Bacteria TMDL Development for Lower Chickahominy River Watershed Located in Charles City, James City, and New Kent Counties, VA

Prepared for:
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Submitted by:
Virginia Institute of Marine Science

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LIST OF ABBREVIATIONS

BMP	Best Management Practice
CFR	Code of Federal Regulations
CWA	Clean Water Act
EFDC	Environmental Fluid Dynamics Computer Code
EPA	Environmental Protection Agency
FA	Future Allocation
GIS	Geographic Information System
IP	Implementation Plan
LA	Load Allocation
LSPC	Loading Simulation Program C++
MGD	Million Gallons Per Day
MOS	Margin of Safety
MOU	Memorandum of Understanding
MS4s	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Data
NPDES	National Pollutant Discharge Elimination System
SSO	Sanitary Sewer Overflow
SWCB	State Water Control Board
TAC	Technical Advisory Committee
TMAL	Total Maximum Annual Load
TMDL	Total Maximum Daily Load
USCB	United States Census Bureau
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VA-DCR	Virginia Department of Conservation and Recreation
VA-DEQ	Virginia Department of Environmental Quality
VA-	Virginia Department of Game and Inland Fisheries
VDH	Virginia Department of Health
VPA	Virginia Pollution Abatement
VPDES	Virginia Pollutant Discharge Elimination System
WLA	Wasteload Allocation
WQAIR	Water Quality Assessment Integrated Report
WQC	Water Quality Criteria
WQMIR	Water Quality Monitoring, Information, and Restoration
WQMP	Water Quality Management Plans
WQS	Water Quality Standard

EXECUTIVE SUMMARY

Introduction

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQSs). TMDLs represent the total pollutant loading that a waterbody can receive without violating WQSs. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish controls based on water quality conditions to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

There are eight bacteria impairments in this study area. The Chickahominy River, Gordon Creek, and Diascund Creek (tidal) are listed on Virginia's 303(d) list because more than 10% of the total samples in the assessment period exceeded the Primary Contact Use (recreational/swimming) enterococci instantaneous standard of 104 colony forming units per 100 mL (cfu/100 mL). The Beaverdam Creek, Unnamed Tributary to Beaverdam Creek, Diascund Creek (non-tidal), Mill Creek, and Barrows Creek are listed on Virginia's 303(d) list because more than 10% of the total samples in the assessment period exceeded the Primary Contact Use (recreational/swimming) *E. coli* instantaneous standard of 235 colony forming units per 100 mL (cfu/100 mL). Table ES.1 shows the details of impairments and Figure ES.1 shows the locations of these impairments.

Table ES.1: Bacteria Impairments within the Lower Chickahominy River Watershed.

Stream Name (Assessment Unit ID)	TMDL ID	Impairment Type	Initial Listing Year	Estuary Area (Mile^2) or River Mile	2012 Listing Violation%	Impairment Location Description
Diascund Creek (VAP-G09R_DSC01A00)	G09R-02-BAC	*E. coli*	2008	6.88	20	Headwaters to the upstream limit of Diascund Creek Reservoir
Beaverdam Creek (VAP-G09R_BDM01A98)	G09R-01-BAC	*E. coli*	2012	4.34	33 at 2-BDM003.16 20 at 2-BDM004.12 33 at 2-BDM004.60 56 at 2-BDM005.70	Headwaters to the upstream limit of Diascund Creek Reservoir
XAH-Beaverdam Creek, UT (VAP-G09R_XAH01A12)	G09R-06-BAC	*E. coli*	2012	2.23	33	Headwaters to mouth at Beaverdam Creek

Stream Name (Assessment Unit ID)	TMDL ID	Impairment Type	Initial Listing Year	Estuary Area ($Mile^2$) or River Mile	2012 Listing Violation%	Impairment Location Description
Barrows Creek (VAP-G08R_BRW01A14)	G08R-05-BAC	*E. coli*	2014	6.93	50	Headwaters to tidal limit
Mill Creek (VAP-G08R_MCR01A04)	G08R-02-BAC	*E. coli*	2012	4.81	23	Headwaters to tidal limit
Diascund Creek (VAP-G08E_DSC01A00)	G08E-03-BAC	Enterococci	2010	0.27	17	From the Diascund Reservoir Dam downstream to the mouth at the Chickahominy River
Chickahominy River (VAP-G08E_CHK02A00)	G08E-04-BAC	Enterococci	2006	5.92	13 at 2-CHK006.14 and 28 at 2-CHK014.33	From the confluence with Diascund Creek downstream to the James River
Gordon Creek (VAP-G08E_GOR01A06)	G08E-05-BAC	Enterococci	2012	0.20	12	Tidal limit to the mouth at the Chickahominy River

TMDL Endpoint

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.

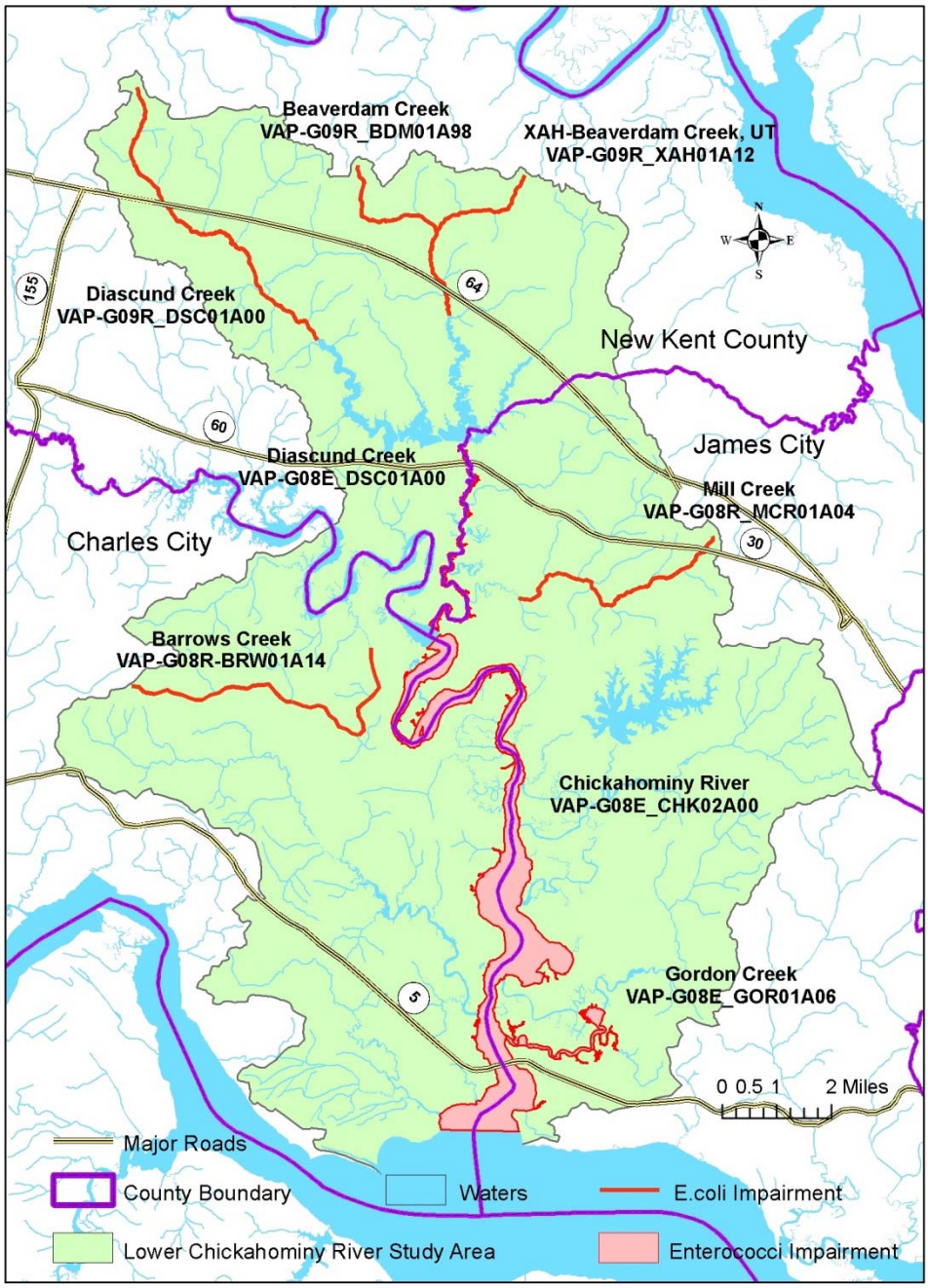

Figure ES.1: The Impaired Waters in the Lower Chickahominy River Watershed

Sources of Bacteria

The watershed approach was applied to conduct the source assessment. The Lower Chickahominy River watershed drainage area was divided into twenty six (26) subwatersheds and the source assessment is conducted on the subwatershed level. There are nine (9) point sources in the watershed that will be assigned bacteria wasteload allocations (WLAs). The dominant sources of bacteria in the watersheds are nonpoint sources, including residential sewage disposal systems, sanitary sewer overflows (SSOs), biosolids, pets, wildlife, livestock, recreational boating, and straight pipes. Where appropriate, the spatial distribution of sources was also determined.

Modeling Approach

A system of numerical models was applied to simulate the loadings of *E. coli* and enterococci from the Lower Chickahominy River watershed, and the resulting response of in-stream water quality variables. The watershed model, Loading Simulation Program in C++ (LSPC), developed by the USEPA, was selected to simulate the watershed hydrology and bacteria load. The Environmental Fluid Dynamics Computer Code (EFDC) was used to simulate the transport and fate of bacteria in the receiving waters.

Load Allocation Scenarios

The most stringent WQSs were determined to be the single sample maximum (no more than 10% of samples shall exceed 235 *E. coli* CFU/100ml) in freshwater and a geomean of 35 enterococci CFU/100 ml) in salt water and transitional zones. Calibrated model simulation results were used to establish the existing loads in the system. The daily maximum loading was computed using long-term mean daily loading with statistical adjustment based on a USEPA recommendation. The loads that are necessary to meet WQSs were established for the TMDLs. The difference between the TMDL and the existing loading represents the necessary level of reduction. The bacterial TMDL and total maximum annual load (TMAL) for the watersheds are summarized in Tables ES.2 and ES.3.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. This was done in this study by use of long-term water quality and model data that cover different flow regimes and temperatures, and a long-term simulation to estimate the current bacteria loads and load reduction targets. A Margin of Safety (MOS) is required as part of a TMDL in recognition of uncertainties in the understanding and simulation of water quality in natural systems. A MOS can be implicit or explicit. In this TMDL an implicit MOS is used as a result of the conservative assumptions used in the load calculations (Tables ES.2 and ES.3).

Table ES.2: *E. Coli* and Enterococci TMDLs in Lower Chickahominy River (cfu/Day)

Impaired Water (Pollutant)	WLA		LA	MOS	TMDL
	Permit #	WLA			
Diascund Creek (Non-tidal) (*E. coli*)	NA	0	6.63E+10	Implicit	6.70E+10
	FA (1%)	6.70E+08			
	Total WLA	6.70E+08			
Beaverdam Creek (*E. coli*)	NA	0	3.30E+10	Implicit	3.33E+10
	FA (1%)	3.33E+08			
	Total WLA	3.33E+08			
XAH-Beaverdam Creek, UT (*E. coli*)	NA	0	1.16E+10	Implicit	1.17E+10
	FA (1%)	1.17E+08			
	Total WLA	1.17E+08			
Barrow's Creek (*E. coli*)	NA	0	1.79E+10	Implicit	1.81E+10
	FA (1%)	1.81E+08			
	Total WLA	1.81E+08			
Mill Creek (E. *coli*)	VAR040037 and VAR040115	4.43E+09	3.05E+10	Implicit	3.53E+10
	FA (1%)	3.53E+08			
	Total WLA	4.78E+09			
Diascund Creek (Tidal) (Enterococci)	VAG404284	2.11E+06	7.19E+11	Implicit	7.55E+11
	VAR040037 and VAR040115	2.86E+10			
	FA (1%)	7.55E+09			
	Total WLA	3.62E+10			
Chickahominy River (Enterococci)	VA0080233	5.17E+07	1.32E+13	Implicit	1.36E+13
	VAG403039	1.32E+06			
	VAG404050	2.11E+06			
	VAG404144	1.32E+06			
	VAG404152	1.32E+06			
	VAG404198	2.11E+06			
	VAG404284	2.11E+06			
	VAR040037 and VAR040115	3.07E+11			
	FA (1%)	1.36E+11			
	Total WLA	4.43E+11			
Gordon Creek (Enterococci)	VAR040037 and VAR040115	1.25E+10	1.17E+12	Implicit	1.19E+12
	FA (1%)	1.19E+10			
	Total WLA	2.44E+10			

Table ES.3: *E. Coli* and Enterococci TMALs in Lower Chickahominy River (cfu/Year)

Impaired Water (Pollutant)	WLA		LA	MOS	TMAL
	Permit #	WLA			
Diascund Creek (Non-tidal) (*E. coli*)	NA	0	1.24E+13	Implicit	1.25E+13
	FA (1%)	1.25E+11			
	Total WLA	1.25E+11			
Beaverdam Creek (*E. coli*)	NA	0	6.28E+12	Implicit	6.34E+12
	FA (1%)	6.34E+10			
	Total WLA	6.34E+10			
XAH-Beaverdam Creek, UT (*E. coli*)	NA	0	2.24E+12	Implicit	2.26E+12
	FA (1%)	2.26E+10			
	Total WLA	2.26E+10			
Barrow's Creek (*E. coli*)	NA	0	3.42E+12	Implicit	3.45E+12
	FA (1%)	3.45E+10			
	Total WLA	3.45E+10			
Mill Creek (*E. coli*)	VAR040037 and VAR040115	8.54E+11	5.88E+12	Implicit	6.80E+12
	FA (1%)	6.80E+10			
	Total WLA	9.22E+11			
Diascund Creek (Tidal) (Enterococci)	VAG404284	7.71E+08	1.17E+14	Implicit	1.23E+14
	VAR040037 and VAR040115	4.66E+12			
	FA (1%)	1.23E+12			
	Total WLA	5.89E+12			
Chickahominy River (Enterococci)	VA0080233	1.9E+10	2.19E+15	Implicit	2.26E+15
	VAG403039	4.8E+08			
	VAG404050	7.7E+08			
	VAG404144	4.8E+08			
	VAG404152	4.8E+08			
	VAG404198	7.7E+08			
	VAG404284	7.7E+08			
	VAR040037 and VAR040115	5.05E+13			
	FA (1%)	2.26E+13			
	Total WLA	7.31E+13			
Gordon Creek (Enterococci)	VAR040037 and VAR040115	2.12E+12	1.98E+14	Implicit	2.02E+14
	FA (1%)	2.02E+12			
	Total WLA	4.14E+12			

Where in Tables ES.2 and ES.3:
TMDL = Total Maximum Daily Load
TMAL = Total Maximum Annual Load
LA = Load Allocation (nonpoint source)
WLA = Wasteload Allocation
FA = Future Allocation
MOS = Margin of Safety

The existing and allowable daily and annual loads for each county are listed in Table ES.4.

Table ES.4: Estimated Daily/Annual Maximum Loads and Load Reductions for Fecal Bacteria by County

County	Pollutant	Current Load		Allowable Load		Required Reduction
		Daily (cfu/Day)	Annual (cfu/Year)	Daily (cfu/Day)	Annual (cfu/Year)	
New Kent	*E. coli*	5.37E+11	1.02E+14	1.12E+11	2.11E+13	79%
Charles City		6.59E+11	1.26E+14	1.81E+10	3.45E+12	97%
James City		1.71E+11	3.30E+13	3.53E+10	6.80E+12	79%
New Kent	Enterococci	3.00E+12	4.88E+14	2.25E+12	3.66E+14	25%
Charles City		9.55E+12	1.58E+15	5.83E+12	9.68E+14	39%
James City		1.72E+13	2.88E+15	5.52E+12	9.27E+15	68%

The nonpoint source loads (LA) and the corresponding load reductions for each source category for Chickahominy River and its tributaries are presented in Table ES.5.

Table ES.5: Estimated Daily Loads and Load Reductions by Nonpoint Source Category for Bacteria Impaired Waters

Impaired Water	Pollutant	Source	Current Load (cfu/day)	Allowable Load (cfu/day)	Reduction Needed
Diascund Creek (Non-tidal)	*E. coli*	Wildlife	1.79E+11	6.63E+10	63.0%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	1.33E+10	0.00E+00	100.0%
		Human	1.09E+10	0.00E+00	100.0%
		Total	2.04E+11	6.63E+10	67.4%
Beaverdam Creek	*E. coli*	Wildlife	2.21E+11	3.30E+10	85.1%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	1.43E+10	0.00E+00	100.0%
		Human	1.38E+10	0.00E+00	100.0%
		Total	2.49E+11	3.30E+10	86.8%
XAH-Beaverdam Creek, UT	*E. coli*	Wildlife	7.64E+10	1.16E+10	84.8%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	4.91E+09	0.00E+00	100.0%
		Human	2.37E+09	0.00E+00	100.0%
		Total	8.37E+10	1.16E+10	86.1%
Barrow's Creek	*E. coli*	Wildlife	1.63E+11	1.79E+10	89.0%
		Agriculture	4.50E+11	0.00E+00	100.0%
		Pets	6.16E+09	0.00E+00	100.0%
		Human	4.00E+10	0.00E+00	100.0%
		Total	6.59E+11	1.79E+10	97.3%

Mill Creek	*E. coli*	Wildlife	1.28E+11	3.05E+10	76.1%
		Agriculture	6.13E+08	0.00E+00	100.0%
		Pets	3.48E+09	0.00E+00	100.0%
		Human	1.79E+10	0.00E+00	100.0%
		Total	1.50E+11	3.05E+10	79.6%
Diascund Creek (Tidal)	Enterococci	Wildlife	2.61E+12	7.19E+11	72.5%
		Agriculture	2.30E+09	0.00E+00	100.0%
		Pets	1.32E+11	0.00E+00	100.0%
		Human	3.30E+11	0.00E+00	100.0%
		Total	3.08E+12	7.19E+11	76.7%
Chickahominy River	Enterococci	Wildlife	2.06E+13	1.32E+13	36.0%
		Agriculture	5.02E+12	0.00E+00	100.0%
		Pets	8.31E+11	0.00E+00	100.0%
		Human	2.62E+12	0.00E+00	100.0%
		Total	2.90E+13	1.32E+13	54.7%
Gordon Creek	Enterococci	Wildlife	4.04E+12	1.17E+12	71.1%
		Agriculture	5.07E+10	0.00E+00	100.0%
		Pets	6.43E+10	0.00E+00	100.0%
		Human	2.53E+11	0.00E+00	100.0%
		Total	4.41E+12	1.17E+12	73.5%

Implementation

The goal of this TMDL is to develop an allocation plan that achieves WQS during the implementation phase. 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."

Once the TMDLs developed for the Lower Chickahominy River watershed have been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES)/National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. 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 implementation plan.

In general, Virginia intends for the required pollutant reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality.

There is reasonable assurance that the load reductions will be met when the implementation strategies are employed. Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program, and use these data to evaluate reductions in pollutants, the effectiveness of the TMDL in attaining and maintaining WQSs, and the success of implementation efforts. Both federal and state regulations require reasonable assurance that the LAs and WLAs can and will be implemented.

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." Potential sources for implementation 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, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions.

Public participation is critical to the implementation process. Reductions in non-point source loading are the crucial factor in addressing the problem. These sources cannot be addressed without public understanding of, and support for, the implementation process. Stakeholder input will be critical from the onset of the implementation process in order to develop an implementation plan that will be truly effective.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. The first public meeting was held on July 28, 2015 at the Heritage Public Library located at 6215 D Chesapeake Circle, New Kent, VA 23124, which informed the stakeholders of the TMDL development process and was intended to obtain feedback. A Technical Advisory Committee (TAC) was formed and the first TAC meeting was held on October 7, 2015 at the Charles City County Social Center at 8320 Ruthville Rd in Providence Forge, VA. The source assessment methods were refined and information updated. The second TAC meeting was held on January 19, 2016 at the Charles City County Social Center. The source assessment method was finalized and the model results were presented. The second public meeting was held on April 26, 2016, again at the Charles City County Social Center. The TMDL was presented and discussed.

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 water quality standards (WQSs). 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 Commonwealth of Virginia has identified the stream segments that do not meet the Commonwealth's WQSs 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 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 WQSs. 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 WQSs.

1.2 Watershed Characteristics

The Chickahominy River watershed (USGS Hydrologic Unit Code 02080206) is located in Hanover, Charles City, New Kent, James City, 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 bacteria impairments addressed in this project are located in the Lower Chickahominy River (Figure 1.1), with a drainage area of approximately 106,300 acres.

