

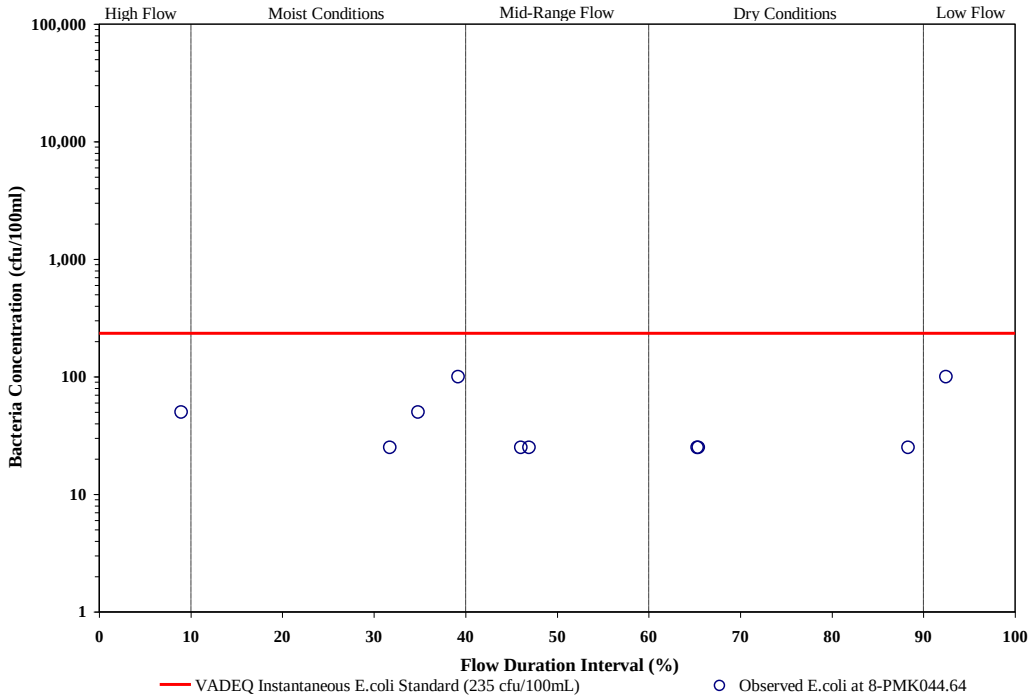

Figure B-48 ***E. coli*** **bacteria concentrations at 8-PMK044.64 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

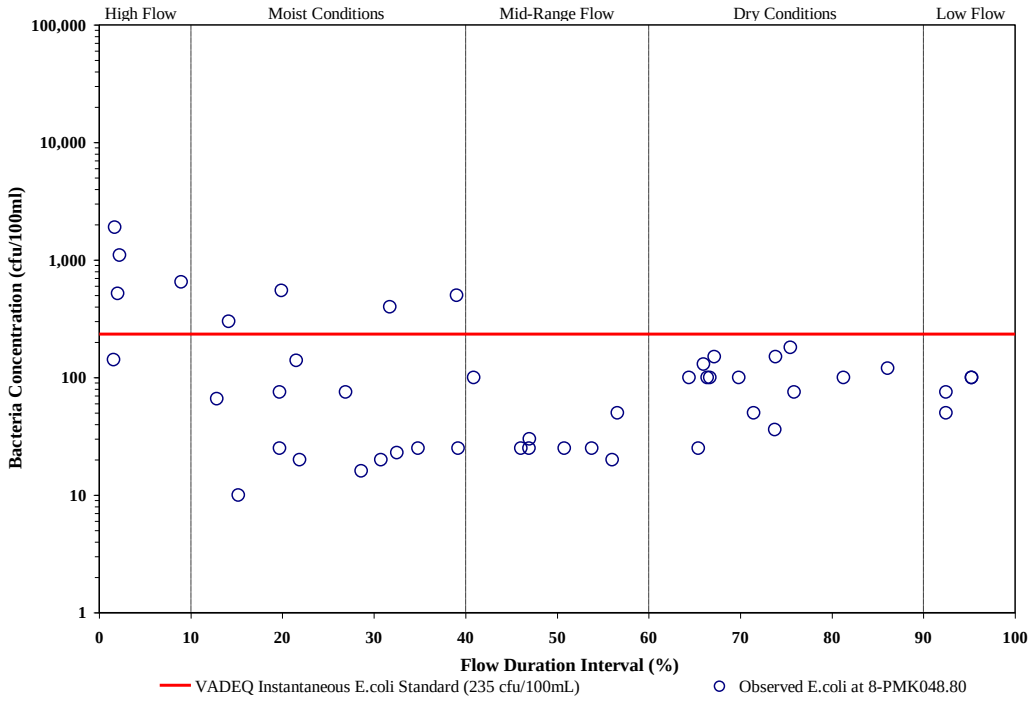

Figure B-49 ***E. coli*** **bacteria concentrations at 8-PMK048.80 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

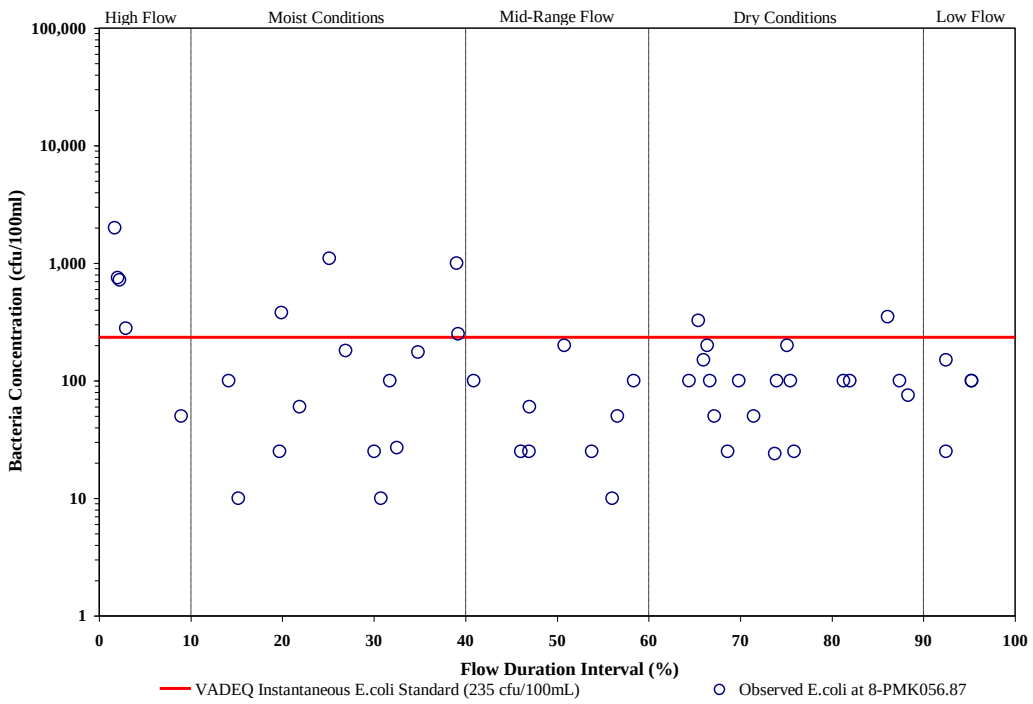

Figure B-50 ***E. coli*** **bacteria concentrations at 8-PMK056.87 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

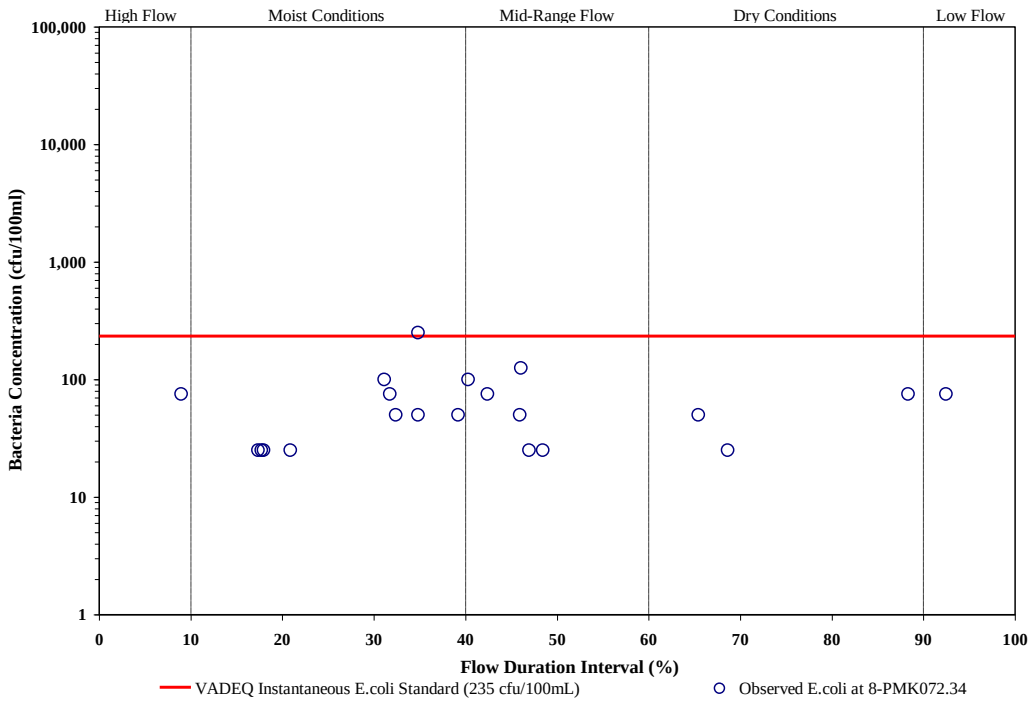

Figure B-51 ***E. coli*** **bacteria concentrations at 8-PMK072.34 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

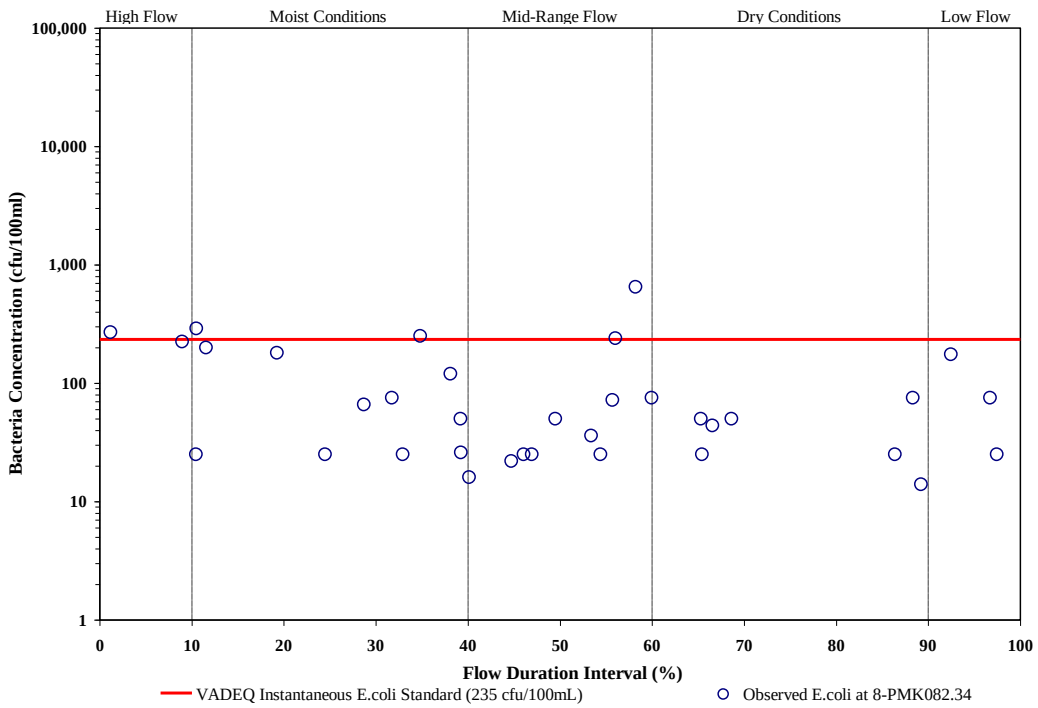

Figure B-52 ***E. coli*** **bacteria concentrations at 8-PMK082.34 on the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

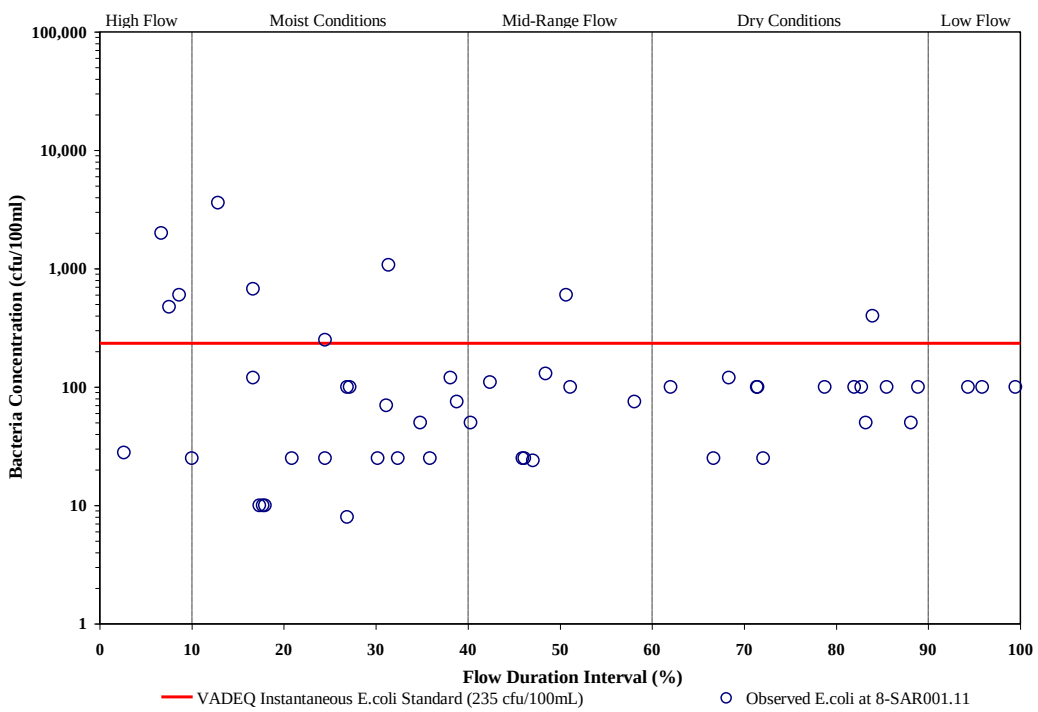

Figure B-53 ***E. coli*** **bacteria concentrations at 8-SAR001.11 on the South Anna River versus discharge at USGS Gaging Station # 01673000.**

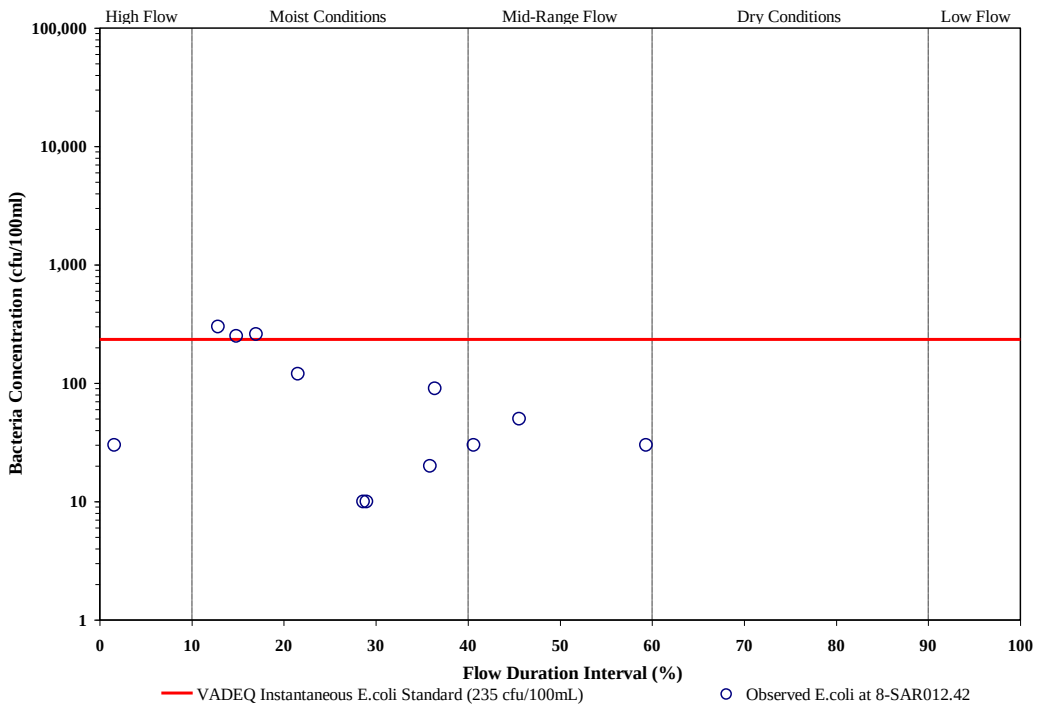

Figure B-54 ***E. coli*** **bacteria concentrations at 8-SAR012.42 on the South Anna River versus discharge at USGS Gaging Station # 01673000.**

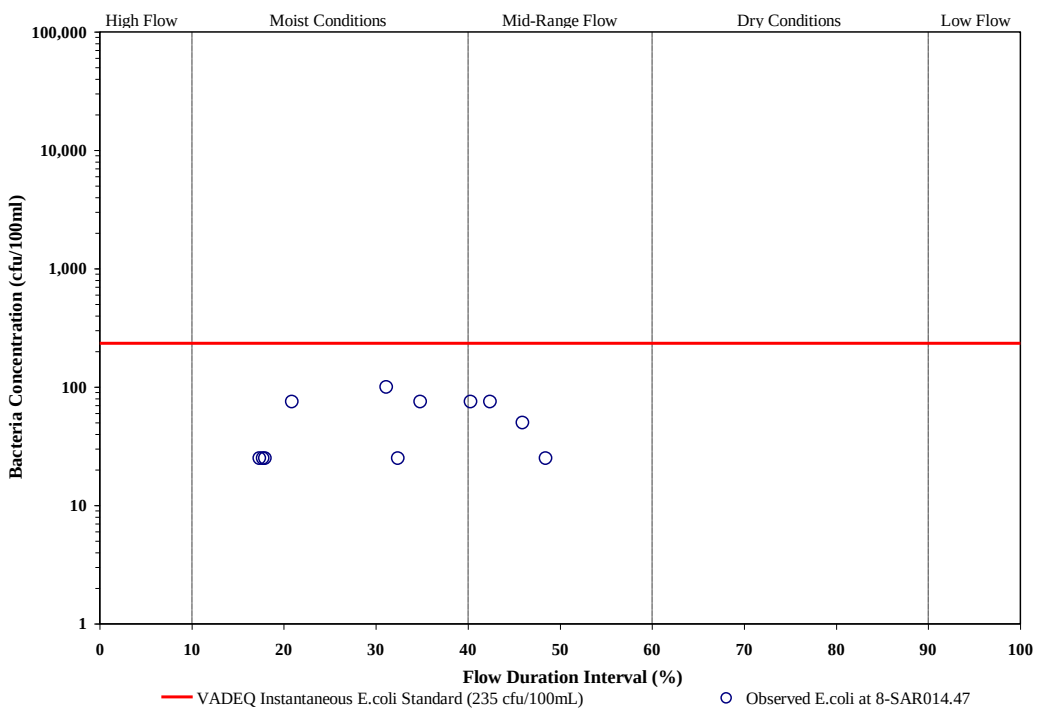

Figure B-55 ***E. coli*** **bacteria concentrations at 8-SAR014.47 on the South Anna River versus discharge at USGS Gaging Station # 01673000.**

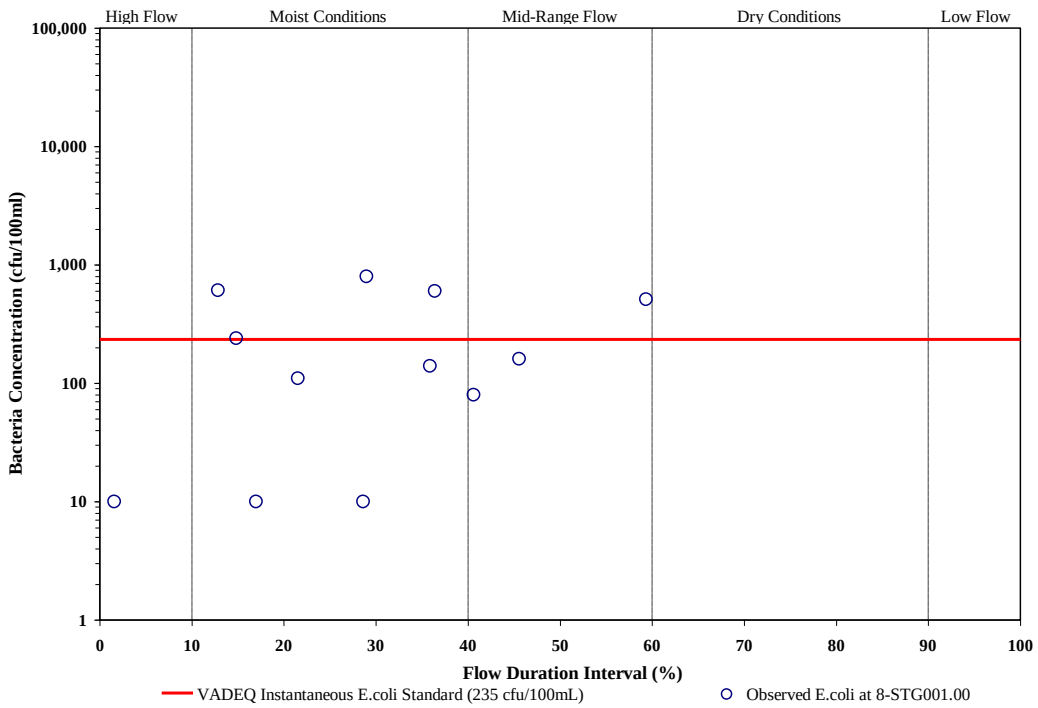

Figure B-56 ***E. coli*** **bacteria concentrations at 8-STG001.00 on Stagg Creek versus discharge at USGS Gaging Station # 01673000.**

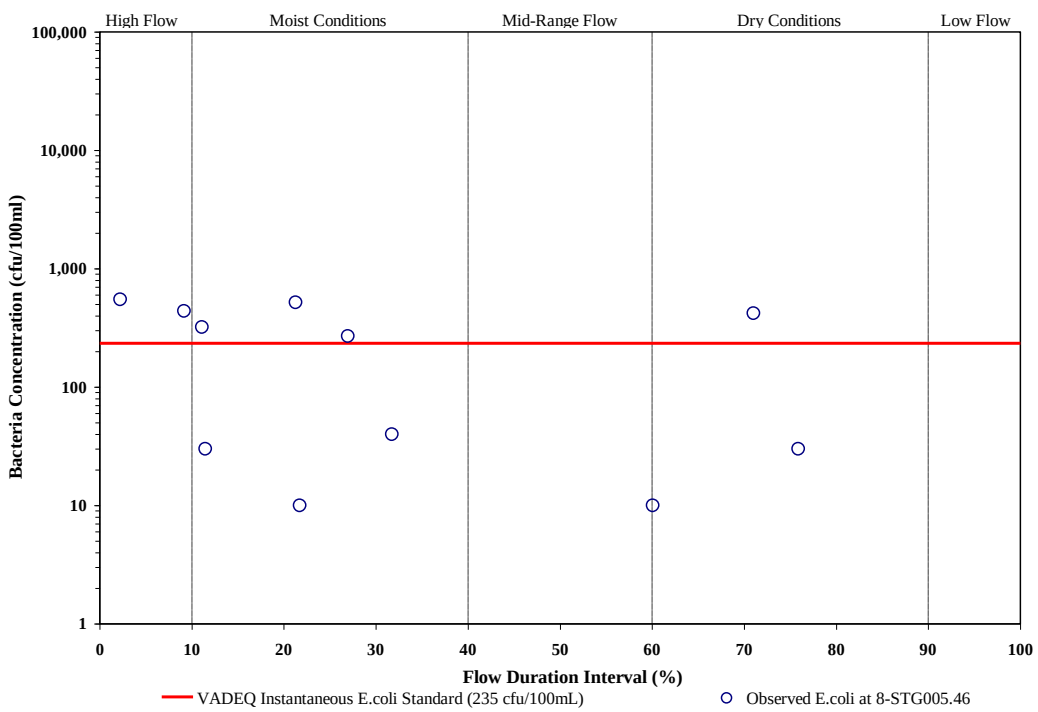

Figure B-57 ***E. coli*** **bacteria concentrations at 8-STG005.46 on Stagg Creek versus discharge at USGS Gaging Station # 01673000.**

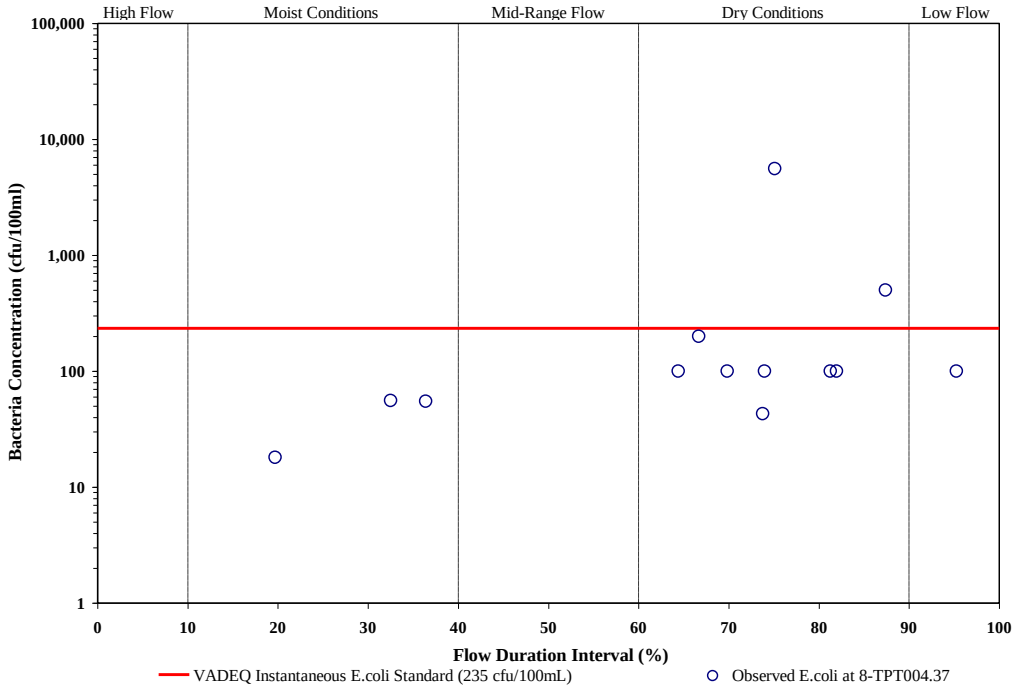

Figure B-58 ***E. coli*** **bacteria concentrations at 8-TPT004.37 on Totopotomoy Creek versus discharge at USGS Gaging Station # 01673000.**

