E.coli TMDL Development for Chickahominy River and Tributaries, VA

(A Nested TMDL Approach)

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CONTENTS

ACKNOWLEDGEMENTS i
CONTENTS iii
LIST OF FIGURES vii
LIST OF TABLES xv
EXECUTIVE SUMMARY xix
1. INTRODUCTION 1-1
1.1 Regulations Background 1-1
1.2 Chickahominy River and Tributaries Watershed Characteristics 1-2
1.3 Chickahominy River and Tributaries Recreation Use Impairments 1-3
1.3.1 Collins Run (VAP-G07_CNR01A00) 1-5
1.3.2 Beaverdam Creek (VAP-G06R_BEV01A00) 1-5
1.3.3 Boatswain Creek (VAP-G06R_BTS01A02) 1-5
1.3.4 Chickahominy River (VAP-G06R_CHK01A98) 1-5
1.3.5 Stony Run (VAP-G05R_SNF01A02) 1-6
2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT 2-1
2.1 Applicable Water Quality Standards 2-1
2.2 Selection of a TMDL Endpoint 2-2
2.3 Discussion of In-stream Water Quality 2-3
2.3.1 Inventory of Water Quality Monitoring Data 2-3
3. BACTERIA SOURCE ASSESSMENT 3-1
3.1 Assessment of Sources 3-1
3.2 Assessment of Nonpoint Sources 3-5
3.2.1 Private Residential Sewage Treatment 3-6
3.2.2 Sanitary Sewer Overflows (SSOs) 3-8
3.2.3 Biosolids 3-9
3.2.4 Pets 3-10

3.2.5 Livestock 3-11

3.2.6 Wildlife 3-15

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) 5-2

5.3 Load Allocations (LAs) 5-3

5.4 Final Total Maximum Daily Loads (TMDLs) 5-3

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 A-1

APPENDIX B B-1

APPENDIX C C-1

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LIST OF FIGURES

Figure 1.1 Location of the Chickahominy River and Tributaries watershed. 1-2

Figure 1.2 The impaired segments in the Chickahominy River and Tributaries watershed. 1-7

Figure 2.1 Location of VADEQ water quality monitoring stations in the upper portion of the Chickahominy River and Tributaries watershed. 2-5

Figure 2.2 Location of VADEQ water quality monitoring stations in the lower portion of the Chickahominy River and Tributaries watershed. 2-6

Figure 3.1 All subwatersheds delineated for modeling in the Chickahominy River study area. 3-3

Figure 5.1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 24. 5-7

Figure A. 1 Frequency analysis of *E. coli* concentrations at station 2-BEV002.00 in Beaverdam Creek for the period from August 2003 to November 2010. ..... A-2

Figure A. 2 Frequency analysis of *E. coli* concentrations at station 2-BTS002.62 in Boatswain Creek for the period from May 2004 to November 2006. ..... A-3

Figure A. 3 Frequency analysis of *E. coli* concentrations at station 2-CHK032.77 in the Chickahominy River for the period from July 2003 to March 2006. ..... A-4

Figure A. 4 Frequency analysis of *E. coli* concentrations at station 2-CHK042.22 in the Chickahominy River for the period from January 2007 to November 2008. ..... A-5

Figure A. 5 Frequency analysis of *E. coli* concentrations at station 2-CHK062.57 in the Chickahominy River for the period from August 2003 to January 2011. ..... A-6

Figure A. 6 Frequency analysis of *E. coli* concentrations at station 2-CHK067.30 in the Chickahominy River for the period from February 2009 to November 2010. ..... A-7

Figure A. 7 Frequency analysis of *E. coli* concentrations at station 2-CHK071.66 in the Chickahominy River for the period from February 2009 to November 2010. ..... A-8

Figure A. 8 Frequency analysis of *E. coli* concentrations at station 2-CHK076.59 in the Chickahominy River for the period from July 2003 to January 2011. ..... A-9

Figure A. 9 Frequency analysis of *E. coli* concentrations at station 2-CHK079.23 in Chickahominy River for the period from January 2006 to December 2006. ..... A-10

Figure A. 10 Frequency analysis of *E. coli* concentrations at station 2-FLP000.92 in Flippen Creek for the period from January 2006 to December 2006. ..... A-11

Figure A. 11 Frequency analysis of *E. coli* concentrations at station 2-HOH000.57 in Horsepen Branch for the period from January 2006 to December 2006. ..... A-12

Figure A. 12 Frequency analysis of *E. coli* concentrations at station 2-HUN000.80 in Hungary Creek for the period from January 2006 to December 2006. ..... A-13

Figure A. 13 Frequency analysis of *E. coli* concentrations at station 2-HUN002.11 in Hungary Creek for the period from January 2006 to December 2006. ..... A-14

Figure A. 14 Frequency analysis of *E. coli* concentrations at station 2-JRN000.81 in Jones Run for the period from June 2005 to December 2006. ..... A-15

Figure A. 15 Frequency analysis of *E. coli* concentrations at station 2-JOP001.27 in Jordan Branch for the period from January 2006 to December 2006. ..... A-16

Figure A. 16 Frequency analysis of *E. coli* concentrations at station 2-LKH000.04 in Lickinghole Creek for the period from January 2009 to December 2009. ..... A-17

Figure A. 17 Frequency analysis of *E. coli* concentrations at station 2-LKH001.00 in Lickinghole Creek for the period from January 2009 to December 2009. ..... A-18

Figure A. 18 Frequency analysis of *E. coli* concentrations at station 2-LKH001.46 in Lickinghole Creek for the period from January 2009 to December 2009. ..... A-19

Figure A. 19 Frequency analysis of *E. coli* concentrations at station 2-LKH002.42 in Lickinghole Creek for the period from January 2009 to December 2009. ..... A-20

Figure A. 20 Frequency analysis of *E. coli* concentrations at station 2-LKH003.42 in Lickinghole Creek for the period from January 2009 to December 2009. ..... A-21

Figure A. 21 Frequency analysis of *E. coli* concentrations at station 2-NTR000.23 in North Run for the period from June 2005 to December 2006. ..... A-22

Figure A. 22 Frequency analysis of *E. coli* concentrations at station 2-NTR003.42 in North Run for the period from July 2003 to December 2006. ..... A-23

Figure A. 23 Frequency analysis of *E. coli* concentrations at station 2-NTR004.77 in North Run for the period from January 2006 to December 2006. ..... A-24

Figure A. 24 Frequency analysis of *E. coli* concentrations at station 2-PBR000.12 in Piney Branch for the period from January 2006 to December 2006. ..... A-25

Figure A. 25 Frequency analysis of *E. coli* concentrations at station 2-PWH002.12 in Powhite Creek for the period from May 2004 to November 2006. ..... A-26

Figure A. 26 Frequency analysis of *E. coli* concentrations at station 2-RUM004.38 in Rumley Marsh for the period from June 2005 to December 2006. ..... A-27

Figure A. 27 Frequency analysis of *E. coli* concentrations at station 2-SMN001.42 in Schiminoe Creek for the period from February 2009 to November 2010. ..... A-28

Figure A. 28 Frequency analysis of *E. coli* concentrations at station 2-SNF000.04 in Stony Run for the period from January 2007 to December 2009. ..... A-29

Figure A. 29 Frequency analysis of *E. coli* concentrations at station 2-SNF000.23 in Stony Run for the period from January 2009 to December 2009. ..... A-30

Figure A. 30 Frequency analysis of *E. coli* concentrations at station 2-SNF000.87 in Stony Run for the period from January 2009 to December 2009. ..... A-31

Figure A. 31 Frequency analysis of *E. coli* concentrations at station 2-SNF001.27 in Stony Run for the period from January 2009 to December 2009. ..... A-32

Figure A. 32 Frequency analysis of *E. coli* concentrations at station 2-SNF001.58 in Stony Run for the period from January 2009 to November 2009. ..... A-33

Figure A. 33 Frequency analysis of *E. coli* concentrations at station 2-SNF003.70 in Stony Run for the period from January 2009 to December 2009. ..... A-34

Figure A. 34 Frequency analysis of *E. coli* concentrations at station 2-SNF005.59 in Stony Run for the period from January 2009 to December 2009. ..... A-35

Figure A. 35 Frequency analysis of *E. coli* concentrations at station 2-SNF006.44 in Stony Run for the period from January 2009 to December 2009. ..... A-36

Figure A. 36 Frequency analysis of *E. coli* concentrations at station 2-TPT000.31 in Trumpet Branch for the period from January 2006 to December 2006. ..... A-37

Figure A. 37 Frequency analysis of *E. coli* concentrations at station 2-UPM000.26 in Upham Brook for the period from January 2006 to December 2006. ..... A-38

Figure A. 38 Frequency analysis of *E. coli* concentrations at station 2-UPM001.35 in Upham Brook for the period from June 2005 to January 2011. ..... A-39

Figure A. 39 Frequency analysis of *E. coli* concentrations at station 2-UPM002.41 in Upham Brook for the period from January 2006 to December 2006. ..... A-40

Figure A. 40 Frequency analysis of *E. coli* concentrations at station 2-UPM003.53 in Upham Brook for the period from January 2006 to December 2006. ..... A-41

Figure A. 41 Frequency analysis of *E. coli* concentrations at station 2-UPM005.26 in Upham Brook for the period from January 2006 to December 2006. ..... A-42

Figure A. 42 Frequency analysis of *E. coli* concentrations at station 2-UPM007.03 in Upham Brook for the period from July 2003 to December 2006. ..... A-43

Figure A. 43 Frequency analysis of *E. coli* concentrations at station 2-UPM008.76 in Upham Brook for the period from January 2006 to December 2006. ..... A-44

Figure A. 44 Frequency analysis of *E. coli* concentrations at station 2-WOS002.69 in White Oak Swamp for the period from January 2003 to November 2008. ..... A-45

Figure A. 45 Frequency analysis of *E. coli* concentrations at station 2-WOS002.69 in Lickinghole Creek X-Trib for the period from January 2009 to December 2009. ..... A-46

Figure A. 46 Frequency analysis of *E. coli* concentrations at station 2-XXP000.23 in Upham Brook X-Trib for the period from January 2006 to December 2006. ..... A-47

Figure A. 47 Frequency analysis of *E. coli* concentrations at station 2-XXQ000.12 in Upham Brook X-Trib for the period from January 2006 to December 2006. ..... A-48

Figure A. 48 Frequency analysis of *E. coli* concentrations at station 2-XAG000.50 in Stony Run X-Trib for the period from January 2009 to December 2009. ..... A-49

Figure A. 49 Frequency analysis of Fecal Coliform concentrations at station 2-CHK032.77 in the Chickahominy River for the period from January 2001 to March 2006. ..... A-50

Figure A. 50 Frequency analysis of Fecal Coliform concentrations at station 2-CHK042.22 in the Chickahominy River for the period from May 2001 to June 2003. ..... A-51

Figure A. 51 Frequency analysis of Fecal Coliform concentrations at station 2-CHK055.04 in the Chickahominy River for the period from January 2001 to May 2003. ..... A-52

Figure A. 52 Frequency analysis of Fecal Coliform concentrations at station 2-CHK062.57 in the Chickahominy River for the period from January 2001 to January 2011. ..... A-53

Figure A. 53 Frequency analysis of Fecal Coliform concentrations at station 2-CHK067.30 in the Chickahominy River for the period from June 2001 to May 2003. ..... A-54

Figure A. 54 Frequency analysis of Fecal Coliform concentrations at station 2-CHK076.59 in the Chickahominy River for the period from June 2001 to January 2011. ..... A-55

Figure A. 55 Frequency analysis of Fecal Coliform concentrations at station 2-CHK079.23 in the Chickahominy River for the period from June 2001 to May 2003. ..... A-56

Figure A. 56 Frequency analysis of Fecal Coliform concentrations at station 2-SNF000.04 in Stony Run for the period from June 2001 to May 2003. ..... A-57

Figure A. 57 Frequency analysis of Fecal Coliform concentrations at station 2-WOS002.69 in White Oak Swamp for the period from June 2001 to July 2003. ..... A-58

Figure A. 58 Frequency analysis of *E. coli* concentrations at station 2-CNR000.66 in Collins Run for the period from July 2008 to June 2009. ..... A-59

Figure A. 59 Frequency analysis of *E. coli* concentrations at station 2-CNR001.54 in Collins Run for the period from July 2008 to June 2009. ..... A-60

Figure A. 60 Frequency analysis of *E. coli* concentrations at station 2-CNR001.58 in Collins Run for the period from July 2008 to June 2009. ..... A-61

Figure A. 61 Frequency analysis of *E. coli* concentrations at station 2-CNR002.69 in Collins Run for the period from July 2008 to June 2009. ..... A-62

Figure A. 62 Frequency analysis of *E. coli* concentrations at station 2-CHK025.15 in the Chickahominy River for the period from April 2006 to October 2006. ..... A-63

Figure A. 63 Frequency analysis of *E. coli* concentrations at station 2-CHK026.94 in the Chickahominy River for the period from April 2006 to October 2006. ..... A-64

Figure A. 64 Frequency analysis of *E. coli* concentrations at station 2-CHK029.54 in the Chickahominy River for the period from April 2006 to October 2006. ..... A-65

Figure A. 65 Frequency analysis of *E. coli* concentrations at station 2-XAR000.57 in an X-Trib to Upham Brook for the period from May 2004 to August 2010..... A-66

Figure B. 1 All subwatersheds delineated for modeling in the Chickahominy River study area. B-5

Figure B. 2 Land uses in the Chickahominy River study area watershed. B-8

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

Figure B. 4 Modeling time periods, annual historical flow (USGS Station 02042500), and precipitation (Stations 447201/449025/449151) data. B-13

Figure B. 5 Modeling time periods, seasonal historical flow (USGS Station 02042500), and precipitation (Stations 447201/449025/449151) data. B-13

Figure B. 6 Bacteria concentrations at 2-CHK025.15 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-15

Figure B. 7 Bacteria concentrations at 2-CHK026.94 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-16

Figure B. 8 Bacteria concentrations at 2-CHK029.54 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-16

Figure B. 9 Bacteria concentrations at 2-CHK032.77 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-17

Figure B. 10 Bacteria concentrations at 2-CHK042.22 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-17

Figure B. 11 Bacteria concentrations at 2-CHK055.04 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-18

Figure B. 12 Bacteria concentrations at 2-CHK057.85 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-18

Figure B. 13 Bacteria concentrations at 2-CHK062.57 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-19

Figure B. 14 Bacteria concentrations at 2-CHK067.30 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-19

Figure B. 15 Bacteria concentrations at 2-CHK076.59 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-20

Figure B. 16 Bacteria concentrations at 2-CHK079.23 on the Chickahominy vs. discharge at USGS Gaging Station #02042500. ..... B-20

Figure B. 17 Bacteria concentrations at 2-CNR000.89 on Collins Run vs. discharge at USGS Gaging Station #02042500. ..... B-21

Figure B. 18 Bacteria concentrations at 2-CNR001.16 on Collins Run vs. discharge at USGS Gaging Station #02042500. ..... B-21

Figure B. 19 Bacteria concentrations at 2-CNR001.54 on Collins Run vs. discharge at USGS Gaging Station #02042500. ..... B-22

Figure B. 20 Bacteria concentrations at 2-SNF000.04 on Stony Run vs. discharge at USGS Gaging Station #02042500. ..... B-22

Figure B. 21 Bacteria concentrations at 2-WOS002.69 on White Oak Swamp vs. discharge at USGS Gaging Station #02042500. ..... B-23

Figure B. 22 Bacteria concentrations at 2-UPM003.53 on Upham Brook vs. discharge at USGS Gaging Station #02042500. ..... B-23

Figure B. 23 Bacteria concentrations at 2-BEV002.00 on Beaverdam Creek vs. discharge at USGS Gaging Station #02042500. ..... B-24

Figure B. 24 Bacteria concentrations at 2-BTS002.62 on Boatswain Creek vs. discharge at USGS Gaging Station #02042500. ..... B-24

Figure B. 25 Example of raccoon habitat layer in the Chickahominy River study area, as developed by MapTech. B-30

Figure B. 26 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the in-stream first-order decay rate (FSTDEC). B-36

Figure B. 27 Results of sensitivity analysis on monthly mean concentrations as affected by changes in maximum fecal accumulation on land (MON-SQOLIM). B-37

Figure B. 28 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the wash-off rate from land surfaces (WSQOP). B-38

Figure B. 29 Results of total loading sensitivity analysis for outlet of the Chickahominy River Watershed study area. B-39

Figure B. 30 Results of sensitivity analysis on monthly geometric-mean concentrations in the Chickahominy River Watershed study area, as affected by changes in land-based loadings. B-40

Figure B. 31 Results of sensitivity analysis on monthly geometric-mean concentrations in the Chickahominy River Watershed study area, as affected by changes in loadings from direct nonpoint sources..... B-41

Figure B. 32 Chickahominy River modeled flow duration versus USGS Gaging Station #02042500 data from 10/1/1996 to 9/30/2000 (subwatershed 5). B-44

Figure B. 33 Chickahominy River modeled results versus USGS Gaging Station #02042500 data from 10/1/1996 to 9/30/2000 (subwatershed 5). B-45

Figure B. 34 Chickahominy River modeled flow duration versus USGS Gaging Station #02042500 data for validation (subwatershed 4)..... B-47

Figure B. 35 Chickahominy River validation modeled results versus USGS Gaging Station #02042500 data from (subwatershed 5)..... B-48

Figure B. 36 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK076.59 in subwatershed 16 on the Chickahominy River..... B-50

Figure B. 37 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK062.57 in subwatershed 12 on the Chickahominy River..... B-51

Figure B. 38 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK032.77 in subwatershed 3 on the Chickahominy River..... B-51

Figure B. 39 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK025.15 in subwatershed 2 on the Chickahominy River..... B-52

Figure B. 40 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-BEV002.00 in subwatershed 25 on Beaverdam Creek..... B-52

Figure B. 41 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-CHK076.59 in subwatershed 16 on the Chickahominy River..... B-54

Figure B. 42 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-CHK062.57 in subwatershed 12 on the Chickahominy River..... B-55

Figure B. 43 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-BEV002.00 in subwatershed 25 on Beaverdam Creek..... B-55

LIST OF TABLES

Table ES. 1 Impairments within the Chickahominy River watershed included in this study. xx

Table ES. 2 Percent reduction to existing loads needed to meet the water quality standard. xxiii

Table ES. 3 Annual in-stream cumulative pollutant loads modeled after allocation in the Chickahominy River impairments (at main outlet). xxiii

Table 1.1 Impairments within the Chickahominy River Watershed included in this study. 1-8

Table 2.1 Summary of fecal coliform (cfu/100mL) data collected by VADEQ from January 2000 – January 2011. 2-7

Table 2.1 Summary of fecal coliform (cfu/100mL) data collected by VADEQ from January 2001 – January 2011 (cont.). 2-8

Table 2.2 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from January 2001 – October 2011 2-9

Table 2.2 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from January 2001 – October 2011 (cont.). 2-10

Table 3.1 Summary of VPDES point sources in the Chickahominy River and Tributaries watershed study area. 3-4

Table 3.2 Animal feeding operation (AFO), Confined animal feeding operation (CAFO) and Virginia Pollution Abatement (VPA) permits in the Chickahominy River and Tributaries watershed study area. 3-5

Table 3.3 Permits for MS4s in the James River – City of Richmond study area. 3-5

Table 3.4 Human population, housing units, houses on sanitary sewer, septic systems, and straight pipes for areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area. 3-8

Table 3.5 Volume of sanitary sewer overflows reported within the study area between October 2002 and March 2011. 3-9

Table 3.6 Application of biosolids within the Chickahominy River study area (2003 – 2010). 3-10

Table 3.7 Domestic animal population density, waste load, and fecal coliform (FC) density. 3-10

Table 3.8 Estimated domestic animal populations in areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area. 3-11

Table 3.9 Livestock populations in areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area. 3-12

Table 3.10 Average fecal coliform densities and waste loads associated with livestock. 3-13

Table 3.11 Average percentage of collected livestock waste applied throughout year. 3-13

Table 3.12 Average time dairy replacement heifers spend in different areas per day. 3-14

Table 3.13 Average time beef cows not confined in feedlots spend in pasture and stream access areas per day. 3-14

Table 3.14 Wildlife population densities for the Chickahominy River and Tributaries watershed study area. 3-15

Table 3.15 Estimated wildlife populations in the Chickahominy River and Tributaries watershed study area. 3-15

Table 3.16 Wildlife daily waste production and average fecal coliform densities. 3-16

Table 3.17 Wildlife percentage of time spent in stream access areas and habitat. 3-17

Table 5.1 Description of locations where allocation was conducted within the Chickahominy River watershed. 5-5

Table 5.2 Allocation scenarios for reducing current bacteria loads in the Chickahominy River and Tributaries. 5-6

Table 5.3 Estimated existing and allocated *E. coli* in-stream loads at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River. 5-8

Table 5.4 Estimated existing and allocated *E. coli* in-stream loads at the outlet of subwatershed 1 (entire study area) on the Chickahominy River. 5-9

Table 5.5 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River. 5-11

Table 5.6 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation at the outlet of subwatershed 1 (entire study area) on the Chickahominy River. 5-12

Table 5.7 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River. 5-13

Table 5.8 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation at the outlet of subwatershed 1 (entire study area) on the Chickahominy River. 5-14

Table 7.1 Public participation during TMDL development for the Chickahominy River and Tributaries watershed. 7-1

Table B. 1 Impairments and subwatersheds within the Chickahominy River study area. B-6

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

Table B. 3 Area of land use types in acres in the Chiackahominy River study area. B-9

Table B. 4 Example of an F-table calculated for the HSPF model. B-11

Table B. 5 Comparison of modeled period to historical records for the Chickahominy River. B-14

Table B. 6 Flow rates and bacteria loads used to model VADEQ active permits in the Chickahominy River study area. B-26

Table B. 7 Estimated failing septic systems and straight pipes for 2012 in the Chickahominy River study area. B-26

Table B. 8 HSPF base parameter values used to determine hydrologic model response. B-32

Table B. 9 HSPF Sensitivity analysis results for hydrologic model parameters for the Chickahominy River Watershed. B-33

Table B. 10 Base parameter values used to determine water quality model response. B-34

Table B. 11 Percent change in average monthly *E.coli* mean for the years 1998-2000. ..... B-35

Table B. 12 Initial hydrologic parameters estimated for the Chickahominy River TMDL study area, and resulting final values after calibration. B-43

Table B. 13 Hydrology calibration model performance from 10/1/1996 through 9/30/2000 at USGS Gaging Station #02042500 on the Chickahominy River Watershed (subwatershed 5). B-43

Table B. 14 Hydrology validation model performance from 10/1/2004 through 9/30/2008 at USGS Gaging Station #02042500 on the Chickahominy River (subwatershed 5). B-46

Table B. 15 Model parameters utilized for water quality calibration. B-49

Table B. 16 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the calibration period. B-53

Table B. 17 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period. B-56

Table C. 1 Current conditions of land applied fecal coliform load for the Chickahominy River by land-use(all Subwatersheds): C-2

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches): C-3

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-4

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-5

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-6

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-7

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-8

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-9

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued): C-10

Table C. 3 Existing annual (2012) loads from land-based sources for the Chickahominy River (all Subwatersheds): C-11

Table C. 4 Existing annual loads from direct-deposition sources for the Chickahominy River (all Reaches): C-12

EXECUTIVE SUMMARY

Background and Applicable Standards

There are five bacteria impairments in this study area including segments on the Chickahominy River, Collins Run, Beaverdam Creek, Boatswain Creek, and Stony Creek. These segments are listed on Virginia's 303(d) list because 10% or more of the total samples in the assessment period exceeded the Primary Contact Use (recreational/swimming) *E.coli* instantaneous standard of 235 colony forming unit per 100 mL (cfu/100 mL).

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** shows the details of impairments including stream name, impairment length and description, and percentage violation of the water quality standard.

The Virginia Department of Environmental Quality has recently moved towards a more cost effective approach to conducting TMDLs. The new approach is called Nested TMDL where the TMDL is developed for a "larger" geographic area that contains smaller sub-areas with impaired segments that formerly were the basis of TMDL projects.

Based on this approach, the downstream end of drainage area of the current TMDL project was extended further downstream in order to contain the Collins Run drainage area. The downstream end of the current study area ends at the tidally influenced portion of the Chickahominy River at around river mile 24.

Table ES. 1 Impairments within the Chickahominy River watershed included in this study.

Stream Name Impairment ID	**Impairment(s) Type**	**Initial Listing Year**	**2010 River Miles**	**2010 Listing Violation %**	**Impairment Location Description**
Collins Run VAP-G07_CNR01A00	*E. coli*	2002	4.50	33 EC	From the headwaters to river mile 0.99.
Beaverdam Creek VAP-G06R_BEV01A00	*E. coli*	2006	6.69	27 EC	From the headwaters to its confluence with the Chickahominy River.
Boatswain Creek VAP-G06R_BTS01A02	*E. coli*	2006	3.76	31 EC	From the headwaters to its confluence with the Chickahominy River.
Chickahominy River VAP-G06R_CHK01A98	*E. coli*	2008	7.54	12 EC	From the Route 360 bridge downstream the Route 156 bridge.
Stony Run VAP-G05R_SNF01A02	*E. coli*	2004	0.21	27 EC	From its confluence with Lickinghole Creek to its mouth at the confluence with the Chickahominy River.

Bacteria impairments are based on the instantaneous *E. coli* WQS of 235 cfu/100mL when violations exceed 10% for samples collected during the most recent data period assessment unless otherwise noted.

TMDL Endpoint and Water Quality Assessment

Fecal bacteria TMDLs in the Commonwealth of Virginia are developed using the *E. coli* standard. Whereas the Instantaneous Maximum Standard of 235 cfu/100ml with no greater than 10% violations is used to assess waters based on monthly or bimonthly samples, for TMDL development, the in-stream *E. coli* target is a geometric mean not exceeding 126 cfu/100 mL.

Source Assessment

Sources of bacteria were identified and quantified in the Chickahominy 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 Chickahominy River watershed ends up in the streams and rivers. Computer models help quantify the portion of bacteria within the Chickahominy River watershed that ends up in the stream and the impact of die-off.

The computer modeling process consists of several steps. First, the characteristics of the drainage area including land use, slopes, stream network, and soil properties, are entered into the model. Bacteria loads and parameters influencing bacteria are also entered into the corresponding 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.

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. For purposes of modeling the Chickahominy River watershed, the drainage area was divided into twenty seven (27) subwatersheds. The subdivision of entire area into smaller contributing areas allows for the placement of sources at the proper geographic location and better resemblance of actual connectivity of streams as observed in the real world.

Precipitation data was available within the watershed at the Richmond International Airport Coop station # 447201. Missing values were filled using daily precipitation from the West Point 2NW NCDC Coop station # 449025and Williamsburg 2N NCDC Coop station 449151. The final filled daily precipitation was disaggregated using the hourly station data.

The model was calibrated for hydrologic accuracy using daily flow data for the period October 1996 through September 2000. The modeled output from subwatershed 5 was compared against the Chickahominy River USGS Gaging Station #02042500 data. The modeled output was validated for the period of October 2004 to September 2008.

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.

The fecal coliform calibration was conducted using monitored data collected at multiple VADEQ monitoring stations for the period of October 2003 to September 2006. Water quality validation was conducted using data collected from multiple VADEQ monitoring stations for the period of October 2006 to September 2009.

Load Allocation Scenarios

Once the model was calibrated, the next step was to simulate reducing various source loads to levels that would result in attainment of the water quality standards. Scenarios were evaluated to predict the effects of different combinations of source reductions on final in-stream water quality. Virginia's water quality standard does not permit any exceedances, therefore, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100mL geometric mean). The final bacterial TMDLs for the Chickahominy River watershed include 100% reductions in straight pipes, sewer overflows, and livestock direct deposition to streams, and 73% reduction to wildlife direct deposition. Modeling results also indicated that considerable reductions to land based sources are needed to meet the water quality standard (**Table ES. 2**). The final TMDL information is shown in **Table ES. 3**.

Allocation scenarios were run for all subwatersheds until all simulated *E.coli* concentrations at the outlet of all impaired subwatersheds were allocated to 0% exceedances. Concentrations at the main outlet of the entire study area (currently not impaired) was also checked against (and met) all applicable water quality standards. In addition, populations were updated for Upham Brook and White Oak swamp (previously developed TMDLs) and simulated concentrations at their outlets were also checked against (and met) all applicable water quality standards. The most limiting subwatershed was subwatershed 24 (Boatswain Creek).

The reductions called for in Table ES.2 apply to the entire drainage area including all 27 subwatersheds. This however does not mean that each subwatershed will experience the same amount of reduction as all other subwatersheds because reduction will be based on actual, on the ground sources. For example while the TMDL calls for eliminating all straight pipes from the entire drainage area, if one of the subwatersheds does not have a straight pipe, no reductions will take place in that subwatershed for the straight pipe category.

Table ES. 2 Percent reduction to existing loads needed to meet the water quality standard.

Source	Needed Reduction (%)
Sanitary Sewer Overflows	100
Straight Pipes	100
Direct Livestock Deposition to Stream	100
Direct Wildlife Deposition to Stream	77
Load from Forest, Barren, Commercial, and Wetlands	77
Load from Agricultural and Developed Lands	99

Table ES. 3 Annual in-stream cumulative pollutant loads modeled after allocation in the Chickahominy River impairments (at main outlet).

Pollutant	Units	Impairment	WLA[1]	LA	MOS	TMDL
E. coli	cfu/yr	**Chickahominy River**	2.41E+12	5.66E+12	*Implicit*	8.07E+12

[1] WLA by permit can be found in the corresponding allocation chapters.

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 Chickahominy River watershed. Development of TMDL implementation plans (IP) will immediately follow the TMDL process. 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. Also, VADEQ will request SWCB authorization to incorporate the TMDL implementation plan into the appropriate waterbody. With successful completion of implementation plans, Virginia continues the process of restoring impaired waters and enhancing the value of this important resource.

In some streams for which a TMDL has 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 or modified. 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. Should a UAA be conducted for use removal or change be recommended in the future for any of the waterbodies within this study, 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 TMDLs for the impairments in the Chickahominy River study area, public involvement was encouraged through a set of first public meetings (8/3/2011), and final public meetings (5/24/2012). An introduction of the agencies involved, an overview of the TMDL process, details of the pollutant sources, and the

specific approach to developing the Chickahominy River watershed TMDL were presented at the first public meetings. 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. There were 30-day public comment periods after both first and final public meetings. Written comments were addressed, and where applicable, reflected in the final document.

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1. INTRODUCTION

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 *Chickahominy River and Tributaries Watershed Characteristics*

The Chickahominy River watershed (USGS Hydrologic Unit Code 02080206) is located in Hanover, Charles City, New Kent and Henrico Counties, Virginia. A portion of the watershed is also within the City of Richmond. This watershed is a part of the James River basin, which drains to the Chesapeake Bay. The location of the watershed is shown in **Figure 1.1**. The drainage area flowing into the most downstream impairment in this project is approximately 194,000 acres.

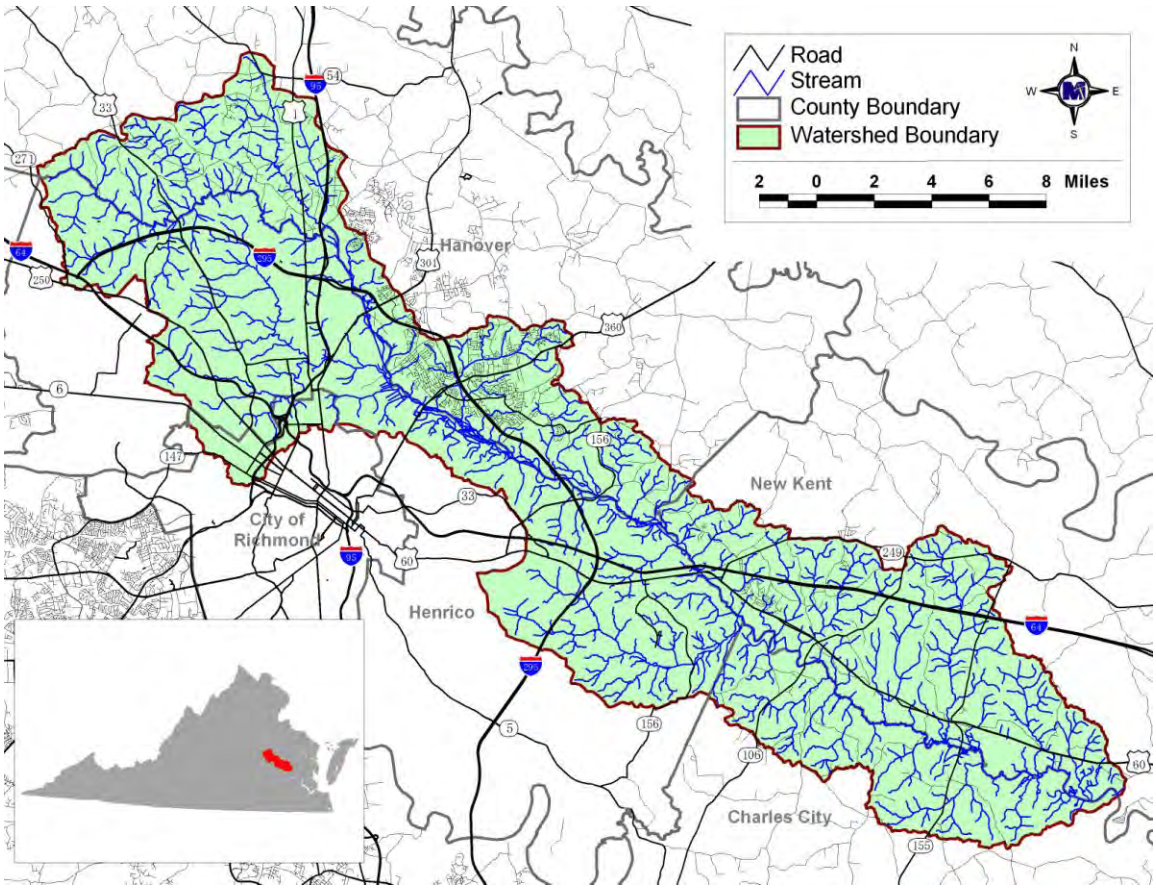

Figure 1.1 Location of the Chickahominy River and Tributaries watershed.

The Chickahominy River and Tributaries 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 (65) 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 Chickahominy 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).

As for the climatic conditions in the the Chickahominy River watershed, during the period from 1893 to 2010 Ashland, Virginia (NCDC station# 440327) received an average annual precipitation of 42.14 inches, with 54% of the precipitation occurring during the May through October growing season (SERCC, 2011). Average annual snowfall is 15 inches, with the highest snowfall occurring during January (SERCC, 2011). The highest average daily temperature of 86.6 ºF occurs in July, while the lowest average daily temperature of 26.0 ºF occurs in January (SERCC, 2011).

Land use in the study area was characterized using the National Land Cover Database 2001 (NLCD). The drainage area is predominantly forest with woodlands covering approximately 50% of the area. Developed areas in the watershed comprise roughly 16%. Pasture and hay land covers account for roughly 12% of the drainage area with croplands covering around 6% of the area. Wetlands are a sizable portion covering roughly 10% of the drainage area. Lands designated as commercial account for around 5% with water and barren comprising around 1% each. Land use grouping is provided in **Table B. 2** and land use acreage is provided in **Table B. 3** in Appendix B.

1.3 Chickahominy River and Tributaries Recreation Use Impairments

There are five different impaired streams in this study area, Chickahominy River, Collins Run, Beaverdam Creek, Boatswain Creek and Stony Run. In the sections below each impaired stream segment is described. **Figure 1.2** shows the impaired segments of the

Chickahominy River outlined in this study. **Table 1.1** details information regarding the impairments to the Chickahominy River and Tributaries covered in this study.

The Virginia Department of Environmental Quality has recently moved towards a more cost effective approach to conducting TMDLs. In the new approach, TMDLs may be developed for large areas containing several impaired stream segments. These large geographic units are herein called "nested TMDL units" or "NTUs" because they consist of watersheds that formerly were the basis of TMDL projects.. Using this approach, NTUs are designed to provide TMDLs that are cost effective, while being scientifically defensible.

The building blocks for the NTUs are U. S. Geological Survey (USGS) 12-digit hydrologic units (HUCs). The HUCs were attributed with land cover and use values through GIS-extraction of information from the National Land Classification Dataset (2001), hydrologic connectivity from the USGS National Watershed Boundary dataset, and U. S. Environmental Protection Agency Ecoregion Level III features. HUCs were aggregated in an upstream fashion if their properties indicated the likelihood of similar TMDL conclusions. Aggregation continued until a HUC was encountered that had a substantially different potential TMDL conclusion, was a headwater, or had exceeded the cluster size limit. When a TMDL is to be developed for an impaired segment within a nested area, a decision is made as to whether develop the TMDL only for that segment or expand the TMDL development for the entire NTU.

The current project contains two previously developed TMDLs each making up an NTU. These projects are the Upham Brook bacteria TMDL and the White Oak Swamp Bacteria TMDL. Two NTUs (103 and 104) in the upland area of the Chickahominy River watershed were combined due to similarities. Two other NTUs (101 and 100) towards the downstream end of the watershed were also combined along with a portion of NTU 90. This portion is herein called NTU 90.1 with downstream limit ending at the tidally influenced portion of the Chickahominy River at around river mile 24.

1.3.1 Collins Run (VAP-G07_CNR01A00)

Collins Run in Charles City County, VA flows northeast into the Chickahominy River near river mile 30.

Collins Run is listed as impaired from its headwaters to river mile 0.99. It was initially listed in 2002 as impaired for not supporting the recreation/swimming use. VADEQ monitoring at station 2-CNR001.58 showed a 33% bacteria standard violation rate in the 2010 assessment.

1.3.2 Beaverdam Creek (VAP-G06R_BEV01A00)

Beaverdam Creek, in Hanover County, flows south before its confluence with the Chickahominy River.

Beaverdam Creek from its headwaters to its mouth (6.69 stream miles) was listed as impaired on the 2006 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-BEV002.00 had a 27% violation rate in the 2010 assessment.

1.3.3 Boatswain Creek (VAP-G06R_BTS01A02)

Boatswain Creek, in Hanover County, flows south before its confluence with the Chickahominy River.

Boatswain Creek from its headwaters to its mouth (3.76 stream miles) was initially listed as impaired on the 2006 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-BTS002.62 had a 31% violation rate in the 2010 assessment.

1.3.4 Chickahominy River (VAP-G06R_CHK01A98)

This impaired segment was added to the 2008 impaired waters list for not supporting the recreation/swimming use. This impaired segment extends from the Route 360 bridge downstream the Route 156 bridge (7.54 stream miles based on the 2010 assessment). VADEQ monitoring station 2-CHK062.57 had a bacteria standard violation rate of 12% in the 2010 assessment.

1.3.5 Stony Run (VAP-G05R_SNF01A02)

Stony Run, in Hanover County, flows south-east before its confluence with the Chickahominy River.

Stony Run from its confluence with Lickinghole Creek to its mouth (0.21 stream miles) was listed as impaired on the 2004 303(d) list for not supporting the recreation/swimming use. VADEQ monitoring station 2-SNF000.04 had a 27% violation rate in the 2010 assessment.

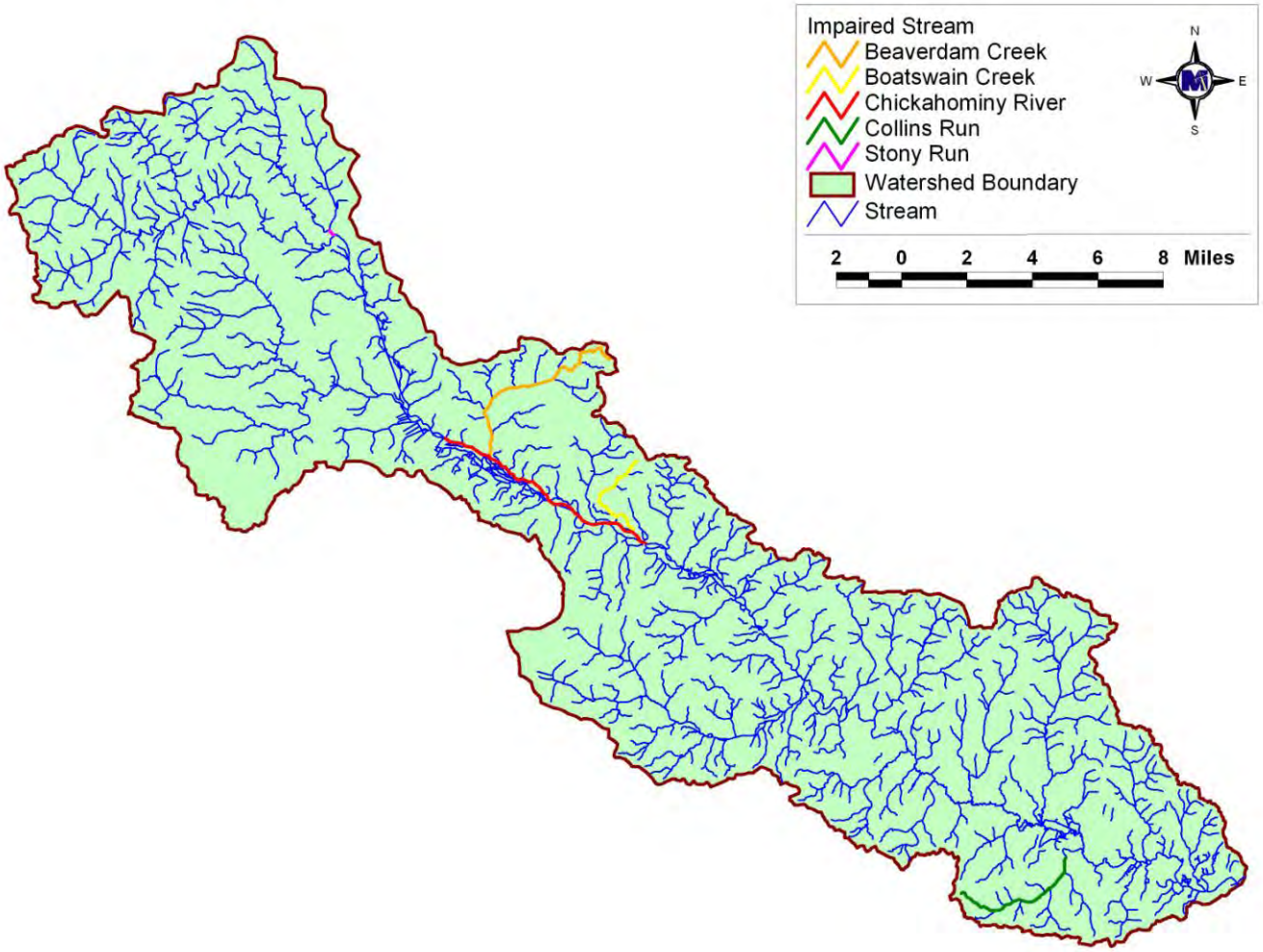

Figure 1.2 The impaired segments in the Chickahominy River and Tributaries watershed.

Table 1.1 Impairments within the Chickahominy River Watershed included in this study.

Stream Name Impairment ID	**Impairment(s) Contracted**	**Initial Listing Year**	**2010 River Miles**	**2010 Listing Violation%**	**Impairment Location Description**
Collins Run VAP-G07_CNR01A00	*E. coli*	2002	4.50	33 EC	From the headwaters to river mile 0.99.
Beaverdam Creek VAP-G06R_BEV01A00	*E. coli*	2006	6.69	27 EC	From the headwaters to its confluence with the Chickahominy River.
Boatswain Creek VAP-G06R_BTS01A02	*E. coli*	2006	3.76	31 EC	From the headwaters to its confluence with the Chickahominy River.
Chickahominy River VAP-G06R_CHK01A98	*E. coli*	2008	7.54	12 EC	From the Route 360 bridge downstream the Route 156 bridge.
Stony Run VAP-G05R_SNF01A02	*E. coli*	2004	0.21	27 EC	From its confluence with Lickinghole Creek to its mouth at the confluence with the Chickahominy River.

EC - Bacteria impairments are based on the instantaneous *E. coli* WQS of 235 cfu/100mL when violations exceed 10% for samples collected during the most recent data period assessment unless otherwise noted.

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

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

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

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

Virginia adopted its current *E. coli* and *enterococci* standard in January 2003. *E. coli* and *enterococci* are both bacteriological organisms that can be found in the intestinal tract of warm-blooded animals; there is a strong correlation between these and the incidence of gastrointestinal illness. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination. Prior to January 2003, Virginia water quality standard in fresh water for swimming/recreational use was based on fecal coliform rather than *E.coli.* The move was based on EPA 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.

The criteria which were used in developing the bacteria TMDL in this study 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

The first step in developing a TMDL is the establishment of in-stream numeric endpoints, which are used to evaluate the attainment of acceptable water quality. In-stream numeric endpoints, therefore, represent the water quality goals that are to be achieved by implementing the load reductions specified in the TMDL. For the bacteria impairments in the Chickahominy 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.

Since modeling provided simulated output of *E. coli* concentrations at 1-hour intervals, assessment of TMDLs was made using the geometric mean standard. Therefore, the in-stream *E. coli* target for the TMDL in this study was a monthly geometric mean not exceeding 126 cfu/100 ml.

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 Chickahominy River and Tributaries watershed. An examination of data from water quality stations used in the 303(d) 2010 assessment as well as data from other stations was performed. Sources of data and pertinent results are discussed.

2.3.1 Inventory of Water Quality Monitoring Data

The primary sources of available water quality information are:

- Bacteria enumerations from seventy three (73) VADEQ in-stream monitoring stations dating from January 1990 to October 2011.

2.3.1.1 VADEQ Water Quality Monitoring

Data from in-stream water samples, collected at VADEQ monitoring stations from January 2000 to October 2011 (**Figure 2.1** and **Figure 2.2**), were analyzed for fecal coliform (**Table 2.1**) and *E.coli* (**Table 2.2**). The 2010 DEQ Integrated report covered an assessment window of monitoring data collected from 1/1/03 – 12/31/08. DEQ performed additional monitoring at several stations after the assessment in preparation for the TMDL, therefore, bacteria violations in Table 2.2 may reflect more current exceedance rates than those in the introduction section of the report. Samples were taken for the express purpose of determining compliance with the state instantaneous bacteria standards. Until recent years, and as a matter of economy, samples showing fecal coliform concentrations below 100 cfu/100 mL or in excess of a detection limit (*e.g.*, 8,000 or 16,000 cfu/100 mL, depending on the laboratory procedures employed for the sample) were not analyzed further to determine the precise concentration of fecal coliform bacteria. The result is that reported values of 100 cfu/100 mL most likely represent concentrations below 100 cfu/100 mL, and reported concentrations of 8,000 or 16,000 cfu/100 mL most likely represent concentrations in excess of these values. Information in the tables is arranged in alphabetical order by stream name then from downstream to upstream station location.

Appendix A shows the frequency plots for fecal coliform and *E.coli* at VADEQ monitoring stations.

Figure 2.1 Location of VADEQ water quality monitoring stations in the upper portion of the Chickahominy River and Tributaries watershed.

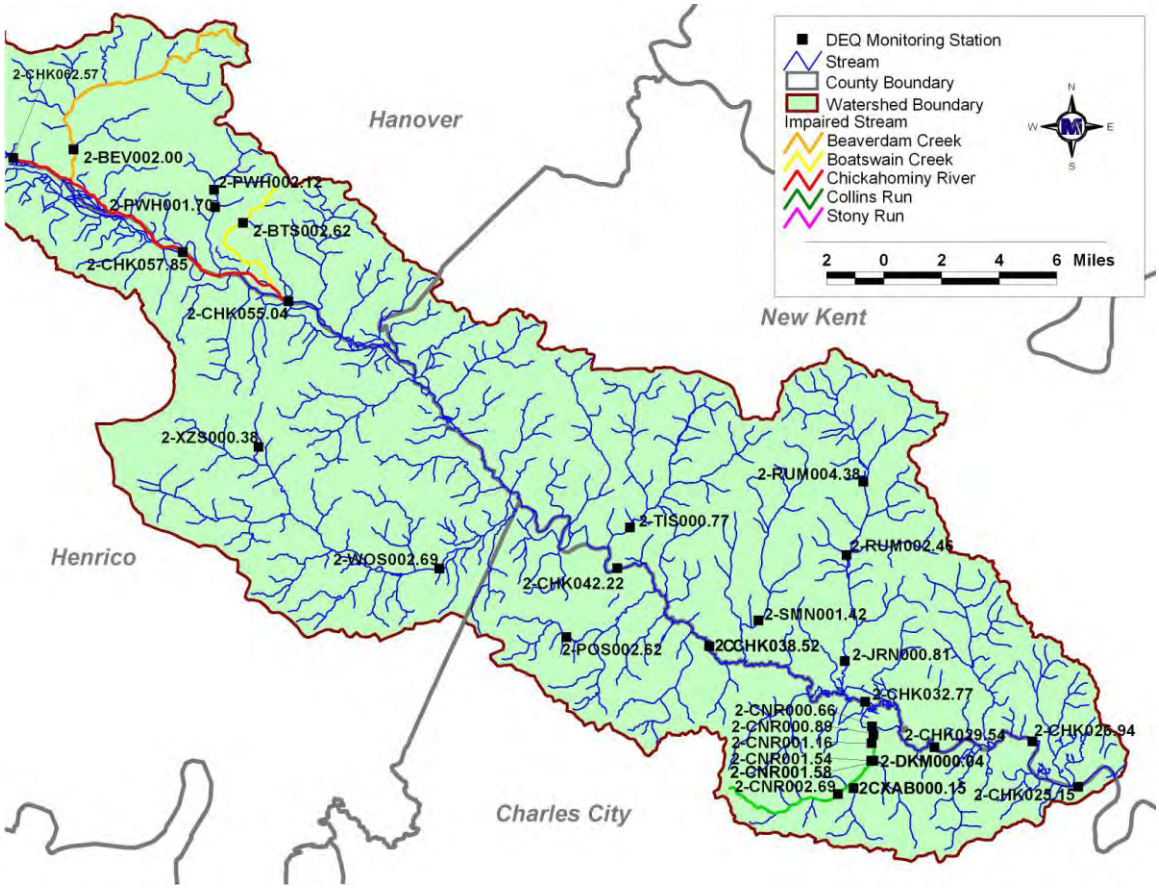

Figure 2.2 Location of VADEQ water quality monitoring stations in the lower portion of the Chickahominy River and Tributaries watershed.

Table 2.1 Summary of fecal coliform (cfu/100mL) data collected by VADEQ from January 2000 – January 2011.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Chickahominy River	2-CHK025.15	4/2001 - 10/2001	7	100	100	100	100	0	0.0
Chickahominy River	2-CHK026.94	4/2001 - 10/2001	7	100	100	100	100	0	0.0
Chickahominy River	2-CHK029.54	4/2001 - 10/2001	7	100	200	114	100	38	0.0
Chickahominy River	2-CHK032.77	1/2001 - 3/2006	32	25	1,100	107	100	186	3.1
Chickahominy River	2-CHK042.22	5/2001 - 6/2003	13	100	400	162	100	112	0.0
Chickahominy River	2-CHK055.04	1/2001 - 5/2003	27	100	2,200	207	100	403	3.7
Chickahominy River	2-CHK057.85	5/2004	1	2,000	2,000	2,000	NA	NA	100.0
Chickahominy River	2-CHK062.57	1/2001 - 1/2011	47	25	1,200	195	100	281	19.1
Chickahominy River	2-CHK067.30	6/2001 - 5/2003	13	100	500	154	100	120	7.7
Chickahominy River	2-CHK070.14	3/2007	1	25	25	25	NA	NA	0.0
Chickahominy River	2-CHK076.59	1/2001 – 1/2011	34	25	2,000	315	100	562	14.7
Chickahominy River	2-CHK079.23	6/2001 - 5/2003	13	100	1,200	323	100	352	15.4
Chickahominy River X-Trib	2-XYC000.31	4/2006	1	25	25	25	NA	NA	0.0
Collins Run	2-CNR000.89	3/2001 - 4/2002	6	18	1,300	301	120	500	16.7
Collins Run	2-CNR001.16	3/2001 - 4/2002	6	45	2,200	479	114	850	16.7
Collins Run	2-CNR001.54	3/2001 - 4/2002	6	18	2,400	425	19	968	16.7
Jones Run	2-JRN000.81	1/2001 - 3/2001	2	100	100	100	NA	100	0.0
North Run	2-NTR005.53	2/2002 - 3/2004	3	50	200	117	100	76	0.0
Possum Run	2-POS002.62	3/2006	1	25	25	25	NA	NA	0.0
Powhite Creek	2-PWH001.70	3/2005	1	25	25	25	NA	NA	0.0
Stony Run	2-SNF000.04	6/2001 - 5/2003	12	100	1,000	258	100	326	16.7
Toe Ink Swamp	2-TIS000.77	8/2003	1	75	75	75	NA	NA	0.0

NA – Not applicable
[1] Based on an instantaneous fecal coliform standard of 400 cfu/100mL.

Table 2.1 Summary of fecal coliform (cfu/100mL) data collected by VADEQ from January 2001 – January 2011 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Upham Brook	2-UPM003.53	10/2001 - 3/2001	3	330	3,500	1,643	1,100	1,653	66.7
White Oak Swamp	2-WOS002.69	1/2000 - 7/2003	34	20	2,700	433	100	692	20.6
White Oak Swamp X-Tributary	2-XZS000.38	5/2008	1	25	25	25	NA	NA	0.0

NA – Not applicable
[1] Based on the interim instantaneous fecal coliform standard of 400 cfu/100mL.

Table 2.2 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from January 2001 – October 2011.

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Beaverdam Creek	2-BEV002.00	8/2003 - 11/2010	23	25	1,300	231	100	352	26.1
Boatswain Creek	2-BTS002.62	5/2004 - 11/2006	16	25	650	215	88	236	31.3
Chickahominy River	2-CHK025.15	4/2006 – 10/2011	14	25	25	25	25	25	0.0
Chickahominy River	2-CHK026.94	4/2006 - 10/2011	14	25	50	27	25	8	0.0
Chickahominy River	2-CHK029.54	4/2006 - 10/2011	14	25	175	50	25	45	0.0
Chickahominy River	2-CHK032.77	7/2003 - 3/2006	21	25	880	86	25	186	4.8
Chickahominy River	2CCHK038.52	6/2011	1	40	40	40	NA	NA	0.0
Chickahominy River	2-CHK042.22	1/2007 - 11/2008	12	2	200	102	100	71	0.0
Chickahominy River	2-CHK057.85	5/2004	1	800	800	800	NA	NA	100.0
Chickahominy River	2-CHK062.57	8/2003 – 9/2011	50	2	2,000	229	100	443	11.8
Chickahominy River	2-CHK067.30	2/2009 - 11/2010	12	25	1,100	206	100	314	25.0
Chickahominy River	2-CHK070.14	3/2007	1	10	10	10	NA	NA	0.0
Chickahominy River	2CCHK071.66	2/2009 - 11/2010	12	25	2,000	273	100	560	16.7
Chickahominy River	2-CHK076.59	7/2003 - 9/2011	51	10	2,000	208	100	443	11.8
Chickahominy River	2-CHK079.23	1/2007 - 11/2008	12	24	400	119	100	99	8.3
Chickahominy River X-Tributary	2-XYC000.31	4/2006	1	10	10	10	NA	NA	0.0
Collins Run	2-CNR000.66	7/2008 - 6/2009	12	100	200	117	100	39	0.0
Collins Run	2-CNR001.54	7/2008 - 6/2009	12	100	300	125	100	62	8.3
Collins Run	2-CNR001.58	7/2008 - 6/2009	12	100	500	175	100	129	25.0
Collins Run	2-CNR002.69	7/2008 - 6/2009	12	100	700	258	100	243	33.3
Collins Run X-Trib	2CXAB000.15	7/2008 - 6/2009	12	100	400	133	100	89	8.3
Dockman Swamp	2-DKM000.04	7/2008 - 6/2009	12	100	200	108	100	29	0.0
Flippen Creek	2-FLP000.92	1/2006 - 12/2006	12	12	4,600	1,047	260	1,586	58.3
Horsepen Branch	2-HOH000.57	1/2006 - 12/2006	12	11	8,000	1,634	425	2,985	66.7
Hungary Creek	2-HUN000.80	1/2006 - 12/2006	12	14	620	253	205	211	33.3
Hungary Creek	2-HUN002.11	1/2006 - 12/2006	12	15	900	298	240	282	50.0
Jones Run	2-JRN000.81	6/2005 - 12/2006	10	25	280	60	25	83	10.0

NA – Not applicable

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

Table 2.2 Summary of *E. coli* (cfu/100mL) data collected by VADEQ from January 2001 – October 2011 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Jordan Branch	2-JOP001.27	1/2006 - 12/2006	12	41	8,000	1,045	390	2,221	58.3
Lickinghole Creek	2-LKH000.04	1/2009 - 12/2009	12	100	300	142	100	79	16.7
Lickinghole Creek	2-LKH001.00	1/2009 - 12/2009	12	100	800	167	100	202	8.3
Lickinghole Creek	2-LKH001.46	1/2009 - 12/2009	12	100	500	158	100	124	16.7
Lickinghole Creek	2-LKH002.42	1/2009 - 12/2009	12	100	1,200	317	100	351	33.3
Lickinghole Creek	2-LKH003.42	1/2009 - 12/2009	12	100	900	200	100	237	16.7
Lickinghole Creek X-Trib.	2-XOI000.65	1/2009 - 12/2009	12	100	700	183	100	185	16.7
North Run	2-NTR000.23	6/2005 - 5/2011	23	19	2,000	321	150	465	34.8
North Run	2-NTR003.42	7/2003 - 12/2006	23	25	1,300	248	150	352	30.4
North Run	2-NTR004.77	1/2006 - 12/2006	12	20	900	348	305	273	66.7
North Run	2-NTR005.53	6/2003 - 3/2004	2	10	160	85	NA	106	0.0
Piney Branch	2-PBR000.12	1/2006 - 12/2006	12	37	7,700	1,363	370	2,514	66.7
Possum Run	2-POS002.62	3/2006	1	50	50	50	NA	NA	0.0
Powhite Creek	2-PWH001.70	3/2005	1	10	10	10	NA	NA	0.0
Powhite Creek	2-PWH002.12	5/2004 - 11/2006	15	25	650	70	25	161	6.7
Rumley Marsh	2-RUM002.46	1/2011 – 9/2011	5	25	150	75	50	59	0.0
Rumley Marsh	2-RUM004.38	6/2005 - 12/2006	10	25	120	66	63	42	0.0
Schiminoe Creek	2-SMN001.42	2/2009 - 11/2010	12	25	1,600	333	125	473	25.0
Stony Run	2-SNF000.04	1/2007 - 12/2009	23	66	900	181	100	188	21.7
Stony Run	2-SNF000.23	1/2009 - 12/2009	12	100	1,100	267	150	293	25.0
Stony Run	2-SNF000.87	1/2009 - 12/2009	12	100	800	175	100	201	8.3
Stony Run	2-SNF001.27	1/2009 - 12/2009	12	100	1,000	217	100	259	25.0
Stony Run	2-SNF001.58	1/2009 - 11/2009	11	100	1,500	345	100	437	45.5
Stony Run	2-SNF003.70	1/2009 - 12/2009	12	100	1,500	283	100	402	25.0
Stony Run	2-SNF005.59	1/2009 - 12/2009	10	100	2,400	730	300	815	60.0
Stony Run	2-SNF006.44	1/2009 - 12/2009	10	100	1,400	250	100	406	10.0
Stony Run X-Trib	2CXAG000.50	1/2009 - 12/2009	12	100	1,200	267	100	358	25.0

NA – Not applicable

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

Table 2.2 Summary of E. coli (cfu/100mL) data collected by VADEQ from January 2001 – October 2011 (cont.).

Stream	Station	Date	Count	Minimum	Maximum	Mean	Median	Standard Deviation	Violation[1] %
Toe Ink Swamp	2-TIS000.77	8/2003	1	40	40	40	NA	NA	0.0
Trumpet Branch	2-TPT000.31	1/2006 - 12/2006	12	49	20,000	2,607	575	5,617	75.0
Upham Brook	2-UPM000.26	1/2006 - 12/2006	12	18	5,000	681	140	1,412	33.3
Upham Brook	2-UPM001.35	6/2005 – 9/2011	26	25	5,200	630	150	1,171	34.6
Upham Brook	2-UPM002.41	1/2006 - 12/2006	12	27	5,400	998	97	1,736	41.7
Upham Brook	2-UPM003.53	1/2001 - 12/2006	16	47	6,700	977	205	2,008	50.0
Upham Brook	2-UPM005.26	1/2006 - 12/2006	12	23	8,000	1,305	130	2,492	41.7
Upham Brook	2-UPM007.03	7/2003 - 12/2006	23	15	8,000	1,068	75	2,419	26.1
Upham Brook	2-UPM008.76	1/2006 - 12/2006	12	15	5,200	1,106	405	1,824	58.3
Upham Brook X-Trib	2CXAR000.57	5/2004 - 12/2006	27	21	5,400	1,064	420	1,558	66.7
Upham Brook X-Trib	2-XAX000.73	8/2010	1	4,600	4,600	4,600	NA	NA	100.0
Upham Brook X-Trib	2-XAX000.85	8/2010	1	8,000	8,000	8,000	NA	NA	100.0
Upham Brook X-Trib	2-XXP000.23	1/2006 - 12/2006	12	14	4,000	763	43	1,362	33.3
Upham Brook X-Trib	2-XXQ000.12	1/2006 - 12/2006	12	60	4,500	1,001	445	1,399	66.7
White Oak Swamp	2-WOS002.69	1/2003 - 11/2008	15	15	300	136	100	101	26.7
White Oak Swamp X-Trib	2-XZS000.38	5/2008	1	60	60	60	NA	NA	0.0

NA – Not applicable

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

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3. BACTERIA SOURCE ASSESSMENT

The TMDL development described in this report includes examination of all potential sources of fecal bacteria in the Chickahominy 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 Chickahominy River Watershed drainage area was divided into twenty seven (27) subwatersheds (**Figure 3.1**). Source assessment is conducted on subwatershed level where estimates of all potential pollutants are generated for each individual subwatershed.

3.1 Assessment of Sources

Table 3.1 lists permitted point sources that discharge to surface water bodies in the Chickahominy River and Tributaries watershed study area. The first permit listed is the only facility permitted to discharge bacteria to the stream. The permitted facilities within the project watershed in **Table 3.1** are regulated through the Virginia Pollutant Discharge Elimination System (VPDES). The remaining facilities in **Table 3.1** are permitted to discharge water to the streams but are not permitted to discharge bacteria. The use of "UT" in this table refers to Unnamed Tributaries. 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 standard. There are no single family home permits within the Chickahominy River and Tributaries watershed study area permitted by DEQ at this time.

There is one VPDES Animal Feeding Operations (AFO), one VPDES Confined Animal Feeding Operation (CAFO) and one Virginia Pollution Abatement (VPA) facility in the study area (**Table 3.2**). A CAFO is an animal feeding operation that is large enough to require a wasteload allocation. At this time, a wasteload allocation of "0.00" will be

assigned, however, the WLA should not be interpreted as a permit limit. Rather, it indicates that this facility is not assigned a WLA in the TMDL because its permit does not include a limit for bacteria.