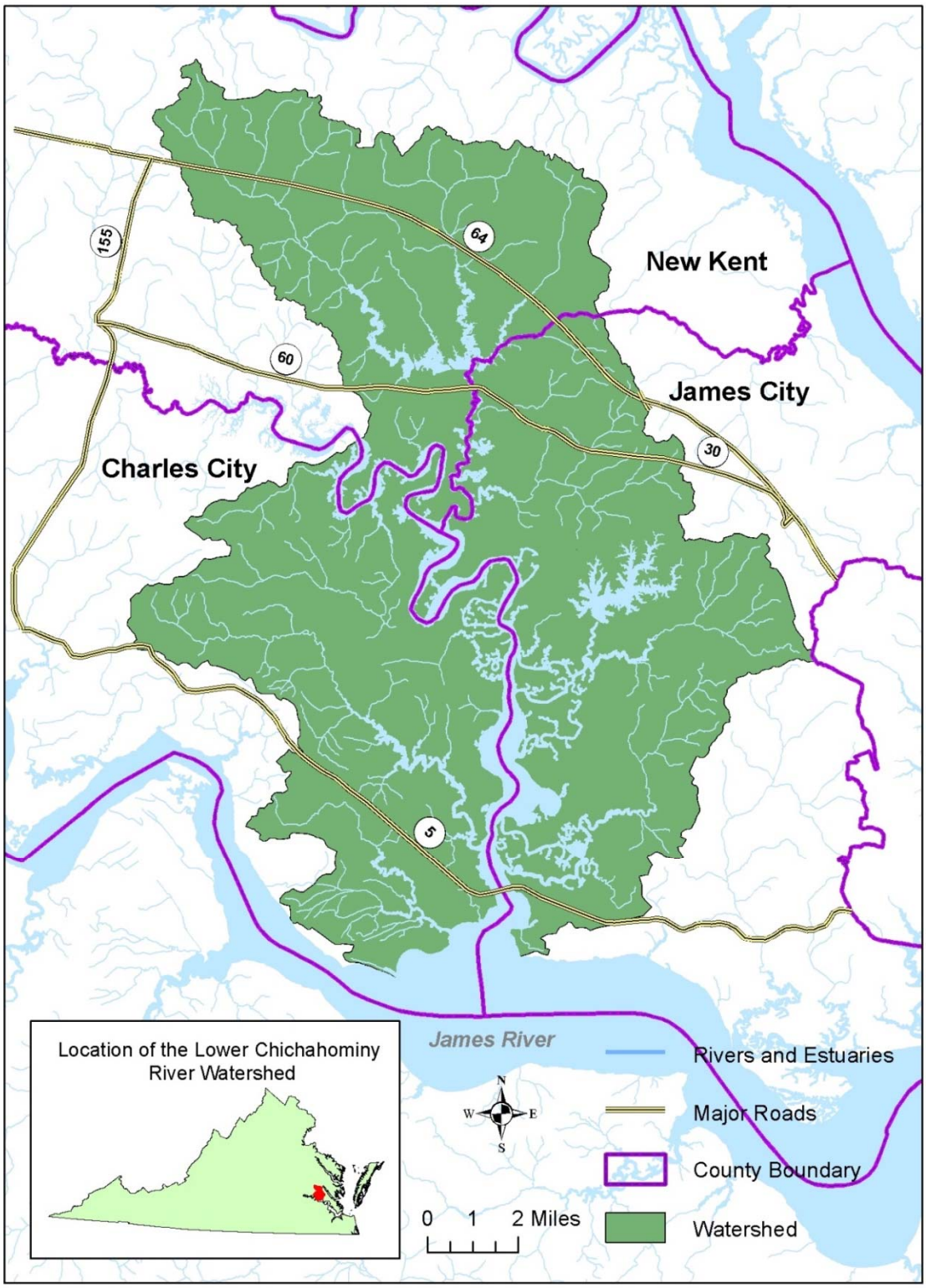

Figure 1.1: Location of the Lower Chickahominy River Watershed

The Lower Chickahominy River watershed is located within the Level III Southeastern Plains (65) (Level IV subsets –Rolling Coastal Plain (65m)). The Southeastern Plains ecoregion has elevations from sea level to 300 feet. The geology is primarily newer sedimentary rock. Stream flow is very sluggish and stream bottoms are sandy. Swampy stained water is common. The Level IV area has a little more gradient and more defined stream flow than streams further east. (https://www.epa.gov/eco-research/ecoregion-download-files-state-region-3#pane-36).

As for the climatic conditions in the Chickahominy River watershed, during the period from 1993 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 by using the National Land Cover Database 2011 (NLCD, Figure 1.2). The land use was further merged into six groups (Table 1.1). The drainage area is predominantly forest (56%). Developed areas in the watershed comprise roughly 7%. Pasture and hay land covers account for roughly 4% and croplands 6% of the area. Wetlands are a sizable portion covering about 18% of the drainage area (Table 1.1 and Figure 1.3).

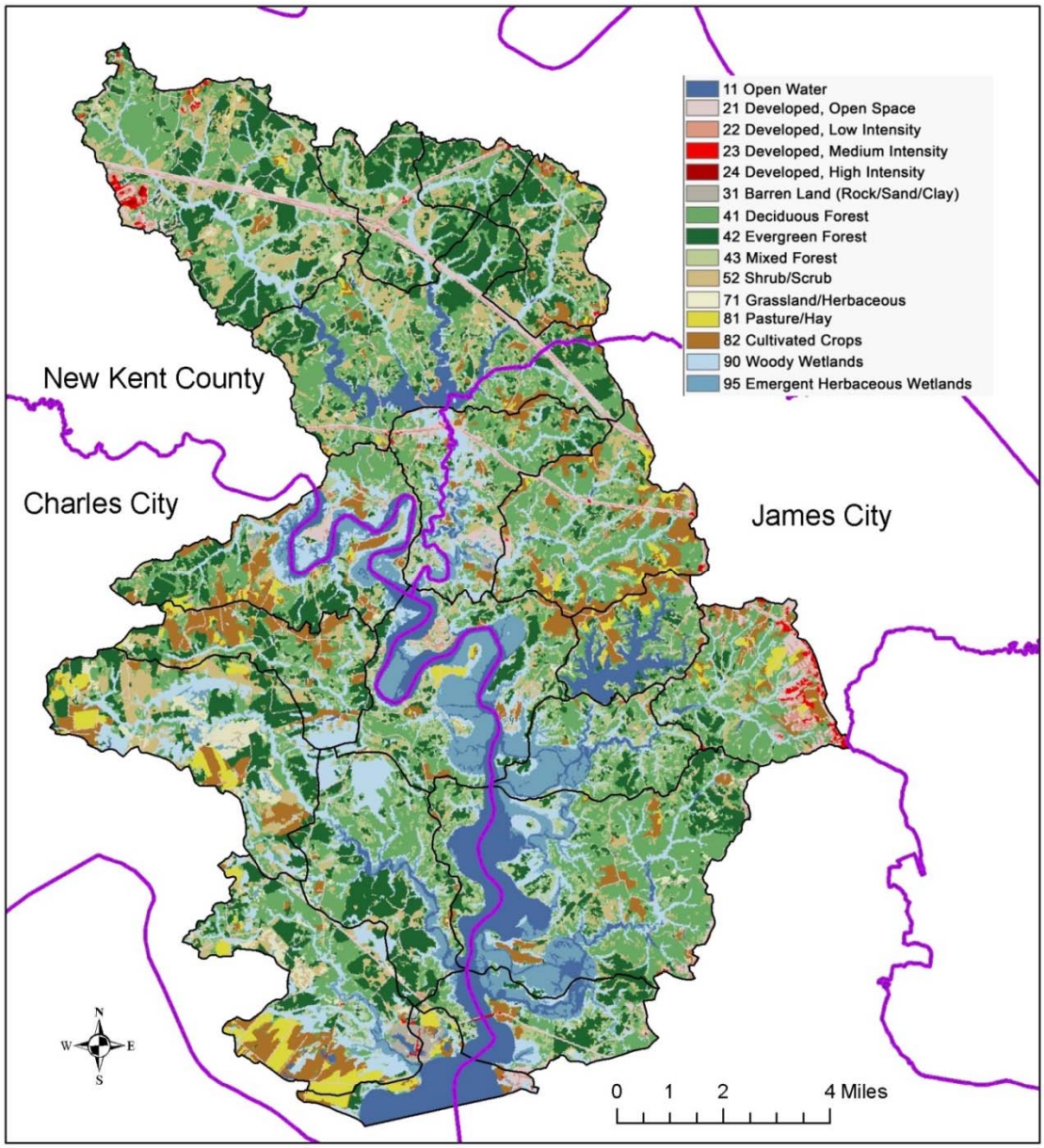

Figure 1.2: Landuse of the Lower Chickahominy River Watershed

Table 1.1: Landuse Types, Areas (Acres), and Percentages for the Lower Chickahominy River Area

Watershed Name	Developed	Cropland	Pasture /Hay	Forest	Wetland	Other	Total
Chickahominy River Study Area	7,350 (7%)	6,944 (6%)	3,865 (4%)	59,487 (56%)	18,955 (18%)	9,746 (9%)	106,346 (100%)

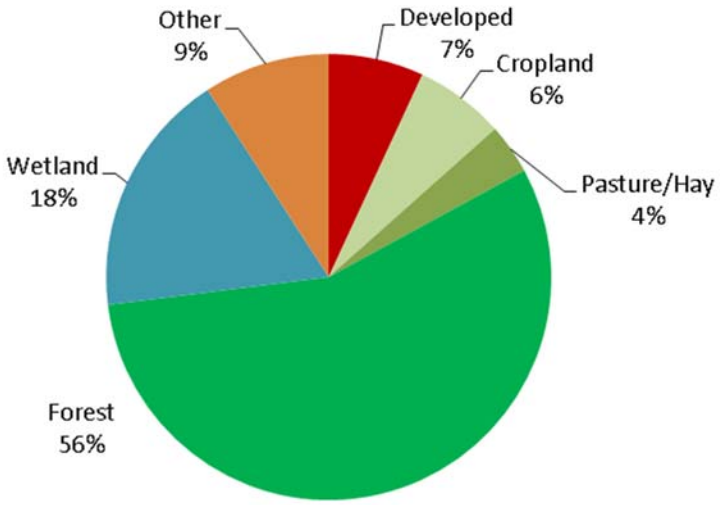

Figure 1.3: Landuse Distribution in the Lower Chickahominy River Watershed

1.3 Recreation Use Impairments

There are eight different bacteria-impaired waters in this study area, lower Chickahominy River, Gordon Creek, Diascund Creek (tidal), Diascund Creek (non-tidal), Beaverdam Creek, Unnamed Tributary to Beaverdam Creek, Mill Creek, and Barrows Creek. Figure 1.4 shows the impaired segments of the lower Chickahominy River, and Table 1.2 details information regarding the impairments covered in this study.

Tidal Morris Creek in Charles City County is also impaired due to bacteria. However, that watershed was separately addressed in the TMDL "Morris Creek (tidal), Charles City County Total Maximum Daily Load (TMDL) for Bacteria Contamination Impaired for Recreational Use", which was approved by the EPA on 12/3/2009 and by the State Water Control Board (SWCB) on 9/30/2010.

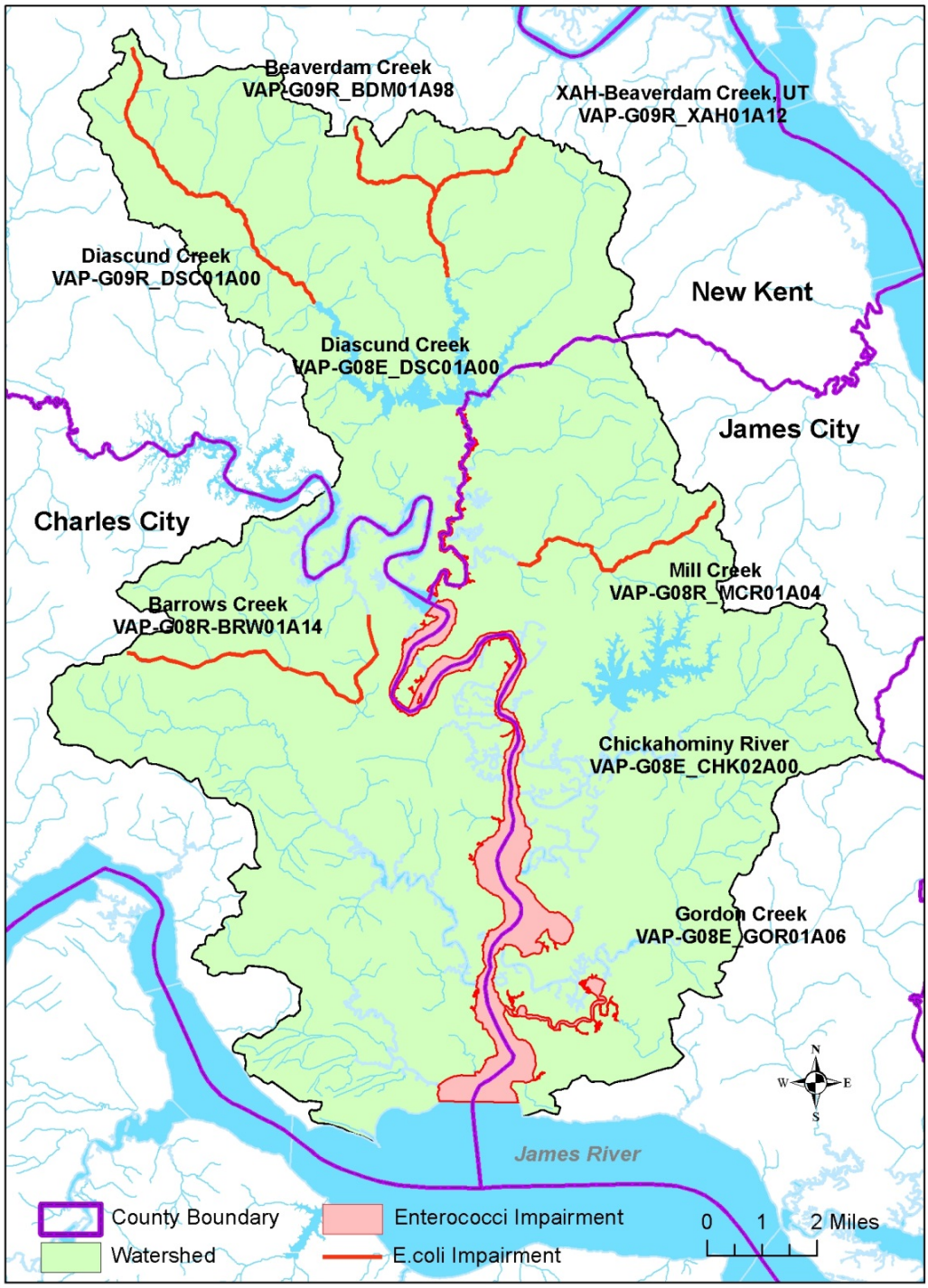

Figure 1.4: Segments in the Lower Chickahominy River Watershed Impaired for Bacteria

Table 1.2: Segments in the Lower Chickahominy River Watershed Impaired for Bacteria

Stream Name (Impairment ID)	Impairment Type	Initial Listing Year	Estuary Area ($Mile^2$) or River Mile	2012 Listing Violation%	Impairment Location Description
Diascund Creek (VAP-G09R_DSC01A00)	*E. coli*	2008	6.88	20	Headwaters to the upstream limit of Diascund Creek Reservoir
Beaverdam Creek (VAP-G09R_BDM01A98)	*E. coli*	2012	4.34	33 at 2-BDM003.16 20 at 2-BDM004.12 33 at 2-BDM004.60 56 at 2-BDM005.70	Headwaters to the upstream limit of Diascund Creek Reservoir
XAH-Beaverdam Creek, UT (VAP-G09R_XAH01A12)	*E. coli*	2012	2.23	33	Headwaters to mouth at Beaverdam Creek
Barrows Creek (VAP-G08R_BRW01A14)	*E. coli*	2014	6.93	50	Headwaters to tidal limit
Mill Creek (VAP-G08R_MCR01A04)	*E. coli*	2012	4.81	23	Headwaters to tidal limit
Diascund Creek (VAP-G08E_DSC01A00)	Enterococci	2010	0.27	17	From the Diascund Reservoir dam downstream to the mouth at the Chickahominy River
Chickahominy River (VAP-G08E_CHK02A00)	Enterococci	2006	5.92	13 at 2-CHK006.14 and 28 at 2-CHK014.33	From the confluence with Diascund Creek downstream to the James River
Gordon Creek (VAP-G08E_GOR01A06)	Enterococci	2012	0.20	12	Tidal limit to the mouth at the Chickahominy River

2. TMDL ENDPOINT AND WATER QUALITY ASSESSMENT

2.1 Applicable Water Quality Standards

According to 9 VAC 25-260-5 of Virginia's SWCB WQSs, the term "water quality standards" means "…provisions of Commonwealth's 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 Commonwealth 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.*
>
> *E. At a minimum, uses are deemed attainable if they can be achieved by the imposition of effluent limits required under §§301(b)(1)(A) and (B) and 306 of the Clean Water Act and cost-effective and reasonable best management practices for nonpoint source control.*

Virginia adopted its current *E. coli* and enterococci standards 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, the Virginia WQS in fresh water for swimming/recreational use was based on fecal coliform rather than *E. coli*. The move was based on the 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 that 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 lower Chickahominy River watershed, the applicable endpoints and associated target values can be determined directly from the Virginia WQSs. In order to remove a waterbody from a state's list of impaired waters, the Clean Water Act requires compliance with that state's WQS.

Since modeling provided simulated output of bacteria concentrations at daily intervals, assessment of TMDLs was made using both the geometric mean and single sample maximum standards. The more stringent of the two was used to ensure a conservative approach. Therefore, for the non-tidal waters, the in-stream *E. coli* target was for no more than 10% of the samples in the assessment periods to exceed 235 cfu/100 ml, and for tidal waters the in-stream enterococci target was for a geometric mean of 35 cfu/100ml.

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 lower Chickahominy River watershed. An examination of all the data from water quality stations used in the 303(d) 2012 assessment was performed. Sources of data and pertinent results are discussed.

The primary sources of available water quality information are bacteria enumerations from twenty-five (25) VA-DEQ in-stream monitoring stations dating from July 2003 to March 2015 (Figure 2.1 and Figure 2.2). These data were analyzed for enterococci (Table 2.1) and *E. coli* (Table 2.2).

