Bacteria TMDL for the

Tidal Four Mile Run Watershed

Submitted by:

Virginia Department of Environmental Quality

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Interstate Commission on the Potomac River Basin

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List of Acronyms

ARA	Antibiotic Resistance Analysis
BMP	Best Management Practices
BST	Bacteria Source Tracking
cfs	cubic feet per second
cfu	colony forming units
CSO	Combined Sewer Overflows
DCDOE	District of Columbia Department of the Environment
DCR	Department of Conservation and Recreation
DCWASA	District of Columbia Water and Sewer Authority
DEM	Digital Elevation Model
DEQ	Department of Environmental Quality
DMR	Discharge Monitoring Report
DMME	Department of Mines, Minerals, and Energy
DO	Dissolved Oxygen
EPA	Environmental Protection Agency
GIS	Geographic Information System
HSPF	Hydrological Simulation Program Fortran
IP	Implementation Plan
LA	Load Allocation
LID	Low Impact Development
LTCP	Long-Term Control Plan
MGD	Million Gallons per Day
MHHW	Mean Higher High Water Level
mL	milliliters
MLLW	Mean Lower Low Water Level
MOS	Margin of Safety
MOU	Memorandum of Understanding
MS4	Municipal Separate Storm Sewer
NCDC	National Climatic Data Center
NHD	National Hydrography Dataset
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NRCS	Natural Resources Conservation Service
NVRC	Northern Virginia Regional Commission
SPD	Stormwater Planning Division
SSO	Sanitary Sewer Overflows
STATSGO	State Soil Geographic
SWCB	State Water Control Board
TAC	Technical Advisory Committee
TMDL	Total Maximum Daily Load
VADEQ	Virginia Department of Environmental Quality
VDH	Virginia Department of Health
VDOT	Virginia Department of Transportation

VPDES	Virginia Pollutant Discharge Elimination System
VSMP	Virginia Stormwater Management Program Permits
UAA	Use Attainability Analysis
USGS	U.S. Geological Survey
USACE	U. S. Army Corps of Engineers
W2	CE-QUAL-W2 water quality simulation model
WLA	Wasteload Allocation
WQMIRA	Water Quality Monitoring, Information, and Restoration Act
WQMP	Water Quality Management Plan
WWTP	Wastewater Treatment Plant

Executive Summary

This report presents the development of the bacteria TMDL for the tidal Four Mile Run watershed. Segment VAN-A12E-01 of Four Mile Run was listed as impaired for bacteria on Virginia's 2008 303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed on Virginia's 1996 303(d) List for exceedances of the state's water quality criterion for fecal coliform bacteria.

Description of the Study Area

The impaired segment is located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Arlington County, Virginia. The impaired segment of tidal Four Mile Run (VAN-A12E-01) extends from the confluence with the Potomac River at the state boundary to the upstream limit of tidal waters (approximately 0.0516mi$^{2)}$.

The Northern Virginia Regional Commission (NVRC, 2002) developed a TMDL for the non-tidal portion of Four Mile Run. The TMDL was approved in 2002, and an implementation plan (IP) for the TMDL was subsequently completed in 2004 (NVRC, 2004). The TMDL for tidal Four Mile Run will build upon the TMDL for the non-tidal river; load and waste load allocations will be developed only for the tidal drainage below the watershed for the non-tidal portion of Four Mile Run.

Impairment Description

During the 2006 assessment period (January 2000 through December 2004), 2 out of 5 *E. coli* samples (40%) collected at listing station 1AFOU000.19 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml. The data collected at this same station during the 2008 assessment period (January 2001 through December 2006) showed an 18% exceedance rate, with 3 of 17 samples exceeding the maximum criterion.

Applicable Water Quality Standards

At the time of the initial listing of the Tidal Four Mile Run segment, the Virginia Bacteria Water Quality Criteria was expressed in fecal coliform bacteria; however, the bacteria water quality criteria has been recently changed and is now expressed in *E. coli*. Virginia's bacteria water quality criteria currently states that *E. coli* bacteria shall not exceed a geometric mean of 126 *E. coli* counts per 100 mL of water for four or more weekly samples within a calendar-month. If there are insufficient samples to calculate the calendar-month geometric mean, no more than 10% of the total samples in an assessment period can exceed an *E. coli* concentration of 235 counts per 100 mL.