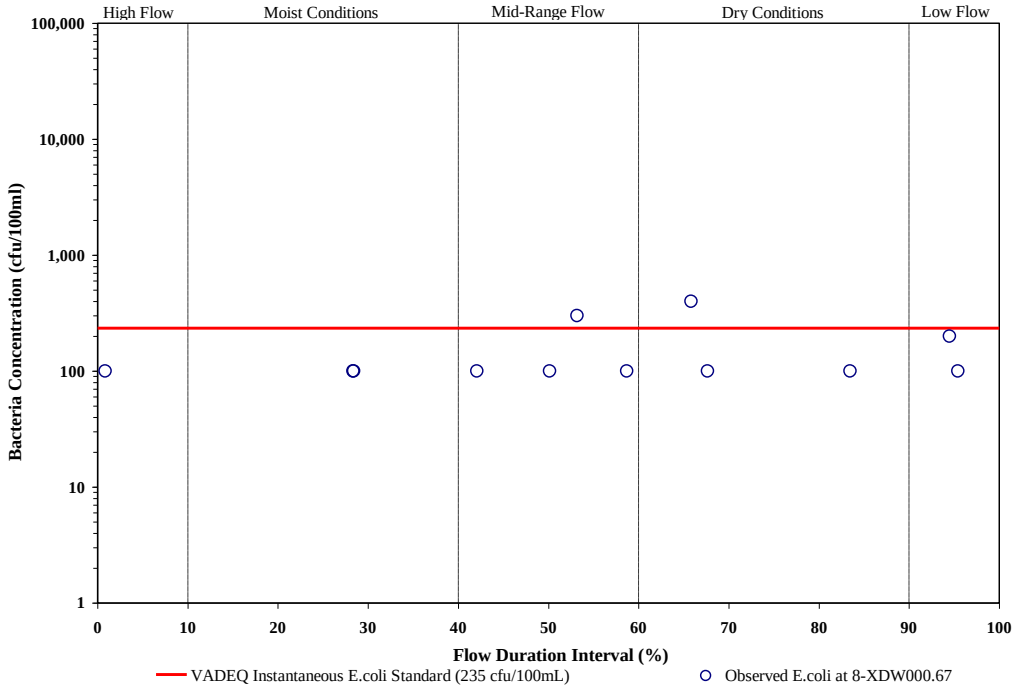

Figure B-59 ***E. coli*** **bacteria concentrations at 8-XDW000.67 on an unnamed tributary to the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

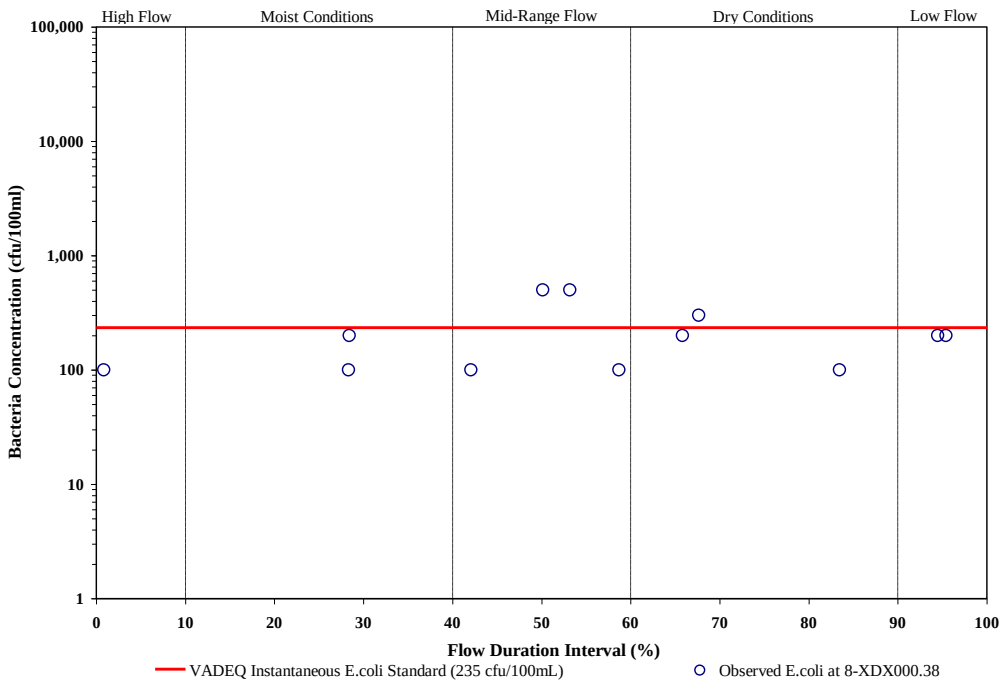

Figure B-60 ***E. coli*** **bacteria concentrations at 8-XDX000.38 on an unnamed tributary to the Pamunkey River versus discharge at USGS Gaging Station # 01673000.**

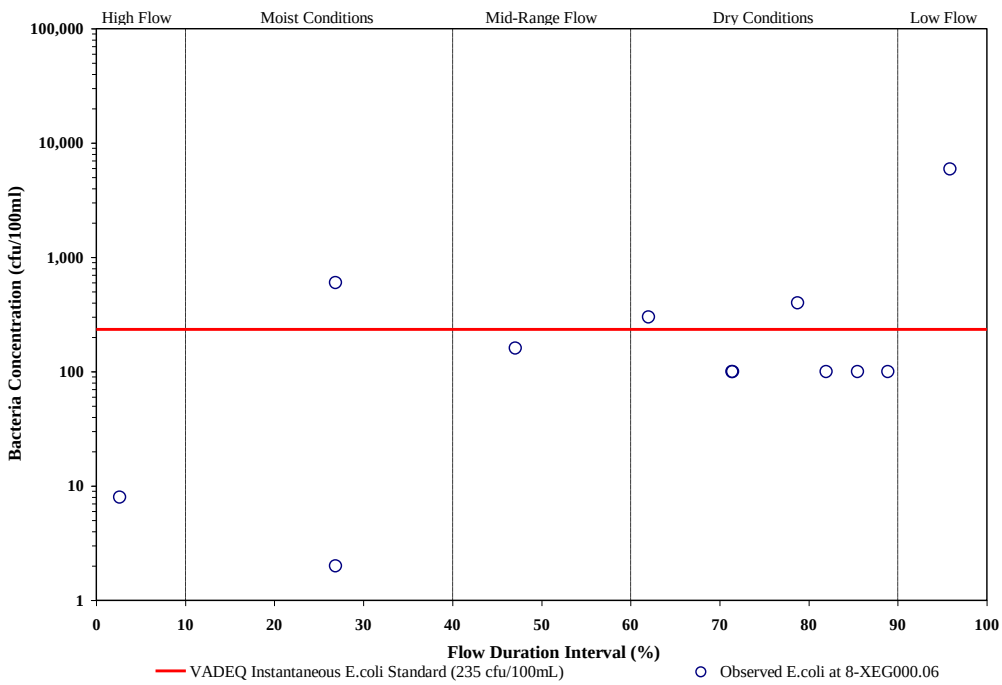

Figure B-61 ***E. coli*** **bacteria concentrations at 8-XEG000.06 on an unnamed tributary to Mechumps Creek versus discharge at USGS Gaging Station # 01673000.**

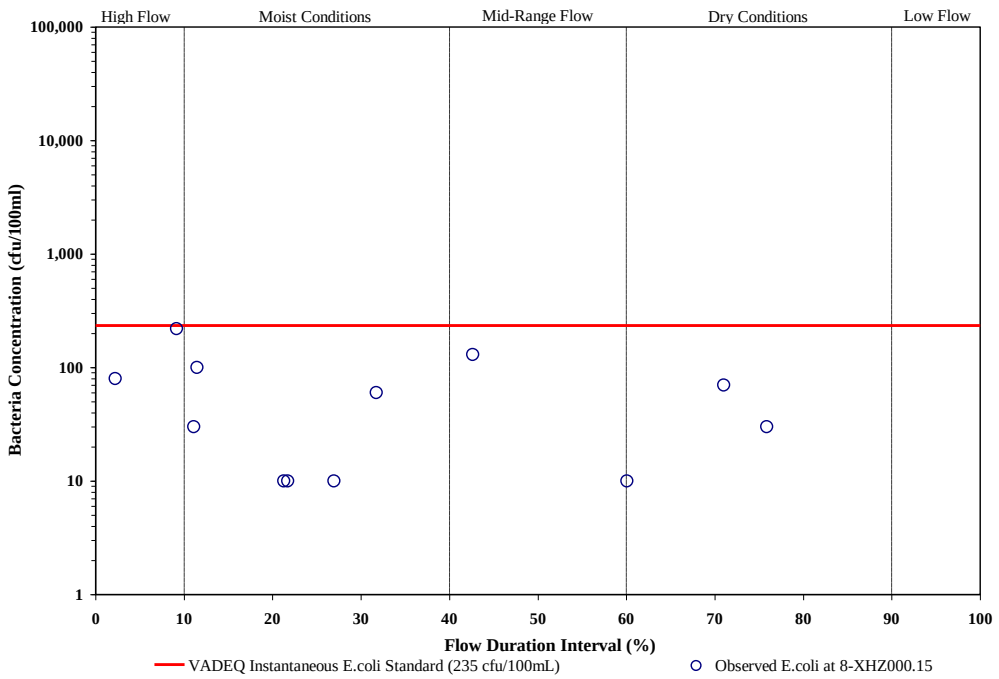

Figure B-62 ***E. coli*** **bacteria concentrations at 8-XHZ000.15 on an unnamed tributary to Northeast Creek versus discharge at USGS Gaging Station # 01673000.**

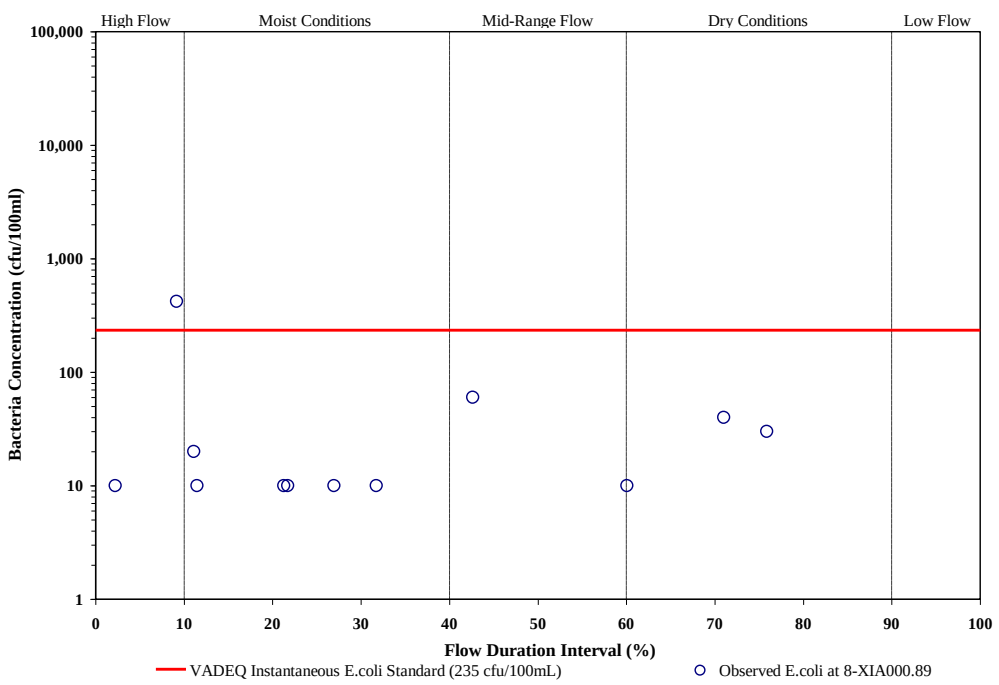

Figure B-63 ***E. coli*** **bacteria concentrations at 8-XIA000.89 on an unnamed tributary to Music Branch versus discharge at USGS Gaging Station # 01673000.**

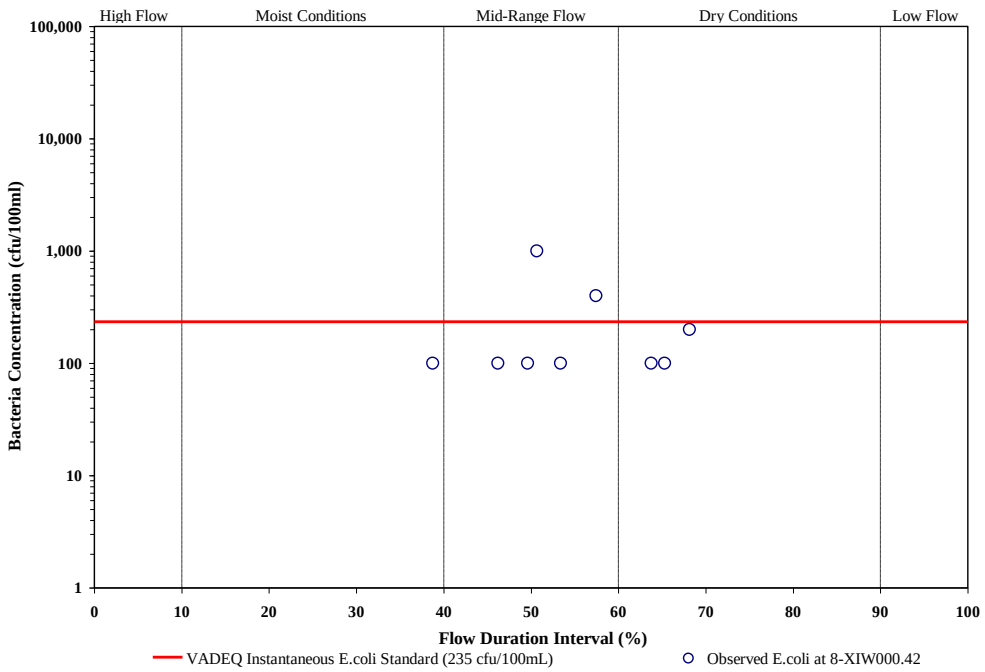

Figure B-64 ***E. coli*** **bacteria concentrations at 8-XIW000.42 on an unnamed tributary to Jacks Creek versus discharge at USGS Gaging Station # 01673000.**

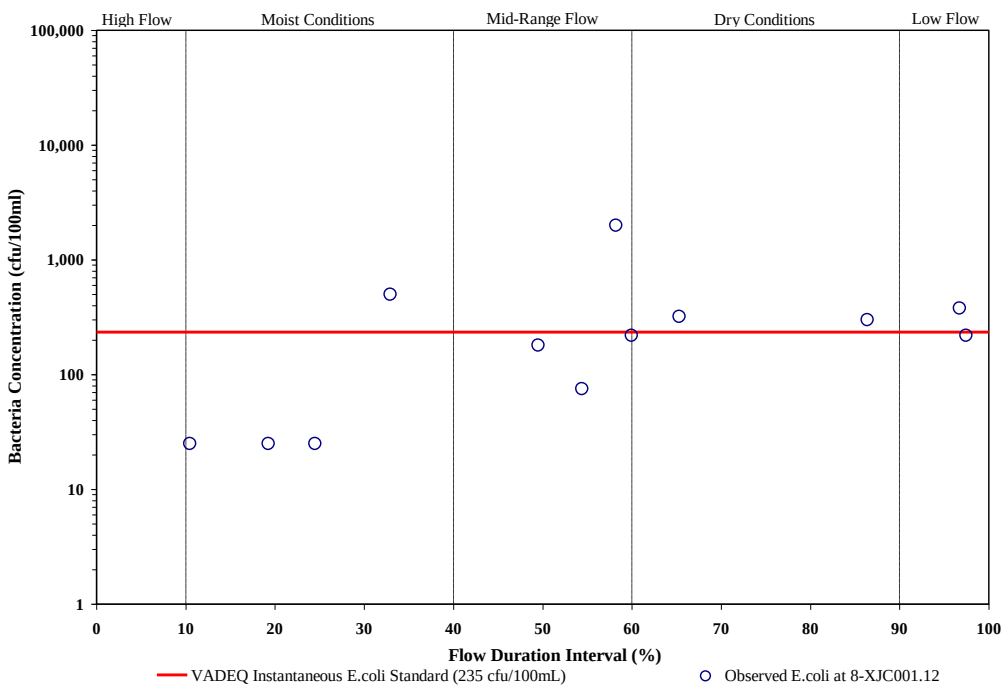

Figure B-65 ***E. coli*** **bacteria concentrations at 8-XJC001.12 on an unnamed tributary to Crump Creek versus discharge at USGS Gaging Station # 01673000.**

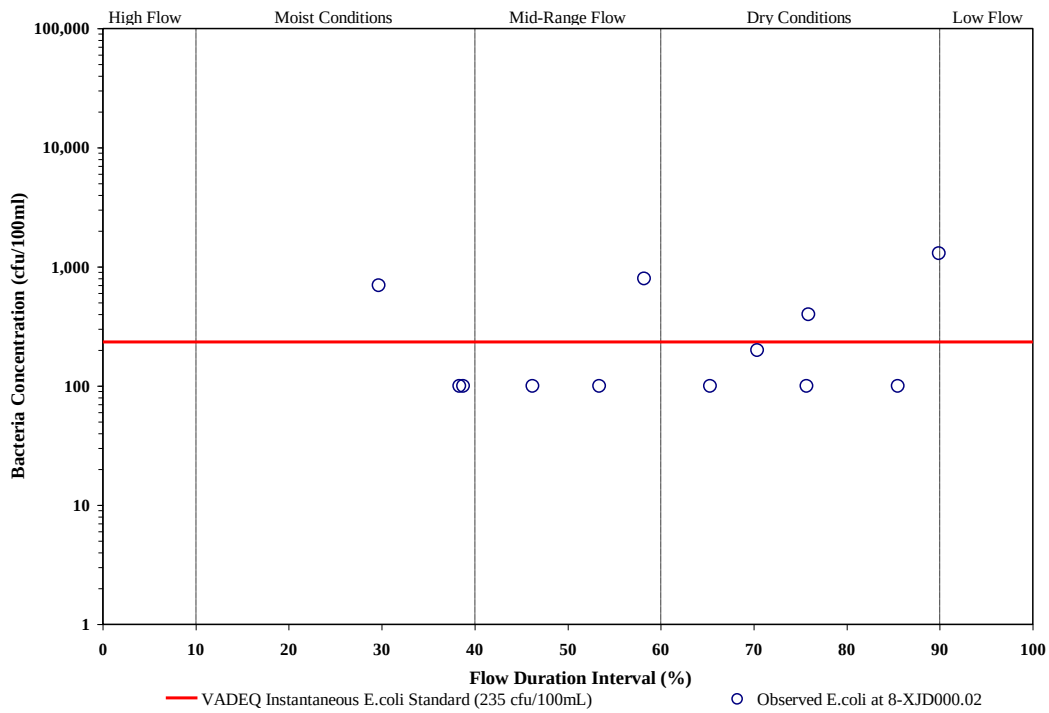

Figure B-66 ***E. coli* bacteria concentrations at 8-XJD000.02 on an unnamed tributary to Harrison Creek versus discharge at USGS Gaging Station # 01673000.**

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

Selection of the modeling period was based on two factors: availability of data (discharge and water quality) and the need to represent critical hydrological conditions. Mean daily discharge at USGS Gaging Station 01673000 in the Pamunkey River near Hanover was available from October 1941 to the present. Daily precipitation data was available from the Richmond International Airport NCDC Coop station #447201. The hydrologic calibration period was October 2002 to September 2005 and hydrologic validation period was October 1994 to September 1997. The fecal concentration data 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 hydrological condition included a wide range of wet and dry

seasons. Multiple periods were used for water quality calibration and validation depending on the availability of monitored data.

Figure B-67 and **Figure B-68** are shown here to demonstrate the historical annual and seasonal stream flow and precipitation and how the selected time period encompasses a representative range of values. **Table B- 7** shows the statistical comparison between calibration/validation time periods and historic time period.

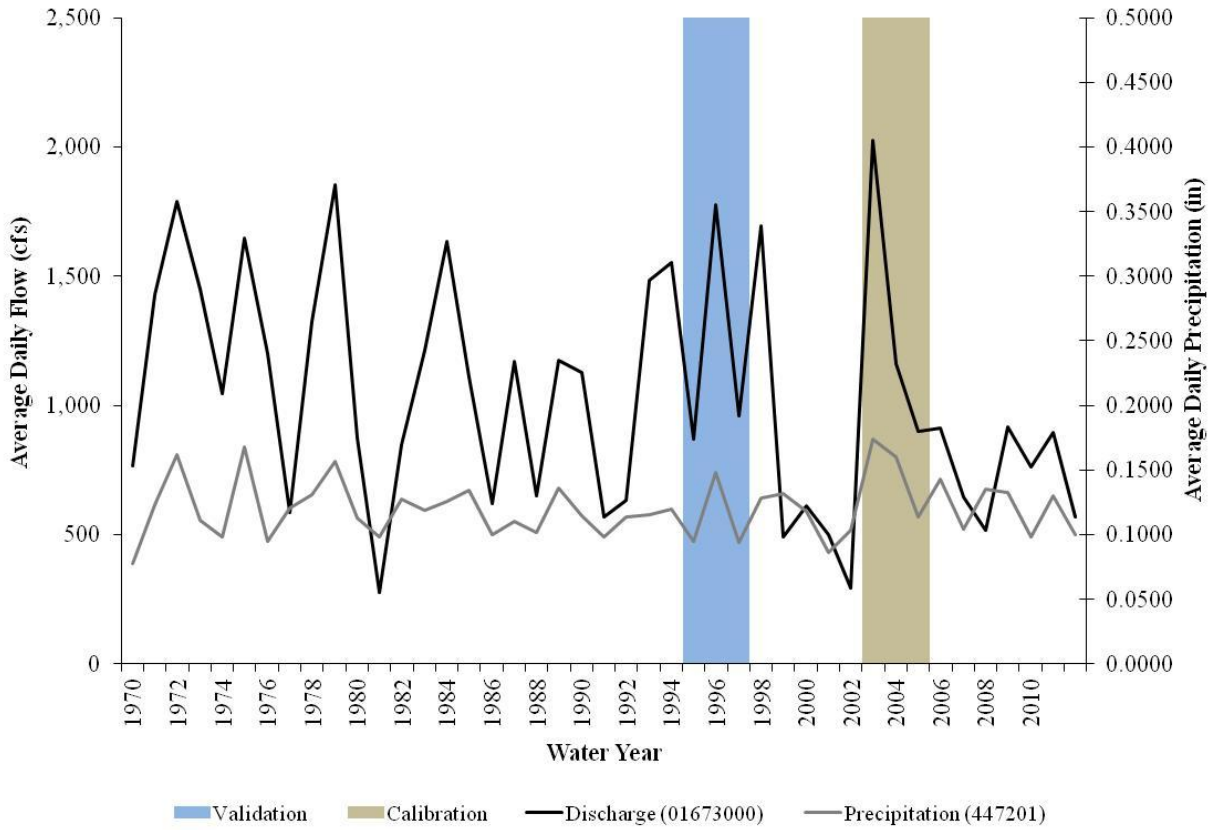

Figure B-67 Modeling time periods, annual historical flow (USGS Station 01673000), and precipitation (Station 447201) data.

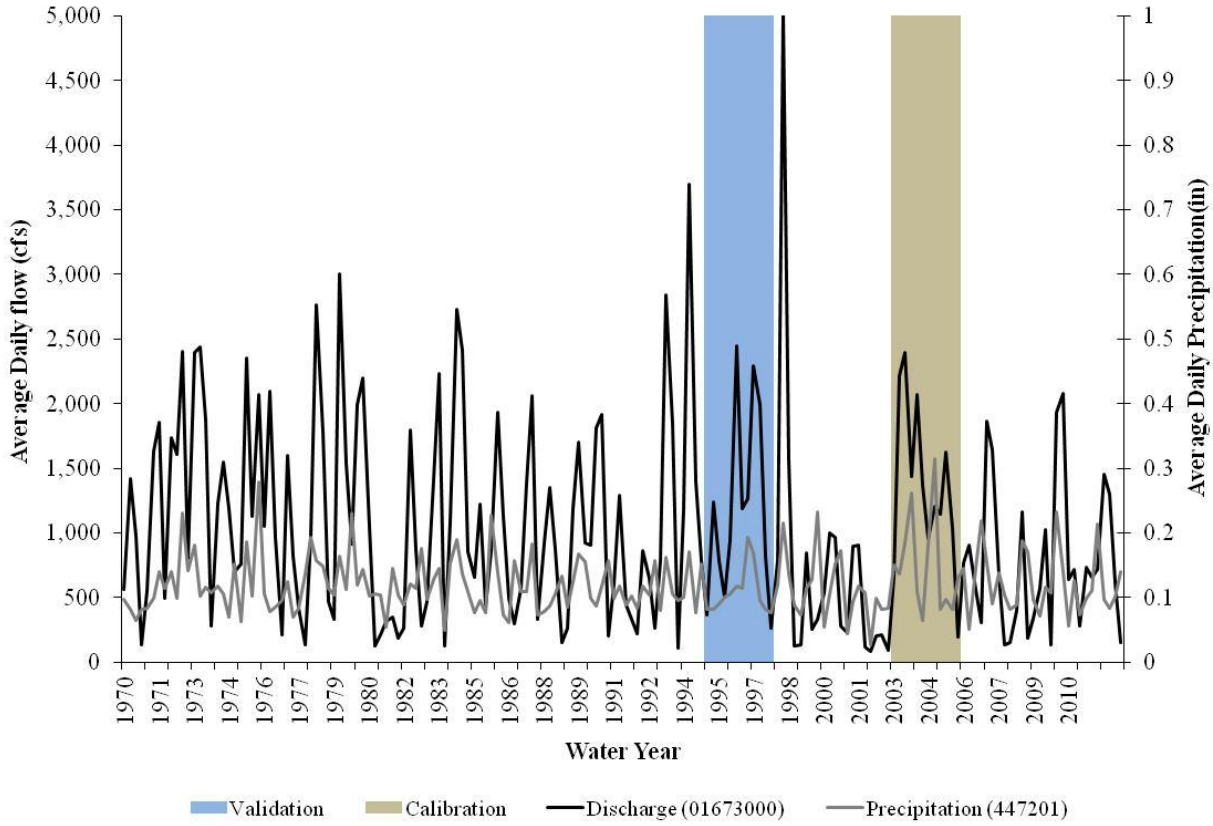

Figure B-68 Modeling time periods, seasonal historical flow (USGS Station 01673000), and precipitation (Station 447201) data.

Table B- 7 Comparison of modeled period to historical records for the Pamunkey River watershed.