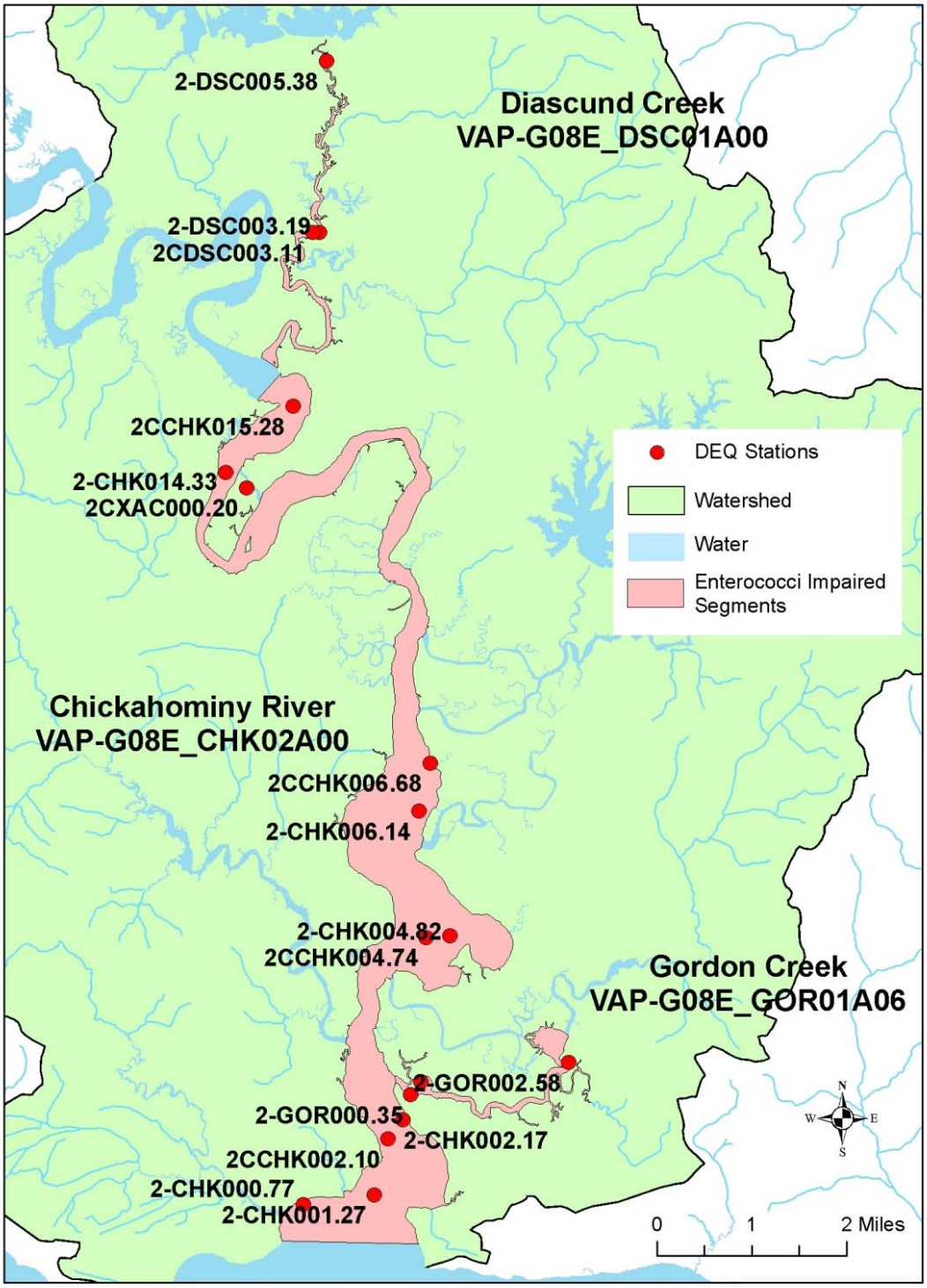

Figure 2.1: VA-DEQ Monitoring Stations in the Enterococci Impaired Waters

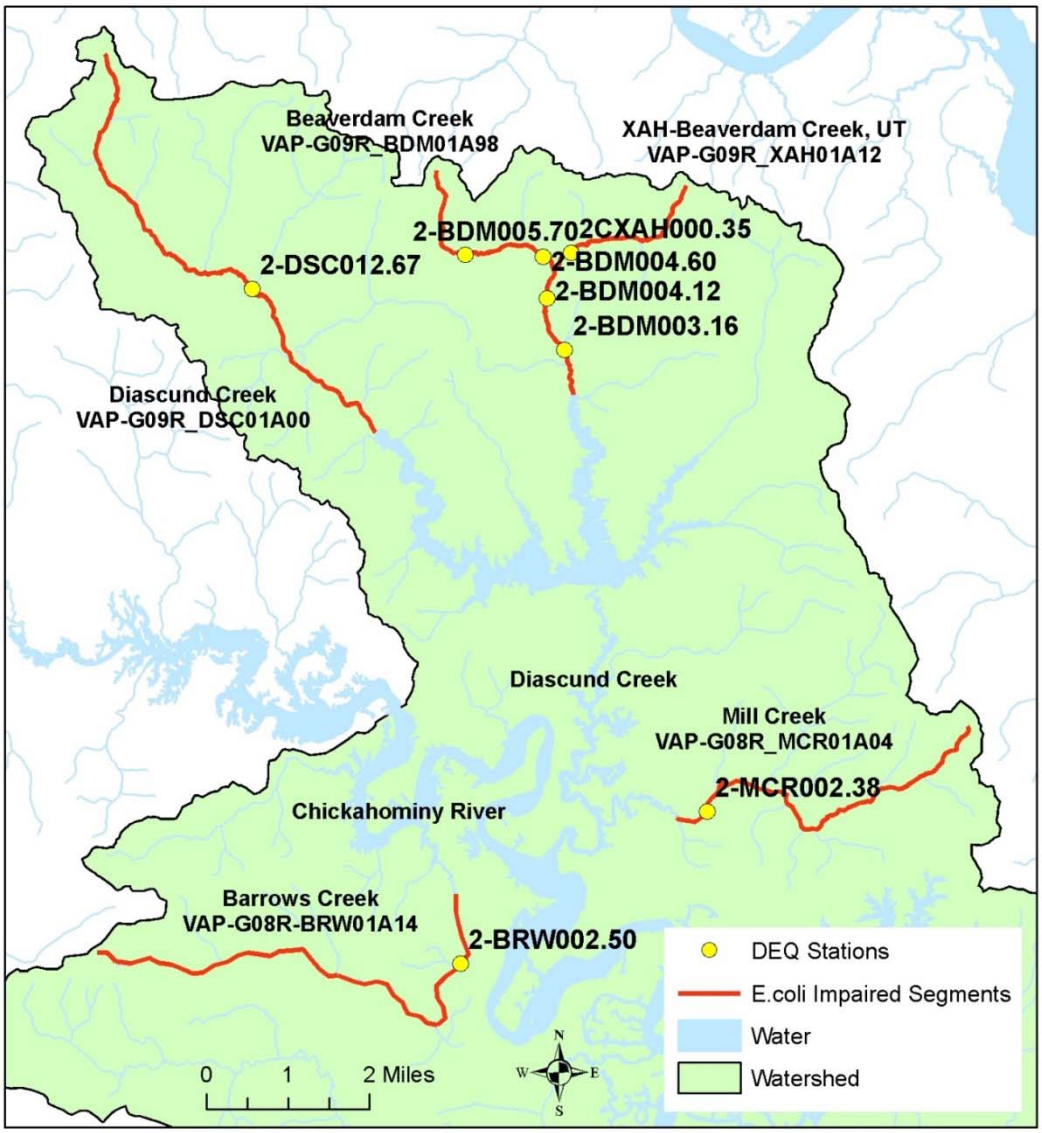

Figure 2.2: VA-DEQ Monitoring Stations in the *E. coli* Impaired Waters

Table 2.1: Summary of Enterococci (cfu/100 ml) Data Collected by VA-DEQ

Stream Name	Station Id	Count	Mean	Standard Deviation	Minimum	Maximum	Monitoring Period	Violation of Single Sample Maximum
Diascund Creek (Tidal)	2CDSC003.11	1	10		10	10	6/27/11	0%
	2-DSC003.19	22	120	82	25	400	3/1/07-12/16/14	14%
	2-DSC005.38	12	233	257	100	1,000	1/13/14-12/16/14	33%
Chickahominy River	2CCHK002.10	1	50	-	50	50	7/16/08	0%
	2CCHK004.74	1	130	-	130	130	6/21/11	100%
	2CCHK006.68	1	10	-	10	10	7/7/14	0%
	2CCHK015.28	1	20	-	20	20	7/1/13	0%
	2CXAC000.20	1	70	-	70	70	7/21/08	0%
	2-CHK000.77	1	30	-	30	30	7/10/07	0%
	2-CHK001.27	1	10	-	10	10	8/12/04	0%
	2-CHK002.17	64	62	94	10	700	7/2/03-2/3/15	6%
	2-CHK004.82	1	10		10	10	7/10/07	0%
	2-CHK006.14	95	91	218	10	2,000	2/20/07-3/12/15	9%
	2-CHK014.33	24	119	58	25	300	1/4/07-12/16/14	17%
Gordon Creek	2-GOR000.35	45	135	185	25	1,300	2/20/07-12/16/14	13%
	2-GOR000.42	1	10	-	10	10	8/12/04	0%
	2-GOR002.58	1	80	-	80	80	8/27/03	0%

Table 2.2: Summary of *E. coli* (cfu/100mL) Data Collected by VA-DEQ

Stream Name	Station Id	Count	Mean	Standard Deviation	Minimum	Maximum	Monitoring Period	Violation of Single Sample Maximum
Diascund Creek	2-DSC012.67	31	168	445	3	2,500	7/2/03-8/6/04	13%
Beaverdam Creek	2-BDM003.16	9	311	395	100	1,300	4/29/09-12/14/09	33%
	2-BDM004.12	20	208	362	1	1,700	1/4/07-12/14/09	20%
	2-BDM004.60	9	267	218	100	700	4/29/09-12/14/09	33%
	2-BDM005.70	9	500	394	100	1,000	4/29/09-12/14/09	56%
XAH-Beaverdam Creek, UT	2CXAH000.35	6	367	513	100	1,400	4/29/09-12/14/09	33%
Barrows Creek	2-BRW002.50	12	444	684	25	2,000	1/10/11-12/10/12	50%
Mill Creek	2-MCR002.38	24	271	338	25	1,450	2/9/09-12/9/13	25%

3. BACTERIA SOURCE ASSESSMENT

A primary component of TMDL development for the lower Chickahominy River is the evaluation of potential sources of bacteria in the watershed. The source assessment was used as the basis of model development and the ultimate analysis of TMDL allocation options. In the evaluation of sources, a watershed approach was applied and loads were characterized by the best available information, landowner and citizen input, literature values, and local government agencies. The source assessment chapter is organized into point and nonpoint sections and summarizes the available information and interpretation for the analysis. To adequately represent the spatial variation in the watershed, the lower Chickahominy River Watershed drainage area was divided into twenty-six (26) subwatersheds (Figure 3.1). Source assessment is conducted on the subwatershed level where estimates of all potential bacteria sources are compiled for each individual subwatershed. Table 3.1 lists the subwatersheds of each bacteria impaired water segment by the localities with which they overlap.

Table 3.1: Subwatersheds Contained by Each Impaired Area and Localities They Overlap

Impaired Segment	**Subwatersheds**
Chickahominy River	1-26
Diascund Creek (Non-tidal)	1
Beaverdam Creek	2, 3
UT Beaverdam Creek	3
Diascund Creek (Tidal)	1-6, 9-11
Mill Creek	11
Barrows Creek	17
Gordon Creek	22
Locality	**Overlapping Subwatersheds**
Charles City County	7, 16-20, 23-25
James City County	5, 10-15, 21, 22, 26
New Kent County	1-4, 6, 8, 9

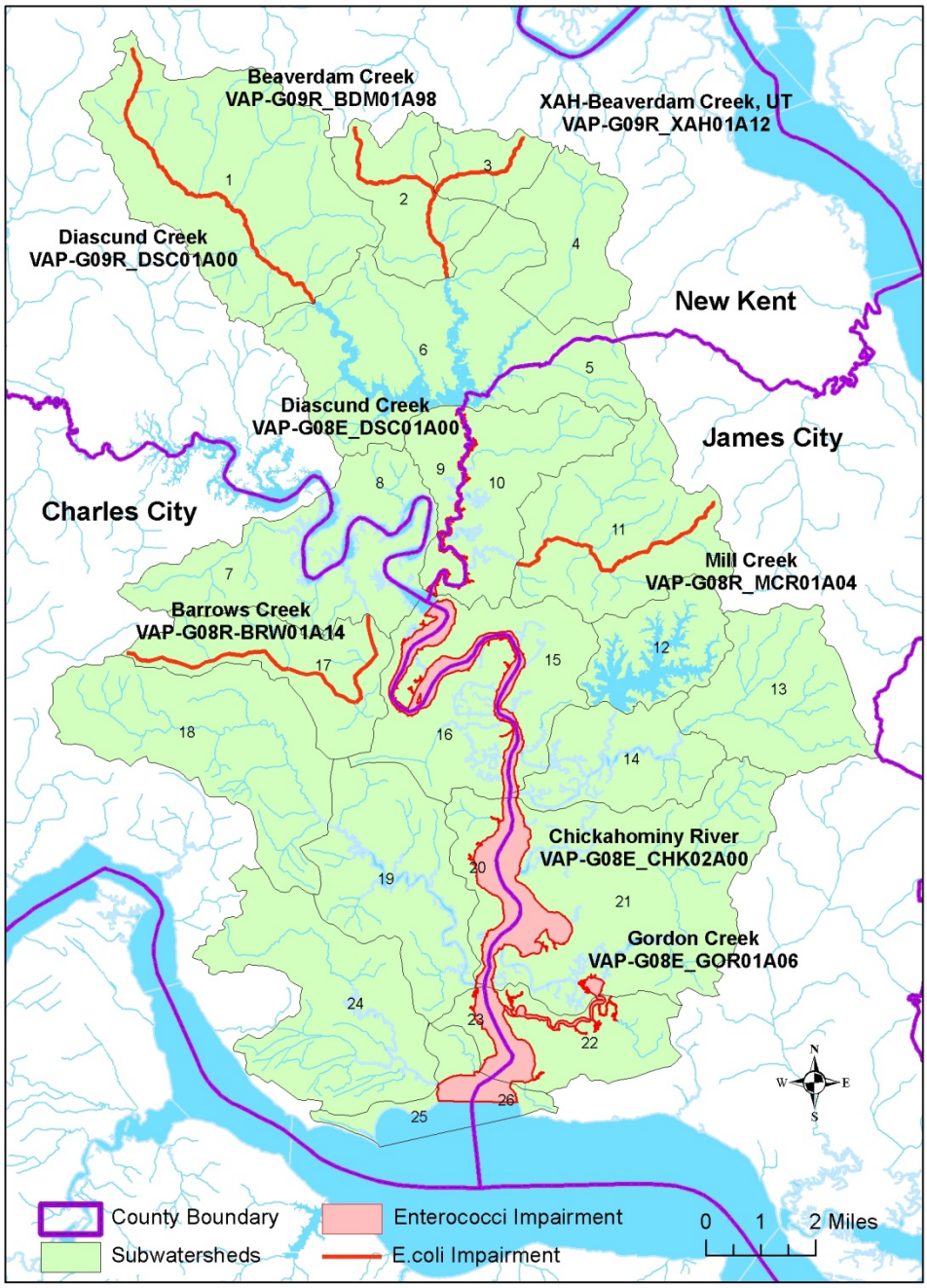

Figure 3.1: Subwatershed Delineation in the Lower Chickahominy River Watershed

3.1 Point Sources

There are 16 permitted point sources that discharge to the surface water bodies in the lower Chickahominy River watershed. Nine of them (Table 3.2) will be assigned with bacteria wasteload allocations (WLAs), and 7 of them (Table 3.3) will not be assigned with any WLA.

Figure 3.2 shows the locations of the individual permits with WLAs, and the James City County VDOT (roads within James City County) and MS4 areas within the Lower Chickahominy River watershed. The James City County storm water regulated area map file was provided by the County. The loading of VDOT roads is calculated based on the road length and a 20-meter buffer width on each side of the road. It is the preference of DEQ to aggregate the WLAs of these two MS4 permits.

Table 3.2: Permits That Need Bacteria WLAs in the Chickahominy River Watershed*

Permit Number	Facility Name	Permit Type	Category	Subwatershed	Designed Flow (MGD)
VA0080233	Hideaway STP	Minor Municipal	VPDES-IP	16	0.039
VAG403039	Single Family Home	General Permit	Domestic Discharger	15	0.001
VAG404050	Single Family Home	General Permit	Domestic Discharger	16	0.001
VAG404144	Single Family Home	General Permit	Domestic Discharger	23	0.001
VAG404152	Single Family Home	General Permit	Domestic Discharger	23	0.001
VAG404198	Single Family Home	General Permit	Domestic Discharger	7	0.001
VAG404284	Single Family Home	General Permit	Domestic Discharger	6	0.001
VAR040037	Locality urbanized service area – James City	General Permit	MS4-Phase II	Various	SW Only - Use model
VAR040115	VDOT roads within James City County	General Permit	MS4-Phase II	Various	SW Only - Use model

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

Table 3.3: Permits That Do Not Need Bacteria WLA in the Chickahominy River Watershed

Permit Number	Facility Name	Permit Type	Category	Subwatershed	Designed Flow (MGD)
VA0085936	Mt. Zion - Rustic WTP	Minor Industrial	VPDES-IP	19	0.009
VAG110166 (001)	Branscome, Inc. - Charles City Concrete	General Permit	Concrete Products	23	Comingled Outfall (Process + SW) TBD
VAG110166 (002)	Branscome, Inc. - Charles City Concrete	General Permit	Concrete Products	23	SW Only - Use model
VAG840116 (001)	Hofmeyer Pit	General Permit	Non-Metallic Mineral Mining	24	Comingled Outfall (Process + SW) TBD
VAG840116 (002)	Hofmeyer Pit	General Permit	Non-Metallic Mineral Mining	24	Comingled Outfall (Process + SW) TBD
VAG840135	Sandy Point Sand & Gravel	General Permit	Non-Metallic Mineral Mining	24	Comingled Outfall (Process + SW) TBD
VAR051899	Total Area of facility 4.3 acres, Area of industrial activity 1.4 acres.	General Permit	Industrial SW	11	SW Only - Use model

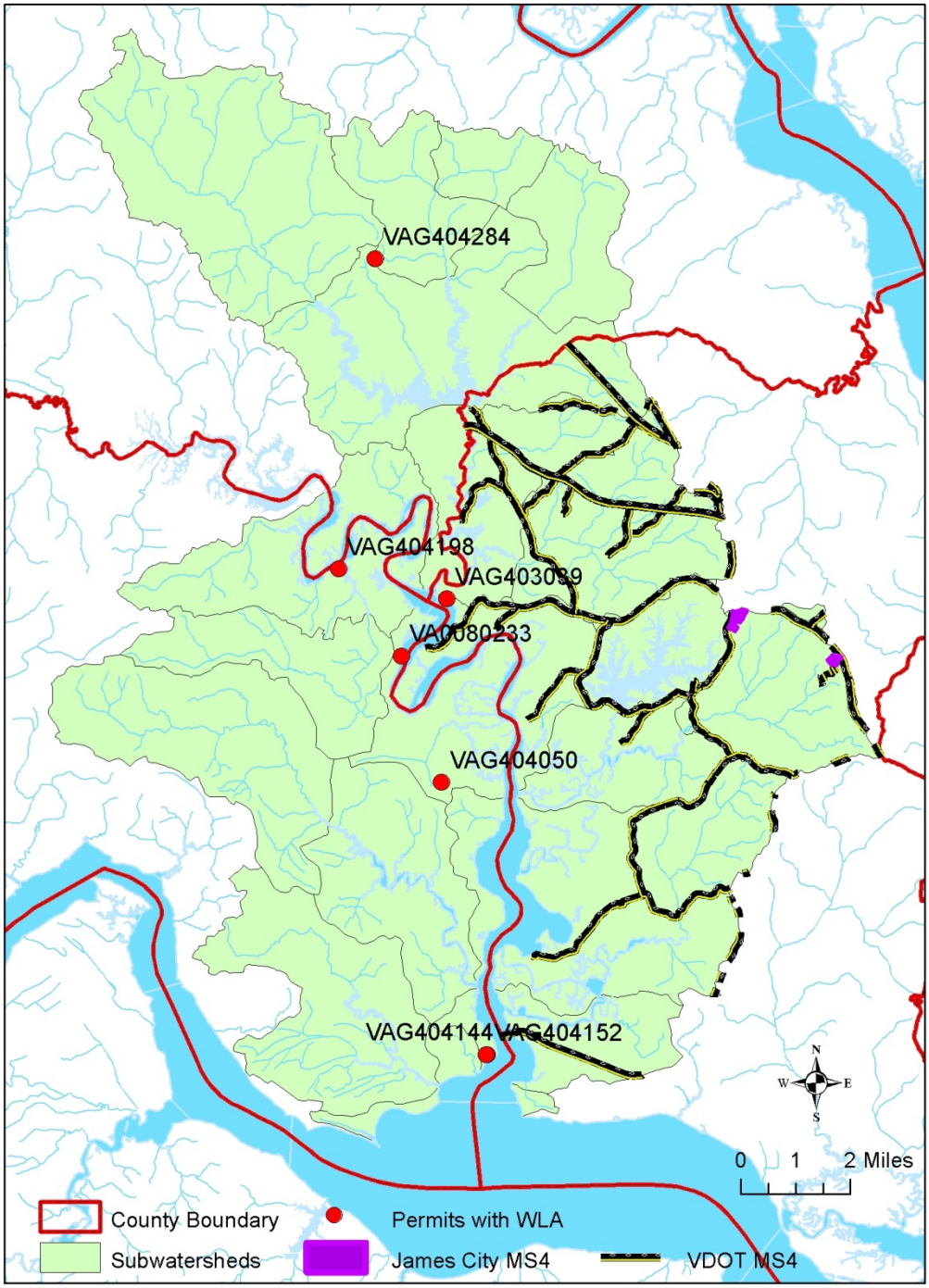

Figure 3.2: Locations of the Individual Permits with WLAs, and the James City County VDOT and MS4 Areas

3.2 Nonpoint Sources

In the Lower Chickahominy River watershed, nonpoint sources of bacteria include residential sewage disposal systems, sanitary sewer overflows (SSOs), biosolids, pets, wildlife, livestock, recreational boating, and straight pipes. Sources were identified and enumerated. Where appropriate, the spatial distribution of sources was also determined.

3.1.1 Private Residential Sewage Treatment

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.

For the subwatersheds located within James City County, the number of homes that have septic tanks are based on the data provided by the County. The accuracy of the estimates is enhanced by the geographic information (discussed below) showing the locations of septic systems.

For the subwatersheds located within Charles City and New Kent Counties, the “911” street address GIS layers were obtained from the County offices. Since the GIS layer identifies individual houses located within the Chickahominy River watershed, it provides a more accurate estimation of septic tank numbers. It was discussed in the Technical Advisory Committee (TAC) meeting that, in the northern part of the watershed, New Kent County has small areas that are serviced by wastewater treatment facilities. The service map was provided by the New Kent Department of Public Utilities and overlaid with the “911” GIS layer to exclude the public service area from septic systems. There is no public sewage service area in Charles City County, therefore, all 911 addresses are assumed to have septic systems. Another subwatershed within the watershed, Morris Creek (Subwatersheds 18 and 19), underwent a bacteria TMDL by DEQ in 2009 (VA-DEQ, 2009). Therefore, the number of septic tanks noted in the TMDL for these two subwatersheds has been used. There are a total of 4,314 septic tanks in the entire area. Table 3.4 lists the number of septic tanks by subwatershed.