The loading rates for watershed-based modeling are available only in terms of the previous standard, fecal coliform bacteria. Therefore, the TMDL was expressed in *E. coli* by converting modeled daily fecal coliform concentrations to daily *E. coli* concentrations using an instream translator. As of the approval of the latest revisions to Virginia's Water Quality Standards (February 1, 2010), bacteria TMDLs in Virginia are only required to meet the geometric mean criteria.

Watershed Characterization

The land use characterization for the Tidal Four Mile Run watershed was based on land use data developed by the NVRC (2002) for the non-tidal bacteria TMDL. There is no agriculture in the watershed. Less than 10% of the watershed is made up of parks, golf courses, or open space. The rest of the watershed is developed. Potential key sources of bacteria include pets, wildlife, and sanitary sewer cross-connections, spills, or leaks.

Arlington County's Water Pollution Control Facility (WPCF) is the only facility in the bacteria-impaired tidal Four Mile Run watershed that holds an active, individual, municipal Virginia Pollutant Discharge Elimination System (VPDES) permit, issued through the VPDES permitting program. Arlington WPCF is a major municipal wastewater treatment plant permitted to discharge at a maximum rate of 40 million gallons per day (MGD). Arlington County, the City of Alexandria, the Virginia Department of Transportation, and the George Washington Memorial Parkway hold municipal separate storm sewer system (MS4) permits in the watershed. There are also general VPDES permits issued within the watershed, but none of these are permitted to discharge bacteria.

Bacteria Source Tracking

Dr. George Simmons of Virginia Tech (2001) performed an extensive Bacteria Source Tracking (BST) study of the entire Four Mile Run watershed, including the tidal drainage area, in 1998-2000. The study used the "genetic fingerprinting" methodology to identify the source of the *E. coli* bacteria. Genetic fingerprinting attempts to match the DNA found in an unknown sample to DNA from a library of samples with known sources. Wildlife was identified as the predominant source of bacteria in the watershed. There was also a substantial contribution from pets and human sources.

Additional BST sampling was conducted monthly from January 2006 to December 2006 at station 1AFOU000.19 to support the development of the bacteria TMDL for the tidal portion of the watershed. An Antibiotic Resistance Analysis (ARA) method of BST analysis was used. The results were consistent with the earlier BST study.

TMDL Technical Approach

The technical approach for developing the bacteria TMDL for tidal Four Mile Run is built on the earlier TMDL for non-tidal Four Mile Run. The Hydrologic Simulation Program-Fortran (HSPF) model developed for the non-tidal TMDL was extended to simulate bacteria loads from the tidal drainage. In accordance with the non-tidal TMDL, fecal coliform bacteria were simulated by the model and converted to the equivalent *E. coli* bacteria concentrations using the instream translator. January 1999 through May 2001 was chosen as the simulation period, which is the same time frame the non-tidal TMDL used.

HSPF is not capable of simulating tidal waterbodies. The CE-QUAL-W2 model was chosen to simulate the fate and transport of bacteria in tidal Four Mile Run. CE-QUAL-W2 (or W2) is a laterally-averaged, two-dimensional model capable of simulating both hydrodynamics and the water quality of rivers, lakes and reservoirs, and estuaries. It has been used for many TMDLs for these types of waterbodies in EPA Region III and is currently being used to develop bacteria TMDLs for the tidal portions of the James River.

Tidal Four Mile Run was divided into nine active segments, each with up to seven layers, 0.34 feet (1.0 meter) in depth, for a total of 48 cells. Flows and bacteria loads from the HSPF model were used to represent the inputs from both the upstream non-tidal river and tidal drainage. The downstream boundary of the W2 model at the confluence of Four Mile Run and the Potomac River was simulated using tidal elevations from the National Oceanic and Atmospheric Administration's (NOAA) station 8594900 in the Washington Ship Channel and bacteria concentrations collected in the Potomac River by the District of Columbia's Department of the Environment (DCDOE). Flows and bacteria concentrations for Arlington WPCF were taken from the facility's Discharge Monitoring Reports.