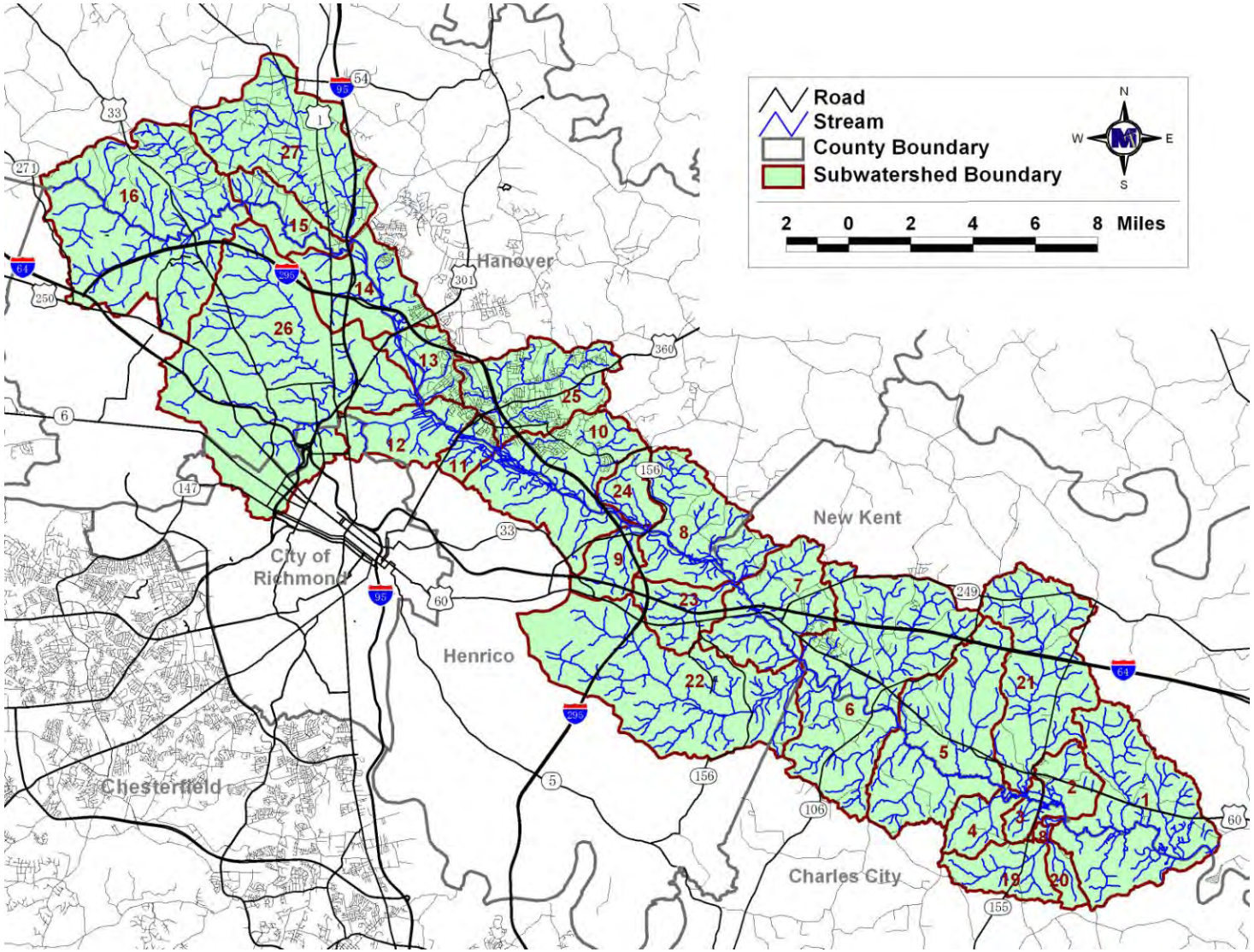

Figure 3.1 All subwatersheds delineated for modeling in the Chickahominy River study area.

Table 3.1 Summary of VPDES point sources in the Chickahominy River and Tributaries watershed study area.

Permit Number	Facility Name	Type	Permitted for EC	Design Flow (MGD)	Receiving Waterbody	Sub-watershed
VA0004031	Tyson Foods Incorporated - Glen Allen	Industrial	Yes	1.25	UT to Chickahominy River	16
VA0058041	Vulcan Construction Materials LP - Springfield	Industrial	No	1.22[1]	Chickahominy River	16
VA0061972	TravelCenters of America - Richmond Travel Center	Industrial	No	0.01[2]	UT to Lickinghole Creek	27
VA0090301	Richmond International Airport	Municipal	No	23.86[3]	White Oak Swamp	22
VAG250093	INGENCO - Charles City	General	No	0.01	UT to Chickahominy River	5

[1] Outfall includes storm flow and consequently the discharge volume varies with storm size.
[2] Outfall includes storm flow and consequently the discharge volume varies with storm size.
[3] Outfall includes storm flow and consequently the discharge volume varies with storm size.

Table 3.2 Animal feeding operation (AFO), Confined animal feeding operation (CAFO) and Virginia Pollution Abatement (VPA) permits in the Chickahominy River and Tributaries watershed study area.

Permit	Facility Name	Nearest Adjacent Stream	Facility Type	Sub-watershed
VPG100120	White Oak Farm	Stony Run	AFO	27
VPG100026	Bailey Pig LC	Collins Run	CAFO*	17
VPA00524	Roxbury Industrial Park	Possum Run	VPA	6

* CAFOs require a wasteload allocation based on EPA's criteria. At this time a wasteload allocation of 0.00 is assigned, however, the WLA should not be interpreted as a permit limit. Rather, it indicates that this facility is not assigned a WLA in the TMDL because its permit does not include a limit for bacteria.”.

Table 3.3 shows the Municipal Separate Storm Sewer System (MS4) permits. These are areas of land with stormwater runoff collection that discharge to surface waters. The land area within these permit boundaries has bacteria from land-based sources (pet, human, wildlife) which can be present in the runoff.

Table 3.3 Permits for MS4s in the James River – City of Richmond study area.

Permit	Phase	Facility Name	Bacteria Contribution
VAR040107	Phase II	J. Sargeant Reynolds Community College	Yes
VA0088617	Phase I	Henrico County	Yes
VAR040011	Phase II	Town of Ashland	Yes
VAR040012	Phase II	Hanover County	Yes
VAR040005	Phase II	Richmond City	Yes
VAR040115	Phase II	VDOT	Yes

3.2 Assessment of Nonpoint Sources

In the Chickahominy River and Tributaries watershed study area, both developed and agricultural nonpoint sources of fecal coliform 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.

3.2.1 Private Residential Sewage Treatment

Population, housing units, and type of sewage treatment from U.S. Census Bureau (USCB, 1990, 2000) were calculated using GIS (**Table 3.4**). 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 pipe (direct stream outfall).

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. 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 districts were incorporated and the initial estimates were generally reduced. In the case of straight pipes, the estimates were reduced considerably. The estimates shown in **Table 3.4** 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 13,000,000cfu/g and a total waste load of 75 gal/day/person was reported by Geldreich (1978).

Table 3.4 Human population, housing units, houses on sanitary sewer, septic systems, and straight pipes for areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area.

Sub-watershed	Human Population	Housing Units	Homes with Sewer	Homes with Septic	Estimated Homes with Straight Pipes	Estimated Homes with Failing Septic Systems
1	696	333	6	326	1	11
2	181	73	1	72	0	2
3	108	45	0	45	0	1
4	254	100	0	100	0	3
5	1,192	471	0	469	2	16
6	4,522	1,823	27	1,794	2	60
7	2,770	1,133	21	1,111	1	37
8	1,502	618	225	393	0	13
9	3,356	1,523	1,428	95	0	3
10	13,995	5,502	4,592	909	1	30
11	5,820	2,211	2,169	42	0	1
12	12,658	5,656	5,592	63	1	2
13	4,839	1,833	1,689	144	0	5
14	12,135	5,306	5,051	254	1	8
15	1,525	670	255	413	2	14
16	34,755	13,285	12,095	1,187	3	40
17	2	1	0	1	0	0
18	14	6	0	6	0	0
19	315	152	0	152	0	5
20	75	28	0	28	0	1
21	596	267	0	267	0	9
22	6,126	2,507	2,330	171	6	6
23	876	434	416	17	1	1
24	307	136	0	136	0	5
25	20,769	8,100	6,930	1,167	3	39
26	101,467	47,745	46,398	1,341	6	45
27	5,296	2,187	1,295	887	5	30
Total	236,151	102,145	90,520	11,590	35	387

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 3.5** details the volume of overflows reported between October, 2002 and March, 2011.

Table 3.5 Volume of sanitary sewer overflows reported within the study area between October 2002 and March 2011.

Subwatershed	Volume (1,000 Gallon)
8	13
9	10,737
10	25
11	108
12	121,164
13	182
14	8
15	2
16	265
22	504
25	2,205
26	8,626
27	154
Total	143,993

3.2.3 Biosolids

Between 2003 and 2010 biosolids were applied to fields within the Chickahominy River and Tributaries study area (**Table 3.6**). The total amount of biosolids applied was 8,028 wet tons. This amount was applied mostly in subwatershed 6. 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 3.6 Application of biosolids within the Chickahominy River study area (2003 – 2010).

Year	Wet Tons (as is)
2003	660
2008	6,223
2009	821
2010	324
Total	**8,028**

3.2.4 Pets

Among pets, cats and dogs are the predominant contributors of fecal coliform in the Chickahominy 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 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 3.7**. **Table 3.8** lists the domestic animal populations for impairments in the Chickahominy River and Tributaries watershed study area by subwatershed

Table 3.7 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 3.8 Estimated domestic animal populations in areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area.

Sub-watershed	Dogs	Cats
1	178	199
2	39	44
3	24	27
4	53	60
5	252	282
6	973	1,090
7	605	678
8	330	370
9	813	911
10	2,938	3,290
11	1,181	1,322
12	3,020	3,382
13	979	1,096
14	2,833	3,173
15	358	401
16	7,094	7,944
17	1	1
18	3	4
19	81	91
20	15	17
21	143	160
22	1,339	1,499
23	232	260
24	73	81
25	4,325	4,844
26	25,496	28,552
27	1,168	1,308
Total	**54,546**	**61,086**

3.2.5 Livestock

The predominant type of livestock in the Chickahominy River and Tributaries watershed study area is beef cattle, horses, and hogs, although other types of livestock identified were considered in modeling the watershed. The estimates shown in **Table 3.9** 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 (CSWCD), Henricopolis Soil and Water Conservation District (HSWCD), Hanover-Caroline Soil and Water Conservation District (HCSWCD), watershed visits, and communication with citizens at the first public meeting and afterwards.

Table 3.9 Livestock populations in areas contributing to impaired segments in the Chickahominy River and Tributaries watershed study area.

Sub-watershed	Beef	Beef Calves	Dairy Replacements	Horse	Sheep	Hog
1	15	22	0	63	0	0
2	6	8	0	26	0	0
3	0	1	0	0	0	0
4	1	2	0	0	0	0
5	12	19	0	36	0	0
6	33	47	0	124	0	0
7	24	25	0	110	5	0
8	43	32	0	101	7	0
9	6	5	0	30	0	0
10	71	52	0	164	6	0
11	3	3	0	8	0	0
12	17	15	0	35	1	0
13	6	4	0	22	2	0
14	30	23	0	63	5	0
15	23	18	0	54	4	0
16	76	56	0	236	9	0
17	0	0	0	0	0	4,440
18	1	1	0	0	0	0
19	2	3	0	0	0	0
20	1	1	0	0	0	0
21	19	25	0	82	0	0
22	49	39	0	231	19	0
23	10	8	0	48	0	0
24	4	3	0	24	2	0
25	19	14	0	116	9	0
26	29	28	0	141	0	0
27	24	18	30	147	11	0
Total	**524**	**472**	**30**	**1,861**	**80**	**4,440**

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 3.10.**

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

Type	Waste Load (lb/d/an)	Fecal Coliform Density (cfu/g)	Waste Storage Die-off factor
Beef stocker (850 lb)	51.0	101,000	NA
Beef calf (350 lb)	21.0	101,000	NA
Dairy Replacements (850 lb)	70.0	271,329	0.25
Hog (135 lb)	11.3	400,000	0.8
Horse (1,000 lb)	51.0	94,000	NA
Sheep (60 lb)	2.4	43,000	NA

[1]units are cfu/100ml

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 3.11** 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 3.11 Average percentage of collected livestock waste applied throughout year.

Month	Applied % of Total			Land use
	Dairy	Beef	Swine	
January	2.00	4.00	0.00	Cropland
February	2.00	4.00	0.00	Cropland
March	20.00	12.00	20.00	Cropland
April	20.00	12.00	20.00	Cropland
May	5.00	12.00	20.00	Cropland
June	2.00	8.00	0.00	Pasture
July	2.00	8.00	0.00	Pasture
August	2.00	8.00	0.00	Pasture
September	21.00	12.00	0.00	Cropland
October	20.00	12.00	20.00	Cropland
November	2.00	4.00	20.00	Cropland
December	2.00	4.00	0.00	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 were expected to make a contribution through direct deposition with access to flowing water. 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 3.12** and **Table 3.13**

Table 3.12 Average time dairy 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 3.13 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 Chickahominy 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 3.14** (Bidrowski, 2004; Farrar, 2003; Fies, 2004; Knox, 2004; Norman, 2004; Raftovich, 2004; Rose and Cranford, 1987; Mayhorn, 2005).

Table 3.14 Wildlife population densities for the Chickahominy River and Tributaries watershed study area.

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

The numbers of animals estimated to be in the Chickahominy River and Tributaries watershed study area are reported in **Table 3.15.** 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 3.15 Estimated wildlife populations in the Chickahominy River and Tributaries watershed study area.

Deer	Turkey	Beaver	Raccoon	Muskrat	Duck	Goose
6,318	**1,384**	**1,514**	**13,311**	**7,537**	**840**	**1,410**

Fecal coliform densities and fecal production information are reported in **Table 3.16**. 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 3.16 Wildlife daily waste production and average fecal coliform densities.

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

Table 3.17 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

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

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. The model used in the analysis was the USGS Hydrologic Simulation Program - Fortran (HSPF) water quality model. The HSPF model is a continuous simulation model that can account for NPS pollutants in runoff, as well as pollutants entering the flow channel from point sources.

To adequately represent the spatial variation in the watershed parameters and pollutant quantification, the Chickahominy River Watershed drainage area was divided into twenty seven (27) subwatersheds (Figure 3.1). Hydrologic parameters collected for the watershed were used to calibrate and validate the simulated flow. Flow was calibrated by comparing model output to observed flow within the Chickahominy River and making the proper adjustments to obtain the best match between simulated and observed flow. Once the flow component was built, quantified bacteria sources were entered into the model and simulated bacteria concentration was generated. The simulated bacteria concentration was calibrated by comparing model simulations of bacteria to observed bacteria values collected by VADEQ at multiple locations. Finally the bacteria concentration was validated using a different time period from the calibration period.

Existing conditions of bacteria were then entered into the model to simulate the baseline conditions. This stage gives an indication of the current, predicted, violation rates of the geometric mean standard. At this point, the model was used in the allocation process where reductions 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.

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5. BACTERIAL ALLOCATION

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

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

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 (or resulting concentration).

Allocation scenarios were modeled using the HSPF model. 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 Chickahominy River and Tributaries study area were based on the *E. coli* riverine Virginia State standards. As detailed in Section 2.1, the VADEQ riverine primary contact recreational use *E. coli* standards state that the calendar month geometric-mean concentration shall not exceed 126 cfu/100 ml.

According to the guidelines put forth by the VADEQ (VADEQ, 2003a) 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. The development of the allocation scenarios was an iterative process that required many runs with each followed by an assessment of load reduction against the applicable water

quality standards. Allocation was conducted in a way where simulated concentration from all subwatersheds that include an impaired segment as well as the output subwatershed met the standard. Subwatersheds containing the previously approved TMDLs in Upham Brook and White Oak Swamp were included in the allocation process where output from these two areas met the standard as well.

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.
- Modeling all outflow from straight pipes and failing septic systems at the human waste concentration including the gray-water portion.

5.2 Waste Load Allocations (WLAs)

There is one VPDES point source currently permitted to discharge bacteria into the Chickahominy River watershed study area. The allocation for this discharge is equivalent to its current permit levels (design discharge and 126 cfu/100 ml). Future growth was accounted for by setting aside 1% of the TMDL for growth in the permitted discharge or creation of new ones. There several Municipal Separate Storm Sewer

System (MS4) permits in the Chickahominy River and Tributaries study area which are noted in **Table 3.3**.

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. Reductions to direct non-point sources were performed by source. Appendix C shows tables of the breakdown of the annual fecal coliform per animal per land use for contributing subwatersheds to each impairment.

5.4 Final Total Maximum Daily Loads (TMDLs)

Virginia's water quality standard does not permit any exceedances, therefore, modeling was conducted for a target value of 0% exceedance of the VADEQ riverine primary contact recreational use (swimming) 30-day geometric mean standard (126 cfu/100mL geometric mean). Allocation scenarios were run for all subwatersheds until all simulated *E.coli* concentrations at the outlet of all impaired subwatershed were allocated to 0% exceedances. Concentrations at the main outlet of the entire study area (currently not impaired) was also checked against (and met) all applicable water quality standards. In addition, populations were updated for Upham Brook and White Oak swamp (previously developed TMDLs) and simulated concentrations at their outlets were also checked against (and met) all applicable water quality standards. **Table 5.1** shows all the locations where allocation was conducted. **Table 5.2** represents the scenarios developed to determine the TMDLs.

Reduction scenarios exploring the role of anthropogenic sources in standards violations were explored first to determine the feasibility of meeting standards without wildlife

reductions. Scenario 0 describes a baseline scenario that corresponds to the existing conditions in the watershed. Scenario 1 reflects the impact of eliminating sanitary sewer overflows (SSOs). Scenario 2 illustrates the impact of eliminating straight pipes. Both Scenario 1 and 2 represent the human impact on bacteria levels in the streams. The achieved reduction in percentage violation of the water quality standard is a function of the extent of these two sources within the drainage area of each subwatershed outlet. Scenario 3 explores the impact of fencing out all cattle. This scenario had less impact on percentage violation as did the human related direct sources. Eliminating SSOs and straight pipes along with direct livestock contribution was not enough to meet the water quality standard.

Scenario 4 and further scenarios illustrate the impact of land-based bacteria sources. Scenario 4 shows the impact of reducing load from developed lands by 50%. Similar reductions to loads from agricultural lands are shown in Scenario 5. A 50% reduction of load from agricultural lands did not impact the percentage violation of the geometric mean water quality standard. In Scenario 6, contribution from land-based dominated by anthropogenic sources was almost entirely eliminated. However, this was not enough to meet the standard at all impaired outlets. Scenarios 7 and 8 explore the impact of reducing loads from direct deposition by wildlife and lands dominated by wildlife sources. Scenario 8 meets the geometric mean standard of 126 cfu/100mL at all impaired outlets and main watershed outlet. As shown in scenario 8 in Table 5.2, reductions were proposed until all concerned subwatershed outlets met the geometric mean standard with zero percent violation rate. As can be seen from the table, subwatershed 24 (Boatswain Creek) needed the most reductions and therefore was considered the most limiting subwatershed. It should be noted that bacterial source assessment indicated that subwatershed 24 had no straight pipes or sanitary sewer overflows and therefore, eliminating these two sources as suggested by scenarios 1 and 2 did not benefit water quality conditions within this subwatershed and hence, the reliance on additional land-based reductions to meet the water quality standard than other subwatersheds.

As per the request of DCR, a ninth scenario was run where bacteria loading from all anthropogenic sources is eliminated while not applying any reductions to SSOs. The results of this scenario are given in Scenario 9.

Table 5.1 Description of locations where allocation was conducted within the Chickahominy River watershed.

Subwatershed	Impairment
18	Collins Run Impairment
19	Collins Run Impairment
25	Beaverdam Creek Impairment
24	Boatswain Creek Impairment
9	Chickahominy River Impairment, Outlet of NTU 103
10	Chickahominy River Impairment
11	Chickahominy River Impairment
1	Main outlet of entire study area, Outlet of NTU 90.1
27	Stony Run Impairment
26	Upham Brook TMDL
22	White Oak Swamp TMDL

Table 5.2 Allocation scenarios for reducing current bacteria loads in the Chickahominy River and Tributaries.

Scenario	Wildlife Direct	Forest, Wetlands, Barren[1], Comm.	Livestock Direct	Cropland, Pasture, LAX[2]	SSOs[3]	Straight Pipes	Developed	sub 27 (%)	Sub 26 (%)	Sub 25 (%)	Sub 24 (%)	Sub 22 (%)	Sub 19 (%)	Sub 18 (%)	Sub 11 (%)	Sub 10 (%)	Sub 9 (%)	Sub 1 (%)
0	0	0	0	0	0	0	0	30.73	19.69	51.54	6.49	32.05	4.19	3.35	10.68	11.66	7.12	1.19
1	0	0	0	0	100	0	0	29.05	14.25	29.54	6.49	29.12	4.19	3.35	6.84	6.91	3.84	0.77
2	0	0	0	0	100	100	0	6.91	1.40	1.75	6.49	9.08	4.19	3.35	0.91	0.84	0.63	0.00
3	0	0	100	0	100	100	0	6.56	1.40	1.47	5.94	8.24	3.98	2.86	0.84	0.77	0.42	0.00
4	0	0	100	0	100	100	50	5.31	1.12	0.98	4.61	7.54	2.44	2.03	0.63	0.49	0.00	0.00
5	0	0	100	50	100	100	50	5.31	1.12	0.98	4.61	7.54	2.44	2.03	0.63	0.49	0.00	0.00
6	0	0	100	99	100	100	99	3.70	0.00	0.00	3.35	6.35	0.21	0.35	0.00	0.00	0.00	0.00
7	50	50	100	99	100	100	99	0.00	0.00	0.00	2.09	0.91	0.00	0.00	0.00	0.00	0.00	0.00
8[4]	77	77	100	99	100	100	99	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0	0	100	99	0	100	99	4.05	0.35	1.96	3.35	8.03	0.21	0.35	0.00	0.98	0.00	0.77

[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]SSOs – Sanitary Sewer Overflows
[4]Final TMDL Scenario

Figure 5.1 shows the existing and allocated monthly geometric mean E. coli concentrations at the most limiting subwatershed outlet (subwatershed 24, Boatswain Creek). The graph shows existing conditions in black, with allocated conditions overlaid in blue.

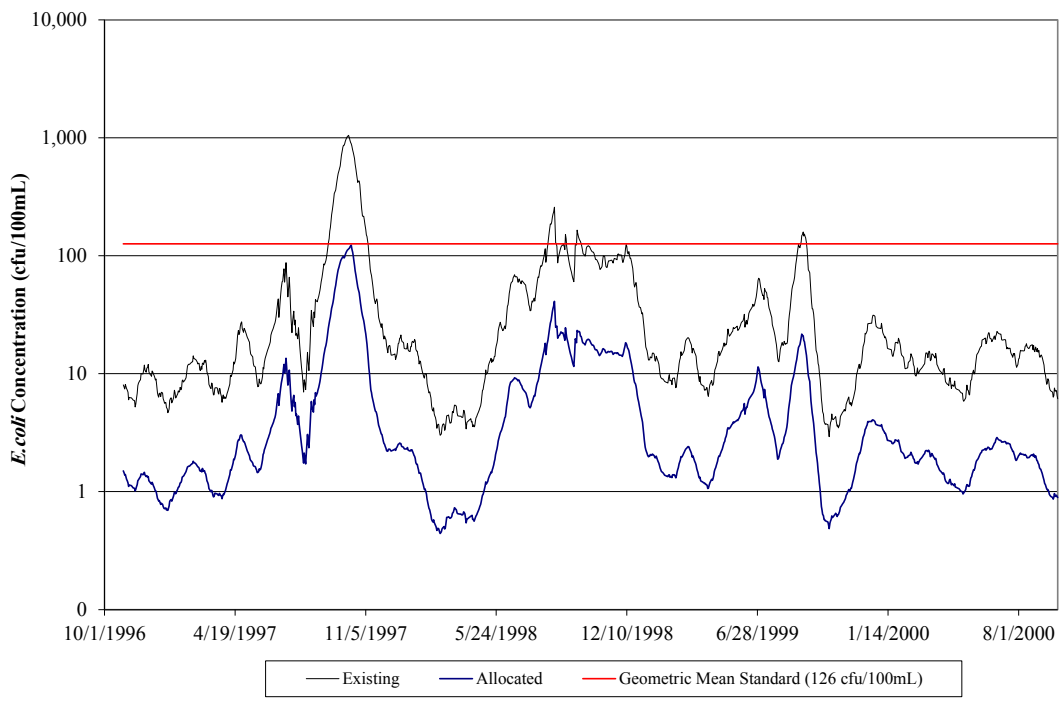

Figure 5.1 Existing and allocated monthly geometric mean in-stream *E. coli* concentrations in subwatershed 24.

Table 5.3 and **Table 5.4** contain estimates of existing and allocated in-stream *E. coli* loads at the outlet of combined NTUs 103 and 104, and the main watershed outlet, respectively. The estimates in these tables are reported as average annual cfu per year and are generated from available data. These values are specific to the given locations for the allocation rainfall and current land use distribution in the watershed. These values are output from the HSPF model and incorporate in-stream die-off (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework. The percent

reductions needed to meet zero percent violations of the 126 cfu/100mL geometric mean standard are given in the final column.

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

Table 5.3 Estimated existing and allocated *E. coli* in-stream loads at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Developed	7.34E+13	7.34E+11	99.0%
	Commercial	3.27E+12	7.51E+11	77.0%
	*Barren	1.66E+11	3.81E+10	77.0%
	Forest	3.83E+11	8.80E+10	77.0%
	Pasture	5.28E+11	5.28E+09	99.0%
	Cropland	6.31E+10	6.31E+08	99.0%
	Wetland	1.09E+11	2.51E+10	77.0%
	**LAX	1.99E+10	1.99E+08	99.0%
Direct				
	Human	1.48E+11	0.00E+00	100.0%
	Livestock	4.71E+11	0.00E+00	100.0%
	Wildlife	3.31E+12	7.61E+11	77.0%
	Permitted Sources	2.45E+12	2.45E+12	0%
	SSOs	3.85E+14	0.00E+00	100%
Future Growth	Future Growth	0.00E+00	4.90E+10	NA
Total Loads		**4.69E+14**	**4.90E+12**	**99.4%**

* 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 5.4 Estimated existing and allocated *E. coli* in-stream loads at the outlet of subwatershed 1 (entire study area) on the Chickahominy River.

Source		Total Annual Loading for Existing Run (cfu/yr)	Total Annual Loading for Allocation Run (cfu/yr)	Percent Reduction
Land Based				
	Developed	2.81E+13	2.81E+11	99.0%
	Commercial	1.13E+12	2.59E+11	77.0%
	*Barren	1.07E+12	2.47E+11	77.0%
	Forest	1.86E+12	4.29E+11	77.0%
	Pasture	5.71E+13	5.71E+11	99.0%
	Cropland	3.50E+11	3.50E+09	99.0%
	Wetland	5.83E+12	1.34E+12	77.0%
	**LAX	1.18E+11	1.18E+09	99.0%
Direct				
	Human	7.10E+12	0.00E+00	100.0%
	Livestock	6.86E+11	0.00E+00	100.0%
	Wildlife	1.10E+13	2.53E+12	77.0%
	Permitted Sources	2.33E+12	2.33E+12	0%
	SSOs	4.84E+13	0.00E+00	100%
Future Growth	Future Growth	0.00E+00	8.07E+10	NA
Total Loads		**1.65E+14**	**8.07E+12**	**96.3%**

* 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 5.5 and **Table 5.6** show 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 (except for permitted point sources) and other hydrological and environmental processes involved during runoff and stream routing techniques within the HSPF model framework.

Multiple Municipal 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, one percent of the final TMDL was set aside for future growth in the WLA portion.

It can be seen from **Table 5.5** and **Table 5.6** that the WLA for the permitted point source (VPDES permit VA0004031 Tyson Foods Inc.) accounts for a considerable portion of the annual load. The reality however is not the case. The contribution from land-based sources (LA), as shown in these tables, is subject to die-off. On the other hand, the WLA is calculated using the facility's design flow with an assumed bacteria concentration equal to the water quality standard. In effect, the two tables show the impact of land-based sources as simulated by the model at the given subwatershed outlet while the permitted point source WLA is given as a maximum load the facility is allowed to discharge into the river system before the load is subject to die-off.

Table 5.5 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
Chickahominy River at Subwatershed 9 outlet	**2.50E+12**	**2.40E+12**		**4.90E+12**
Tyson Foods (VA0004031)	*2.18E+12*			
J. Sargeant Reynolds Community College MS4(VAR040107)	*3.50E+08*			
MS4 Henrico County (VA0088617) *MS4 VDOT in Henrico County*	[2] *1.77E+11*		*Implicit*	
MS4 Hanover County (VAR040012 *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County*	[2] *6.52E+10*			
MS4 Richmond City (VAR040005) *MS4 VDOT in Richmond City*	[2] *2.58E+10*			
Future Load	*4.90E+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] 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.

Table 5.6 Final annual in-stream *E. coli* bacterial loads (cfu/year) modeled after TMDL allocation at the outlet of subwatershed 1 (entire study area) on the Chickahominy River.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
Chickahominy River at Subwatershed 1 outlet	**2.41E+12**	**5.66E+12**		**8.07E+12**
Tyson Foods (VA0004031)	2.18E+12			
J. Sargeant Reynolds Community College MS4(VAR040107)	3.50E+08			
MS4 Henrico County (VA0088617) *MS4 VDOT in Henrico County* [2]	1.04E+11		*Implicit*	
MS4 Hanover County (VAR040012 *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County* [2]	3.43E+10			
MS4 Richmond City (VAR040005) *MS4 VDOT in Richmond City* [2]	1.26E+10			
VPG100026 [3]	0			
Future Load	8.07E+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] 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] WLA should not be interpreted as a permit limit. Rather, it indicates that this facility is not assigned a WLA in the TMDL because its permit does not include a limit for bacteria.

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 at the same locations shown in **Table 5.5** and **Table 5.6** of the Chickahominy River are shown in **Table 5.7** and **Table 5.8**. 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.

The daily WLA, including that of future load, is calculated as the annual WLA divided by 365.25. Daily load allocation is calculated as the difference between the daily TMDL and daily WLA. Load allocation is calculated as the difference between the daily TMDL and daily WLA. This calculation of the daily TMDL does not account for varying stream flow conditions.

Table 5.7 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation at the outlet of subwatershed 9 (NTU103, 104) on the Chickahominy River.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
Chickahominy River	**6.83E+09**	**6.80E+12**		**6.81E+12**
Tyson Foods (VA0004031)	5.96E+09			
J. Sargeant Reynolds Community College MS4(VAR040107)	9.58E+05			
MS4 Henrico County (VA0088617) *MS4 VDOT in Henrico County* [2]	4.85E+08		*Implicit*	
MS4 Hanover County (VAR040012 *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County* [2]	1.78E+08			
MS4 Richmond City (VAR040005) *MS4 VDOT in Richmond City* [2]	7.07E+07			
Future Load	1.34E+08			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 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 5.8 Final daily in-stream *E. coli* bacterial loads (cfu/day) modeled after TMDL allocation at the outlet of subwatershed 1 (entire study area) on the Chickahominy River.

Impairment	WLA[1] (cfu/yr)	LA (cfu/yr)	MOS	TMDL (cfu/yr)
Chickahominy River	**6.60E+09**	**1.26E+13**		**1.26E+13**
Tyson Foods (VA0004031)	5.96E+09			
J. Sargeant Reynolds Community College MS4(VAR040107)	9.5E+05			
MS4 Henrico County (VA0088617) *MS4 VDOT in Henrico County* [2]	2.85E+08		*Implicit*	
MS4 Hanover County (VAR040012 *MS4 Town of Ashland (VAR040011)* *MS4 VDOT in Hanover County* [2]	9.38E+07			
MS4 Richmond City (VAR040005) *MS4 VDOT in Richmond City* [2]	3.45E+07			
VPG100026 [3]	0			
Future Load	2.21E+08			

[1] The WLA reflects an allocation for potential future permits issued for bacteria control. Any issued permit will include bacteria effluent limits in accordance with applicable permit guidance and will ensure that the discharge meets the applicable numeric water quality criteria for bacteria at the end-of-pipe.
[2] The TMDL is presented for the 99th percentile daily flow condition at the numeric water quality criterion of 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] WLA should not be interpreted as a permit limit. Rather, it indicates that this facility is not assigned a WLA in the TMDL because its permit does not include a limit for bacteria.

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 http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/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

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

6.3.2 TMDL Modifications for New or Expanding Discharges

Permits issued for facilities with waste load allocations developed as part of a Total Maximum Daily Load (TMDL) must be consistent with the assumptions and requirements of these waste load allocations (WLA), as per EPA regulations. In cases where a proposed permit modification is affected by a TMDL WLA, permit and TMDL staff must coordinate to ensure that new or expanding discharges meet this requirement. In 2005, VADEQ issued guidance memorandum 05-2011 describing the available options and the process that should be followed under those circumstances, including public participation, EPA approval, State Water Control Board actions, and coordination between permit and TMDL staff. The guidance memorandum is available on VADEQ's web site at http://www.deq.virginia.gov/Portals/0/DEQ/Water/Guidance/052011.pdf.

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 nonpoint 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 and VADCR TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf.

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

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

6.4.2 Staged Implementation Scenarios

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

Actions identified during TMDL implementation plan development that go beyond what can be considered cost-effective and reasonable will only be included as implementation

actions if there are reasonable grounds for assuming that these actions will in fact be implemented.

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

6.4.3 Link to Ongoing Restoration Efforts

Implementation of these TMDLs will contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chickahominy River watershed. Implementation plan will include measures for the two previously developed bacteria TMDLs in Upham Brook and White Oak Swamp. Implementation of these TMDLs will also contribute to on-going water quality improvement efforts aimed at restoring water quality in the Chesapeake Bay.

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, bi-monthly for two consecutive years 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 bimonthly monitoring for two consecutive years.

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 are expected to 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 http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityStandards/DesignatedUses.aspx.

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 amendment further states that "If applicable, the schedule shall also address whether TMDL development or implementation for the water shall be delayed".

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7. PUBLIC PARTICIPATION

Public participation during TMDL development for the Chickahominy River and Tributaries watershed was encouraged. Two public meetings were held on August 3, 2011 to introduce the public to the project and present initial estimates of bacteria sources within the study area. The meetings were held at the Mechanicsville Branch Library in Mechanicsville, Virginia. Two final public meetings were held on May 24, 2012 to present the allocation results and final TMDL tables. The final public meetings were also used as kickoff meetings for the implementation plan phase. A summary of the meetings is presented in **Table 7.1**.

Table 7.1 Public participation during TMDL development for the Chickahominy River and Tributaries watershed.

Date	Location	Attendance[1]	Type
8/03/2011	Mechanicsville Branch Library Mechanicsville, VA	18 in first meeting, 6 in second meeting	1st public
5/24/2012	Mechanicsville Branch Library Mechanicsville, VA	21 in first meeting, 9 in second meeting	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.

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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.

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APPENDIX A

Frequency Analysis of Bacteria Data

Legend for Appendix A figures:

- Samples meeting standard
- Samples violating standard

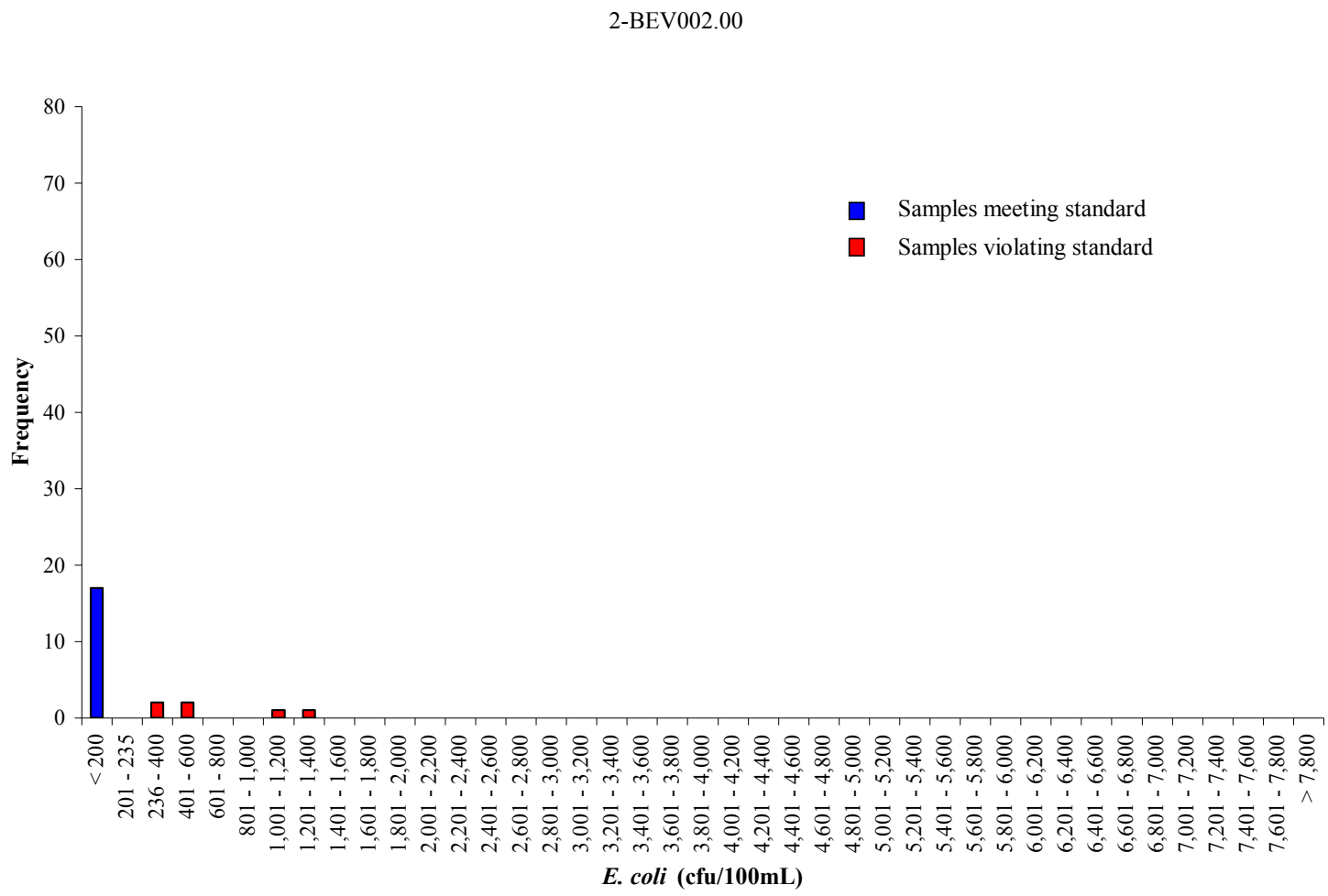

Figure A. 1 Frequency analysis of *E. coli* concentrations at station 2-BEV002.00 in Beaverdam Creek for the period from August 2003 to November 2010.

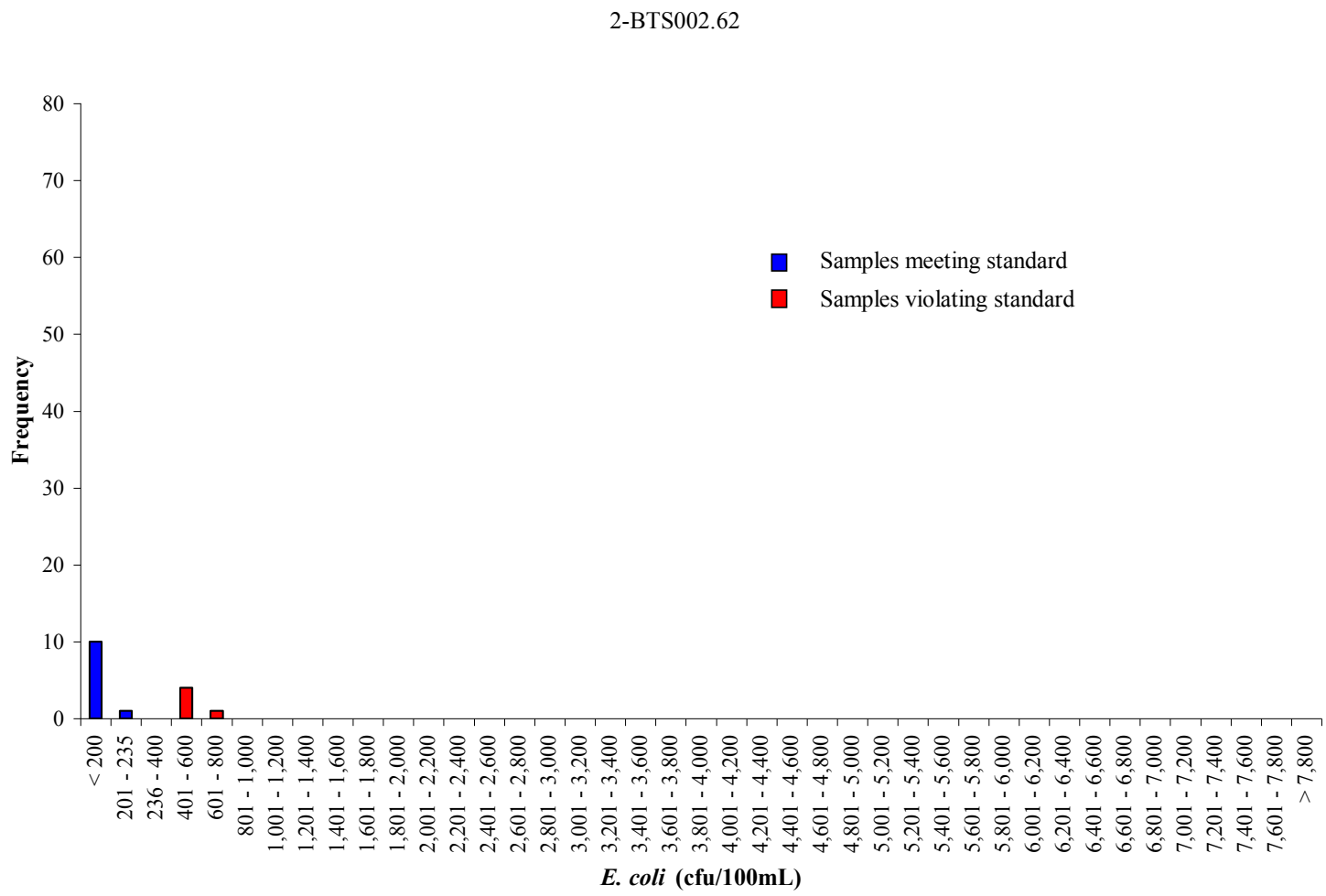

Figure A. 2 Frequency analysis of *E. coli* concentrations at station 2-BTS002.62 in Boatswain Creek for the period from May 2004 to November 2006.

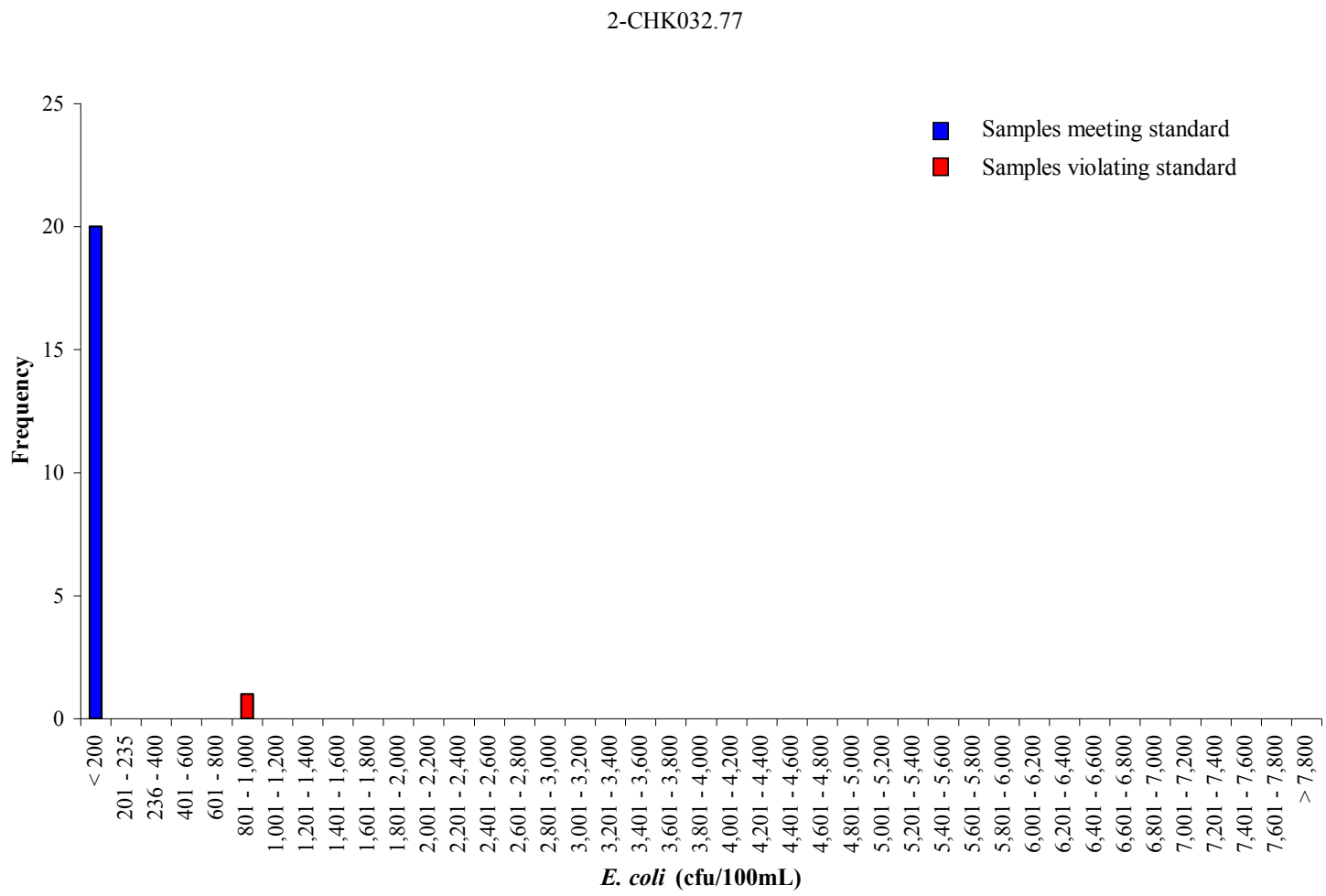

Figure A. 3 Frequency analysis of *E. coli* concentrations at station 2-CHK032.77 in the Chickahominy River for the period from July 2003 to March 2006.

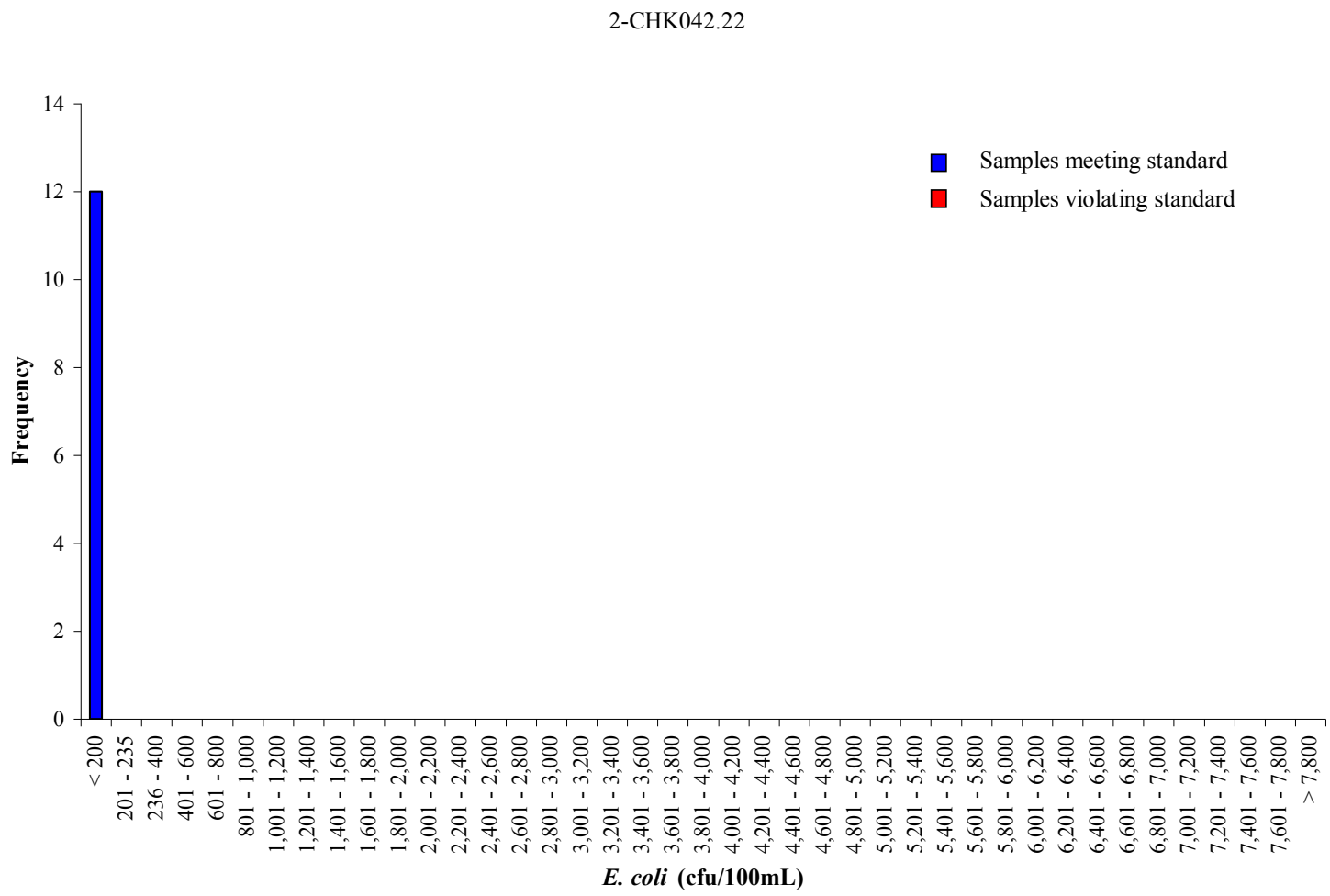

Figure A. 4 Frequency analysis of *E. coli* concentrations at station 2-CHK042.22 in the Chickahominy River for the period from January 2007 to November 2008.

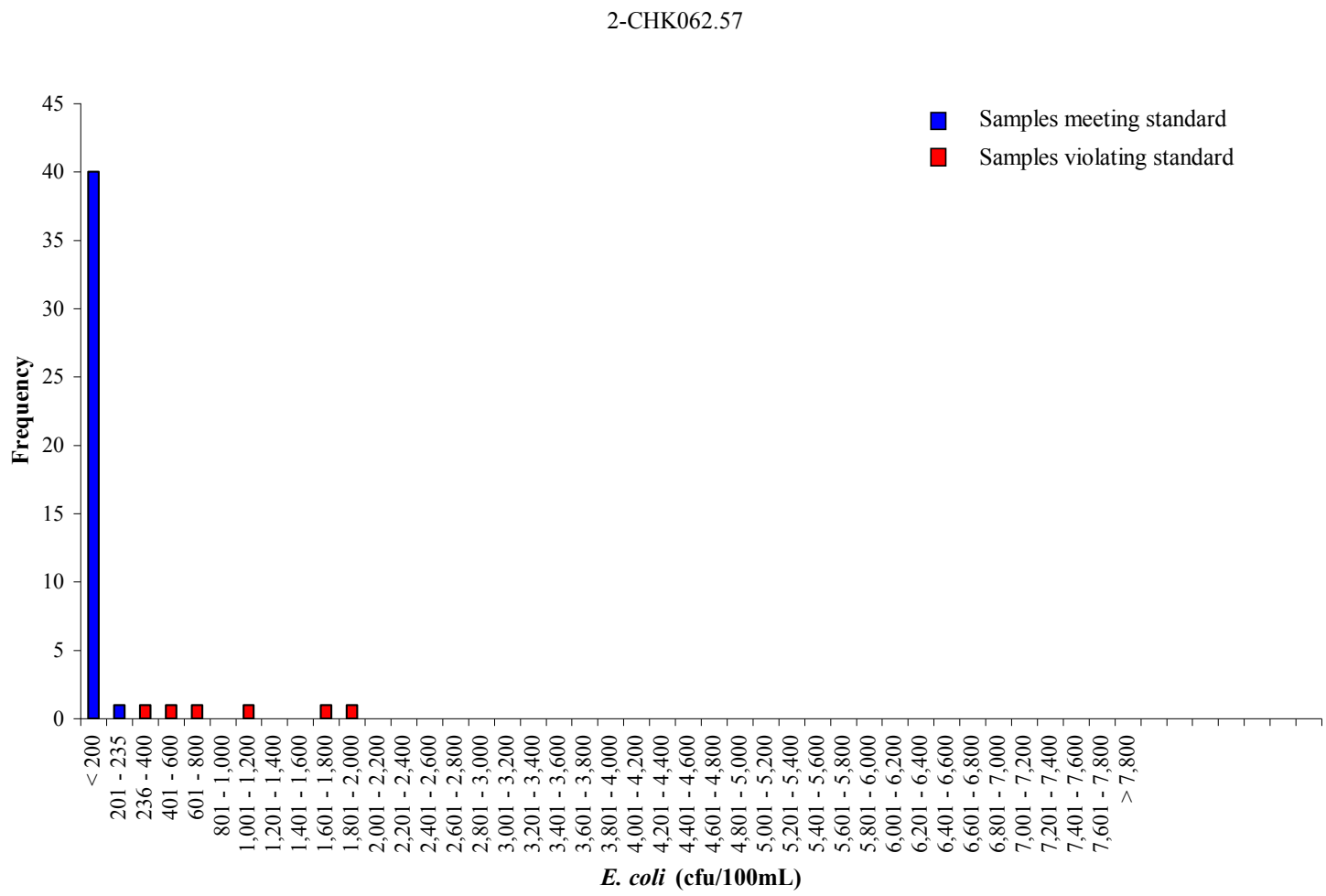

Figure A. 5 Frequency analysis of *E. coli* concentrations at station 2-CHK062.57 in the Chickahominy River for the period from August 2003 to January 2011.

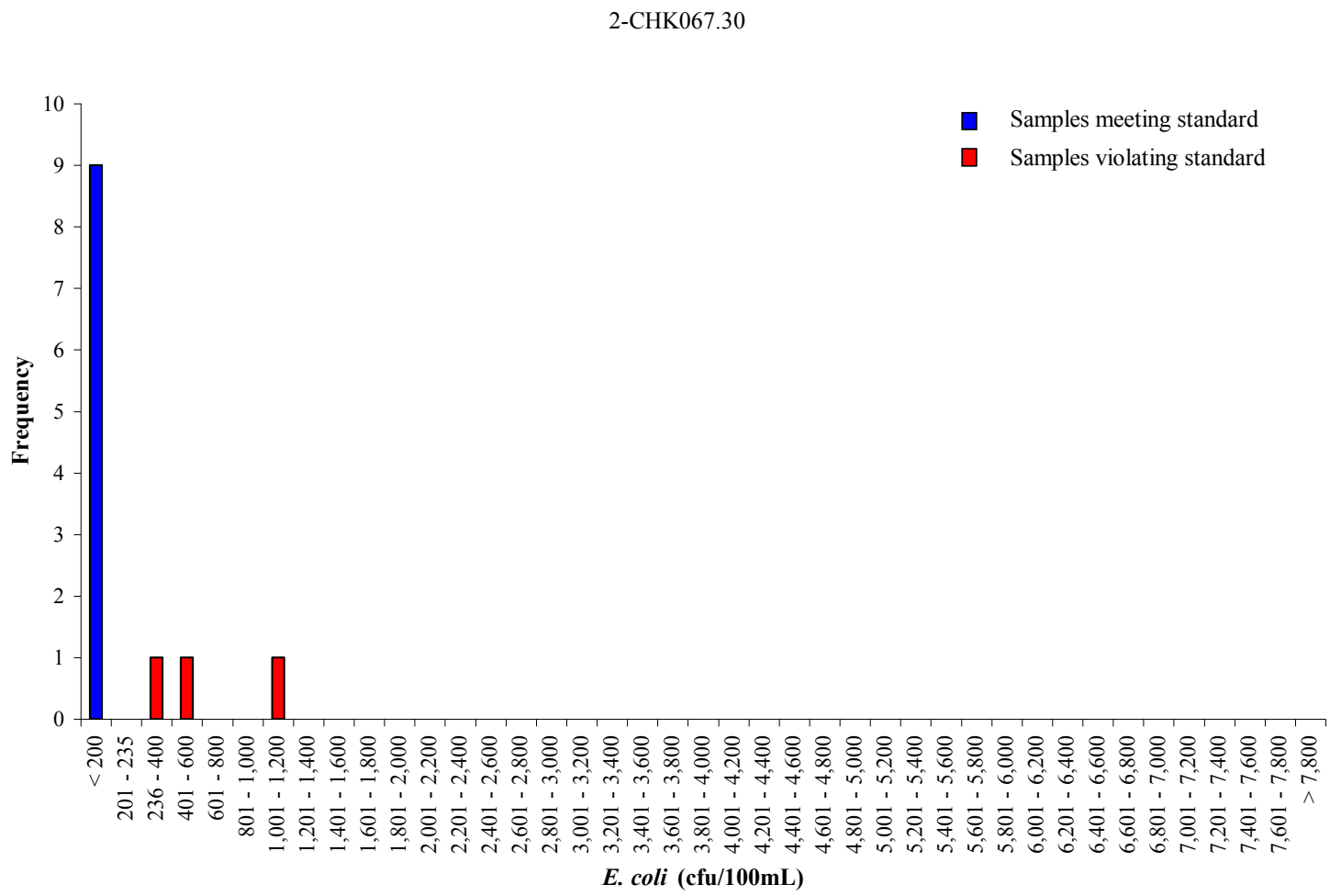

Figure A. 6 Frequency analysis of *E. coli* concentrations at station 2-CHK067.30 in the Chickahominy River for the period from February 2009 to November 2010.

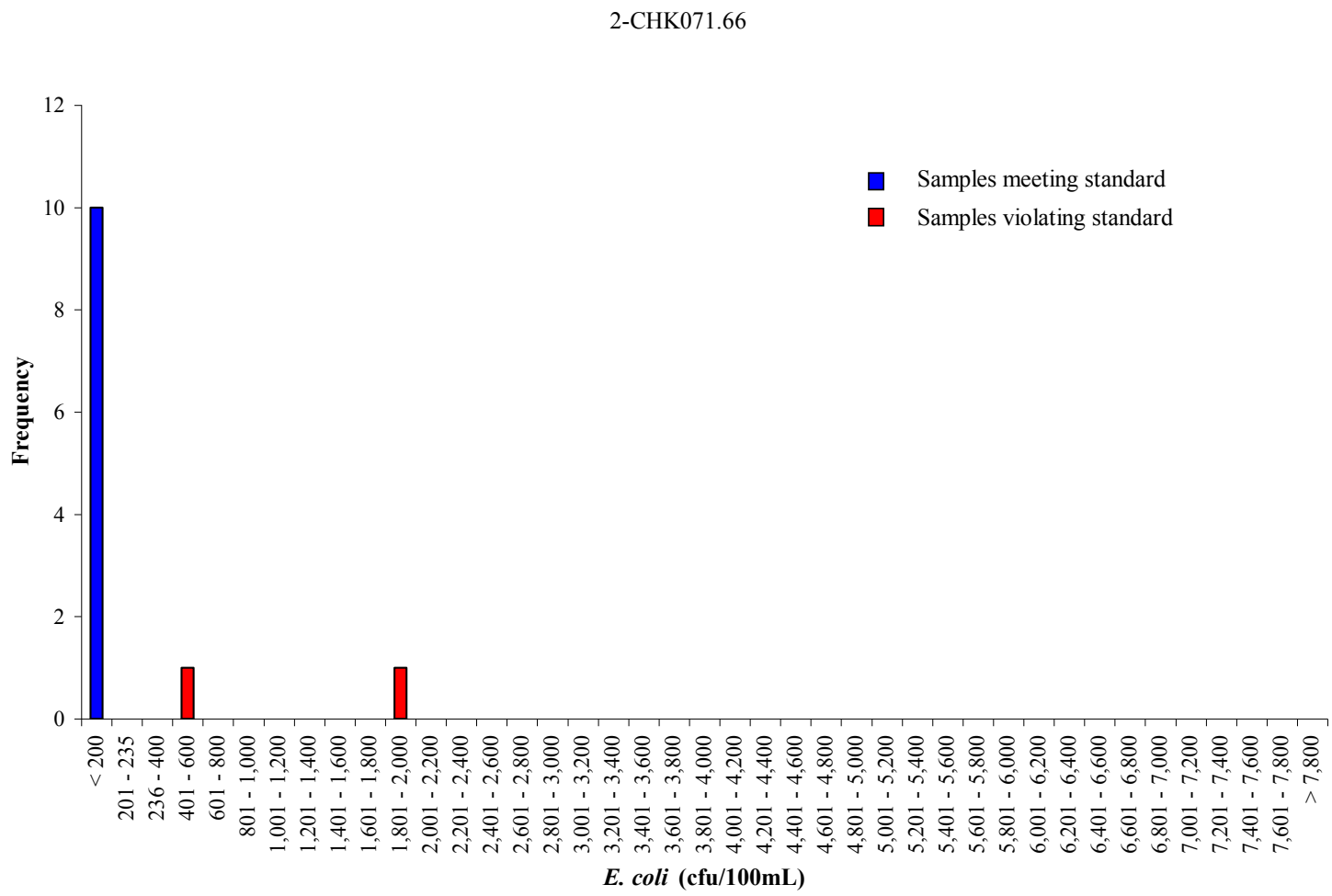

Figure A. 7 Frequency analysis of *E. coli* concentrations at station 2-CHK071.66 in the Chickahominy River for the period from February 2009 to November 2010.

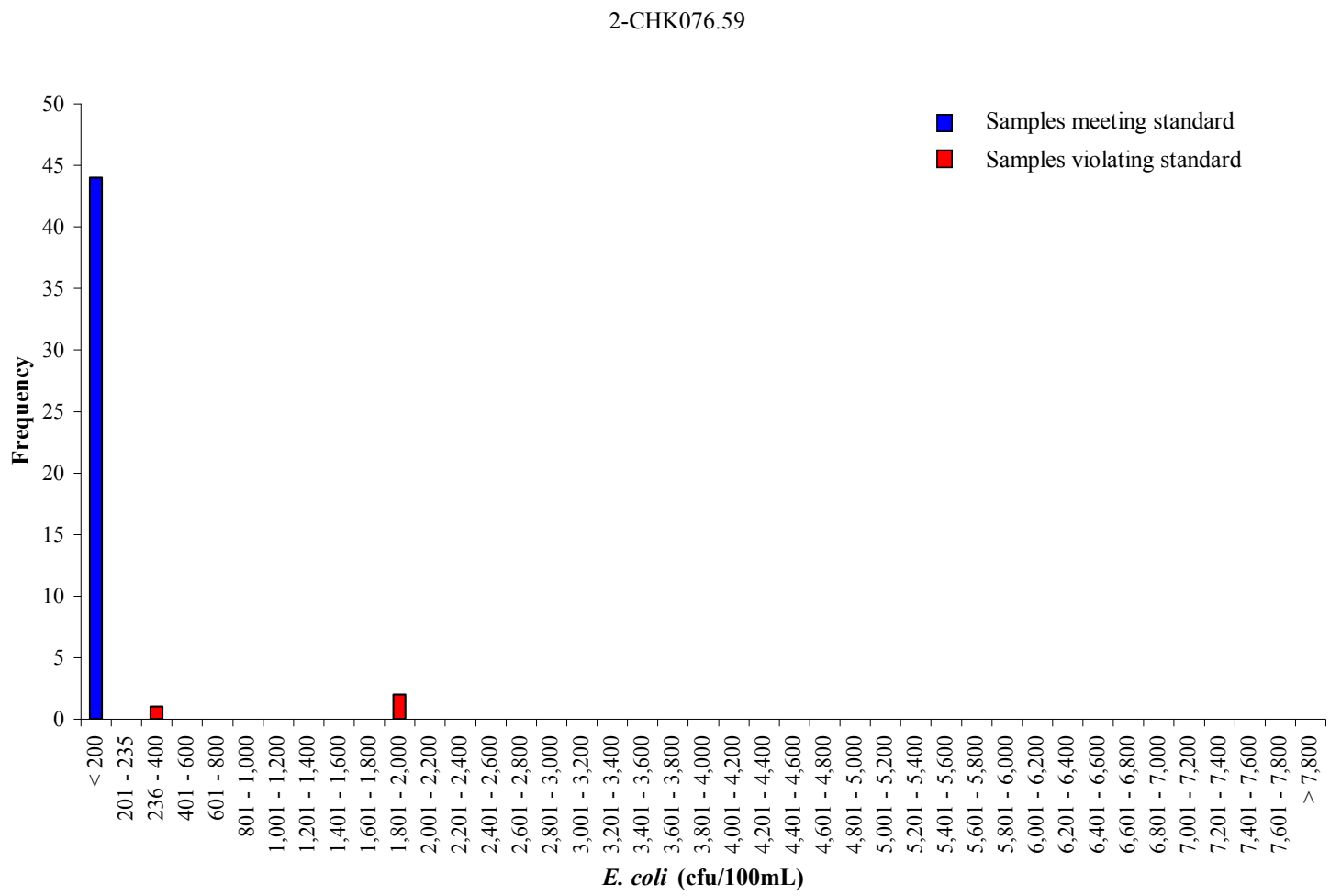

Figure A. 8 Frequency analysis of *E. coli* concentrations at station 2-CHK076.59 in the Chickahominy River for the period from July 2003 to January 2011.