Table 3.4: Total Number of Septic Tanks by Subwatershed

Subwatershed	Number of Septic Tanks	Subwatershed	Number of Septic Tanks
1	268	**14**	61
2	106	**15**	439
3	20	**16**	83
4	101	**17**	114
5	64	**18 and 19 (Morris Creek)**	97
6	346		
7	58	**20**	4
8	382	**21**	195
9	271	**22**	41
10	435	**23**	38
11	400	**24**	57
12	289	**25**	8
13	436	**26**	1

A failure rate of 10% is used according to the data provided by James City County. The average number of persons per household is obtained from US Census Bureau (USCB, 2015). The septic loading rate is estimated as the septic overcharge flow rate of 70 gal/person/day (USEPA, 2001) multiplying the overcharge concentration of 1.0×10^6 cfu/100 ml (EPA, 2001). The fecal coliform loading from the failed septic tank systems then is estimated as the product of the number of failed septic tanks, the number of persons per household, and the septic loading rate.

3.1.2 Recreational Boating

Marina and boating activities can contribute bacteria loading when their wastes are not adequately collected in pump stations or the pump stations do not work properly. The amount of open water area in each subwatershed and county was estimated using NLCD (2011) landuse category “Open Water”. Bacteria contributions are expected to occur in subwatersheds containing the “Open Water” category. Information of the number of registered boats in each county was obtained from VA-DGIF personnel. These numbers were divided by the county open water area and then multiplied by the subwatershed open water area to estimate the number of boats in each subwatershed (Table 3.5). To calculate an estimate of loading, the method used in VA-DEQ (2014) was adopted. On average there are 3 persons per boat, only 10% of the boats will illicitly discharge and therefore contribute to the loading, and a fecal coliform production rate of 2.0E+09 cfu/day/person is assumed. The total loading contribution from boats was estimated as the product of the aforementioned 3 numbers. Note that this is a conservative method of calculating fecal coliform loadings from marina and boating activities.

Table 3.5: Number of Boats in the Subwatershed of Lower Chickahominy River

Subwatershed	Number of Boats	Subwatershed	Number of Boats
1	4	**14**	36
2	0	**15**	111
3	0	**16**	80
4	2	**17**	2
5	15	**18 and 19 (Morris Creek)**	27
6	366		
7	56	**20**	85
8	157	**21**	244
9	36	**22**	100
10	31	**23**	35
11	5	**24**	14
12	145	**25**	104
13	5	**26**	60

3.1.3 Straight Pipes

Besides public sanitary sewer and septic tank systems, the sewage from a house may also be disposed by straight pipe, which consists of untreated (or raw) sewage being directly discharged by pipe to a waterway. Generally, when a septic system fails, the property owner contacts the VDH to initiate a remedy. Depending on the circumstance, VDH may facilitate a repair of the failing system, initiate a permit for the construction of a new alternative system, or, if service is available, the owner may opt to connect to the public sewer. However, straight pipes may be adapted to a dwelling by an owner as an inexpensive and illegal means of disposing household sewage. Because any illicit discharge of untreated human waste is illegal under the Commonwealth's law due to the potential impact to human health and wildlife, straight pipes are prioritized for load reduction in the TMDL model. Unless VDH is notified, corrective actions with the property owner may not be initiated. Therefore, it is possible that not all of these straight pipes are present in a watershed at any given time as the number of failing systems occurring at a given time may also fluctuate (see Section 3.2.1).

For this study, the method of straight pipe estimation has been adopted from the Upper York River bacteria TMDL (VA-DEQ, 2010). The 1990 census data (USCB, 2011) documents the distribution of houses on sewage systems, septic systems, and other means (considered to be straight pipes). Assuming the percent distribution of the current sewage disposal method is the same as that of 1990, the 1990 estimated distribution (1.90% for straight pipes for Virginia) was multiplied by the estimated number of houses in each subwatershed to estimate the number of houses with straight pipes (Table 3.6). Note that using 1.90% is conservative since some of the "other means" category could include alternative treatment systems.

The average number of persons per household by county was obtained (USCB 2015; Charles City, 2.59; James City, 2.47; New Kent, 2.65). For each subwatershed, the total number of persons utilizing straight pipes was then estimated through a calculation where the number of persons per household was multiplied by the number of houses with straight pipes. According to a report by the EPA (2001), about 70 gallons/person/day of water are discharged by this means. According to VA-DEQ (2014), the raw sewage fecal coliform concentration is 2,700,000

MPN/100ml. The bacteria loading from straight pipes can then be estimated as the product of the total number of persons utilizing straight pipes, the water discharge rate of each person, and the raw sewage fecal coliform concentration.

Table 3.6: Number of Straight Pipes in Each Subwatershed in the Lower Chickahominy River Watershed

Subwatershed	Number of Straight Pipes	Subwatershed	Number of Straight Pipes
1	5	**14**	1
2	2	**15**	8
3	0	**16**	2
4	2	**17**	2
5	1	**18**	1
6	7	**19**	2
7	1	**20**	0
8	7	**21**	4
9	5	**22**	1
10	8	**23**	1
11	8	**24**	1
12	5	**25**	0
13	8	**26**	0

3.1.4 Sanitary Sewer Overflows (SSOs)

Sanitary sewers are piping systems designed to collect wastewater from individual homes and businesses for transport 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 will discharge 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 3.7 details the volume of overflows reported since year 2010 from VA-DEQ.

Table 3.7: The SSOs in the Lower Chickahominy River Watershed Since Year 2010

Permit Number	Permittee	Date	Sub-watershed	Volume (Gallons)
VA0080233	Hideaway STP	2/5/2010	18	500-1000
VA0080233	Hideaway STP	8/27/2011 -9/1/2011	17	1400-20000

VA0080233	Hideaway STP	7/31/2013 -8/5/2013	16	22500
VA0080233	Hideaway STP	11/20/2013	18	Not reported, but limited according to the comments
VA0080233	Hideaway STP	9/25/2013	18	250
VA0080233	Hideaway STP	1/29/2014	18	350
VA0080233	Hideaway STP	3/8/2014	18	Not reported, but limited according to the comments
VA0080233	Hideaway STP	9/3/2014	18	<1440

To estimate bacteria loadings from SSOs, the method of DEQ (2014) is adopted for conservative purposes. The accumulative spillage distribution using available data is plotted (Figure 3.3). The loading corresponding to a 95% spillage volume (22,000 gallons) is estimated as 25% raw sewage and 75% non-raw sewage (communication with DEQ personnel). The fecal coliform concentrations for raw sewage and non-raw sewage, and the total loading, are listed in Table 3.8. The total loading is distributed to each SSO according to their volume ratio. It can be seen that, on average, SSO spills occurred less than 2 times each year, and they do not contribute significantly on a daily basis. However, when spillage occurs, it can result in a short-term increase of fecal coliform concentration in the receiving waters.

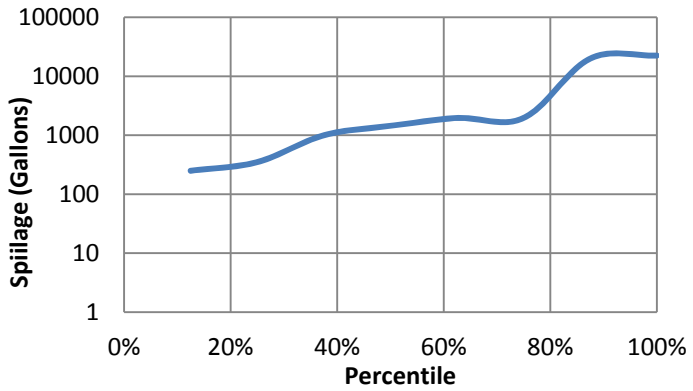

Figure 3.3: Cumulative Frequency Distributions of SSOs in the Lower Chickahominy River Watershed

Table 3.8: Fecal Coliform Information for SSOs in the Lower Chickahominy River Watershed

95% Volume (Gallons)	Raw Sewage Concentration (cfu/100ml)	Non-Raw Sewage Concentration (cfu/100ml)	Fecal Coliform Load (cfu/Day)
22,000	2,700,000	500,000	8.7×10^{11}

3.1.5 Biosolids

Between 2010 and 2014, biosolids were applied to fields within the Lower Chickahominy River watershed (Table 3.9). The total application amount was 6,644 wet tons. Table 3.9 lists the total application amount by subwatershed. Biosolids are required to be spread according to sound agronomic requirements with consideration for topography and hydrology. All applications are done 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), as compared with approximately 240 cfu/g-dry for dairy waste; 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.

In order not to overestimate the loadings, biosolids were modeled as having a fecal coliform concentration of 157,835 cfu/g, the mean value of measured biosolids concentrations observed in several years of samples supplied by VA-DEQ for biosolids applied during 2001 to 2011. Similar to other bacteria sources, the biosolids were simulated using the standard build-up and wash-off processes from land in the watershed model with a die-off rate of 0.1 per day (Appendix A). Note that the estimated loads and the associated percentages (Tables 3.9, 3.16, and 3.17) represent the amount of bacteria deposited in the watershed that do not necessarily reach the impaired water segment. While these loadings were included in the model to represent bacteria deposited within the watershed, Virginia Pollution Abatement (VPA) permits require pollutant management to prevent any discharge to surface waters under normal flow regimes. The permits also require restrictive stream buffers and slope restrictions in order to protect water quality and to prevent alteration of the physical, chemical or biological properties of state waters. Table 3.10 lists all the VPA biosolids permits in counties within this TMDL region.

Table 3.9: Biosolids Application Survey by Subwatershed from 2010 to 2014 in Charles City County

Subwatershed	Year	Total Biosolids Application Weight (Wet Tons)	Fecal Coliform Load (cfu/Day)
7	2010	726	3.1×10^{11}
	2014	469	2.0×10^{11}
17	2014	2,329	1.0×10^{12}
18	2010	991	4.3×10^{11}
	2011	934	4.0×10^{11}
	2014	1,195	5.2×10^{11}

Table 3.10: Biosolids Permits in the Counties of the Lower Chickahominy River Watershed

VPA Permit #	County	Company
VPA00800	New Kent	Recyc Systems, Inc
VPA00828	Charles City	Nutri-Blend, Inc
VPA00832	New Kent	Nutri-Blend, Inc

3.1.6 Pets

According to a previous TMDL study of the Chickahominy River by the VA-DEQ (2012), cats and dogs were the predominant contributors of fecal coliform in the Chickahominy River watershed, and the fecal coliform daily loadings of dogs were 10^6 higher than those of the cats. Therefore, dogs are the only pet considered in this study. The numbers of dogs (i.e., numbers of dog licenses) of Charles City, James City, and New Kent Counties were obtained from each county's Treasurer's Office. The number of dogs in each subwatershed is calculated by dividing the total number of dogs in the county by the county urban area, and then multiplying the subwatershed urban area. As the Morris Creek (Subwatersheds 18 and 19) bacteria TMDL (VA-DEQ, 2009) has been finished, the number of dogs in these two subwatersheds is used. Table 3.11 lists the dog numbers by subwatershed. The fecal coliform production rate used is 4.0×10^9 cfu/dog/day, with 23% of the total dog feces being subject to runoff (VA-DEQ, 2014). The bacteria load is calculated as the product of the dog number, the 23% runoff rate, and the production rate.

Table 3.11: Number of Dogs in Each Subwatershed in the Lower Chickahominy River Watershed

Subwatershed	Number of Dogs	Subwatershed	Number of Dogs
1	371	**14**	8
2	101	**15**	29
3	47	**16**	52
4	72	**17**	78
5	29	**18 and 19 (Morris Creek)**	425
6	179		
7	52	**20**	13
8	61	**21**	40
9	59	**22**	27
10	57	**23**	13
11	82	**24**	130
12	23	**25**	19
13	157	**26**	11

3.1.7 Wildlife

The predominant wildlife species in the Lower Chickahominy River watershed were determined through consultation with wildlife biologists from the VA-DGIF, citizens from the watershed, and other Commonwealth's and local officials. The landuse information of National Land Cover Database (NLCD) 2011 was used to determine the habitat area/location of each wildlife type within each subwatershed. The 15 landuse categories of the Lower Chickahominy River were merged into six categories of developed, forest, cropland, pasture/hay, wetland, and other. The habitat of each wildlife type falls either in the 6 or 15 landuse categories, depending on which assessment method was used. As Morris Creek (Subwatersheds 18 and 19) bacteria TMDL (VA-

DEQ, 2009) has been finished, the number of wildlife in these two subwatersheds is used in this study. The density of each species is listed in Table 3.12. Table 3.13 depicts the wildlife numbers by subwatershed.

Table 3.12: The Densities and Fecal Coliform Production Rates of the Wildlife Species in the Lower Chickahominy River Watershed

Species	Density	Reference of Density	Production Rate (cfu/Animal/Day)	Reference of Production Rate
Deer	Charles City: 33/mile^2 James City: 26/mile^2 New Kent: 31/mile^2	VA-DGIF, 2007	5.00E+08	VA-DEQ, 2007
Ducks	1.532/km^2	VA-DEQ, 2009	2.43E+09	VA-DEQ, 2009
Geese	1.969/km^2	VA-DEQ, 2009	4.90E+10	USEPA, 2001
Beavers	4.8/mile	VA-DEQ, 2009	2.50E+08	ASAE, 1998
Raccoons	Inside Buffer: 0.078/acre Outside Buffer: 0.016/acre	VA-DEQ, 2014	1.25E+08	Best Professional Judgment
Muskrats	10/acre	VA-DEQ, 2009	3.40E+07	VA-DEQ, 2007

3.2.7.1 Deer

The deer habitat is the entire watershed except open water and developed areas. An average deer index by county was obtained from VA-DGIF (2007) (Charles City: 4.3, James City: 3.4, and New Kent: 4.1). The density was calculated as

$$Deer\ Number\ per\ Mile^2 of\ Habitat = -0.64 + (7.74 \times Average\ Deer\ Index)$$

The deer habitat area was determined by the GIS landuse data. The total number of deer in each subwatershed equals to the deer density multiplied by its habitat area. The total fecal coliform loading is calculated as the number of deer multiplied by its fecal coliform production rate.

3.2.7.2 Ducks and Geese

The ducks and geese habitats comprise the entire watershed. The density was multiplied by the subwatershed area to get the total number in each subwatershed. The total fecal coliform loading is calculated as the total numbers of ducks/geese multiplied by their production rates. Depending on the model calibration result, their density for each month may need to be adjusted to incorporate the seasonal migration effect.

3.2.7.3 Beavers

The habitat of beavers is the riparian zone, which is the interface between land and a stream. The river mile of each subwatershed was determined by measuring the total river length using GIS software. The number of beavers in each subwatershed equals to their density multiplied by the number of river miles. The total fecal coliform loading is calculated as the number of beavers in each subwatershed multiplied by their production rate.

3.2.7.4 Raccoons

The raccoon habitats are wetlands and forest. A 600-foot buffer zone was used along the streams and ponds in the Lower Chickahominy River watershed. Different densities were assigned inside and outside of the buffer due to habitat preferences. The numbers of raccoons outside and inside the buffer within each subwatershed were calculated by multiplying their respective densities by the habitat area. These two numbers were added together to obtain the total number in each subwatershed. The fecal coliform loading is calculated as the number of raccoons multiplied by the raccoon production rate.

3.2.7.5 Muskrats

The muskrat habitat is wetlands only. They are most active at night or near dawn and dusk. They are prolific breeders that have two or three litters a year of six to eight young each, which explains their high numbers. Density is multiplied by subwatershed habitat area to get the total population number. The fecal coliform loading in each subwatershed is calculated as the total population multiplied by the muskrat production rate.

Table 3.13: Total Number of Wildlife in Each Subwatershed in the Lower Chickahominy River Watershed

Subwatershed	Deer	Ducks	Geese	Beavers	Raccoons	Muskrats
1	434	63	81	33	449	8,220
2	135	19	25	21	136	2,893
3	64	9	12	11	65	1,381
4	145	20	26	18	138	2,513
5	58	11	14	10	65	1,337
6	327	51	66	192	318	5,446
7	210	29	38	54	205	10,359
8	71	13	17	54	82	6,218
9	54	9	11	42	67	4,041
10	136	25	32	42	181	10,179
11	221	38	48	23	241	6,665
12	73	18	23	165	31	585
13	142	29	37	20	166	4,254
14	129	22	28	66	192	11,513
15	110	22	29	42	152	10,748
16	151	23	30	42	172	14,329
17	192	25	32	32	133	5,667
18 and 19 (Morris Creek)	450	50	65	65	500	9,800
20	47	10	13	19	48	1,332
21	348	65	83	43	466	25,277
22	93	19	25	67	110	7,995
23	16	4	5	9	17	752
24	321	42	54	38	226	15,018
25	40	10	13	6	20	1,386
26	4	3	4	4	5	578

3.1.8 Livestock

An inventory of the livestock of the lower Chickahominy River watershed was conducted using data provided by United States Department of Agriculture (USDA, 2012), the Morris Creek bacteria TMDL, and citizens' input at the first public meeting and TAC meetings. The predominant types of livestock in the watershed are beef cattle, milk cattle, pigs, chickens, horses, and sheep/goats.

Initially, an estimate of the number of each livestock species by county was obtained from USDA county data. The livestock number in a subwatershed was estimated as the county's livestock number divided by its habitat area, and multiplied by the subwatershed habitat area. As Morris Creek (Subwatersheds 18 and 19) bacteria TMDL (VA-DEQ, 2009) has been finished, the numbers of livestock in these two subwatersheds were used. These numbers were validated and updated by consulting with the citizens at the public and TAC meetings. The livestock habitat type and bacteria production rates are listed in Table 3.14. In all three counties farmers practice rotational grazing, which is part of the nutrient management plan. As a result, other than the manure contributed by the grazing livestock, there is no additional manure application occurring watershed-wide. Table 3.15 lists the livestock number by subwatershed.

Table 3.14: Livestock Habitat Type and Fecal Coliform Production Rate (ASAE, 1998)

Livestock	Habitat	Production Rate (cfu/Animal/Day)
Beef Cattle	Pastureland, feedlots	1.04E+11
Milk Cattle	Feedlots	1.01E+11
Pigs	Feedlots	1.08E+10
Chickens	Feedlots	1.36E+08
Horses	Pastureland, feedlots	4.20E+08
Sheep/Goats	Pastureland, feedlots	1.20E+10

Table 3.15: Total Number of Livestock in Each Subwatershed in the Lower Chickahominy River Watershed

Subwatershed	Beef Cattle	Milk Cattle	Pigs	Chickens	Horses	Sheep/Goats
1	0	1	0	0	0	0
2	0	1	0	0	0	0
3	0	0	0	0	0	0
4	0	1	0	0	0	0
5	0	0	0	0	3	0
6	0	1	0	0	0	0
7	0	0	0	0	0	0
8	0	1	0	0	0	0
9	0	0	0	0	0	0
10	0	0	0	0	4	0
11	0	0	0	0	51	0
12	0	0	0	0	24	0
13	0	0	0	0	35	0
14	0	0	0	0	3	0
15	0	0	0	0	4	0
16	0	6	0	0	0	100
17	45	6	0	0	0	100
18 and 19* (Morris Creek)	20	0	0	20	1	185

20	0	0	0	0	0	0
21	0	0	0	0	18	0
22	0	0	0	0	2	0
23	0	0	0	0	0	0
24	0	0	0	0	0	0
25	0	0	0	0	0	0
26	0	0	0	0	0	0

* Morris Creek TMDL results are adopted.

3.1.9 Summary of Source Assessment

A summary of fecal coliform load from each source for all the impaired waters in the watershed is listed in Table 3.16. Table 3.17 summarizes the loads by county.