	Discharge (01673000)				Precipitation (447201)			
	Fall	**Winter**	**Spring**	**Summer**	**Fall**	**Winter**	**Spring**	**Summer**
	Historical Record (1941 - 2013)				**Historical Record (1946 - 2013)**			
Mean	834	1,588	1,053	502	0.106	0.108	0.114	0.146
Variance	343,149	617,743	308,704	247,180	0.002	0.001	0.001	0.004
	Calibration Time Period (10/02-9/05)				**Calibration Time Period (10/02-9/05)**			
Mean	1,293	1,737	1,462	948	0.114	0.100	0.149	0.235
p-value	0.138	0.290	0.194	0.126	0.338	0.351	0.150	0.057
Variance	510,757	188,033	651,163	435,356	0.001	0.001	0.003	0.009
p-value	0.233	0.261	0.129	0.179	0.491	0.370	0.110	0.115
	Validation Time Period (10/94-9/97)				**Validation Time Period (10/94-9/97)**			
Mean	1204	1891	931	678	0.119	0.098	0.096	0.124
p-value	0.260	0.204	0.198	0.285	0.312	0.196	0.049	0.271
Variance	968061	370182	48369	272462	0.002	0.000	0.000	0.004
p-value	0.066	0.448	0.145	0.338	0.301	0.224	0.172	0.603

Source Representation

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

Much of the data used to develop the model inputs for modeling water quality is time-dependent (*e.g.*, population). Depending on the timeframe of the simulation being run, different estimates were used. Data were obtained for the appropriate timeframe for water quality calibration and validation. Data representing 2012 were used for the allocation runs in order to represent current conditions.

Ten (10) point sources are permitted to discharge water into surface waters in the Pamunkey River Watershed study area through the Virginia Pollutant Discharge Elimination System (VPDES) that contains fecal bacteria (**Table 3.2**). **Section 3.1** discusses these permits in more detail. Three (3) additional permits are domestic or single family home permit that discharges less than 1,000 gallons per day (**Table 3.3**). For calibration and validation condition runs, recorded flow and fecal bacteria concentration or Total Residual Chlorine (TRC) levels documented by the VADEQ were used as the input for the permit. The TRC data was related to fecal bacteria concentrations using a regression analysis. **Table B- 8** shows the minimum and maximum discharge rate in million gallons per day (MGD) and the minimum and

maximum fecal coliform bacteria concentration in colony forming units per 100 milliliters (cfu/100mL). These values are the sums of all the data for outfall 001.

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 to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels. The design flow rates and fecal coliform bacteria concentrations are shown in **Table B-8**.

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.

Table B- 8 Flow rates and bacteria loads used to model VADEQ active permits in the Pamunkey River Watershed study area.

		Calibration/Validation				Allocation	
		Flow Rate (MGD)		Bacteria Concentration (cfu/100mL)		Flow Rate (MGD)	Bacteria Concentration(cfu/100mL)
VADEQ Permit Number	Facility Name	Min	Max	Min	Max	Design Flow	Fecal Coliform Geometric Mean Standard
VA0020630	DJJ Barrett Juvenile Correctional Center	0.0001	0.200	0.00	79.594	0.019	200
VA0020664	DJJ Hanover Juvenile Correctional Center	0.000	0.040	3.4	13.7	0.0347	200
VA0023914	Hamilton Holmes WTP	0.001	0.148	0.00	240.00	0.02	200
VA0029521	Hanover County Doswell WWTP	0.500	0.500	1.00	389.00	6.34	200
VA0062154	Hanover Courthouse WWTP	0.006	0.568	0.019	1,491.77	0.08	200
VA0067121	Cumberland Hospital for Children & Adolescents	0.007	0.088	1.894	3.79	0.03	200
VA0068314	Rhapsody Industrial Park – Purgo	0.0001	0.003	2.029	19.73	0.005	200
VA0088102	HRSD King William County STP	0.002	0.038	0.00	5.00	0.100	200
VA0089915	Hanover County Totopotomoy WWTP	0.09	3.1	0.5	13	10.00	200
VA0091537[1]	Mount Olive WTF	NA	NA	NA	NA	0.008	200
VAG404066[2]	S&R Sunoco, Inc., c/o Rose E. Moore	NA	NA	NA	NA	0.001	200
VAG404236[2]	Samuel and Beverly Moody	NA	NA	NA	NA	0.001	200
VAG404258[2]	Wee Care Christian Learning Center, LLC	NA	NA	NA	NA	0.001	200

[1] New discharge no discharge data available. [2] No discharge data available.

The number of septic systems in the Pamunkey River Watershed study area was calculated by overlaying U.S. Census Bureau data (USCB, 1990; USCB, 2000) with the subwatersheds. During allocation runs, the number of households was projected to 2012,

based on current growth rates (USCB, 2000) resulting in 14,128 septic systems, 556 pit privies, and 62 straight pipes (**Table B- 9** and **Table B- 10**).

Table B- 9 Estimated failing septic systems and straight pipes for 2012 in the Pamunkey River study area.

Subwatershed	Septic Systems	Failing Septic Systems	Homes with Pit Privies	Straight Pipes
1	434	9	13	1
2	18	0	1	0
3	4	0	0	0
4	3	0	0	0
5	59	2	1	0
6	47	1	2	0
7	158	4	3	0
8	8	0	0	0
9	250	8	5	1
10	3	0	0	0
11	611	14	9	1
12	200	4	7	1
13	70	3	18	2
15	28	1	6	1
16	125	4	10	1
17	973	32	58	6
18	483	16	21	2
19	165	3	7	1
21	2	0	0	0
22	0	0	0	0
23	57	2	4	0
24	3	0	0	0
25	346	12	12	1
26	1,120	37	9	1
27	1,685	56	14	2
28	975	32	33	4
30	76	3	1	0
31	43	1	1	0
33	96	3	2	0

Table B- 10 Estimated failing septic systems and straight pipes for 2012 in the Pamunkey River study area (cont.).

Subwatershed	Septic Systems	Failing Septic Systems	Homes with Pit Privies	Straight Pipes
34	903	30	69	8
35	1	0	0	0
36	1	0	1	0
37	105	4	16	2
38	295	10	13	1
39	177	6	3	0
40	192	6	13	1
41	576	18	29	3
42	322	8	19	2
43	1,036	21	70	8
44	180	6	7	1
45	602	20	18	2
46	222	7	8	1
47	267	9	4	0
48	417	14	40	4
49	128	4	2	0
50	389	13	2	0
51	273	9	3	0
Total	**14,128**	**432**	**554**	**58**

The initial estimates of the number of failing septic systems were based on the assumption that each septic system fails, on average, once during an expected lifetime of 30 years. Resulting estimates were shared with the region's Health Department and feedback was obtained and used in adjusting numbers. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

Straight pipes were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each

subwatershed. The loadings from straight pipes were modeled in the same manner as direct discharges to the stream.

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Different livestock populations were estimated for each water quality modeling period (calibration/validation/allocation). The numbers are based on data provided by Virginia Agricultural Statistics (VASS), with values updated and discussed by VADCR, NRCS and SWCDs as well as taking into account growth rates in these counties as determined from data reported by the Virginia Agricultural Statistics Service (VASS, 1997; VASS, 2002). For land-applied waste, the fecal coliform density measured from stored waste was used, while the density in as-excreted manure was used to calculate the load for deposition on land and to streams (**Table 3.11**). The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

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

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

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

The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access" areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

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

Investigation of VADEQ data indicated that biosolids applications occurred in the Pamunkey River study area (Table 3.6). Class B biosolids are permitted to contain up to 1,995,262 cfu/g-dry, as compared with approximately 240 cfu/g-dry for dairy waste. Records of biosolids application location, timing, and quantity were available, enabling the water quality modeling to be carried out in an "as applied" fashion, wherein the water quality model received land based inputs of biosolids loads on the day in which they actually occurred. During model runs, biosolids were modeled as having a fecal concentration of 157,835 cfu/g, the mean value of measured biosolids concentrations observed in several years of samples supplied by VADEQ for sources applied during 2001-2011. Applications were modeled as being spread onto the land surface over a six-hour period on the date of reported application. An assumption of proper application was made, wherein no biosolids were modeled as being spread in stream corridors.

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.6). An example of one of these layers is shown in **Figure B-69**. This layer was overlaid with the land use layer and the resulting area was calculated for each land use in each subwatershed. The number of animals per land segment was determined by multiplying the area by the population density. Fecal

coliform loads for each land segment were calculated by multiplying the wasteload, fecal coliform densities, and number of animals for each species.

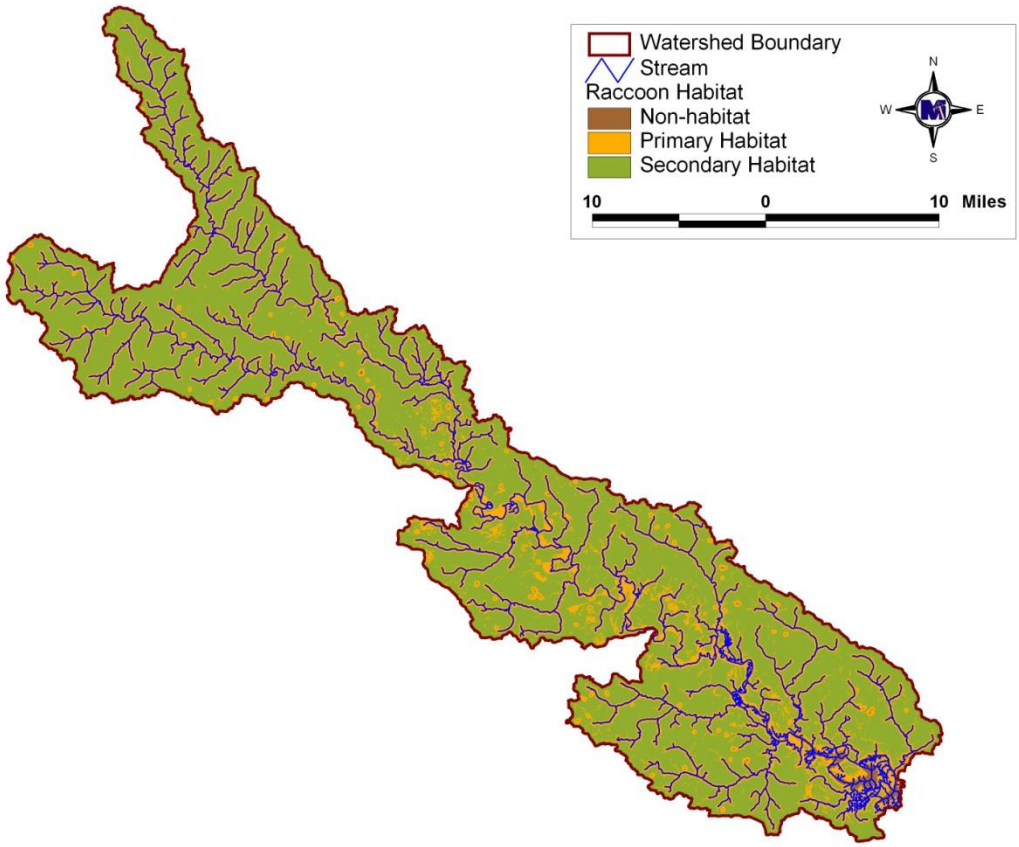

Figure B-69 Example of raccoon habitat layer in the Pamunkey River Watershed study area, as developed by MapTech.

For each species, a portion of the total wasteload was considered land-based, with the remaining portion being directly deposited to streams. The portion being deposited to streams was based on the amount of time spent in stream access areas (**Table 3.14**). 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.

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.2.4. Waste

from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 2000 Census (USCB, 1990 and USCB, 2000). The number of animals per subwatershed was determined by multiplying the number of households by the pet population density. The amount of fecal coliform deposited daily by pets in each subwatershed was calculated by multiplying the wasteload, fecal coliform density, and number of animals for both cats and dogs. The wasteload was assumed not to vary seasonally. The populations of cats and dogs were projected from 2000 data to 2011.

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.

The model was calibrated for hydrologic accuracy using daily flow data for the period October 2002 through September 2005. The daily stream flow used was from the Pamunkey River near Hanover (USGS Gaging Station # 01673000, October 1941 to the present). The modeled output from subwatershed 13 was compared against the flow data for the USGS Gaging Station.

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the length of overland flow (LSUR), the amount of soil moisture storage in the upper zone (UZSN) and lower zone (LZSN), the amount of interception storage (CEPSC), the infiltration capacity (INFILT), the amount of soil water contributing to interflow (INTFW), deep groundwater inflow fraction (DEEPER), baseflow PET (BASETP), groundwater recession flow (KVARY), and active groundwater storage PET (AGWETP). **Table B- 11** contains the possible range for the above parameters along with the initial estimate and final calibrated value. State

variables in the PERLND water (PWAT) section of the User's Control Input (UCI) file were adjusted to reflect initial conditions.

Table B- 11 Initial hydrologic parameters estimated for the Pamunkey River Watershed study area, and resulting final values after calibration.

Parameter	Units	Possible Range of Parameter Value	Initial Parameter Estimate	Final Calibrated Parameter Value
LZSN	in	2.0 – 15.0	10	4.0
INFILT	in/hr	0.001 – 0.50	0.0744 – 0.2479	0.0074 – 0.0248
KVARY	1/in	0.0 – 5.0	1	1
AGWRC	1/day	0.85 – 0.999	0.94	0.996
DEEPFR	---	0.0 – 0.50	0.1	0.1
BASETP	---	0.0 – 0.20	0.3	0.05
AGWETP	---	0.0 – 0.20	0.0	0.0
INTFW	---	1.0 – 10.0	1.0	1.0
IRC	1/day	0.30 – 0.85	0.3	0.3
MON-INTERCEPT	in	0.01 – 0.40	0 – 0.2	0 – 0.4
MON-UZSN	in	0.05 – 2.0	0.4 – 1	0.32 – 0.8
MON-LZETP	---	0.1 – 0.9	0 – 0.4	0 – 0.8

Table B- 12 shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated. **Figure B-70** and **Figure B-71** graphically show these comparisons.

Table B- 12 Hydrology calibration model performance from 10/1/2002 through 9/30/2005 at USGS Gaging Station # 01673000 on the Pamunkey River (subwatershed 13).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	50.08	48.25	-3.67%
Upper 10% Flow Values:	21.32	19.81	-7.08%
Lower 50% Flow Values:	8.19	8.25	0.68%
Winter Flow Volume	15.74	14.14	-10.18%
Spring Flow Volume	13.47	11.80	-12.37%
Summer Flow Volume	8.83	10.53	19.23%
Fall Flow Volume	12.05	11.78	-2.21%
Total Storm Volume	46.74	44.88	-3.99%
Winter Storm Volume	14.91	13.30	-10.79%
Spring Storm Volume	12.63	10.96	-13.30%
Summer Storm Volume	7.99	9.68	21.20%
Fall Storm Volume	11.21	10.94	-2.46%

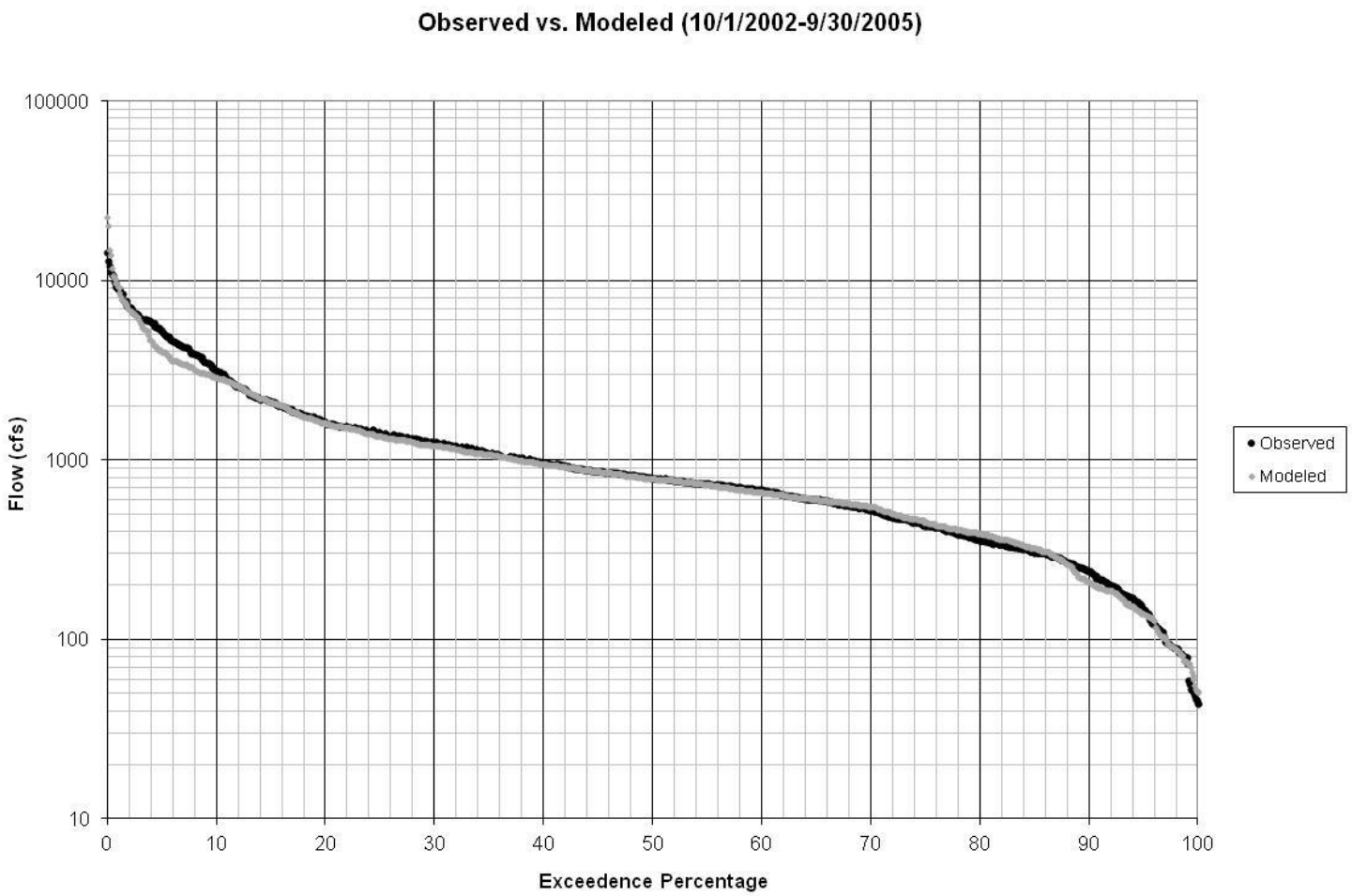

Figure B-70 Pamunkey River modeled flow duration versus USGS Gaging Station # 01673000 data from 10/1/2002 to 9/30/2005 (subwatershed 13).

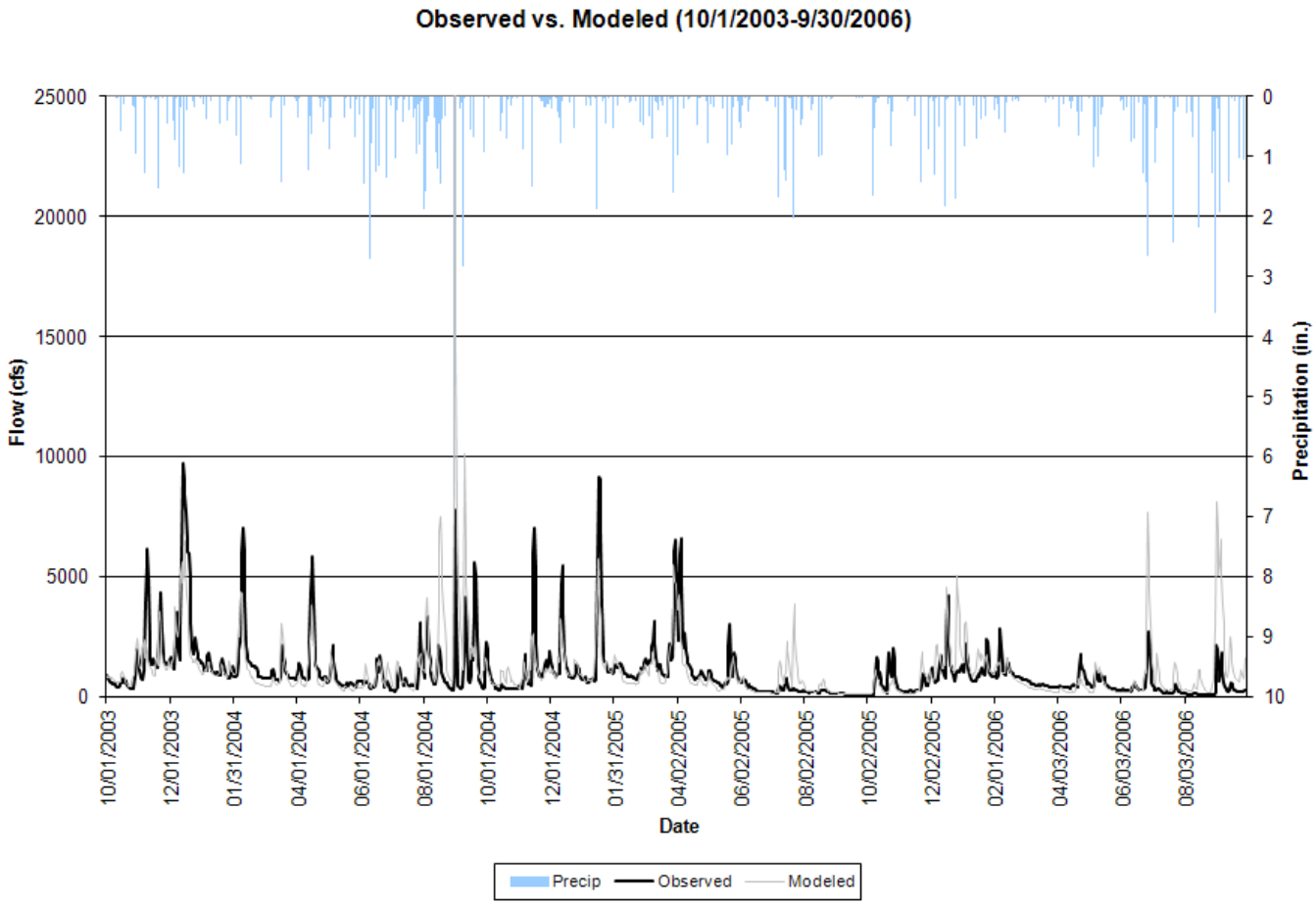

Figure B-71 Pamunkey River modeled results versus USGS Gaging Station # 01673000 data from 10/1/2002 to 9/30/2005 (subwatershed 13).

The modeled output was validated for the period of 10/1994 to 9/30/1997. Simulated flow at subwatershed 13 was compared with daily flow at the Pamunkey River USGS Gaging Station # 01673000. **Table B- 13** shows the percent difference (or error) between observed and modeled data for total in-stream flows, upper 10% flows, and lower 50% flows during model calibration. These values represent a close agreement with the observed data, indicating the model was well calibrated and has been validated during a different time period. **Figure B-72** and **Figure B-73** graphically show these comparisons.

Table B- 13 Hydrology validation model performance from 10/1/1994 through 9/30/1997 at USGS Gaging Station # 01673000 on the Pamunkey River (subwatershed 13).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	43.18	40.54	-6.12%
Upper 10% Flow Values:	18.55	15.83	-14.66%
Lower 50% Flow Values:	6.48	6.97	7.53%
Winter Flow Volume	17.08	16.10	-5.70%
Spring Flow Volume	8.58	8.67	1.05%
Summer Flow Volume	6.31	6.13	-2.96%
Fall Flow Volume	11.22	9.64	-14.02%
Total Storm Volume	39.83	36.01	-9.61%
Winter Storm Volume	16.24	14.98	-7.77%
Spring Storm Volume	7.74	7.54	-2.61%
Summer Storm Volume	5.48	4.99	-9.02%
Fall Storm Volume	10.37	8.50	-18.01%

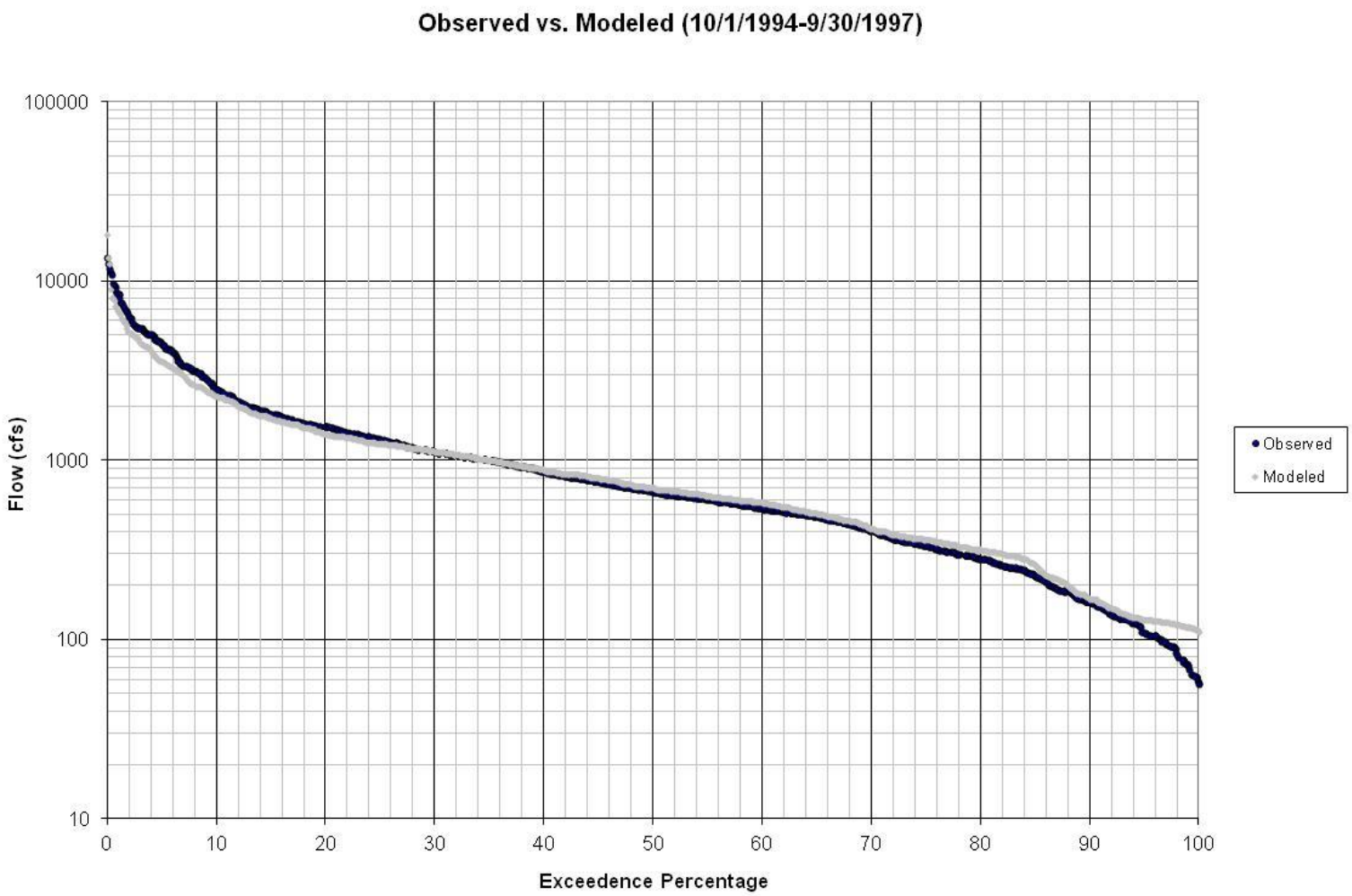

Figure B-72 Pamunkey River modeled flow duration versus USGS Gaging Station # 01673000 data for validation (subwatershed 13).