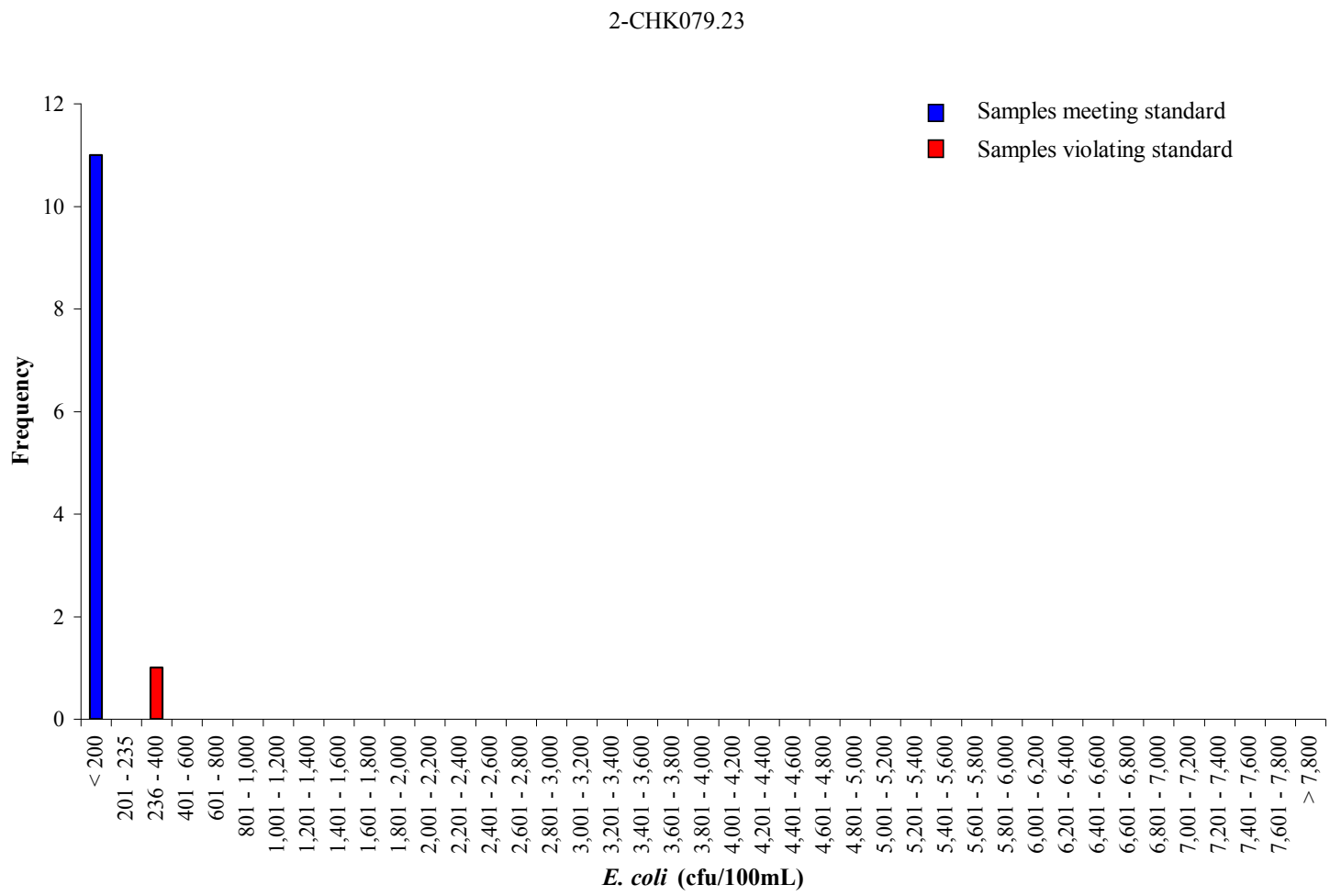

Figure A. 9 Frequency analysis of *E. coli* concentrations at station 2-CHK079.23 in Chickahominy River for the period from January 2006 to December 2006.

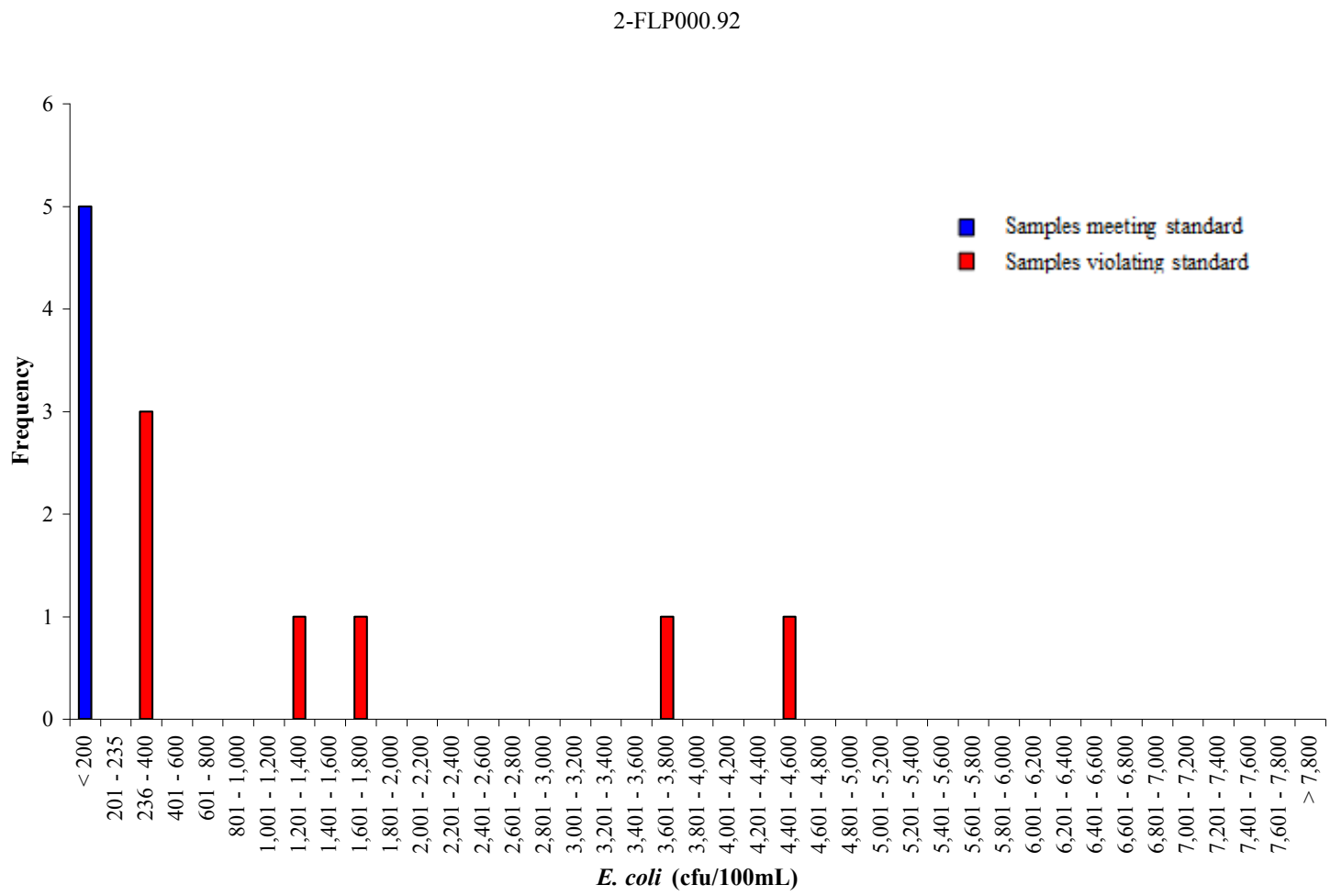

Figure A. 10 Frequency analysis of *E. coli* concentrations at station 2-FLP000.92 in Flippen Creek for the period from January 2006 to December 2006.

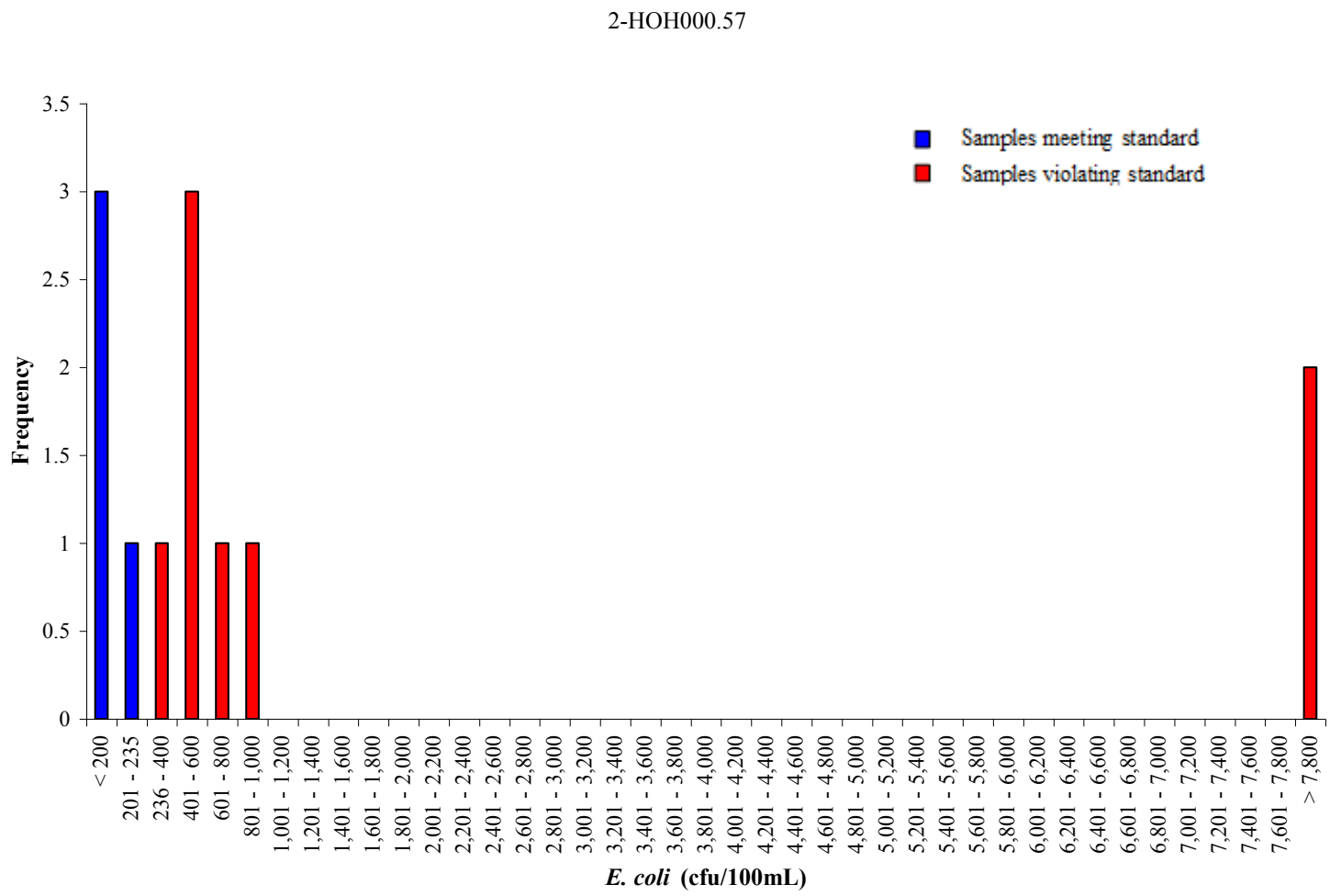

Figure A. 11 Frequency analysis of *E. coli* concentrations at station 2-HOH000.57 in Horsepen Branch for the period from January 2006 to December 2006.

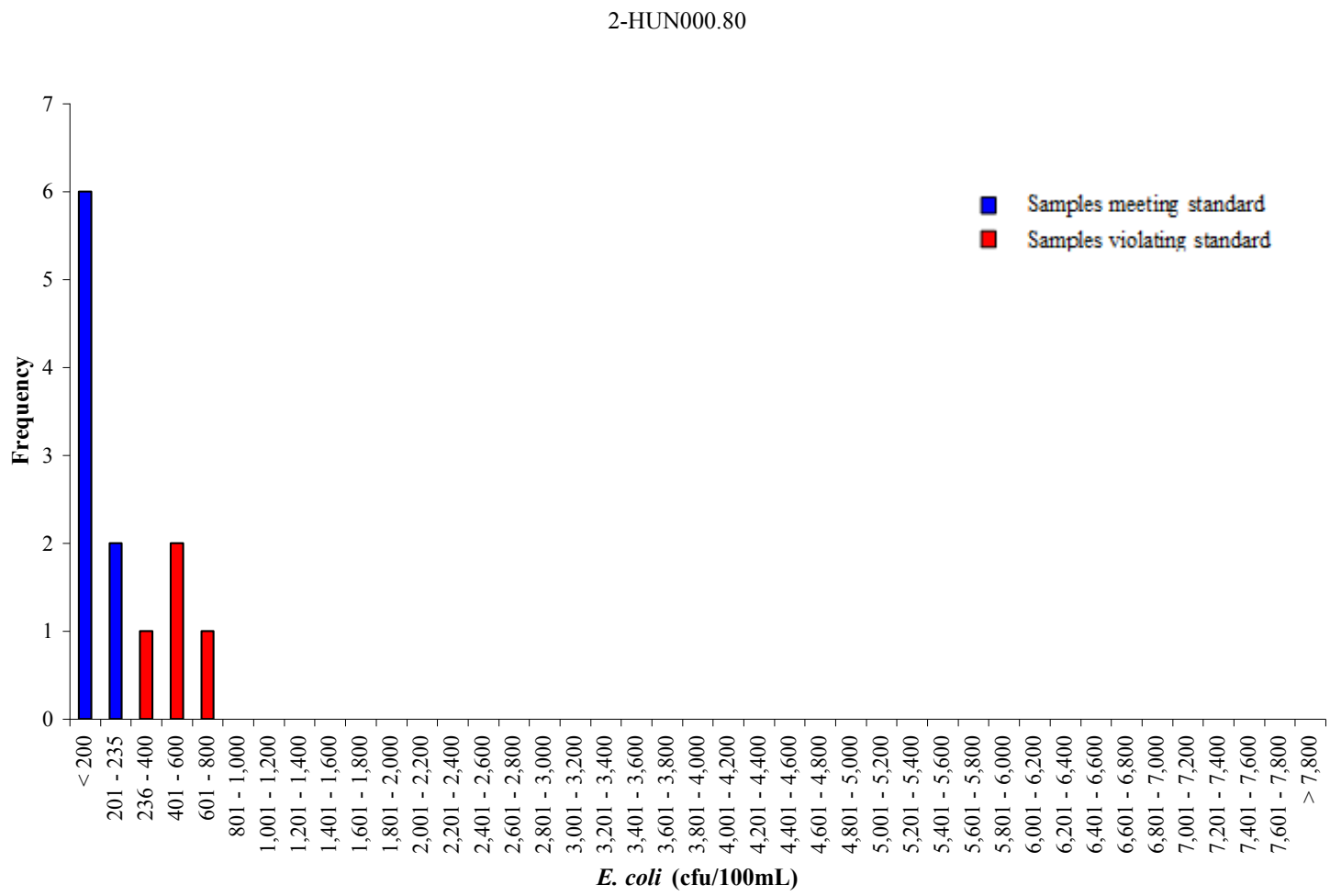

Figure A. 12 Frequency analysis of *E. coli* concentrations at station 2-HUN000.80 in Hungary Creek for the period from January 2006 to December 2006.

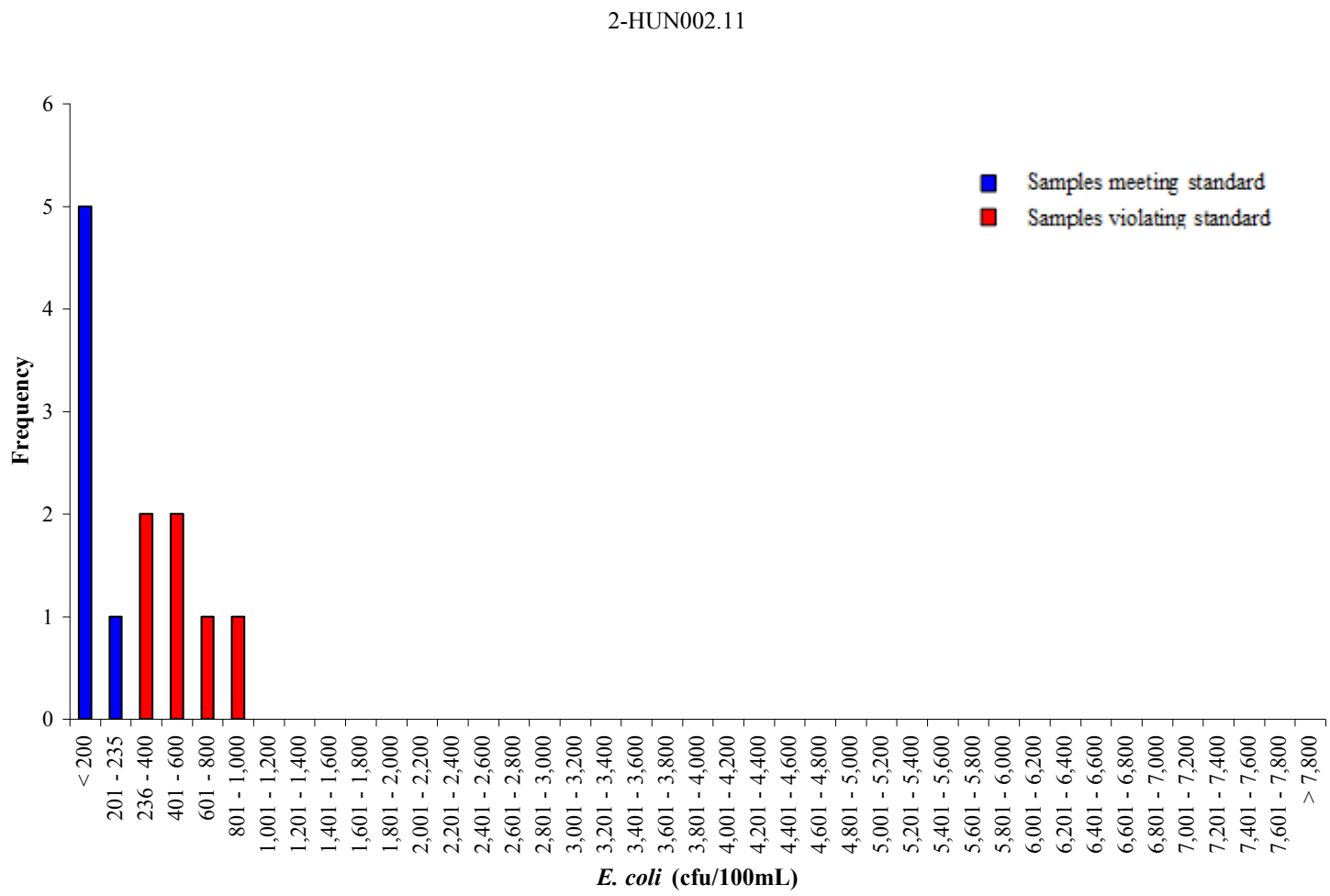

Figure A. 13 Frequency analysis of *E. coli* concentrations at station 2-HUN002.11 in Hungary Creek for the period from January 2006 to December 2006.

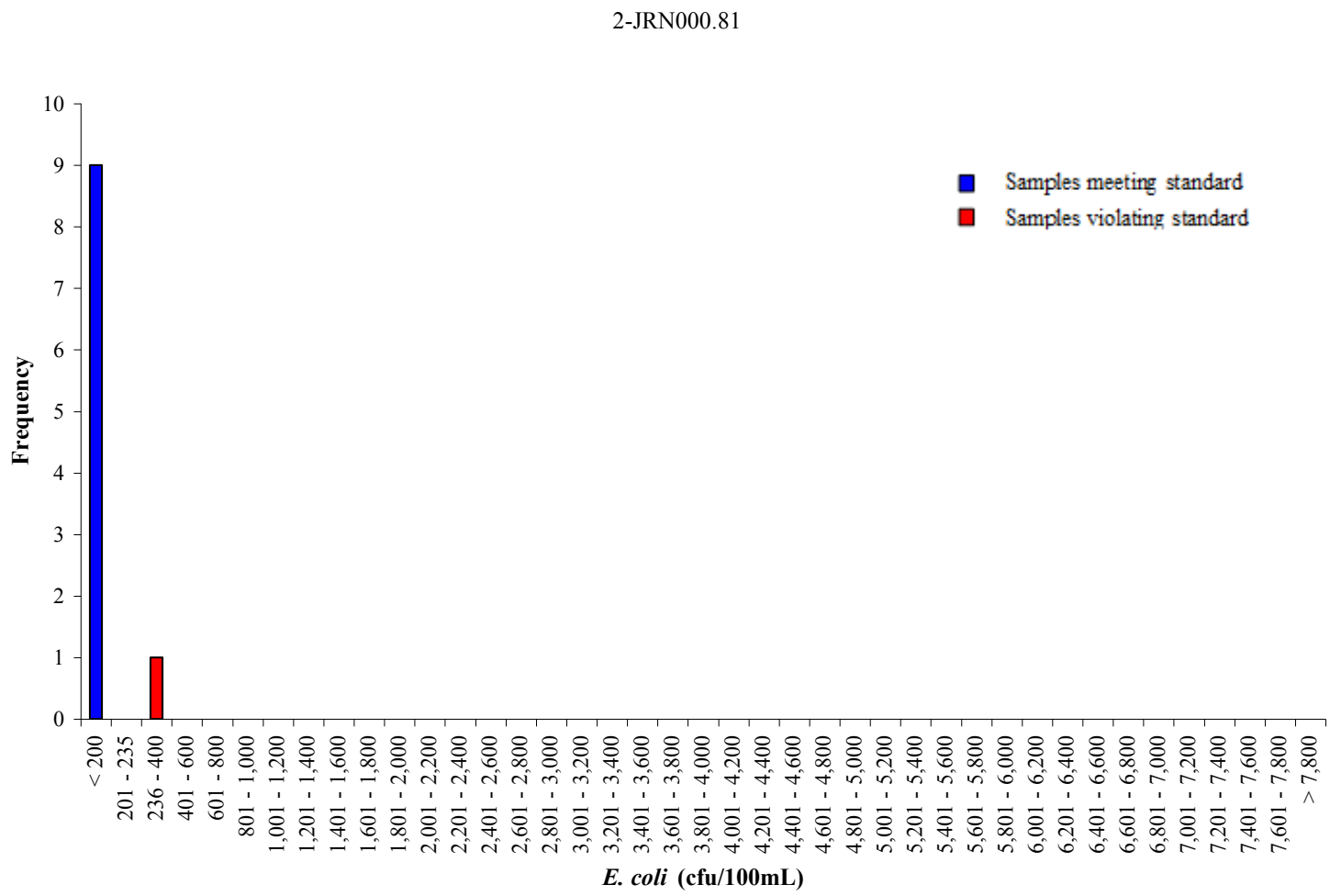

Figure A. 14 Frequency analysis of *E. coli* concentrations at station 2-JRN000.81 in Jones Run for the period from June 2005 to December 2006.

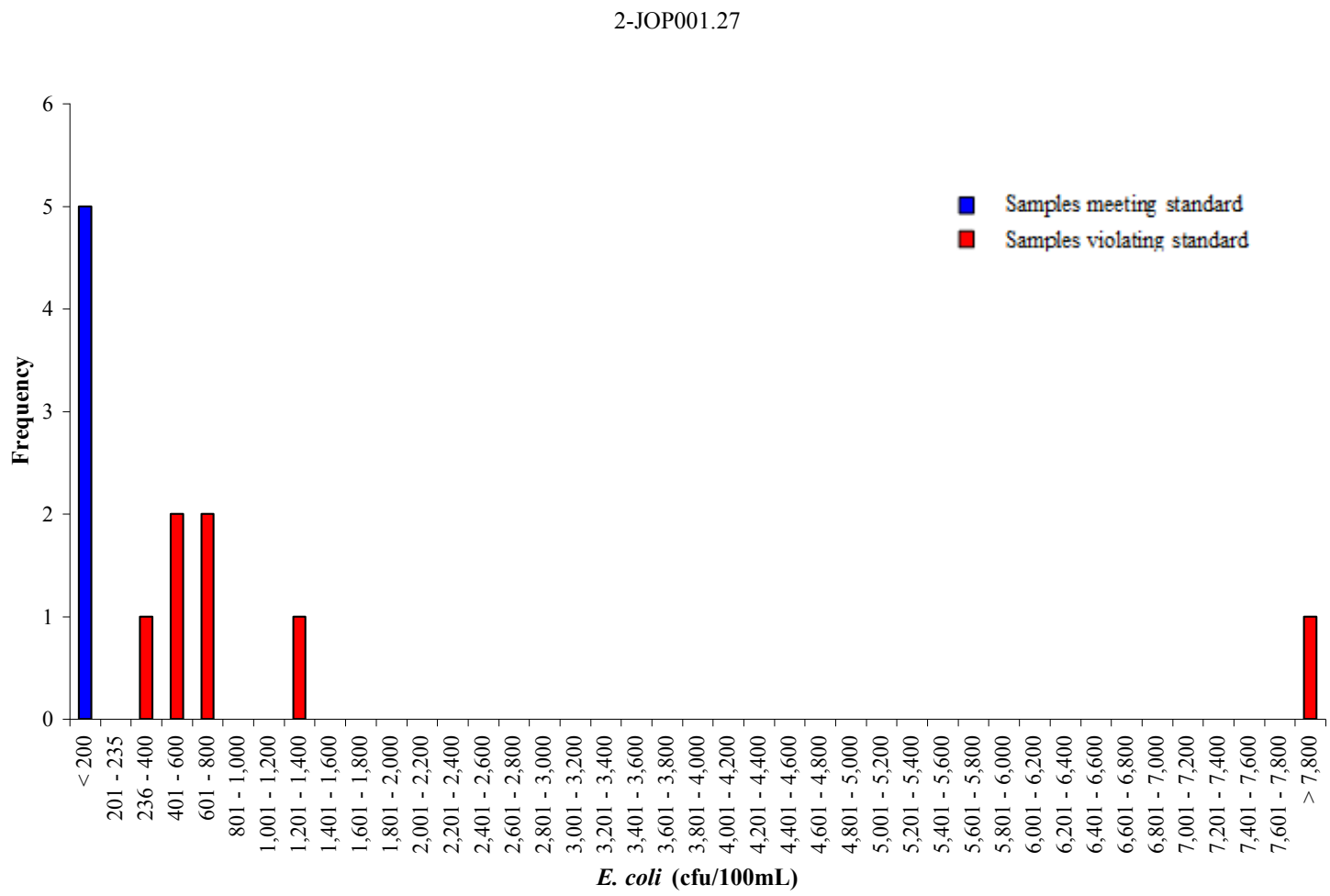

Figure A. 15 Frequency analysis of *E. coli* concentrations at station 2-JOP001.27 in Jordan Branch for the period from January 2006 to December 2006.

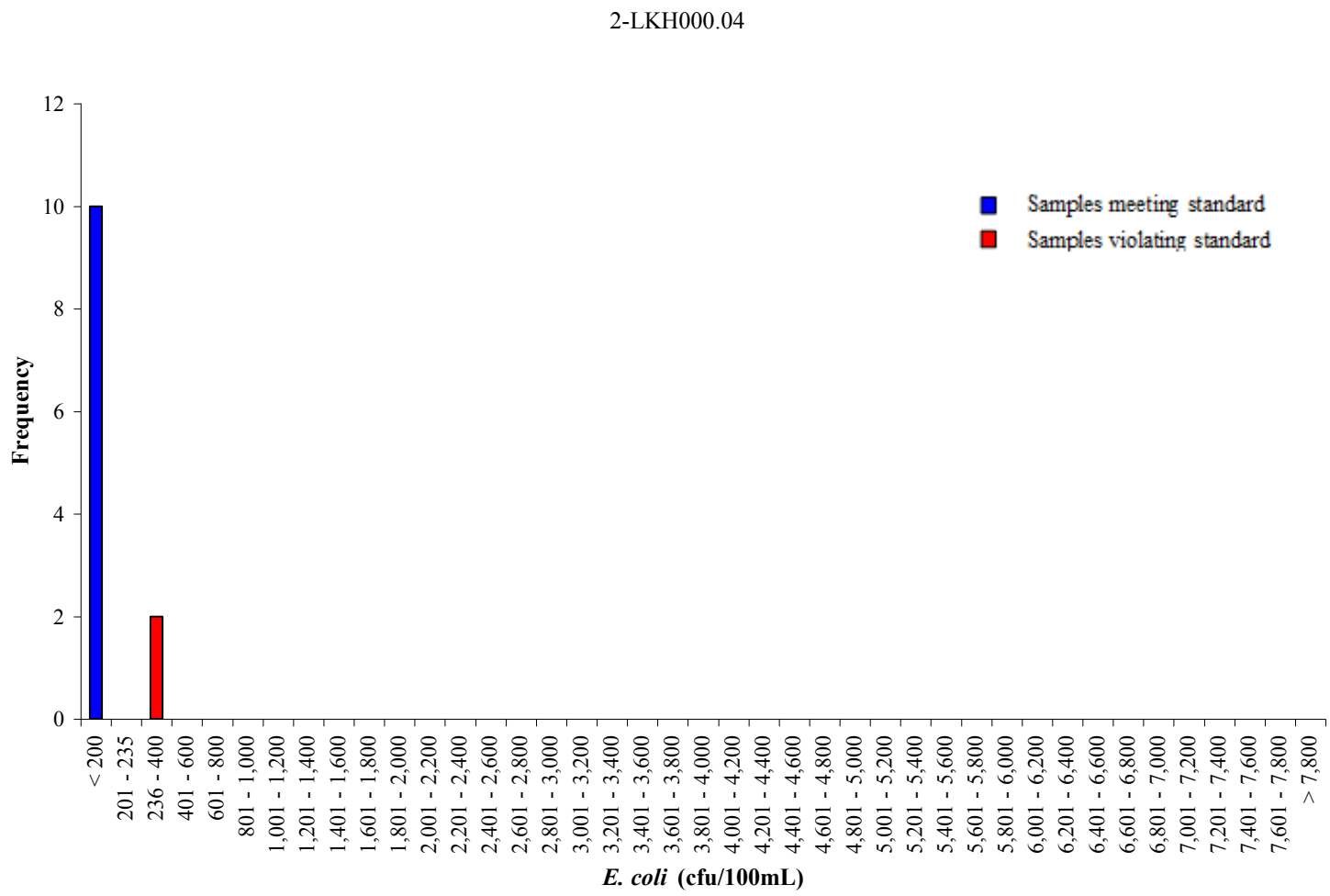

Figure A. 16 Frequency analysis of *E. coli* concentrations at station 2-LKH000.04 in Lickinghole Creek for the period from January 2009 to December 2009.

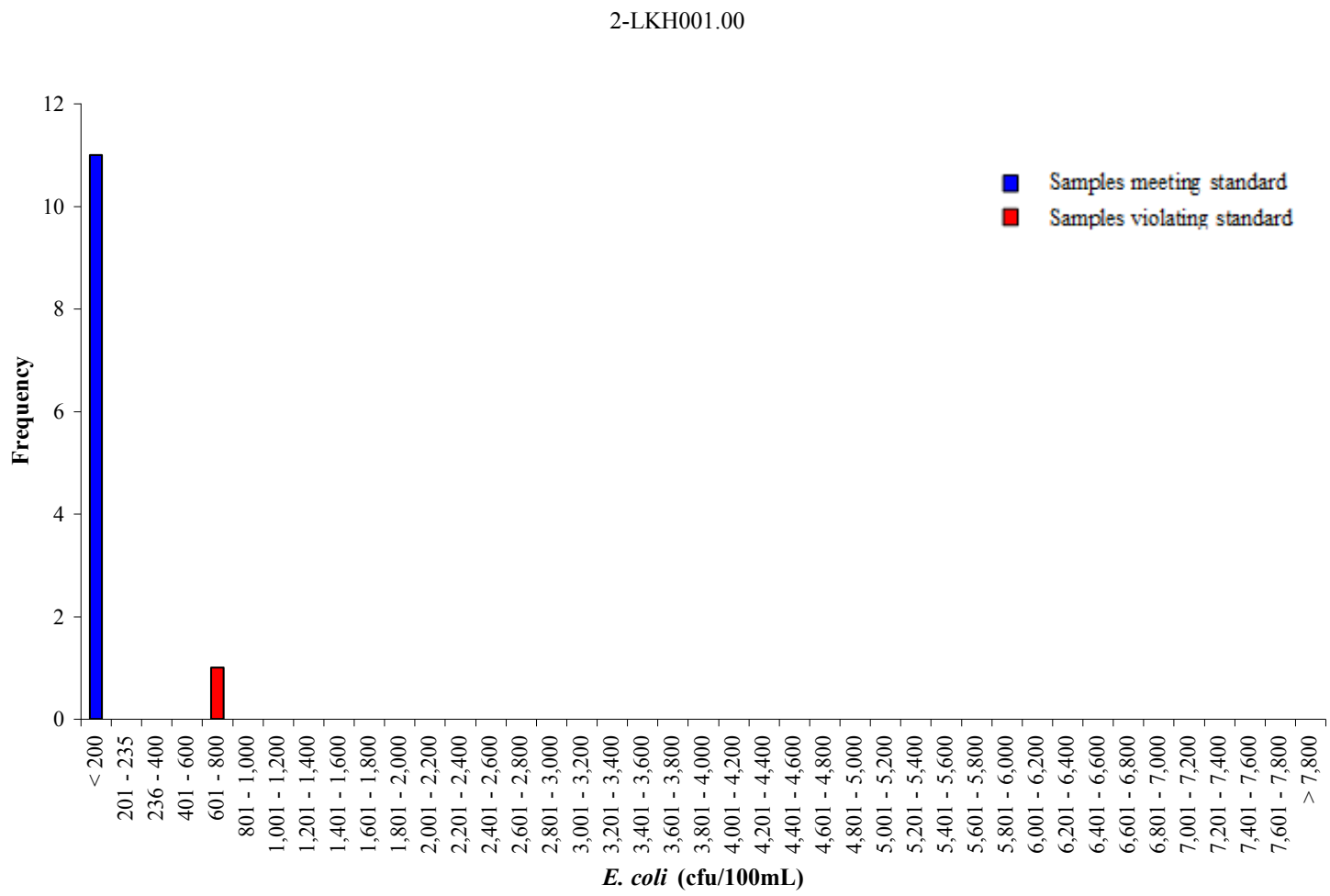

Figure A. 17 Frequency analysis of *E. coli* concentrations at station 2-LKH001.00 in Lickinghole Creek for the period from January 2009 to December 2009.

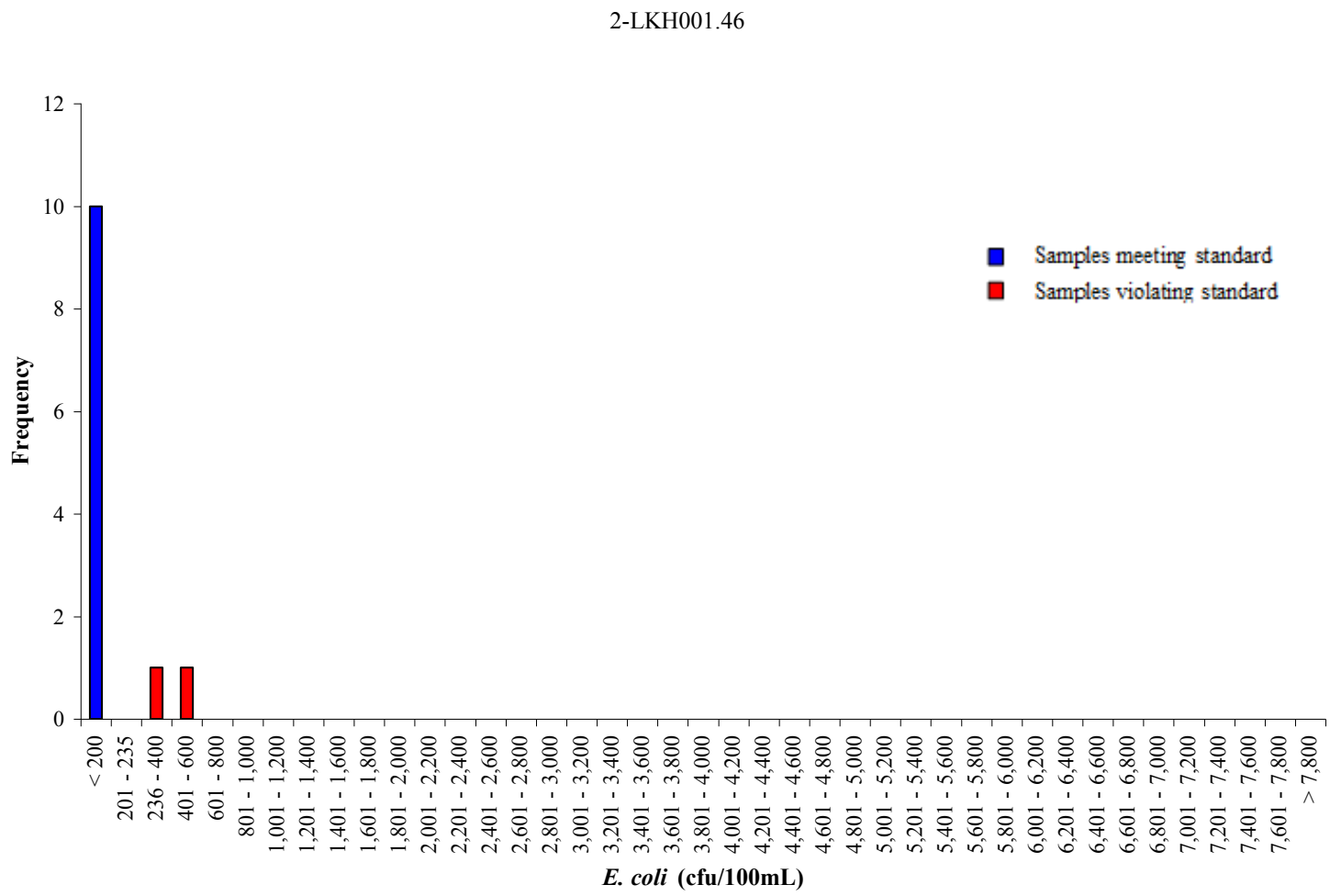

Figure A. 18 Frequency analysis of *E. coli* concentrations at station 2-LKH001.46 in Lickinghole Creek for the period from January 2009 to December 2009.

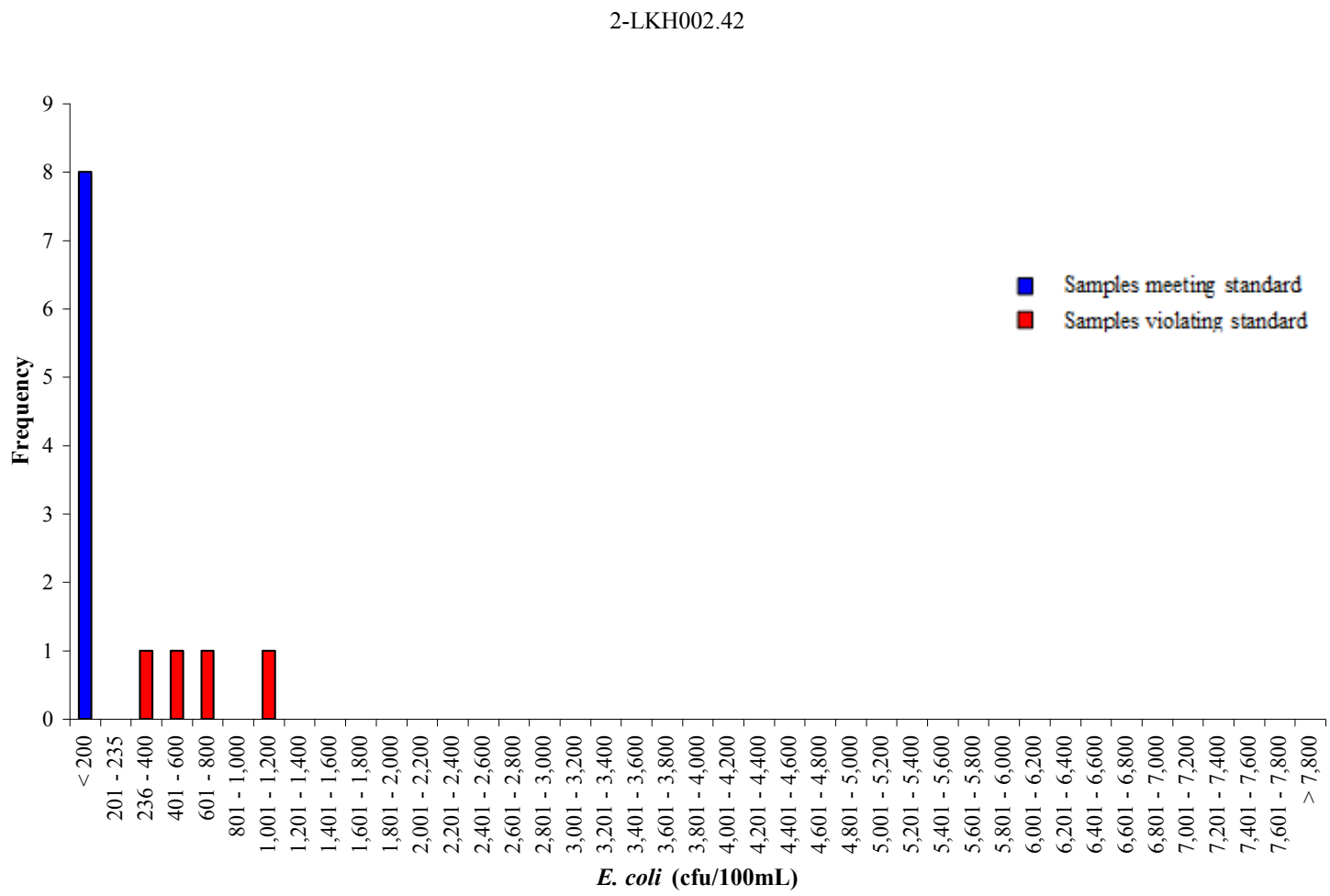

Figure A. 19 Frequency analysis of *E. coli* concentrations at station 2-LKH002.42 in Lickinghole Creek for the period from January 2009 to December 2009.

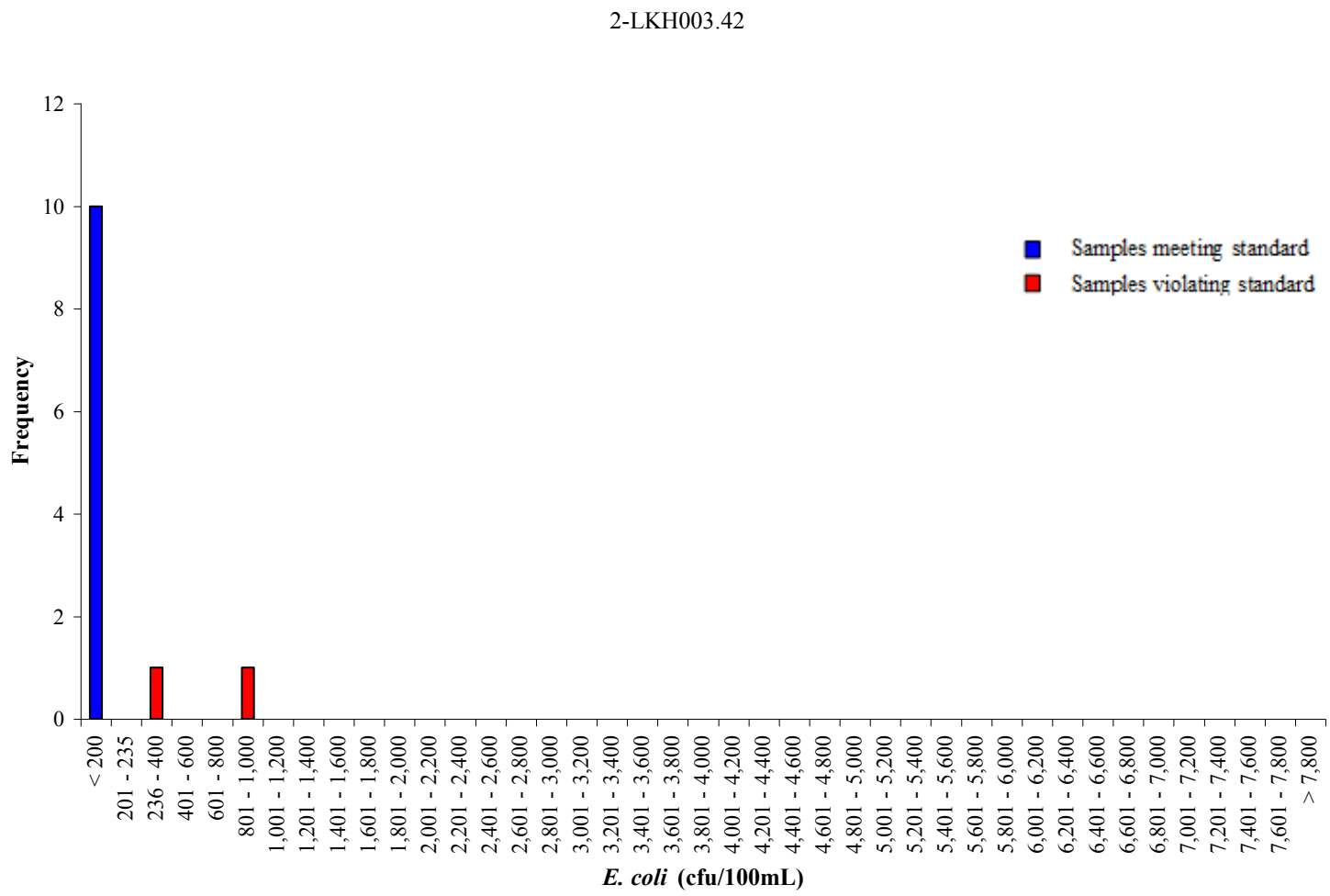

Figure A. 20 Frequency analysis of *E. coli* concentrations at station 2-LKH003.42 in Lickinghole Creek for the period from January 2009 to December 2009.

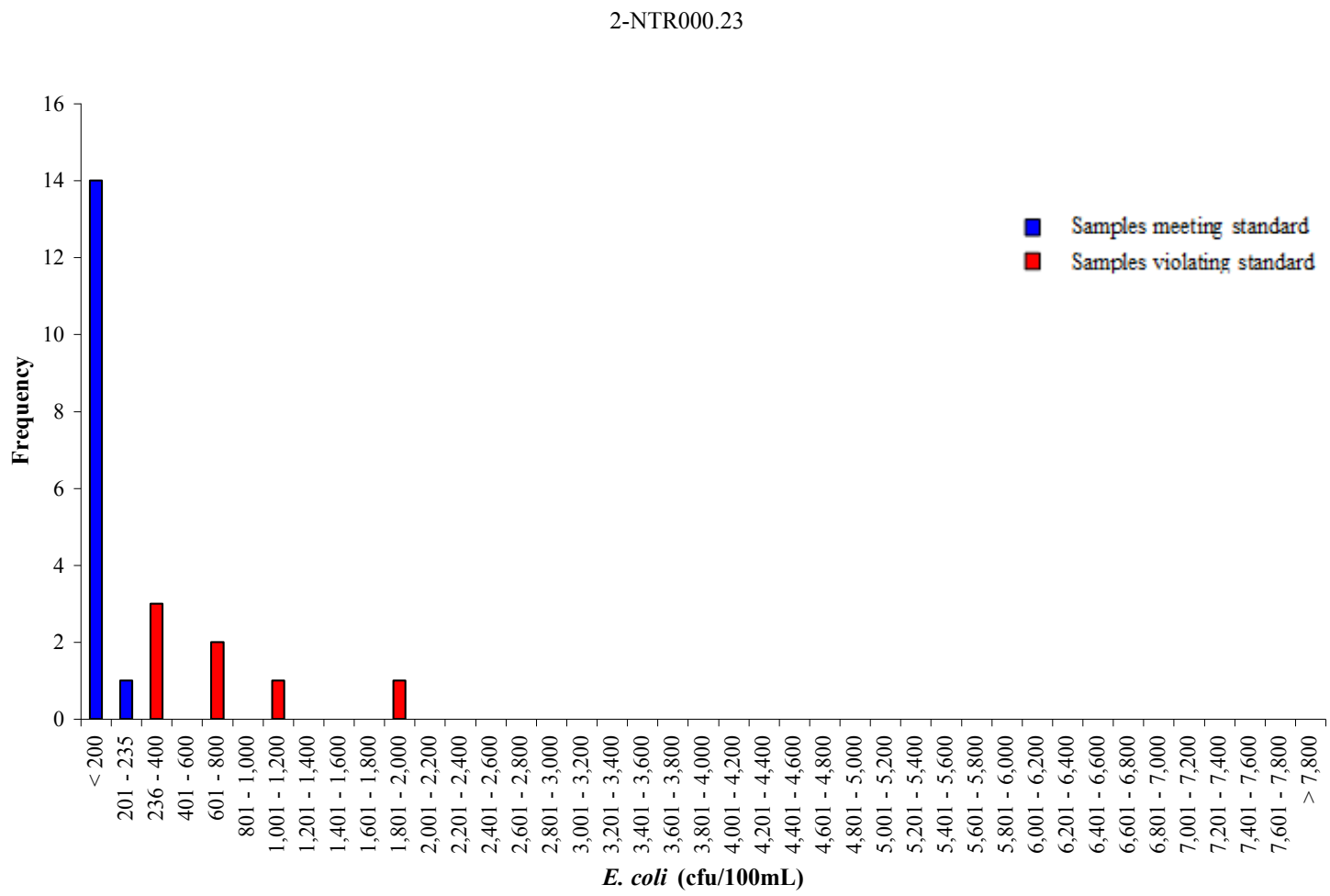

Figure A. 21 Frequency analysis of *E. coli* concentrations at station 2-NTR000.23 in North Run for the period from June 2005 to December 2006.

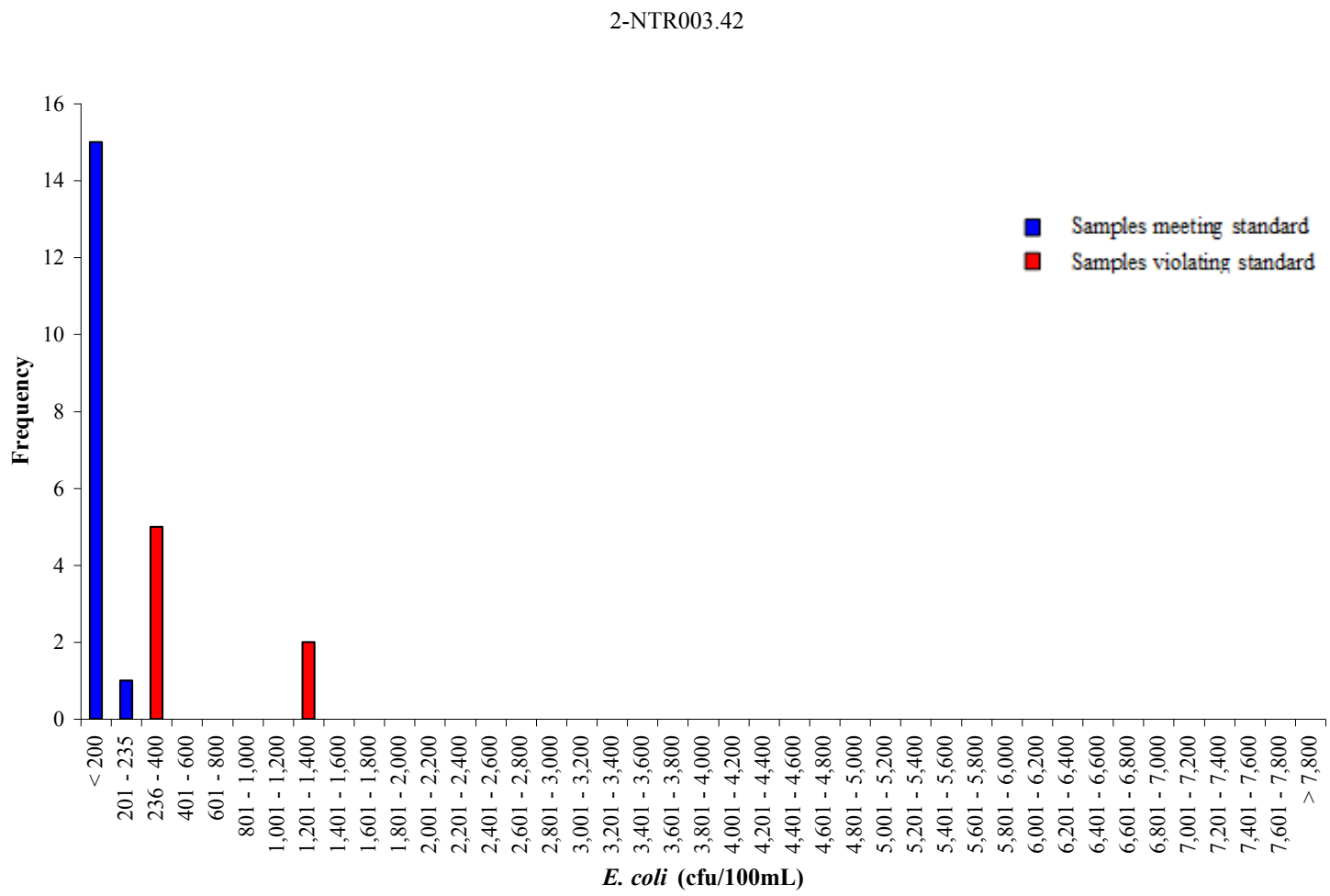

Figure A. 22 Frequency analysis of *E. coli* concentrations at station 2-NTR003.42 in North Run for the period from July 2003 to December 2006.

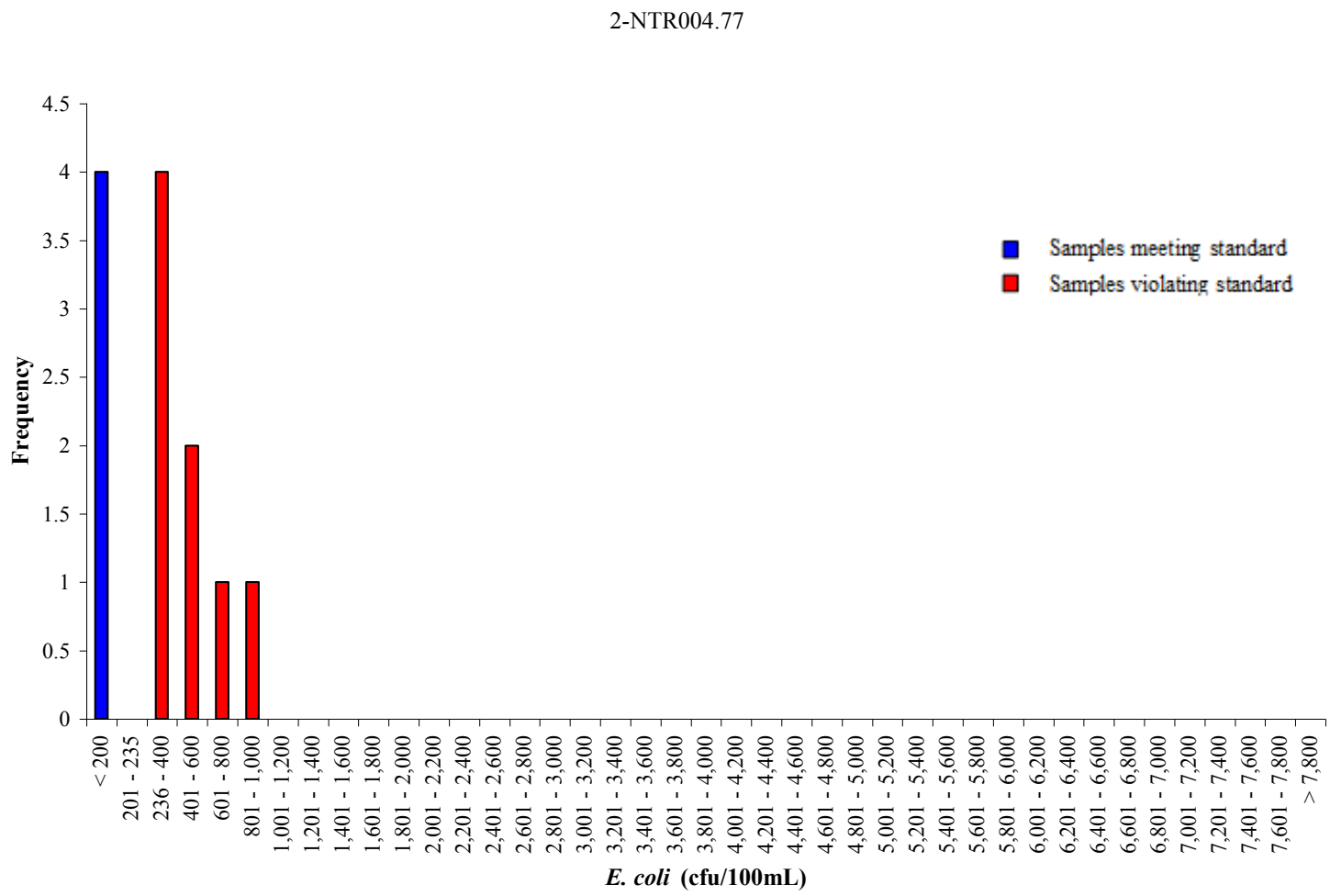

Figure A. 23 Frequency analysis of *E. coli* concentrations at station 2-NTR004.77 in North Run for the period from January 2006 to December 2006.

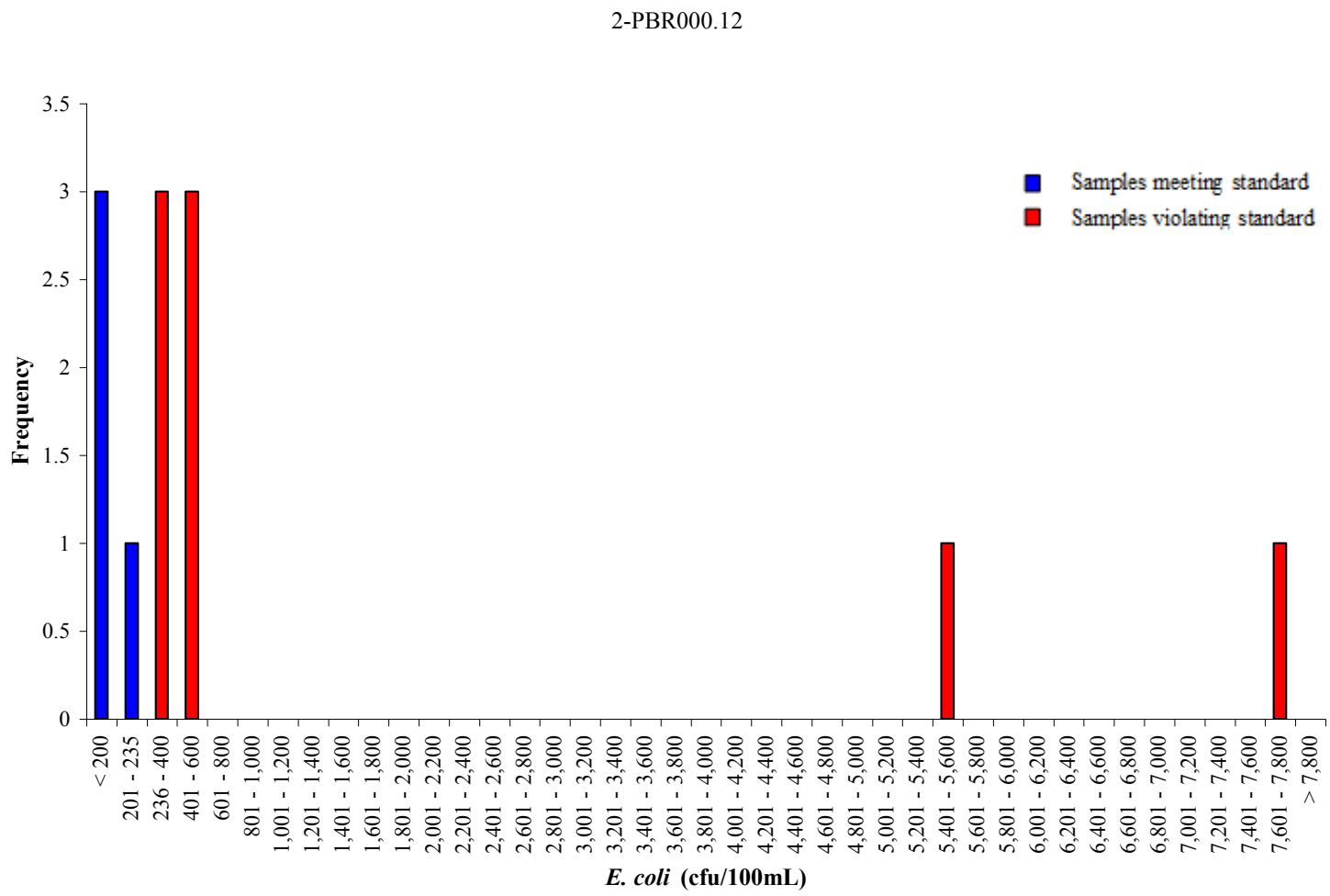

Figure A. 24 Frequency analysis of *E. coli* concentrations at station 2-PBR000.12 in Piney Branch for the period from January 2006 to December 2006.