Table 3.16: Summary of Bacteria Loading by Source Type for Impaired Waters in the Lower Chickahominy River Watershed

Impaired Water	Source		Number	Fecal Coliform Load (cfu/Day)	% Total Load
Lower Chickahominy River (Subwatersheds 1-26)	**Wildlife**	Deer	3971	2.0E+12	2.8%
		Ducks	629	1.5E+12	2.2%
		Geese	809	4.0E+13	56.5%
		Beavers	1120	2.8E+11	0.4%
		Raccoons	4184	5.2E+11	0.7%
		Muskrats	168488	5.7E+12	8.2%
		Totals	179199	5.0E+13	70.8%
	Agriculture	Livestock	635	9.2E+12	13.1%
		Biosolids	6644 (tons)	2.9E+12	4.2%
		Totals		1.2E+13	17.3%
	Pets	Dogs	2136	2.0E+12	2.9%
	Humans	Septic Tanks	4314	2.9E+12	4.1%
		Boating	1718	1.0E+12	1.5%
		Straight Pipes	83	1.5E+12	2.2%
		SSOs	8	8.7E+11	1.2%
	Totals			**7.0E+13**	**100%**
Diascund Creek (Tidal) (Subwatersheds 1-6, 9-11)	**Wildlife**	Deer	1575	7.9E+11	3.6%
		Ducks	245	6.0E+11	2.7%
		Geese	315	1.5E+13	70.5%
		Beavers	393	9.8E+10	0.4%
		Raccoons	1660	2.1E+11	0.9%
		Muskrats	42675	1.5E+12	6.6%
		Totals	46863	1.9E+13	84.9%
	Agriculture	Livestock	62	1.6E+10	0.1%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		1.6E+10	0.1%
	Pets	Dogs	998	9.4E+11	4.3%
	Humans	Septic Tanks	2011	1.4E+12	6.3%
		Boating	458	2.7E+11	1.3%
		Straight Pipes	39	7.0E+11	3.2%
		SSOs	0	0.0E+00	0.0%
	Totals			**2.2E+13**	**100%**

Impaired Water	Source		Number	Fecal Coliform Load (cfu/Day)	% Total Load
Gordon Creek (Subwatershed 22)	**Wildlife**	Deer	93	4.6E+10	2.6%
		Ducks	19	4.7E+10	2.7%
		Geese	25	1.2E+12	69.0%
		Beavers	67	1.7E+10	1.0%
		Raccoons	110	1.4E+10	0.8%
		Muskrats	7995	2.7E+11	15.6%
		Totals	8308	1.6E+12	91.6%
	Agriculture	Livestock	26	2.0E+10	1.1%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		2.0E+10	1.1%
	Pets	Dogs	27	2.5E+10	1.5%
	Humans	Septic Tanks	195	2.7E+10	1.5%
		Boating	100	6.0E+10	3.4%
		Straight Pipes	1	1.4E+10	0.8%
		SSOs	0	0.0E+00	0.0%
	Totals			**1.7E+12**	**100%**
Diascund Creek (Non-tidal) (Subwatershed 1)	**Wildlife**	Deer	434	2.2E+11	4.1%
		Ducks	63	1.5E+11	2.9%
		Geese	81	4.0E+12	74.7%
		Beavers	33	8.3E+09	0.2%
		Raccoons	449	5.6E+10	1.1%
		Muskrats	8220	2.8E+11	5.2%
		Totals	9281	4.7E+12	88.1%
	Agriculture	Livestock	1	0.0E+00	0.0%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		0.0E+00	0.0%
	Pets	Dogs	371	3.5E+11	6.5%
	Humans	Septic Tanks	268	1.9E+11	3.5%
		Boating	4	2.2E+09	0.0%
		Straight Pipes	5	9.7E+10	1.8%
		SSOs	0	0.0E+00	0.0%
	Totals			**5.3E+12**	**100%**
Beaverdam Creek (Subwatersheds 2, 3)	**Wildlife**	Deer	200	1.0E+11	4.1%
		Ducks	29	6.9E+10	2.9%
		Geese	37	1.8E+12	74.4%
		Beavers	32	7.9E+09	0.3%
		Raccoons	202	2.5E+10	1.0%
		Muskrats	4274	1.5E+11	6.0%
		Totals	4773	2.1E+12	88.7%
	Agriculture	Livestock	1	0.0E+00	0.0%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		0.0E+00	0.0%
	Pets	Dogs	148	1.4E+11	5.7%
	Humans	Septic Tanks	126	8.8E+10	3.7%
		Boating	1	4.1E+08	0.0%
		Straight Pipes	2	4.5E+10	1.9%
		SSOs	0	0.0E+00	0.0%
	Totals			**2.5E+12**	**100%**

Impaired Water	Source		Number	Fecal Coliform Load (cfu/Day)	% Total Load
Beaverdam Creek, UT (Subwatershed 3)	**Wildlife**	Deer	64	3.2E+10	4.2%
		Ducks	9	2.2E+10	3.0%
		Geese	12	5.8E+11	76.5%
		Beavers	11	2.7E+09	0.4%
		Raccoons	65	8.2E+09	1.1%
		Muskrats	1381	4.7E+10	6.2%
		Totals	1543	6.9E+11	91.3%
	Agriculture	Livestock	0	0.0E+00	0.0%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		0.0E+00	0.0%
	Pets	Dogs	47	4.4E+10	5.9%
	Humans	Septic Tanks	20	1.4E+10	1.9%
		Boating	0	2.6E+08	0.0%
		Straight Pipes	0	0.0E+00	1.0%
		SSOs	0	0.0E+00	0.0%
	Totals			**7.6E+11**	**100%**
Mill Creek (Subwatershed 11)	**Wildlife**	Deer	221	1.1E+11	3.3%
		Ducks	38	9.2E+10	2.8%
		Geese	48	2.4E+12	71.3%
		Beavers	23	5.9E+09	0.2%
		Raccoons	241	3.0E+10	0.9%
		Muskrats	6665	2.3E+11	6.8%
		Totals	7237	2.8E+12	85.3%
	Agriculture	Livestock	51	1.4E+10	0.4%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		1.4E+10	0.4%
	Pets	Dogs	82	7.8E+10	2.3%
	Humans	Septic Tanks	400	2.6E+11	7.9%
		Boating	5	2.7E+09	0.1%
		Straight Pipes	8	1.3E+11	4.0%
		SSOs	0	0.0E+00	0.0%
	Totals			**3.3E+12**	**100%**
Barrows Creek (Subwatershed 17)	**Wildlife**	Deer	192	9.6E+10	1.2%
		Ducks	25	6.0E+10	0.8%
		Geese	32	1.6E+12	19.9%
		Beavers	32	7.9E+09	0.1%
		Raccoons	133	1.7E+10	0.2%
		Muskrats	5667	1.9E+11	2.5%
		Totals	6079	1.9E+12	24.7%
	Agriculture	Livestock	151	4.3E+12	55.4%
		Biosolids	2329 (tons)	1.0E+12	12.8%
		Totals		5.3E+12	68.2%
	Pets	Dogs	78	7.3E+10	0.9%
	Humans	Septic Tanks	114	7.8E+10	1.0%
		Boating	2	1.2E+09	0.0%
		Straight Pipes	2	4.2E+10	0.5%
		SSOs	1	3.5E+11	4.5%
	Totals			**7.8E+12**	**100%**

Table 3.17: Summary of Bacteria Loading from Each Source in the Lower Chickahominy River Watershed by County

County	Source		Number	Fecal Coliform Load (cfu/Day)	% Total Load
Charles City (Subwatersheds 7, 16-20, 23-25)	**Wildlife**	Deer	1426	7.1E+11	2.4%
		Ducks	194	4.7E+11	1.6%
		Geese	250	1.2E+13	40.7%
		Beavers	265	6.6E+10	0.2%
		Raccoons	1320	1.7E+11	0.5%
		Muskrats	58642	2.0E+12	6.6%
		Totals	62098	1.6E+13	52.1%
	Agriculture	Livestock	484	9.1E+12	30.4%
		Biosolids	6644 (tons)	2.9E+12	9.7%
		Totals		1.2E+13	40.1%
	Pets	Dogs	781	7.3E+11	2.4%
	Humans	Septic Tanks	488	3.1E+11	1.0%
		Boating	402	2.4E+11	0.8%
		Straight Pipes	10	1.8E+11	0.6%
		SSOs	8	8.7E+11	2.9%
	Totals			**3.0E+13**	**100%**
James City (Subwatersheds 5, 10-15, 21, 22, 26)	**Wildlife**	Deer	1314	6.6E+11	2.8%
		Ducks	250	6.1E+11	2.6%
		Geese	321	1.6E+13	67.6%
		Beavers	483	1.2E+11	0.5%
		Raccoons	1608	2.0E+11	0.9%
		Muskrats	79133	2.7E+12	11.5%
		Totals	83108	2.0E+13	85.9%
	Agriculture	Livestock	146	5.3E+10	0.2%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		5.3E+10	0.2%
	Pets	Dogs	464	4.4E+11	1.9%
	Humans	Septic Tanks	2331	1.5E+12	6.6%
		Boating	750	4.5E+11	1.9%
		Straight Pipes	45	7.9E+11	3.4%
		SSOs	0	0.0E+00	0.0%
	Totals			**2.3E+13**	**100%**
New Kent (Subwatersheds 1-4, 6, 8, 9)	**Wildlife**	Deer	1231	6.2E+11	3.7%
		Ducks	185	4.5E+11	2.7%
		Geese	238	1.2E+13	69.4%
		Beavers	371	9.3E+10	0.6%
		Raccoons	1256	1.6E+11	0.9%
		Muskrats	30713	1.0E+12	6.2%
		Totals	33993	1.4E+13	83.5%
	Agriculture	Livestock	5	3.8E+09	0.0%
		Biosolids	0 (tons)	0.0E+00	0.0%
		Totals		3.8E+09	0.0%
	Pets	Dogs	891	8.4E+11	5.0%
	Humans	Septic Tanks	1494	1.0E+12	6.3%
		Boating	565	3.4E+11	2.0%
		Straight Pipes	28	5.4E+11	3.2%
		SSOs	0	0.0E+00	0.0%
	Totals			**1.7E+13**	**100%**

4 TMDL DEVELOPMENT

4.1 Overview

A TMDL is the total amount of a pollutant that a waterbody can receive and still meet WQSs. A TMDL may be expressed as a "mass per unit time, toxicity, or other appropriate measure" (CFR, 2006). These loads are based on an averaging period that is defined by the specific WQSs. A TMDL is the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, where applicable, the TMDL may include a future allocation (FA) as necessary. This definition is denoted by the following equation:

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS} + (\text{FA, where applicable})$$

This section documents the detailed *E. coli* and enterococci TMDLs and LA development for lower Chickahominy River and its tributaries.

4.2 Selection of A TMDL Endpoint

An important step in developing the TMDL is the establishment of in-stream numerical endpoints, which are used to evaluate the attainment of acceptable water quality and allowable loading capacity. According to WQS 9VAC25-260-170, for recreational use, the numerical criterion in freshwater is an *E. coli* Geometric Mean of 126 CFU/100 ml and a single sample maximum of 235 CFU/100 ml, and in transition and saltwater is an enterococci Geometric Mean of 35 CFU/100 ml and a single sample maximum of 104 CFU/100 ml. In this study, to be consistent, all source assessment and numerical model results are quantified by fecal coliform, as most of the literature and model parameters are documented for fecal coliform. The following translator equations (VA-DEQ, 2003; VA-DEQ and VA-DCR, 2008) were used to convert fecal coliform concentrations to enterococci and *E. coli* concentrations:

$$\log_2(Enterococci) = 1.2375 + 0.59984 \times \log_2(Fecal\ Coliform)$$
$$\log_2(E.coli) = -0.0172 + 0.91905 \times \log_2(Fecal\ Coliform)$$

4.3 Model Development for Computing TMDL

The use of numerical models is a widely used approach for TMDL and other water quality studies. In this study, a system of numerical models was applied to simulate the loadings of bacteria and the resulting response of in-stream bacteria. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model Loading Simulation Program in C++ (LSPC), developed by the USEPA (Shen *et al*., 2005), was selected to simulate the watershed hydrology and bacteria loadings in the watershed. The Environmental Fluid Dynamics Computer Code (EFDC) (Hamrick, 1992a; Park *et al*., 1995) was used to simulate bacteria transport in the receiving water. A detailed model description, model setup, model calibration, and scenario runs are presented in Appendix A.

The LSPC model is driven by hourly precipitation and was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flows and bacteria loadings from each subwatershed were fed into the adjacent water quality model segments. The EFDC model simulates the transport and fate of bacteria in the stream. Figure 4.1 shows the modeling process.

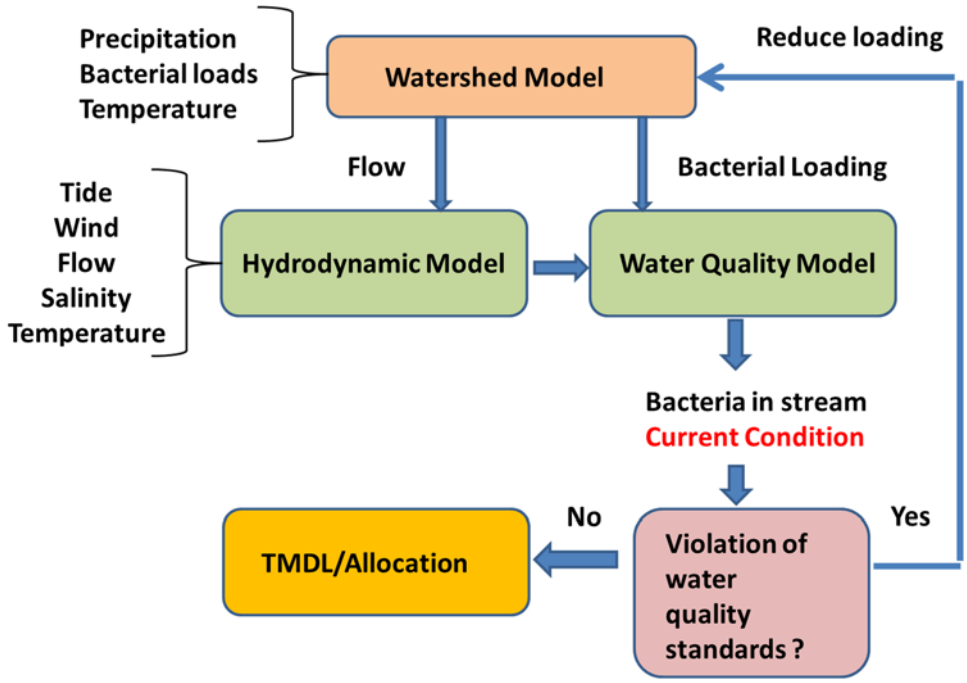

Figure 4.1: Modeling Process for TMDL Development

There is no USGS gage station in the lower Chickahominy River watershed. Therefore, the watershed model was calibrated for the upper Chickahominy River watershed where USGS long-term flow measurements are available (USGS 02042500 - Chickahominy River near Providence Forge, VA). An example of model calibration of the flow is shown in Figure 4.2. Detailed modeling processes and the calibration procedure are presented in Appendix A.

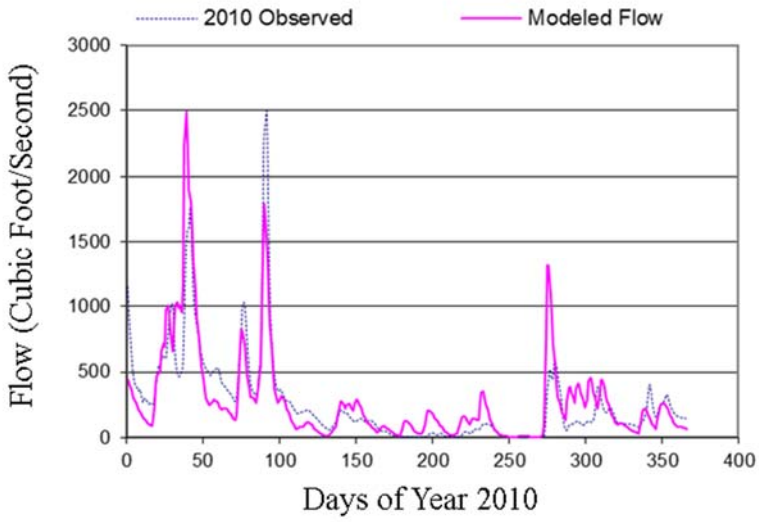

Figure 4.2: Time Series Comparison of Daily Stream Flow between Model Simulation and Observations from USGS Stream Gage 2042500 in 2010

The watershed model was calibrated using non-tidal instream observations. The model simulated daily watershed run-off discharged to the surface of the impaired non-tidal streams from adjacent watersheds and small creeks connected to them. A constant decay rate of 0.5 per day was used for the bacterial loss in the stream. Figure 4.3 illustrates the model output and compares that with instream observations in Mill Creek. The criteria to judge the model performance are 1) whether model result covers the observation range, and 2) whether the observed and modeled violation rates are comparable. The *E. coli* single sample maximum criterion (235 cfu/100 ml) was used to determine violation rates. It can be seen that the model simulates the bacteria variations during the calibration period well, indicating that the model is capable of TMDL development. The detailed model calibration at all stations that violate the WQSs is presented in Appendix A.

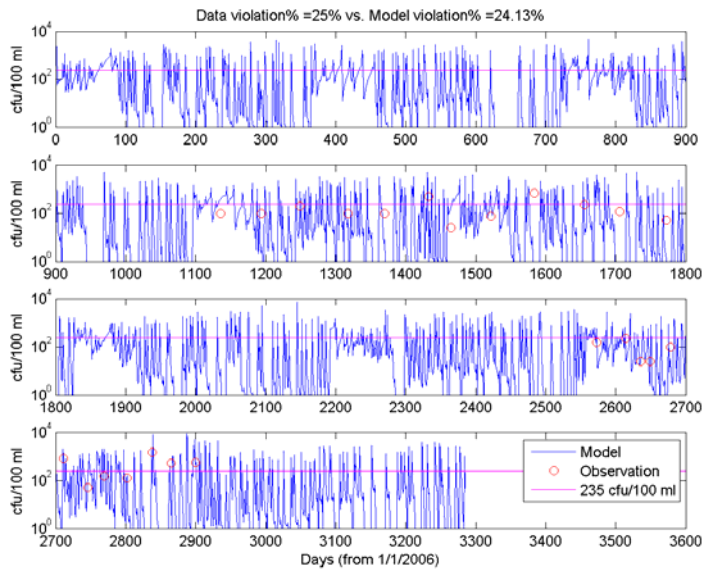

Figure 4.3: Time Series Comparison of *E. coli* between Model Simulation and Observations in Mill Creek

The estuarine model (EFDC) was calibrated for tide, salinity, and bacteria concentration using hydrodynamic and water quality measurements. All had satisfactory results. An example of the bacteria concentration calibration at two stations in the lower Chickahominy River is presented in Figure 4.4. The bacteria concentration calibrations used a 10-year model simulation (2006-2016) and a constant bacteria decay rate of 0.5/day. It can be seen that the model simulated observations well for both the violation rates and observation ranges. The bacteria concentration calibrations at all stations that violate the WQSs are presented in Appendix A, along with calibration results for tide and salinity.

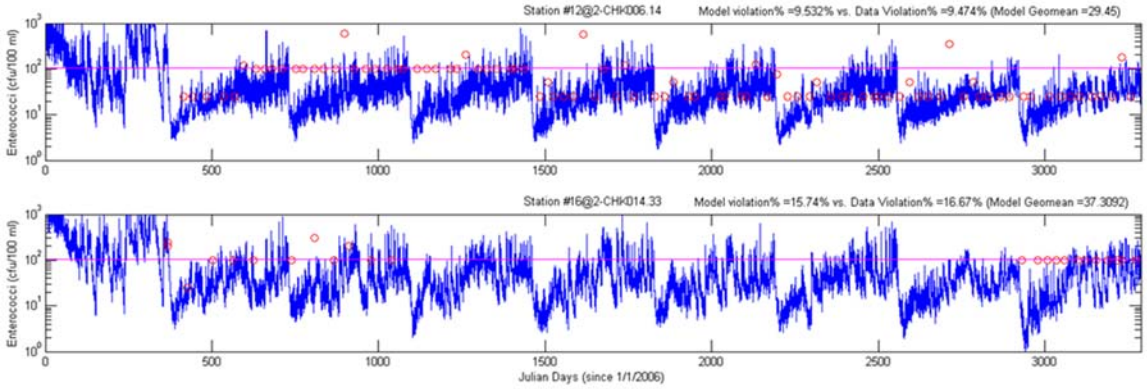

Figure 4.4: Time Series Comparison of Enterococci between Model Simulation and Observations at Two Stations in the Lower Chickahominy River. The Red Line Denotes the Single Sample Maximum of 104 cfu/100ml.

4.4 Consideration of Critical Conditions and Seasonal Variation

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs to 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 waterbody is protected during times when they are most vulnerable. Critical conditions are important because they describe the factors that combine to cause a violation of WQSs and help to identify the actions that may have to be undertaken to meet WQSs.

The current loadings to the waterbody were determined using a long-term record of water quality monitoring (observation) data. The period of record for the data was 2003 to 2015, which spans different flow regimes and temperatures, and includes the period that has the highest violation in the River. A 10-year period of model simulation (from 2006-2016) with highest fecal coliform concentration over the entire simulation period was used to develop the TMDL, which is the most stringent period for the attainment of WQSs. The resulting estimate is quite robust. Seasonal variations involved changes in surface runoff, stream flow, and water quality as a result of hydrologic and climatologic patterns. These are accounted for by the use of this long-term simulation to estimate the current load and reduction targets.