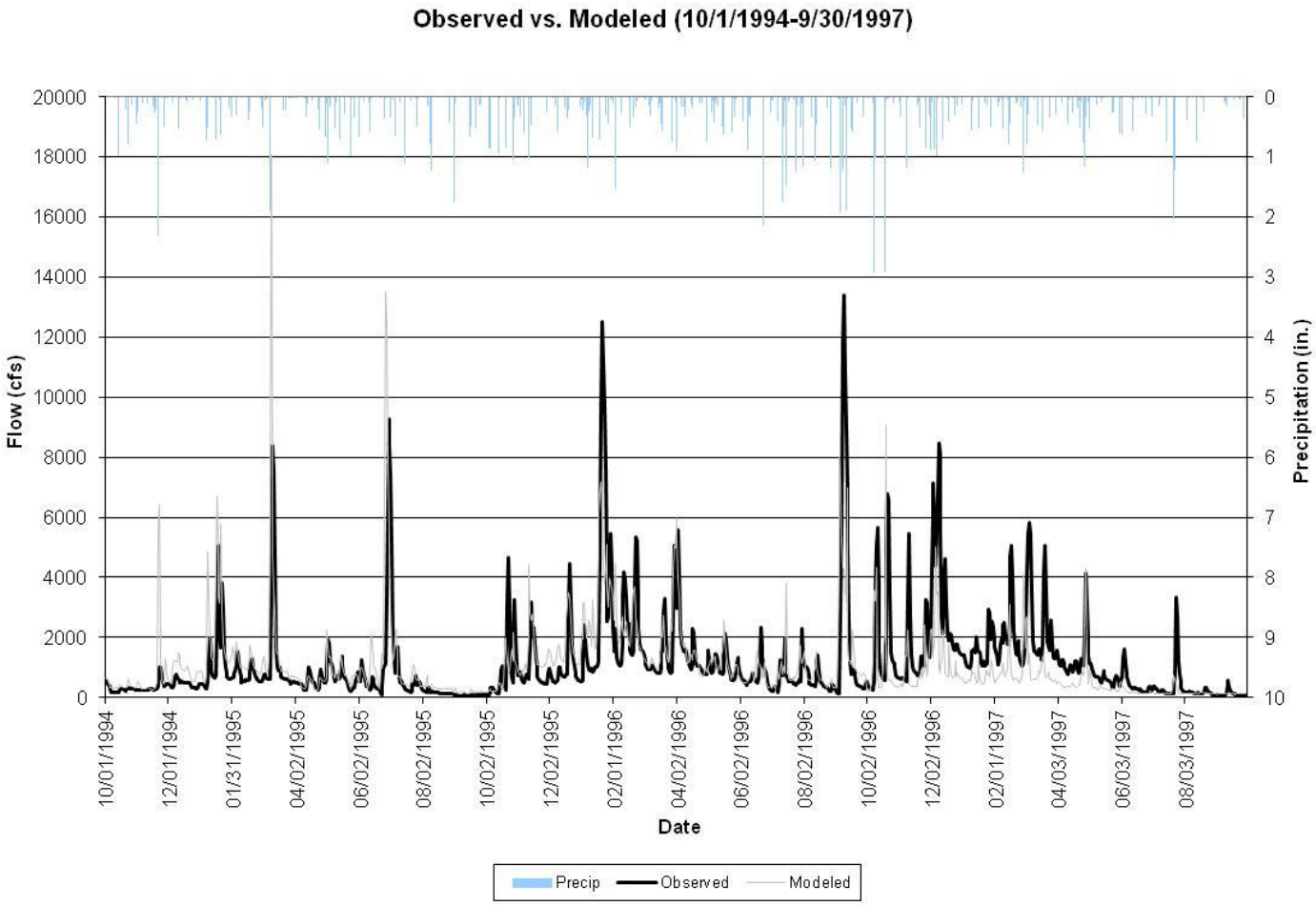

Figure B-73 Pamunkey River validation modeled results versus USGS Gaging Station # 01673000 data from (subwatershed 13).

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

Four parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), the rate of surface runoff that will remove 90% of stored fecal bacteria per hour (WSQOP), and the temperature correction coefficient for first-order decay of quality (THFST). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established. Depending on the type of available bacteria data, either fecal coliform or *E. coli* monitored data were used. **Table B- 14** shows the model parameters utilized in calibration with their typical ranges, initial estimates, and final calibrated values.

Table B- 14 Model parameters utilized for water quality calibration.

Parameter	Units	Typical Range	Initial Parameter Estimate	Calibrated Parameter Value
MON-SQOLIM	FC/ac	1.0E-02 – 1.0E+30	0.0 – 5.3E+10	0.0 – 1.0E+12
WSQOP	in/hr	0.05 – 3.00	0 – 2.8	0 – 2.8
FSTDEC	1/day	0.01 – 10.00	1.0	0.01 – 3
THFST	none	1.0 – 2.0	1.07	1.07

Figure B-74 through **Figure B-89** show the results of water quality calibration. Monitored values are an instantaneous snapshot of the bacteria level, whereas the

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

Careful inspection of graphical comparisons between continuous simulation results and limited observed points was the primary tool used to guide the calibration process. **Table B- 15** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the Pamunkey River stream segments.

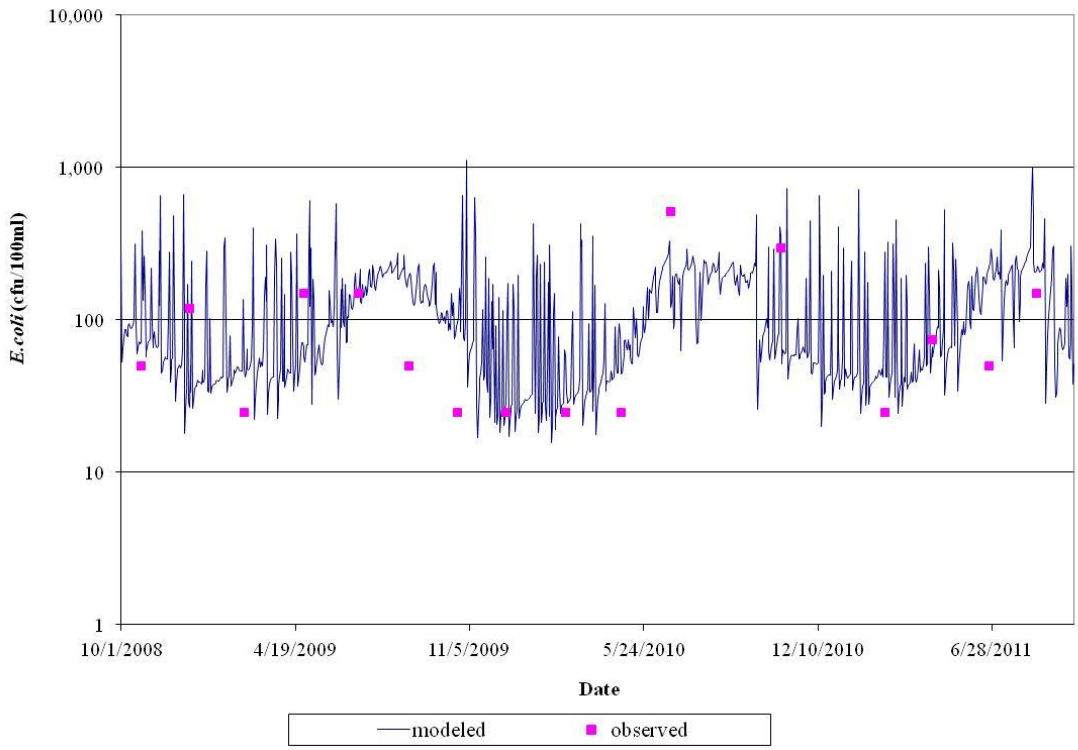

Figure B-74 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-NST003.46 in subwatershed 45 on Northeast Creek.

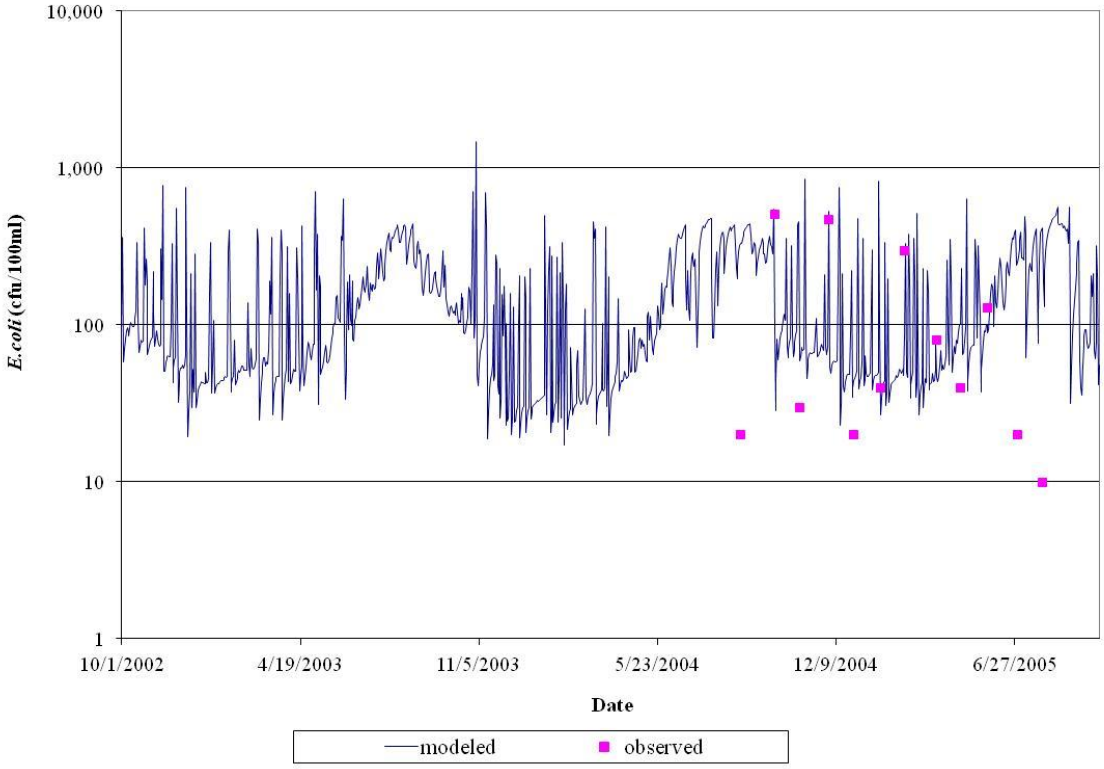

Figure B-75 ***E. coli*** **calibration for 10/1/2002 to 9/30/2005 for VADEQ station 8-NST000.58 in subwatershed 44 on Northeast Creek.**

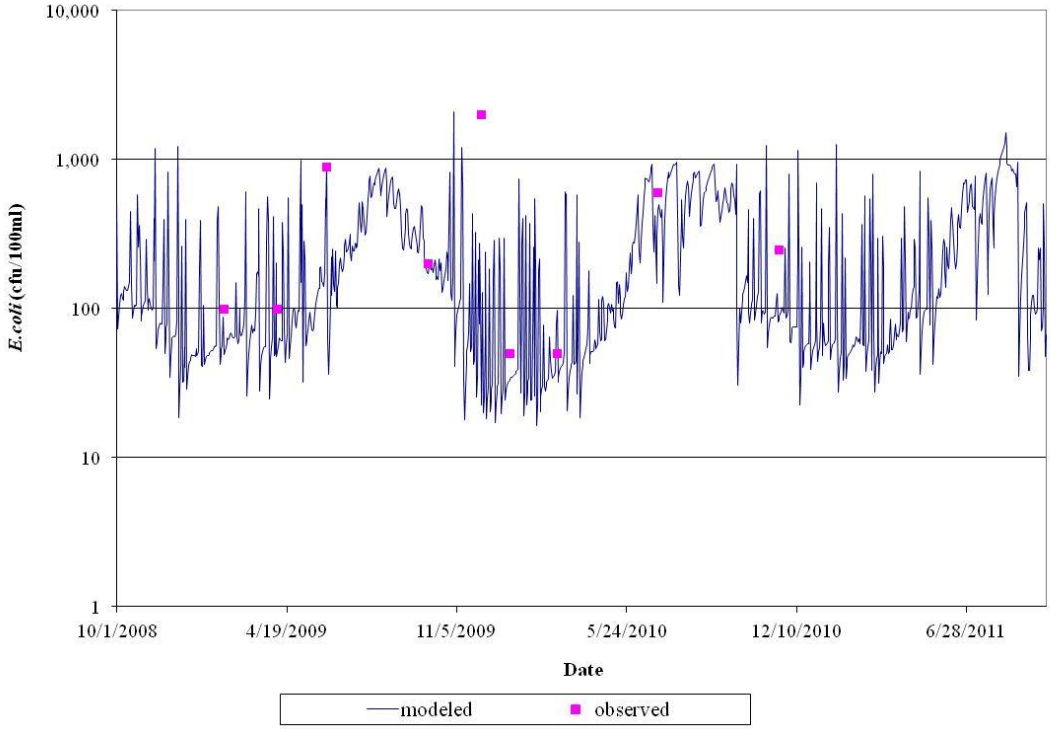

Figure B-76 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-BDC000.05 in subwatershed 40 on Beaverdam Creek.**

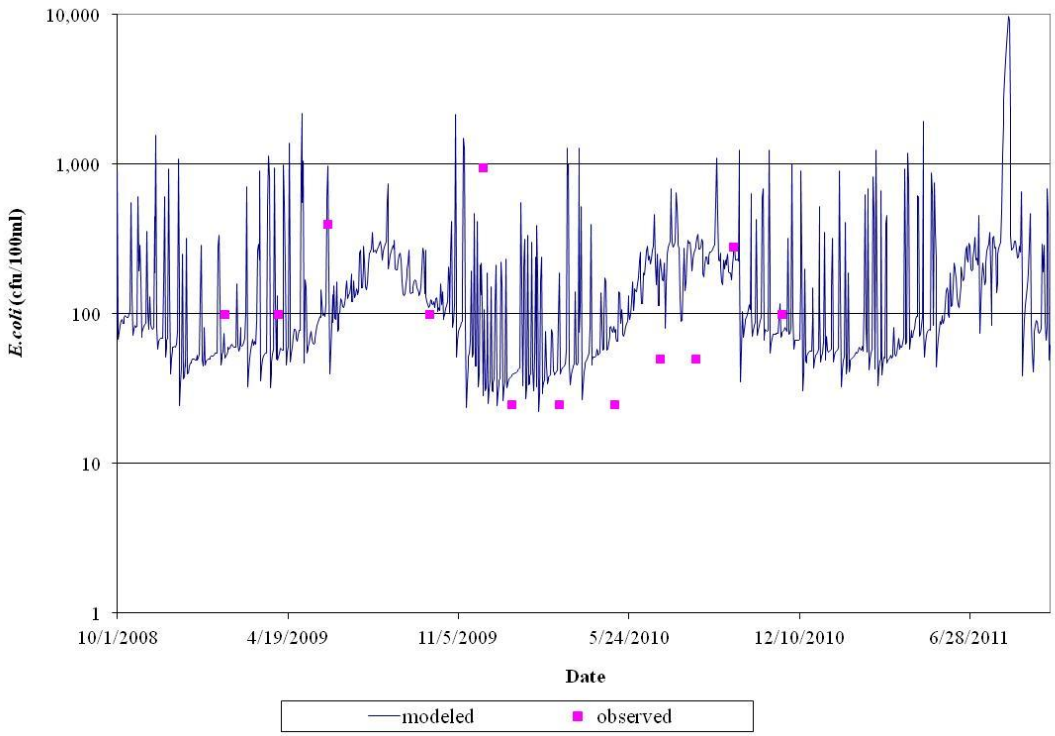

Figure B-77 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-LTL018.80 in subwatershed 41 on the Little River.**

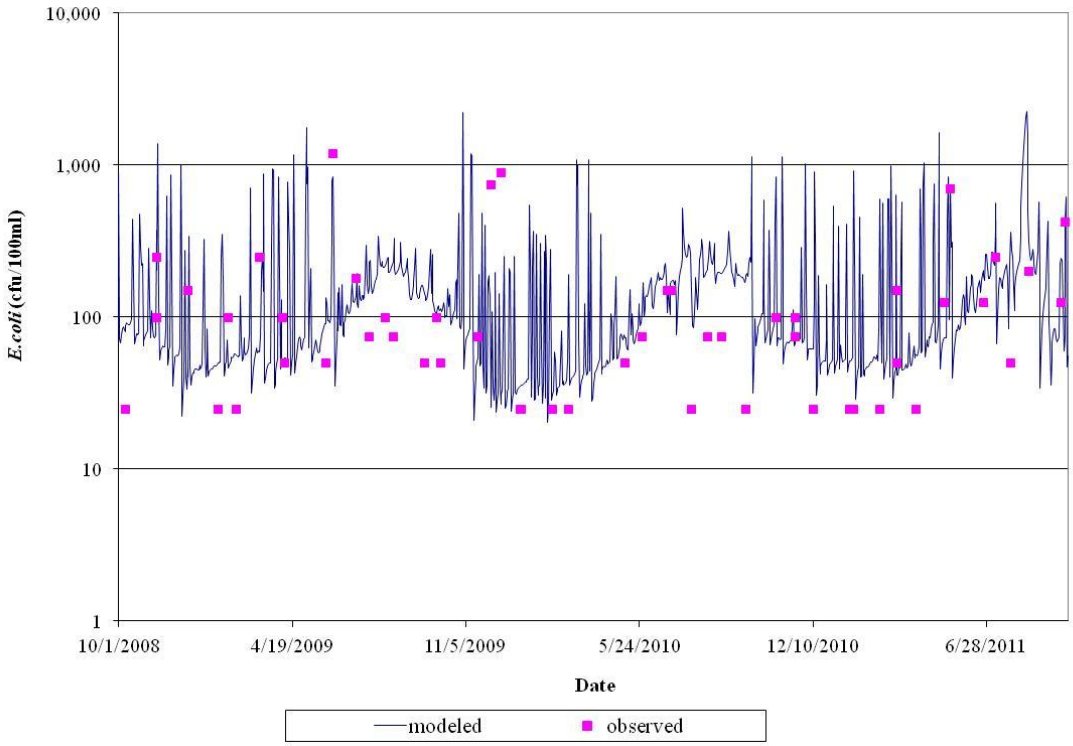

Figure B-78 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-LTL009.54 in subwatershed 39 on the Little River.**

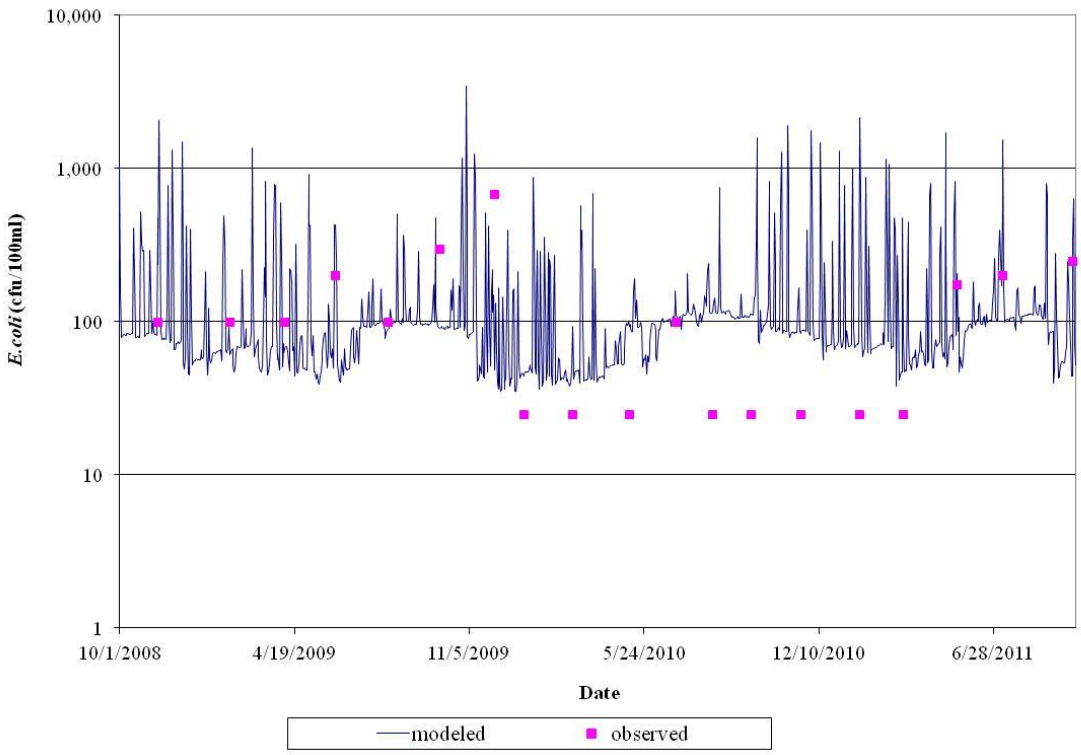

Figure B-79 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-NAR005.42 in subwatershed 17 on the North Anna River.**

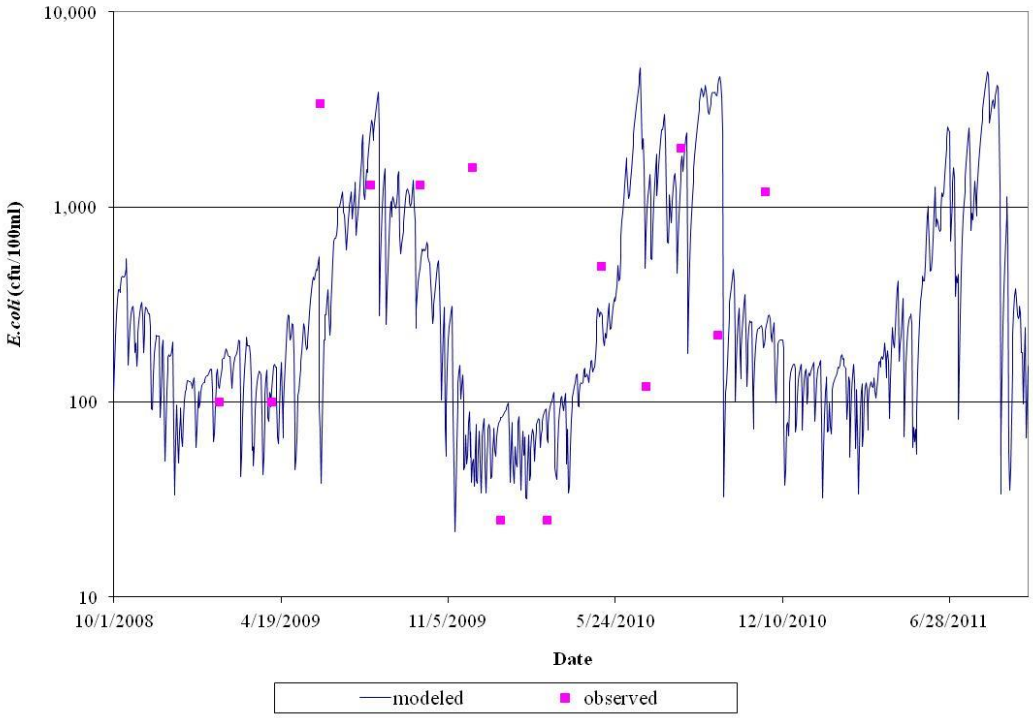

Figure B-80 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-MLL001.19 in subwatershed 37 on Mill Creek.**

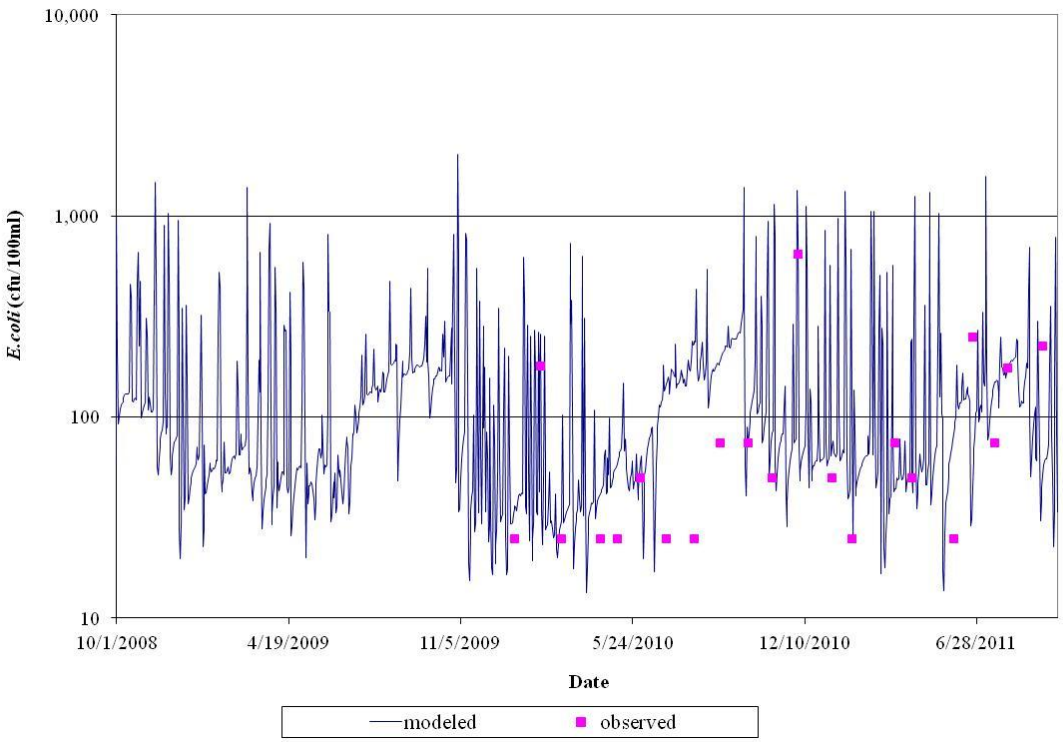

Figure B-81 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK082.34 in subwatershed 13 on the Pamunkey River.**