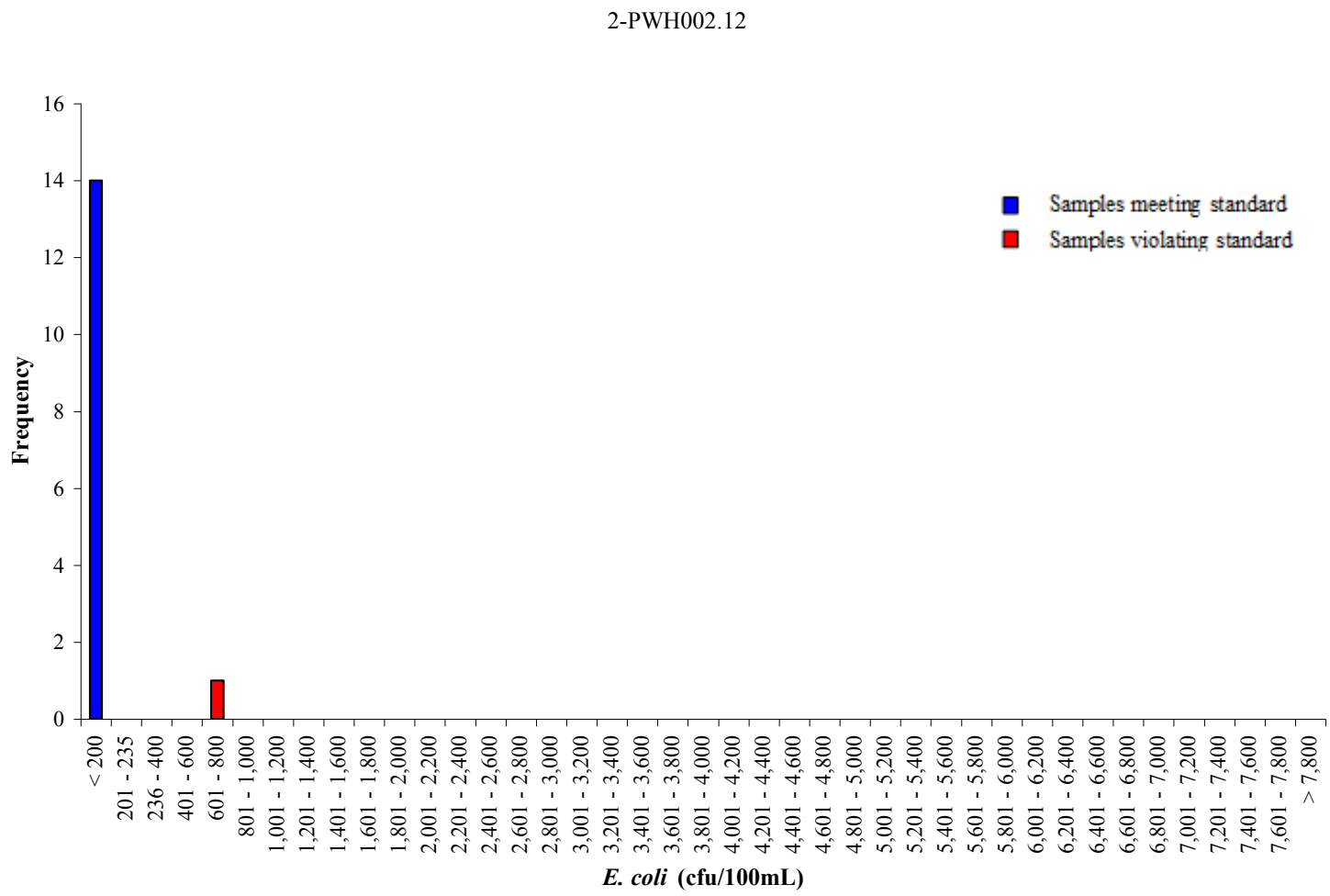

Figure A. 25 Frequency analysis of *E. coli* concentrations at station 2-PWH002.12 in Powhite Creek for the period from May 2004 to November 2006.

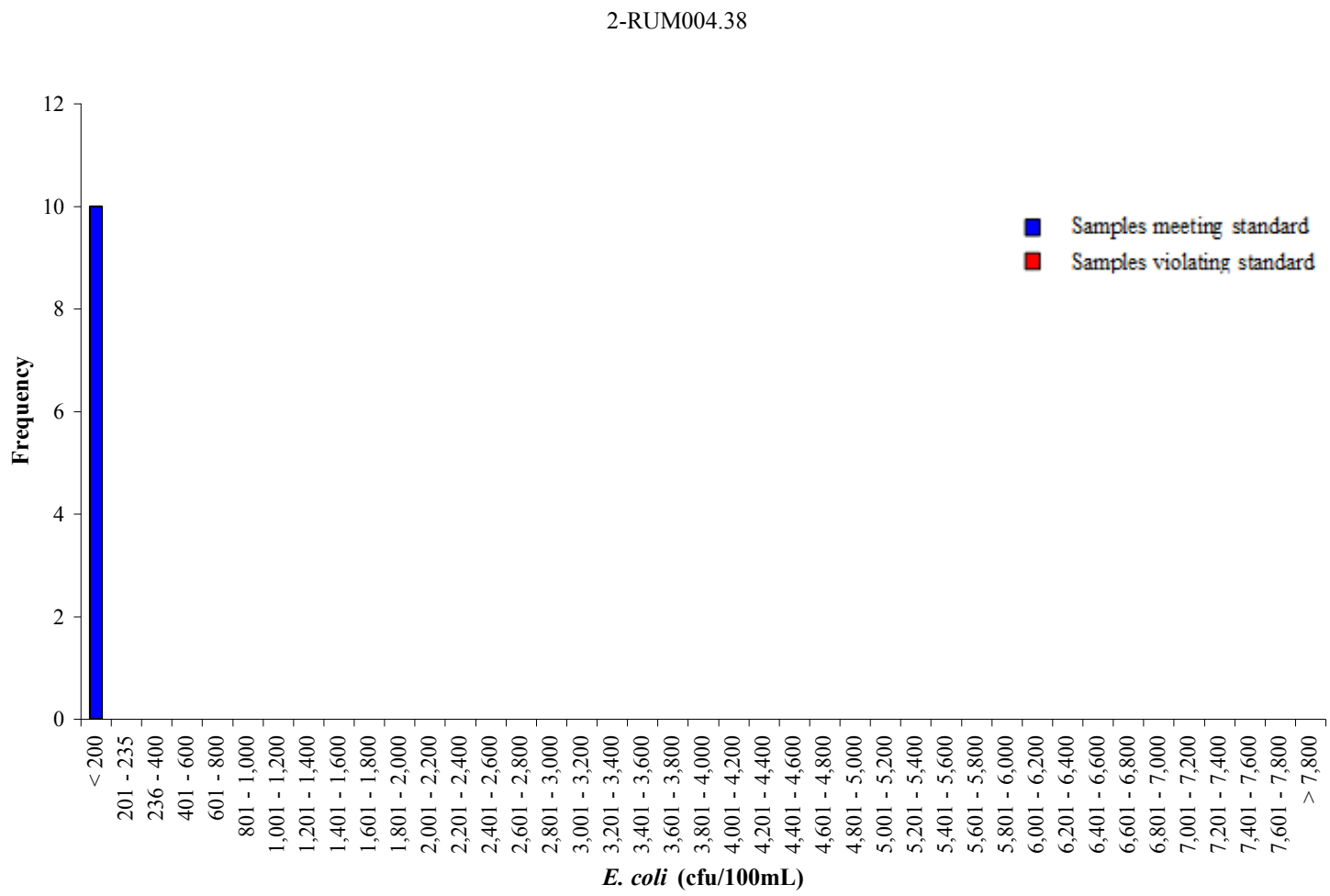

Figure A. 26 Frequency analysis of *E. coli* concentrations at station 2-RUM004.38 in Rumley Marsh for the period from June 2005 to December 2006.

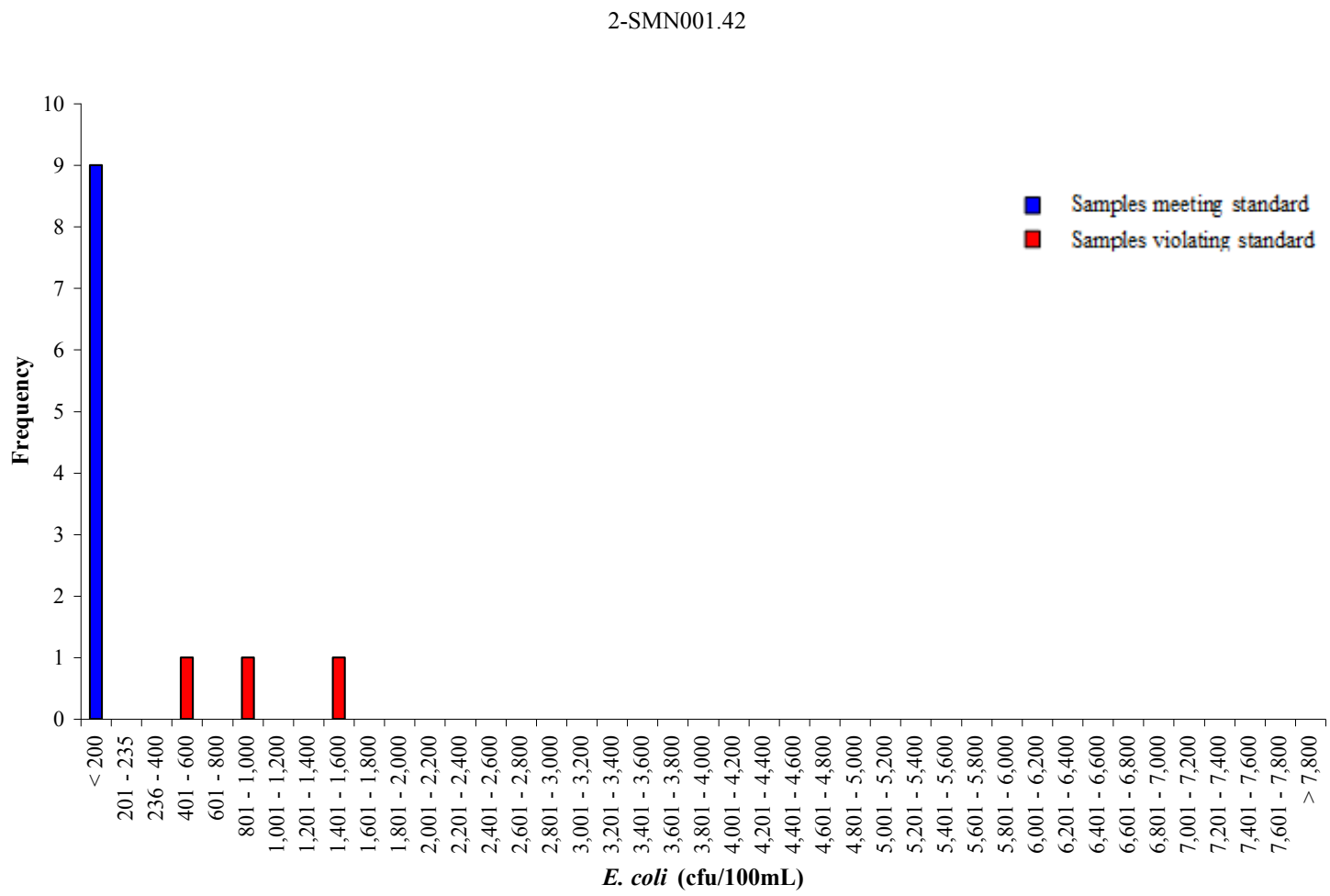

Figure A. 27 Frequency analysis of *E. coli* concentrations at station 2-SMN001.42 in Schiminoe Creek for the period from February 2009 to November 2010.

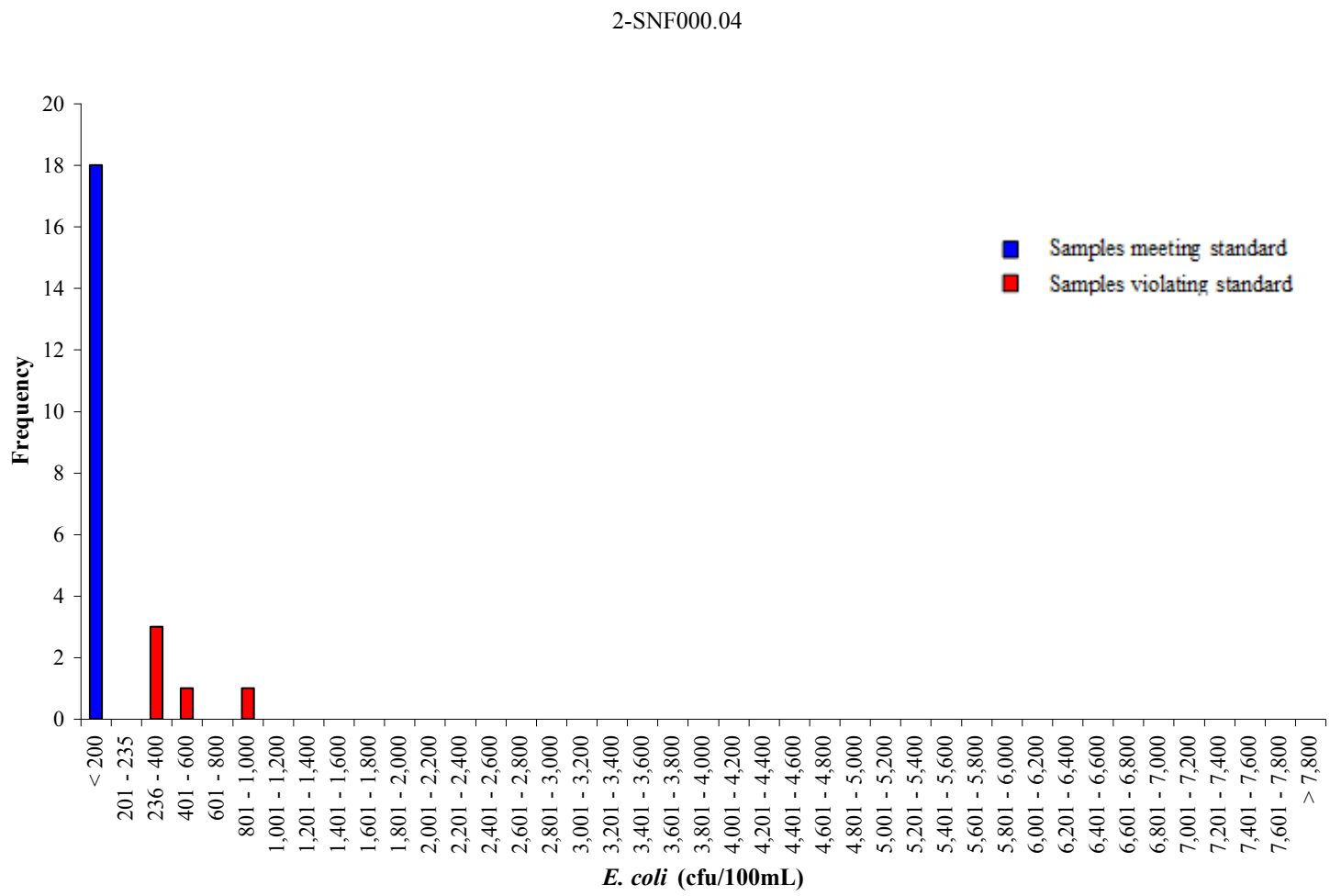

Figure A. 28 Frequency analysis of *E. coli* concentrations at station 2-SNF000.04 in Stony Run for the period from January 2007 to December 2009.

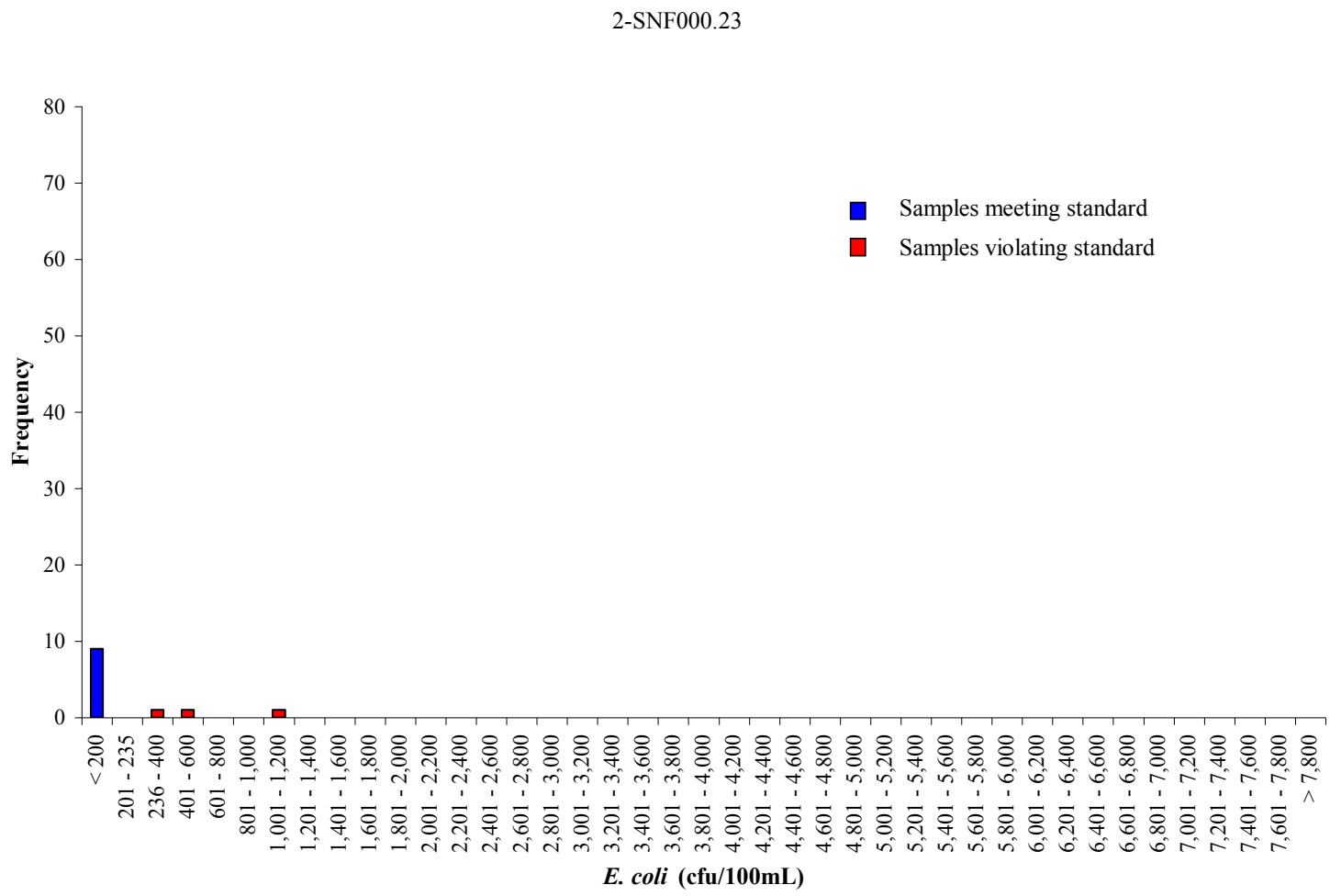

Figure A. 29 Frequency analysis of *E. coli* concentrations at station 2-SNF000.23 in Stony Run for the period from January 2009 to December 2009.

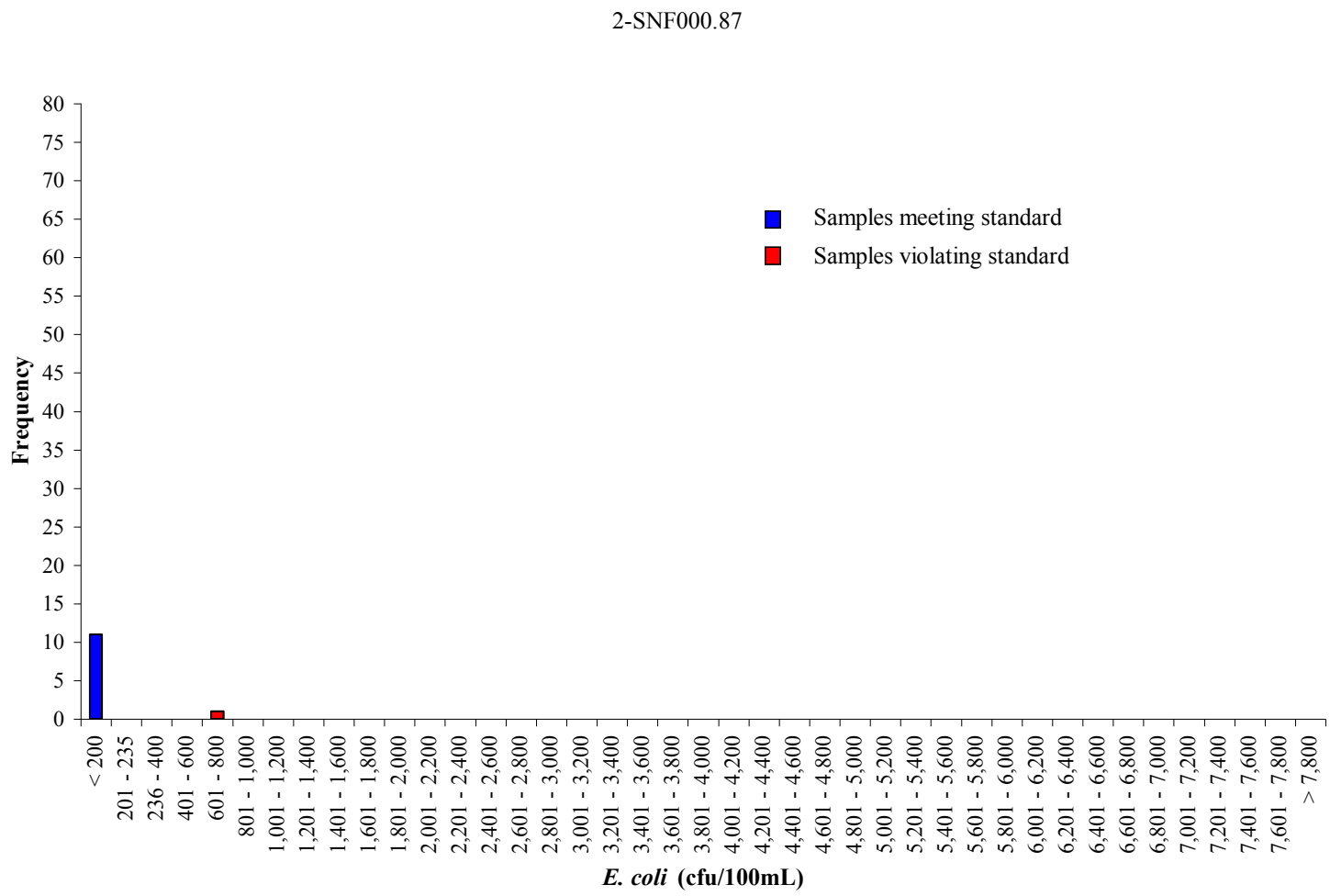

Figure A. 30 Frequency analysis of *E. coli* concentrations at station 2-SNF000.87 in Stony Run for the period from January 2009 to December 2009.

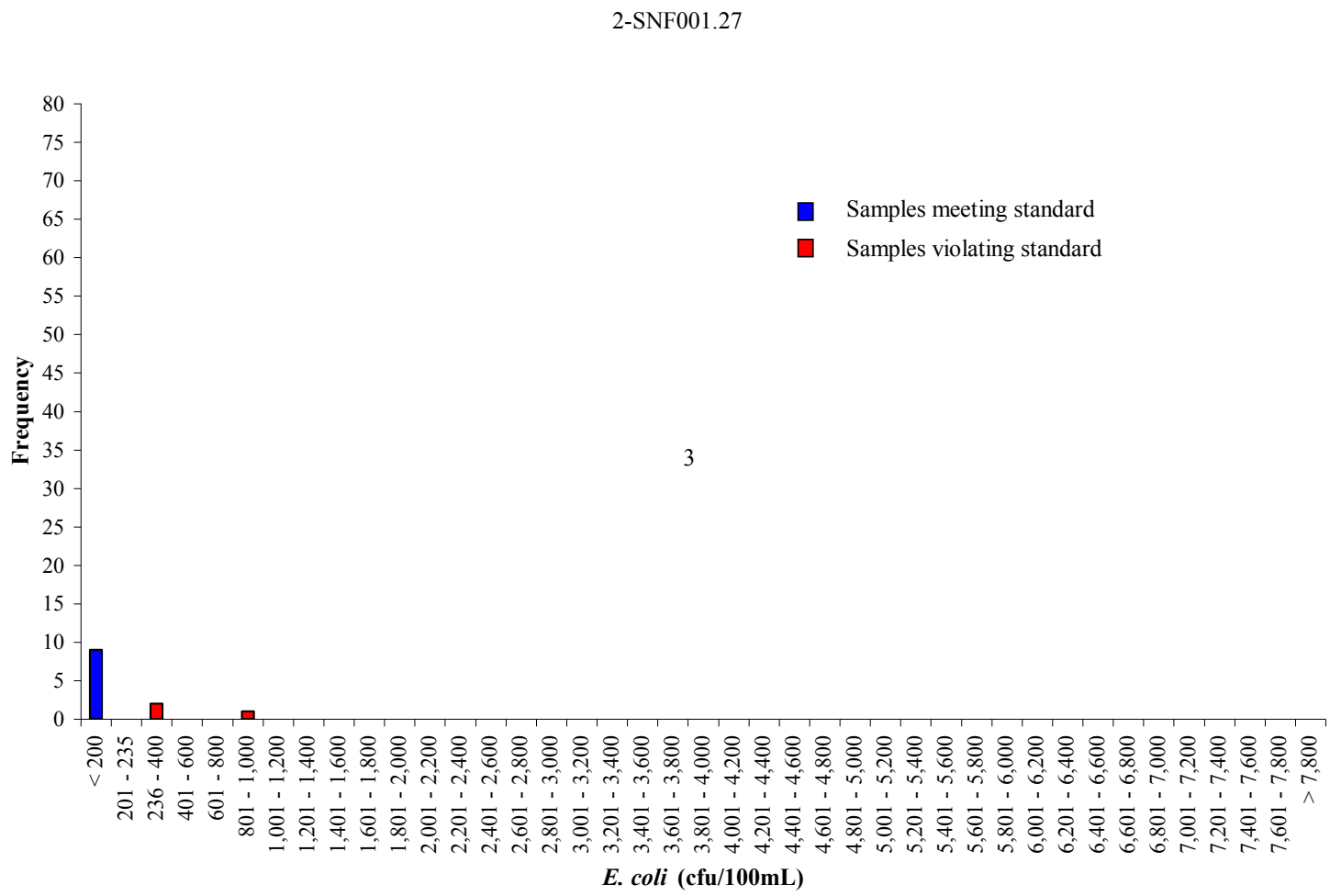

Figure A. 31 Frequency analysis of *E. coli* concentrations at station 2-SNF001.27 in Stony Run for the period from January 2009 to December 2009.

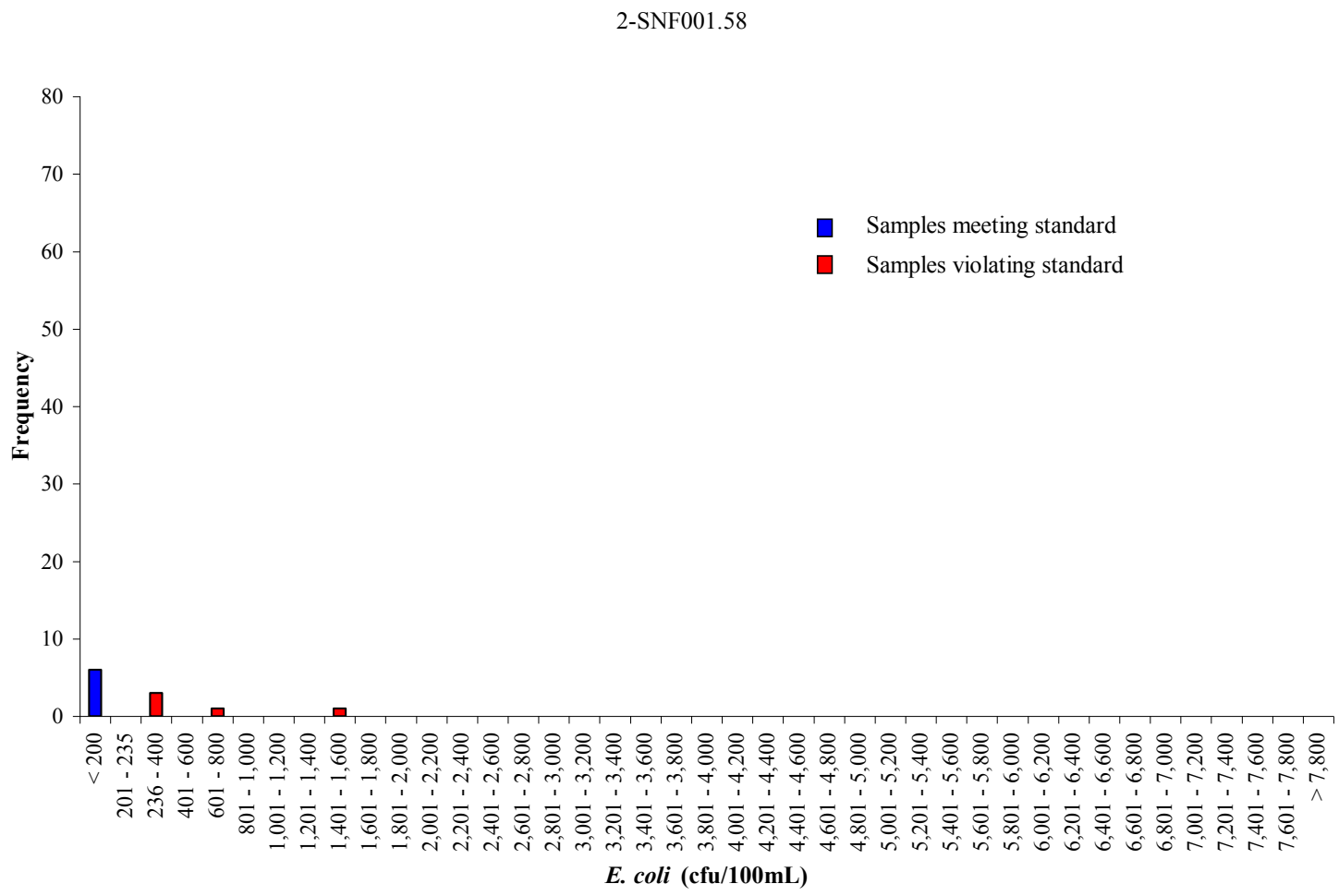

Figure A. 32 Frequency analysis of *E. coli* concentrations at station 2-SNF001.58 in Stony Run for the period from January 2009 to November 2009.

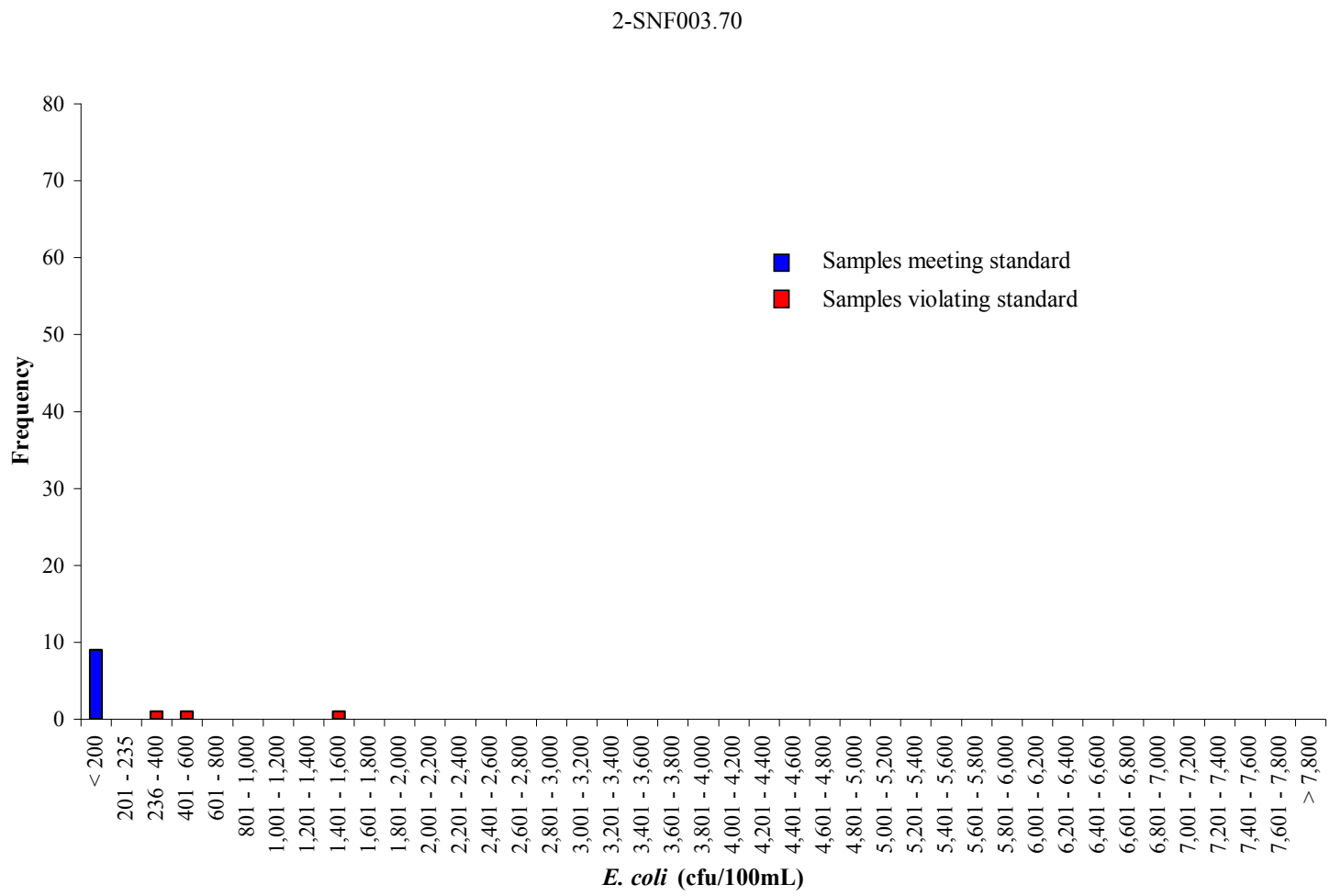

Figure A. 33 Frequency analysis of *E. coli* concentrations at station 2-SNF003.70 in Stony Run for the period from January 2009 to December 2009.

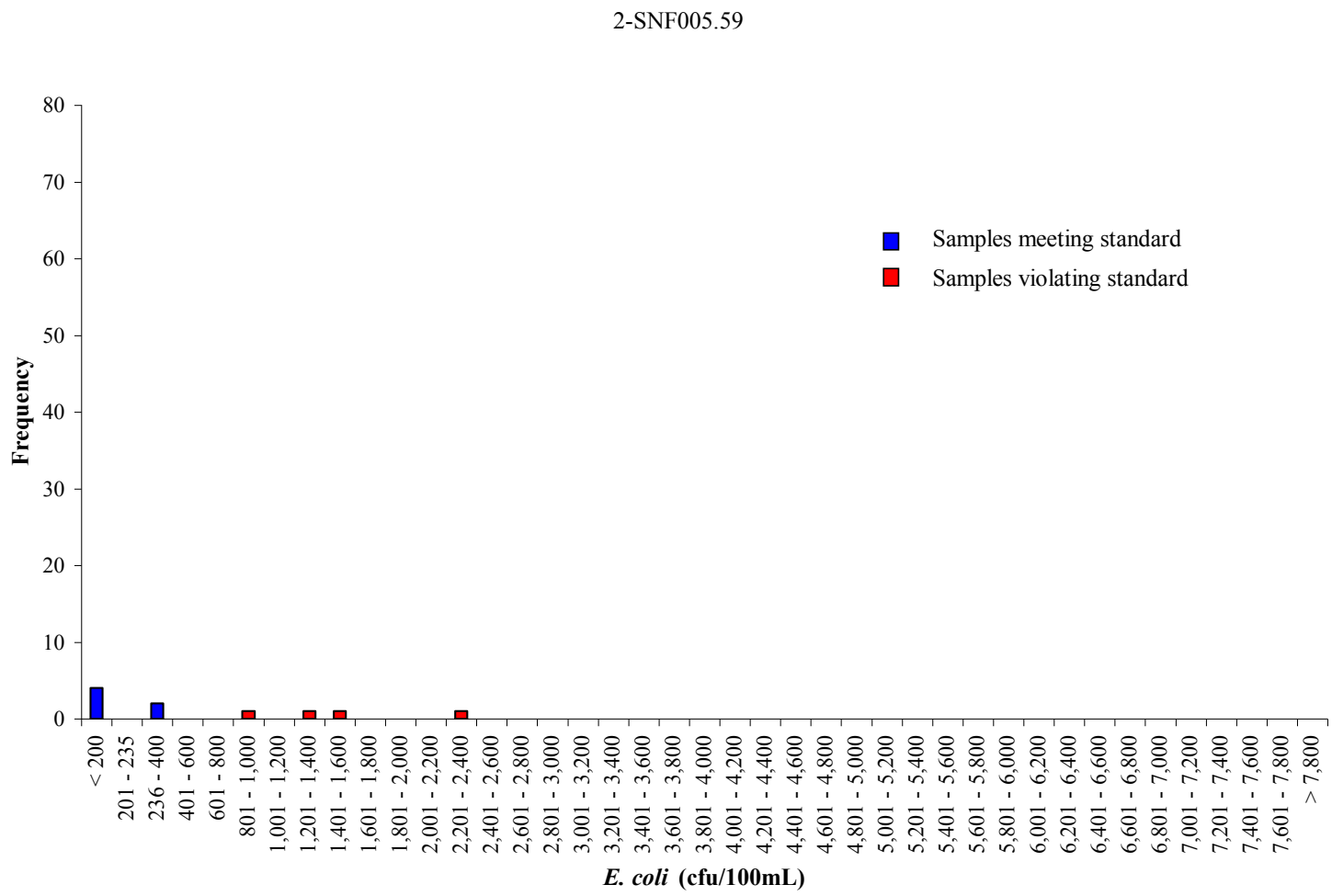

Figure A. 34 Frequency analysis of *E. coli* concentrations at station 2-SNF005.59 in Stony Run for the period from January 2009 to December 2009.

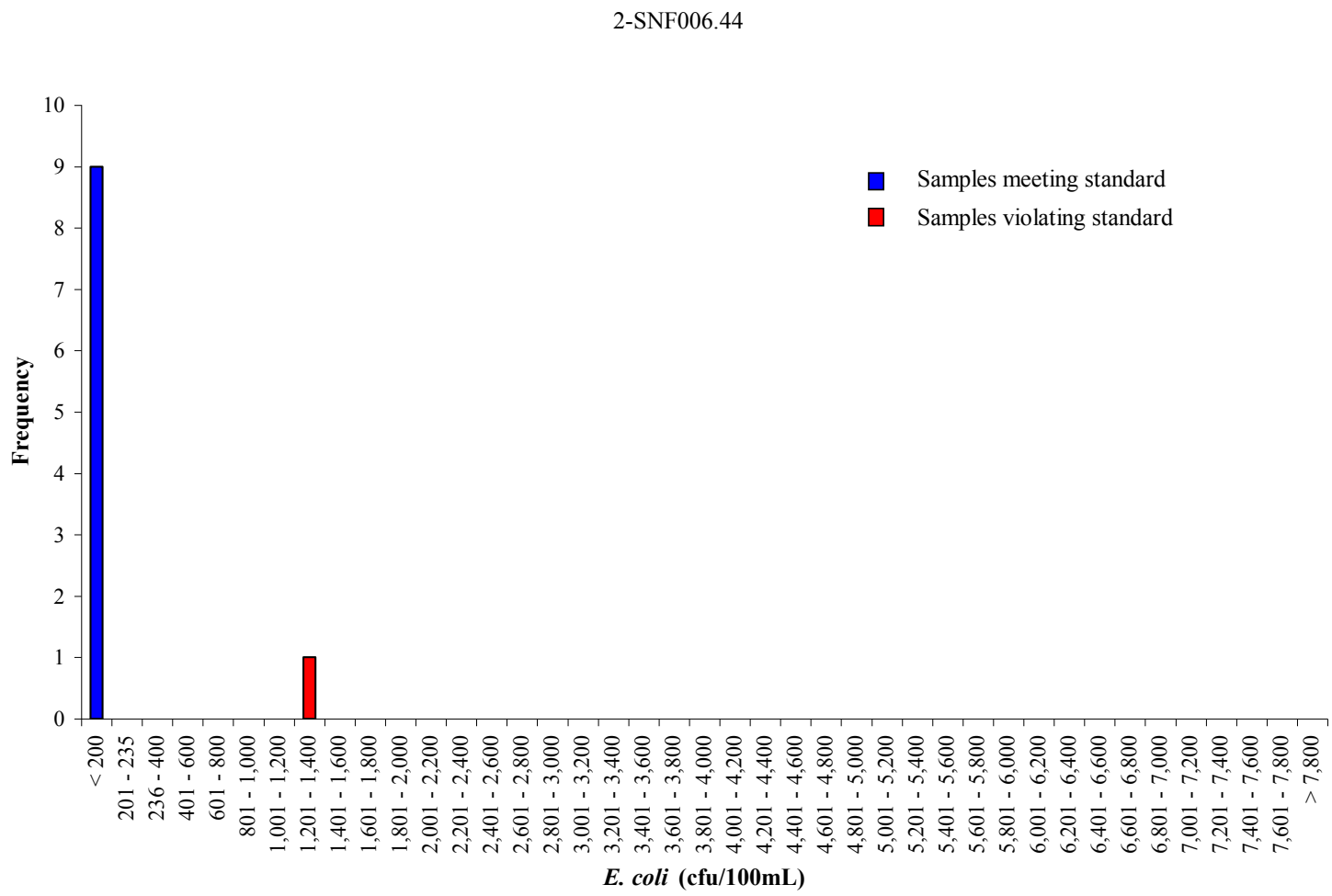

Figure A. 35 Frequency analysis of *E. coli* concentrations at station 2-SNF006.44 in Stony Run for the period from January 2009 to December 2009.

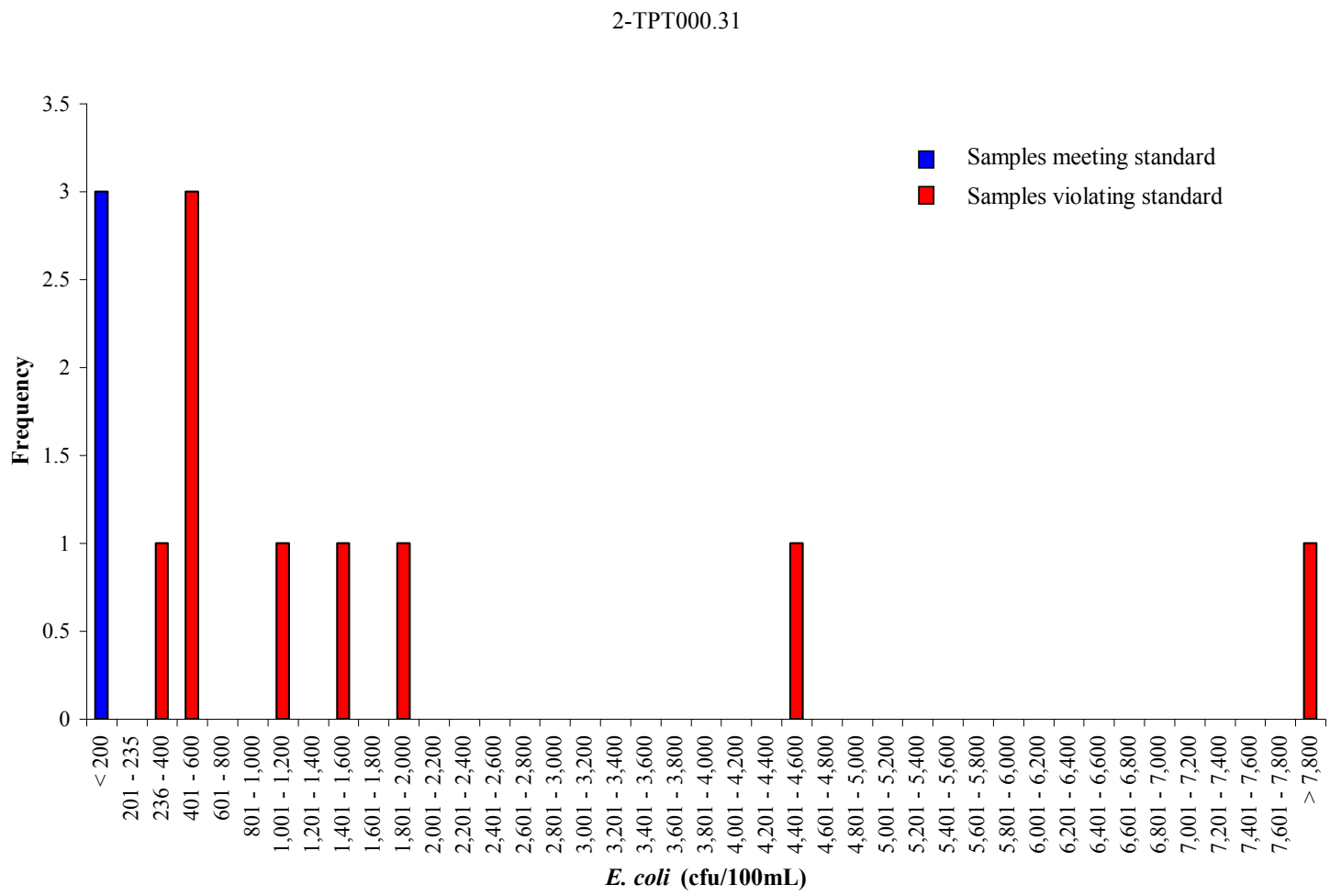

Figure A. 36 Frequency analysis of *E. coli* concentrations at station 2-TPT000.31 in Trumpet Branch for the period from January 2006 to December 2006.

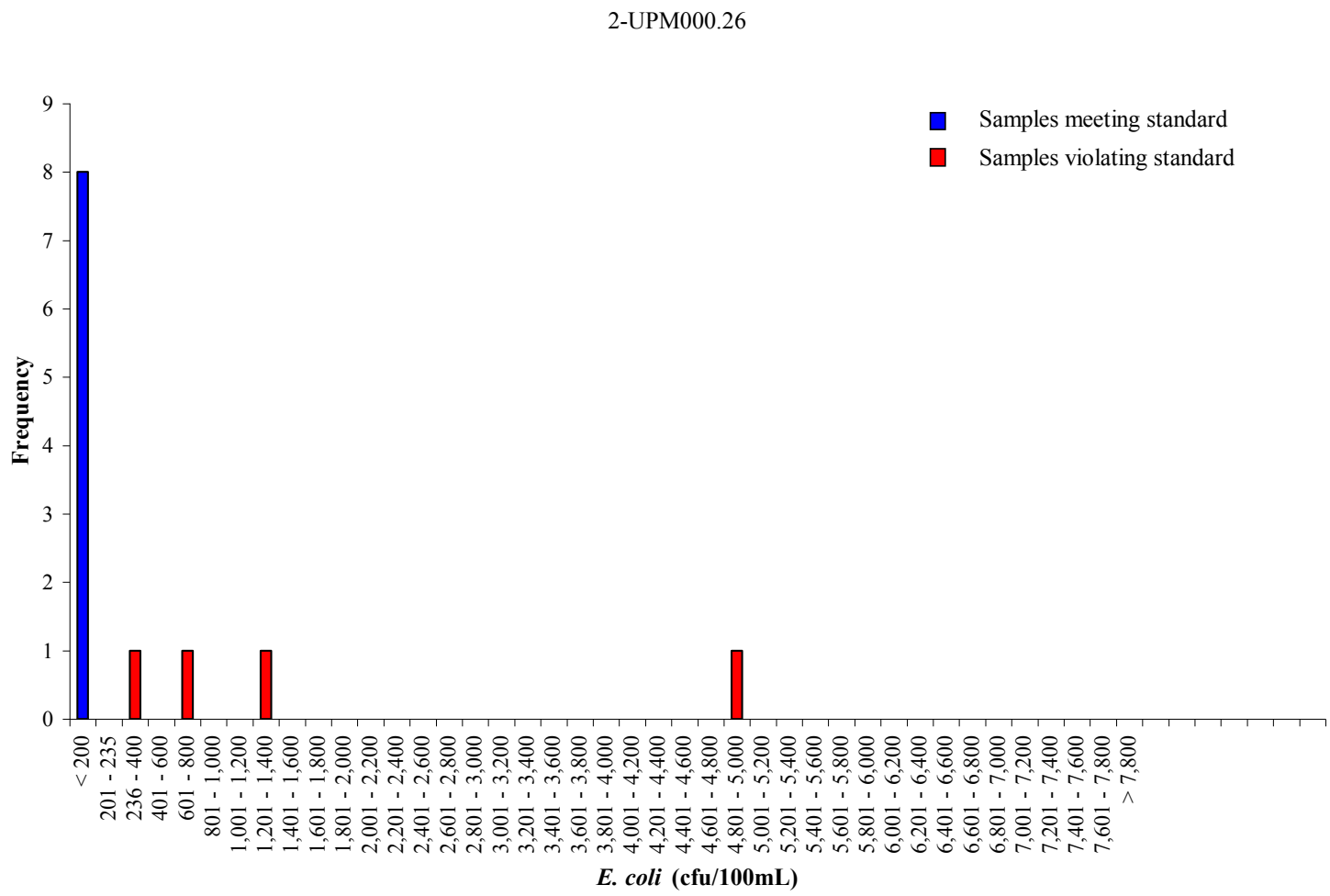

Figure A. 37 Frequency analysis of *E. coli* concentrations at station 2-UPM000.26 in Upham Brook for the period from January 2006 to December 2006.

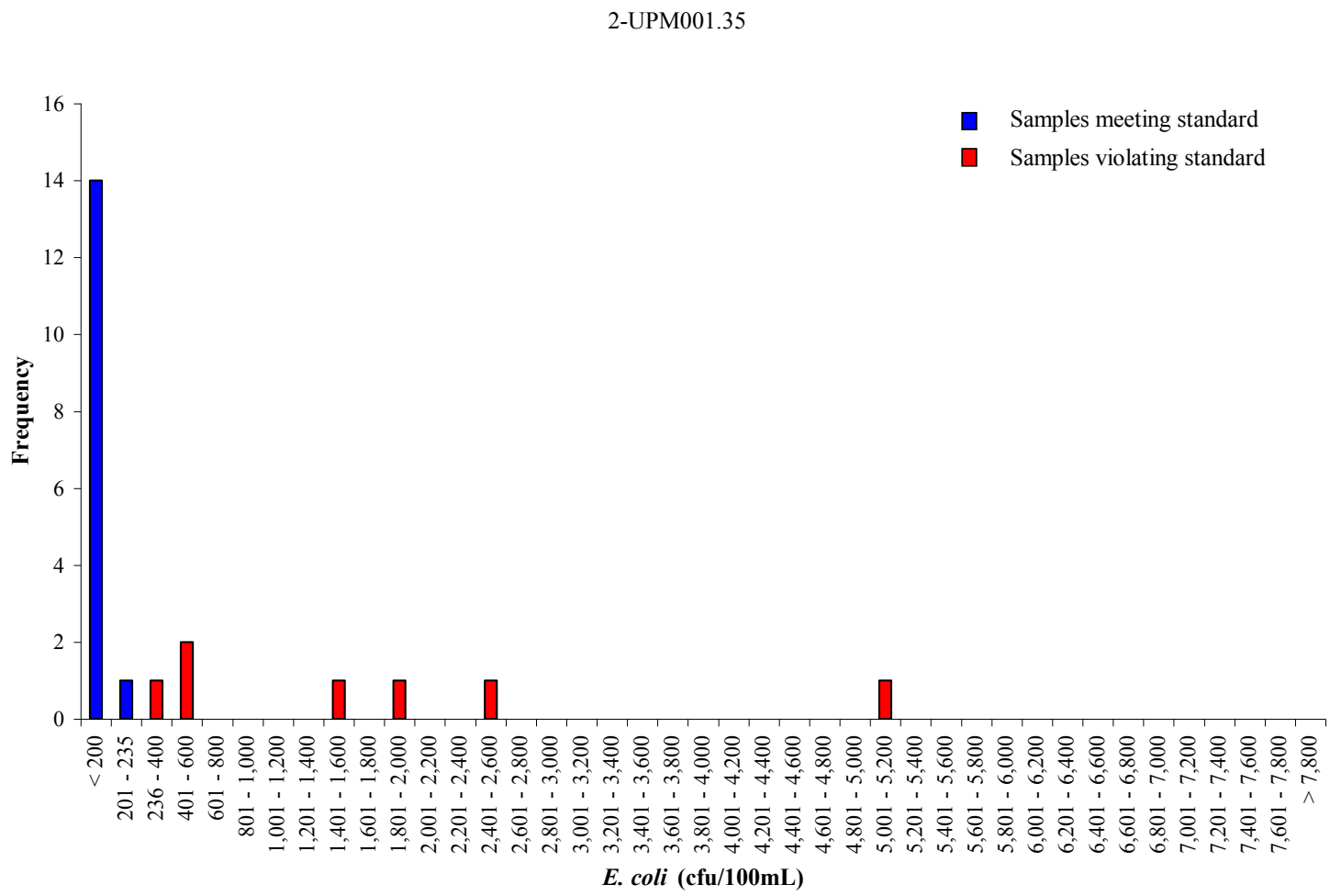

Figure A. 38 Frequency analysis of *E. coli* concentrations at station 2-UPM001.35 in Upham Brook for the period from June 2005 to January 2011.

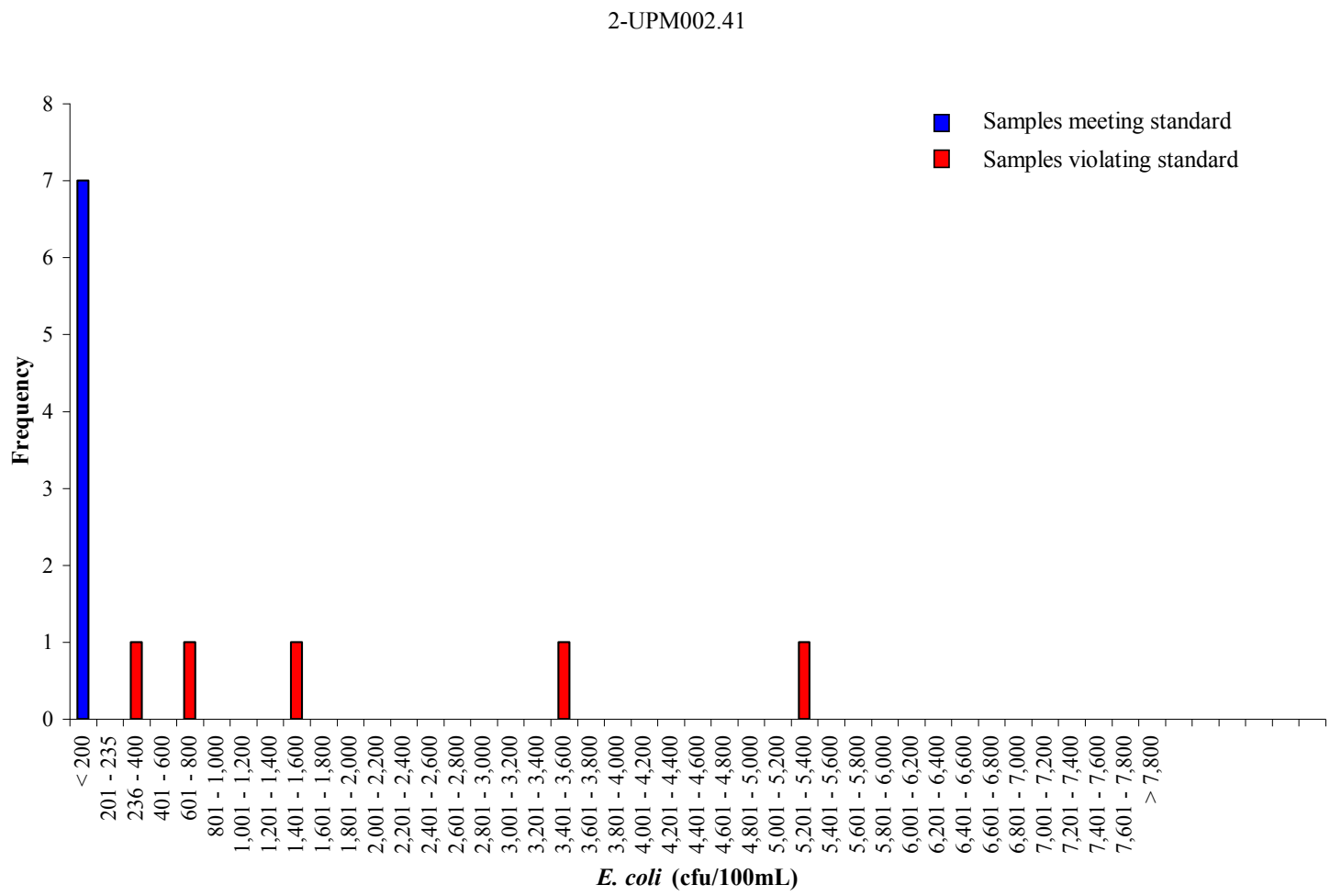

Figure A. 39 Frequency analysis of *E. coli* concentrations at station 2-UPM002.41 in Upham Brook for the period from January 2006 to December 2006.

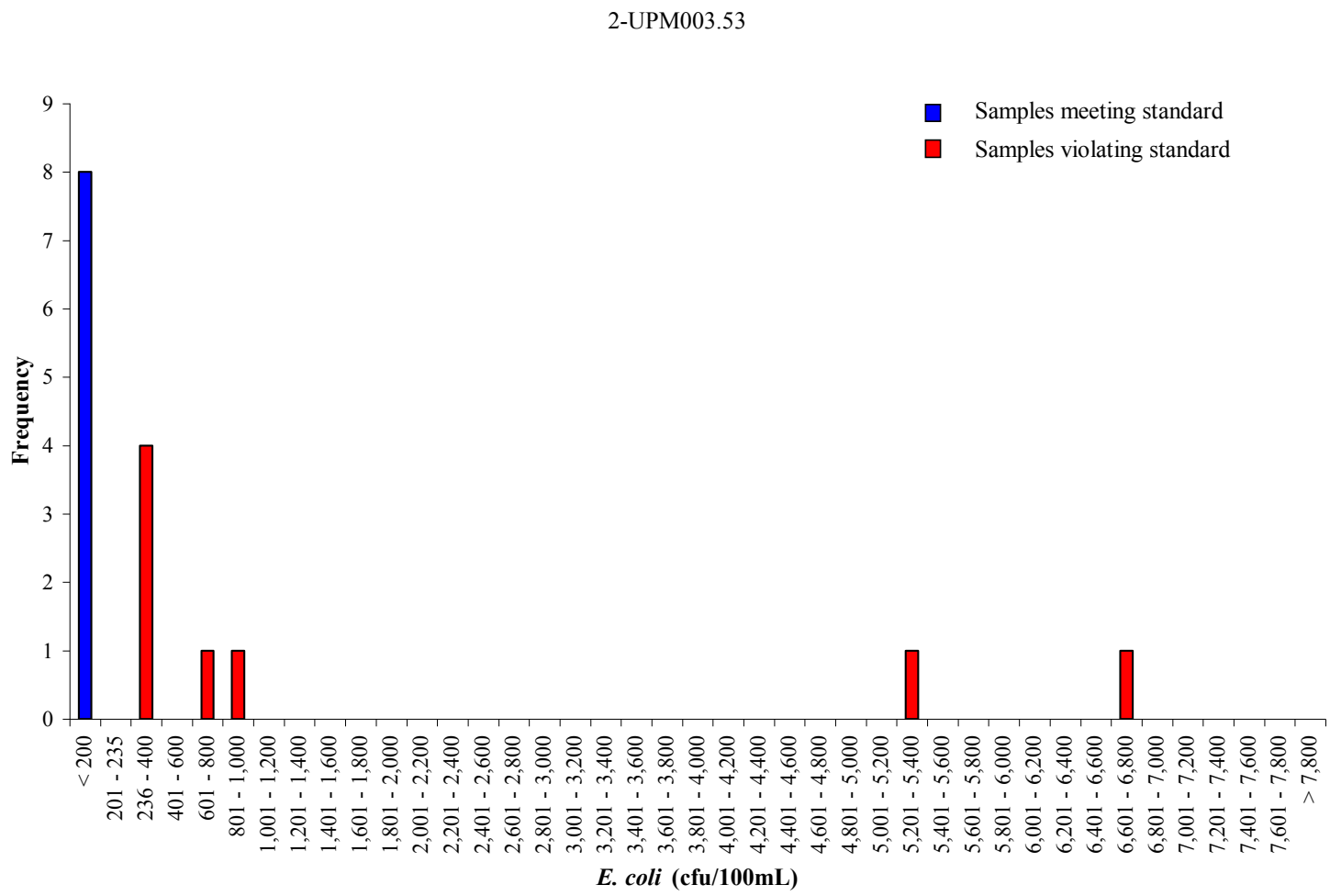

Figure A. 40 Frequency analysis of *E. coli* concentrations at station 2-UPM003.53 in Upham Brook for the period from January 2006 to December 2006.

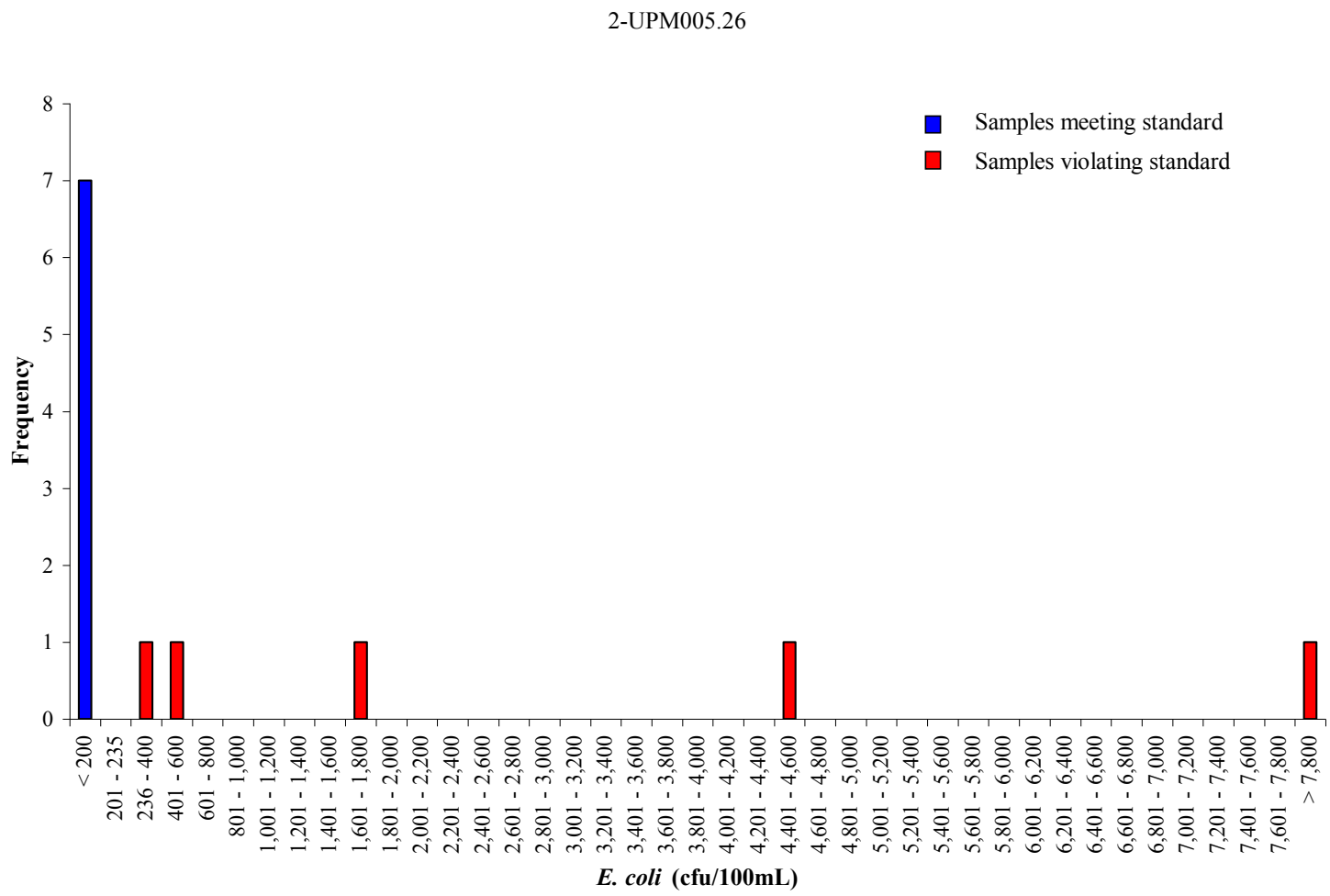

Figure A. 41 Frequency analysis of *E. coli* concentrations at station 2-UPM005.26 in Upham Brook for the period from January 2006 to December 2006.