4.5 Margin of Safety

Because of uncertainty of model and data, a margin of safety (MOS) needs to be considered to allocate loads while protecting the aquatic environment. A MOS is typically expressed either as an unallocated assimilative capacity or as conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed controls). In the TMDL calculation, the MOS can either be explicitly stated as an additional separate quantity, or implicitly stated, as in conservative assumptions. For the Lower Chickahominy River and its tributaries, an implicit MOS was included in the TMDLs as a result of the conservative assumptions used in the load calculations. Examples of the implicit MOS used in the development of the TMDLs are:

- Selecting conservative modeling parameters in developing the TMDLs,
- Selecting long term modeling periods that cover the critical hydrologic and water quality conditions, and
- Allocating permitted point sources at the maximum allowable bacteria concentrations.

4.6 TMDL Computation

According to the endpoints for the established pollutant reduction target, the allowable bacteria loading reduction to meet the criteria can be computed. The load reduction needed for the attainment of the criteria was determined as follows:

$$\textbf{Load Reduction} = \frac{\textbf{Current Load} - \textbf{Allowable Load}}{\textbf{Current Load}} \times 100\,\%$$

All TMDLs have some probability of being exceeded. That probability is either explicitly specified or implicitly assumed. EPA guidance states that the probability component of a calculated maximum daily load from daily simulation should be "based on a representative statistical measure" that is dependent upon the specific TMDL and best professional judgment of the developers (USEPA, 2007). The maximum daily load (MDL) for this analysis is determined based on a pre-defined probability and long-term simulation. The computed MDL is consistent with achieving the annual cumulative load target. A 90th percentile was selected as the pre-defined probability, which agrees with the single sample maximum criteria. The results of load and load reduction for each listed segment and for each county are listed in Table 4.1 and Table 4.2. The annual load was computed as multiple year mean annual load, or mean daily load times 365.25 day. The results and reductions expressed as annual loads are listed in Tables 4.1 and 4.2.

The loadings for each bacterial source were determined based on source assessment. Load allocations for each source category were determined by multiplying the total current and allowable loads by the representative percentage of Table 3.14. The percent reduction needed to attain the water quality criteria (WQC) was allocated to each source category. The loads and load reductions for each source category for Chickahominy River and its tributaries are presented in Table 4.3. The loads were allocated to the LA. The WLAs for the individual permits are estimated based on design flow and permitted bacterial concentration. The VDOT MS4 loading is estimated based on the total road length within each subwatershed. The James City County MS4 loading was based on the regulated area map provided by the County. The total allowable loading was divided by the urban landuse area of the subwatershed, and then multiplied by the total MS4 area of VDOT and James City County. The urban landuse is comprised of the sum of High Intensity Residential, Median Intensity Residential, Low Intensity Residential areas, and open space based on 2011 NLCD data.

The TMDL seeks to eliminate 100% of the human-derived fecal component regardless of the allowable load determined through the LA process. Human-derived fecal coliforms are a serious concern in the estuarine environment and the discharge of human waste is precluded by the Commonwealth's law and by federal law. According to the preceding analysis and model simulations, except for the enterococci reduction of the whole Chickahominy River, reduction of the controllable loads, i.e., human, livestock and pets, will not result in achievement of the WQS. Absent any other sources to which a reduction can be applied, a reduction is also applied to wildlife. The allocations presented demonstrate how the TMDLs could be implemented to achieve WQS; however, the Commonwealth reserves the right to allocate differently, as long as consistency with the achievement of WQS is maintained.

Table 4.1: Estimated Daily/Annual Maximum Loads and Load Reductions for Fecal Bacteria by Impaired Waters

Impaired Water	Pollutant	Current Load		Allowable Load		Required Reduction
		Daily (cfu/Day)	Annual (cfu/Year)	Daily (cfu/Day)	Annual (cfu/Year)	
Diascund Creek (Non-tidal)	*E. coli*	2.04E+11	3.81E+13	6.70E+10	1.25E+13	67.1%
Beaverdam Creek		2.49E+11	4.73E+13	3.33E+10	6.34E+12	86.6%
XAH-Beaverdam Creek, UT		8.37E+10	1.61E+13	1.17E+10	2.26E+12	86.0%
Barrows Creek		6.59E+11	1.26E+14	1.81E+10	3.45E+12	97.3%
Mill Creek		1.71E+11	3.30E+13	3.53E+10	6.80E+12	79.4%
Diascund Creek (Tidal)	Enterococci	3.20E+12	5.22E+14	7.55E+11	1.23E+14	76.4%
Chickahominy River (Entire Watershed)		2.97E+13	4.94E+15	1.36E+13	2.26E+15	54.2%
Gordon Creek		4.46E+12	7.54E+14	1.19E+12	2.02E+14	73.2%

Table 4.2: Estimated Daily/Annual Maximum Loads and Load Reductions for Fecal Bacteria by County

County	Pollutant	Current Load		Allowable Load		Required Reduction
		Daily (cfu/Day)	Annual (cfu/Year)	Daily (cfu/Day)	Annual (cfu/Year)	
New Kent	*E. coli*	5.37E+11	1.02E+14	1.12E+11	2.11E+13	79%
Charles City		6.59E+11	1.26E+14	1.81E+10	3.45E+12	97%
James City		1.71E+11	3.30E+13	3.53E+10	6.80E+12	79%
New Kent	Enterococci	3.00E+12	4.88E+14	2.25E+12	3.66E+14	25%
Charles City		9.55E+12	1.58E+15	5.83E+12	9.68E+14	39%
James City		1.72E+13	2.88E+15	5.52E+12	9.27E+14	68%

Table 4.3: Estimated Daily Loads and Load Reductions by Nonpoint Source Category for Bacteria Impaired Waters[1]

Impaired Water	Pollutant	Source	Current Load (cfu/day)	Allowable Load (cfu/day)	Reduction Needed
Diascund Creek (Non-tidal)	*E. coli*	Wildlife	1.79E+11	6.63E+10	63.0%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	1.33E+10	0.00E+00	100.0%
		Human	1.09E+10	0.00E+00	100.0%
		Total	2.04E+11	6.63E+10	67.4%
Beaverdam Creek	*E. coli*	Wildlife	2.21E+11	3.30E+10	85.1%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	1.43E+10	0.00E+00	100.0%
		Human	1.38E+10	0.00E+00	100.0%
		Total	2.49E+11	3.30E+10	86.8%

Impaired Water	Pollutant	Source	Current Load (cfu/day)	Allowable Load (cfu/day)	Reduction Needed
XAH-Beaverdam Creek, UT	*E. coli*	Wildlife	7.64E+10	1.16E+10	84.8%
		Agriculture	0.00E+00	0.00E+00	NA
		Pets	4.91E+09	0.00E+00	100.0%
		Human	2.37E+09	0.00E+00	100.0%
		Total	8.37E+10	1.16E+10	86.1%
Barrow's Creek	*E. coli*	Wildlife	1.63E+11	1.79E+10	89.0%
		Agriculture	4.50E+11	0.00E+00	100.0%
		Pets	6.16E+09	0.00E+00	100.0%
		Human	4.00E+10	0.00E+00	100.0%
		Total	6.59E+11	1.79E+10	97.3%
Mill Creek	*E. coli*	Wildlife	1.28E+11	3.05E+10	76.1%
		Agriculture	6.13E+08	0.00E+00	100.0%
		Pets	3.48E+09	0.00E+00	100.0%
		Human	1.79E+10	0.00E+00	100.0%
		Total	1.50E+11	3.05E+10	79.6%
Diascund Creek (Tidal)	Enterococci	Wildlife	2.61E+12	7.19E+11	72.5%
		Agriculture	2.30E+09	0.00E+00	100.0%
		Pets	1.32E+11	0.00E+00	100.0%
		Human	3.30E+11	0.00E+00	100.0%
		Total	3.08E+12	7.19E+11	76.7%
Chickahominy River	Enterococci	Wildlife	2.06E+13	1.32E+13	36.0%
		Agriculture	5.02E+12	0.00E+00	100.0%
		Pets	8.31E+11	0.00E+00	100.0%
		Human	2.62E+12	0.00E+00	100.0%
		Total	2.90E+13	1.32E+13	54.7%
Gordon Creek	Enterococci	Wildlife	4.04E+12	1.17E+12	71.1%
		Agriculture	5.07E+10	0.00E+00	100.0%
		Pets	6.43E+10	0.00E+00	100.0%
		Human	2.53E+11	0.00E+00	100.0%
		Total	4.41E+12	1.17E+12	73.5%

1. The loadings of this table (modeled result) are different from those of Table 3.15 (source assessment). The percentage of each source category in the source assessment process was multiplied by the modelled loading to get the current load of this table.

4.7 Summary of TMDL and Load Allocation

The TMDLs for Chickahominy River and its tributaries are presented in Table 4.4. The loads were allocated to the LA after subtraction of WLA, FA, and MOS from the TMDL. The annual

total maximum load is listed in Table 4.5. The loading provided in the table is estimated based on design flow and permitted bacterial concentration. Because of the nature of the bacteria TMDL, any new or expanded permittee may discharge into the watershed at the bacteria water quality criteria without a TMDL revision.

Table 4.4: *E. Coli* and Enterococci TMDLs in Lower Chickahominy River (cfu/Day)

Impaired Water (Pollutant)	WLA		LA	MOS	TMDL
	Permit #	WLA			
Diascund Creek (Non-tidal) (*E. coli*)	NA	0	6.63E+10	Implicit	6.70E+10
	FA (1%)	6.70E+08			
	Total WLA	6.70E+08			
Beaverdam Creek (*E. coli*)	NA	0	3.30E+10	Implicit	3.33E+10
	FA (1%)	3.33E+08			
	Total WLA	3.33E+08			
XAH-Beaverdam Creek, UT (*E. coli*)	NA	0	1.16E+10	Implicit	1.17E+10
	FA (1%)	1.17E+08			
	Total WLA	1.17E+08			
Barrow's Creek (*E. coli*)	NA	0	1.79E+10	Implicit	1.81E+10
	FA (1%)	1.81E+08			
	Total WLA	1.81E+08			
Mill Creek (E. *coli*)	VAR040037 and VAR040115	4.43E+09	3.05E+10	Implicit	3.53E+10
	FA (1%)	3.53E+08			
	Total WLA	4.78E+09			
Diascund Creek (Tidal) (Enterococci)	VAG404284	2.11E+06	7.19E+11	Implicit	7.55E+11
	VAR040037 and VAR040115	2.86E+10			
	FA (1%)	7.55E+09			
	Total WLA	3.62E+10			
Chickahominy River (Enterococci)	VA0080233	5.17E+07	1.32E+13	Implicit	1.36E+13
	VAG403039	1.32E+06			
	VAG404050	2.11E+06			
	VAG404144	1.32E+06			
	VAG404152	1.32E+06			
	VAG404198	2.11E+06			
	VAG404284	2.11E+06			
	VAR040037 and VAR040115	3.07E+11			
	FA (1%)	1.36E+11			
	Total WLA	4.43E+11			
Gordon Creek (Enterococci)	VAR040037 and VAR040115	1.25E+10	1.17E+12	Implicit	1.19E+12
	FA (1%)	1.19E+10			
	Total WLA	2.44E+10			

Table 4.5: *E. Coli* and Enterococci TMALs in Lower Chickahominy River (cfu/Year)

Impaired Water (Pollutant)	WLA		LA	MOS	TMAL
	Permit #	WLA			
Diascund Creek (Non-tidal) (*E. coli*)	NA	0	1.24E+13	Implicit	1.25E+13
	FA (1%)	1.25E+11			
	Total WLA	1.25E+11			
Beaverdam Creek (*E. coli*)	NA	0	6.28E+12	Implicit	6.34E+12
	FA (1%)	6.34E+10			
	Total WLA	6.34E+10			
XAH-Beaverdam Creek, UT (*E. coli*)	NA	0	2.24E+12	Implicit	2.26E+12
	FA (1%)	2.26E+10			
	Total WLA	2.26E+10			
Barrow's Creek (*E. coli*)	NA	0	3.42E+12	Implicit	3.45E+12
	FA (1%)	3.45E+10			
	Total WLA	3.45E+10			
Mill Creek (*E. coli*)	VAR040037 and VAR040115	8.54E+11	5.88E+12	Implicit	6.80E+12
	FA (1%)	6.80E+10			
	Total WLA	9.22E+11			
Diascund Creek (Tidal) (Enterococci)	VAG404284	7.71E+08	1.17E+14	Implicit	1.23E+14
	VAR040037 and VAR040115	4.66E+12			
	FA (1%)	1.23E+12			
	Total WLA	5.89E+12			
Chickahominy River (Enterococci)	VA0080233	1.9E+10	2.19E+15	Implicit	2.26E+15
	VAG403039	4.8E+08			
	VAG404050	7.7E+08			
	VAG404144	4.8E+08			
	VAG404152	4.8E+08			
	VAG404198	7.7E+08			
	VAG404284	7.7E+08			
	VAR040037 and VAR040115	5.05E+13			
	FA (1%)	2.26E+13			
	Total WLA	7.31E+13			
Gordon Creek (Enterococci)	VAR040037 and VAR040115	2.12E+12	1.98E+14	Implicit	2.02E+14
	FA (1%)	2.02E+12			
	Total WLA	4.14E+12			

Where in Tables 4.4 and 4.5:
TMDL = Total Maximum Daily Load
TMAL = Total Maximum Annual Load
LA = Load Allocation (nonpoint source)
WLA = Wasteload Allocation
FA = Future Allocation
MOS = Margin of Safety

5 IMPLEMENTATION AND PUBLIC PARTICIPATION

5.1 General

Once a TMDL has been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream. For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES)/National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. 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 implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf. 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.

5.2 Staged Implementation

In general, Virginia intends for the required pollutant reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, BMP technology can be used to reduce the runoff of bacteria discharging to the waters. It will be efficient to remove the livestock impact. Additionally, in both urban and rural areas, reducing the human loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

The iterative implementation of BMPs in the watershed has several benefits:

1. To enable tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. To provide a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. To provide a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. To help to ensure that the most cost-effective practices are implemented first; and
5. To allow for the evaluation of the adequacy of the TMDL in achieving WQSs.

Watershed stakeholders will have the opportunity to participate in the development of the TMDL implementation plan.

5.3 Reasonable Assurance for Implementation

5.3.1 Follow-Up Monitoring

Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or, when deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

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

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Ancillary monitoring by citizens', 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 quality assurance/quality control (QA/QC) guidelines in order to maximize compatibility with DEQ 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 that they monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bi-monthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.state.va.us/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring.aspx.

To demonstrate that the watershed is meeting WQSs for watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, DO, etc.) is bi-monthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

5.3.2 Regulatory Framework

While Section 303(d) of the CWA and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the LAs and WLAs can and will be implemented. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act ("WQMIRA") directs the SWCB to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). WQMIRA also establishes that 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 WQSs, monitoring plans and milestones for attaining WQSs.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater-related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing, at a minimum, the WQMIRA requirements will be developed. An exception is the municipal separate storm sewer systems (MS4s), which are both covered by NPDES permits and expected to be included in TMDL implementation plans. Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional and local offices of DEQ, DCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between the EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

DEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the SWCB for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning.

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

5.3.3 Implementation Funding Sources

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." Potential sources for implementation 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, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions.

The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

5.4 Public Participation

The development of the TMDL would not have been possible without public participation. The first public meeting was held on July 28, 2015 at Heritage Public Library located at 6215 D Chesapeake Circle, New Kent, VA 23124. The public meeting informed the stakeholders of the TMDL development process and was intended to obtain feedback. Methods of the hydrologic calibration, bacteria source estimates, and TMDL development were discussed in the public meeting. A TAC was formed and the first TAC meeting was held on October 7, 2015 in Charles City County Social Center located at 8320 Ruthville Road, Providence Forge, VA 23140. The source assessment methods were refined and information updated. The second TAC meeting was held on January 19, 2016 at the same location. The source assessment method was finalized and the model results were presented. The second public meeting was held on April 26, 2016, again at the Charles City County Social Center. The TMDL was presented and discussed.

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APPENDIX A. MODEL DEVELOPMENT

A.1 Model Development

Numerical models are widely used for TMDLs and other water quality studies. In this study, a system of numerical models was developed to simulate the loadings of bacteria, and the resulting response of in-stream bacteria transport and fate. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-transport model. The watershed model LSPC, developed by the USEPA, was selected to simulate bacteria loads to the receiving waterbody of the Lower Chickahominy River watershed. The EFDC model (Hamrick, 1992a; Park *et al*., 1995) was used to simulate the water quality of the receiving water.

A.1.1 Model Description

A.1.1.1 Watershed Model

The LSPC model is a stand-alone, personal computer-based watershed modeling program developed in Microsoft C++ (Shen *et al*., 2005). It includes selected Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream transport model (USEPA, 2001, 2004; Shen *et al*., 2002a, b). Like other watershed models, LSPC is a precipitation-driven model and requires necessary meteorological data as model input.

LSPC was configured for the Lower Chickahominy River watershed to simulate it as 26 hydrologically connected subwatersheds (Figure 3.1). The subwatersheds were used as modeling units and LSPC was used to simulate the freshwater flow and its associated nonpoint source bacteria. The simulated flow and load for each subwatershed were fed into the adjacent water quality model grid cells. In simulating nonpoint source bacteria from the watershed, LSPC uses a traditional build-up and wash-off approach. Bacteria from various sources (livestock, wildlife, septic systems, etc.) accumulate on the land surface and are subject to runoff during rainfall events. Different land uses are associated with various anthropogenic and natural processes that determine the potential load. The pollutants that are contributed by interflow and groundwater are also modeled in LSPC for each land use category. Bacteria loadings from surface runoff, interflow, and groundwater outflow are combined to form the final loading output from LSPC. In summary, nonpoint sources from the watershed are represented in the model as landuse-based runoff from the landuse categories to account for their contribution (USEPA, 2001).

For this study, the final loads were converted to model accumulation rates (ACQOP, units of cfu/acre/day for bacteria). The ACQOP can be calculated for each land use based on all sources contributing bacteria to the land surface. Sources of bacteria are described in Section 3. The dominant bacterial sources are from wetlands, forest, and urban landuse. Wildlife contributions from different animals are summed together to obtain total loading as cfu per day and applied to forest and wetland. Contributions from wildlife (birds/ducks) and humans (including pets) are

summed together and then applied to the urban landuse. Contributions from livestock were applied only to the subwatershed(s) where sources are located. A loading estimation was conducted for each subwatershed and each landuse so that spatial loading variations can be simulated. The final loads discharged to the stream were estimated based on model simulation results to minimize the uncertainty of source variations in different subwatersheds. The other two major parameters governing bacteria simulation, the maximum storage limit (SQOLIM, units in cfu/acre/day) and the wash-off rate (WSQOP, units in inches/hour), were specified based on soil characteristics and land use practices (Shen *et al*., 2005). The WSQOP is defined as the rate of surface runoff that results in 90% removal of pollutants in one hour. The lower the value, the more easily wash-off occurs.

A.1.1.2 Hydrodynamic Model

Hydrodynamic transport is the essential dynamic for driving the movement of dissolved and particulate substances in aquatic waters. Hydrodynamic models are used to represent transport patterns in complex aquatic systems. For the Lower Chickahominy River study, the EFDC model was selected to simulate hydrodynamics. EFDC is a general purpose modeling package for simulating 1-, 2-, and 3-dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and oceanic coastal regions. It was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software (Hamrick, 1992a, 1992b). The model code has been extensively tested and documented. The EFDC model has been integrated into the EPA's TMDL Modeling Toolbox for supporting TMDL development (http://www.epa.gov/exposure-assessment-models/efdc).

Inputs to the EFDC model for the Lower Chickahominy River include:

- Bathymetry
- Freshwater inputs (lateral and upstream) from watersheds
- Surface meteorological parameters such as wind
- Bacteria loadings from watershed
- Tide and salinity at the open boundary

The model uses a grid to represent the study area (Figure A-1). The grid is comprised of cells connected through the modeling process. The scale of the grid (cell size) determines the level of resolution in the model and the model efficiency from an operational perspective. The smaller the cell size, the higher the resolution and the lower the computational efficiency. The model grid used for the Lower Chickahominy River was developed based on the high-resolution shoreline digital files from USEPA and USGS topographic maps. The grid covers the entire Lower Chickahominy River so that the mouth of the River can be used to set the boundary condition. There are a total of 1,279 cells in the horizontal surface grid and 8 vertical layers. Long-term mean salinity at the surface and the bottom, and harmonic tidal constituents were

used for the model open boundary. Daily flow and bacteria loading were discharged to the River for the simulations.