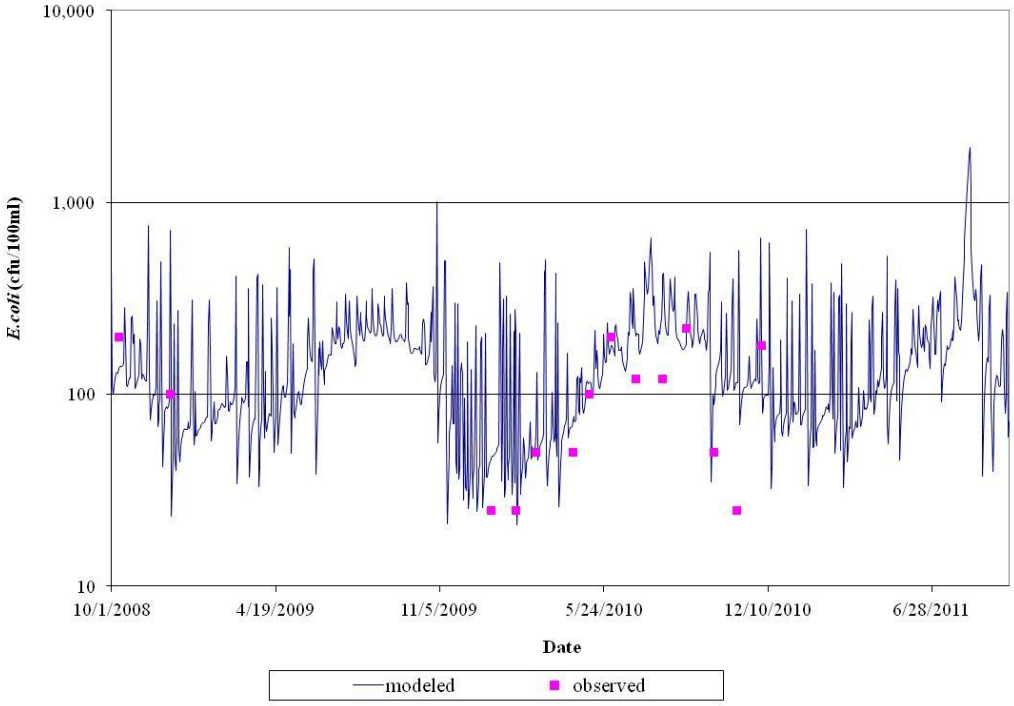

Figure B-82 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-CRU000.92 in subwatershed 33 on Crump Creek.**

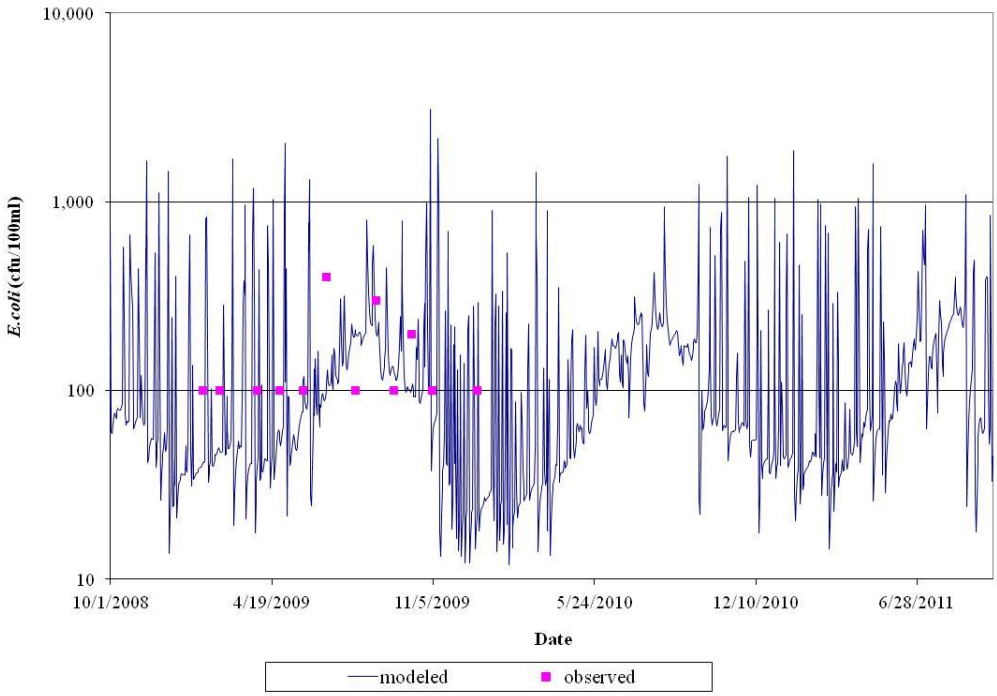

Figure B-83 ***E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-XDW000.67 in subwatershed 30 on an unnamed tributary to the Pamunkey River.**

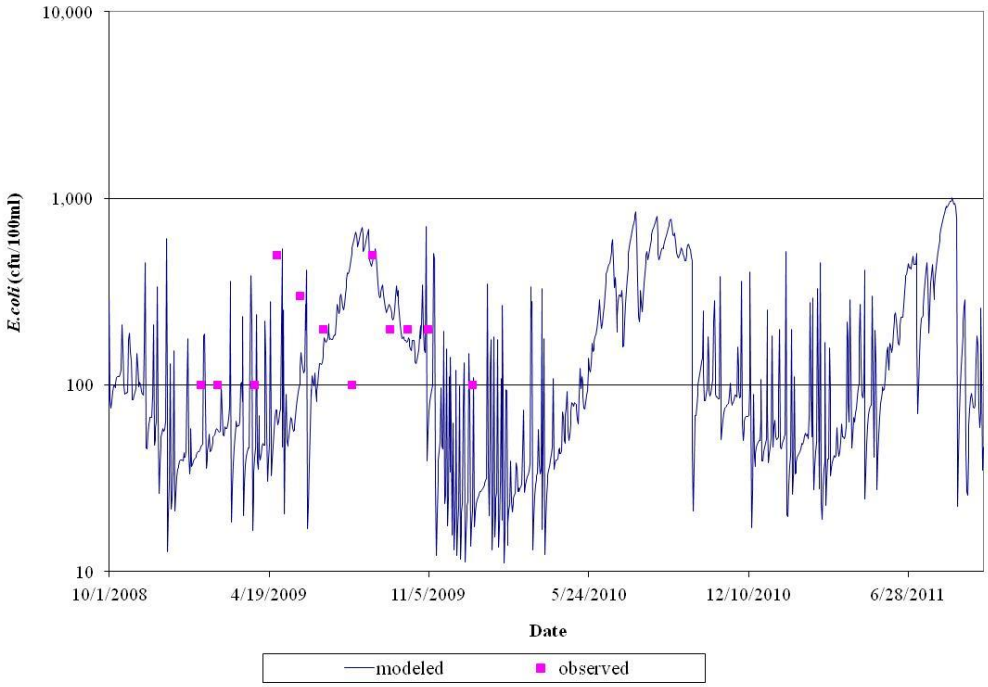

Figure B-84 ***E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-XDX000.38 in subwatershed 31 on an unnamed tributary to the Pamunkey River.**

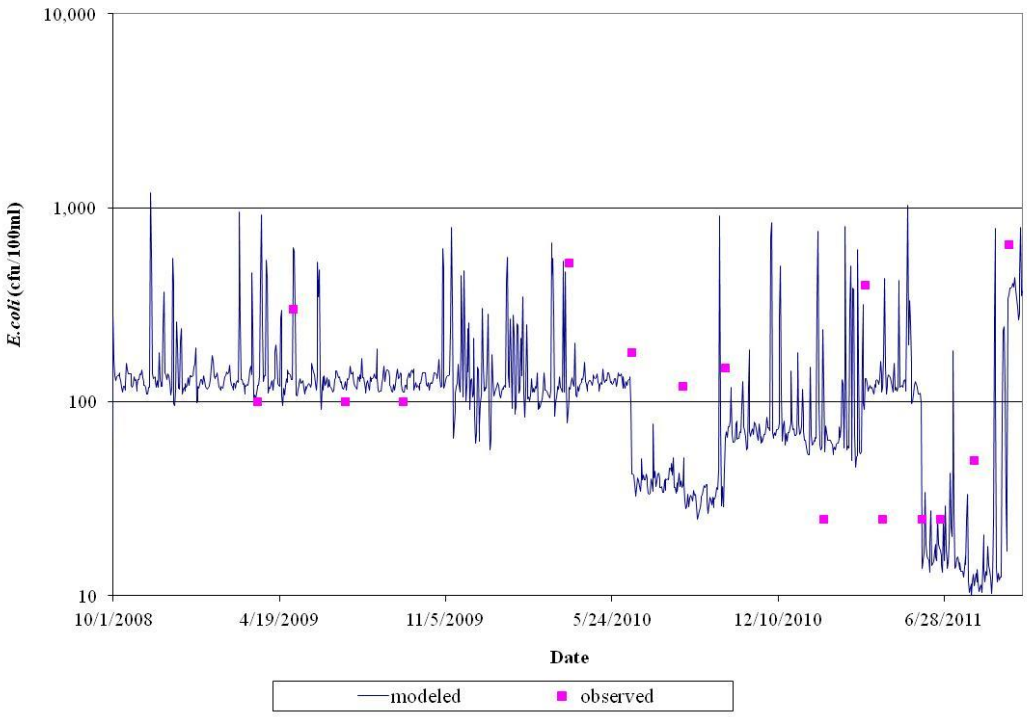

Figure B-85 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK048.80 in subwatershed 8 on the Pamunkey River.**

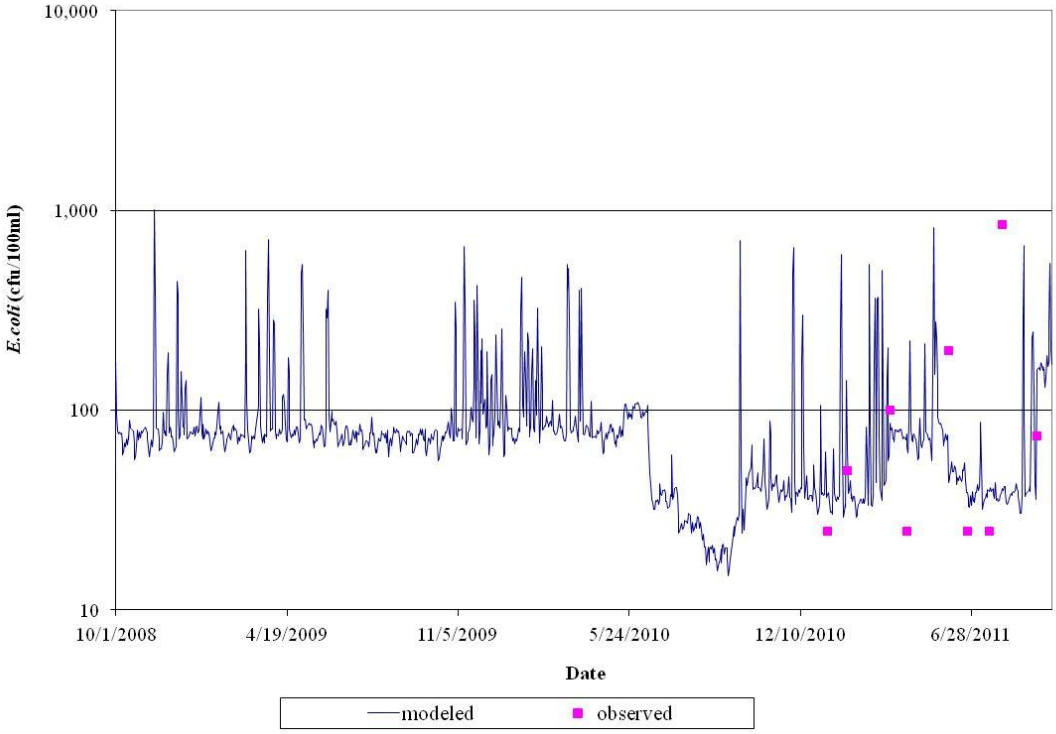

Figure B-86 ***E. coli*** **calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK039.74 in subwatershed 6 on the Pamunkey River.**

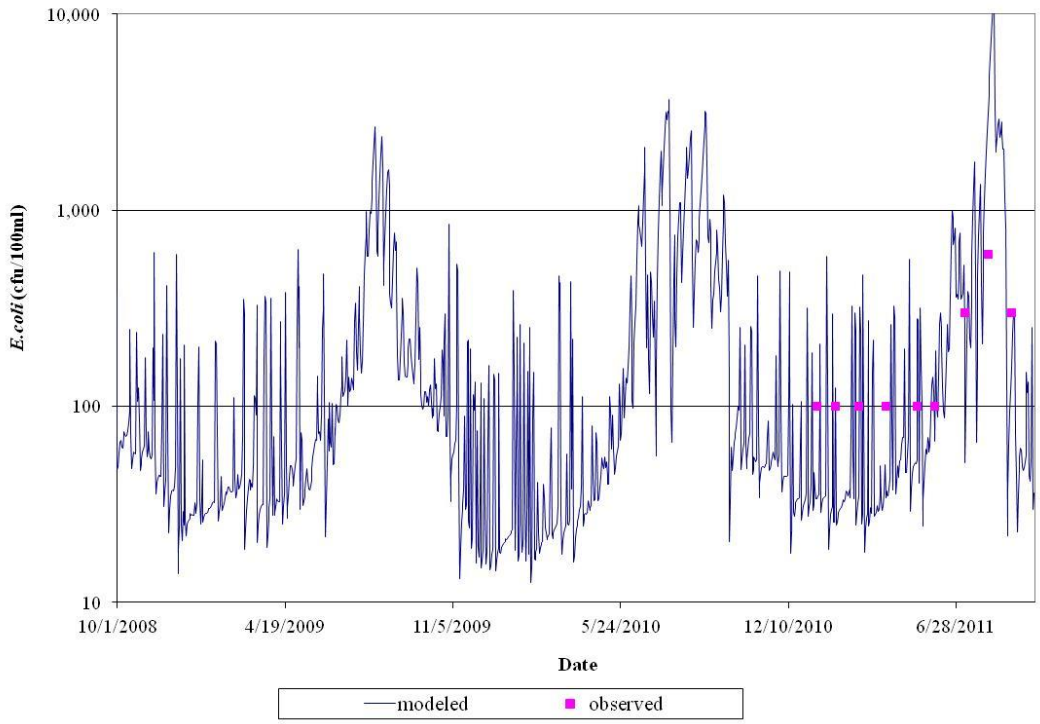

Figure B-87 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-JKC004.15 in subwatershed 25 on Jacks Creek.

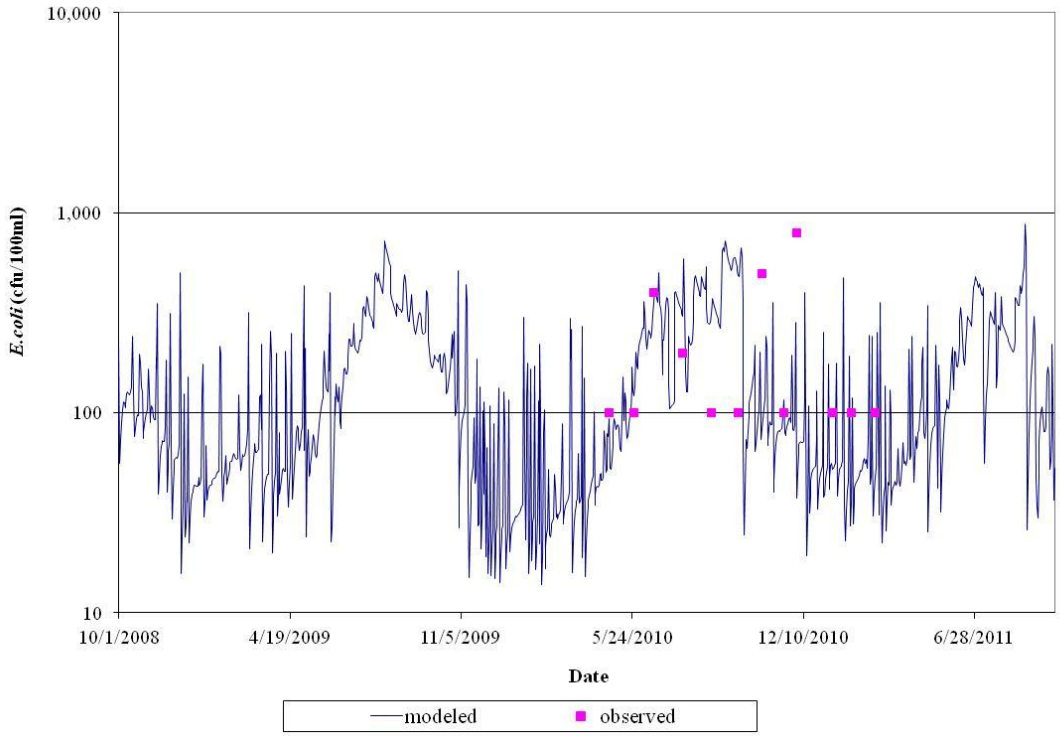

Figure B-88 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-HSN000.92 in subwatershed 22 on Harrison Creek.

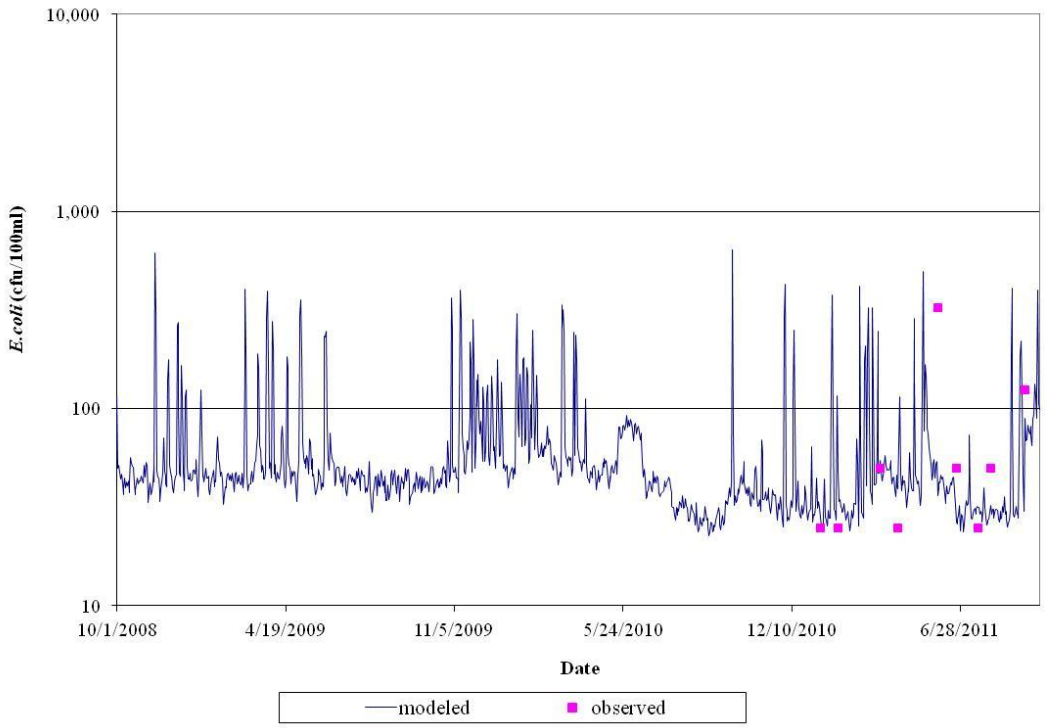

Figure B-89 *E. coli* calibration for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK025.87 in subwatershed 1 on the Pamunkey River.

Table B- 15 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the calibration period.

Station	Subwatershed	Maximum Value (cfu/100ml)		Geometric Mean (cfu/100ml)		SS % violations [1]	
		Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
8-NST003.46	45	520	1110.58	66.45	87.35	12.50%	9.68%
8-NST000.58	44	510	1478.35	61.40	104.86	25.00%	24.47%
8-BDC000.05	40	2000	2088.45	222.75	142.65	44.44%	35.25%
8-LTL018.80	41	950	9744.85	92.94	116.02	25.00%	21.83%
8-LTL009.54	39	1200	2261.95	80.88	105.00	15.09%	15.25%
8-NAR005.42	17	680	3465.06	76.01	96.83	15.79%	10.96%
8-MLL001.19	37	3400	5150.05	327.40	269.45	50.00%	45.48%
8-PMK082.34	13	650	2012.17	58.88	93.33	9.09%	13.33%
8-CRU000.92	33	220	1927.23	80.07	126.71	0.00%	16.80%
8-XDW000.67	30	400	3099.95	130.32	91.66	16.67%	14.79%
8-XDX000.38	31	500	1005.26	180.55	106.20	25.00%	25.94%
8-PMK048.80	8	650	1198.90	106.49	94.43	26.67%	9.04%
8-PMK039.74	6	850	1006.82	66.34	68.04	11.11%	5.02%
8-JKC004.15	25	600	11558.21	155.77	99.52	33.33%	25.39%
8-HSN000.92	22	800	874.26	161.72	104.04	25.00%	24.38%
8-PMK025.87	1	325	636.04	50.09	49.72	11.11%	3.47%

[1] SS = single sample instantaneous standard violations (>235 cfu/100mL for *E. coli*)

Bacteria water quality model validation was performed, the results of which are shown in **Figure B-90** through **Figure B-97**. **Table B- 16** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the Pamunkey River stream segment.

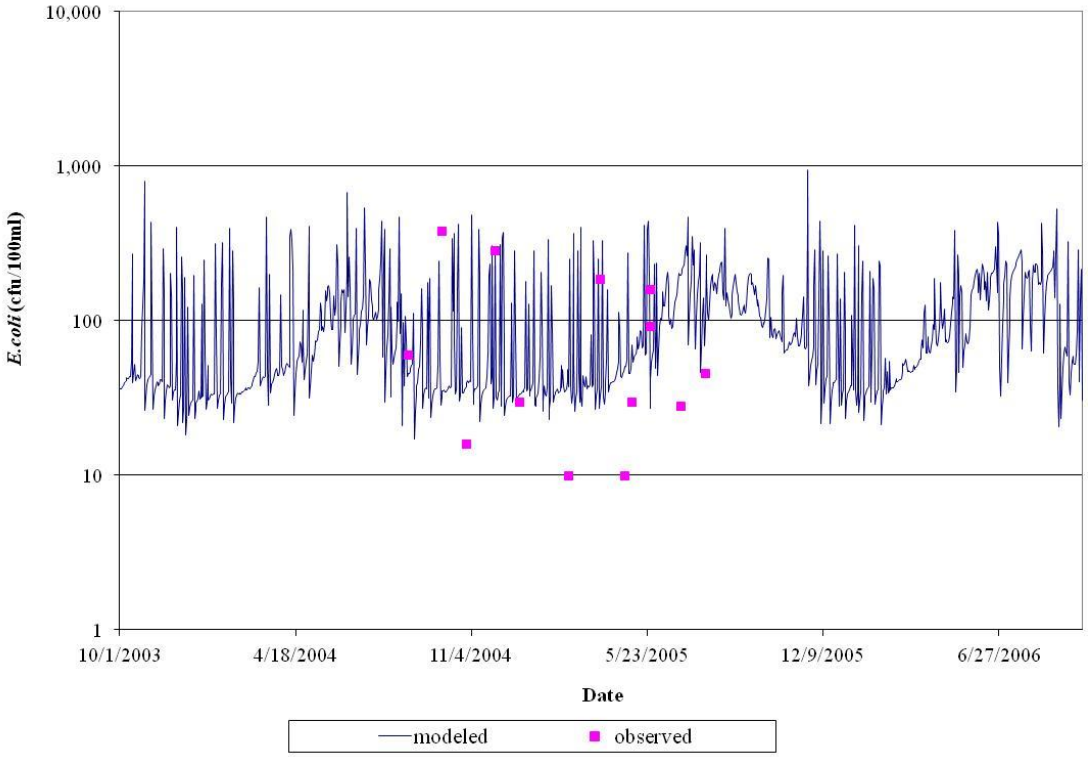

Figure B-90 *E. coli* validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-NST003.46 in subwatershed 45 on Northeast Creek.

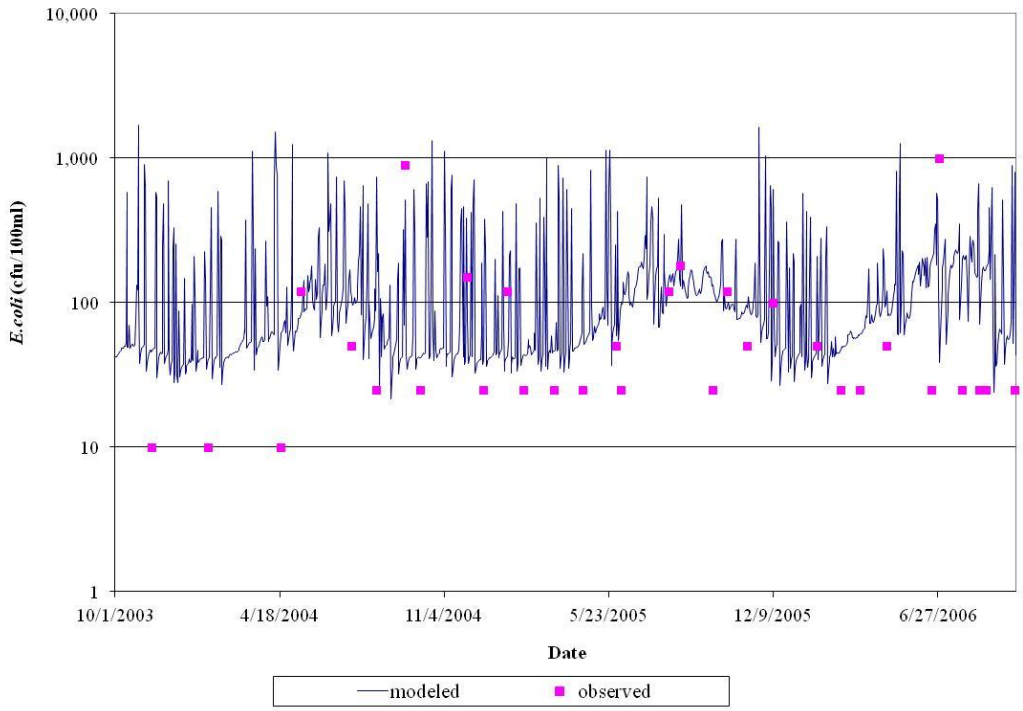

Figure B-91 ***E. coli*** **validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-LTL009.54 in subwatershed 39 on the Little River.**

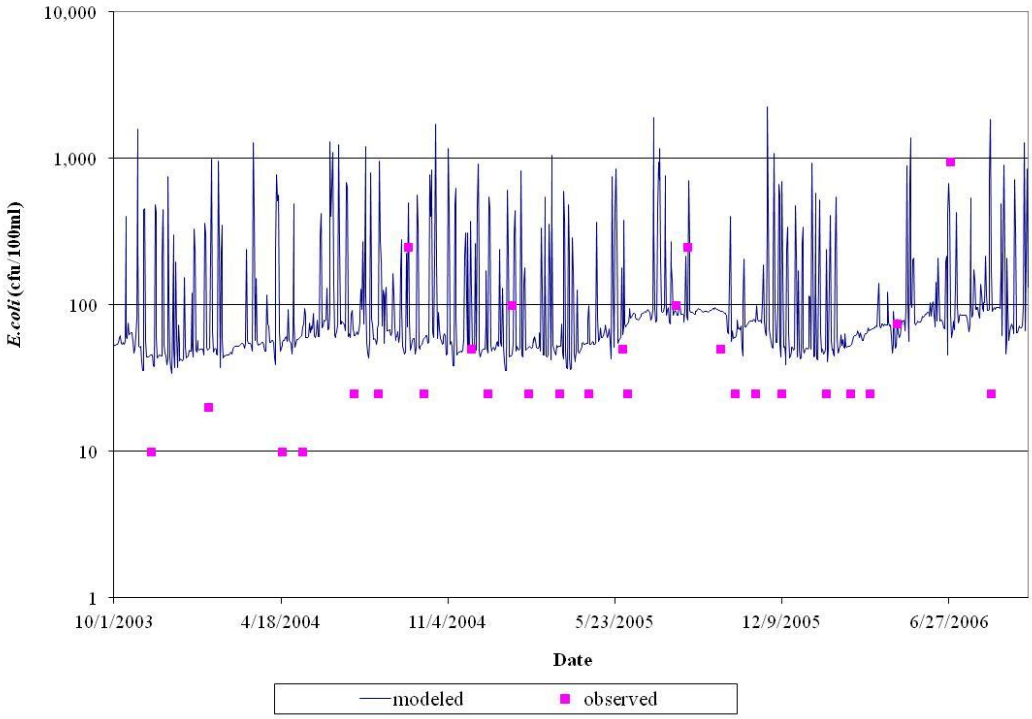

Figure B-92 ***E. coli*** **validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-NAR005.42 in subwatershed 17 on the North Anna River.**