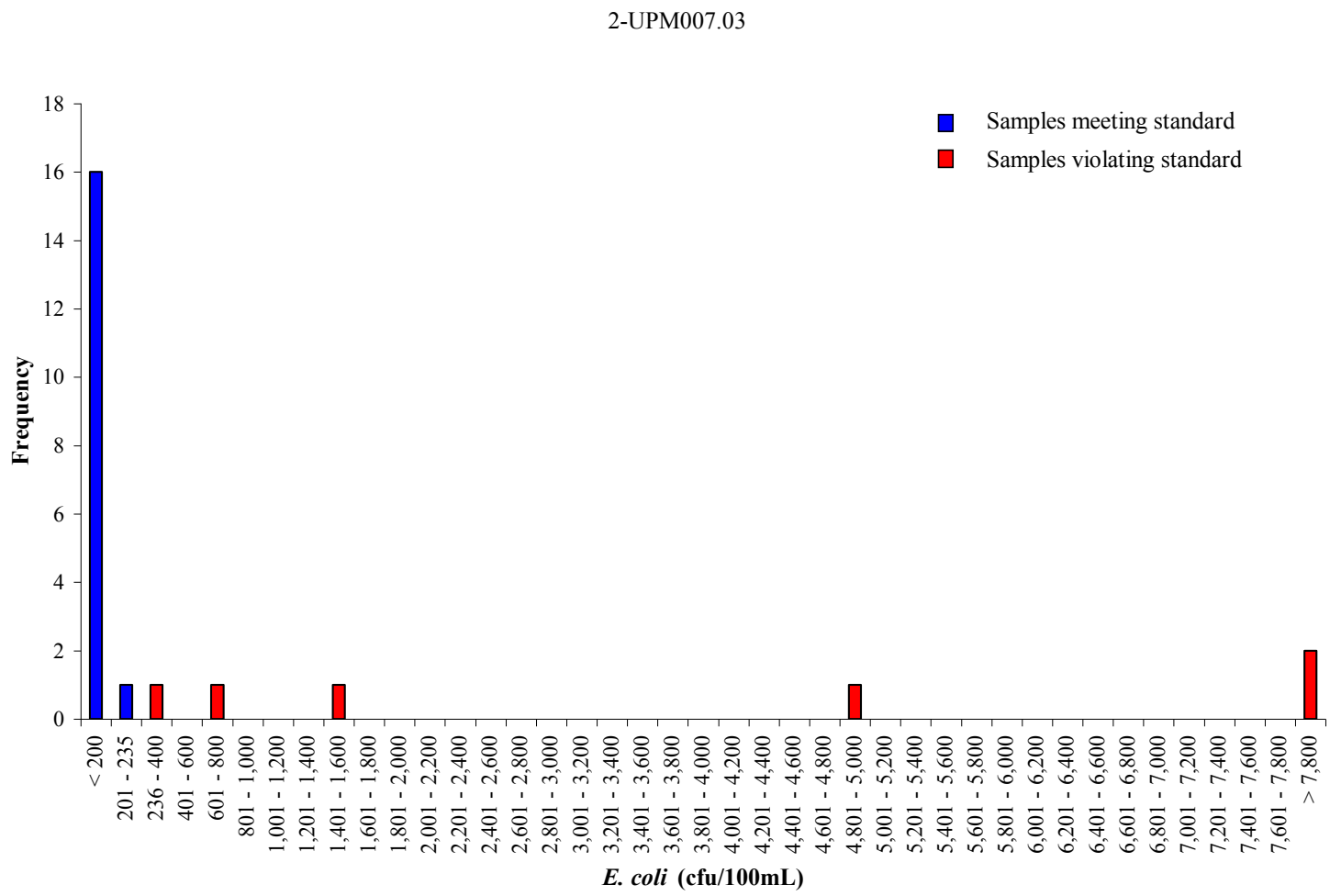

Figure A. 42 Frequency analysis of *E. coli* concentrations at station 2-UPM007.03 in Upham Brook for the period from July 2003 to December 2006.

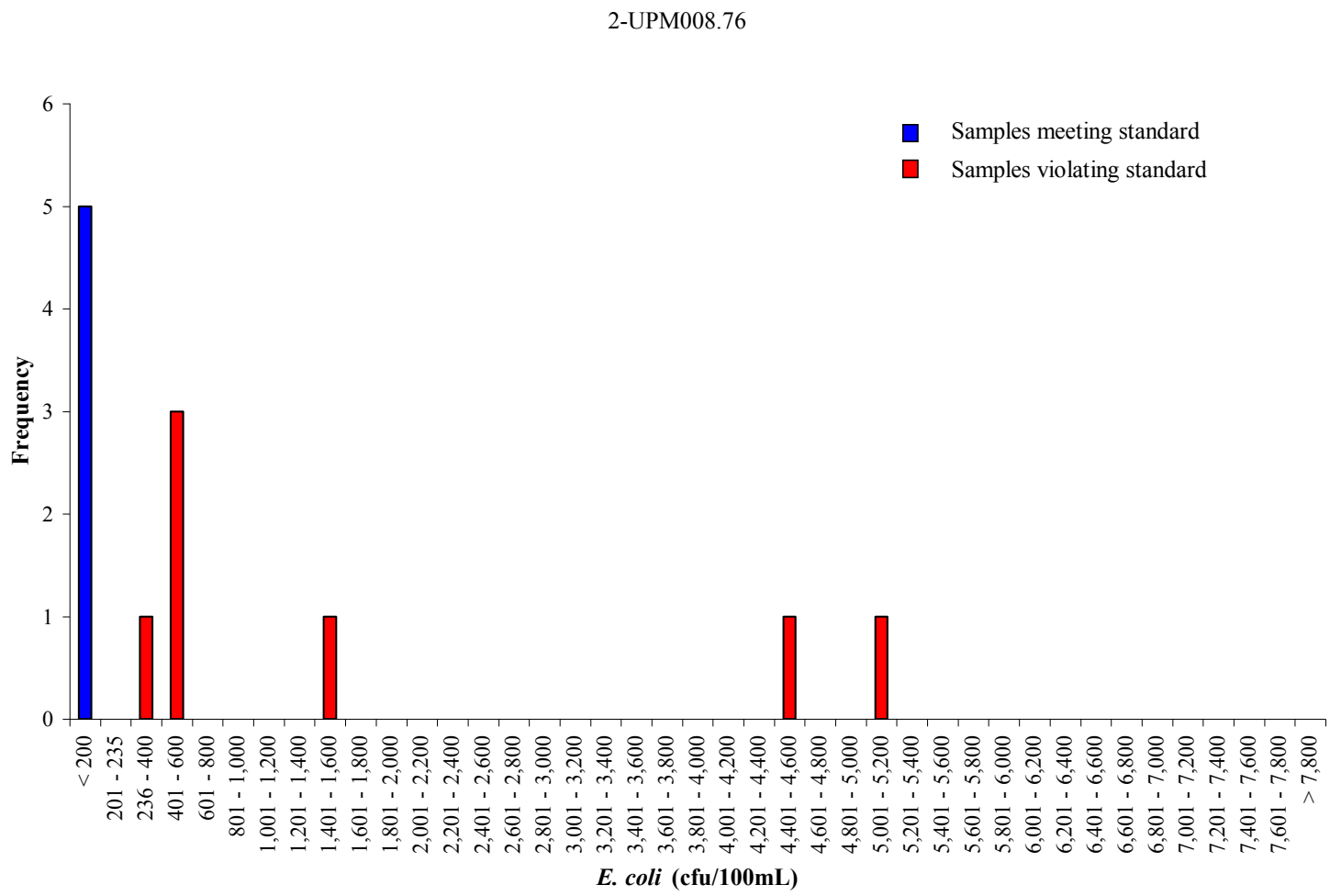

Figure A. 43 Frequency analysis of *E. coli* concentrations at station 2-UPM008.76 in Upham Brook for the period from January 2006 to December 2006.

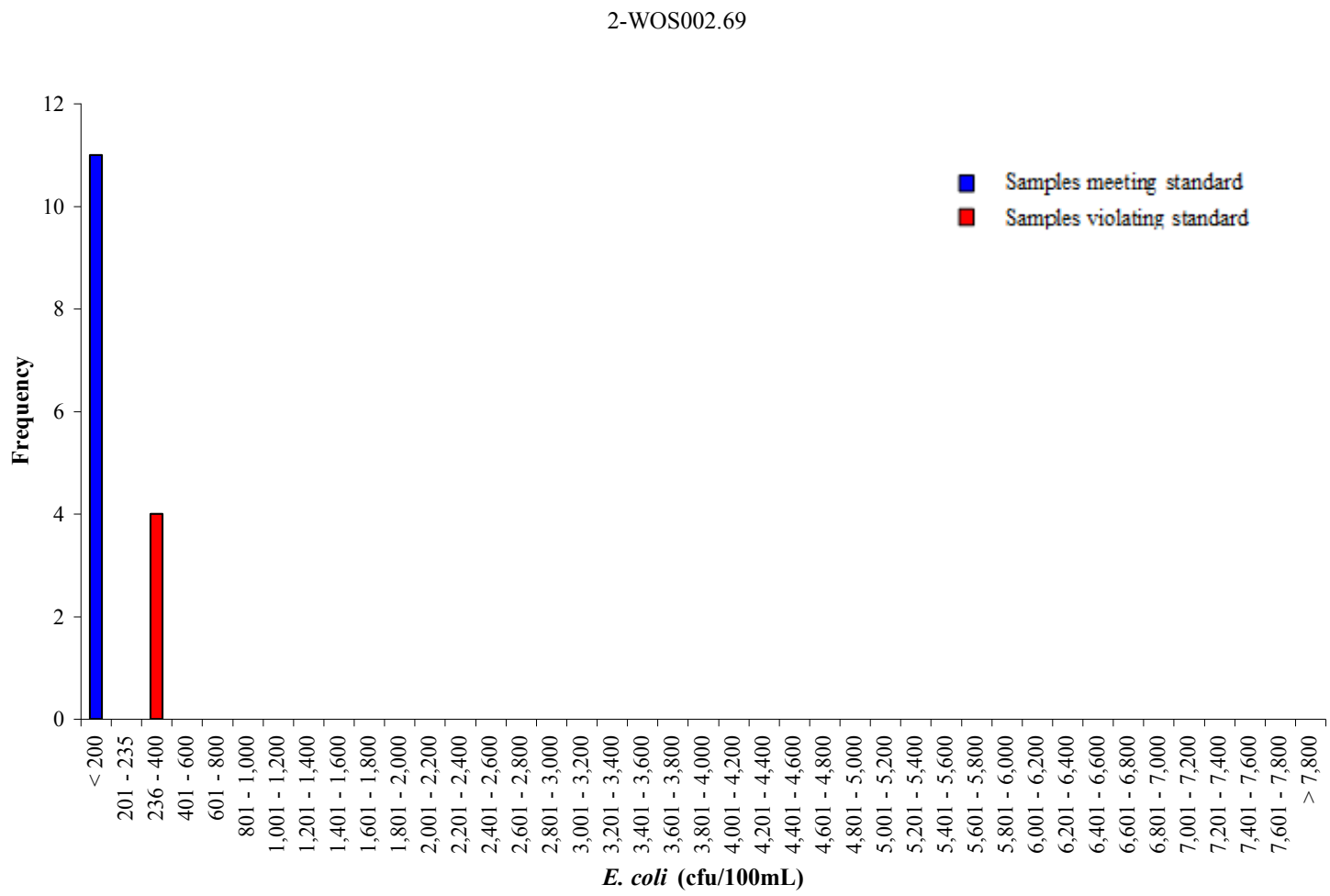

Figure A. 44 Frequency analysis of *E. coli* concentrations at station 2-WOS002.69 in White Oak Swamp for the period from January 2003 to November 2008.

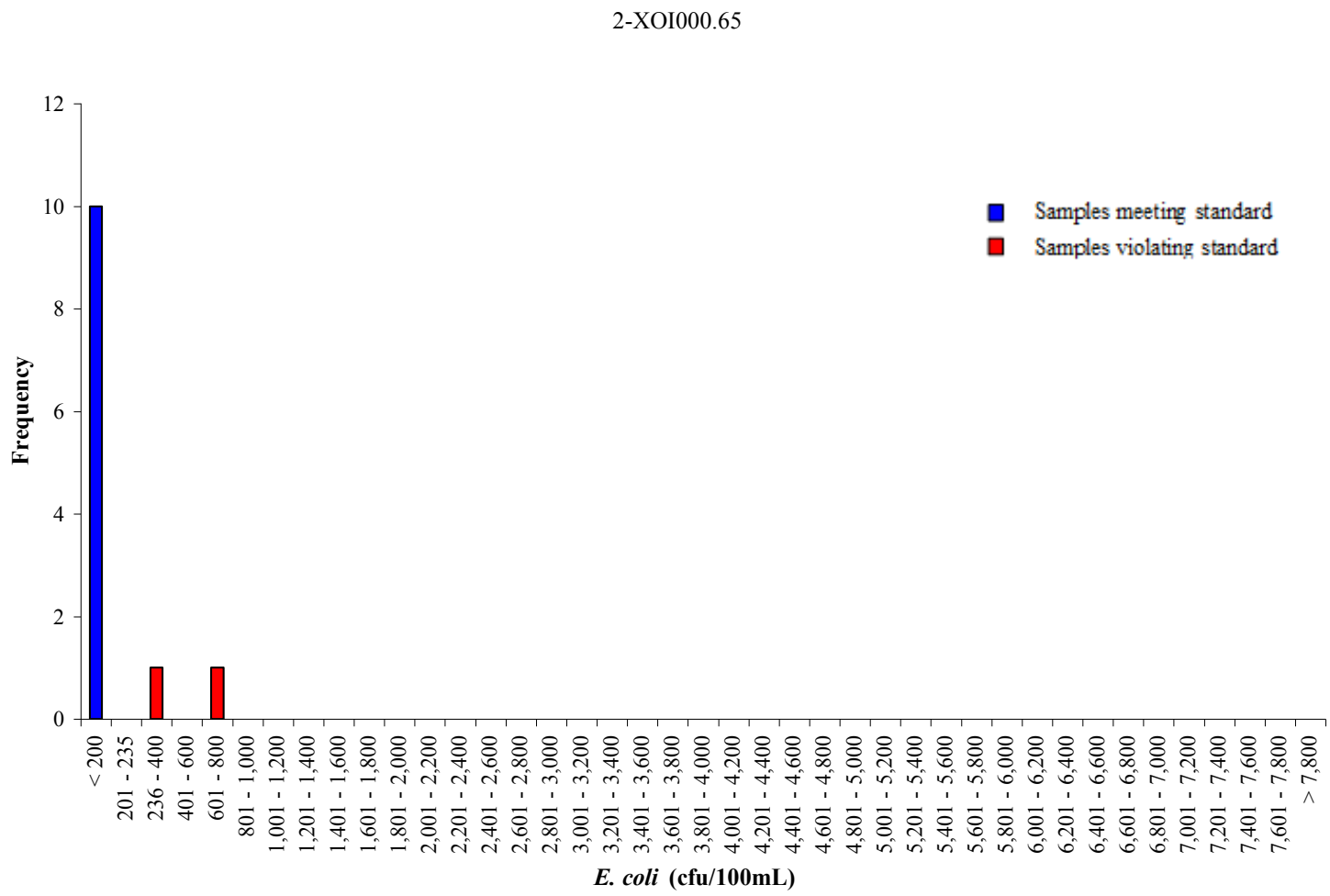

Figure A. 45 Frequency analysis of *E. coli* concentrations at station 2-WOS002.69 in Lickinghole Creek X-Trib for the period from January 2009 to December 2009.

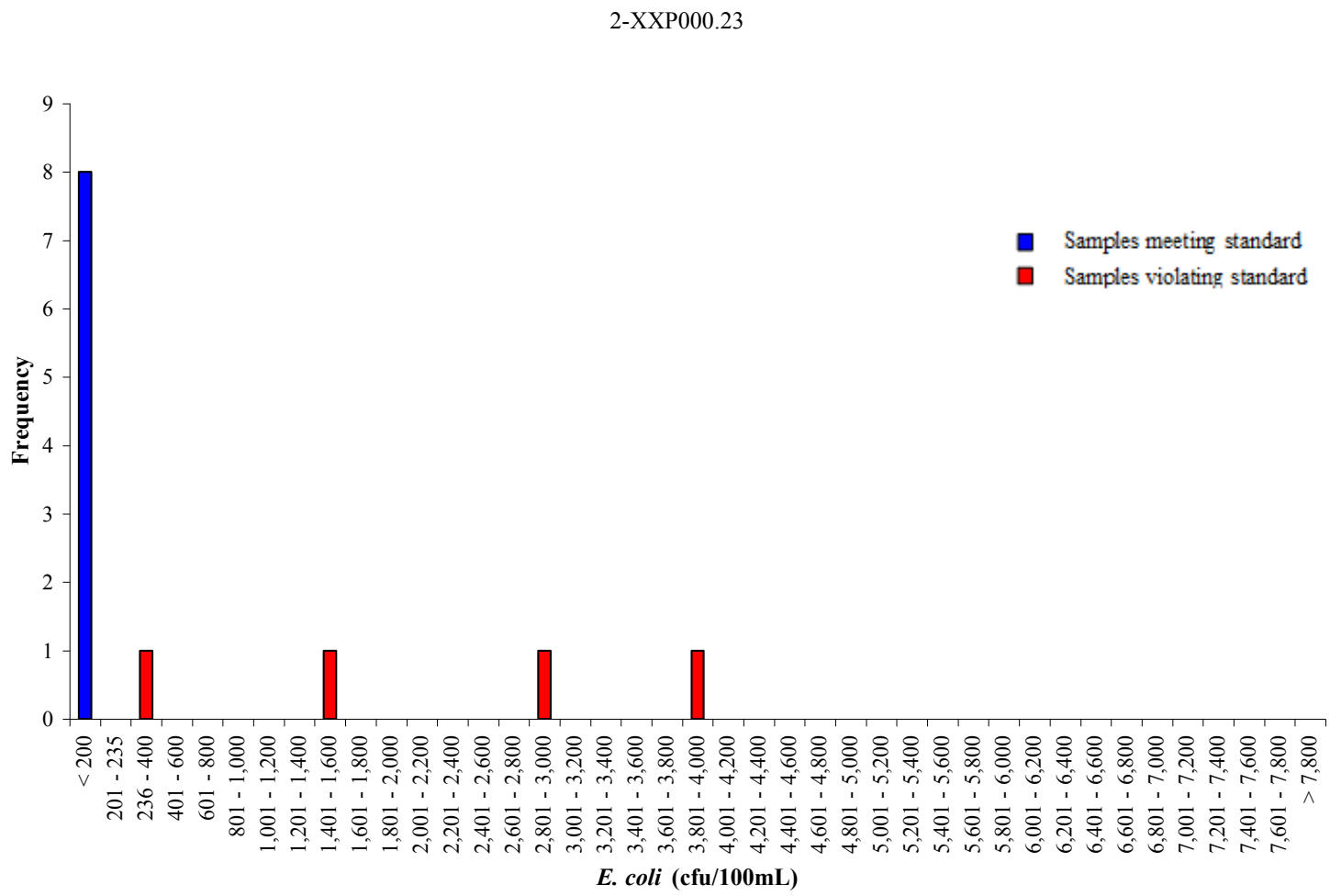

Figure A. 46 Frequency analysis of *E. coli* concentrations at station 2-XXP000.23 in Upham Brook X-Trib for the period from January 2006 to December 2006.

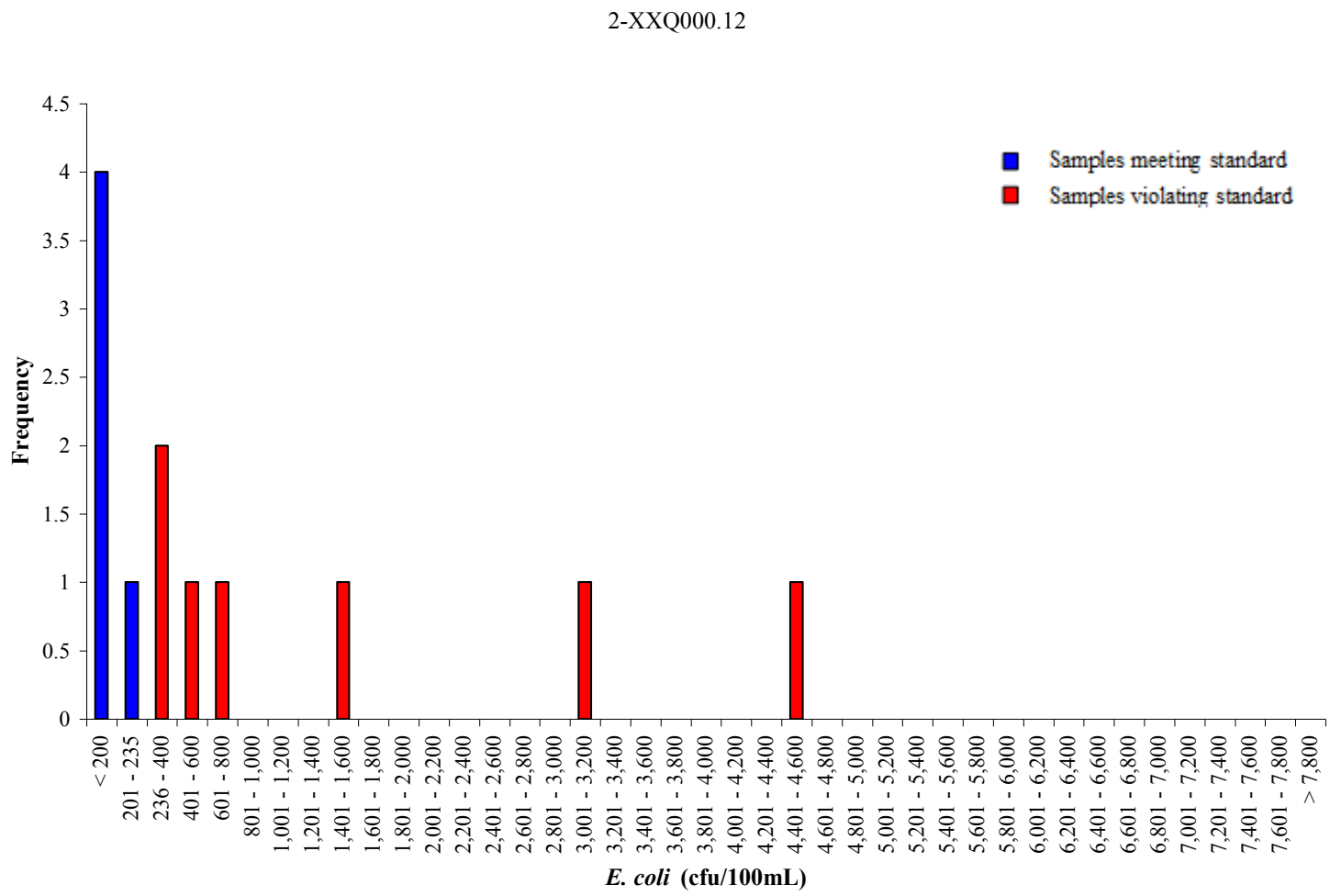

Figure A. 47 Frequency analysis of *E. coli* concentrations at station 2-XXQ000.12 in Upham Brook X-Trib for the period from January 2006 to December 2006.

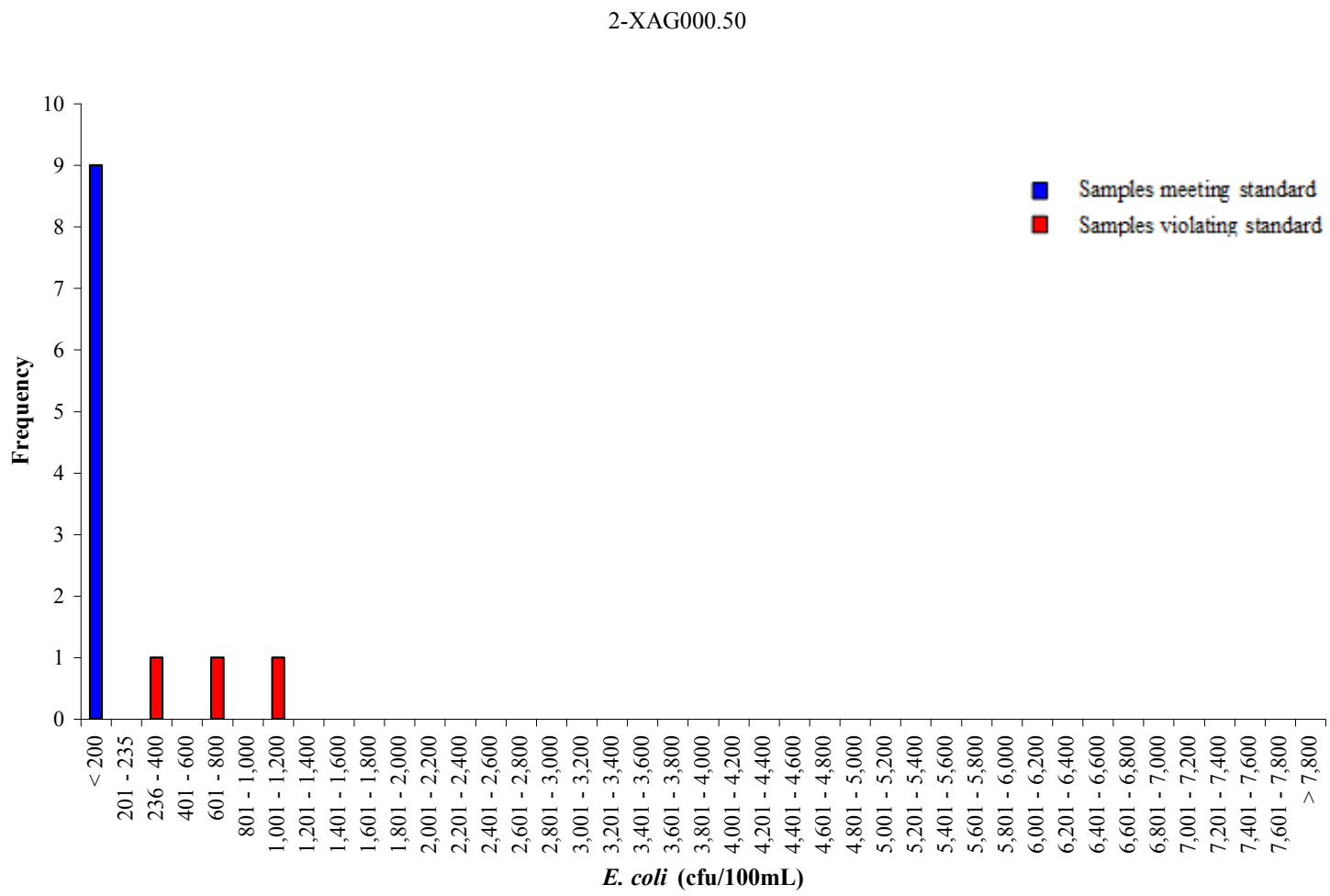

Figure A. 48 Frequency analysis of *E. coli* concentrations at station 2-XAG000.50 in Stony Run X-Trib for the period from January 2009 to December 2009.

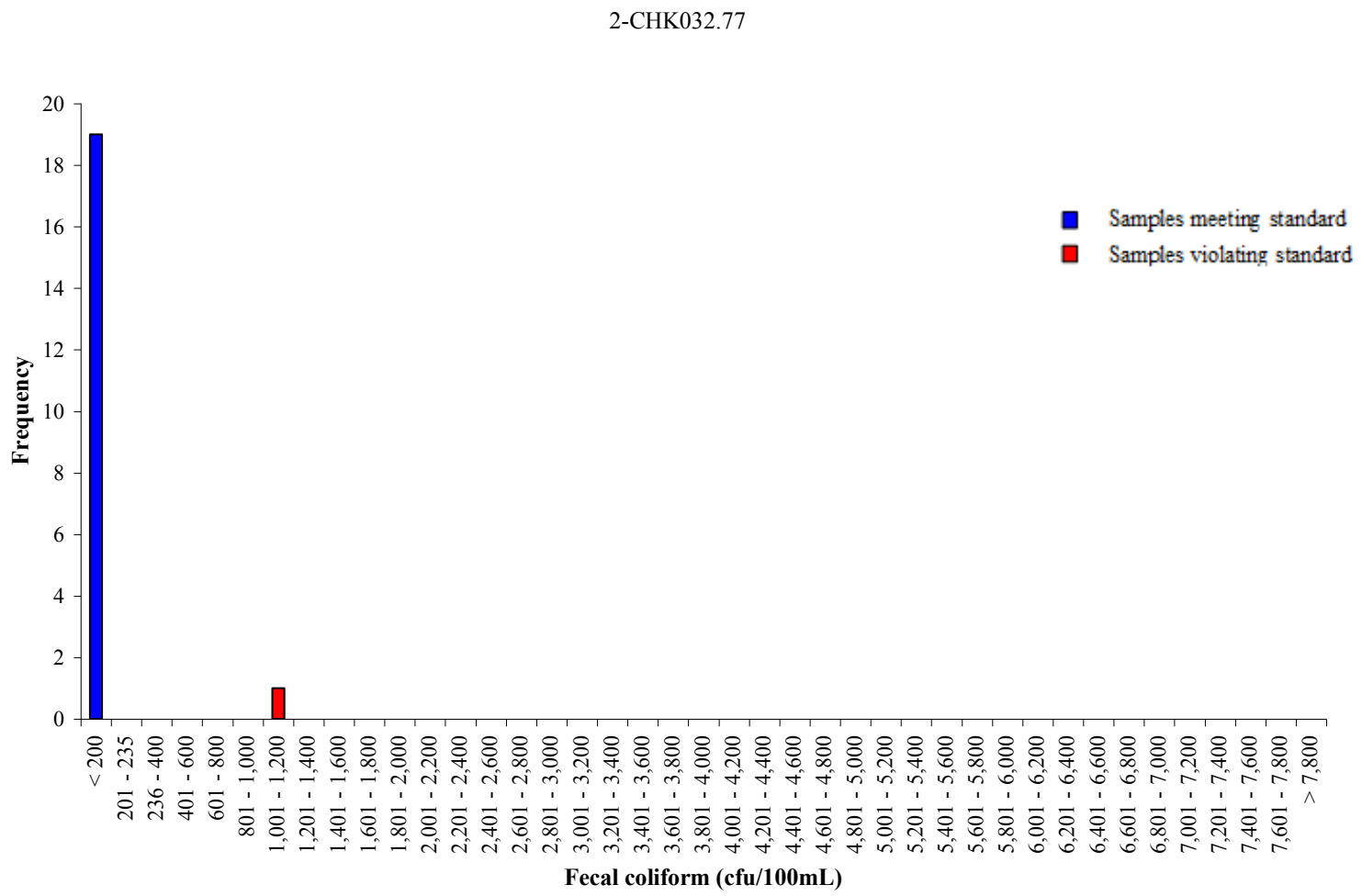

Figure A. 49 Frequency analysis of Fecal Coliform concentrations at station 2-CHK032.77 in the Chickahominy River for the period from January 2001 to March 2006.

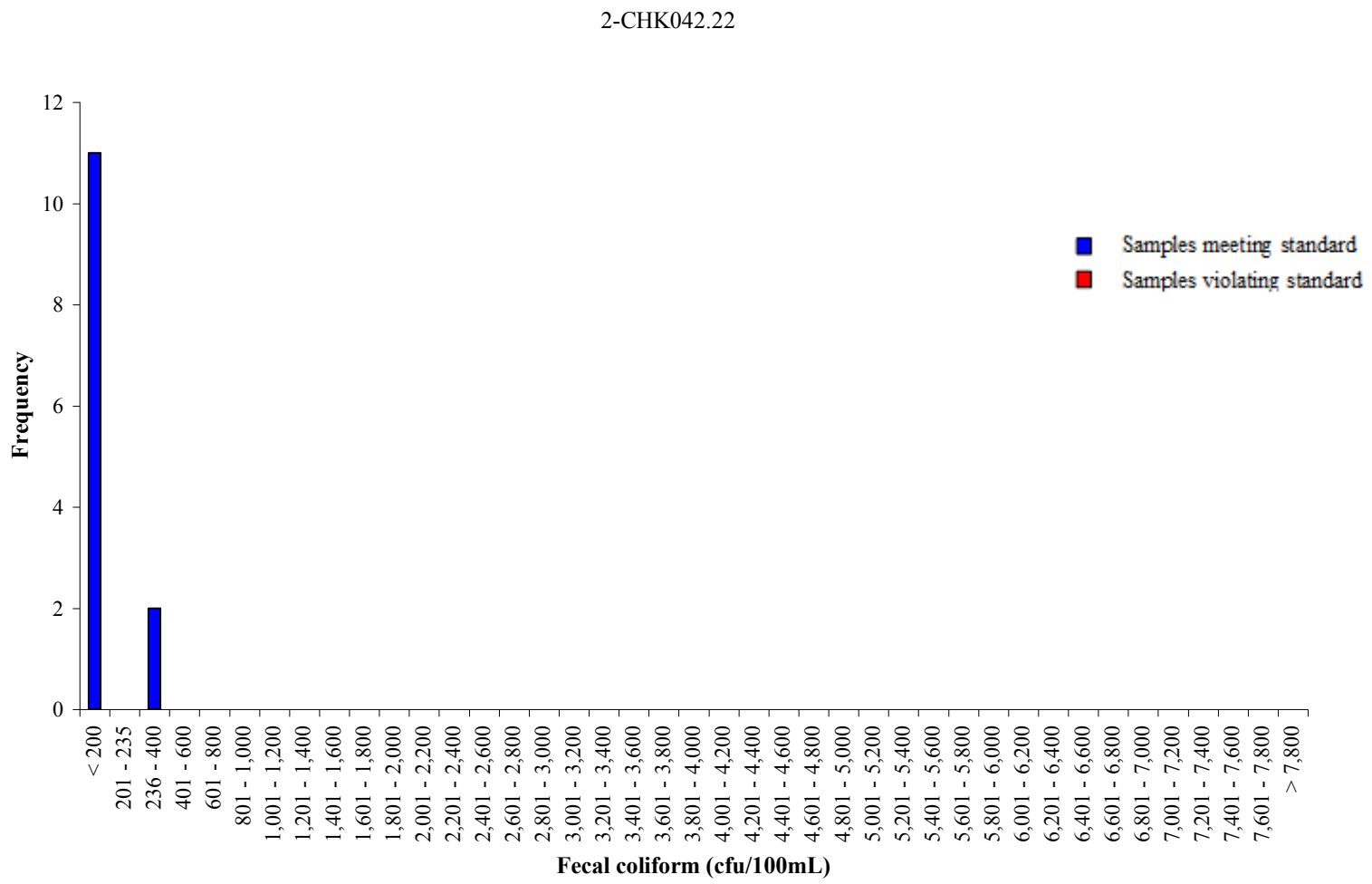

Figure A. 50 Frequency analysis of Fecal Coliform concentrations at station 2-CHK042.22 in the Chickahominy River for the period from May 2001 to June 2003.

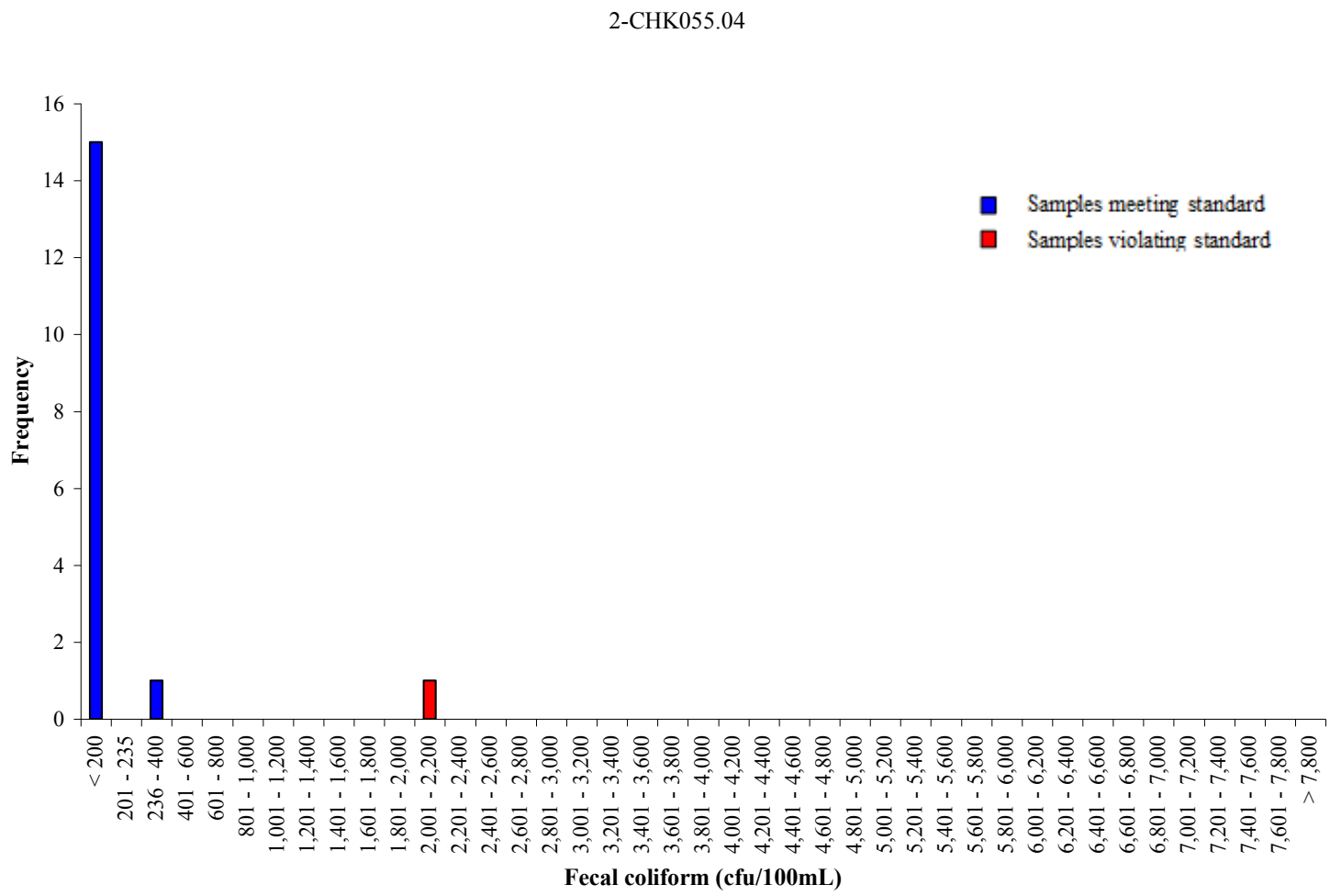

Figure A. 51 Frequency analysis of Fecal Coliform concentrations at station 2-CHK055.04 in the Chickahominy River for the period from January 2001 to May 2003.

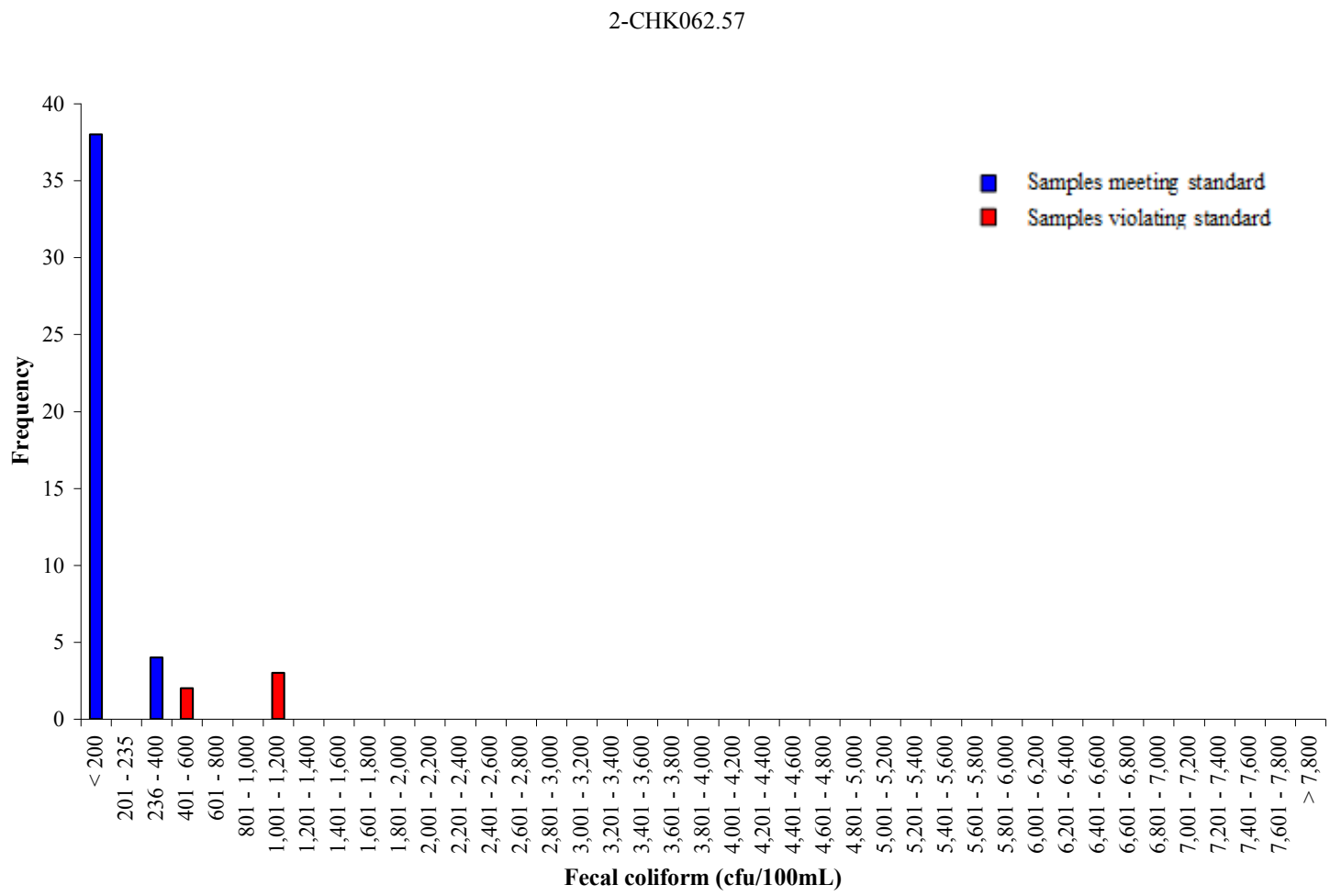

Figure A. 52 Frequency analysis of Fecal Coliform concentrations at station 2-CHK062.57 in the Chickahominy River for the period from January 2001 to January 2011.

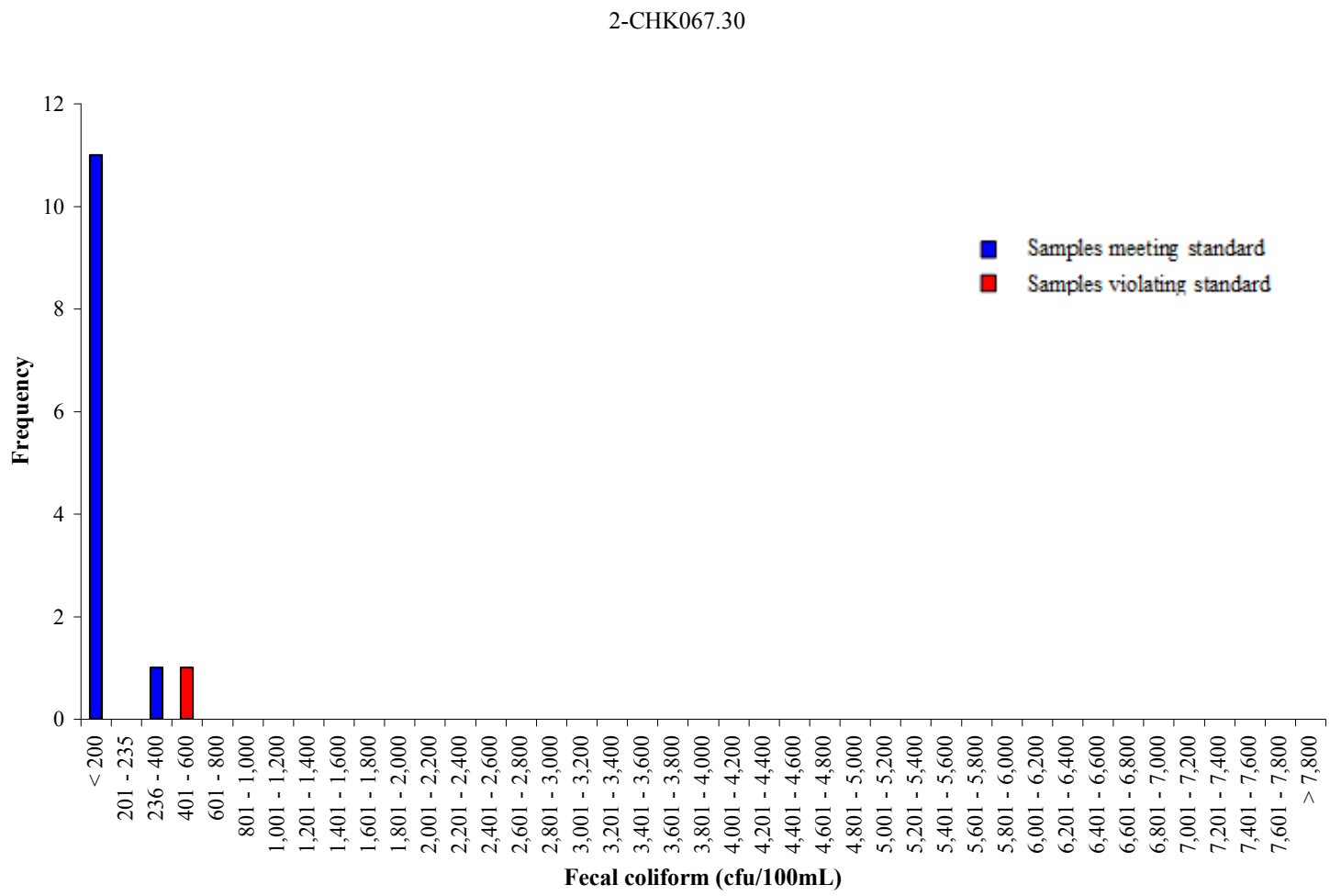

Figure A. 53 Frequency analysis of Fecal Coliform concentrations at station 2-CHK067.30 in the Chickahominy River for the period from June 2001 to May 2003.

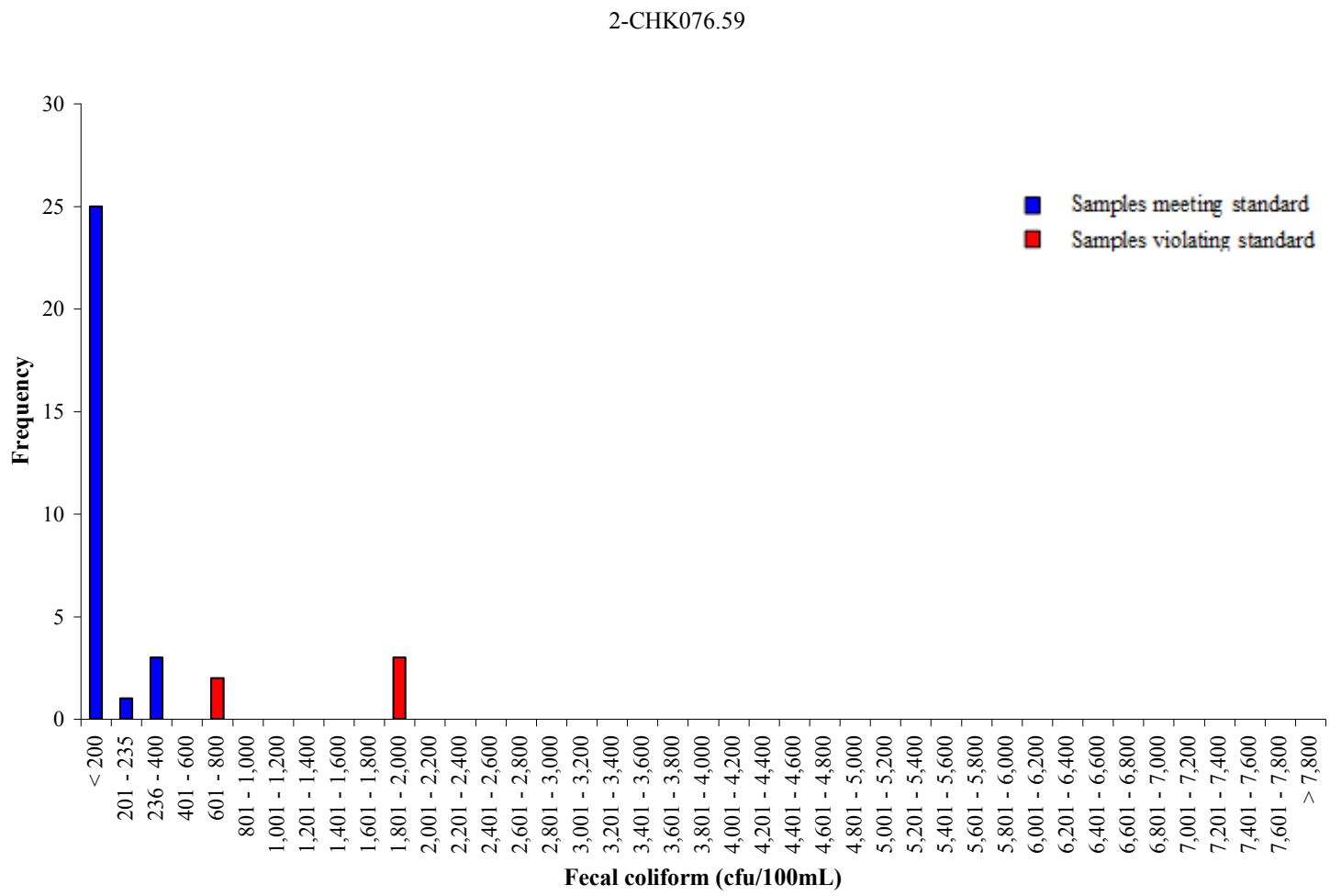

Figure A. 54 Frequency analysis of Fecal Coliform concentrations at station 2-CHK076.59 in the Chickahominy River for the period from June 2001 to January 2011.

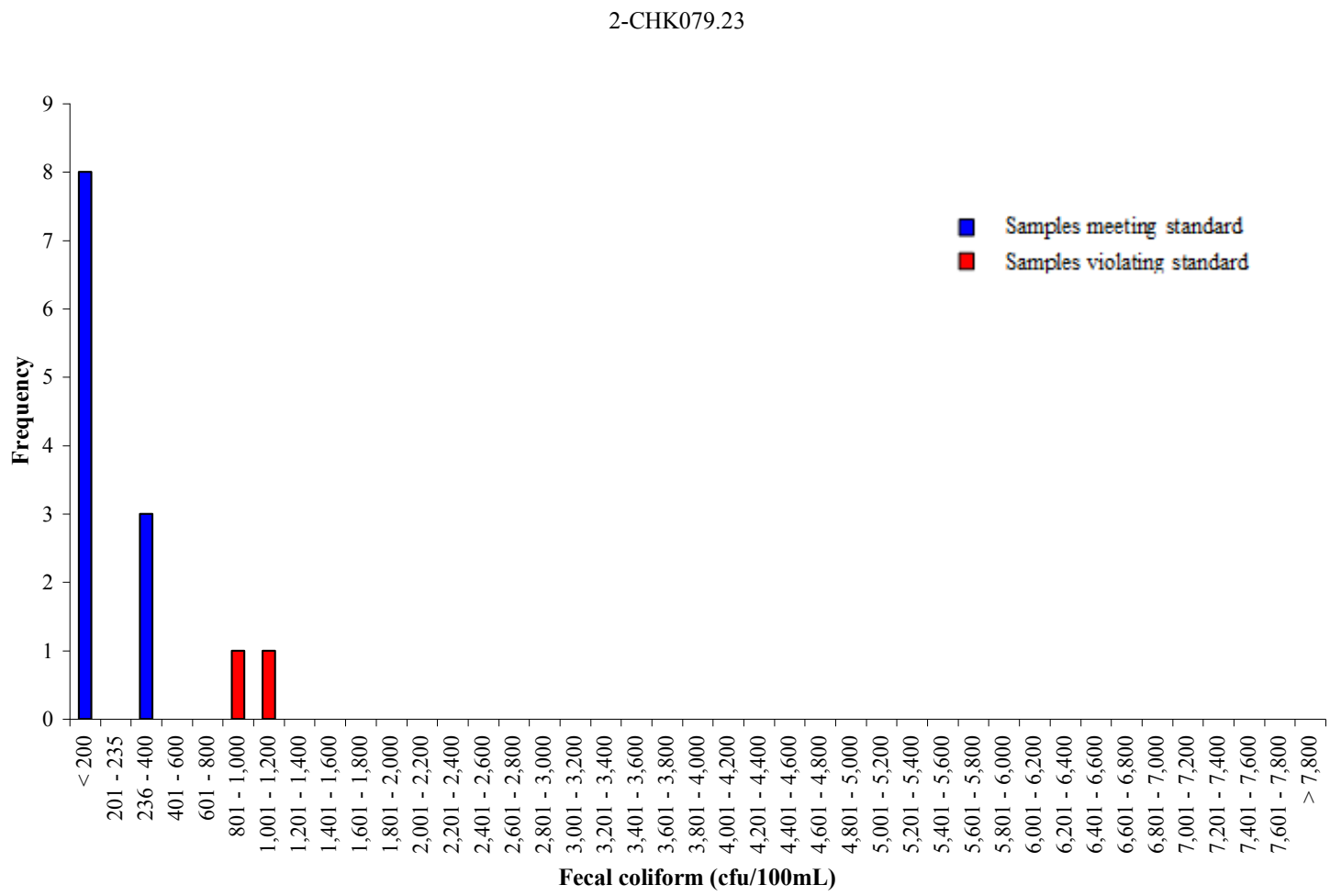

Figure A. 55 Frequency analysis of Fecal Coliform concentrations at station 2-CHK079.23 in the Chickahominy River for the period from June 2001 to May 2003.

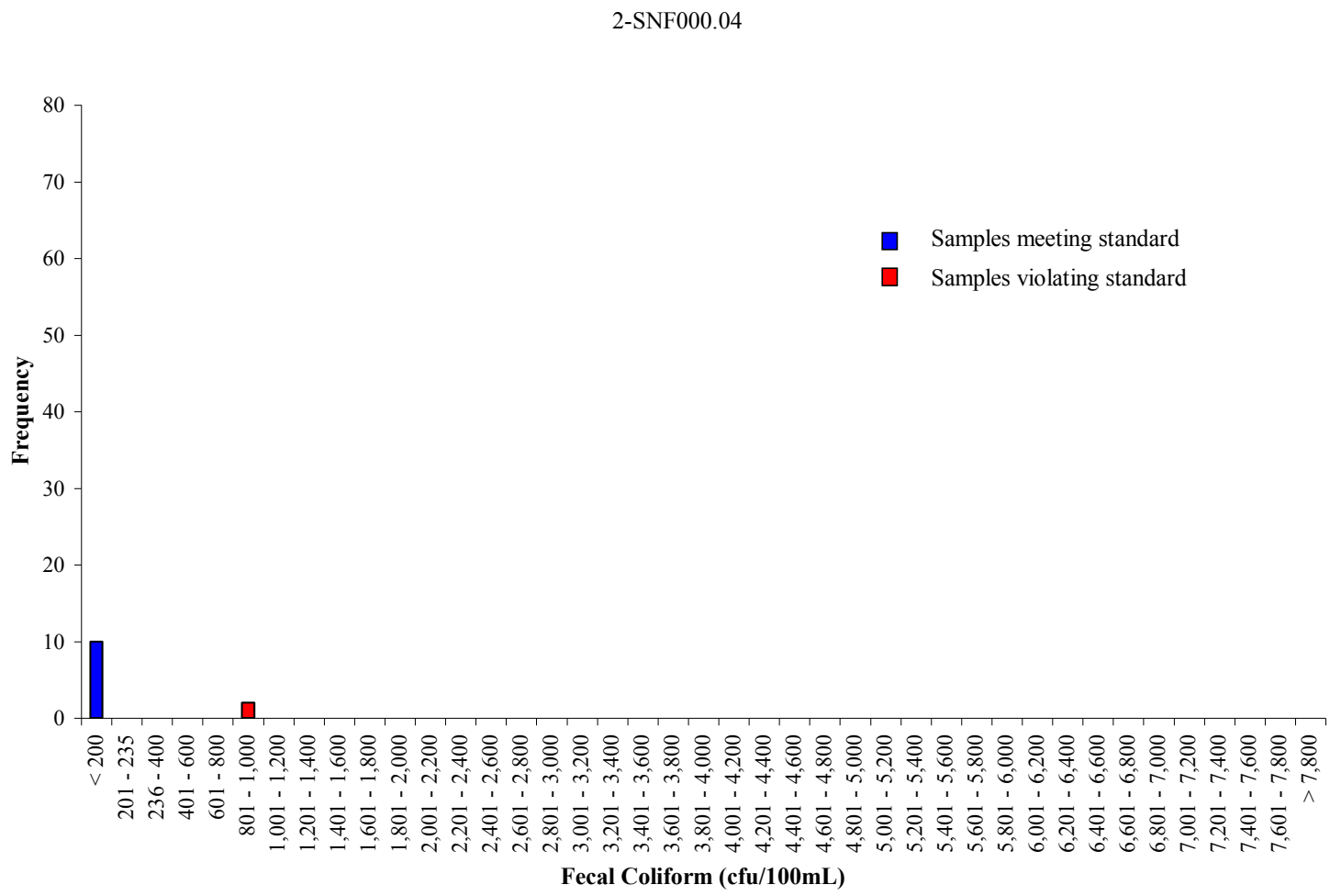

Figure A. 56 Frequency analysis of Fecal Coliform concentrations at station 2-SNF000.04 in Stony Run for the period from June 2001 to May 2003.

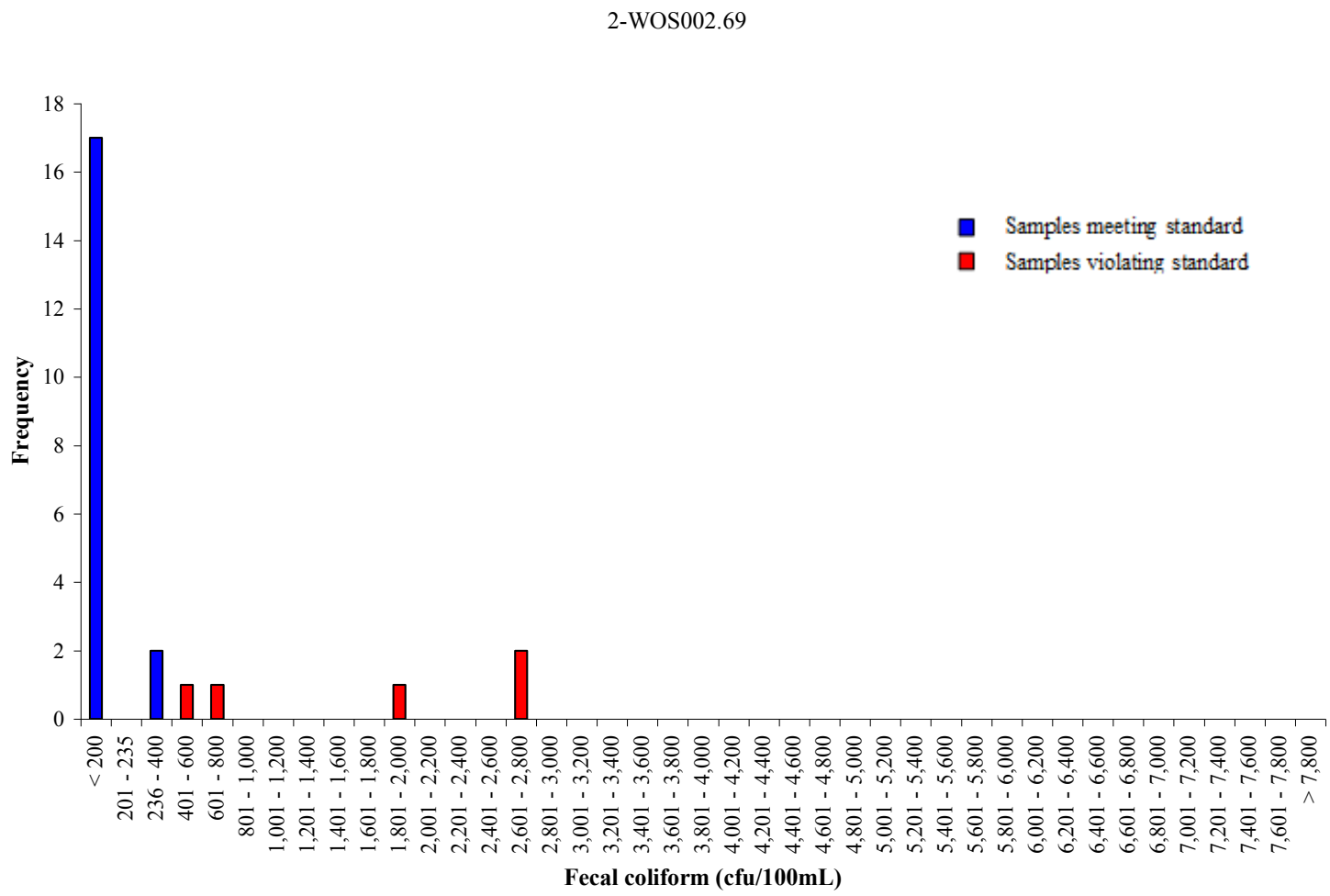

Figure A. 57 Frequency analysis of Fecal Coliform concentrations at station 2-WOS002.69 in White Oak Swamp for the period from June 2001 to July 2003.