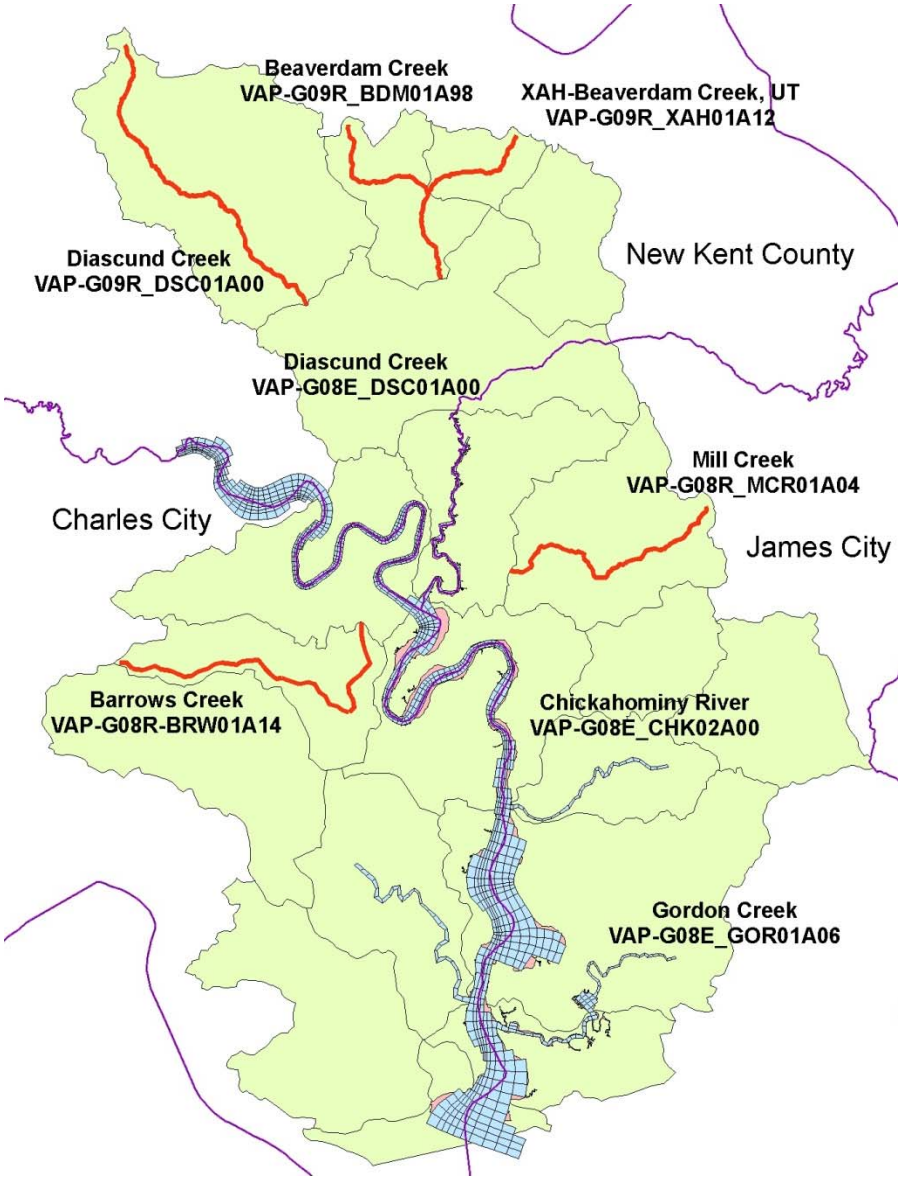

Figure A-1: Receiving Water Model Grid

A.1.2 Model Calibration and Verification

A.1.2.1 Watershed Model

The calibration process involved adjustment of the model parameters used to represent the hydrologic processes until acceptable agreement between simulated flows and field measurements were achieved. The USGS Gage 02042500 - Chickahominy River near

Providence Forge, VA was used to calibrate the model parameters for hydrology simulation. This is the only gage station in this region. The observation period is from 2007-2016.

Figure A-2 shows the time series comparison of daily stream flow for years 2010, 2011, 2012, and 2013 using USGS and model-simulated data. It can be seen that model results match the observations well. Figure A-3 shows the long-term daily stream flow frequency comparison between the model results and USGS field data. Figures A-4 through A-8 show the in-stream bacteria calibration results of the impaired non-tidal watersheds. The criteria to judge the model performance are 1) whether model result covers the observation range, and 2) whether the observed and modeled violation rates are comparable. It can be seen that the model concentration range covers the observed concentration range, and the violations rates of the modeled and observed data are similar. Based on the aforementioned comparisons, it can be concluded that the LSPC model has reasonably reproduced the observations.

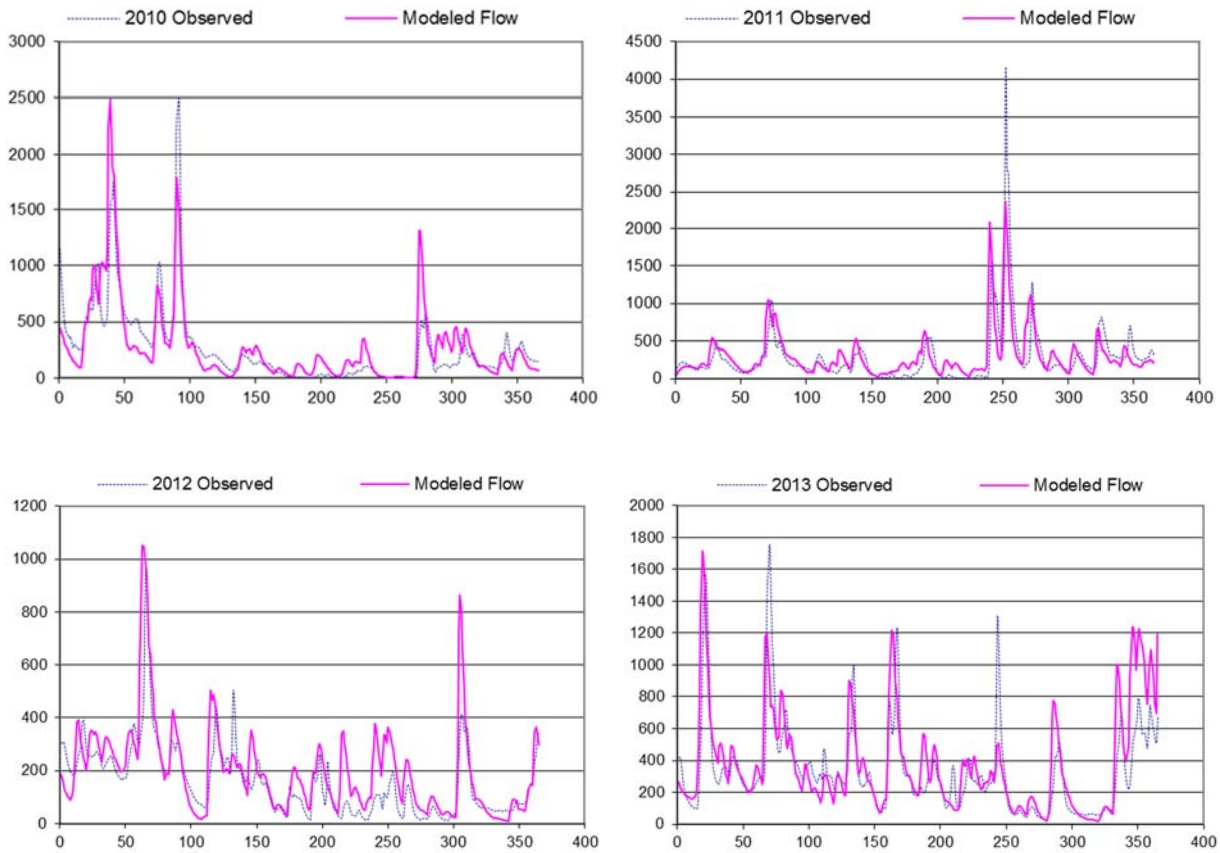

Figure A-2: Time Series Comparison of the Daily Stream Flow between Model Simulation and Observed Data from USGS Gage 01484800 from 2010 to 2013. The X-axis is Days of the Year, and the Y-Axis is Flow in cfs.

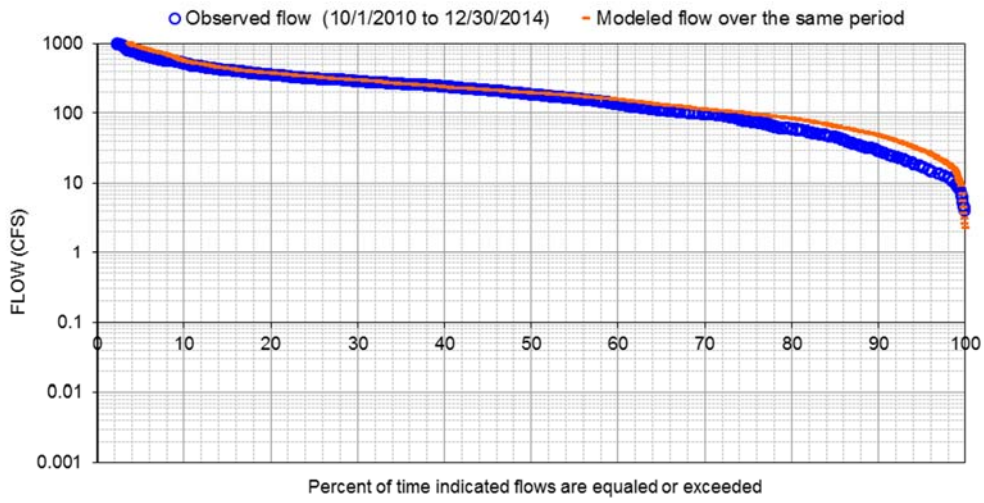

Figure A-3: 4-year Accumulated Daily Stream Flow Comparison between Model Simulation and USGS Observations

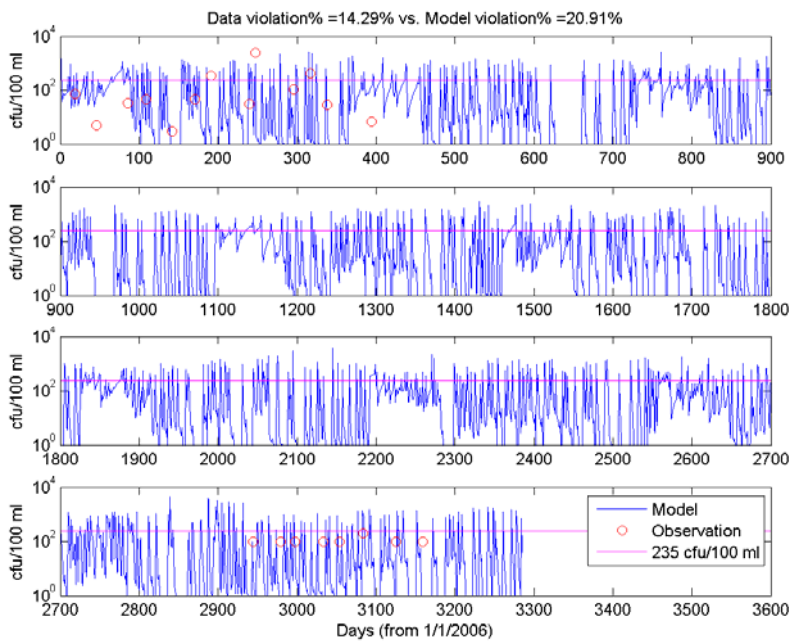

Figure A-4: Comparison of the Modeled and Observed Bacteria Concentrations in Non-tidal Diascund Creek

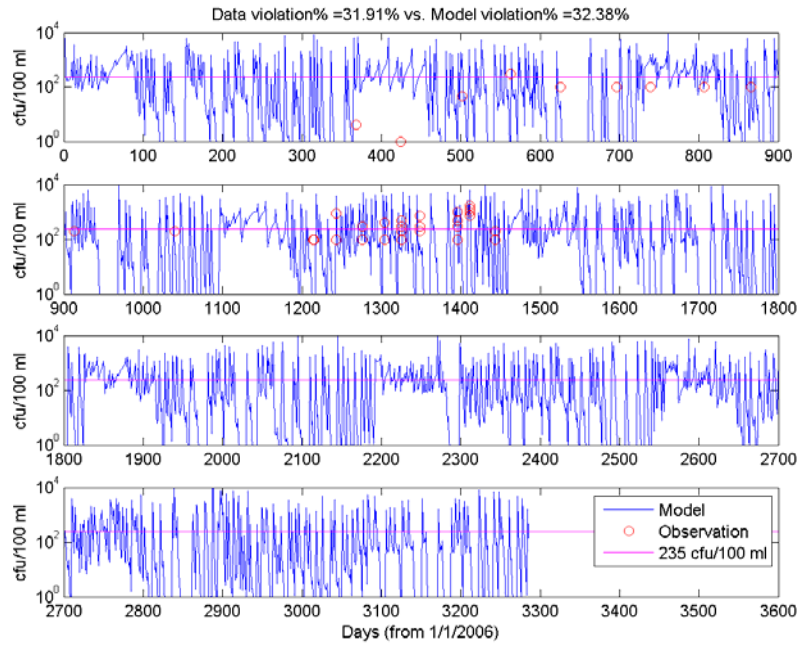

Figure A-5: Comparison of the Modeled and Observed Bacteria Concentrations in Beaverdam Creek. (Data from All Stations are Merged Together.)

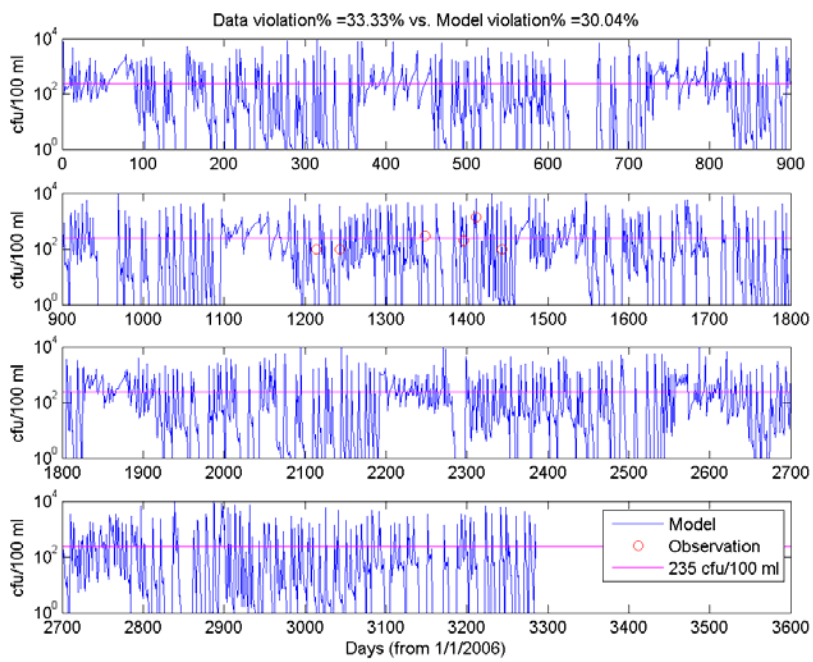

Figure A-6: Comparison of the Modeled and Observed Bacteria Concentrations in the Unnamed Tributary of Beaverdam Creek

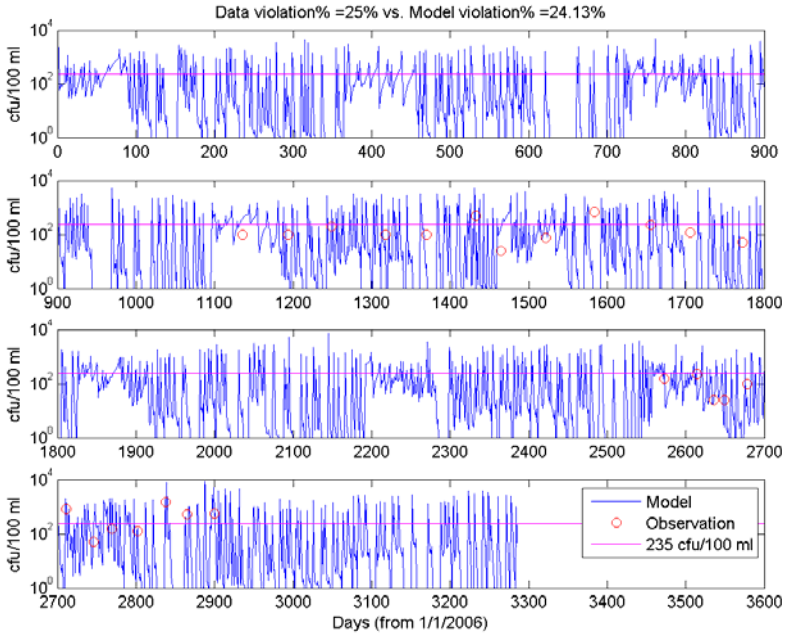

Figure A-7: Comparison of the Modeled and Observed Bacteria Concentrations in Mill Creek

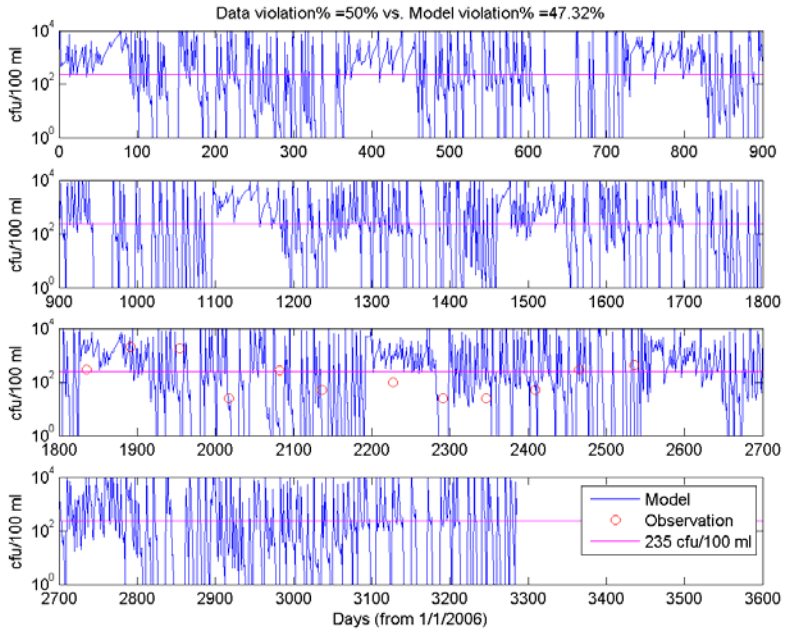

Figure A-8: Comparison of the Modeled and Observed Bacteria Concentrations in Barrows Creek

A.1.2.2 Estuarine Model

The 3D EFDC model was calibrated for tide, salinity, and bacteria concentration. The open boundary was driven by hourly tide output from a large domain Chesapeake Bay model (Du and Shen, 2015). The wind data obtained from the NOAA station at the Chesapeake Bay Bridge Tunnel were used for the model. Figure A-9 shows the tide calibration result. The predicted water surface elevations at Station CHK015.12 (Latitude 37.3722, Longitude -76.8991) located at Lower Chickahominy River in Year 2008 were used. The model predictions are satisfactory.

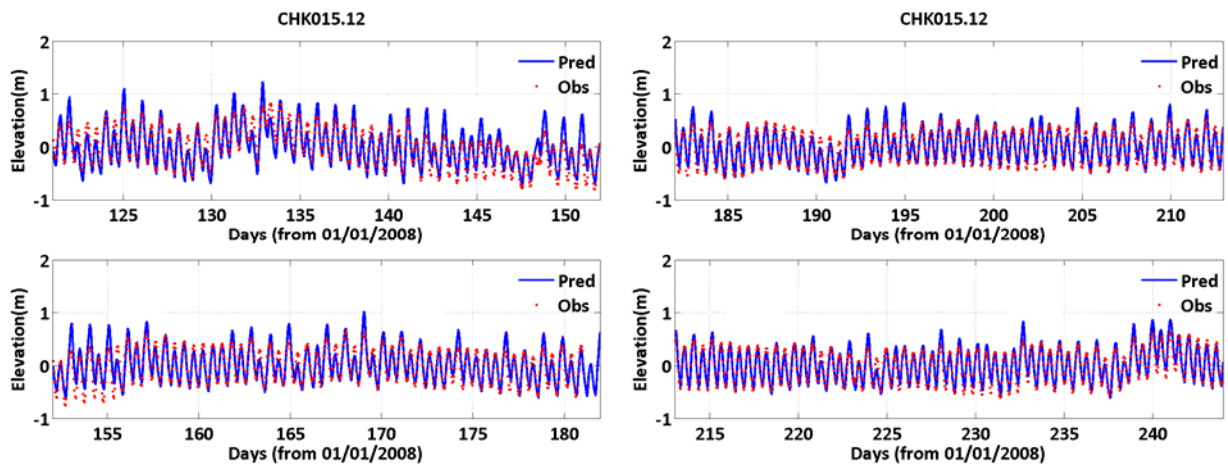

Figure A-9: Comparison of the Predicted and Observed Surface Elevation at Station CHK015.12

An accurate simulation of salinity is more important for the model to correctly simulate estuarine circulation and transport processes of bacteria. There are two stations in the Lower Chickahominy River, which are located at Chickahominy Haven at its upstream and the Route 5 Bridge at its downstream. The salinity is driven by both freshwater inflow and tide, and wind forcing. When freshwater discharge is large, low salinity can be observed. When tide is dominant, high salinity can be observed. The comparison of modeled and observed salinity is shown in Figure A-10.