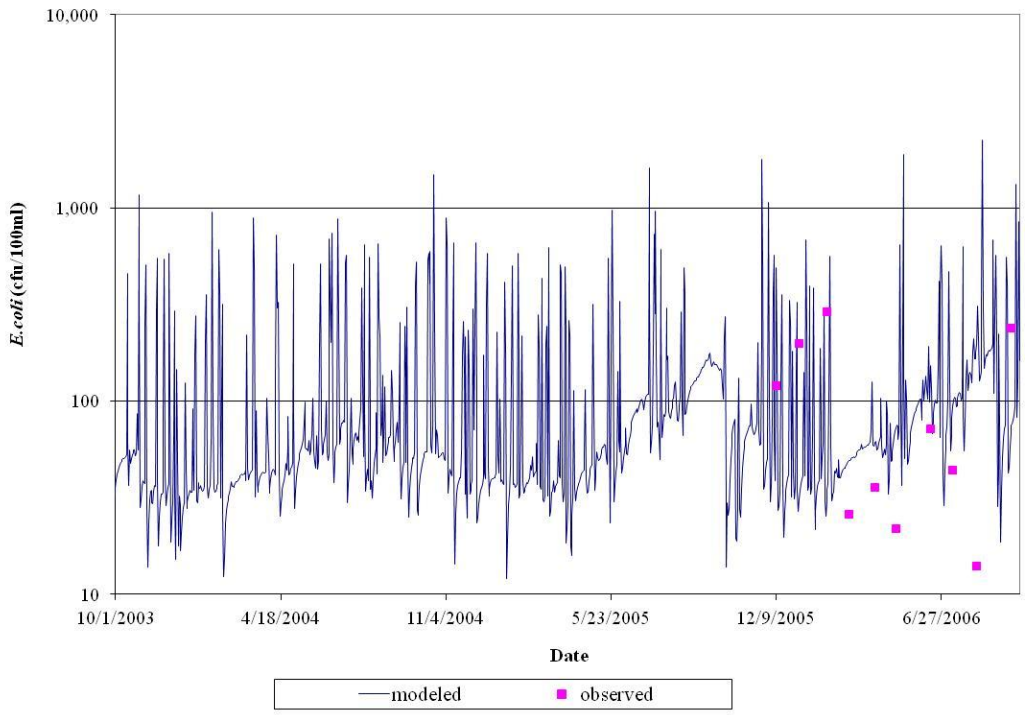

Figure B-93 ***E. coli*** **validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-PMK082.34 in subwatershed 13 on the Pamunkey River.**

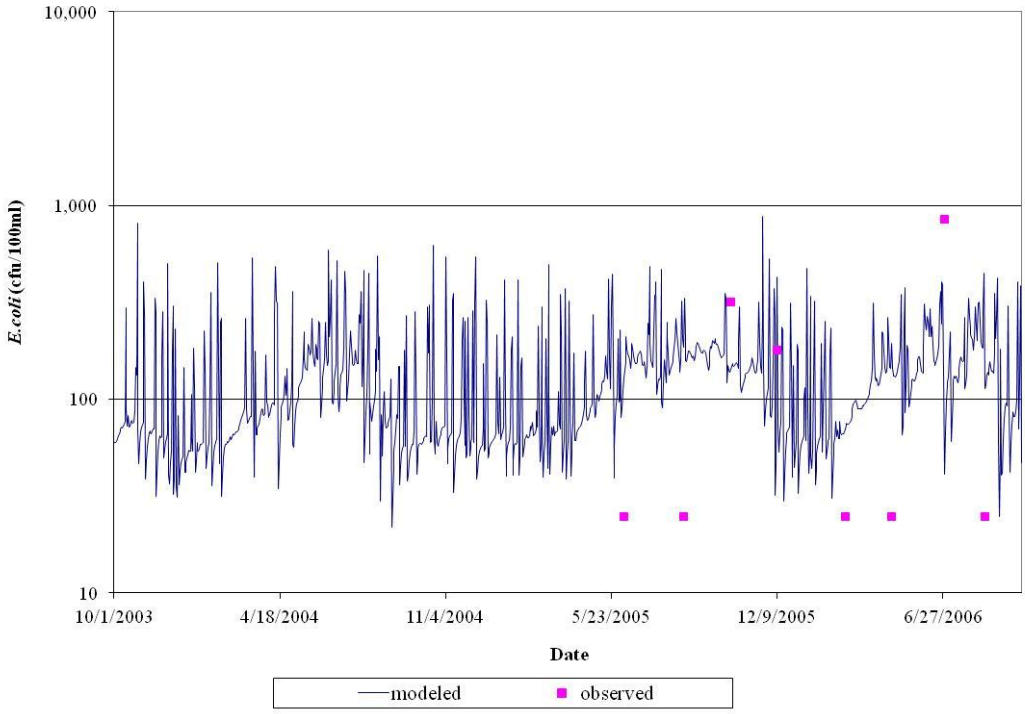

Figure B-94 ***E. coli*** **validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-CRU000.92 in subwatershed 33 on Crump Creek.**

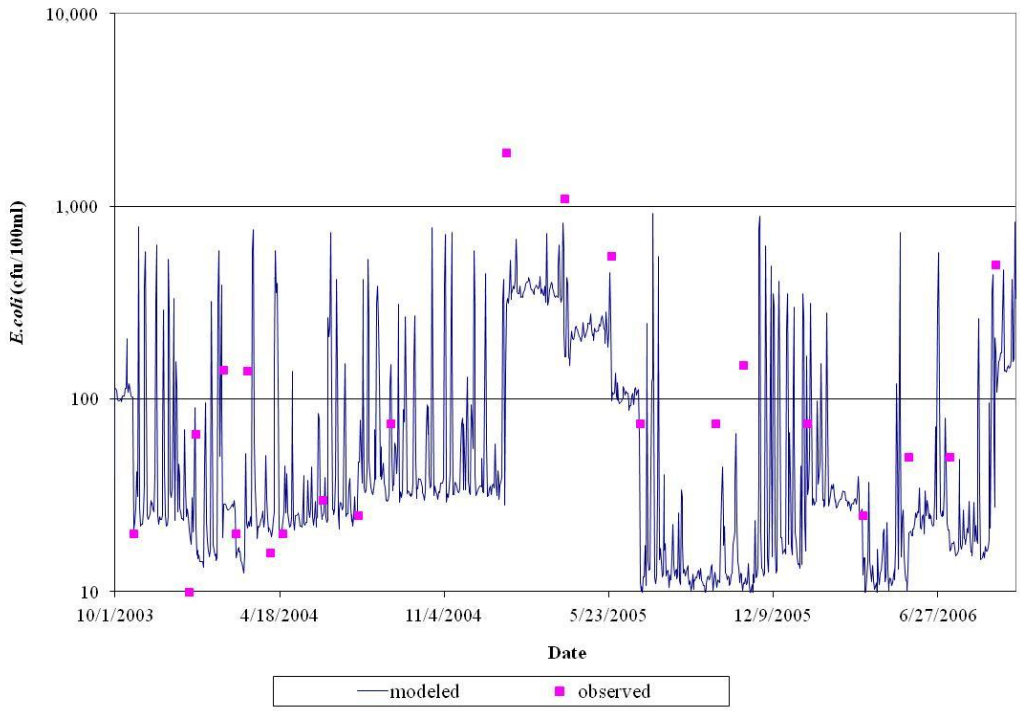

Figure B-95 ***E. coli*** **validation for 10/1/2003 to 9/30/2006 for VADEQ station 8-PMK048.80 in subwatershed 8 on the Pamunkey River.**

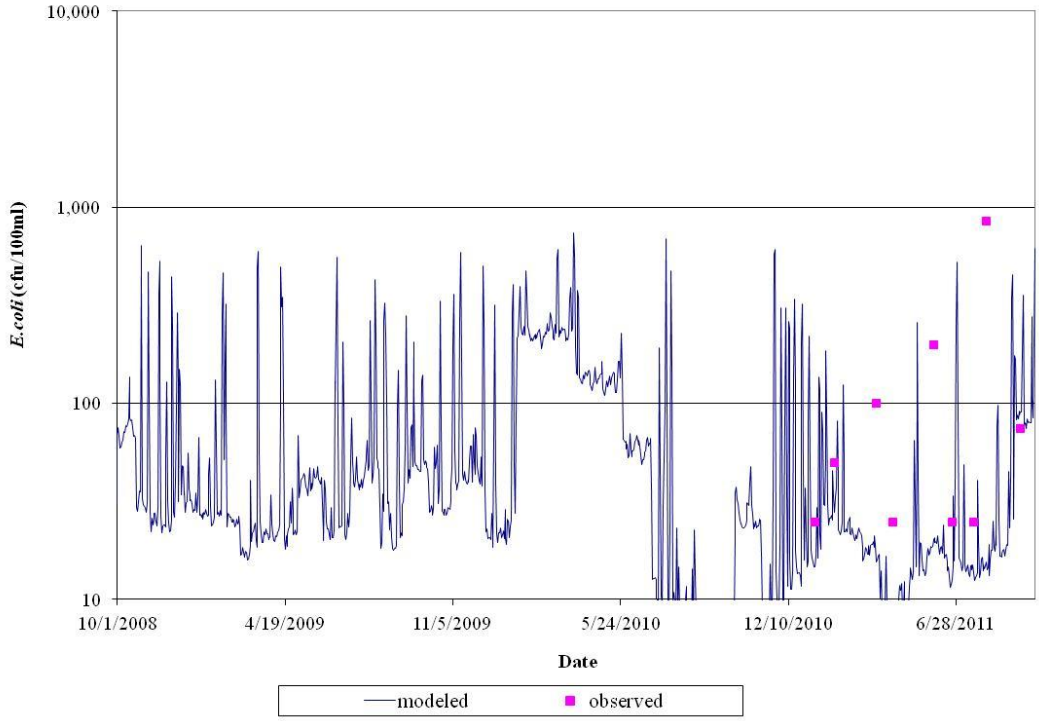

Figure B-96 ***E. coli*** **validation for 10/1/2008 to 9/30/2011 for VADEQ station 8-PMK039.74 in subwatershed 6 on the Pamunkey River.**

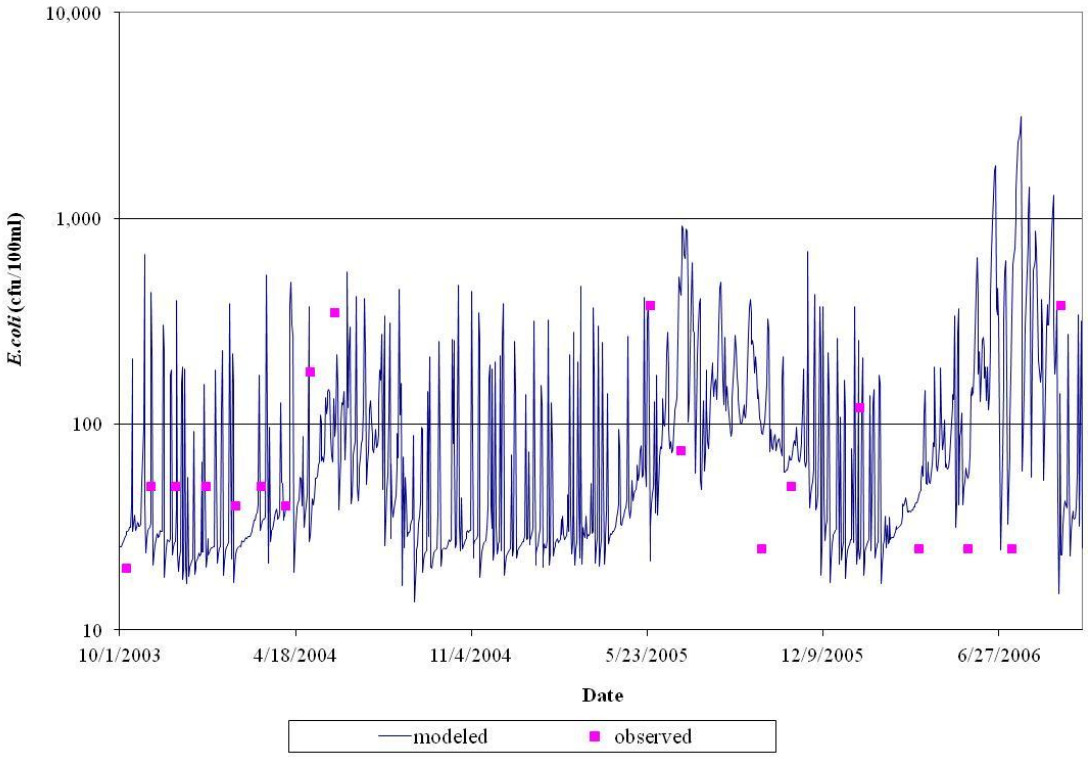

Figure B-97 *E. coli* validation for 10/1/2003 to 9/30/20106for VADEQ station 8-JKC004.15 in subwatershed 25 on Jacks Creek.

Table B- 16 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period.

Station	Subwatershed	Maximum Value (cfu/100ml)		SS % violations [1]		Geometric Mean (cfu/100ml)	
		Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
8-NST003.46	45	380	945.78	43.38	74.14	9.52%	8.95%
8-LTL009.54	39	1000	1693.50	46.96	88.93	6.06%	11.32%
8-NAR005.42	17	950	2238.66	39.33	85.84	10.34%	11.60%
8-PMK082.34	13	290	2240.00	65.82	72.01	23.08%	10.78%
8-CRU000.92	33	850	875.33	68.38	107.49	25.00%	10.96%
8-PMK048.80	8	1900	913.60	75.64	45.68	18.18%	14.34%
8-PMK039.74	6	150	735.58	42.96	38.20	0.00%	7.31%
8-JKC004.15	25	380	3127.34	67.11	66.28	15.79%	13.70%

[1] SS = single sample instantaneous standard violations (>235 cfu/100mL for *E. coli*)

Sensitivity Analysis

Sensitivity analyses are performed to determine a model's response to changes in certain parameters. This process involves changing a single parameter a certain percentage from a baseline value while holding all other parameters constant. This process is repeated for several parameters in order to gain a complete picture of the model's behavior. The information gained during sensitivity analysis can aid in model calibration, and it can also help to determine the potential effects of uncertainty in parameter estimation. 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 waster production rates for wildlife, livestock, septic system failures, uncontrolled discharges, background loads, and point source loads).

Hydrology Sensitivity Analysis

The HSPF parameters adjusted for the hydrologic sensitivity analysis are presented in **Table B- 17**, with base values for the model runs given. The parameters were adjusted to -50%, -10%, +10%, and +50% of the base value, and the model was run for water years 2004 - 2006. Where an increase or decrease of 50% exceeded the possible ranges of values for a parameter, the maximum and/or minimum value was used and the parameter values used in the sensitivity analysis were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliform from the land surface to the stream. Peak flows were most sensitive to changes in the parameters governing infiltration, such as INFILT (infiltration) and UZSN (upper zone storage), as well as LZETP (lower zone evapotranspiration) and AGWRC (active groundwater recession coefficient). 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, KVARY (enables variable groundwater recession rates), LZETP, and INFILT. The responses of these and other hydrologic outputs are reported in **Table B- 18**.

Table B- 17 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	10
INFILT	Soil Infiltration Capacity	in/hr	0.0744 - 0.2479
BASETP	Base Flow Evapotranspiration	---	0.3
INTFW	Interflow Inflow	---	1
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.1
AGWRC	Groundwater Recession rate	---	0.94
KVARY	Groundwater Recession Flow	1/in	1
MON-INTERCEP	Monthly Interception Storage Capacity	in	0 - 0.2
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.4 - 1
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0 – 0.4

Table B- 18 HSPF sensitivity analysis for hydrologic model parameters.

		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	0.17	4.80	-7.56	-0.20	1.98	-0.63	0.38	1.05
AGWRC[1]	0.92	0.02	1.49	-2.38	-0.15	0.60	-0.25	0.16	0.08
AGWRC[1]	0.96	0.03	-2.01	3.24	0.53	-0.76	0.30	-0.29	-0.61
AGWRC[1]	0.999	-4.80	-12.26	13.22	1.59	-2.70	-8.84	-7.11	-17.87
BASETP	-50	0.38	-0.37	2.25	0.09	1.54	0.44	-0.07	0.05
BASETP	-10	0.07	-0.07	0.44	0.02	0.30	0.09	-0.02	0.07
BASETP	10	-0.07	0.07	-0.43	-0.02	-0.29	-0.09	0.01	-0.05
BASETP	50	-0.35	0.36	-2.06	-0.08	-1.39	-0.42	0.06	-0.36
DEEPFR	-50	1.43	1.32	1.34	1.01	1.72	1.58	1.46	1.61
DEEPFR	-10	0.29	0.26	0.27	0.20	0.34	0.32	0.29	0.32
DEEPFR	10	-0.29	-0.26	-0.27	-0.20	-0.34	-0.32	-0.29	-0.32
DEEPFR	50	-1.43	-1.30	-1.39	-1.01	-1.71	-1.59	-1.46	-1.61
INFILT	-50	-0.62	3.02	-4.78	0.02	-2.74	-0.40	-0.26	-0.67
INFILT	-10	-0.13	0.41	-0.69	-0.01	-0.52	-0.08	-0.08	-0.14
INFILT	10	0.13	-0.35	0.60	0.01	0.49	0.08	0.09	0.14
INFILT	50	0.64	-1.39	2.56	0.02	2.25	0.37	0.58	0.70
INTFW	-50	-0.16	-0.20	0.08	-0.07	-0.16	-0.30	-0.09	-0.18
INTFW	-10	-0.02	-0.03	0.01	0.00	-0.02	-0.05	-0.01	-0.02
INTFW	10	0.02	0.03	-0.01	0.00	0.02	0.04	0.01	0.02
INTFW	50	0.07	0.12	-0.06	0.01	0.09	0.15	0.03	0.08
LZSN	-50	0.10	1.03	-2.21	1.43	-0.26	-1.01	0.36	0.11
LZSN	-10	0.04	0.17	-0.27	0.23	0.04	-0.09	0.03	0.04
LZSN	10	-0.06	-0.18	0.24	-0.23	-0.06	0.05	-0.03	-0.07
LZSN	50	-0.46	-0.98	0.74	-1.03	-0.38	-0.08	-0.44	-0.52
INTERCEP	-50	0.94	-0.43	3.69	0.51	4.27	0.57	-0.12	1.06
INTERCEP	-10	0.15	-0.07	0.66	0.07	0.78	0.10	-0.09	0.17
INTERCEP	10	-0.14	0.05	-0.60	-0.07	-0.75	-0.11	0.09	-0.16
INTERCEP	50	-0.69	0.17	-2.43	-0.28	-3.26	-0.43	0.09	-0.79
LZETP	-50	4.12	6.33	2.34	1.56	2.98	5.55	5.41	4.67
LZETP	-10	0.98	1.33	0.97	0.29	0.69	1.42	1.27	1.11
LZETP	10	-1.07	-1.36	-1.13	-0.31	-0.77	-1.62	-1.31	-1.22
LZETP	50	-3.89	-4.66	-4.50	-1.11	-3.30	-5.75	-4.58	-4.18
KVARY	-50	0.05	-2.29	3.34	0.66	-0.62	0.08	-0.17	-0.48
KVARY	-10	0.00	-0.39	0.56	0.08	-0.11	0.04	-0.03	-0.01
KVARY	10	0.00	0.35	-0.53	-0.06	0.11	-0.04	0.03	0.03
KVARY	50	0.01	1.53	-2.27	-0.20	0.51	-0.19	0.14	0.05
UZSN	-50	1.93	4.18	0.32	-0.21	3.46	4.24	0.36	2.18
UZSN	-10	0.27	0.63	0.08	-0.05	0.45	0.60	0.08	0.31
UZSN	10	-0.24	-0.58	-0.10	0.05	-0.40	-0.52	-0.08	-0.27
UZSN	50	-0.99	-2.43	-0.38	0.24	-1.68	-2.20	-0.32	-1.13

[1]Actual parameter value used.

Water Quality Parameter Sensitivity Analysis

For the water quality sensitivity analysis, an initial base run was performed using precipitation data from water years 2003 – 2005 and model parameters established for 2012 conditions. The outlet of subwatershed 25 was used for assessing the water quality parameter sensitivity. The three HSPF parameters impacting the model's water quality response (**Table B- 19**) were increased and decreased by amounts that were consistent with the range of values for the parameter. MON-SQOLIM (maximum fecal coliform accumulation on the land) and WSQOP (wash-off rate for fecal coliform on land surface) were the parameters with the greatest influence on monthly geometric mean concentration (**Table B- 20**). Graphical depictions of the results of this sensitivity analysis can be seen in **Figure B-98**, **Figure B-99**, and **Figure B-100**.

Table B- 19 Base parameter values used to determine water quality model response.

Parameter	Description	Units	Base Value
MON-SQOLIM	Maximum FC Accumulation on Land	FC/ac	0.0 – 1.0E+12
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	0 – 2.8
FSTDEC	In-stream First Order Decay Rate	1/day	0.01 – 3

Table B- 20 Percent change in average monthly *E. coli* geometric mean for water years 2003-2005 at the outlet of subwatershed 25.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	-8.74	-11.62	-9.03	-6.65	-8.94	-6.77	-10.58	-4.26	-1.87	-11.98	-10.73	-10.37
FSTDEC	-10	-1.16	-1.65	-1.27	-0.94	-1.27	-1.02	-1.60	-0.57	-0.24	-1.78	-1.58	-1.42
FSTDEC	10	1.18	1.70	1.29	0.94	1.32	1.08	1.70	0.65	0.22	2.09	1.51	1.36
FSTDEC	50	5.39	7.80	5.65	3.99	5.31	4.80	7.66	2.59	0.97	8.76	7.22	6.67
MON-SQOLIM	-50	9.86	14.04	8.42	6.53	11.17	8.25	11.86	5.06	2.83	14.80	9.13	10.01
MON-SQOLIM	-10	1.48	2.06	1.33	0.99	1.55	1.17	1.71	0.68	0.39	2.07	1.49	1.55
MON-SQOLIM	10	-1.32	-1.82	-1.21	-0.89	-1.36	-1.03	-1.52	-0.60	-0.35	-1.79	-1.37	-1.40
MON-SQOLIM	50	-5.53	-7.53	-5.18	-3.84	-5.55	-4.24	-6.28	-2.46	-1.44	-7.26	-5.94	-5.98
WSQOP	-50	0.74	0.73	0.78	0.76	0.92	1.38	2.13	1.70	1.94	4.89	0.76	0.77
WSQOP	-10	0.15	0.15	0.15	0.15	0.18	0.27	0.42	0.34	0.38	0.92	0.15	0.15
WSQOP	10	-0.15	-0.15	-0.15	-0.15	-0.18	-0.27	-0.41	-0.33	-0.38	-0.90	-0.15	-0.15
WSQOP	50	-0.73	-0.72	-0.77	-0.75	-0.90	-1.34	-2.01	-1.64	-1.85	-4.28	-0.75	-0.76

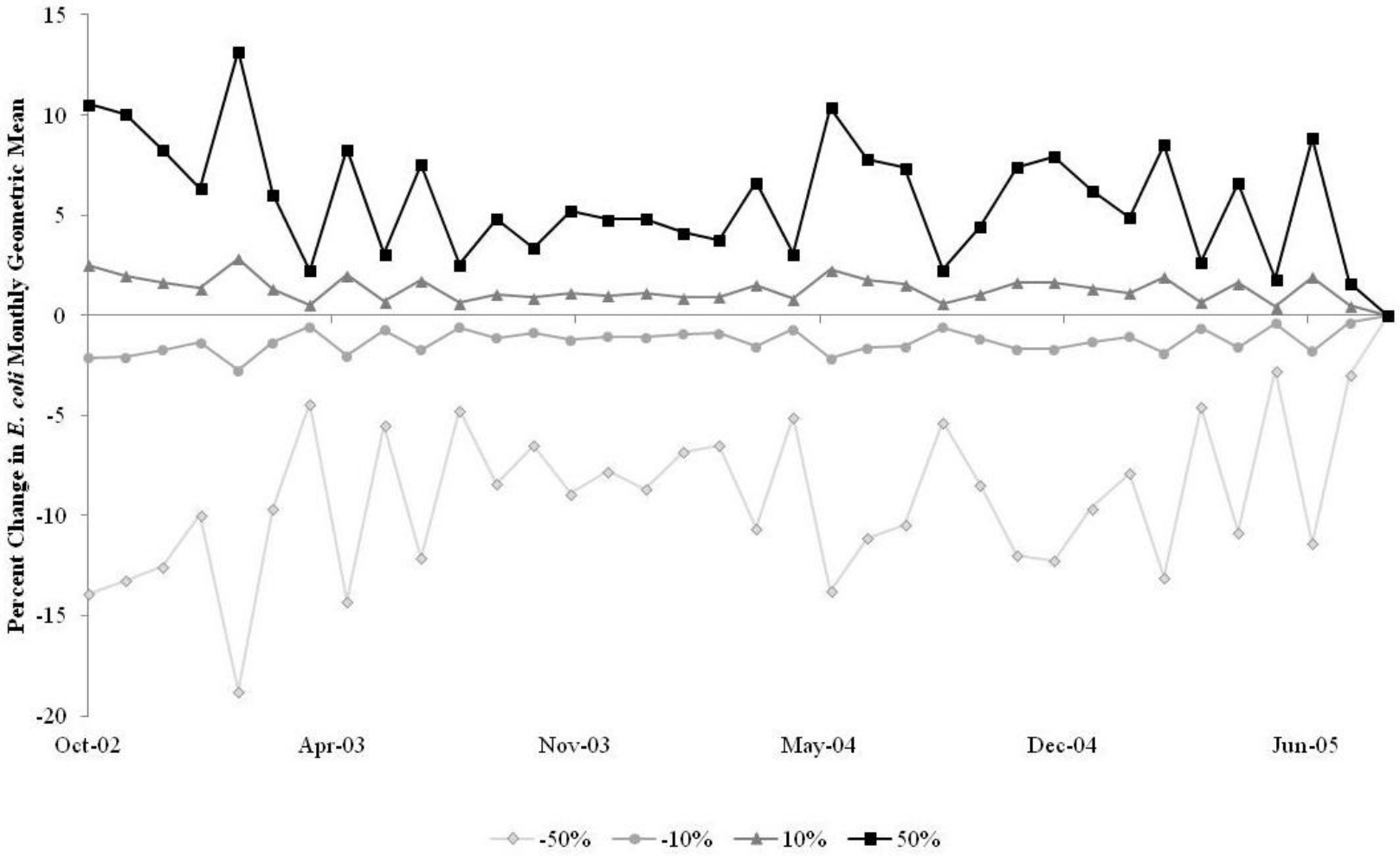

Figure B-98 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in maximum fecal coliform accumulation on land (MON-SQOLIM).