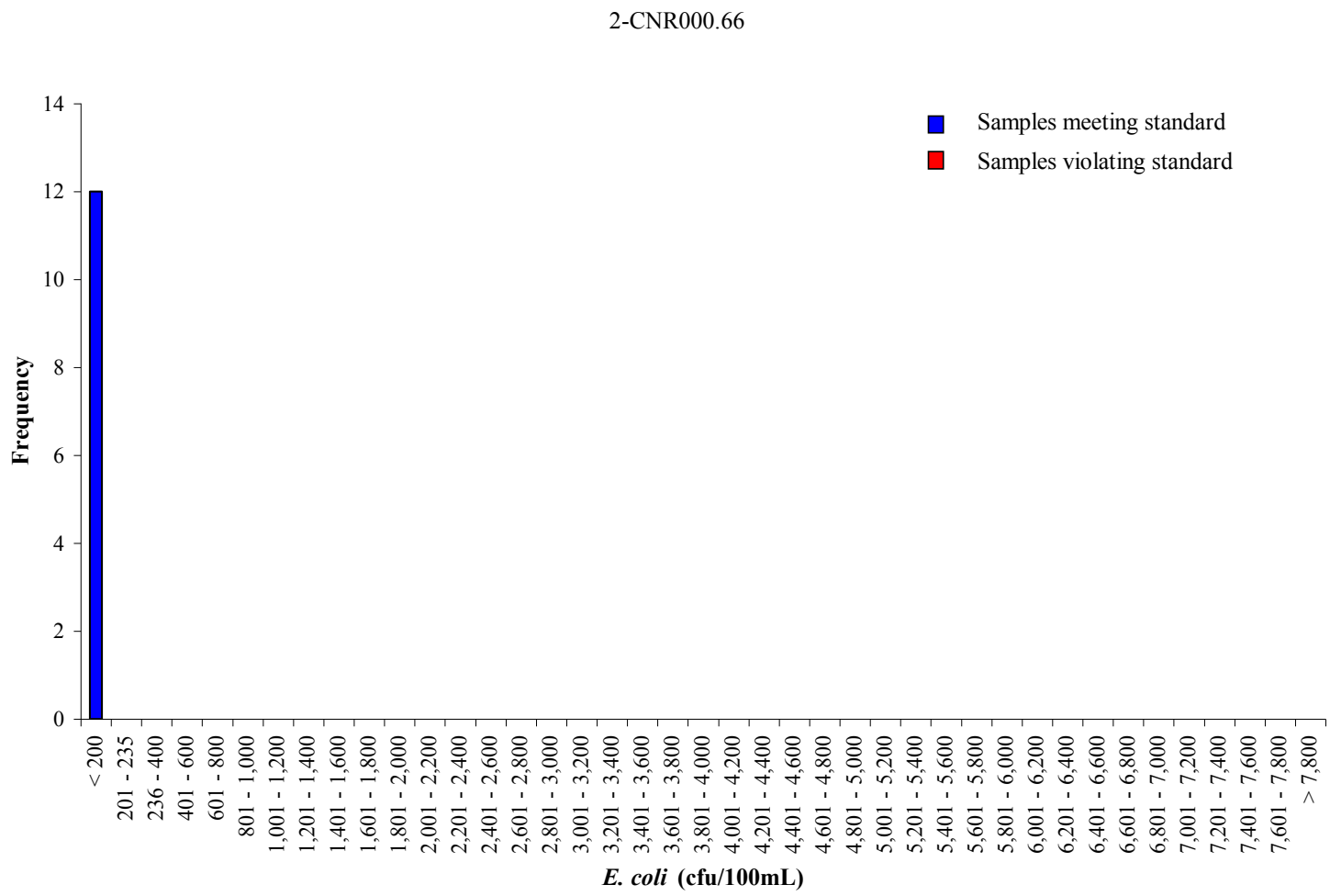

Figure A. 58 Frequency analysis of *E. coli* concentrations at station 2-CNR000.66 in Collins Run for the period from July 2008 to June 2009.

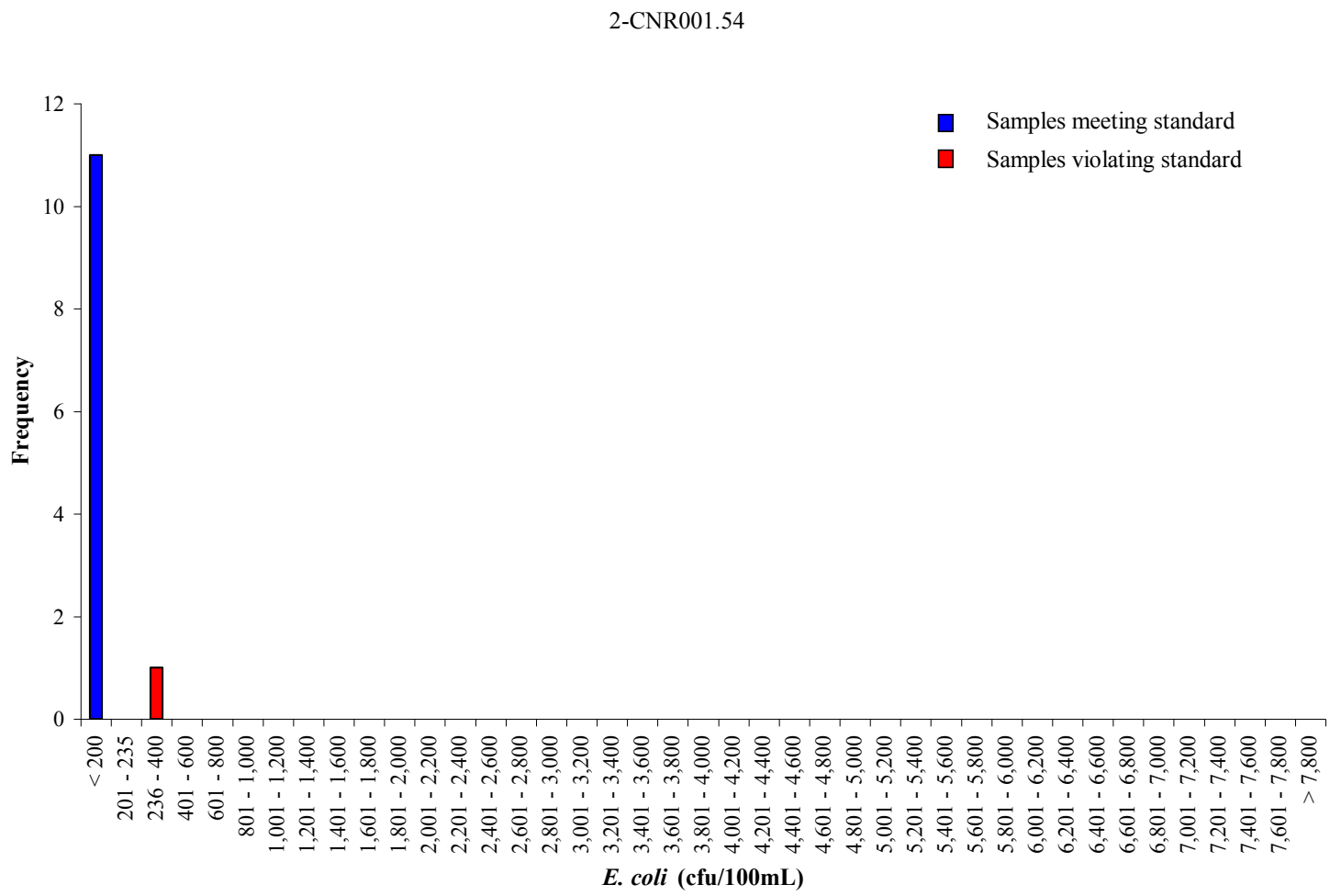

Figure A. 59 Frequency analysis of *E. coli* concentrations at station 2-CNR001.54 in Collins Run for the period from July 2008 to June 2009.

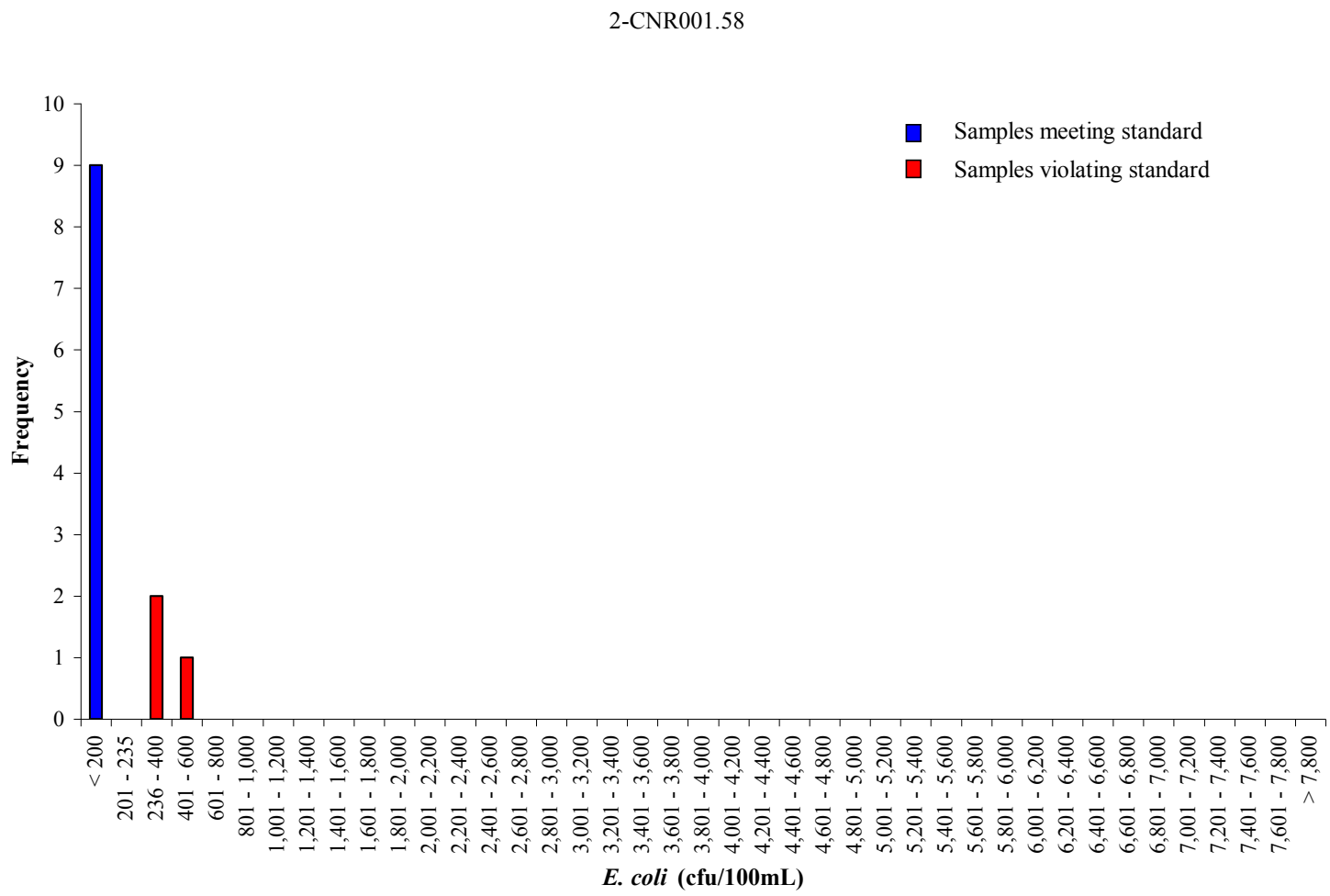

Figure A. 60 Frequency analysis of *E. coli* concentrations at station 2-CNR001.58 in Collins Run for the period from July 2008 to June 2009.

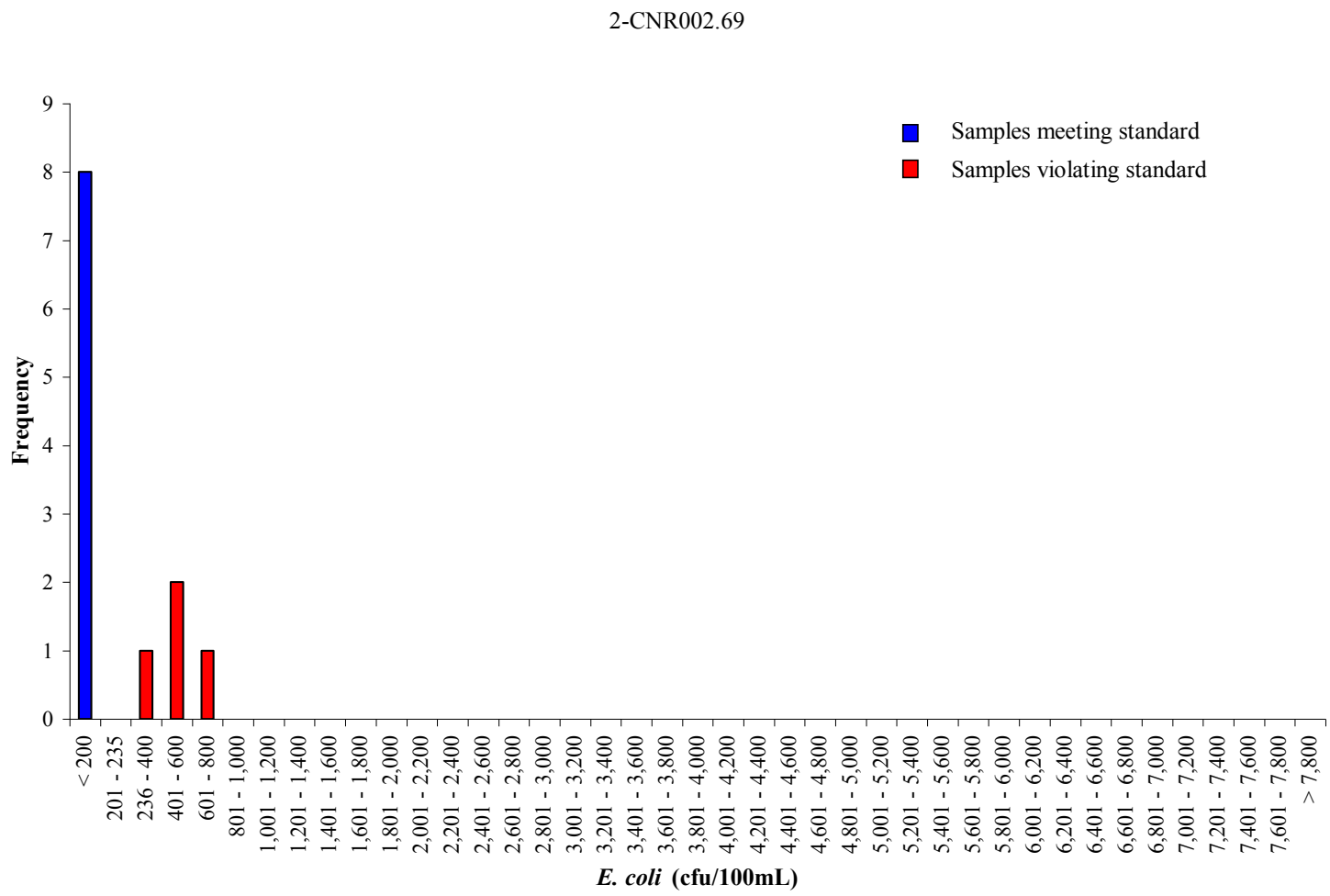

Figure A. 61 Frequency analysis of *E. coli* concentrations at station 2-CNR002.69 in Collins Run for the period from July 2008 to June 2009.

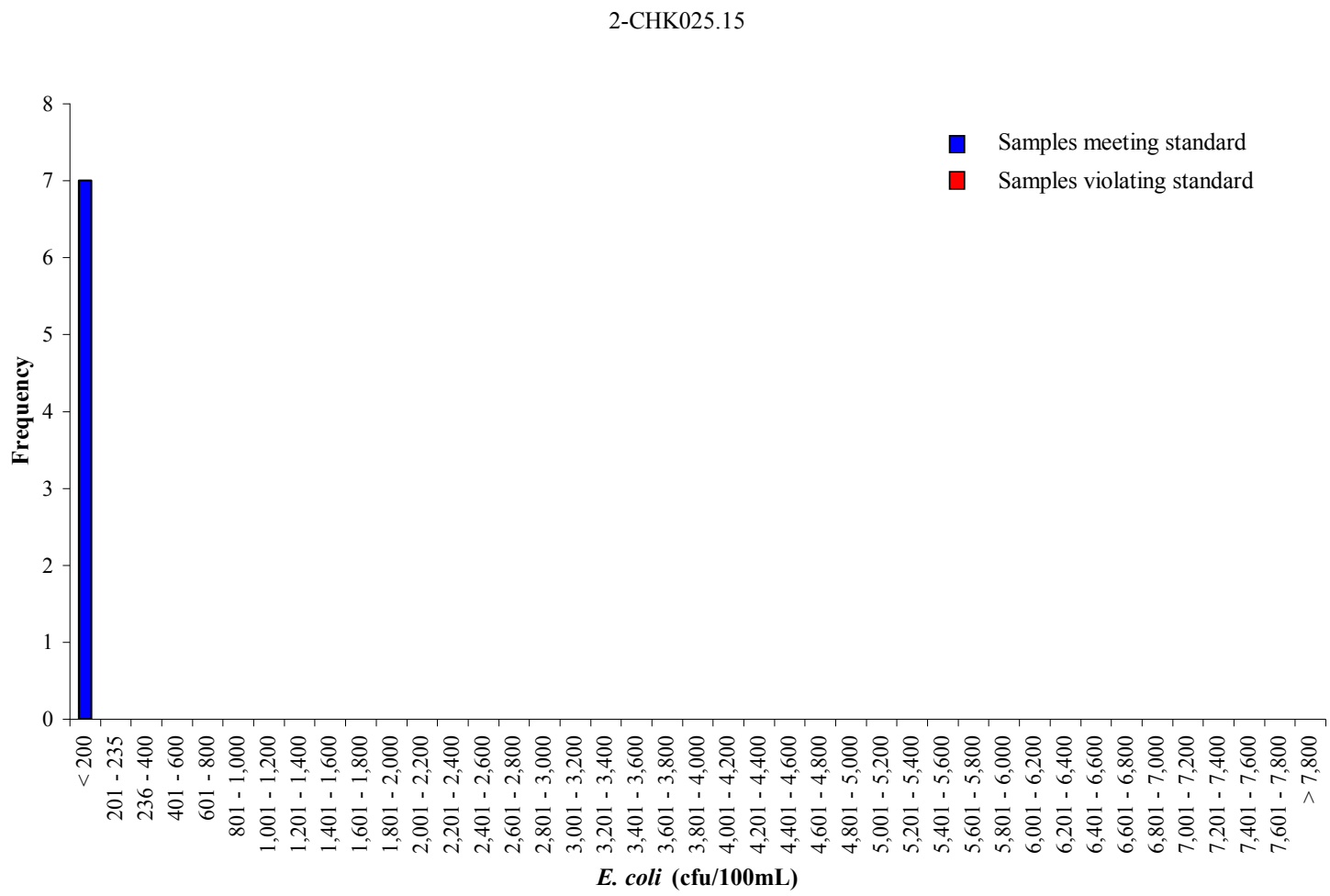

Figure A. 62 Frequency analysis of *E. coli* concentrations at station 2-CHK025.15 in the Chickahominy River for the period from April 2006 to October 2006.

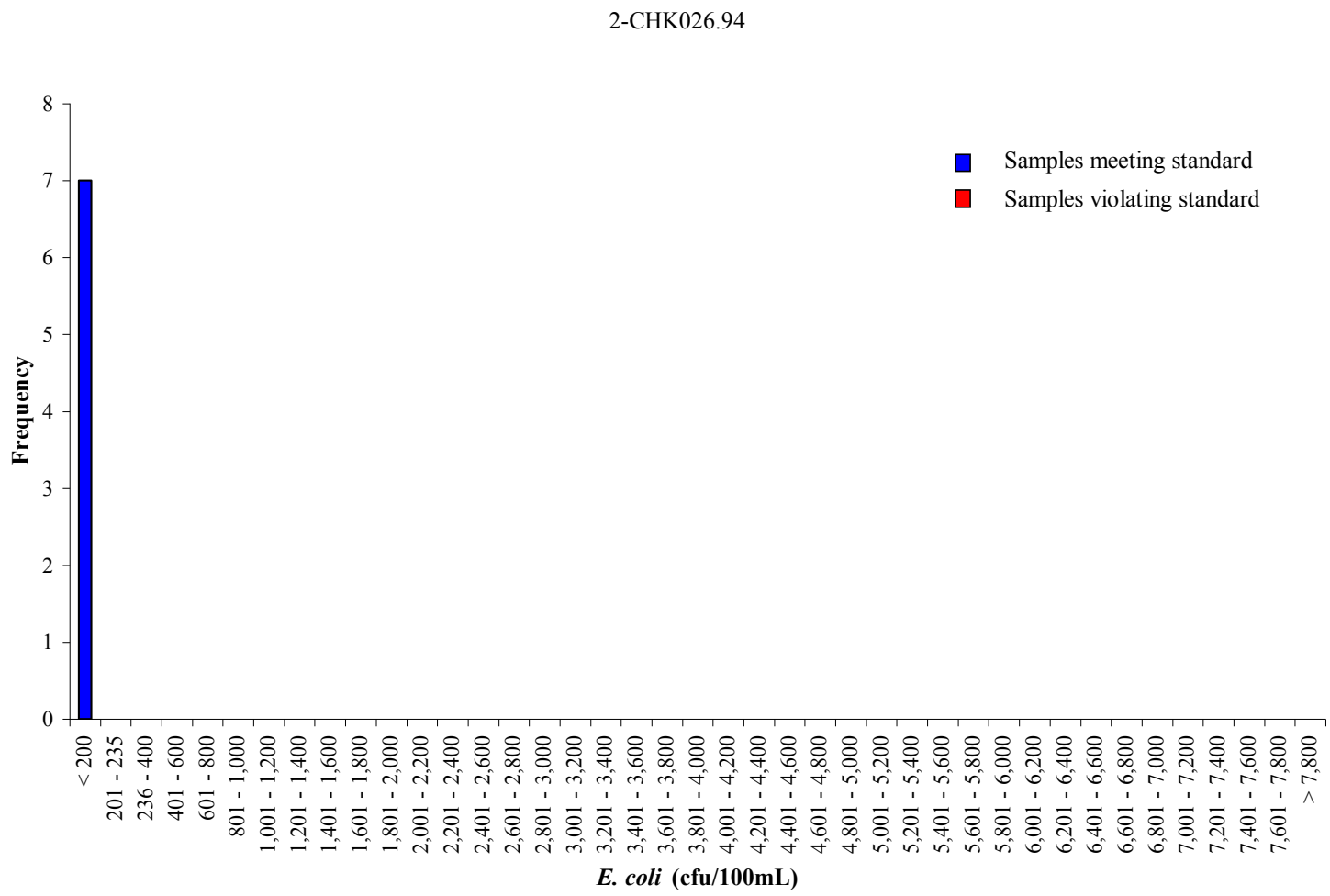

Figure A. 63 Frequency analysis of *E. coli* concentrations at station 2-CHK026.94 in the Chickahominy River for the period from April 2006 to October 2006.

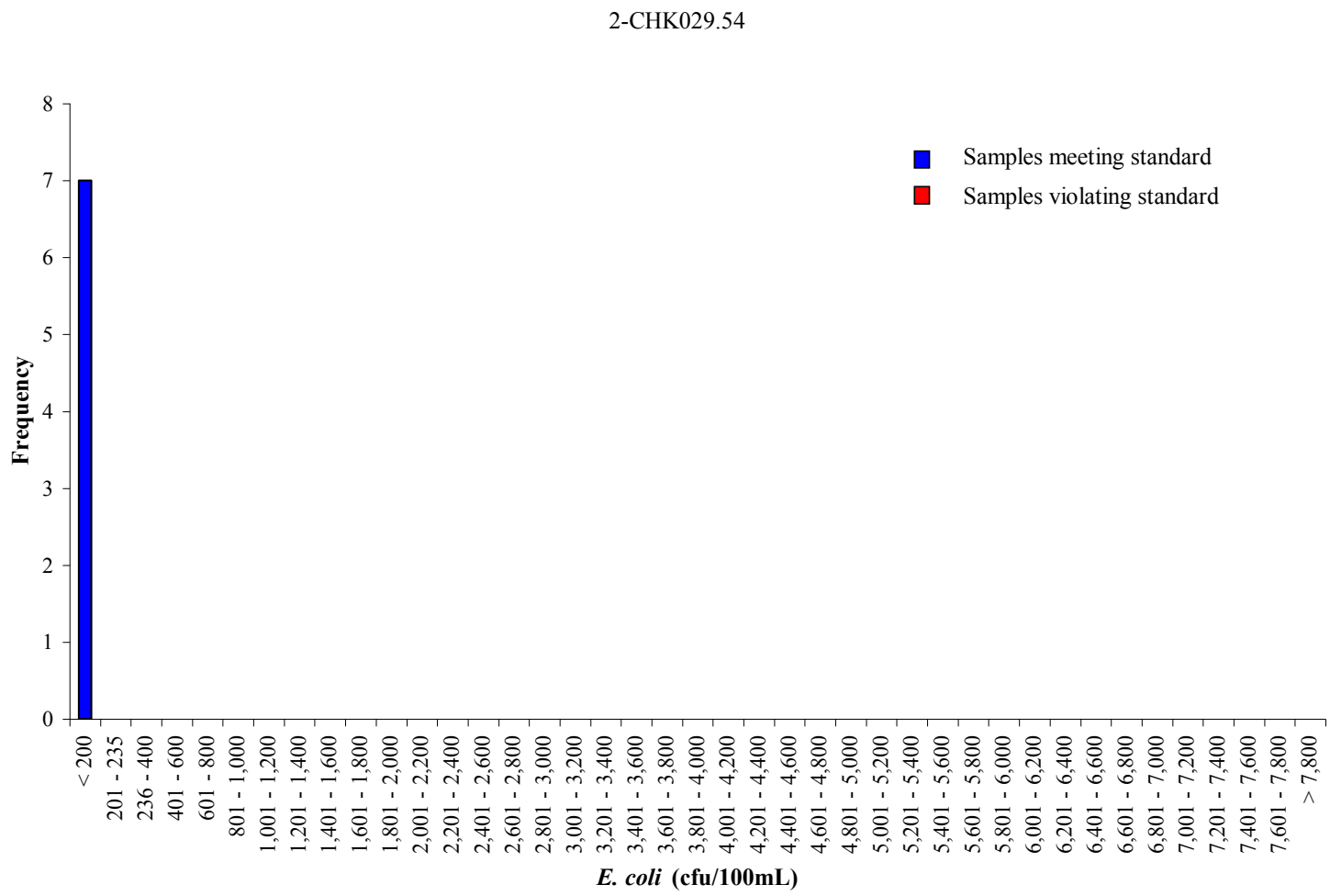

Figure A. 64 Frequency analysis of *E. coli* concentrations at station 2-CHK029.54 in the Chickahominy River for the period from April 2006 to October 2006.

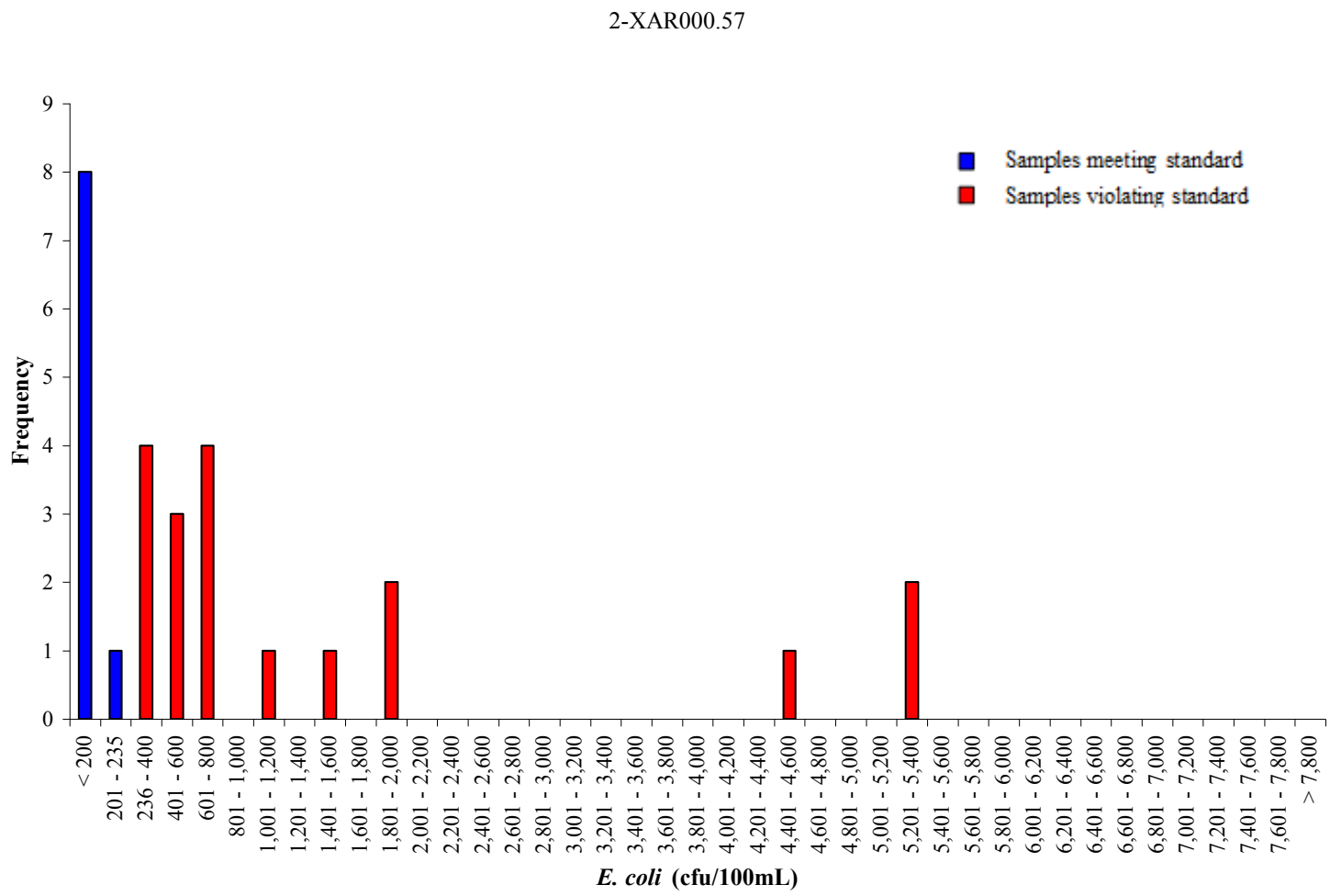

Figure A. 65 Frequency analysis of *E. coli* concentrations at station 2-XAR000.57 in an X-Trib to Upham Brook for the period from May 2004 to August 2010.

APPENDIX B

Bacteria modeling procedure: Linking the sources to the endpoint

Bacteria modeling procedure: Linking the sources to the endpoint

Establishing the relationship between in-stream water quality and the source loadings is a critical component of TMDL development. It allows for the evaluation of management options that will achieve the desired water quality endpoint. In the development of TMDLs in the Chickahoming River and Tributaries 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 bacteria 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

Precipitation data was available within the watershed at the Richmond International Airport Coop station # 447201. Missing values were filled using daily precipitation from the West Point 2NW NCDC Coop station # 449025and Williamsburg 2N NCDC Coop station 449151. The final filled daily precipitation was disaggregated using the hourly station data.

Subwatersheds

To adequately represent the spatial variation in the watershed, the Chickahominy River Watershed drainage area was divided into twenty seven (27) subwatersheds (**Figure B.** 1). The rationale for choosing these subwatersheds was based on the availability of water quality and flow data, the stream network configuration, and the limitations of the HSPF model. Eighteen of these subwatersheds were used in hydrologic calibration since they were upstream of the flow gage with observed data (outlet of subwatershed 5). The entire set of 27 subwatersheds was used in the bacteria calibration.

Figure B. 1 shows all subwatersheds, which were used to achieve the unified model. **Table B. 1** notes the subwatersheds contained within each impairment, the impaired stream segments, and the outlet subwatershed for each impairment.

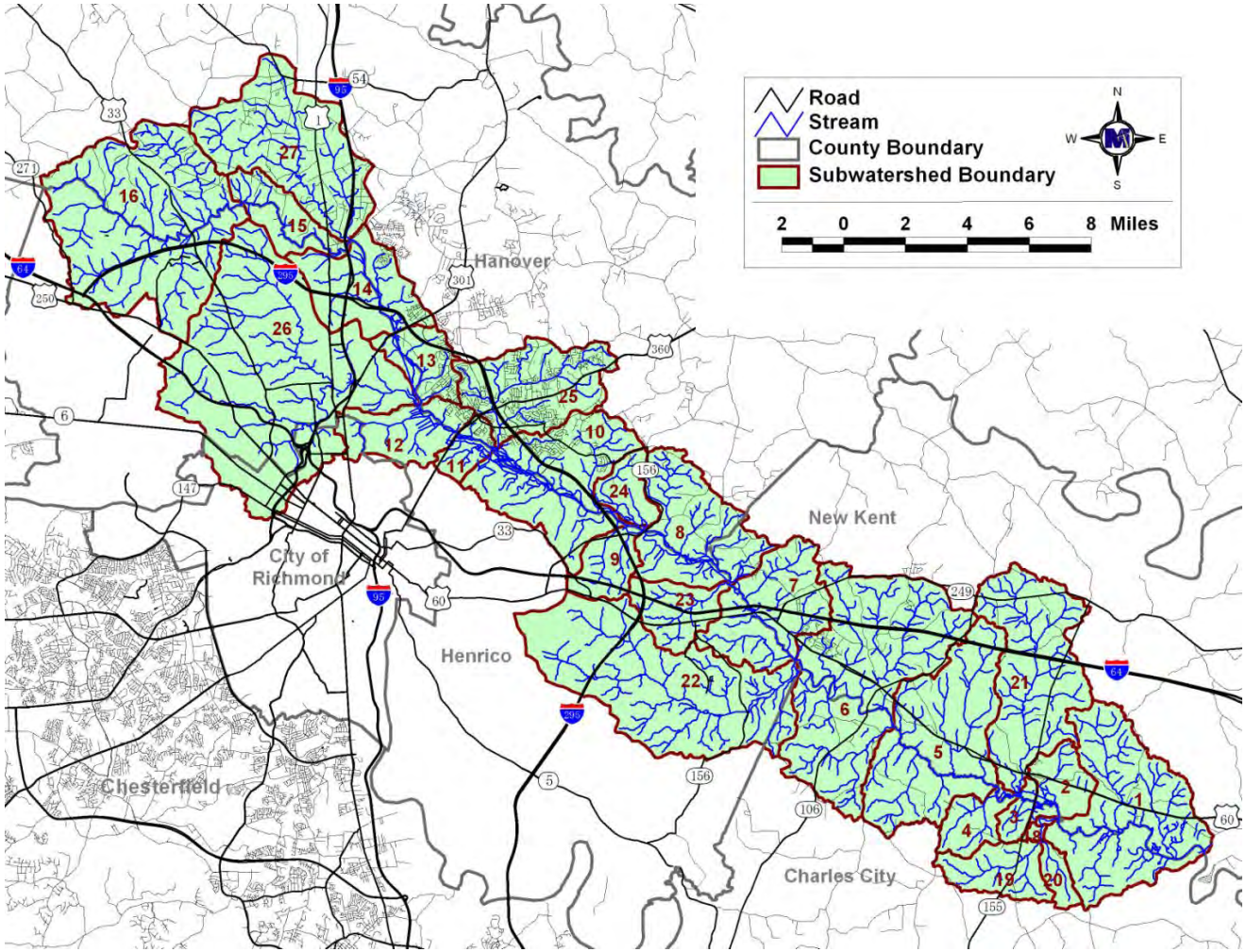

Figure B. 1 All subwatersheds delineated for modeling in the Chickahominy River study area.

Table B. 1 Impairments and subwatersheds within the Chickahominy River study area.

Impairment	Impaired Subwatershed(s)	Outlet	Contributing Subwatersheds
Collins Run VAP-G07_CNR01A00	18,19	18	18,19,20
Beaverdam Creek VAP-G06R_BEV01A00	25	25	25
Boatswain Creek VAP-G06R_BTS01A02	24	24	24
Chickahominy River VAP-G06R_CHK01A98	9,10,11	9	9,10,11,12,13,14,15,16,25,26,27
Stony Run VAP-G05R_SNF01A02	27	27	27
Upham Brook TMDL	26	26	26
White Oak Swamp TMDL	22	22	22

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

Land Uses

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 three IMPLND types, while there are nine PERLND types, each with parameters describing a particular land

use. Some IMPLND and PERLND parameters (*e.g.,* slope length) vary with the particular subwatershed in which they are located. Others vary with the season (*e.g.,* upper zone storage) to account for plant growth, die-off, and removal.

Table B. 2 shows the percentage pervious for each land use as used in modeling the Chickahominy River study area. **Table B. 3** shows the breakdown of land uses within the drainage area. Land use distribution within the watershed is shown in **Figure B. 2**.

Table B. 2 Consolidated land use categories for the Chickahominy River drainage area used in HSPF modeling.

TMDL Land use Categories	Pervious / Impervious (%)
Barren	Pervious (90%) Impervious (10%)
Cropland	Pervious (100%)
Commercial	Pervious (60%) Impervious (40%)
Developed	Pervious (70%) Impervious (30%)
Forest	Pervious (100%)
Livestock Access	Pervious (100%)
Pasture	Pervious (100%)
Water	Pervious (100%)
Wetland	Pervious (100%)

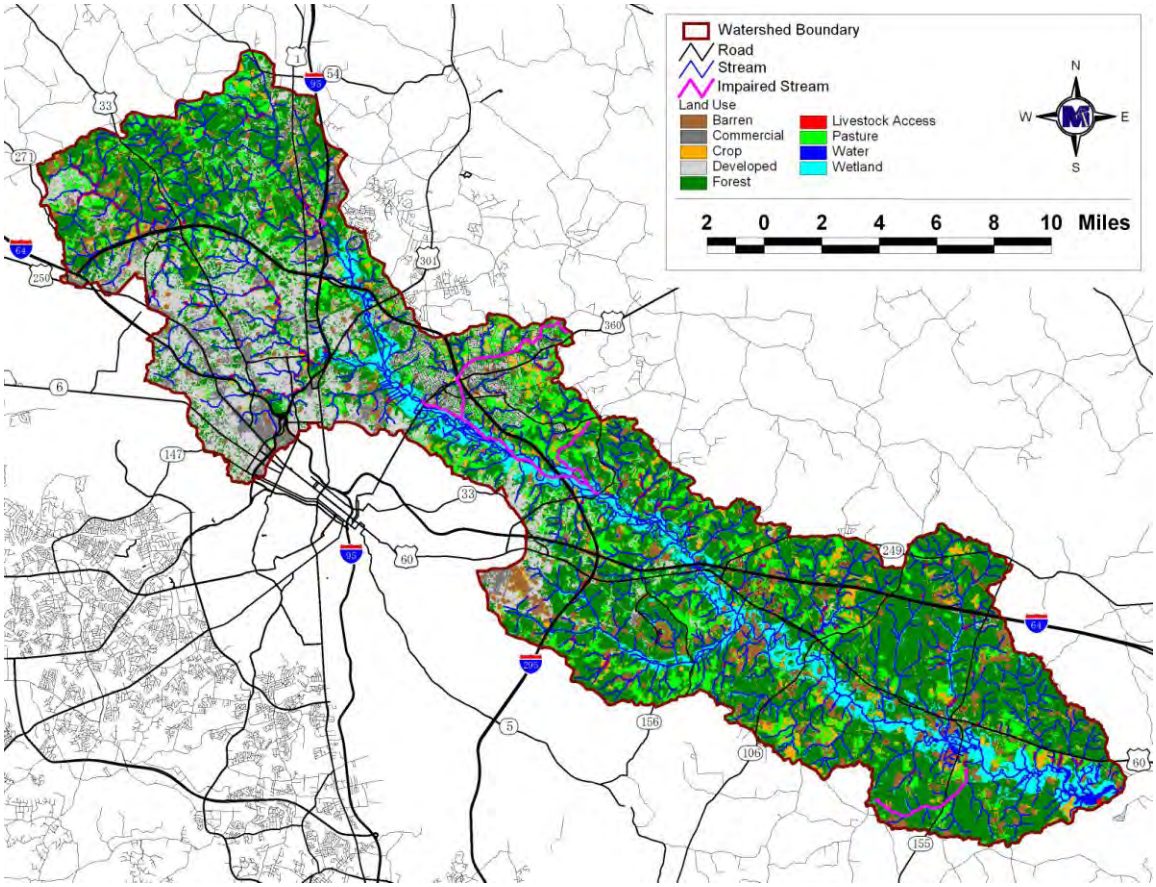

Figure B. 2 Land uses in the Chickahominy River study area watershed.

Table B. 3 Area of land use types in acres in the Chiackahominy River study area.

Impairment	Barren	Commercial	Cropland	Developed	Forest	Livestock Access	Pasture/ Hay	Water	Wetland	Total Acres
Chickahominy River Watershed	2,052 (1.06%)	8,927 (4.60%)	12,305 (6.34%)	30,929 (15.93%)	96,301 (49.62%)	47 (0.02%)	23,198 (11.95%)	1,841 (0.95%)	18,492 (9.53%)	194,093

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

In order to develop the entries for the F-tables, a combination of the NRCS Regional Hydraulic Geometry Curves (NRCS, 2012) and Digital Elevation Models (DEM) data was used. The NRCS has developed empirical formulas for estimating stream top width, cross-sectional area, average depth, and flow rate, at bank-full depth as functions of the drainage area for regions of the United States. Appropriate equations were selected based on the geographic location of the Chickahominy River watershed. Using these NRCS equations, an entry was developed in the F-table that represented a bank-full situation for the streams at each subwatershed outlet. A profile perpendicular to the channel was generated showing the stream profile height with distance for each subwatershed outlet

(**Figure B. 3**). Consecutive entries to the F-table are generated by estimating the volume of water and surface area in the reach at incremental depths taken from the profile. An example of an F-table used in HSPF is shown in **Table B. 4**.

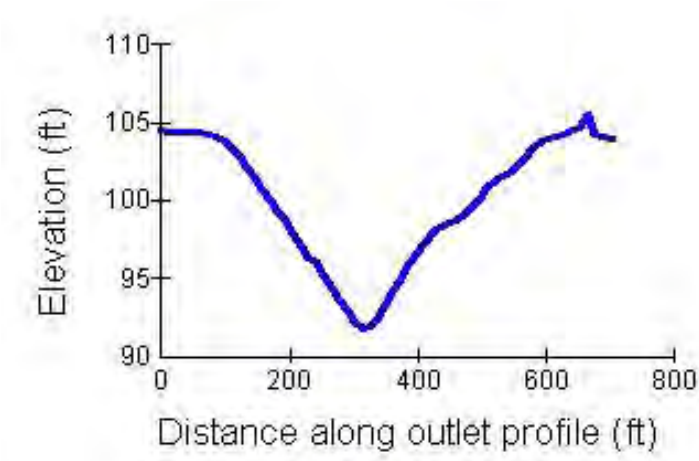

Figure B. 3 Stream profile representation in HSPF.

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

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

Selection of Representative Modeling Periods

Selection of the modeling period was based on two factors: availability of data (discharge and water-quality) and the need to represent critical hydrological conditions. Mean daily discharge at USGS Gaging Station 02042500 in the Chickahominy River near Providence Forge, Virginia was available from 1942 through 2010. The modeling period was selected to include the VADEQ assessment period from July 1992 through December

2010 that led to the inclusion of the impaired streams in this TMDL study area on the 1996, 1998, 2002, 2004, 2006, 2008, and 2010 Section 303(d) lists. Hydrologic calibration period was October 1996 to September 2000 and hydrologic validation period was October 2004 to September 2008. The fecal concentration data from this period were evaluated to determine the relationship between concentration and the level of flow in the stream. High concentrations of fecal coliform were recorded in all flow regimes, thus it was concluded that the critical hydrological condition included a wide range of wet and dry seasons. Bacteria model calibration and validation were conducted for the period of October 2003 to September 2009.

The hydrology calibration/validation/water quality calibration and validation time period, have both the high and low daily average streamflow and precipitation, which represent the high and low flow critical regimes (**Figure B. 4** and **Figure B. 5**). The figures 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. 5** shows the statistical comparison between calibration/validation time periods and historic time period.

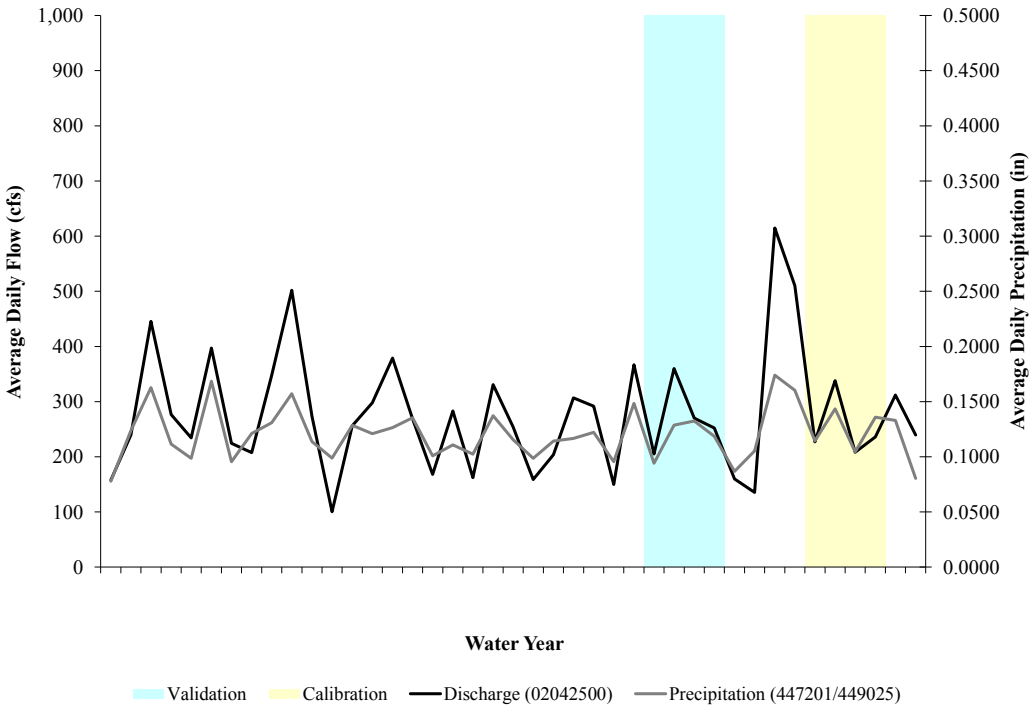

Figure B. 4 Modeling time periods, annual historical flow (USGS Station 02042500), and precipitation (Stations 447201/449025/449151) data.

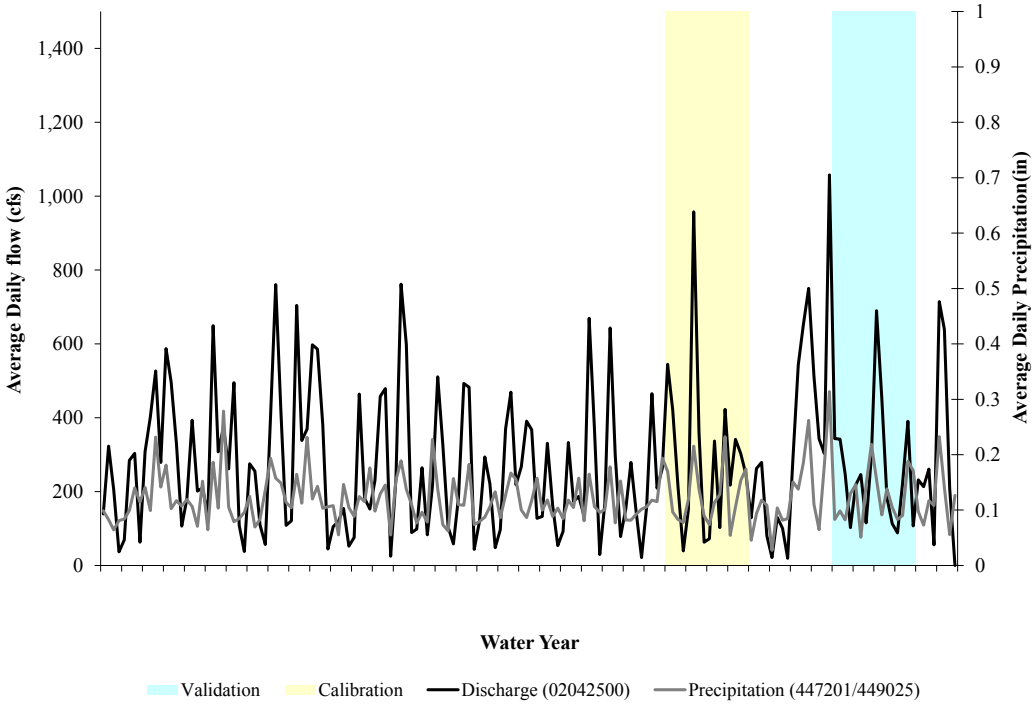

Figure B. 5 Modeling time periods, seasonal historical flow (USGS Station 02042500), and precipitation (Stations 447201/449025/449151) data.

Table B. 5 Comparison of modeled period to historical records for the Chickahominy River.

	Discharge (02042500)				Precipitation (447201/449025)			
	Fall	Winter	Spring	Summer	Fall	Winter	Spring	Summer
	Historical Record (1942 - 2010)				Historical Record (1946 - 2010)			
Mean	220	414	264	164	0.106	0.109	0.116	0.148
Variance	23,462	29,708	17,763	36,332	0.001	0.001	0.001	0.004
	Calibration and Validation Time Periods (10/97-9/00; 10/06-9/09)				Calibration and Validation Time Periods (10/97-9/00; 10/06-9/09)			
Mean	243	421	239	202	0.103	0.110	0.136	0.164
Variance	39,927	54,258	11,334	15,621	0.001	0.0022	0.001	0.003
	p-values				p-values			
Mean	0.381	0.470	0.276	0.223	0.391	0.469	0.047	0.204
Variance	0.124	0.096	0.277	0.120	0.518	0.093	0.351	0.348

Bacteria TMDL Critical Condition

EPA regulations at 40 CFR 130.7 (c)(1) require that TMDLs take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the Chickahominy River 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 Chickahominy River study area are attributed to both point and nonpoint sources. Critical conditions for waters impacted by land-based nonpoint sources generally occur during periods of wet weather and high surface runoff. In contrast, critical conditions for point source-dominated systems generally occur during low flow and low dilution conditions. Point sources, in this context also, include nonpoint sources that are not precipitation driven (*e.g.*, fecal deposition to stream).

A description of the data used in these analyses is shown in Tables 2.1 and 2.2 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 19 VADEQ monitoring stations in the Chickahominy River watershed (**Figure B. 6 - Figure**

B. 24). This demonstrates that this stream should have all flow regimes represented in the allocation modeling time period. Therefore, to account for critical conditions for bacteria in the watershed, the allocation modeling period is selected to coincide with the hydrologic calibration period since the later was selected to include both low and high flow conditions.

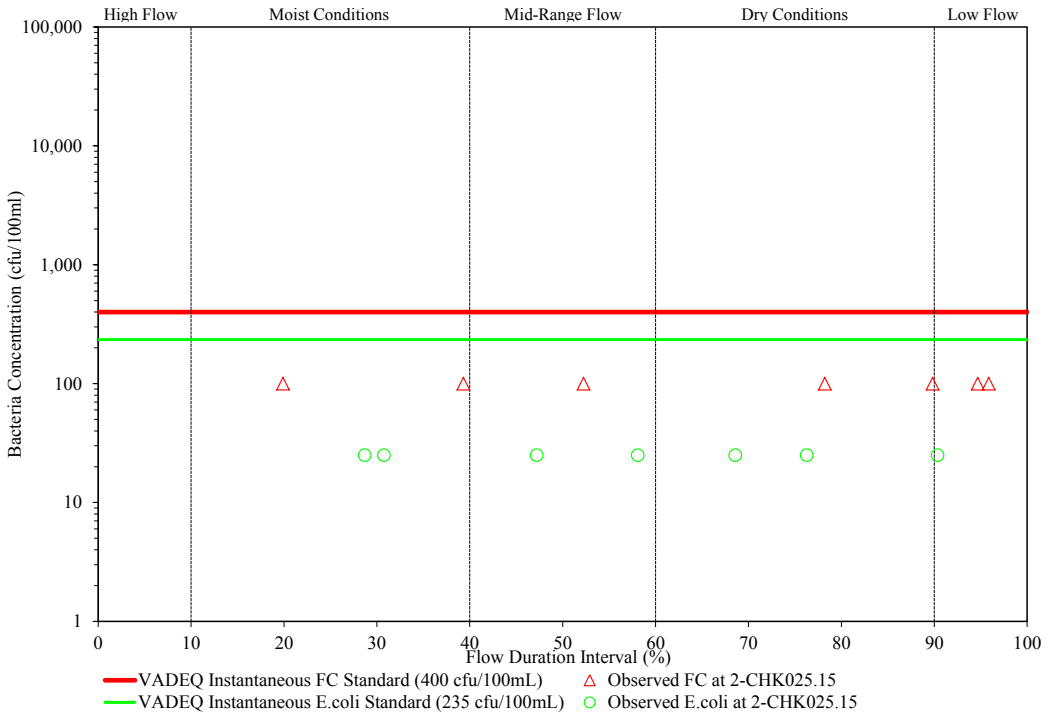

Figure B. 6 Bacteria concentrations at 2-CHK025.15 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

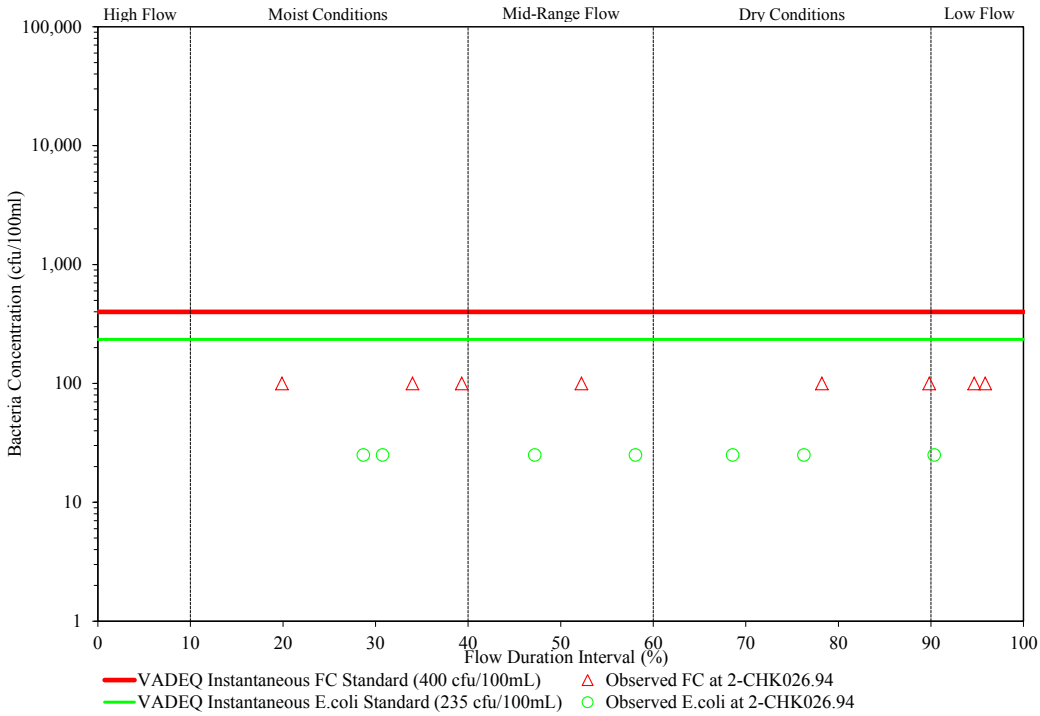

Figure B. 7 Bacteria concentrations at 2-CHK026.94 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

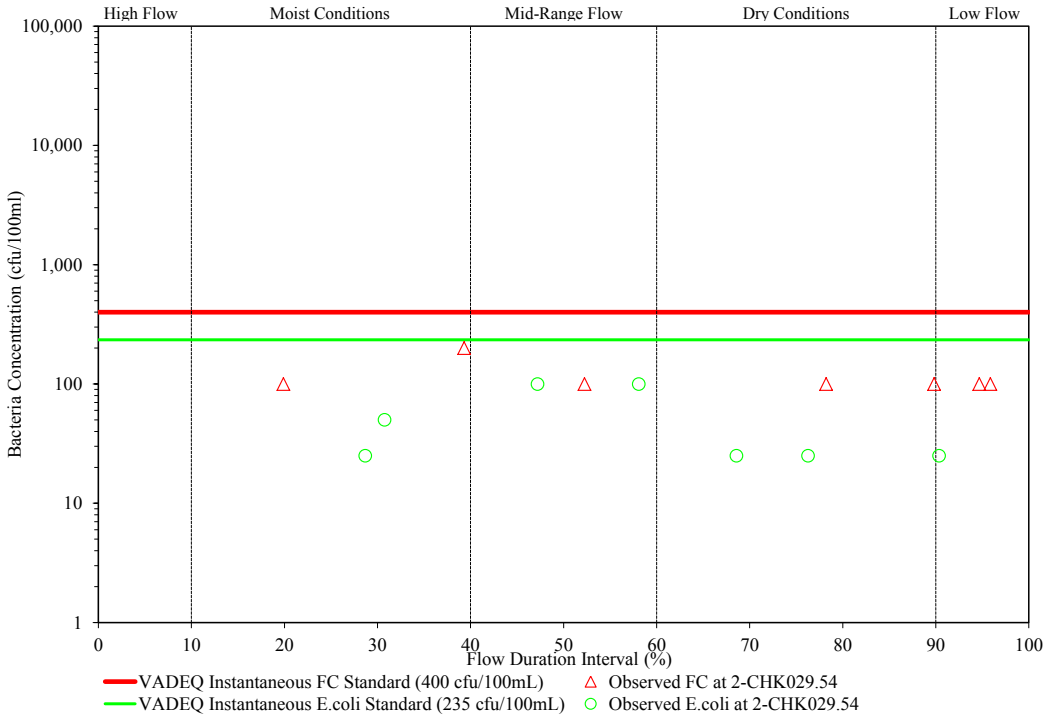

Figure B. 8 Bacteria concentrations at 2-CHK029.54 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

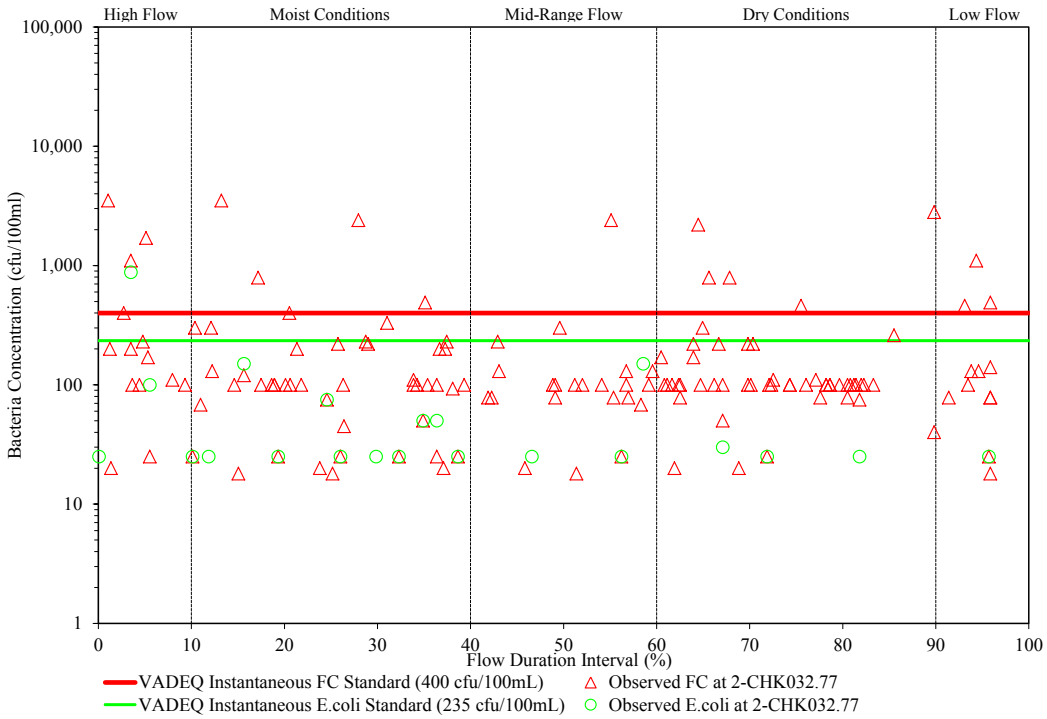

Figure B. 9 Bacteria concentrations at 2-CHK032.77 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

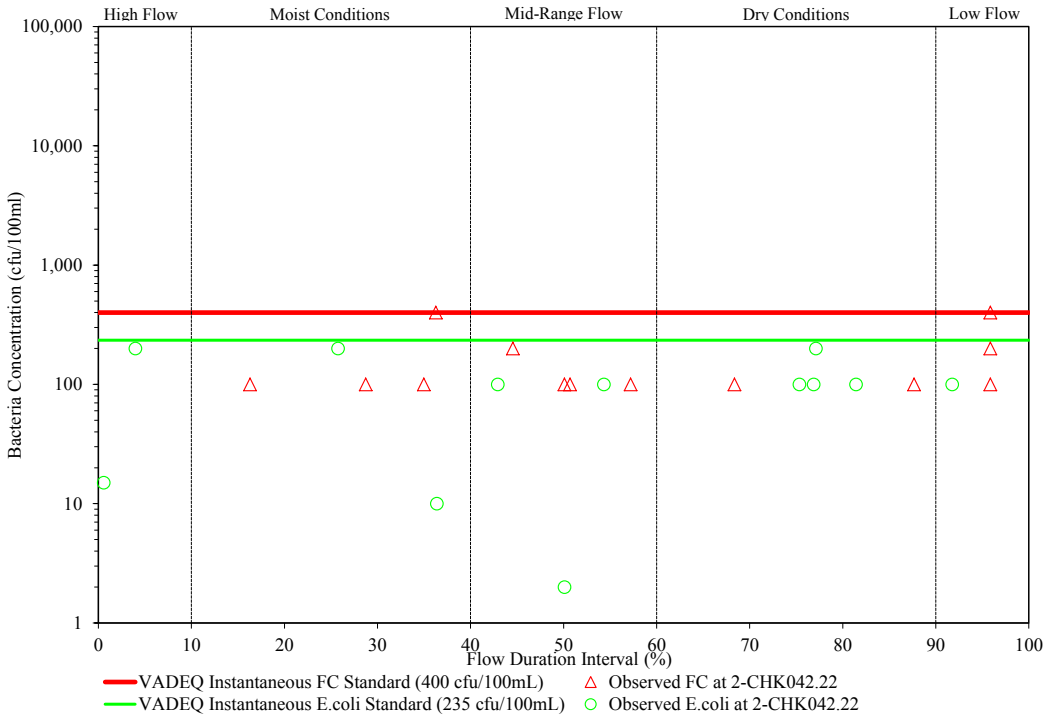

Figure B. 10 Bacteria concentrations at 2-CHK042.22 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

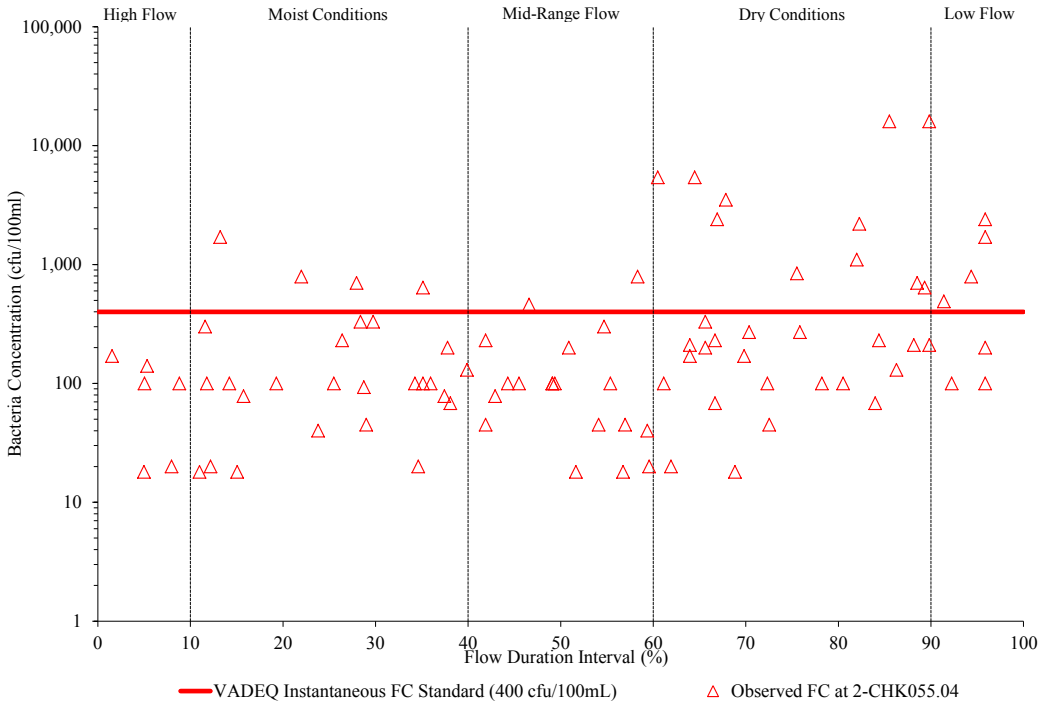

Figure B. 11 Bacteria concentrations at 2-CHK055.04 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