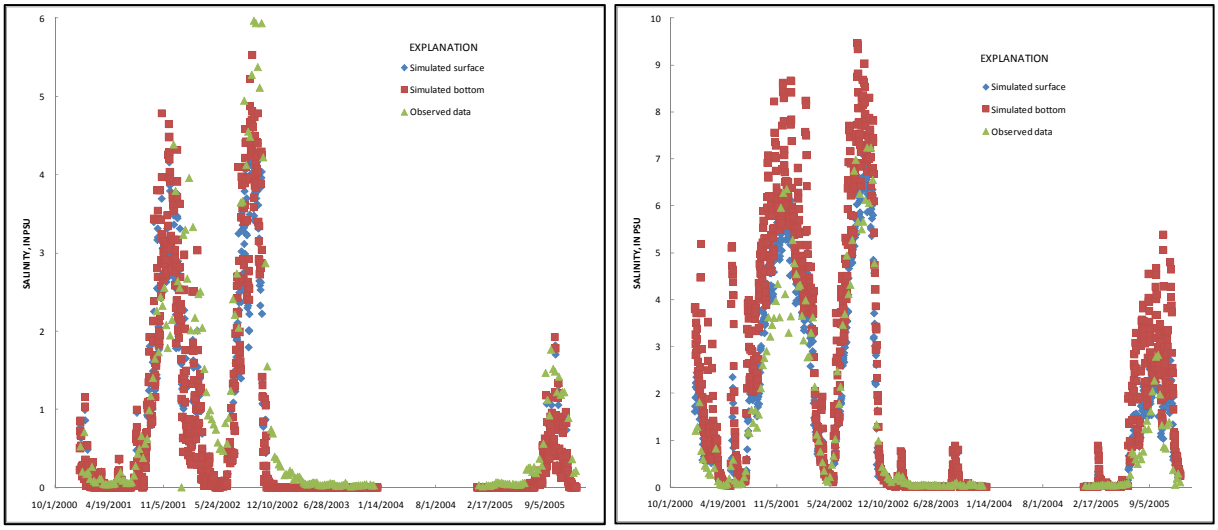

Figure A-10: Comparison of Modeled and Observed Salinity at Stations Chickahominy Haven (Left) and Route 5 Bridge (Right)

Calibration of the bacteria transport model is typically performed using water quality measurements. A 10-year model simulation (2006-2016) is presented in Figure A-11 for comparison. A constant bacteria decay rate of 0.5/day is used, which was derived based upon observations, model calibration, and literature review (Shen and Zhao, 2010). It can be seen that the model simulates observations well for both the violation rates and observation ranges.

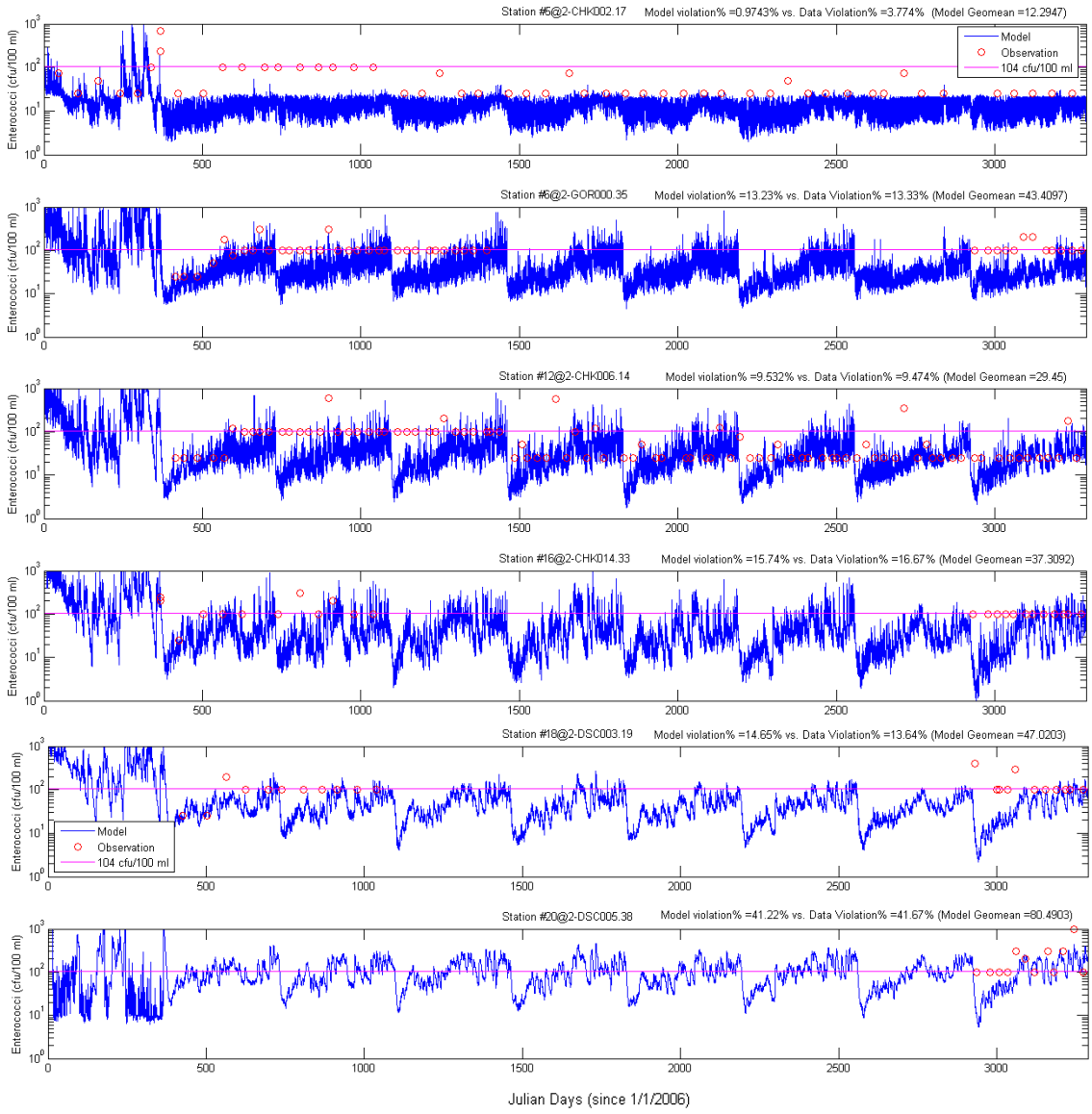

Figure A-11: Model Calibration of Enterococci at the Stations in the Estuary of Lower Chickahominy River

A.2 Allowable Load Calculation

To determine allowable loads and development TMDLs, loadings from each subwatershed were reduced so that the receiving water bacterial concentration will meet the WQC endpoints. The model simulation period from 1999-2014 was used to determine the allowable load. The attainment of water quality is assessed at each station for the geometric mean of 126 cfu/100ml and no more than 10% exceedance of the single sample maximum of 235 for *E. coli*, and for the geometric mean of 35 cfu/100ml and the no more than 10% exceedance of the single sample

maximum of 104 cfu/100ml for enterococci. The most stringent criterion was used for determining the reduction. It was found that, for *E. coli*, the criterion of no more than 10% exceedance of the single maximum of 235 cfu/100ml is the most stringent criterion and, for enterococci, the criterion of the geometric mean of 35 cfu/100ml is the most stringent criterion. When these criteria are met, the WQSs are met. The modeled allowable concentrations of *E. coli* in the non-tidal waters are shown in Figures A-12 to A-16. The modeled allowable concentrations of enterococci in the tidal waters are shown in Figure A-17. It can be seen that the WQSs will be met after the reductions.

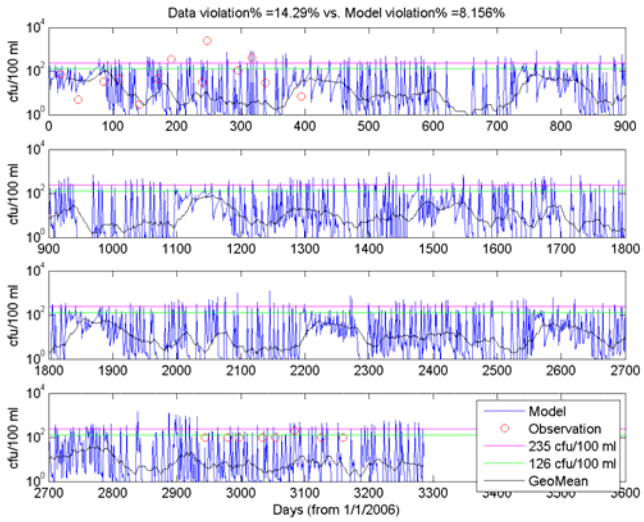

Figure A-12: Modeled and Observed Allowable Bacteria Concentrations in Non-tidal Diascund Creek

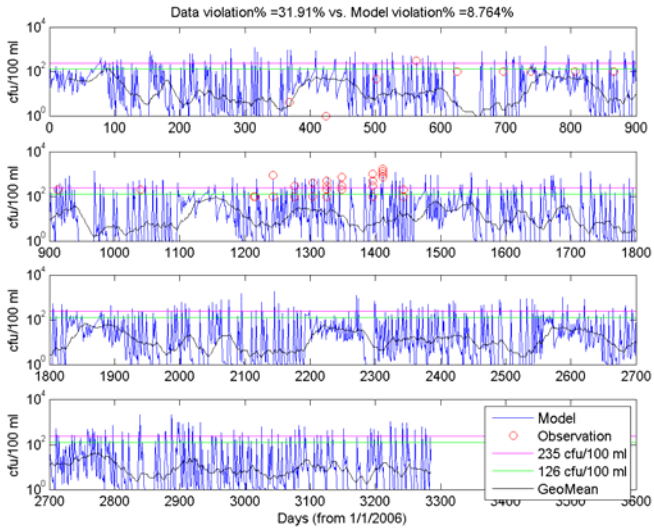

Figure A-13: Modeled and Observed Allowable Bacteria in Beaverdam Creek

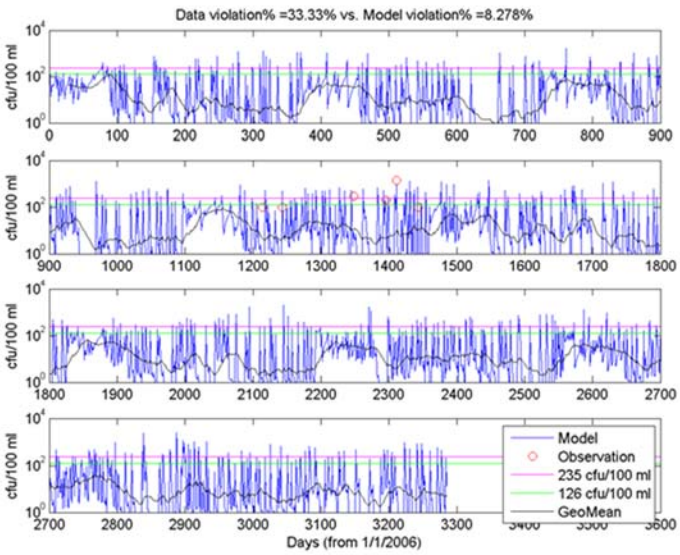

Figure A-14: Modeled and Observed Allowable Bacteria Concentrations in the Unnamed Tributary of Beaverdam Creek

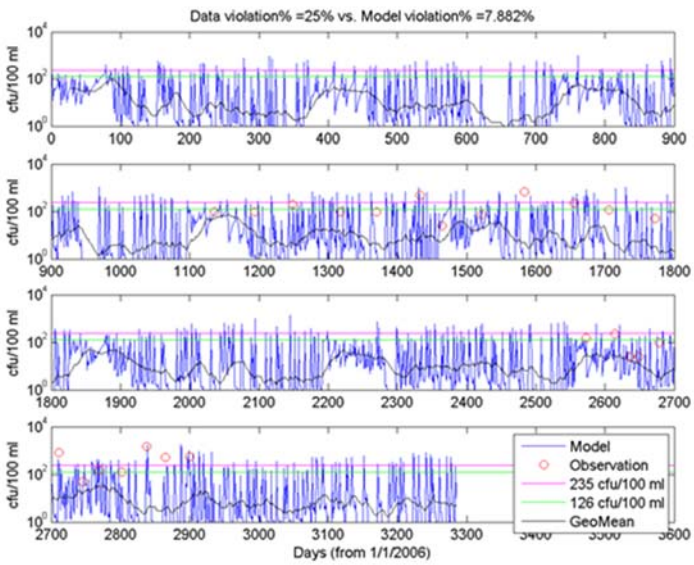

Figure A-15: Modeled and Observed Allowable Bacteria Concentrations in Mill Creek

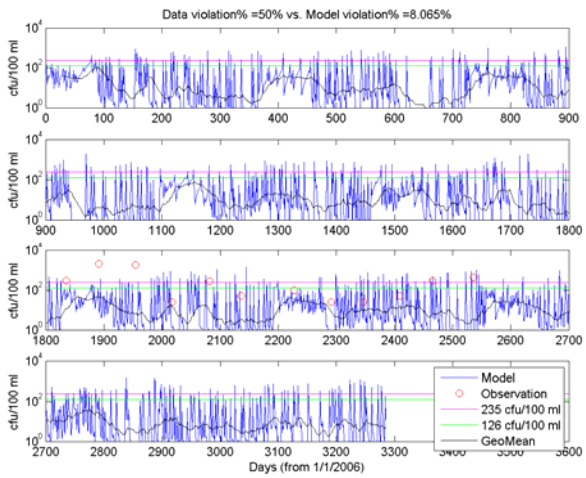

Figure A-16: Modeled and Observed Allowable Bacteria in Barrows Creek

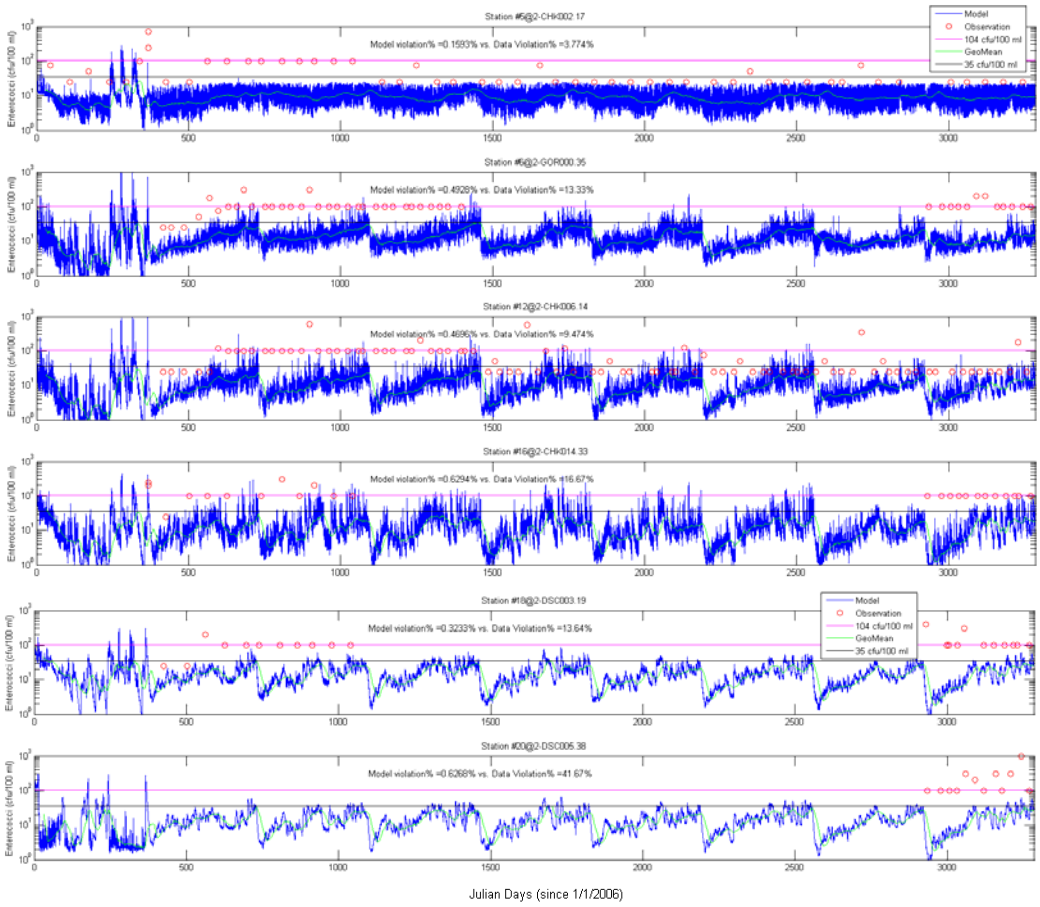

Figure A-17: Modeled and Observed Allowable Bacteria Concentrations in the Tidal Waters

A.3 Sensitivity Test on Single Maximum Criteria by Reducing 50% of the Anthropogenic Source

A sensitivity test was conducted in order to explore the effect of reducing 50% anthropogenic source (Table A.1).

Table A.1: Sensitivity Test on Single Maximum Criteria by Reducing 50% of the Anthropogenic Source.

Stream Name (Impairment ID)	Impairment Type	Monitoring Station	Model Estimated Violation% after 50% Anthropogenic Source Reduction
Chickahominy River (VAP-G08E_CHK02A00)	Enterococci	2-CHK002.17	0.96
		2-CHK006.14	8.55
		2-CHK014.33	12.02
		2-CHK023.64	4.71
Gordon Creek (VAP-G08E_GOR01A06)	Enterococci	2-GOR000.35	12.35
Diascund Creek (VAP-G08E_DSC01A00)	Enterococci	2-DSC003.19	12.58
		2-DSC005.38	38.03
Diascund Creek (VAP-G09R_DSC01A00)	*E. coli*	2-DSC012.67	18.82
Beaverdam Creek (VAP-G09R_BDM01A98)	*E. coli*	2-BDM005.70/ 2-BDM004.60/ 2-BDM004.12/ 2-BDM003.16 (Grouped Together)	29.71
XAH-Beaverdam Creek, UT (VAP-G09R_XAH01A12)	*E. coli*	2-CXAH000.35	27.64
Mill Creek (VAP-G08R_MCR01A04)	*E. coli*	2-MCR002.38	21.23
Barrows Creek (VAP-G08R_BRW01A14)	*E. coli*	2-BRW002.50	28.39

A.4 Total Maximum Daily Load

The TMDL seeks to eliminate 100% of the human-derived fecal component, regardless of the allowable load determined through the LA process. Human-derived forms of fecal bacteria are a serious concern in the estuarine environment and both state and federal laws preclude the discharge of human waste. According to the preceding analysis, except for the whole Chickahominy River enterococci loadings, reduction of the controllable loads (human, livestock, and pets) will not result in achievement of the WQS. Absent any other sources, the reduction is allocated to wildlife. The allocations presented demonstrate how the TMDLs could be implemented to achieve WQSs; however, the Commonwealth reserves the right to allocate differently, as long as consistency with the achievement of WQSs is maintained.

All TMDLs have some probability of being exceeded, with the probability being either explicitly specified or implicitly assumed. EPA guidance states that the probability component of a

calculated maximum daily load (MDL) should be "based on a representative statistical measure" that is dependent upon the specific TMDL and best professional judgment of the developers (USEPA, 2007). This statistical measure represents how often the MDL is expected, or allowed, to be exceeded. The primary options for selecting this level of protection would be:

1. **The maximum daily load reflects some central tendency:** In this option, the maximum daily load is based upon the mean or median value of the range of loads expected to occur. The variability in the actual loads is not addressed.
2. **The maximum daily load reflects a level of protection implicitly provided by the selection of some "critical" period**: In this option, the maximum daily load is based upon the allowable load that is predicted to occur during some critical period examined during the analysis. The developer does not explicitly specify the probability of occurrence.
3. **The maximum daily load is a value that will be exceeded with a pre-defined probability:** In this option, a "reasonable" upper-bound percentile is selected for the maximum daily load based upon a characterization of the variability of daily loads. For example, selection of the 95th percentile value would result in a maximum daily load that would be exceeded 5% of the time.

Because time variable model simulations were conducted, daily loads vary significantly. Daily loading varies both seasonally and annually with respect to different hydrological years. Therefore, the MDL for this analysis is determined based on a pre-defined probability. The computed MDL is consistent with achieving the annual cumulative load target. A 90th percentile was selected as the pre-defined probability, which agrees with the single sample maximum criteria. Because loading distribution is better described by a log-normal distribution in the Lower Chickahominy River and its tributaries, the MDL is computed as follows (USEPA, 2007):

$$TMDL = LTA \cdot \exp(Z_p \sigma_y - 0.5\sigma_y^2)$$

Where Z_p is pth percentage point of the standard normal distribution. For the 95th percentile, Z_p = 1.28. LTA is long-term mean daily loading and σ_y is computed as:

$$\sigma_y = \sqrt{\ln(CV^2 + 1)}$$

where CV is the coefficient of variation of the untransformed data, which equals to the standard deviation divided by the mean.