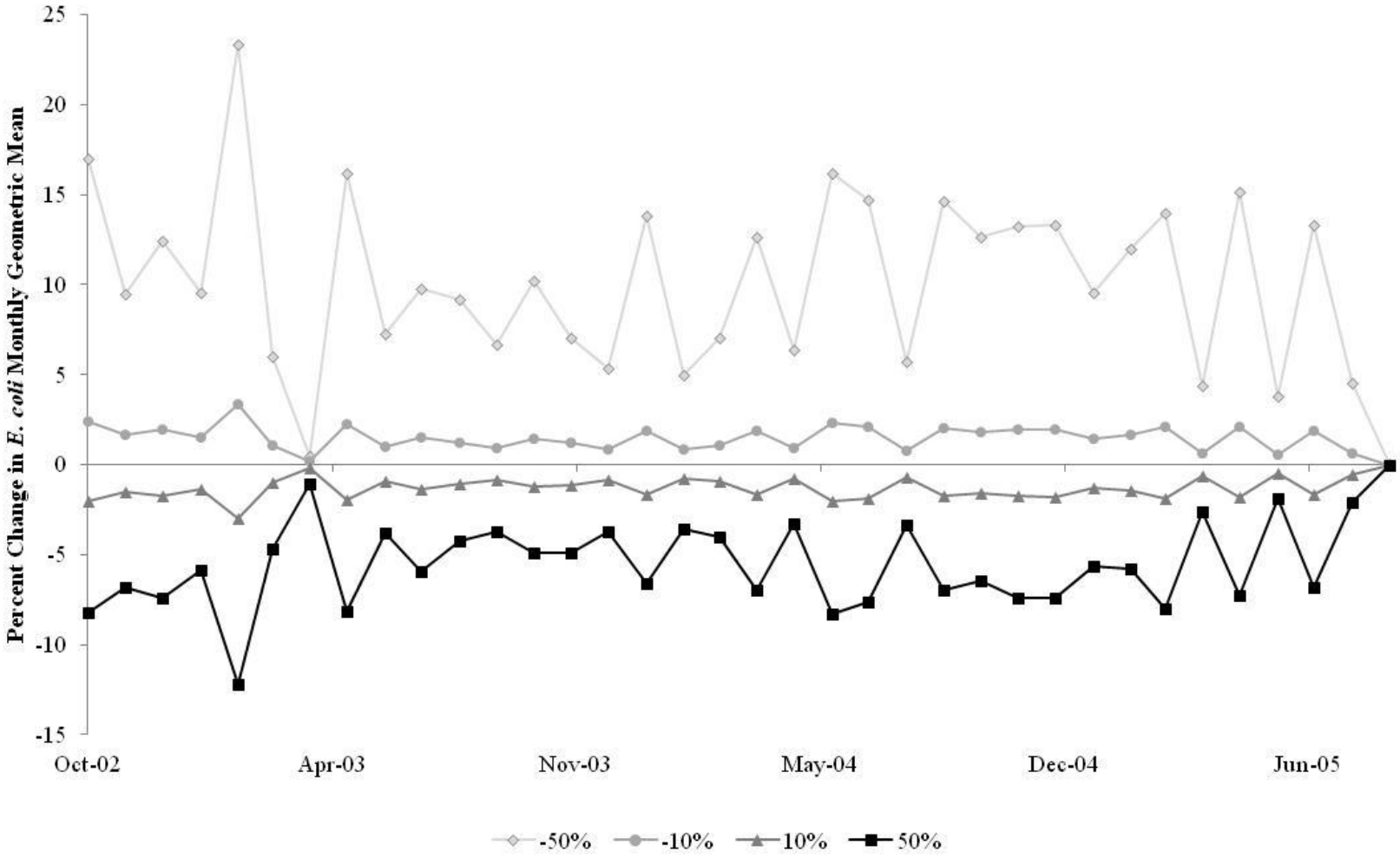

Figure B-99 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in the wash-off rate from land surfaces (WSQOP).

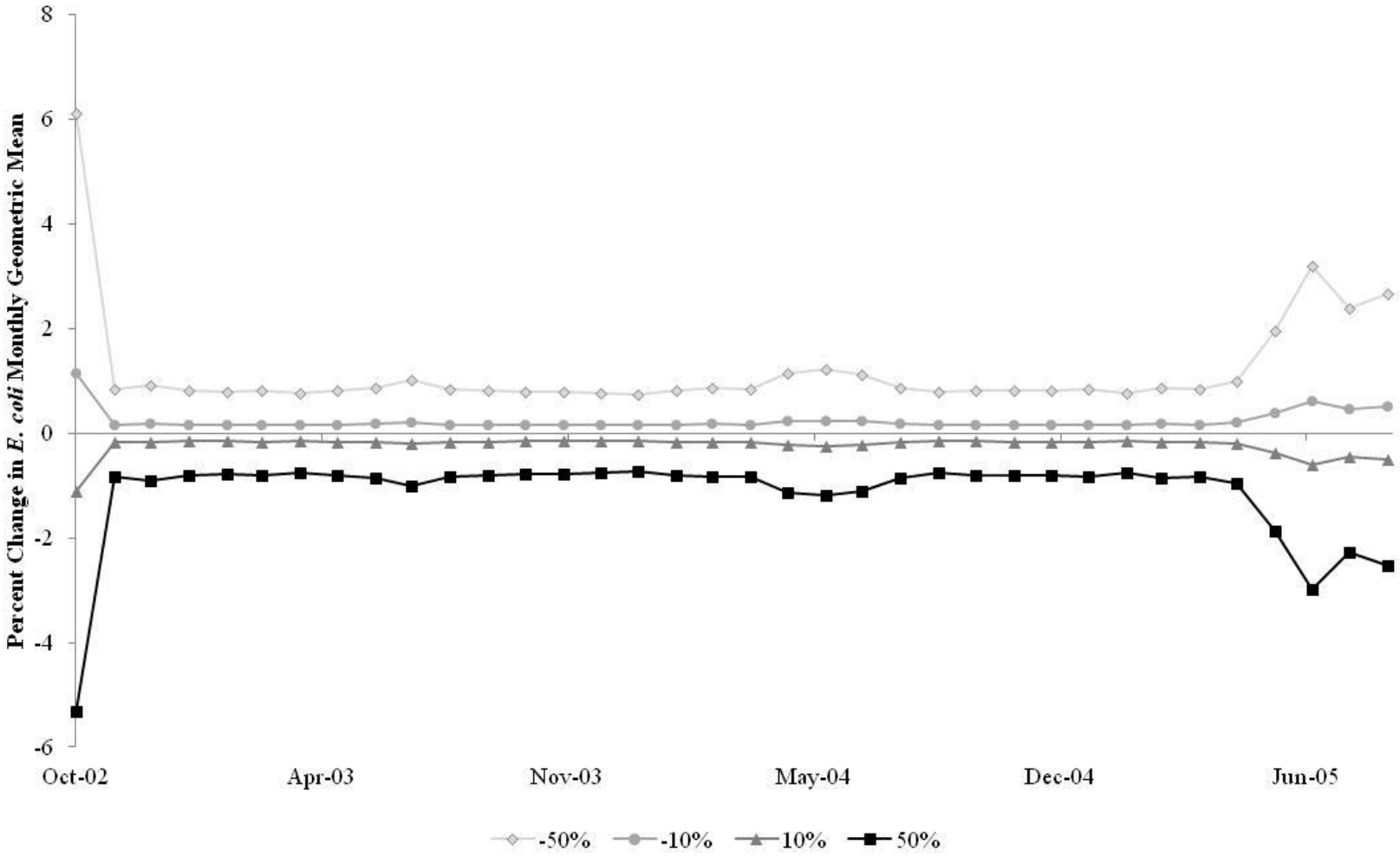

Figure B-100 Results of sensitivity analysis on monthly geometric mean concentration as affected by first-order decay rate (FSTDEC).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in amount of land-based and direct loads was also analyzed. It is evident in **Figure B-101** that the model predicts a roughly linear relationship between increased fecal coliform concentrations in direct and land-based applications and total load reaching the stream. Decreases in both direct and land-based loadings cause a slightly greater drop in response than the rise caused by similar increases in loading. Both direct loads and land applied loads have a significant impact on the geometric mean concentrations (**Figure B-102** and **Figure B-103**).

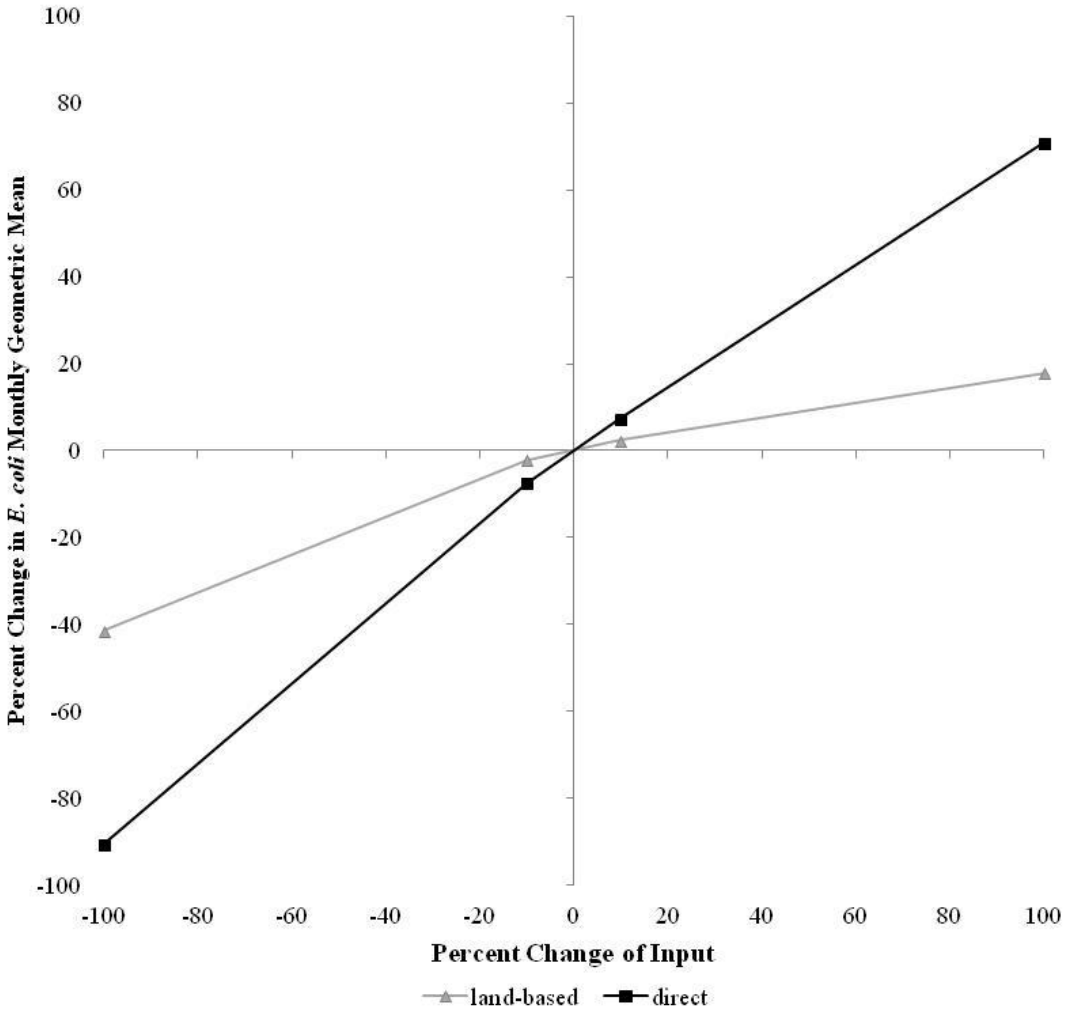

Figure B-101 Results of total loading sensitivity analysis for subwatershed 25 of the Pamunkey River watershed.

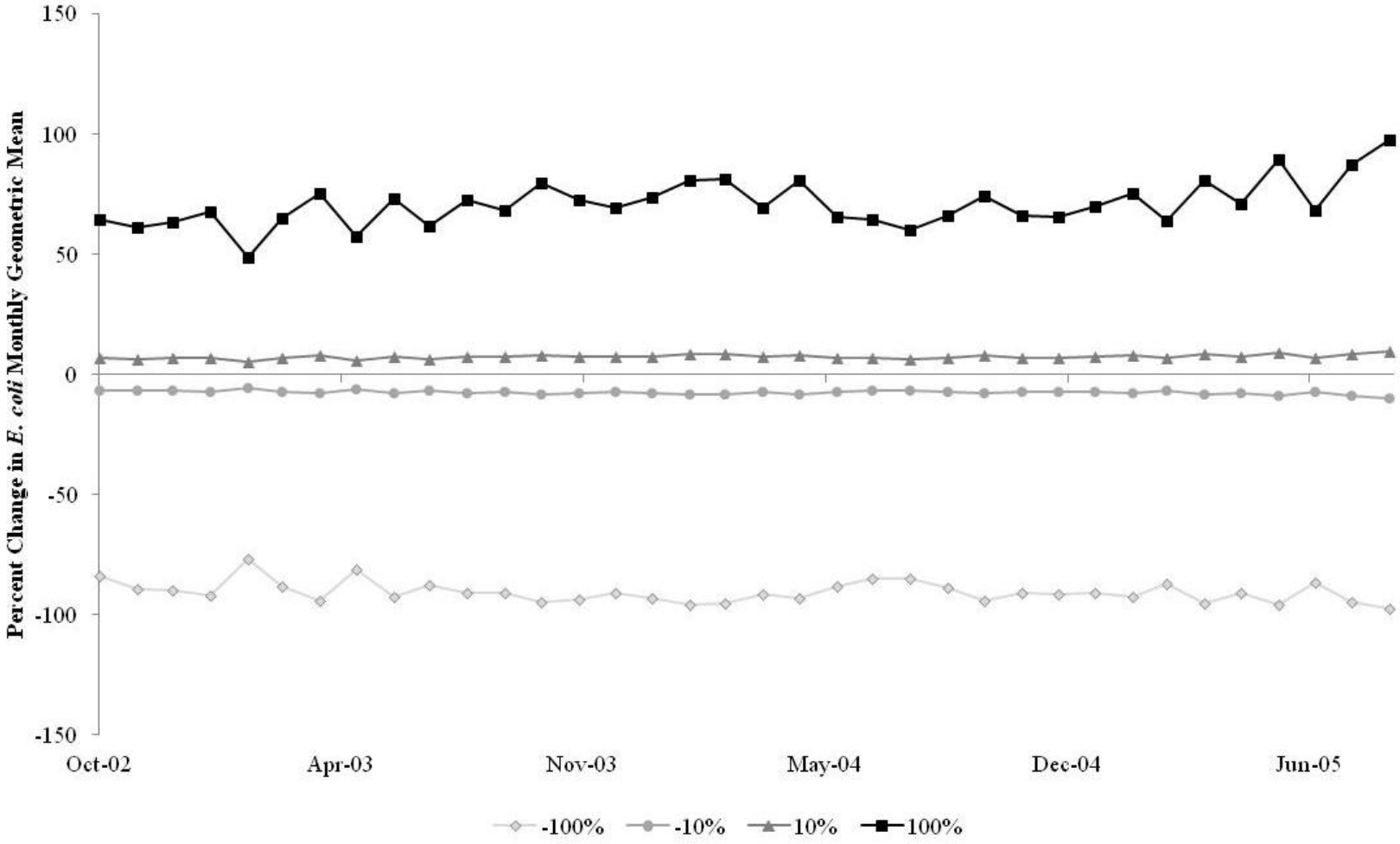

Figure B-102 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in loadings from direct nonpoint sources.

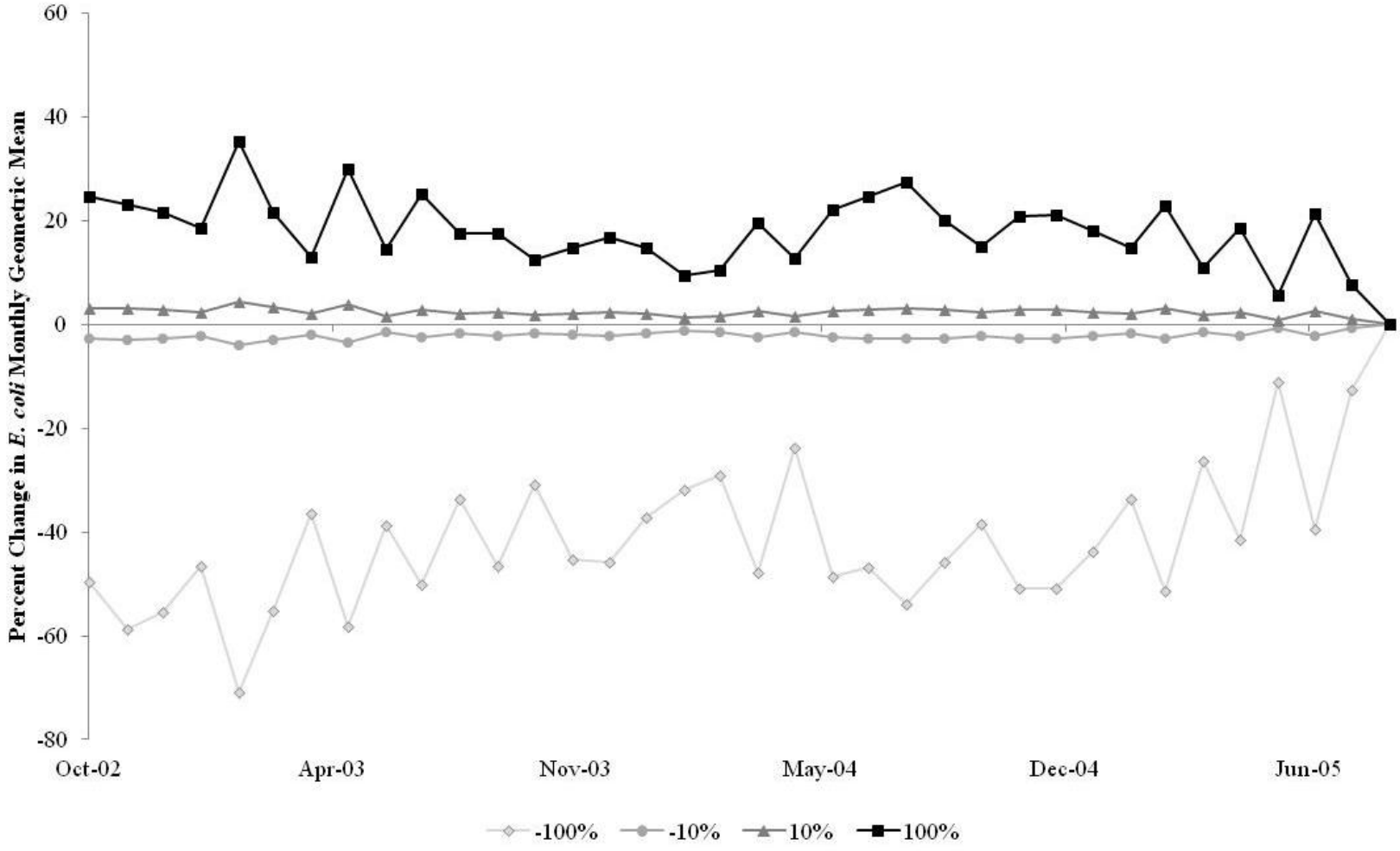

Figure B-103 Results of sensitivity analysis on monthly geometric mean concentrations as affected by changes in land-based loadings.

APPENDIX C: CURRENT CONDITIONS - FECAL COLIFORM LOADS

Table C- 1 Current conditions of land applied fecal coliform load for the Pamunkey River study area by land use.

Land-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Crop	1.75E+14	1.82E+14	1.12E+15	1.12E+15	1.12E+15	8.04E+13	8.31E+13	8.31E+13	3.86E+14	1.12E+15	1.12E+15	1.75E+14	6.77E+15
LAX	9.91E+12	8.95E+12	1.35E+13	1.75E+13	1.80E+13	2.09E+13	2.16E+13	2.16E+13	1.75E+13	1.35E+13	1.31E+13	9.91E+12	1.86E+14
Developed	2.88E+13	2.60E+13	2.88E+13	2.78E+13	2.88E+13	2.78E+13	2.88E+13	2.88E+13	2.78E+13	2.88E+13	2.78E+13	2.88E+13	3.39E+14
Wetland	2.32E+14	2.09E+14	2.32E+14	2.24E+14	2.32E+14	2.24E+14	2.32E+14	2.32E+14	2.24E+14	2.32E+14	2.24E+14	2.32E+14	2.73E+15
Commercial	1.72E+12	1.55E+12	1.72E+12	1.66E+12	1.72E+12	1.66E+12	1.72E+12	1.72E+12	1.66E+12	1.72E+12	1.66E+12	1.72E+12	2.02E+13
Forest	5.54E+14	5.00E+14	5.54E+14	5.36E+14	5.54E+14	5.36E+14	5.54E+14	5.54E+14	5.36E+14	5.54E+14	5.36E+14	5.54E+14	6.52E+15
Barren	1.22E+12	1.11E+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
Pasture	4.54E+14	4.10E+14	4.50E+14	4.31E+14	4.45E+14	5.34E+14	5.48E+14	5.48E+14	4.31E+14	4.50E+14	4.36E+14	4.54E+14	5.59E+15

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	1	3.3E+11	3.0E+11	3.3E+11	3.2E+11	3.3E+11	3.2E+11	3.3E+11	3.3E+11	3.2E+11	3.3E+11	3.2E+11	3.3E+11	3.9E+12
Livestock	1	1.5E+10	1.4E+10	2.0E+10	2.9E+10	3.0E+10	3.4E+10	3.5E+10	3.5E+10	2.9E+10	2.0E+10	1.9E+10	1.5E+10	3.0E+11
Wildlife	1	6.6E+11	6.0E+11	6.6E+11	6.4E+11	6.6E+11	6.4E+11	6.6E+11	6.6E+11	6.4E+11	6.6E+11	6.4E+11	6.6E+11	7.8E+12
Human/Pet	2	1.0E+10	9.1E+09	1.0E+10	9.7E+09	1.0E+10	9.7E+09	1.0E+10	1.0E+10	9.7E+09	1.0E+10	9.7E+09	1.0E+10	1.2E+11
Livestock	2	1.9E+09	1.7E+09	2.6E+09	3.7E+09	3.9E+09	4.4E+09	4.5E+09	4.5E+09	3.7E+09	2.6E+09	2.5E+09	1.9E+09	3.8E+10
Wildlife	2	6.6E+10	6.0E+10	6.6E+10	6.4E+10	6.6E+10	6.4E+10	6.6E+10	6.6E+10	6.4E+10	6.6E+10	6.4E+10	6.6E+10	7.8E+11
Human/Pet	3	9.1E+08	8.3E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	1.1E+10
Livestock	3	9.2E+08	8.3E+08	1.2E+09	1.8E+09	1.8E+09	2.1E+09	2.1E+09	2.1E+09	1.8E+09	1.2E+09	1.2E+09	9.2E+08	1.8E+10
Wildlife	3	3.2E+10	2.9E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.8E+11
Human/Pet	4	9.1E+08	8.3E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	1.1E+10
Livestock	4	9.2E+08	8.3E+08	1.2E+09	1.8E+09	1.8E+09	2.1E+09	2.1E+09	2.1E+09	1.8E+09	1.2E+09	1.2E+09	9.2E+08	1.8E+10
Wildlife	4	3.8E+10	3.4E+10	3.8E+10	3.7E+10	3.8E+10	3.7E+10	3.8E+10	3.8E+10	3.7E+10	3.8E+10	3.7E+10	3.8E+10	4.5E+11
Human/Pet	5	2.6E+10	2.3E+10	2.6E+10	2.5E+10	2.6E+10	2.5E+10	2.6E+10	2.6E+10	2.5E+10	2.6E+10	2.5E+10	2.6E+10	3.0E+11
Livestock	5	3.4E+09	3.0E+09	4.5E+09	6.5E+09	6.7E+09	7.6E+09	7.9E+09	7.9E+09	6.5E+09	4.5E+09	4.4E+09	3.4E+09	6.6E+10
Wildlife	5	5.2E+10	4.7E+10	5.2E+10	5.0E+10	5.2E+10	5.0E+10	5.2E+10	5.2E+10	5.0E+10	5.2E+10	5.0E+10	5.2E+10	6.1E+11
Human/Pet	6	3.8E+10	3.4E+10	3.8E+10	3.6E+10	3.8E+10	3.6E+10	3.8E+10	3.8E+10	3.6E+10	3.8E+10	3.6E+10	3.8E+10	4.4E+11
Livestock	6	1.2E+10	1.1E+10	1.6E+10	2.3E+10	2.4E+10	2.7E+10	2.8E+10	2.8E+10	2.3E+10	1.6E+10	1.5E+10	1.2E+10	2.4E+11
Wildlife	6	1.1E+11	9.9E+10	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.3E+12
Human/Pet	7	7.3E+10	6.6E+10	7.3E+10	7.1E+10	7.3E+10	7.1E+10	7.3E+10	7.3E+10	7.1E+10	7.3E+10	7.1E+10	7.3E+10	8.6E+11
Livestock	7	2.1E+10	1.9E+10	2.8E+10	4.1E+10	4.2E+10	4.8E+10	4.9E+10	4.9E+10	4.1E+10	2.8E+10	2.7E+10	2.1E+10	4.1E+11
Wildlife	7	1.6E+11	1.5E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.6E+11	1.9E+12
Human/Pet	8	1.0E+10	9.1E+09	1.0E+10	9.7E+09	1.0E+10	9.7E+09	1.0E+10	1.0E+10	9.7E+09	1.0E+10	9.7E+09	1.0E+10	1.2E+11
Livestock	8	3.1E+09	2.8E+09	4.1E+09	5.9E+09	6.1E+09	6.9E+09	7.2E+09	7.2E+09	5.9E+09	4.1E+09	4.0E+09	3.1E+09	6.0E+10
Wildlife	8	5.2E+10	4.7E+10	5.2E+10	5.0E+10	5.2E+10	5.0E+10	5.2E+10	5.2E+10	5.0E+10	5.2E+10	5.0E+10	5.2E+10	6.1E+11

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.(cont.)