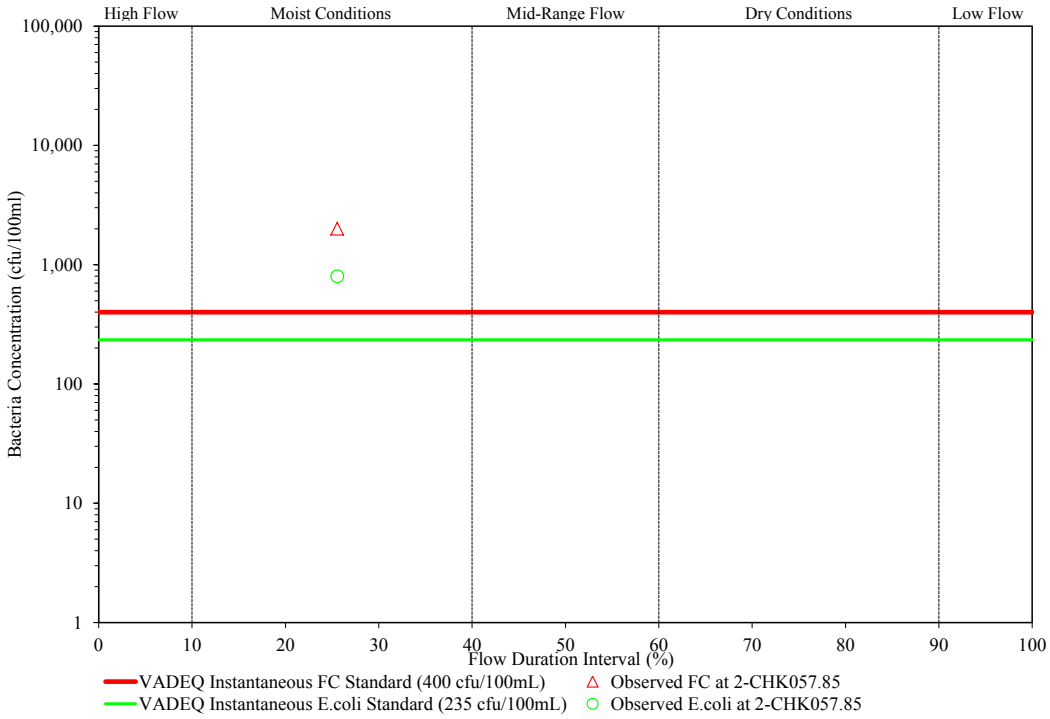

Figure B. 12 Bacteria concentrations at 2-CHK057.85 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

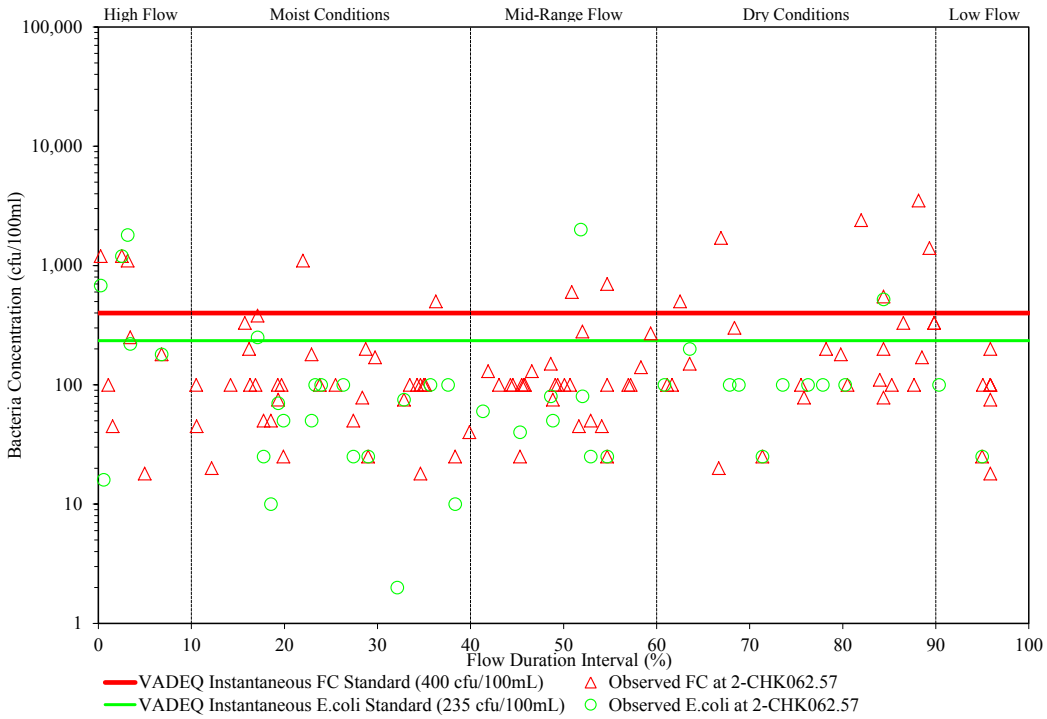

Figure B. 13 Bacteria concentrations at 2-CHK062.57 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

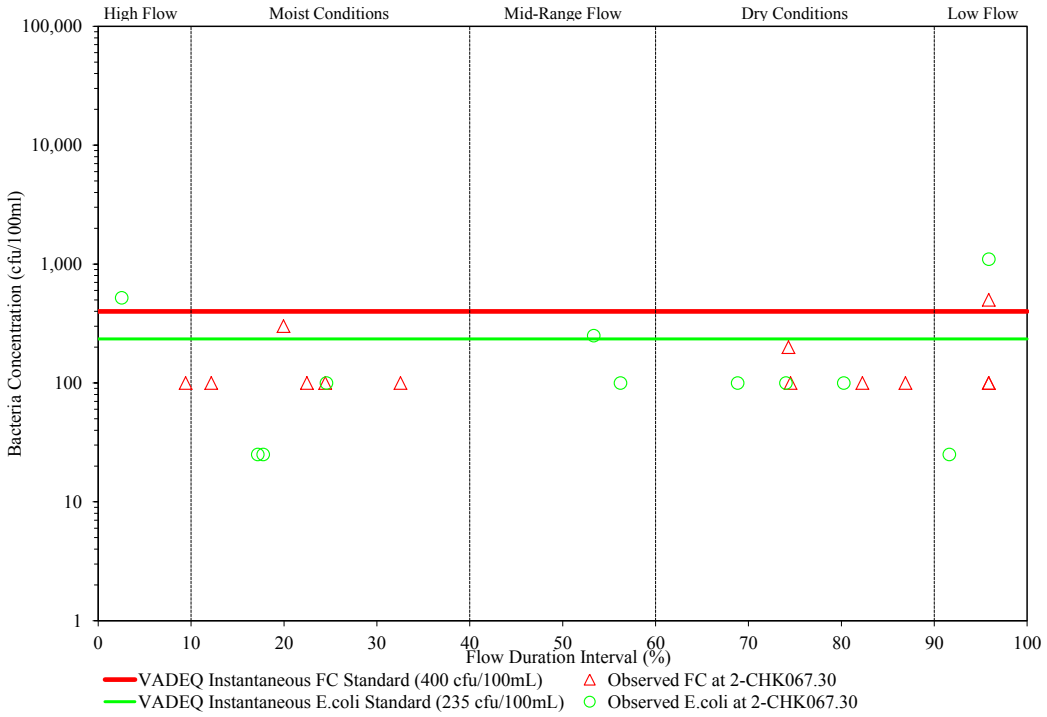

Figure B. 14 Bacteria concentrations at 2-CHK067.30 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

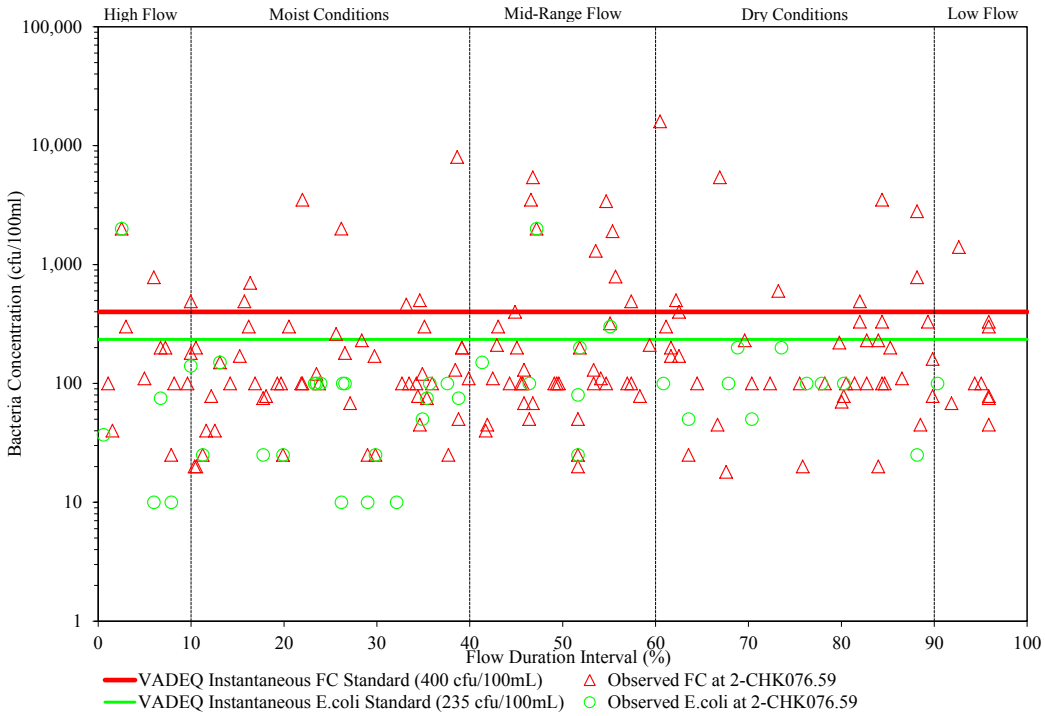

Figure B. 15 Bacteria concentrations at 2-CHK076.59 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

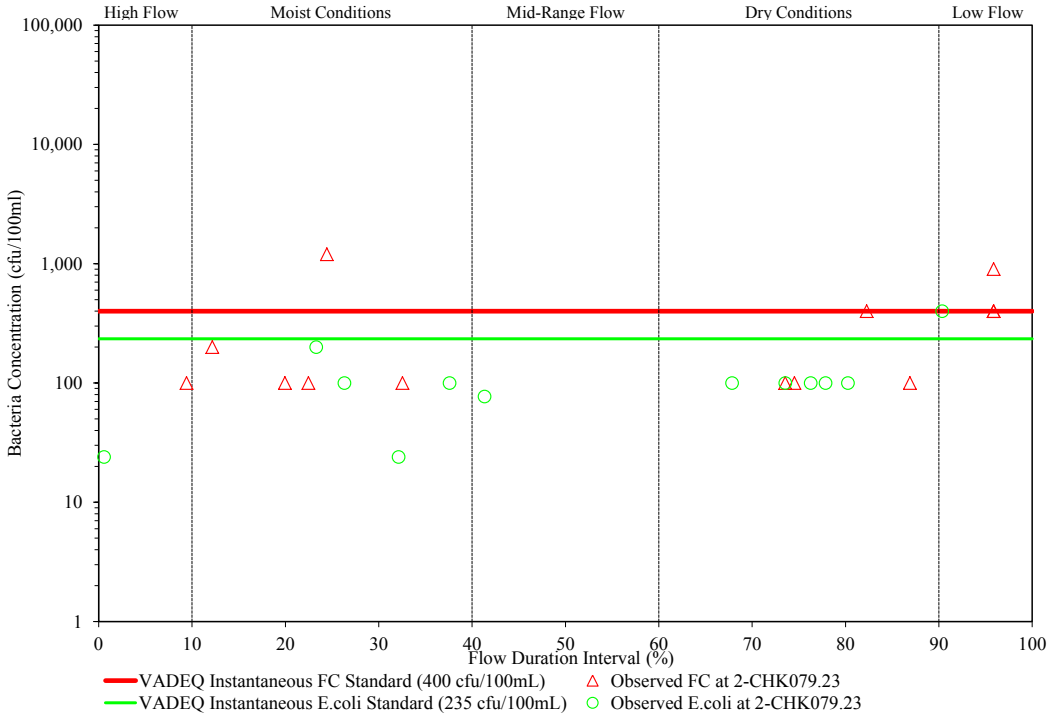

Figure B. 16 Bacteria concentrations at 2-CHK079.23 on the Chickahominy vs. discharge at USGS Gaging Station #02042500.

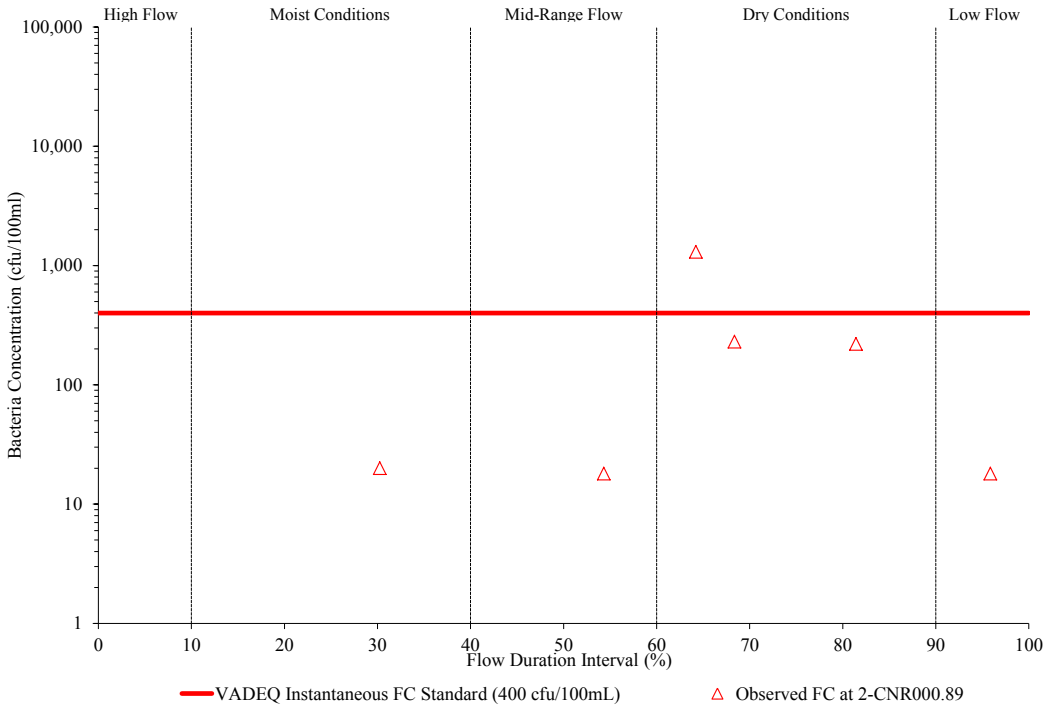

Figure B. 17 Bacteria concentrations at 2-CNR000.89 on Collins Run vs. discharge at USGS Gaging Station #02042500.

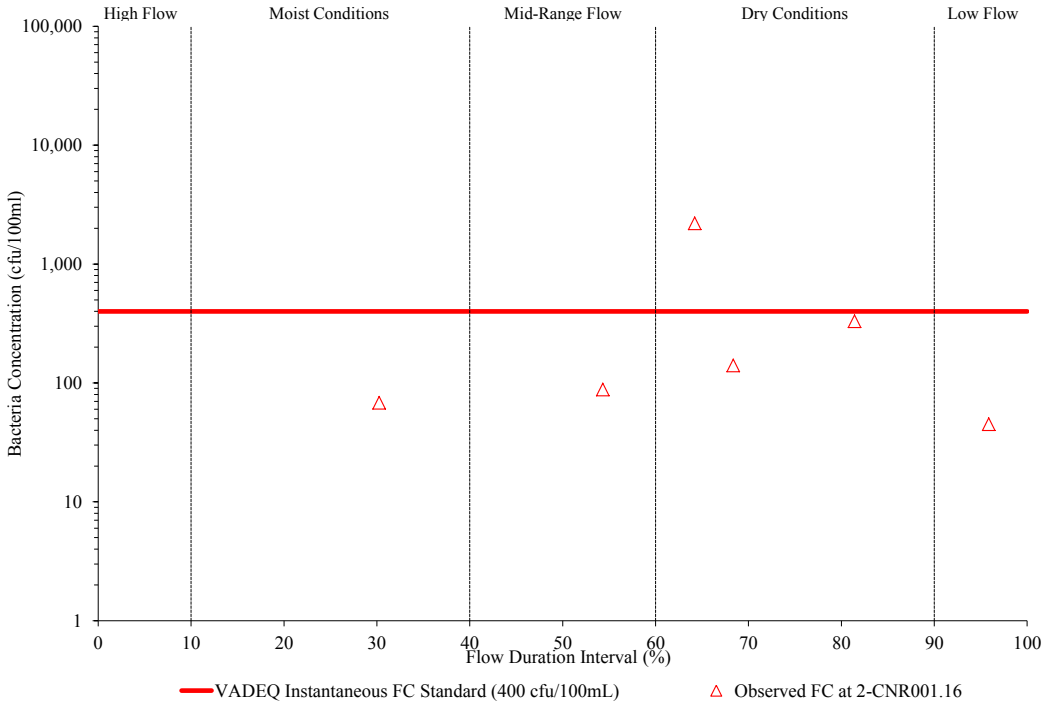

Figure B. 18 Bacteria concentrations at 2-CNR001.16 on Collins Run vs. discharge at USGS Gaging Station #02042500.

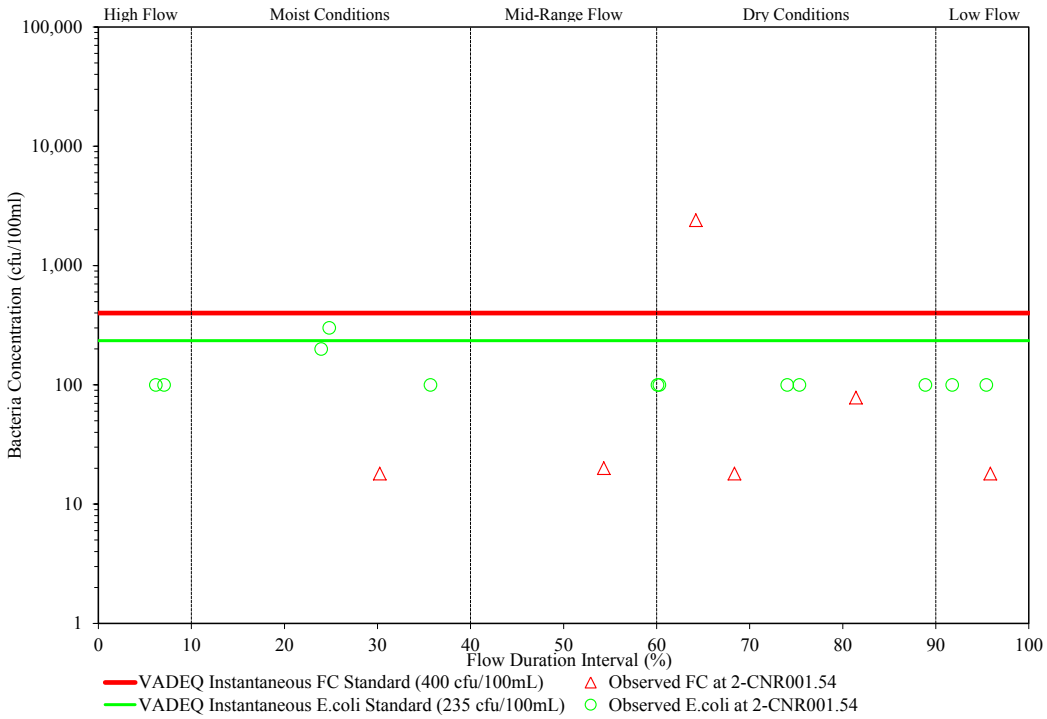

Figure B. 19 Bacteria concentrations at 2-CNR001.54 on Collins Run vs. discharge at USGS Gaging Station #02042500.

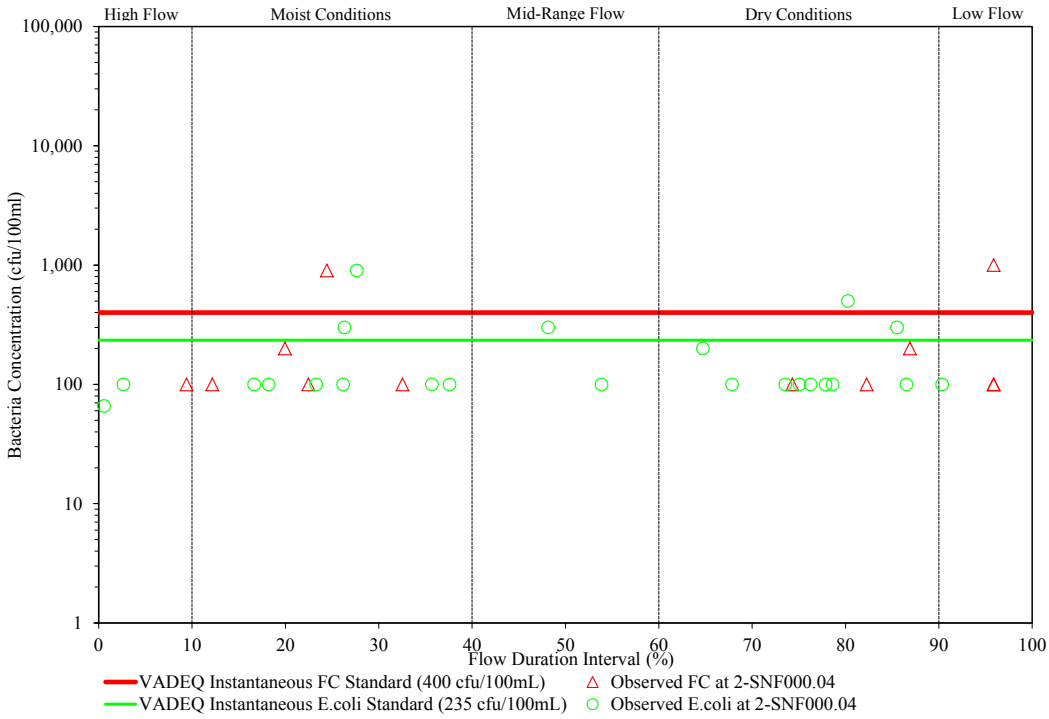

Figure B. 20 Bacteria concentrations at 2-SNF000.04 on Stony Run vs. discharge at USGS Gaging Station #02042500.

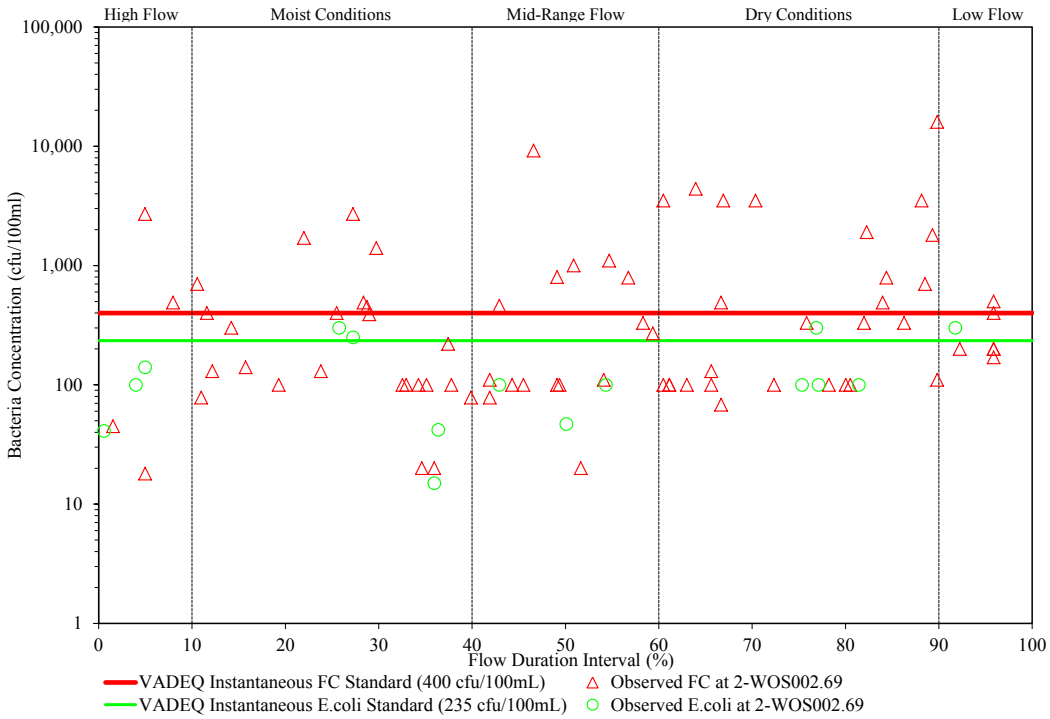

Figure B. 21 Bacteria concentrations at 2-WOS002.69 on White Oak Swamp vs. discharge at USGS Gaging Station #02042500.

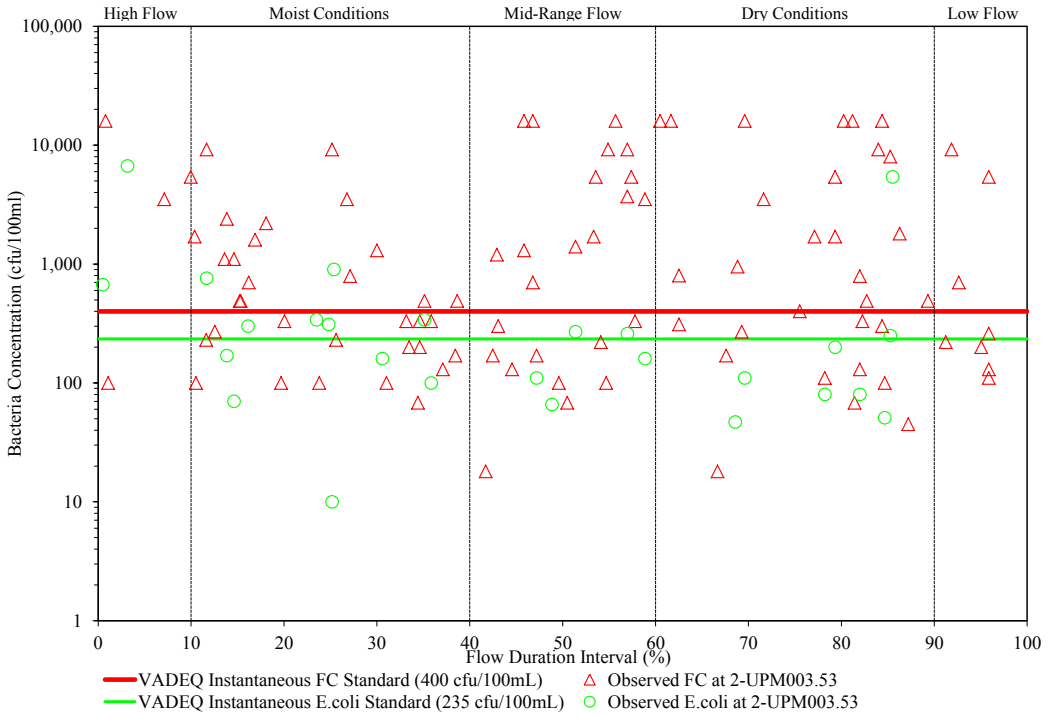

Figure B. 22 Bacteria concentrations at 2-UPM003.53 on Upham Brook vs. discharge at USGS Gaging Station #02042500.

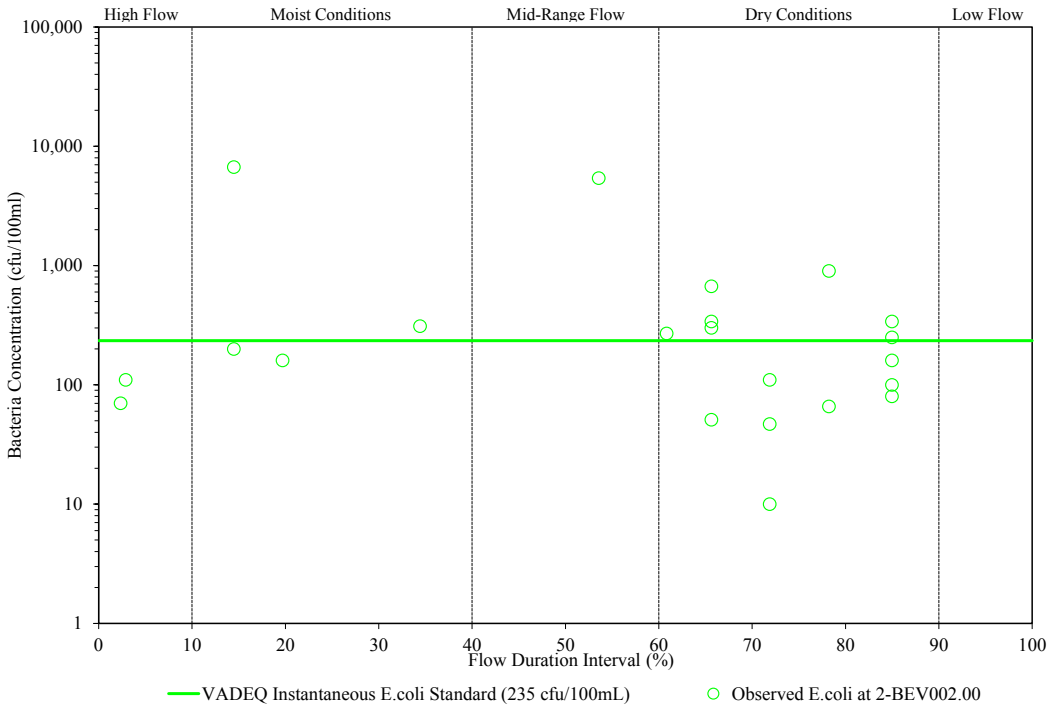

Figure B. 23 Bacteria concentrations at 2-BEV002.00 on Beaverdam Creek vs. discharge at USGS Gaging Station #02042500.

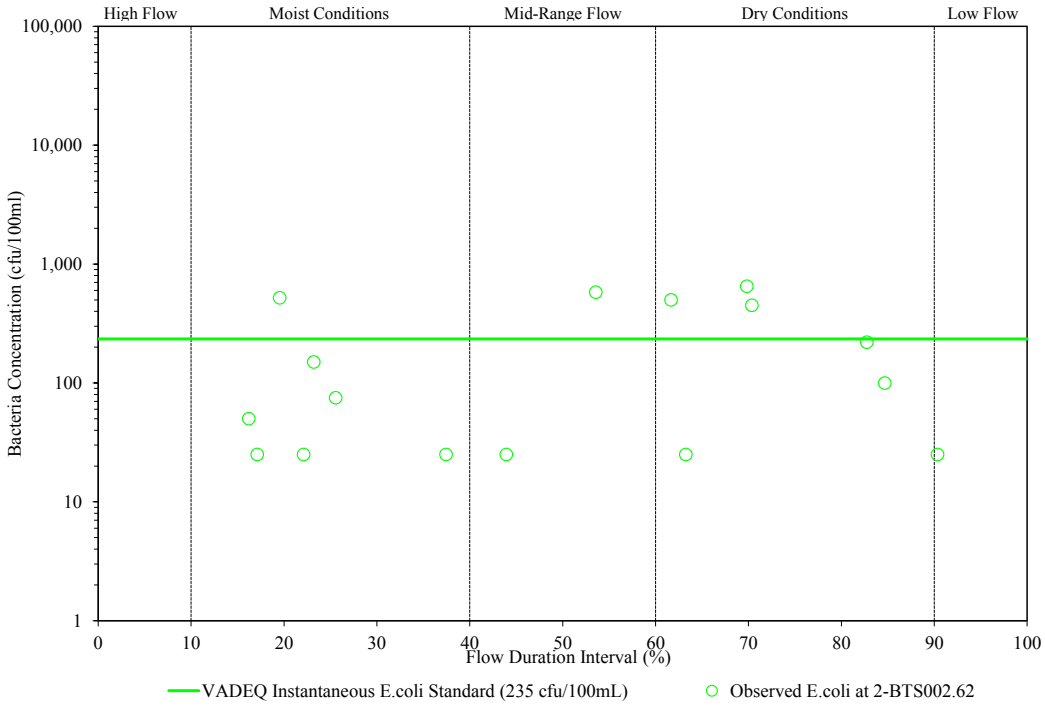

Figure B. 24 Bacteria concentrations at 2-BTS002.62 on Boatswain Creek vs. discharge at USGS Gaging Station #02042500.

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

Permitted Sources

One facility exists within the watershed that is permitted thorugh the Virginia Pollutant Discharge Elimination System (VPDES) which is permitted to discharge bacteria into surface waters at the standard within the Chickahominy River study area (Table 3.1). During water quality calibration and validation phase of the modeling effort, observed discharge rate and bacteria content data provided by DEQ was used. During the allocation phase of modeling, the maximum design flow of 2.067 million gallon per day (MGD) was used along with a fecal coliform concentration of 200 cfu/100 mL to ensure that compliance with state water quality standards could be met even if permitted loads were at maximum levels (**Table B. 6**).

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. 6 Flow rates and bacteria loads used to model VADEQ active permits in the Chickahominy River study area.

		Calibration/Validation		Allocation	
		Flow Rate (Gallon per Day)	Bacteria Concentration (cfu/100 mL)	Flow Rate (Million Gallon per Day)	Bacteria Concentration (cfu/100mL)
VADEQ Permit Number	Facility Name		Fecal Coliform Geometric Mean Standard		Fecal Coliform Geometric Mean Standard[1]
VA0004031	Tyson Foods Incorporated – Glenn Alen	variable	variable	1.25	200

[1] Fecal coliform standard is used since fecal colifom is modeled and not *E.coli* as explained in Chapter 5's introduction.

The MS4 loads are calculated as the loads coming from impervious surfaces within the MS4 permit boundaries after load allocation is completed. Source loads on contributing lands are identified and quantified. Once allocation is completed, the load coming from the impervious portion of the contributing lands is estimated and summed to represent the MS4 load.

Private Residential Sewage Treatment

The number of septic systems in the Chickahominy River 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 11,590 septic systems, of which, 387 were assumed to be failing for part of the year and 35 straight pipes (**Table B. 7**).

Table B. 7 Estimated failing septic systems and straight pipes for 2012 in the Chickahominy River study area.

Watershed	Septic Systems	Failing Septic Systems	Straight Pipes
Chickahominy River	11,590	387	35

Failing septic systems were assumed to deliver all effluent to the soil surface where it was available for wash-off during a runoff event. The initial estimates of the number of failing septic systems was 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. The fecal coliform density for septic system effluent was multiplied by the average design load for the septic systems in the subwatershed to determine the total load from each failing system. Additionally, the loads were distributed seasonally based on a survey of septic pump-out contractors to account for more frequent failures during wet months.

Straight pipes were estimated using 1990 U.S. Census Bureau block demographics. Houses listed in the Census sewage disposal category "other means" were assumed to be disposing sewage via straight pipes. Corresponding block data and subwatershed boundaries were intersected to determine an estimate of uncontrolled discharges in each subwatershed. Initial estimates obtained using this method were reduced considerably based on feedback from the regions Health Departments. The loadings from straight pipes were modeled in the same manner as direct discharges to the stream.

Livestock

Fecal coliform produced by livestock can enter surface waters through four pathways: land application of stored waste, deposition on land, direct deposition to streams, and diversion of wash-water and waste directly to streams. Each of these pathways is accounted for in the model. The amount of fecal coliform directed through each pathway was calculated by multiplying the fecal coliform density with the amount of waste expected through that pathway. Different livestock populations were estimated for each water quality modeling period (calibration/validation/allocation) where necessary. 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, 1999; VASS, 2005). 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. The use of fecal coliform densities measured in stored manure accounts for any die-off that occurs in storage. The modeling of fecal coliform entering the stream through diversion of wash-water was accounted for by the direct deposition of fecal matter to streams by cattle.

Land Application of Collected Manure

The average daily waste production per month was calculated using the number of animal units, weight of animal, and waste production rate as reported in Section 3.2.4. Second, the total amount of waste produced in confinement was calculated based on the proportion of time spent in confinement. Finally, values for the percentage of loafing lot waste collected, based on data provided by SWCD representatives and local stakeholders, were used to calculate the amount of waste available to be spread on pasture and cropland (Table 3.11). Stored waste was spread on pasture and cropland. It was assumed that 100% of land-applied waste is available for transport in surface runoff.

Deposition on Land

For cattle, the amount of waste deposited on land per day was a proportion of the total waste produced per day. The proportion was calculated based on the study entitled "Modeling Cattle Stream Access" conducted by the Biological Systems Engineering Department at Virginia Tech and MapTech, Inc. for VADCR (MapTech, 2002). The proportion was based on the amount of time spent in pasture, but not in close proximity to accessible streams, and was calculated as follows:

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

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

Direct Deposition to Streams

The amount of waste deposited in streams each day was a proportion of the total waste produced per day by cattle. First, the proportion of manure deposited in "stream access"

areas was calculated based on the "Modeling Cattle Stream Access" study. The proportion was calculated as follows:

Proportion = (time in stream access areas)/(24 hr)

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

Biosolids

Investigation of VADEQ data indicated that biosolids applications have occurred within the Chickahominy River study area. 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 2002 to 2010. 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.

Wildlife

For each species of wildlife, a GIS habitat layer was developed based on the habitat descriptions that were obtained (Section 3.2.5). An example of one of these layers is shown in **Figure B. 25**. 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.

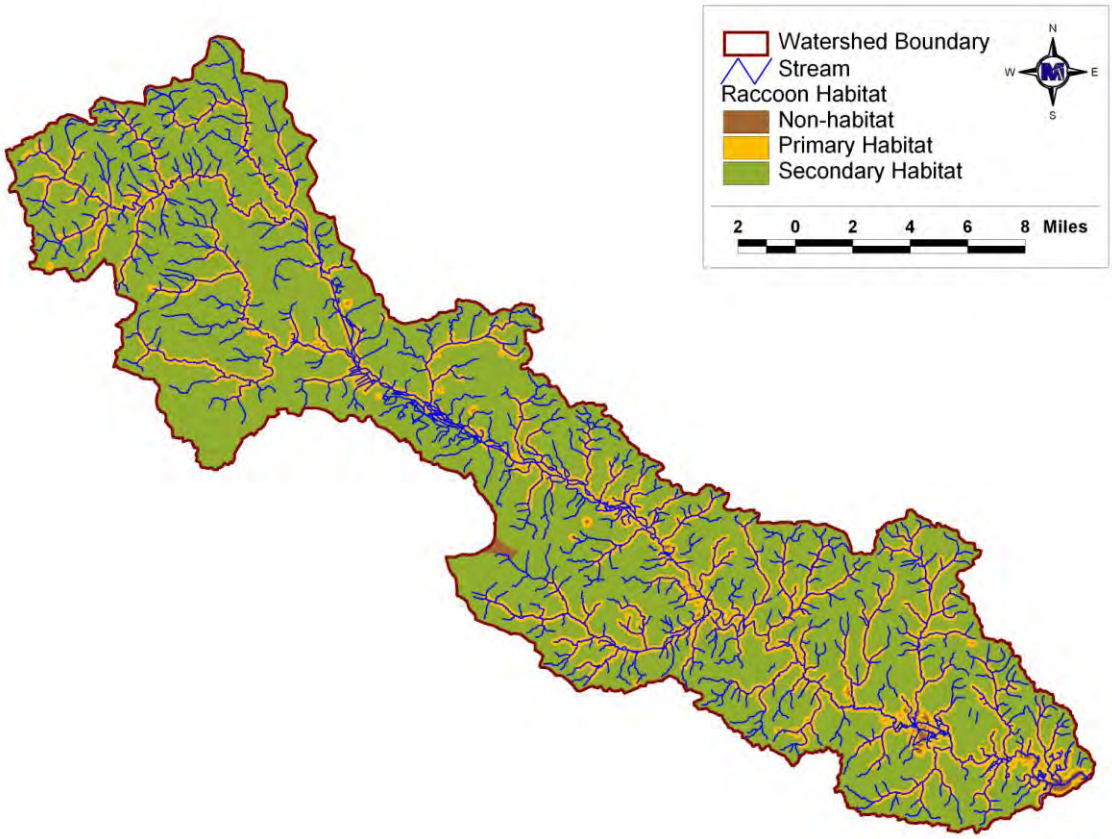

Figure B. 25 Example of raccoon habitat layer in the Chickahominy River study area, as developed by MapTech.

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 3.17). It was estimated that, for all animals other than beaver, 5% of fecal matter produced while in stream access areas was directly deposited to the stream. For beaver, it was estimated that 100% of fecal matter would be directly deposited to streams.

Pets

Cats and dogs were the only pets considered in this analysis. Population density (animals per house), wasteload, and fecal coliform density are reported in Section 3.2.3. Waste

from pets was distributed on residential land uses. The number of households per subwatershed was taken from the 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 2012.

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 waste 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. 8**, 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 2006-2009. Where an increase of 50% exceeded the maximum value for the parameters, the maximum value was used and the parameters increased over the base value were reported. The hydrologic quantities of greatest interest in a fecal coliform model are those that govern peak flows and low flows. Peak flows, being a function of runoff, are important because they are directly related to the transport of fecal coliforms from the land surface to the stream. Peak flows were most sensitive to changes in the parameters

governing infiltration such as INFILT (Infiltration), LZSN (Lower Zone Storage), and by UZSN (Upper Zone Storage), which governs surface transport, LZETP (Lower Zone Evapotranspiration), which affects soil moisture and AGWRC (Groundwater Recession Rate). Low flows are important in a water quality model because they control the level of dilution during dry periods. Parameters with the greatest influence on low flows (as evidenced by their influence in the *Low Flows* and *Summer Flow Volume* statistics) were AGWRC (Groundwater Recession Rate), BASETP (Base Flow Evapotranspiration), LZETP, INFILT, UZSN, CEPSC (Interception Storage Capacity), and LZSN. The responses of these and other hydrologic outputs are reported in **Table B. 9**.

Table B. 8 HSPF base parameter values used to determine hydrologic model response.

Parameter	Description	Units	Base Value
LZSN	Lower Zone Nominal Storage	in	8.0
INFILT	Soil Infiltration Capacity	in/hr	0.034 – 0.259
BASETP	Base Flow Evapotranspiration	---	0.05 - 0.05
INTFW	Interflow Inflow	---	2.0 - 2.0
DEEPFR	Groundwater Inflow to Deep Recharge	---	0.1 - 0.1
AGWRC	Groundwater Recession rate	---	0.94
KVARY	Groundwater Recession Flow	1/in	1.0
MON-INTERCEP	Monthly Interception Storage Capacity	in	0.01-0.2
MON-UZSN	Monthly Upper Zone Nominal Storage	in	0.70-1.0
MON-LZETP	Monthly Lower Zone Evapotranspiration	in	0.01-0.80

Table B. 9 HSPF Sensitivity analysis results for hydrologic model parameters for the Chickahominy River Watershed.

		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	0.82	15.85	-56.84	-1.94	2.34	1.29	1.19	0.90
AGWRC[1]	0.92	0.22	4.22	-18.80	-0.63	0.50	0.31	0.56	0.30
AGWRC[1]	0.96	-0.21	-5.18	26.00	0.67	-0.01	-0.47	-0.93	-1.04
AGWRC[1]	0.999	-18.2	-26.8	73.42	-19.31	-13.42	-13.27	-25.60	-21.41
BASETP	-50	1.75	-1.76	24.03	0.16	3.44	4.10	-0.37	0.84
BASETP	-10	0.32	-0.34	4.32	0.05	0.63	0.73	-0.07	0.23
BASETP	10	-0.31	0.33	-4.08	-0.06	-0.59	-0.69	0.06	-0.24
BASETP	50	-1.41	1.54	-18.27	-0.33	-2.72	-3.06	0.23	-1.33
DEEPFR	-50	3.90	3.02	5.59	4.23	3.66	3.87	3.88	3.84
DEEPFR	-10	0.78	0.60	1.13	0.85	0.73	0.77	0.78	0.77
DEEPFR	10	-0.78	-0.60	-1.13	-0.85	-0.73	-0.77	-0.78	-0.77
DEEPFR	50	-3.89	-2.96	-5.73	-4.23	-3.65	-3.86	-3.87	-3.85
INFILT	-50	-0.22	11.54	-20.98	0.52	1.62	-3.17	-0.42	-0.14
INFILT	-10	-0.11	1.49	-3.08	0.06	0.15	-0.67	-0.09	-0.08
INFILT	10	0.13	-1.23	2.68	-0.05	-0.07	0.63	0.10	0.11
INFILT	50	0.80	-4.37	10.44	-0.05	0.23	2.76	0.58	0.72
INTFW	-50	-0.25	-0.36	0.53	-0.23	-0.10	-0.57	-0.15	-0.25
INTFW	-10	-0.03	-0.05	0.07	-0.03	-0.01	-0.09	-0.01	-0.03
INTFW	10	0.03	0.05	-0.06	0.02	0.01	0.07	0.01	0.03
INTFW	50	0.10	0.21	-0.24	0.08	0.03	0.29	0.05	0.10
LZSN	-50	6.10	9.43	-7.33	10.26	4.41	-5.94	13.38	6.14
LZSN	-10	0.93	1.43	-1.37	1.69	0.98	-1.14	1.81	0.93
LZSN	10	-0.69	-0.88	0.55	-1.46	-0.91	1.49	-1.47	-0.68
LZSN	50	-3.72	-4.55	2.02	-6.99	-4.51	4.22	-6.27	-3.71
CEPSC	-50	1.45	-0.65	10.10	1.35	4.35	-0.50	0.15	1.45
CEPSC	-10	0.24	-0.10	1.65	0.20	0.84	-0.05	-0.11	0.24
CEPSC	10	-0.23	0.09	-1.51	-0.20	-0.81	0.00	0.13	-0.23
CEPSC	50	-1.06	0.31	-6.68	-0.74	-3.32	-0.01	0.11	-1.06
LZETP	-50	17.29	17.99	23.80	9.63	8.93	33.23	19.69	17.31
LZETP	-10	1.99	1.87	2.95	1.35	1.07	3.56	2.23	1.99
LZETP	10	-1.72	-1.59	-2.49	-1.21	-0.91	-3.24	-1.80	-1.73
LZETP	50	-10.4	-9.67	-15.63	-7.00	-5.33	-21.12	-10.08	-10.41
KVARY	-50	-0.16	-5.59	24.85	0.55	0.08	-0.47	-0.73	-0.79
KVARY	-10	-0.03	-0.97	4.13	0.09	-0.03	-0.06	-0.12	-0.04
KVARY	10	0.03	0.92	-3.79	-0.09	0.04	0.06	0.10	0.07
KVARY	50	0.17	4.12	-16.92	-0.42	0.32	0.24	0.43	0.25
UZSN	-50	5.32	11.63	-3.70	2.07	9.73	5.27	3.67	5.33
UZSN	-10	0.78	1.70	-0.68	0.33	1.31	0.83	0.58	0.78
UZSN	10	-0.71	-1.51	0.64	-0.33	-1.24	-0.72	-0.49	-0.71
UZSN	50	-2.84	-5.85	2.85	-1.64	-4.21	-3.33	-2.09	-2.85

[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 1998 through 2000, and model parameters established for 2012 conditions. The three HSPF parameters impacting the model's water quality response (**Table B. 10**) were increased and decreased by amounts that were consistent with the range of values for the parameter. The First Order Decay (FSTDEC) was the parameter with the greatest influence on monthly geometric mean concentration (**Table B. 11**). The reason behind the more pronounced impact of change in decay rate on concentration of bacteria in the stream is that changes in decay rate impact bacteria from nonpoint as well as point sources and direct-nonpoint sources. On the other hand, changes in maximum fecal coliform accumulation on the land (MON-SQOLIM) and wash-off rate for fecal coliform on land surface (WSQOP) only impact the nonpoint portion of the bacteria. Graphical depictions of the results of this sensitivity analysis can be seen in **Figure B. 26** through **Figure B. 28**.

Table B. 10 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 – 1.6E+13
WSQOP	Wash-off Rate for FC on Land Surface	in/hr	2.0 – 2.0
FSTDEC	In-stream First Order Decay Rate	1/day	2

Table B. 11 Percent change in average monthly *E.coli* mean for the years 1998-2000.

Model Parameter	Parameter Change (%)	Percent Change in Average Monthly *E. coli* Geometric Mean for 1998-2000											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
FSTDEC	-50	37.87	37.92	36.16	36.97	40.08	39.54	41.61	35.44	39.60	36.79	42.74	40.19
FSTDEC	-10	6.32	6.35	6.06	6.19	6.67	6.67	6.91	5.93	6.64	6.17	7.11	6.69
FSTDEC	10	-5.81	-5.84	-5.58	-5.69	-6.12	-6.16	-6.34	-5.46	-6.11	-5.69	-6.52	-6.15
FSTDEC	50	-24.82	-25.03	-23.94	-24.37	-26.11	-26.50	-26.96	-23.38	-26.13	-24.41	-27.74	-26.21
SQOLIM	-50	-18.89	-15.55	-17.04	-18.46	-17.05	-8.11	-11.54	-17.18	-12.07	-10.07	-14.37	-17.02
SQOLIM	-25	-9.55	-7.88	-8.61	-9.33	-8.69	-4.14	-5.89	-8.73	-6.12	-5.15	-7.32	-8.66
SQOLIM	25	8.88	7.27	8.07	8.68	7.88	3.80	5.41	8.07	5.75	4.70	6.66	7.87
SQOLIM	50	18.07	14.86	16.37	17.62	16.01	7.69	10.97	16.34	11.60	9.56	13.60	16.14
WSQOP	-50	15.38	12.27	12.66	13.68	4.55	4.06	6.31	11.43	7.95	4.49	7.94	8.16
WSQOP	-10	1.91	1.66	1.63	1.80	0.74	0.53	0.88	1.64	1.13	0.57	1.17	1.15
WSQOP	10	-1.62	-1.45	-1.39	-1.55	-0.69	-0.45	-0.77	-1.44	-1.00	-0.48	-1.05	-1.02
WSQOP	50	-6.77	-6.83	-5.76	-6.83	-3.91	-2.17	-3.88	-6.86	-4.42	-2.31	-5.64	-5.24

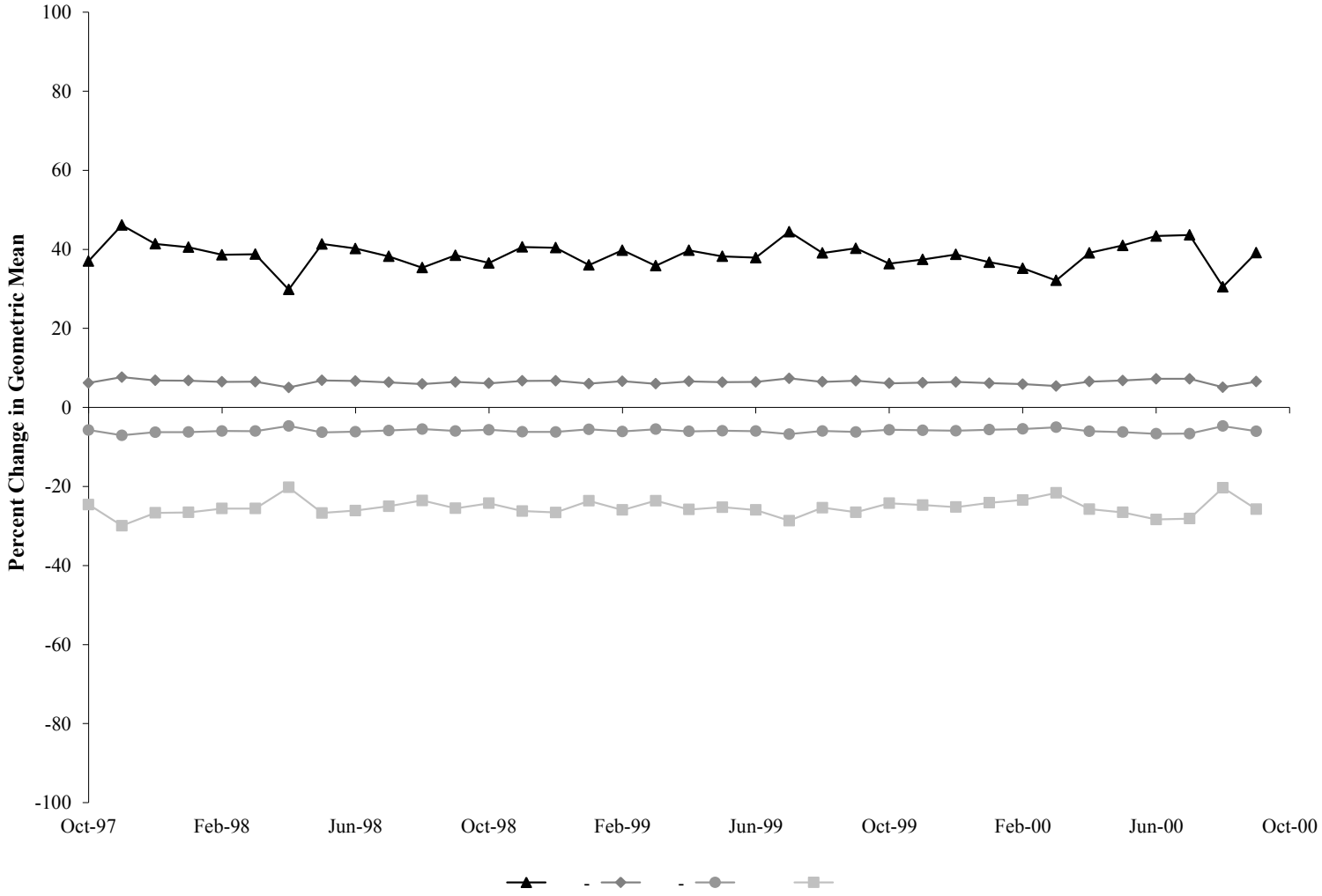

Figure B. 26 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the in-stream first-order decay rate (FSTDEC).

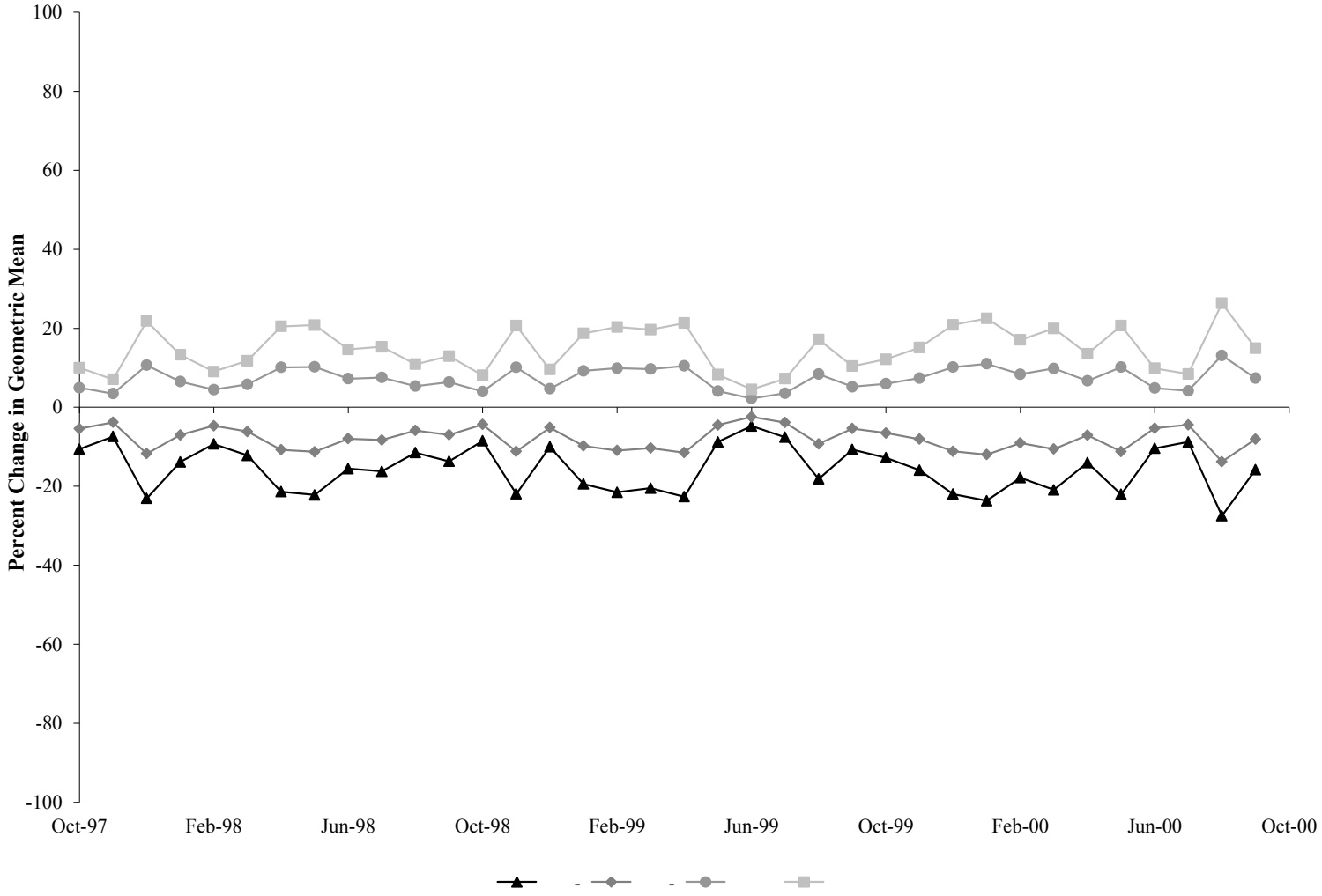

Figure B. 27 Results of sensitivity analysis on monthly mean concentrations as affected by changes in maximum fecal accumulation on land (MON-SQOLIM).

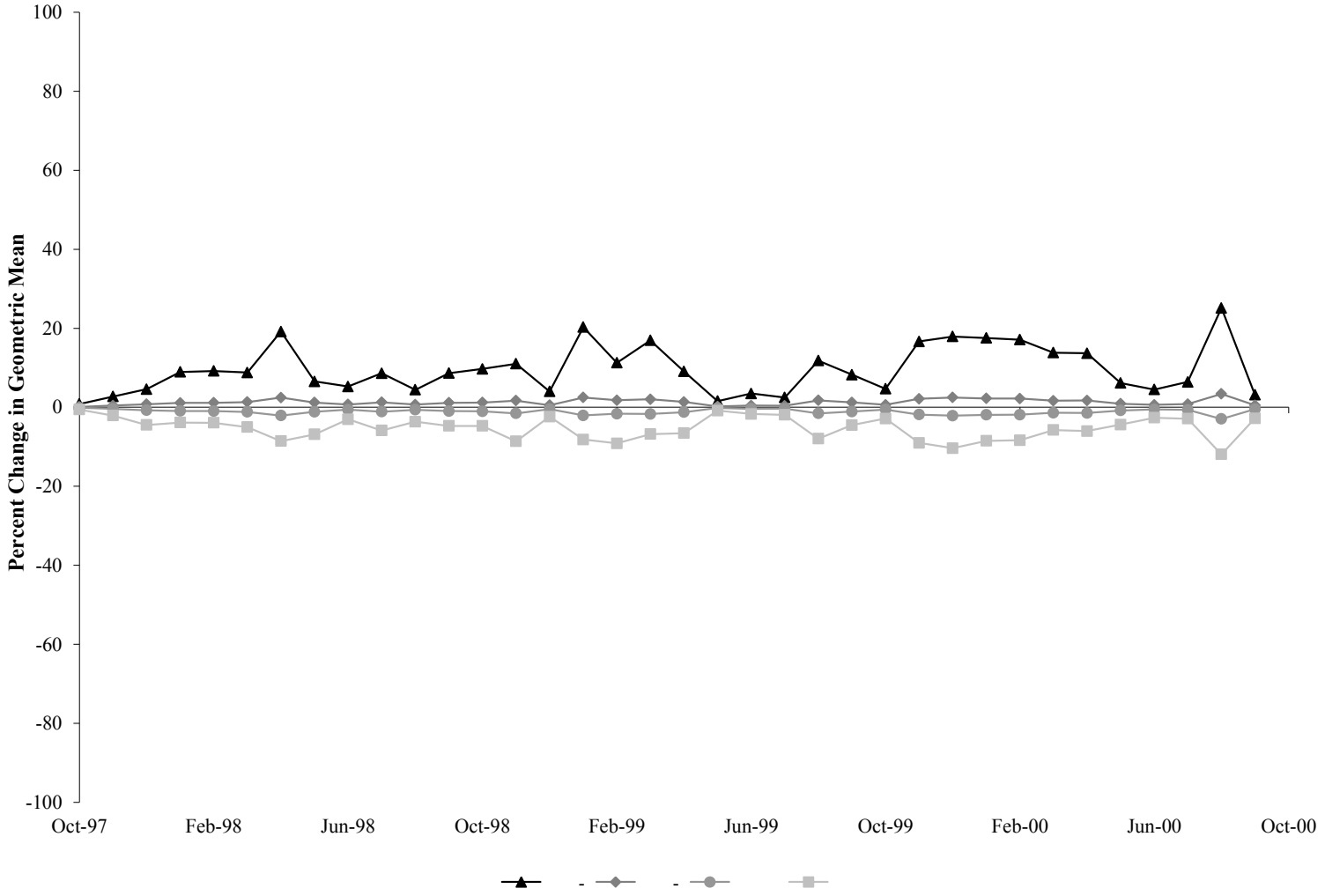

Figure B. 28 Results of sensitivity analysis on monthly mean concentrations as affected by changes in the wash-off rate from land surfaces (WSQOP).

In addition to analyzing the sensitivity of the model response to changes in water quality transport and die-off parameters, the response of the model to changes in land-based and direct loads was also analyzed. It is evident in **Figure B. 29** that the model predicts a linear relationship between increased fecal coliform concentrations in both land and direct applications, and total load reaching the stream. The magnitude of this relationship differs between land applied and direct loadings; a 100% increase in the land applied loads results in an increase of about 40% in stream loads, while a 100% increase in direct loads results in approximately a 60% increase in stream loads. Both direct loads and land applied loads have a significant impact on the geometric mean concentrations (**Figure B. 30** and **Figure B. 31**).