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	9	1.2E+11	1.1E+11	1.2E+11	1.1E+11	1.2E+11	1.1E+11	1.2E+11	1.2E+11	1.1E+11	1.2E+11	1.1E+11	1.2E+11	1.4E+12
Livestock	9	4.7E+10	4.3E+10	6.3E+10	9.1E+10	9.4E+10	1.1E+11	1.1E+11	1.1E+11	9.1E+10	6.3E+10	6.1E+10	4.7E+10	9.3E+11
Wildlife	9	1.7E+11	1.5E+11	1.7E+11	1.6E+11	1.7E+11	1.6E+11	1.7E+11	1.7E+11	1.6E+11	1.7E+11	1.6E+11	1.7E+11	2.0E+12
Human/Pet	10	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Livestock	10	5.3E+09	4.7E+09	7.0E+09	1.0E+10	1.1E+10	1.2E+10	1.2E+10	1.2E+10	1.0E+10	7.0E+09	6.8E+09	5.3E+09	1.0E+11
Wildlife	10	1.9E+10	1.7E+10	1.9E+10	1.8E+10	1.9E+10	1.8E+10	1.9E+10	1.9E+10	1.8E+10	1.9E+10	1.8E+10	1.9E+10	2.2E+11
Human/Pet	11	2.4E+11	2.1E+11	2.4E+11	2.3E+11	2.4E+11	2.3E+11	2.4E+11	2.4E+11	2.3E+11	2.4E+11	2.3E+11	2.4E+11	2.8E+12
Livestock	11	4.5E+10	4.1E+10	6.0E+10	8.7E+10	9.0E+10	1.0E+11	1.1E+11	1.1E+11	8.7E+10	6.0E+10	5.8E+10	4.5E+10	8.8E+11
Wildlife	11	2.9E+11	2.6E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	3.4E+12
Human/Pet	12	3.0E+11	2.7E+11	3.0E+11	2.9E+11	3.0E+11	2.9E+11	3.0E+11	3.0E+11	2.9E+11	3.0E+11	2.9E+11	3.0E+11	3.5E+12
Livestock	12	2.5E+10	2.3E+10	3.4E+10	4.9E+10	5.0E+10	5.7E+10	5.9E+10	5.9E+10	4.9E+10	3.4E+10	3.2E+10	2.5E+10	4.9E+11
Wildlife	12	2.2E+11	2.0E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.6E+12
Human/Pet	13	3.6E+11	3.2E+11	3.6E+11	3.5E+11	3.6E+11	3.5E+11	3.6E+11	3.6E+11	3.5E+11	3.6E+11	3.5E+11	3.6E+11	4.2E+12
Livestock	13	2.1E+10	1.9E+10	2.7E+10	4.0E+10	4.1E+10	4.6E+10	4.8E+10	4.8E+10	4.0E+10	2.7E+10	2.7E+10	2.1E+10	4.0E+11
Wildlife	13	2.2E+11	2.0E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.6E+12
Human/Pet	15	1.5E+11	1.4E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.5E+11	1.8E+12
Livestock	15	8.7E+09	7.8E+09	1.2E+10	1.7E+10	1.7E+10	2.0E+10	2.0E+10	2.0E+10	1.7E+10	1.2E+10	1.1E+10	8.7E+09	1.7E+11
Wildlife	15	7.1E+10	6.4E+10	7.1E+10	6.8E+10	7.1E+10	6.8E+10	7.1E+10	7.1E+10	6.8E+10	7.1E+10	6.8E+10	7.1E+10	8.3E+11
Human/Pet	16	2.3E+11	2.1E+11	2.3E+11	2.2E+11	2.3E+11	2.2E+11	2.3E+11	2.3E+11	2.2E+11	2.3E+11	2.2E+11	2.3E+11	2.7E+12
Livestock	16	1.4E+10	1.2E+10	1.8E+10	2.6E+10	2.7E+10	3.1E+10	3.2E+10	3.2E+10	2.6E+10	1.8E+10	1.8E+10	1.4E+10	2.7E+11
Wildlife	16	4.8E+10	4.4E+10	4.8E+10	4.7E+10	4.8E+10	4.7E+10	4.8E+10	4.8E+10	4.7E+10	4.8E+10	4.7E+10	4.8E+10	5.7E+11
Human/Pet	17	1.4E+12	1.3E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.4E+12	1.7E+13
Livestock	17	5.0E+10	4.5E+10	6.7E+10	9.7E+10	1.0E+11	1.1E+11	1.2E+11	1.2E+11	9.7E+10	6.7E+10	6.5E+10	5.0E+10	9.8E+11
Wildlife	17	4.9E+11	4.5E+11	4.9E+11	4.8E+11	4.9E+11	4.8E+11	4.9E+11	4.9E+11	4.8E+11	4.9E+11	4.8E+11	4.9E+11	5.8E+12

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.(cont.)

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	18	5.5E+11	4.9E+11	5.5E+11	5.3E+11	5.5E+11	5.3E+11	5.5E+11	5.5E+11	5.3E+11	5.5E+11	5.3E+11	5.5E+11	6.4E+12
Livestock	18	6.7E+10	6.0E+10	8.9E+10	1.3E+11	1.3E+11	1.5E+11	1.6E+11	1.6E+11	1.3E+11	8.9E+10	8.6E+10	6.7E+10	1.3E+12
Wildlife	18	2.9E+11	2.6E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	3.4E+12
Human/Pet	19	1.7E+11	1.5E+11	1.7E+11	1.6E+11	1.7E+11	1.6E+11	1.7E+11	1.7E+11	1.6E+11	1.7E+11	1.6E+11	1.7E+11	2.0E+12
Livestock	19	1.8E+10	1.6E+10	2.4E+10	3.4E+10	3.5E+10	4.0E+10	4.1E+10	4.1E+10	3.4E+10	2.4E+10	2.3E+10	1.8E+10	3.5E+11
Wildlife	19	9.4E+10	8.5E+10	9.4E+10	9.1E+10	9.4E+10	9.1E+10	9.4E+10	9.4E+10	9.1E+10	9.4E+10	9.1E+10	9.4E+10	1.1E+12
Human/Pet	21	9.1E+08	8.3E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	9.1E+08	8.9E+08	9.1E+08	8.9E+08	9.1E+08	1.1E+10
Livestock	21	3.3E+09	3.0E+09	4.4E+09	6.5E+09	6.7E+09	7.5E+09	7.8E+09	7.8E+09	6.5E+09	4.4E+09	4.3E+09	3.3E+09	6.6E+10
Wildlife	21	2.9E+10	2.6E+10	2.9E+10	2.8E+10	2.9E+10	2.8E+10	2.9E+10	2.9E+10	2.8E+10	2.9E+10	2.8E+10	2.9E+10	3.4E+11
Human/Pet	22	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Livestock	22	1.3E+09	1.2E+09	1.8E+09	2.5E+09	2.6E+09	3.0E+09	3.1E+09	3.1E+09	2.5E+09	1.8E+09	1.7E+09	1.3E+09	2.6E+10
Wildlife	22	9.7E+09	8.8E+09	9.7E+09	9.4E+09	9.7E+09	9.4E+09	9.7E+09	9.7E+09	9.4E+09	9.7E+09	9.4E+09	9.7E+09	1.1E+11
Human/Pet	23	9.5E+10	8.6E+10	9.5E+10	9.2E+10	9.5E+10	9.2E+10	9.5E+10	9.5E+10	9.2E+10	9.5E+10	9.2E+10	9.5E+10	1.1E+12
Livestock	23	1.6E+09	1.5E+09	2.2E+09	3.1E+09	3.2E+09	3.7E+09	3.8E+09	3.8E+09	3.1E+09	2.2E+09	2.1E+09	1.6E+09	3.2E+10
Wildlife	23	7.5E+10	6.8E+10	7.5E+10	7.3E+10	7.5E+10	7.3E+10	7.5E+10	7.5E+10	7.3E+10	7.5E+10	7.3E+10	7.5E+10	8.8E+11
Human/Pet	24	6.4E+09	5.8E+09	6.4E+09	6.2E+09	6.4E+09	6.2E+09	6.4E+09	6.4E+09	6.2E+09	6.4E+09	6.2E+09	6.4E+09	7.5E+10
Livestock	24	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Wildlife	24	2.2E+10	2.0E+10	2.2E+10	2.1E+10	2.2E+10	2.1E+10	2.2E+10	2.2E+10	2.1E+10	2.2E+10	2.1E+10	2.2E+10	2.6E+11
Human/Pet	25	2.8E+11	2.6E+11	2.8E+11	2.7E+11	2.8E+11	2.7E+11	2.8E+11	2.8E+11	2.7E+11	2.8E+11	2.7E+11	2.8E+11	3.3E+12
Livestock	25	1.2E+10	1.1E+10	1.7E+10	2.4E+10	2.5E+10	2.8E+10	2.9E+10	2.9E+10	2.4E+10	1.7E+10	1.6E+10	1.2E+10	2.4E+11
Wildlife	25	2.6E+11	2.3E+11	2.6E+11	2.5E+11	2.6E+11	2.5E+11	2.6E+11	2.6E+11	2.5E+11	2.6E+11	2.5E+11	2.6E+11	3.0E+12
Human/Pet	26	2.5E+11	2.2E+11	2.5E+11	2.4E+11	2.5E+11	2.4E+11	2.5E+11	2.5E+11	2.4E+11	2.5E+11	2.4E+11	2.5E+11	2.9E+12
Livestock	26	1.3E+10	1.2E+10	1.7E+10	2.5E+10	2.6E+10	2.9E+10	3.0E+10	3.0E+10	2.5E+10	1.7E+10	1.7E+10	1.3E+10	2.5E+11
Wildlife	26	3.3E+11	3.0E+11	3.3E+11	3.2E+11	3.3E+11	3.2E+11	3.3E+11	3.3E+11	3.2E+11	3.3E+11	3.2E+11	3.3E+11	3.9E+12

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.(cont.)

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	27	3.6E+11	3.3E+11	3.6E+11	3.5E+11	3.6E+11	3.5E+11	3.6E+11	3.6E+11	3.5E+11	3.6E+11	3.5E+11	3.6E+11	4.3E+12
Livestock	27	4.8E+10	4.3E+10	6.3E+10	9.2E+10	9.5E+10	1.1E+11	1.1E+11	1.1E+11	9.2E+10	6.3E+10	6.1E+10	4.8E+10	9.4E+11
Wildlife	27	2.9E+11	2.6E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	3.4E+12
Human/Pet	28	8.3E+11	7.5E+11	8.3E+11	8.1E+11	8.3E+11	8.1E+11	8.3E+11	8.3E+11	8.1E+11	8.3E+11	8.1E+11	8.3E+11	9.8E+12
Livestock	28	1.4E+10	1.3E+10	1.9E+10	2.7E+10	2.8E+10	3.2E+10	3.3E+10	3.3E+10	2.7E+10	1.9E+10	1.8E+10	1.4E+10	2.8E+11
Wildlife	28	2.5E+11	2.2E+11	2.5E+11	2.4E+11	2.5E+11	2.4E+11	2.5E+11	2.5E+11	2.4E+11	2.5E+11	2.4E+11	2.5E+11	2.9E+12
Wildlife	29	1.8E+08	1.6E+08	1.8E+08	1.7E+08	1.8E+08	1.7E+08	1.8E+08	1.8E+08	1.7E+08	1.8E+08	1.7E+08	1.8E+08	2.1E+09
Human/Pet	30	3.9E+10	3.6E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	3.9E+10	3.8E+10	3.9E+10	3.8E+10	3.9E+10	4.6E+11
Livestock	30	3.9E+09	3.5E+09	5.1E+09	7.5E+09	7.7E+09	8.7E+09	9.0E+09	9.0E+09	7.5E+09	5.1E+09	5.0E+09	3.9E+09	7.6E+10
Wildlife	30	4.3E+10	3.8E+10	4.3E+10	4.1E+10	4.3E+10	4.1E+10	4.3E+10	4.3E+10	4.1E+10	4.3E+10	4.1E+10	4.3E+10	5.0E+11
Human/Pet	31	3.0E+10	2.7E+10	3.0E+10	2.9E+10	3.0E+10	2.9E+10	3.0E+10	3.0E+10	2.9E+10	3.0E+10	2.9E+10	3.0E+10	3.6E+11
Livestock	31	1.0E+09	9.1E+08	1.3E+09	2.0E+09	2.0E+09	2.3E+09	2.4E+09	2.4E+09	2.0E+09	1.3E+09	1.3E+09	1.0E+09	2.0E+10
Wildlife	31	2.4E+10	2.1E+10	2.4E+10	2.3E+10	2.4E+10	2.3E+10	2.4E+10	2.4E+10	2.3E+10	2.4E+10	2.3E+10	2.4E+10	2.8E+11
Human/Pet	33	3.2E+10	2.9E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.8E+11
Livestock	33	7.2E+09	6.5E+09	9.6E+09	1.4E+10	1.4E+10	1.6E+10	1.7E+10	1.7E+10	1.4E+10	9.6E+09	9.3E+09	7.2E+09	1.4E+11
Wildlife	33	4.6E+10	4.2E+10	4.6E+10	4.5E+10	4.6E+10	4.5E+10	4.6E+10	4.6E+10	4.5E+10	4.6E+10	4.5E+10	4.6E+10	5.4E+11
Human/Pet	34	2.0E+12	1.9E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.0E+12	2.4E+13
Livestock	34	4.5E+10	4.0E+10	6.0E+10	8.6E+10	8.9E+10	1.0E+11	1.0E+11	1.0E+11	8.6E+10	6.0E+10	5.8E+10	4.5E+10	8.8E+11
Wildlife	34	2.2E+11	2.0E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.2E+11	2.1E+11	2.2E+11	2.1E+11	2.2E+11	2.6E+12
Human/Pet	35	8.2E+09	7.4E+09	8.2E+09	8.0E+09	8.2E+09	8.0E+09	8.2E+09	8.2E+09	8.0E+09	8.2E+09	8.0E+09	8.2E+09	9.7E+10
Livestock	35	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Wildlife	35	5.8E+08	5.3E+08	5.8E+08	5.7E+08	5.8E+08	5.7E+08	5.8E+08	5.8E+08	5.7E+08	5.8E+08	5.7E+08	5.8E+08	6.9E+09
Human/Pet	36	1.7E+10	1.5E+10	1.7E+10	1.6E+10	1.7E+10	1.6E+10	1.7E+10	1.7E+10	1.6E+10	1.7E+10	1.6E+10	1.7E+10	1.9E+11
Livestock	36	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.(cont.)

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Wildlife	36	4.9E+08	4.4E+08	4.9E+08	4.8E+08	4.9E+08	4.8E+08	4.9E+08	4.9E+08	4.8E+08	4.9E+08	4.8E+08	4.9E+08	5.8E+09
Human/Pet	37	4.1E+11	3.7E+11	4.1E+11	3.9E+11	4.1E+11	3.9E+11	4.1E+11	4.1E+11	3.9E+11	4.1E+11	3.9E+11	4.1E+11	4.8E+12
Livestock	37	6.7E+09	6.0E+09	8.9E+09	1.3E+10	1.3E+10	1.5E+10	1.6E+10	1.6E+10	1.3E+10	8.9E+09	8.6E+09	6.7E+09	1.3E+11
Wildlife	37	4.9E+10	4.4E+10	4.9E+10	4.7E+10	4.9E+10	4.7E+10	4.9E+10	4.9E+10	4.7E+10	4.9E+10	4.7E+10	4.9E+10	5.7E+11
Human/Pet	38	3.2E+11	2.9E+11	3.2E+11	3.1E+11	3.2E+11	3.1E+11	3.2E+11	3.2E+11	3.1E+11	3.2E+11	3.1E+11	3.2E+11	3.8E+12
Livestock	38	1.2E+10	1.1E+10	1.6E+10	2.4E+10	2.4E+10	2.7E+10	2.8E+10	2.8E+10	2.4E+10	1.6E+10	1.6E+10	1.2E+10	2.4E+11
Wildlife	38	1.1E+11	1.0E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.3E+12
Human/Pet	39	8.8E+10	7.9E+10	8.8E+10	8.5E+10	8.8E+10	8.5E+10	8.8E+10	8.8E+10	8.5E+10	8.8E+10	8.5E+10	8.8E+10	1.0E+12
Livestock	39	2.1E+10	1.9E+10	2.8E+10	4.0E+10	4.1E+10	4.7E+10	4.8E+10	4.8E+10	4.0E+10	2.8E+10	2.7E+10	2.1E+10	4.1E+11
Wildlife	39	1.1E+11	1.0E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.3E+12
Human/Pet	40	3.2E+11	2.9E+11	3.2E+11	3.1E+11	3.2E+11	3.1E+11	3.2E+11	3.2E+11	3.1E+11	3.2E+11	3.1E+11	3.2E+11	3.8E+12
Livestock	40	5.1E+10	4.6E+10	6.8E+10	9.8E+10	1.0E+11	1.1E+11	1.2E+11	1.2E+11	9.8E+10	6.8E+10	6.5E+10	5.1E+10	1.0E+12
Wildlife	40	1.1E+11	1.0E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.1E+11	1.3E+12
Human/Pet	41	7.2E+11	6.5E+11	7.2E+11	6.9E+11	7.2E+11	6.9E+11	7.2E+11	7.2E+11	6.9E+11	7.2E+11	6.9E+11	7.2E+11	8.4E+12
Livestock	41	8.1E+10	7.3E+10	1.1E+11	1.6E+11	1.6E+11	1.8E+11	1.9E+11	1.9E+11	1.6E+11	1.1E+11	1.1E+11	8.1E+10	1.6E+12
Wildlife	41	2.9E+11	2.6E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	2.9E+11	2.8E+11	2.9E+11	2.8E+11	2.9E+11	3.4E+12
Human/Pet	42	4.7E+11	4.2E+11	4.7E+11	4.5E+11	4.7E+11	4.5E+11	4.7E+11	4.7E+11	4.5E+11	4.7E+11	4.5E+11	4.7E+11	5.5E+12
Livestock	42	3.5E+10	3.1E+10	4.6E+10	6.7E+10	6.9E+10	7.8E+10	8.1E+10	8.1E+10	6.7E+10	4.6E+10	4.5E+10	3.5E+10	6.8E+11
Wildlife	42	1.4E+11	1.2E+11	1.4E+11	1.3E+11	1.4E+11	1.3E+11	1.4E+11	1.4E+11	1.3E+11	1.4E+11	1.3E+11	1.4E+11	1.6E+12
Human/Pet	43	1.7E+12	1.5E+12	1.7E+12	1.6E+12	1.7E+12	1.6E+12	1.7E+12	1.7E+12	1.6E+12	1.7E+12	1.6E+12	1.7E+12	2.0E+13
Livestock	43	8.1E+10	7.3E+10	1.1E+11	1.6E+11	1.6E+11	1.8E+11	1.9E+11	1.9E+11	1.6E+11	1.1E+11	1.1E+11	8.1E+10	1.6E+12
Wildlife	43	4.8E+11	4.3E+11	4.8E+11	4.6E+11	4.8E+11	4.6E+11	4.8E+11	4.8E+11	4.6E+11	4.8E+11	4.6E+11	4.8E+11	5.6E+12
Human/Pet	44	2.0E+11	1.8E+11	2.0E+11	1.9E+11	2.0E+11	1.9E+11	2.0E+11	2.0E+11	1.9E+11	2.0E+11	1.9E+11	2.0E+11	2.3E+12
Livestock	44	3.5E+10	3.1E+10	4.6E+10	6.7E+10	6.9E+10	7.8E+10	8.1E+10	8.1E+10	6.7E+10	4.6E+10	4.5E+10	3.5E+10	6.8E+11

Table C- 2 Monthly direct deposition fecal coliform loads in each reach of the Pamunkey River study area.(cont.)

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Wildlife	44	8.9E+10	8.1E+10	8.9E+10	8.7E+10	8.9E+10	8.7E+10	8.9E+10	8.9E+10	8.7E+10	8.9E+10	8.7E+10	8.9E+10	1.1E+12
Human/Pet	45	5.0E+11	4.5E+11	5.0E+11	4.8E+11	5.0E+11	4.8E+11	5.0E+11	5.0E+11	4.8E+11	5.0E+11	4.8E+11	5.0E+11	5.9E+12
Livestock	45	5.6E+10	5.1E+10	7.5E+10	1.1E+11	1.1E+11	1.3E+11	1.3E+11	1.3E+11	1.1E+11	7.5E+10	7.3E+10	5.6E+10	1.1E+12
Wildlife	45	2.8E+11	2.5E+11	2.8E+11	2.7E+11	2.8E+11	2.7E+11	2.8E+11	2.8E+11	2.7E+11	2.8E+11	2.7E+11	2.8E+11	3.3E+12
Human/Pet	46	2.1E+11	1.9E+11	2.1E+11	2.0E+11	2.1E+11	2.0E+11	2.1E+11	2.1E+11	2.0E+11	2.1E+11	2.0E+11	2.1E+11	2.5E+12
Livestock	46	1.7E+10	1.5E+10	2.3E+10	3.3E+10	3.4E+10	3.8E+10	3.9E+10	3.9E+10	3.3E+10	2.3E+10	2.2E+10	1.7E+10	3.3E+11
Wildlife	46	9.1E+10	8.2E+10	9.1E+10	8.8E+10	9.1E+10	8.8E+10	9.1E+10	9.1E+10	8.8E+10	9.1E+10	8.8E+10	9.1E+10	1.1E+12
Human/Pet	47	9.9E+10	8.9E+10	9.9E+10	9.6E+10	9.9E+10	9.6E+10	9.9E+10	9.9E+10	9.6E+10	9.9E+10	9.6E+10	9.9E+10	1.2E+12
Livestock	47	4.0E+09	3.6E+09	5.4E+09	7.8E+09	8.0E+09	9.1E+09	9.4E+09	9.4E+09	7.8E+09	5.4E+09	5.2E+09	4.0E+09	7.9E+10
Wildlife	47	3.2E+10	2.9E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.2E+10	3.1E+10	3.2E+10	3.1E+10	3.2E+10	3.8E+11
Human/Pet	48	9.9E+11	9.0E+11	9.9E+11	9.6E+11	9.9E+11	9.6E+11	9.9E+11	9.9E+11	9.6E+11	9.9E+11	9.6E+11	9.9E+11	1.2E+13
Livestock	48	7.0E+09	6.3E+09	9.3E+09	1.4E+10	1.4E+10	1.6E+10	1.6E+10	1.6E+10	1.4E+10	9.3E+09	9.0E+09	7.0E+09	1.4E+11
Wildlife	48	3.5E+10	3.1E+10	3.5E+10	3.4E+10	3.5E+10	3.4E+10	3.5E+10	3.5E+10	3.4E+10	3.5E+10	3.4E+10	3.5E+10	4.1E+11
Human/Pet	49	5.8E+10	5.2E+10	5.8E+10	5.6E+10	5.8E+10	5.6E+10	5.8E+10	5.8E+10	5.6E+10	5.8E+10	5.6E+10	5.8E+10	6.8E+11
Livestock	49	5.6E+09	5.0E+09	7.4E+09	1.1E+10	1.1E+10	1.3E+10	1.3E+10	1.3E+10	1.1E+10	7.4E+09	7.2E+09	5.6E+09	1.1E+11
Wildlife	49	2.1E+10	1.9E+10	2.1E+10	2.0E+10	2.1E+10	2.0E+10	2.1E+10	2.1E+10	2.0E+10	2.1E+10	2.0E+10	2.1E+10	2.4E+11
Human/Pet	50	4.8E+10	4.4E+10	4.8E+10	4.7E+10	4.8E+10	4.7E+10	4.8E+10	4.8E+10	4.7E+10	4.8E+10	4.7E+10	4.8E+10	5.7E+11
Livestock	50	7.2E+09	6.5E+09	9.6E+09	1.4E+10	1.4E+10	1.6E+10	1.7E+10	1.7E+10	1.4E+10	9.6E+09	9.3E+09	7.2E+09	1.4E+11
Wildlife	50	2.3E+10	2.0E+10	2.3E+10	2.2E+10	2.3E+10	2.2E+10	2.3E+10	2.3E+10	2.2E+10	2.3E+10	2.2E+10	2.3E+10	2.7E+11
Human/Pet	51	8.8E+10	7.9E+10	8.8E+10	8.5E+10	8.8E+10	8.5E+10	8.8E+10	8.8E+10	8.5E+10	8.8E+10	8.5E+10	8.8E+10	1.0E+12
Livestock	51	7.0E+09	6.3E+09	9.3E+09	1.4E+10	1.4E+10	1.6E+10	1.6E+10	1.6E+10	1.4E+10	9.3E+09	9.0E+09	7.0E+09	1.4E+11
Wildlife	51	4.3E+10	3.9E+10	4.3E+10	4.2E+10	4.3E+10	4.2E+10	4.3E+10	4.3E+10	4.2E+10	4.3E+10	4.2E+10	4.3E+10	5.1E+11

Table C- 3 Existing annual loads from land based sources for the Pamunkey River study area.

Source	Water	Forest	Commercial	Pasture	Developed	LAX	Crop	Wetland	Barren
Beaver	2.56E+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
Beef Calves	4.41E+12	0.00E+00	0.00E+00	8.37E+14	0.00E+00	3.97E+13	0.00E+00	0.00E+00	0.00E+00
Beef Cattle	1.39E+13	0.00E+00	0.00E+00	2.64E+15	0.00E+00	1.25E+14	0.00E+00	0.00E+00	0.00E+00
Chickens	0.00E+00	0.00E+00	0.00E+00	8.06E+13	0.00E+00	0.00E+00	1.45E+15	0.00E+00	0.00E+00
Dairy Calves	0.00E+00	0.00E+00	0.00E+00	2.04E+13	0.00E+00	0.00E+00	3.69E+14	0.00E+00	0.00E+00
Dairy Heifers	0.00E+00	0.00E+00	0.00E+00	4.94E+13	0.00E+00	0.00E+00	8.91E+14	0.00E+00	0.00E+00
Dairy Milkers	0.00E+00	0.00E+00	0.00E+00	1.71E+14	0.00E+00	0.00E+00	3.07E+15	0.00E+00	0.00E+00
Deer	0.00E+00	9.02E+14	0.00E+00	1.14E+14	1.59E+13	9.51E+11	1.57E+14	1.50E+14	0.00E+00
Duck	0.00E+00	1.37E+11	3.26E+08	4.76E+09	6.10E+09	2.12E+09	1.06E+10	1.61E+11	3.15E+08
Geese	0.00E+00	8.44E+12	2.01E+10	2.93E+11	3.76E+11	1.30E+11	6.53E+11	9.90E+12	1.94E+10
Goats	0.00E+00	0.00E+00	0.00E+00	1.91E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horses	0.00E+00	0.00E+00	0.00E+00	1.07E+15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	4.62E+14	1.10E+12	1.60E+13	2.06E+13	7.13E+12	3.57E+13	5.41E+14	1.06E+12
People on Straight Pipes	1.67E+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
Raccoon	0.00E+00	5.15E+15	1.91E+13	5.63E+14	3.02E+14	1.28E+13	7.85E+14	2.03E+15	1.33E+13
Sheep	0.00E+00	0.00E+00	0.00E+00	3.97E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	3.94E+11	0.00E+00	1.25E+10	0.00E+00	1.04E+08	1.72E+10	6.58E+10	0.00E+00

Table C- 4 Existing annual loads from direct deposition sources for the Pamunkey River study area.

Source	Annual Total Load (cfu/yr)
Beaver	2.58E+11
Beef Calves	4.41E+12
Beef Cattle	1.39E+13
Chickens	0.00E+00
Dairy Calves	0.00E+00
Dairy Heifers	0.00E+00
Dairy Milkers	0.00E+00
Deer	3.36E+12
Duck	1.25E+10
Geese	5.09E+11
Goats	0.00E+00
Horses	0.00E+00
Muskrat	5.11E+13
People on Straight Pipes	1.67E+14
Raccoon	2.22E+13
Sheep	0.00E+00
Turkey	1.23E+09

APPENDIX D: PAMUNKEY RIVER TMDLS, 2006

This page was intentionally left blank.

APPENDIX E: PUBLIC COMMENT AND RESPONSE

This page was intentionally left blank.