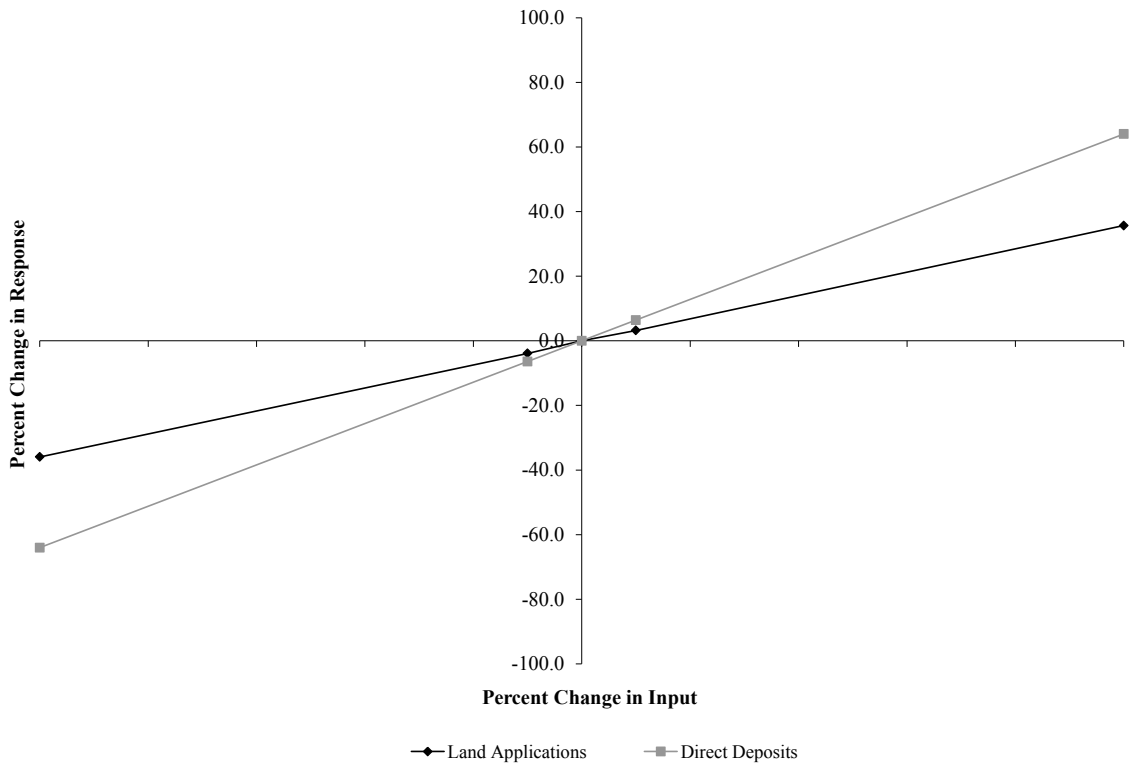

Figure B. 29 Results of total loading sensitivity analysis for outlet of the Chickahominy River Watershed study area.

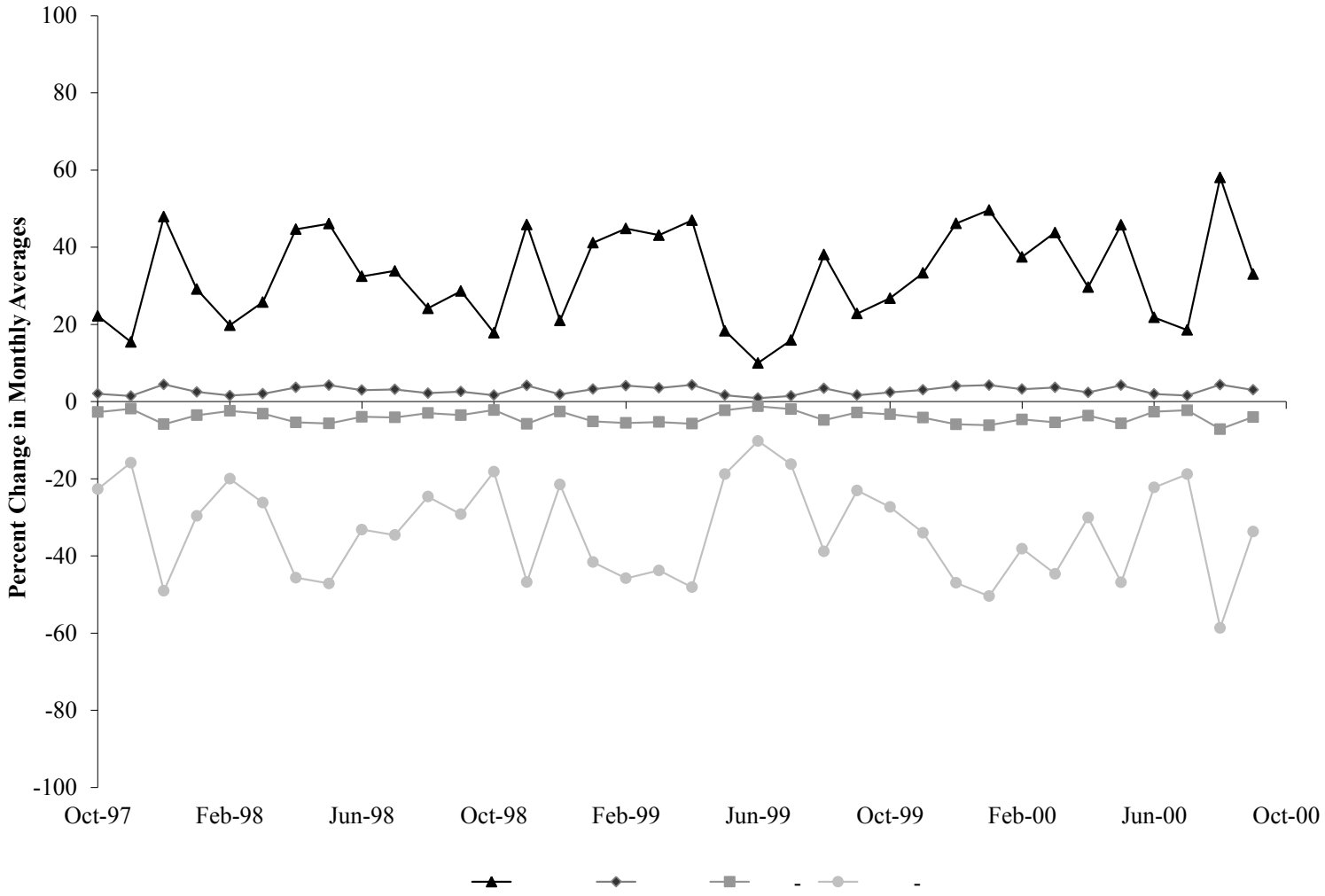

Figure B. 30 Results of sensitivity analysis on monthly geometric-mean concentrations in the Chickahominy River Watershed study area, as affected by changes in land-based loadings.

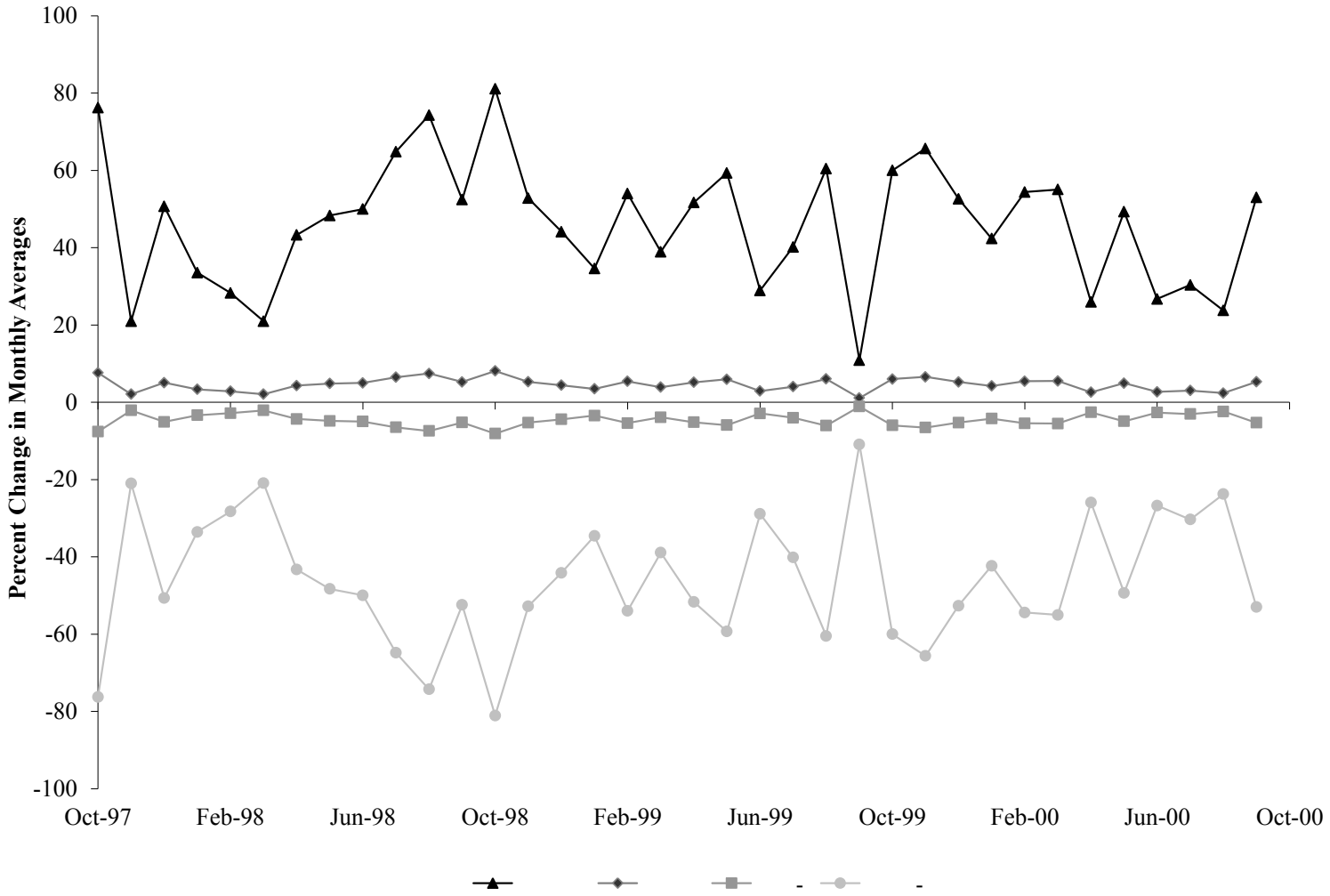

Figure B. 31 Results of sensitivity analysis on monthly geometric-mean concentrations in the Chickahominy River Watershed study area, as affected by changes in loadings from direct nonpoint sources.

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.

HSPF - Hydrologic Calibration and Validation

The model calibrated for hydrologic accuracy using daily flow data for the period October 1996 through September 2000. The modeled output from subwatershed 5 was compared against the Chickahominy River USGS Gaging Station #02042500 data

HSPF parameters that were adjusted during the hydrologic calibration represented: the amount of evapotranspiration from the root zone (LZETP), the recession rates for groundwater (AGWRC) and interflow (IRC), the 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), and groundwater recession flow (KVARY). **Table B. 12** 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. 12 Initial hydrologic parameters estimated for the Chickahominy River TMDL 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	8	8
INFILT	in/hr	0.001 – 0.50	0.034 – 0.2586	0.0612 – 0.4655
KVARY	1/in	0.0 – 5.0	1.0	2.0
AGWRC	1/day	0.85 – 0.999	0.990	0.993
DEEPFR	---	0.0 – 0.50	0.10	0.148
BASETP	---	0.0 – 0.20	0.05	0.07
INTFW	---	1.0 – 10.0	2.0	2.0
IRC	1/day	0.30 – 0.85	0.2	0.2
MON-INTERCEPT	in	0.01 – 0.40	0 - 0.20	0 – 0.4
MON-UZSN	in	0.05 – 2.0	0.7 – 1.0	0.7 – 1.0
MON-LZETP	---	0.1 – 0.9	0.01 – 0.8	0.01 – 0.86

* Represents a multiplier; + represents an addition

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. **Figure B. 32** and **Figure B. 33** graphically show these comparisons.

Table B. 13 Hydrology calibration model performance from 10/1/1996 through 9/30/2000 at USGS Gaging Station #02042500 on the Chickahominy River Watershed (subwatershed 5).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	234.38	211.99	-9.55%
Upper 10% Flow Values:	93.25	86.70	-7.02%
Lower 50% Flow Values:	29.52	28.93	-2.01%
Winter Flow Volume	99.32	81.18	-18.27%
Spring Flow Volume	47.92	41.01	-14.41%
Summer Flow Volume	38.27	44.32	15.83%
Fall Flow Volume	48.88	45.47	-6.97%
Total Storm Volume	234.24	207.82	-11.28%
Winter Storm Volume	99.29	80.14	-19.28%
Spring Storm Volume	47.88	39.97	-16.51%
Summer Storm Volume	38.23	43.29	13.23%
Fall Storm Volume	48.84	44.41	-9.07%

Figure B. 32 Chickahominy River modeled flow duration versus USGS Gaging Station #02042500 data from 10/1/1996 to 9/30/2000 (subwatershed 5).

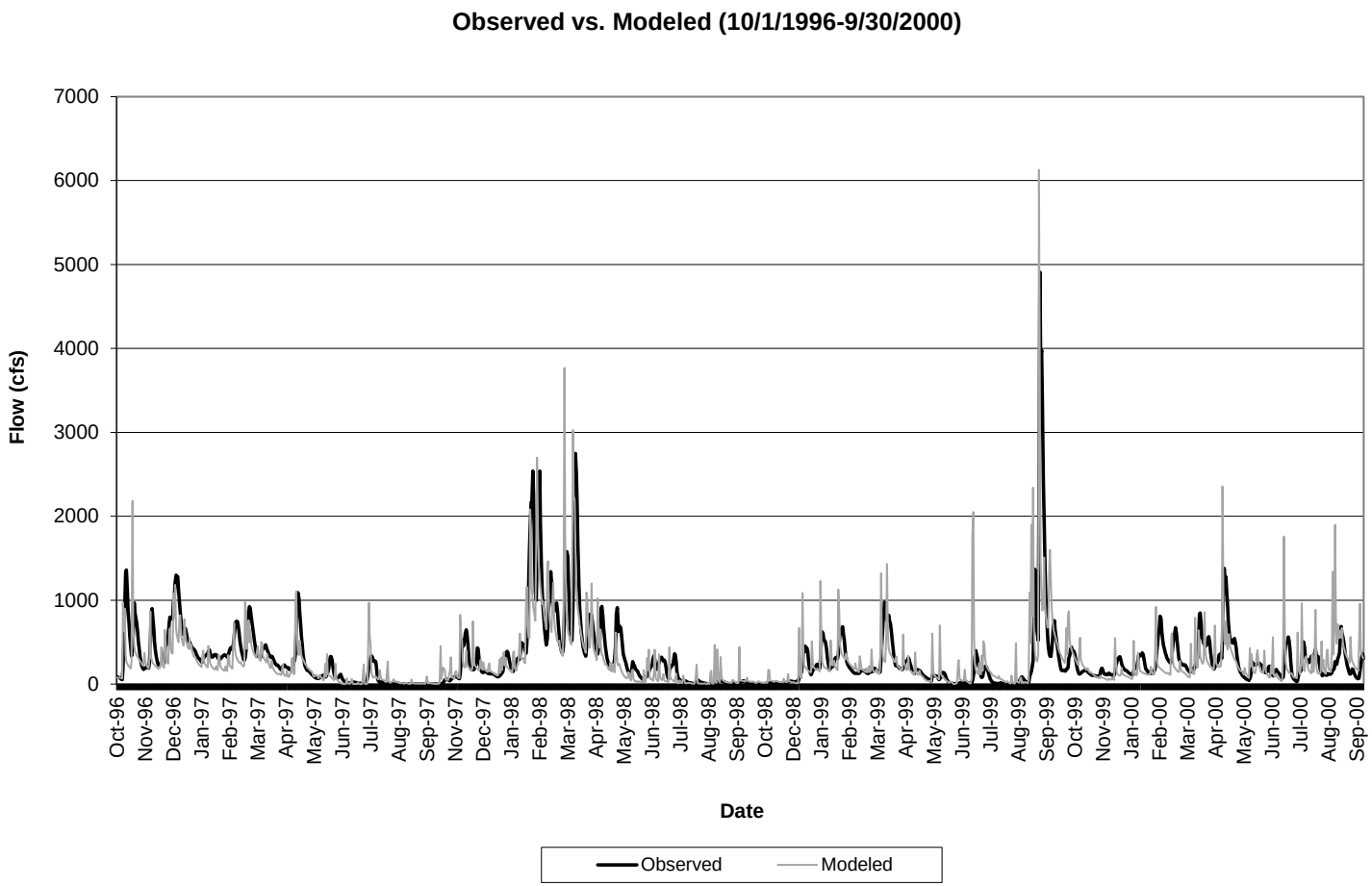

Figure B. 33 Chickahominy River modeled results versus USGS Gaging Station #02042500 data from 10/1/1996 to 9/30/2000 (subwatershed 5).

The modeled output was validated for the period of 10/2004 to 9/2008. Simulated flow at subwatershed 5 was compared with daily observed flow at the Chickahominy River USGS Gaging Station #02042500. **Table B. 14** 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. The lack of representative precipitation gaging stations that cover different parts of the watershed is the main reason the error in summer flows is elevated. Summer storms tend to be localized and intense and therefore, simulated flow rate generated using limited rainfall data may not match well with observed flow in the stream itself. **Figure B. 34** and **Figure B. 35** graphically show these comparisons.

Table B. 14 Hydrology validation model performance from 10/1/2004 through 9/30/2008 at USGS Gaging Station #02042500 on the Chickahominy River (subwatershed 5).

Criterion	Observed	Modeled	Error
Total In-stream Flow:	204.01	219.18	7.44%
Upper 10% Flow Values:	82.67	94.30	14.07%
Lower 50% Flow Values:	30.22	31.46	4.11%
Winter Flow Volume	61.03	54.00	-11.52%
Spring Flow Volume	45.93	50.80	10.60%
Summer Flow Volume	30.68	49.24	60.46%
Fall Flow Volume	66.37	65.15	-1.84%
Total Storm Volume	199.46	214.27	7.43%
Winter Storm Volume	59.89	52.77	-11.89%
Spring Storm Volume	44.78	49.57	10.68%
Summer Storm Volume	29.57	48.02	62.41%
Fall Storm Volume	65.21	63.91	-2.00%

Figure B. 34 Chickahominy River modeled flow duration versus USGS Gaging Station #02042500 data for validation (subwatershed 4).

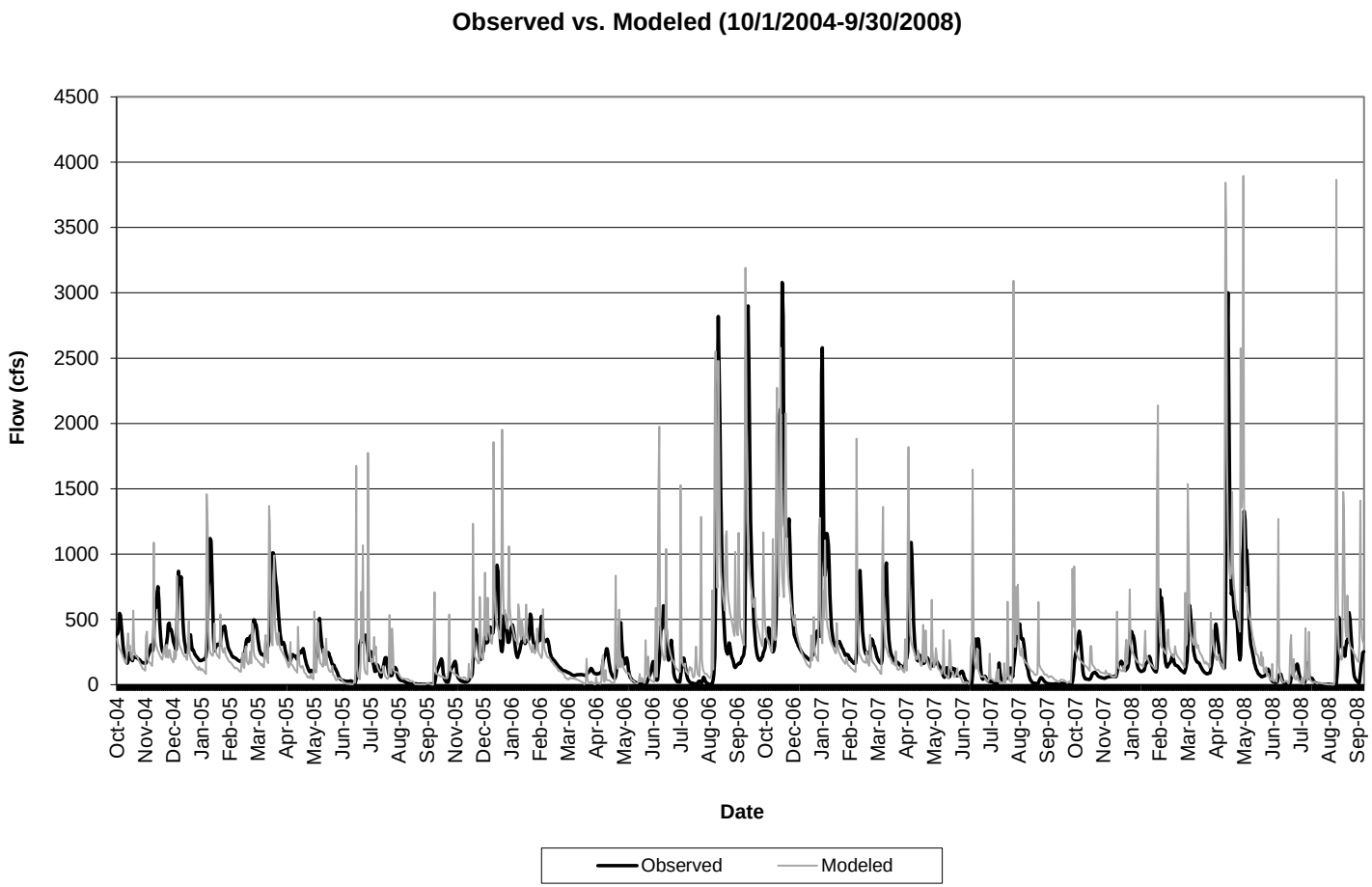

Figure B. 35 Chickahominy River validation modeled results versus USGS Gaging Station #02042500 data from (subwatershed 5).

HSPF – Bacteria Water Quality Calibration

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/100 mL as low value). Limited amount of measured data for use in calibration and the practice of censoring both high and low concentrations impede the calibration process.

Three parameters were utilized for model adjustment: in-stream first-order decay rate (FSTDEC), monthly maximum accumulation on land (MON-SQOLIM), and the rate of surface runoff that will remove 90% of stored fecal bacteria per hour (WSQOP). All of these parameters were initially set at expected levels for the watershed conditions and adjusted within reasonable limits until an acceptable match between measured and modeled bacteria concentrations was established. Observed *E. coli* monitored data were used in the calibration process. **Table B. 15** shows the model parameters utilized in calibration with their typical ranges, initial estimates, and final calibrated values. Bacteria calibration was conducted for the period of October 2003 to September 2006.

Table B. 15 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 – 6.7E+11	0.0 – 1.6E+13
WSQOP	in/hr	0.05 – 3.00	0.0 – 2.80	0.0 – 3.0
FSTDEC	1/day	0.01 – 10.00	1.0	8.0 - 10.0

Figure B. 36 through **Figure B. 40** 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 hourly bacteria concentrations as predicted by the model have a rage wider than the average daily and encompass the high and low observed data points. The modeled data follows the trend of monitored data.

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. 16** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations for the Chickahominy River.

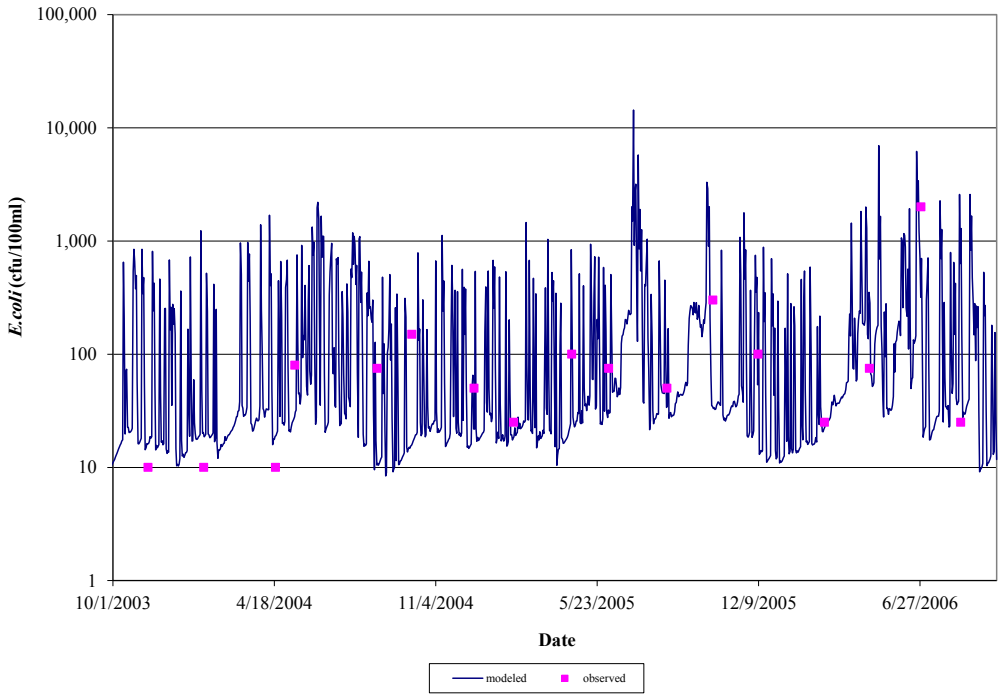

Figure B. 36 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK076.59 in subwatershed 16 on the Chickahominy River.

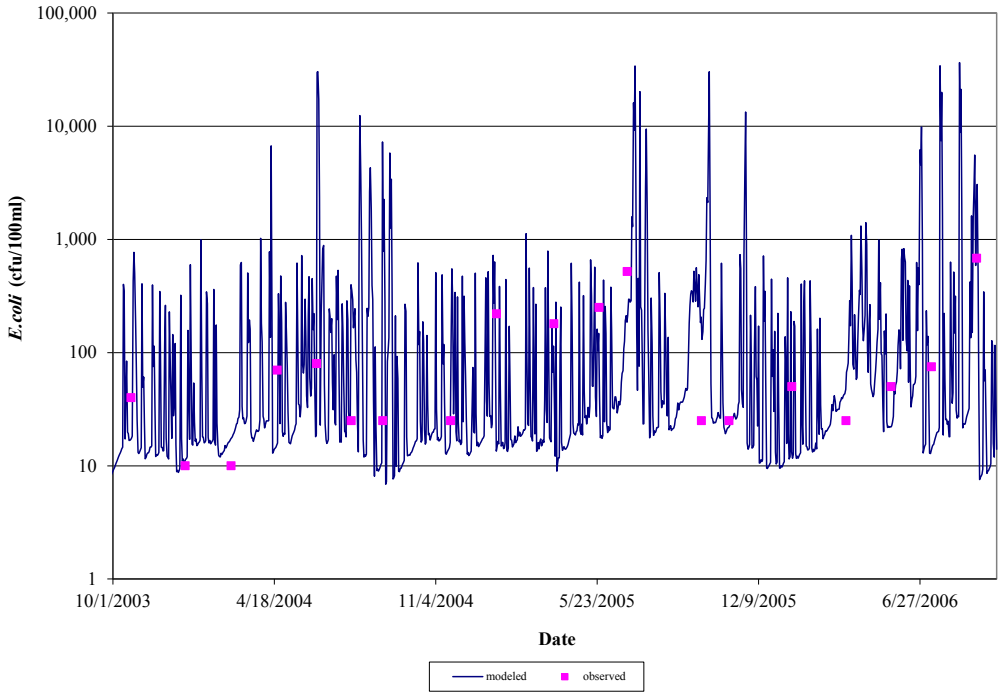

Figure B. 37 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK062.57 in subwatershed 12 on the Chickahominy River.

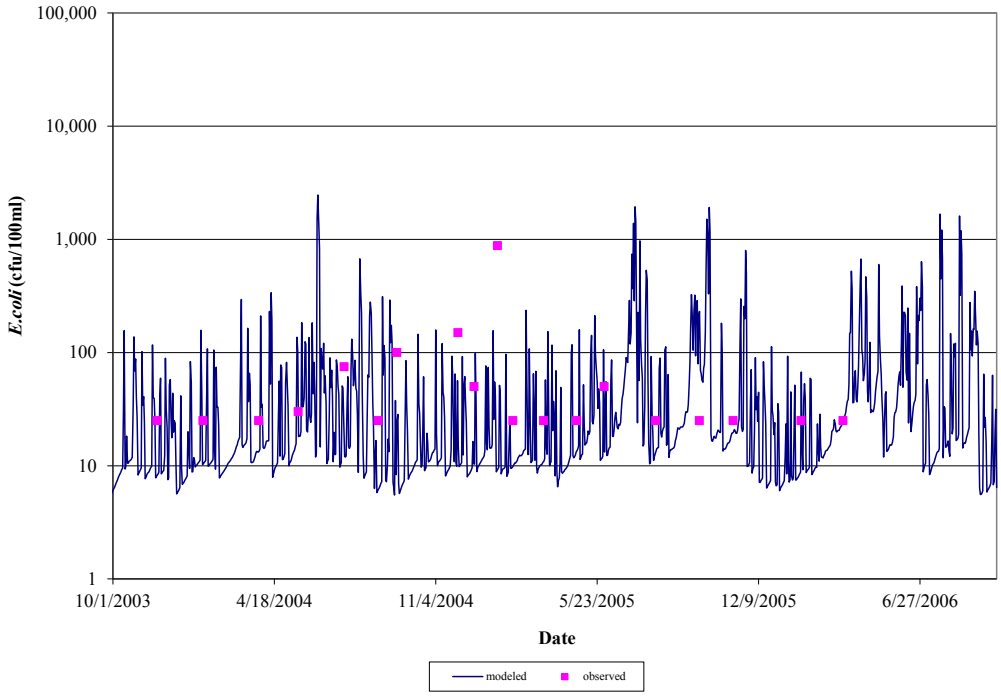

Figure B. 38 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK032.77 in subwatershed 3 on the Chickahominy River.

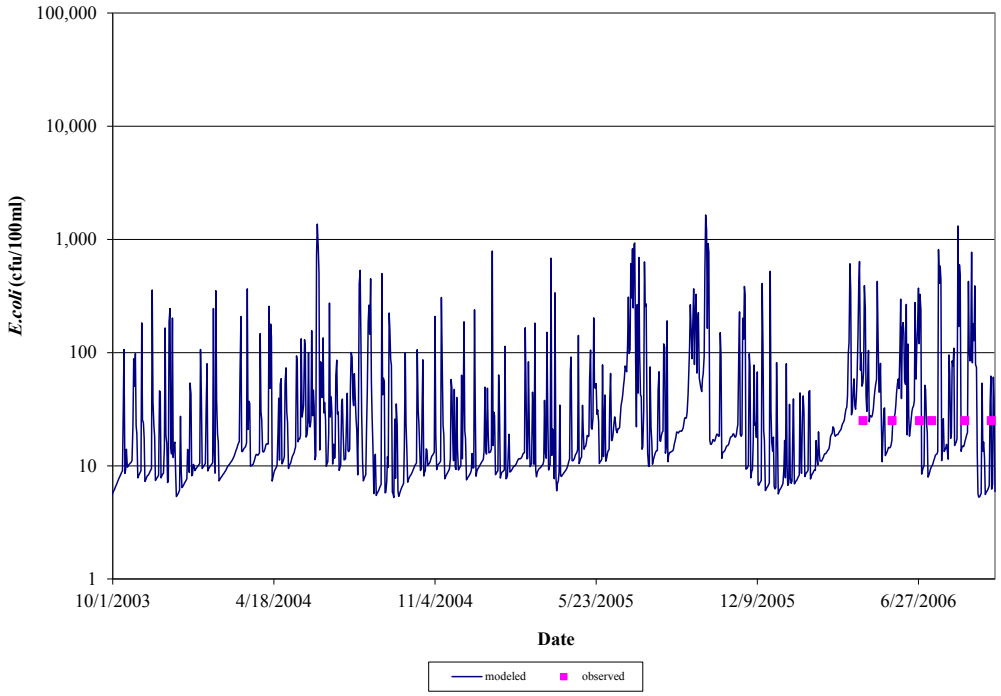

Figure B. 39 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-CHK025.15 in subwatershed 2 on the Chickahominy River.

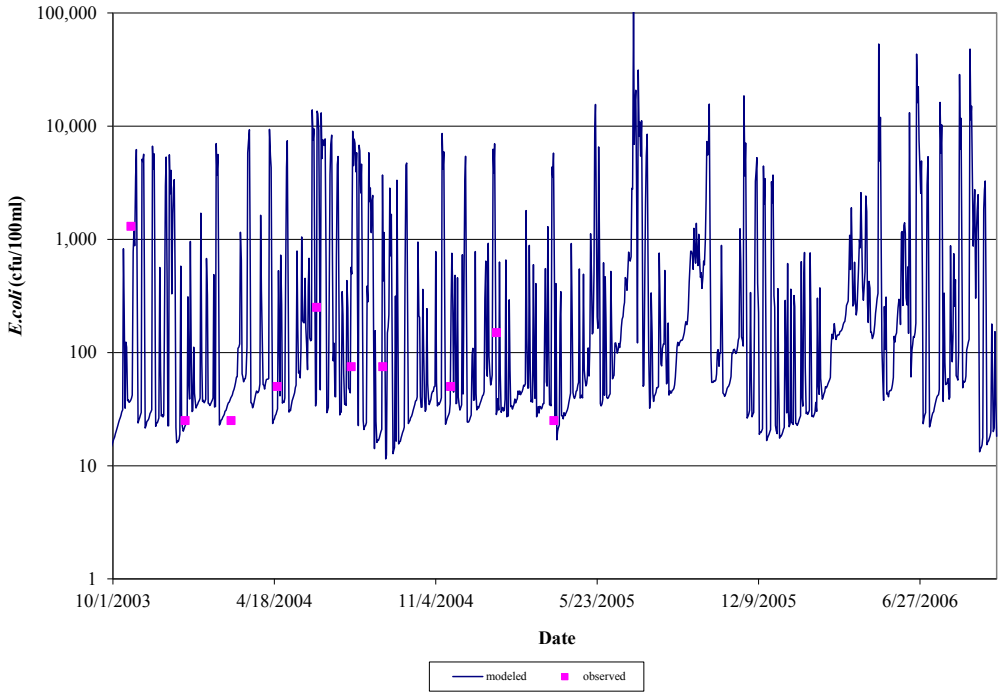

Figure B. 40 *E.coli* calibration for 10/1/2003 to 9/30/2006 for VADEQ station 2-BEV002.00 in subwatershed 25 on Beaverdam Creek.

Table B. 16 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
2-CHK076.59	16	2,000	14,348	58.76	62.43	11.76%	21.81%
2-CHK062.57	12	680	36,486	59.59	53.64	16.67%	18.80%
2-CHK032.77	3	880	2,460	41.02	26.29	5.26%	5.38%
2-CHK025.15	1	25	1,642	25.00	23.95	0.00%	6.20%
2-BEV002.00	25	1,300	110,757	79.98	142.85	20.00%	33.21%

[1] SS = single sample instantaneous standard violations (>235 cfu/100mL)

HSPF – Bacteria Water Quality Validation

Bacteria water quality model validation was performed for the period of October 2006 to September 2009. **Figure B. 41** through **Figure B. 43** show the results of water quality validation. **Table B. 17** shows the predicted and observed values for the maximum value, geometric mean, and single sample (SS) instantaneous violations.

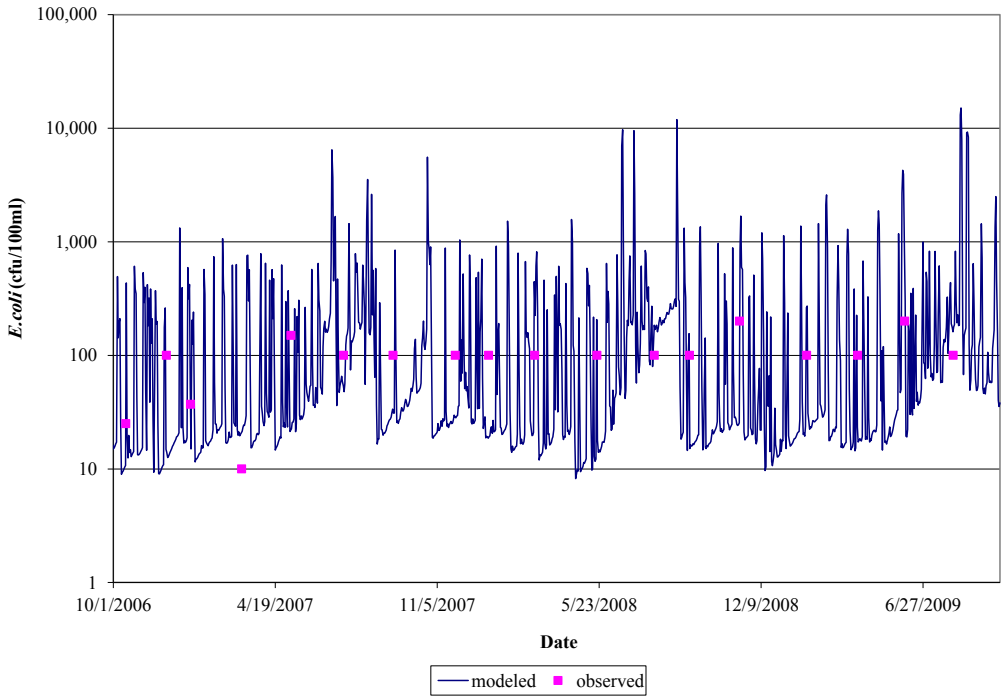

Figure B. 41 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-CHK076.59 in subwatershed 16 on the Chickahominy River.

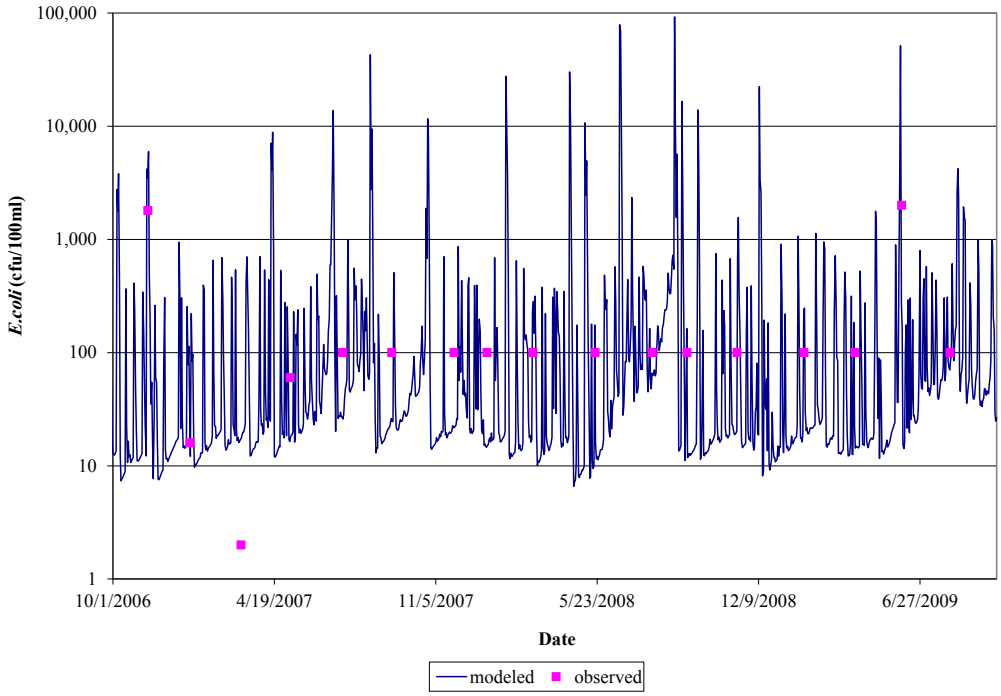

Figure B. 42 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-CHK062.57 in subwatershed 12 on the Chickahominy River.

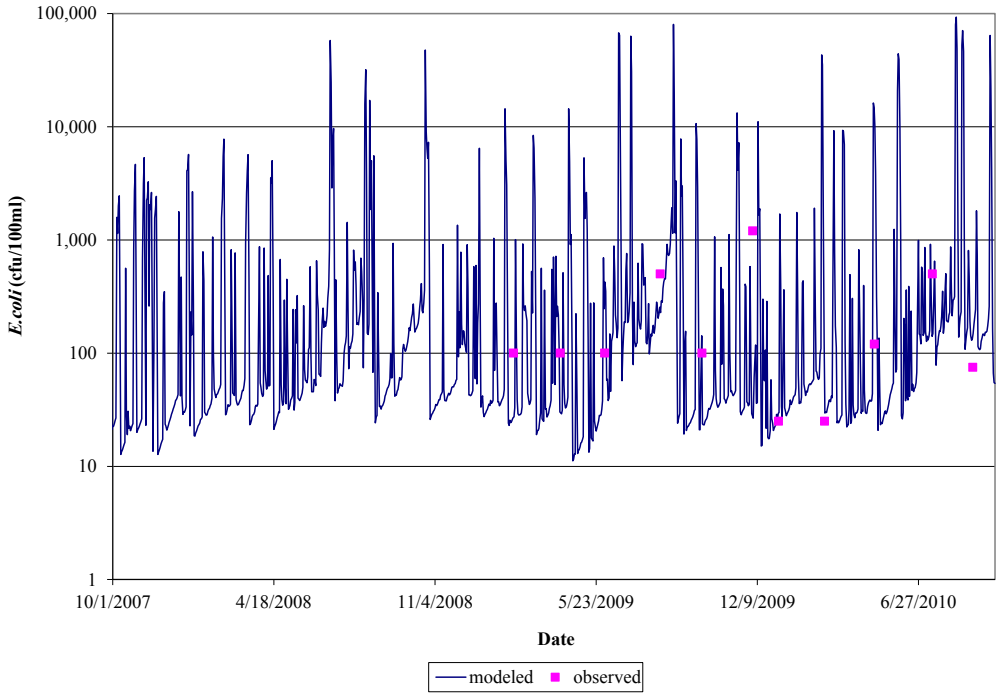

Figure B. 43 *E.coli* validation for 10/1/2006 to 9/30/2009 for VADEQ station 2-BEV002.00 in subwatershed 25 on Beaverdam Creek.

Table B. 17 Monitored and simulated maximum value, geometric mean, and single sample violation percentage for the validation period.

Station	Subwatershed	Maximum Value (cfu/100ml)		Geometric Mean (cfu/100ml)		SS % violations [1]	
		Monitored	Simulated	Monitored	Simulated	Monitored	Simulated
2-CHK076.59	16	200	15,093	85.16	63.33	0.00%	19.71%
2-CHK062.57	12	2,000	92,130	97.85	52.40	11.76%	17.97%
2-BEV002.00	25	1,200	92,996	129.29	120.82	27.27%	27.28%

[1] SS = single sample instantaneous standard violations (>235 cfu/100mL)

APPENDIX C

Current conditions fecal coliform loads

Table C. 1 Current conditions of land applied fecal coliform load for the Chickahominy River by land-use(all Subwatersheds):

Land-use	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Crop	27.8E12	25.5E12	42.4E12	41.6E12	42.4E12	25.6E12	26.4E12	26.4E12	30.3E12	42.4E12	41.6E12	27.8E12	40.0E13
LAX	16.2E11	14.7E11	21.6E11	27.5E11	28.4E11	32.7E11	33.8E11	33.8E11	27.5E11	21.6E11	20.9E11	16.2E11	29.5E12
Developed	43.3E13	39.1E13	43.2E13	41.8E13	43.1E13	41.7E13	43.0E13	43.0E13	41.6E13	43.0E13	41.6E13	43.2E13	50.8E14
Wetland	91.2E12	82.3E12	91.2E12	88.2E12	91.2E12	88.2E12	91.2E12	91.2E12	88.2E12	91.2E12	88.2E12	91.2E12	10.7E14
Commercial	14.7E12	13.3E12	14.7E12	14.2E12	14.7E12	14.2E12	14.7E12	14.7E12	14.2E12	14.7E12	14.2E12	14.7E12	17.3E13
Forest	24.1E13	21.8E13	24.1E13	23.3E13	24.1E13	23.3E13	24.1E13	24.1E13	23.3E13	24.1E13	23.3E13	24.1E13	28.4E14
Barren	47.4E11	42.8E11	47.4E11	45.9E11	47.4E11	45.9E11	47.4E11	47.4E11	45.9E11	47.4E11	45.9E11	47.4E11	55.8E12
Pasture	50.4E13	45.5E13	50.3E13	48.6E13	50.3E13	48.7E13	50.4E13	50.4E13	48.6E13	50.3E13	48.7E13	50.4E13	59.3E14

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches):

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	1	1.83E+11	1.65E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11
Livestock	1	5.22E+09	4.72E+09	6.96E+09	1.01E+10	1.04E+10	1.18E+10
Wildlife	1	3.91E+11	3.53E+11	3.91E+11	3.78E+11	3.91E+11	3.78E+11
Human/Pet	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	2	2.02E+09	1.82E+09	2.69E+09	3.90E+09	4.03E+09	4.55E+09
Wildlife	2	4.88E+10	4.41E+10	4.88E+10	4.72E+10	4.88E+10	4.72E+10
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	8.94E+07	8.07E+07	1.19E+08	1.73E+08	1.79E+08	2.02E+08
Wildlife	3	6.54E+10	5.90E+10	6.54E+10	6.33E+10	6.54E+10	6.33E+10
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	3.96E+08	3.57E+08	5.28E+08	7.66E+08	7.91E+08	8.94E+08
Wildlife	4	4.68E+10	4.23E+10	4.68E+10	4.53E+10	4.68E+10	4.53E+10
Human/Pet	5	4.57E+11	4.13E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11
Livestock	5	4.30E+09	3.89E+09	5.74E+09	8.33E+09	8.60E+09	9.71E+09
Wildlife	5	2.20E+11	1.98E+11	2.20E+11	2.12E+11	2.20E+11	2.12E+11
Human/Pet	6	4.57E+11	4.13E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11
Livestock	6	1.14E+10	1.03E+10	1.51E+10	2.20E+10	2.27E+10	2.57E+10
Wildlife	6	3.00E+11	2.71E+11	3.00E+11	2.91E+11	3.00E+11	2.91E+11

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	1	1.83E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11	1.83E+11	2.15E+12
Livestock	1	1.22E+10	1.22E+10	1.01E+10	6.96E+09	6.74E+09	5.22E+09	1.03E+11
Wildlife	1	3.91E+11	3.91E+11	3.78E+11	3.91E+11	3.78E+11	3.91E+11	4.60E+12
Human/Pet	2	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	2	4.71E+09	4.71E+09	3.90E+09	2.69E+09	2.60E+09	2.02E+09	3.96E+10
Wildlife	2	4.88E+10	4.88E+10	4.72E+10	4.88E+10	4.72E+10	4.88E+10	5.75E+11
Human/Pet	3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	3	2.08E+08	2.08E+08	1.73E+08	1.19E+08	1.15E+08	8.94E+07	1.76E+09
Wildlife	3	6.54E+10	6.54E+10	6.33E+10	6.54E+10	6.33E+10	6.54E+10	7.70E+11
Human/Pet	4	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	4	9.23E+08	9.23E+08	7.66E+08	5.28E+08	5.11E+08	3.96E+08	7.78E+09
Wildlife	4	4.68E+10	4.68E+10	4.53E+10	4.68E+10	4.53E+10	4.68E+10	5.52E+11
Human/Pet	5	4.57E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11	4.57E+11	5.38E+12
Livestock	5	1.00E+10	1.00E+10	8.33E+09	5.74E+09	5.55E+09	4.30E+09	8.46E+10
Wildlife	5	2.20E+11	2.20E+11	2.12E+11	2.20E+11	2.12E+11	2.20E+11	2.58E+12
Human/Pet	6	4.57E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11	4.57E+11	5.38E+12
Livestock	6	2.65E+10	2.65E+10	2.20E+10	1.51E+10	1.47E+10	1.14E+10	2.23E+11
Wildlife	6	3.00E+11	3.00E+11	2.91E+11	3.00E+11	2.91E+11	3.00E+11	3.54E+12

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	7	1.83E+11	1.65E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11
Livestock	7	7.44E+09	6.72E+09	9.92E+09	1.44E+10	1.49E+10	1.68E+10
Wildlife	7	1.80E+11	1.63E+11	1.80E+11	1.74E+11	1.80E+11	1.74E+11
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	1.22E+10	1.10E+10	1.63E+10	2.36E+10	2.44E+10	2.75E+10
Wildlife	8	1.69E+11	1.53E+11	1.69E+11	1.64E+11	1.69E+11	1.64E+11
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	1.75E+09	1.58E+09	2.33E+09	3.38E+09	3.50E+09	3.95E+09
Wildlife	9	3.85E+10	3.48E+10	3.85E+10	3.73E+10	3.85E+10	3.73E+10
Human/Pet	10	2.74E+11	2.48E+11	2.74E+11	2.65E+11	2.74E+11	2.65E+11
Livestock	10	2.01E+10	1.81E+10	2.67E+10	3.88E+10	4.01E+10	4.53E+10
Wildlife	10	1.24E+11	1.12E+11	1.24E+11	1.20E+11	1.24E+11	1.20E+11
Human/Pet	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	11	9.19E+08	8.30E+08	1.23E+09	1.78E+09	1.84E+09	2.08E+09
Wildlife	11	2.11E+10	1.90E+10	2.11E+10	2.04E+10	2.11E+10	2.04E+10
Human/Pet	12	1.83E+11	1.65E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11
Livestock	12	5.03E+09	4.54E+09	6.71E+09	9.73E+09	1.01E+10	1.14E+10
Wildlife	12	6.89E+10	6.23E+10	6.89E+10	6.67E+10	6.89E+10	6.67E+10
Human/Pet	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	13	1.66E+09	1.50E+09	2.21E+09	3.21E+09	3.32E+09	3.75E+09
Wildlife	13	3.99E+10	3.60E+10	3.99E+10	3.86E+10	3.99E+10	3.86E+10

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	7	1.83E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11	1.83E+11	2.15E+12
Livestock	7	1.74E+10	1.74E+10	1.44E+10	9.92E+09	9.60E+09	7.44E+09	1.46E+11
Wildlife	7	1.80E+11	1.80E+11	1.74E+11	1.80E+11	1.74E+11	1.80E+11	2.12E+12
Human/Pet	8	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	8	2.84E+10	2.84E+10	2.36E+10	1.63E+10	1.57E+10	1.22E+10	2.40E+11
Wildlife	8	1.69E+11	1.69E+11	1.64E+11	1.69E+11	1.64E+11	1.69E+11	1.99E+12
Human/Pet	9	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	9	4.08E+09	4.08E+09	3.38E+09	2.33E+09	2.26E+09	1.75E+09	3.44E+10
Wildlife	9	3.85E+10	3.85E+10	3.73E+10	3.85E+10	3.73E+10	3.85E+10	4.53E+11
Human/Pet	10	2.74E+11	2.74E+11	2.65E+11	2.74E+11	2.65E+11	2.74E+11	3.23E+12
Livestock	10	4.68E+10	4.68E+10	3.88E+10	2.67E+10	2.59E+10	2.01E+10	3.94E+11
Wildlife	10	1.24E+11	1.24E+11	1.20E+11	1.24E+11	1.20E+11	1.24E+11	1.46E+12
Human/Pet	11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	11	2.14E+09	2.14E+09	1.78E+09	1.23E+09	1.19E+09	9.19E+08	1.81E+10
Wildlife	11	2.11E+10	2.11E+10	2.04E+10	2.11E+10	2.04E+10	2.11E+10	2.48E+11
Human/Pet	12	1.83E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11	1.83E+11	2.15E+12
Livestock	12	1.17E+10	1.17E+10	9.73E+09	6.71E+09	6.49E+09	5.03E+09	9.89E+10
Wildlife	12	6.89E+10	6.89E+10	6.67E+10	6.89E+10	6.67E+10	6.89E+10	8.12E+11
Human/Pet	13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	13	3.87E+09	3.87E+09	3.21E+09	2.21E+09	2.14E+09	1.66E+09	3.26E+10
Wildlife	13	3.99E+10	3.99E+10	3.86E+10	3.99E+10	3.86E+10	3.99E+10	4.69E+11

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	14	1.83E+11	1.65E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11
Livestock	14	8.57E+09	7.74E+09	1.14E+10	1.66E+10	1.71E+10	1.93E+10
Wildlife	14	5.84E+10	5.27E+10	5.84E+10	5.65E+10	5.84E+10	5.65E+10
Human/Pet	15	4.57E+11	4.13E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11
Livestock	15	6.60E+09	5.96E+09	8.80E+09	1.28E+10	1.32E+10	1.49E+10
Wildlife	15	7.48E+10	6.76E+10	7.48E+10	7.24E+10	7.48E+10	7.24E+10
Human/Pet	16	7.31E+11	6.60E+11	7.31E+11	7.08E+11	7.31E+11	7.08E+11
Livestock	16	2.15E+10	1.94E+10	2.87E+10	4.16E+10	4.30E+10	4.85E+10
Wildlife	16	1.99E+11	1.80E+11	1.99E+11	1.93E+11	1.99E+11	1.93E+11
Human/Pet	17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	17	6.70E+09	6.05E+09	6.70E+09	6.49E+09	6.70E+09	6.49E+09
Human/Pet	18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	18	3.06E+08	2.77E+08	4.08E+08	5.93E+08	6.13E+08	6.92E+08
Wildlife	18	4.76E+09	4.30E+09	4.76E+09	4.60E+09	4.76E+09	4.60E+09
Human/Pet	19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	19	7.02E+08	6.34E+08	9.36E+08	1.36E+09	1.40E+09	1.59E+09
Wildlife	19	3.99E+10	3.61E+10	3.99E+10	3.86E+10	3.99E+10	3.86E+10

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total Load (cfu/yr)
Human/Pet	14	1.83E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11	1.83E+11	2.15E+12
Livestock	14	2.00E+10	2.00E+10	1.66E+10	1.14E+10	1.11E+10	8.57E+09	1.68E+11
Wildlife	14	5.84E+10	5.84E+10	5.65E+10	5.84E+10	5.65E+10	5.84E+10	6.88E+11
Human/Pet	15	4.57E+11	4.57E+11	4.42E+11	4.57E+11	4.42E+11	4.57E+11	5.38E+12
Livestock	15	1.54E+10	1.54E+10	1.28E+10	8.80E+09	8.52E+09	6.60E+09	1.30E+11
Wildlife	15	7.48E+10	7.48E+10	7.24E+10	7.48E+10	7.24E+10	7.48E+10	8.81E+11
Human/Pet	16	7.31E+11	7.31E+11	7.08E+11	7.31E+11	7.08E+11	7.31E+11	8.61E+12
Livestock	16	5.02E+10	5.02E+10	4.16E+10	2.87E+10	2.77E+10	2.15E+10	4.23E+11
Wildlife	16	1.99E+11	1.99E+11	1.93E+11	1.99E+11	1.93E+11	1.99E+11	2.34E+12
Human/Pet	17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	17	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Wildlife	17	6.70E+09	6.70E+09	6.49E+09	6.70E+09	6.49E+09	6.70E+09	7.89E+10
Human/Pet	18	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	18	7.15E+08	7.15E+08	5.93E+08	4.08E+08	3.95E+08	3.06E+08	6.02E+09
Wildlife	18	4.76E+09	4.76E+09	4.60E+09	4.76E+09	4.60E+09	4.76E+09	5.60E+10
Human/Pet	19	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	19	1.64E+09	1.64E+09	1.36E+09	9.36E+08	9.06E+08	7.02E+08	1.38E+10
Wildlife	19	3.99E+10	3.99E+10	3.86E+10	3.99E+10	3.86E+10	3.99E+10	4.70E+11

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jan	Feb	Mar	Apr	May	Jun
Human/Pet	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	20	3.06E+08	2.77E+08	4.08E+08	5.93E+08	6.13E+08	6.92E+08
Wildlife	20	1.30E+10	1.18E+10	1.30E+10	1.26E+10	1.30E+10	1.26E+10
Human/Pet	21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	21	6.36E+09	5.74E+09	8.48E+09	1.23E+10	1.27E+10	1.44E+10
Wildlife	21	2.00E+11	1.81E+11	2.00E+11	1.94E+11	2.00E+11	1.94E+11
Human/Pet	22	1.37E+12	1.24E+12	1.37E+12	1.33E+12	1.37E+12	1.33E+12
Livestock	22	1.41E+10	1.28E+10	1.88E+10	2.73E+10	2.82E+10	3.19E+10
Wildlife	22	2.79E+11	2.52E+11	2.79E+11	2.70E+11	2.79E+11	2.70E+11
Human/Pet	23	1.83E+11	1.65E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11
Livestock	23	2.88E+09	2.61E+09	3.85E+09	5.58E+09	5.77E+09	6.51E+09
Wildlife	23	3.46E+10	3.12E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10
Human/Pet	24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	24	1.14E+09	1.03E+09	1.51E+09	2.20E+09	2.27E+09	2.57E+09
Wildlife	24	2.89E+10	2.61E+10	2.89E+10	2.80E+10	2.89E+10	2.80E+10
Human/Pet	25	7.31E+11	6.60E+11	7.31E+11	7.08E+11	7.31E+11	7.08E+11
Livestock	25	5.37E+09	4.85E+09	7.17E+09	1.04E+10	1.07E+10	1.21E+10
Wildlife	25	1.00E+11	9.05E+10	1.00E+11	9.70E+10	1.00E+11	9.70E+10
Human/Pet	26	1.19E+12	1.07E+12	1.19E+12	1.15E+12	1.19E+12	1.15E+12
Livestock	26	8.80E+09	7.94E+09	1.17E+10	1.70E+10	1.76E+10	1.99E+10
Wildlife	26	2.93E+11	2.64E+11	2.93E+11	2.83E+11	2.93E+11	2.83E+11
Human/Pet	27	1.10E+12	9.91E+11	1.10E+12	1.06E+12	1.10E+12	1.06E+12
Livestock	27	6.82E+09	6.16E+09	9.09E+09	1.32E+10	1.36E+10	1.54E+10
Wildlife	27	1.33E+11	1.20E+11	1.33E+11	1.28E+11	1.33E+11	1.28E+11

Table C. 2 Monthly, directly deposited fecal coliform loads in each reach of the Chickahominy River (all reaches) (Continued):

Source Type	Reach ID	Jul	Aug	Sept	Oct	Nov	Dec	Annual Total Load(cfu/yr)
Human/Pet	20	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	20	7.15E+08	7.15E+08	5.93E+08	4.08E+08	3.95E+08	3.06E+08	6.02E+09
Wildlife	20	1.30E+10	1.30E+10	1.26E+10	1.30E+10	1.26E+10	1.30E+10	1.53E+11
Human/Pet	21	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	21	1.48E+10	1.48E+10	1.23E+10	8.48E+09	8.20E+09	6.36E+09	1.25E+11
Wildlife	21	2.00E+11	2.00E+11	1.94E+11	2.00E+11	1.94E+11	2.00E+11	2.36E+12
Human/Pet	22	1.37E+12	1.37E+12	1.33E+12	1.37E+12	1.33E+12	1.37E+12	1.61E+13
Livestock	22	3.29E+10	3.29E+10	2.73E+10	1.88E+10	1.82E+10	1.41E+10	2.78E+11
Wildlife	22	2.79E+11	2.79E+11	2.70E+11	2.79E+11	2.70E+11	2.79E+11	3.29E+12
Human/Pet	23	1.83E+11	1.83E+11	1.77E+11	1.83E+11	1.77E+11	1.83E+11	2.15E+12
Livestock	23	6.73E+09	6.73E+09	5.58E+09	3.85E+09	3.72E+09	2.88E+09	5.67E+10
Wildlife	23	3.46E+10	3.46E+10	3.35E+10	3.46E+10	3.35E+10	3.46E+10	4.07E+11
Human/Pet	24	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Livestock	24	2.65E+09	2.65E+09	2.20E+09	1.51E+09	1.47E+09	1.14E+09	2.23E+10
Wildlife	24	2.89E+10	2.89E+10	2.80E+10	2.89E+10	2.80E+10	2.89E+10	3.40E+11
Human/Pet	25	7.31E+11	7.31E+11	7.08E+11	7.31E+11	7.08E+11	7.31E+11	8.61E+12
Livestock	25	1.25E+10	1.25E+10	1.04E+10	7.17E+09	6.93E+09	5.37E+09	1.06E+11
Wildlife	25	1.00E+11	1.00E+11	9.70E+10	1.00E+11	9.70E+10	1.00E+11	1.18E+12
Human/Pet	26	1.19E+12	1.19E+12	1.15E+12	1.19E+12	1.15E+12	1.19E+12	1.40E+13
Livestock	26	2.05E+10	2.05E+10	1.70E+10	1.17E+10	1.13E+10	8.80E+09	1.73E+11
Wildlife	26	2.93E+11	2.93E+11	2.83E+11	2.93E+11	2.83E+11	2.93E+11	3.45E+12
Human/Pet	27	1.10E+12	1.10E+12	1.06E+12	1.10E+12	1.06E+12	1.10E+12	1.29E+13
Livestock	27	1.59E+10	1.59E+10	1.32E+10	9.09E+09	8.80E+09	6.82E+09	1.34E+11
Wildlife	27	1.33E+11	1.33E+11	1.28E+11	1.33E+11	1.28E+11	1.33E+11	1.56E+12

Table C. 3 Existing annual (2012) loads from land-based sources for the Chickahominy River (all Subwatersheds):

Source	Water	Forest	Pasture	Commercial	LAX	Developed	Crop	Wetland	Barren
Beaver	5.53E+05	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	2.24E+12	0.00E+00	4.24E+14	0.00E+00	1.80E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Beef calves	8.29E+11	0.00E+00	1.57E+14	0.00E+00	6.75E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Dairy Replacement	0.00E+00	0.00E+00	4.95E+12	0.00E+00	0.00E+00	0.00E+00	8.94E+13	0.00E+00	0.00E+00
Deer	0.00E+00	3.95E+14	9.15E+13	7.36E+12	1.80E+11	4.73E+13	4.83E+13	7.91E+13	2.73E+12
dogs	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	4.35E+15	0.00E+00	0.00E+00	0.00E+00
Duck	0.00E+00	5.68E+10	3.28E+09	1.50E+09	6.19E+08	6.46E+09	3.15E+09	5.73E+10	1.11E+09
Goose	0.00E+00	1.00E+13	4.78E+11	2.28E+11	8.44E+10	1.23E+12	5.54E+11	1.13E+13	1.77E+11
Hog	0.00E+00	0.00E+00	3.32E+15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Horse	0.00E+00	0.00E+00	1.48E+15	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Muskrat	0.00E+00	1.79E+14	1.02E+13	4.81E+12	1.95E+12	2.08E+13	9.93E+12	1.88E+14	3.49E+12
people_on_failing_septics	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	8.37E+13	0.00E+00	0.00E+00	0.00E+00
people_on_straight_pipes	9.04E+13	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Raccoon	0.00E+00	2.25E+15	4.38E+14	1.61E+14	2.55E+12	5.74E+14	2.52E+14	7.95E+14	4.94E+13
Sheep	0.00E+00	0.00E+00	1.37E+12	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Turkey	0.00E+00	1.56E+11	1.22E+10	2.48E+08	4.12E+07	5.42E+09	7.12E+09	3.12E+10	6.85E+08

Table C. 4 Existing annual loads from direct-deposition sources for the Chickahominy River (all Reaches):

Source	Annual Total Loads (cfu/yr)
Beaver	55.3E04
Beef	22.4E11
Beef calves	82.9E10
Dairy Replacement	00E00
Deer	16.9E11
Duck	60.4E08
Goose	72.4E10
Hog	00E00
Horse	00E00
Muskrat	23.5E12
People on straight pipes	90.4E12
Raccoon	11.5E12
Sheep	00E00
Turkey	53.8E07