The W2 model was calibrated against observed data collected by DEQ at monitoring station 1AFOU000.19 by adjusting the bacteria decay coefficient until the geometric mean of the simulated fecal coliform concentrations matched the geometric mean of the observed data and the simulated exceedance rate of the maximum *E. coli* criterion, when translated into the equivalent fecal coliform concentration, matched the observed exceedance rate over the simulation period.

Both the HSPF and the W2 models are continuous simulation models. Over the course of the simulation period January 1999 through May 2001, seasonal variations and a variety of hydrological conditions are simulated, covering a range of potential critical conditions for meeting water quality standards in Tidal Four Mile Run.

TMDL Calculations

The TMDL represents the maximum amount of a pollutant that the stream can receive without exceeding the water quality standard. The load allocation for the selected scenarios was calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

WLA = wasteload allocation (point source contributions)
LA = load allocation (non-point source allocation)
MOS = margin of safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. The MOS was implicitly incorporated in this TMDL. Implicitly incorporating the MOS required that allocation scenarios be designed to meet a calendar-month geometric mean *E. coli* criterion of 126 cfu/100 mL with 0% exceedance.

The calibrated W2 model was used to test whether potential TMDL scenarios would meet water quality standards for bacteria. Under each potential scenario, it was assumed that water quality standards were met upstream in the non-tidal river and downstream at the confluence with the Potomac River. Simulated bacteria concentrations were set at the upstream and downstream boundaries at a constant 195 cfu/100 mL, the fecal coliform concentration equivalent to the *E. coli* geometric mean criterion. Under each potential scenario, Arlington WPCF was given a wasteload allocation (WLA) equivalent to its permitted *E. coli* concentration of 126 cfu/100 mL and its design flow of 40 MGD. An additional loading (equivalent to 20 MGD discharged at the E. coli geometric mean criterion of 126 cfu/100mL) was also included to allow for the potential growth of point sources in the watershed. Potential load allocations for other sources were based on reductions specified by the potential TMDL scenarios, which were taken from the previously developed non-tidal TMDL. After using the instream translator, the TMDL allocation scenario was selected which met the geometric mean *E. coli* criterion. It was determined that a 98% reduction from pet and human sources and a 95% reduction from wildlife would be required for Tidal Four Mile Run to meet the calendar-month *E. coli* geometric mean water quality criterion of 126 cfu/100 mL. These levels of reduction are the same that were required in the non-tidal Four Mile Run TMDL to meet water quality standards. The bacteria TMDLs for tidal Four Mile Run, in terms of a daily and a yearly load, are presented in Tables E-1 and E-2.

Table E-1: Tidal Four Mile Run TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
1.52E+12	1.08E+11	Implicit	1.63E+12

Table E-2: Tidal Four Mile Run TMDL (cfu/year) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
1.42E+14	3.26E+12	Implicit	1.45E+14

TMDL Implementation

The Commonwealth intends for this TMDL to be implemented through best management practices (BMPs) in the watershed. Implementation will occur in stages. The benefits of staged implementation are: 1) as stream monitoring continues to occur, it allows for water quality improvements to be recorded as they are being achieved; 2) it provides a measure of quality control, given the uncertainties that exist in any model; 3) it provides a mechanism for developing public support; 4) it helps to ensure the most cost effective practices are implemented initially, and 5) it allows for the evaluation of the TMDL's adequacy in achieving the water quality standard.

While section 303(d) of the Clean Water Act 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 load and waste load allocations can and will be implemented. Additionally, Virginia's 1997 Water Quality Monitoring Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act 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 water quality standards, monitoring plans, and milestones for attaining water quality standards.

A TMDL implementation plan already exists for the non-tidal portion of the Four Mile Run Watershed. Arlington County, the City of Alexandria, the City of Falls Church, Fairfax County and other stakeholders in the watershed are performing many of the actions specified in the plan.

Once developed, VADEQ intends to incorporate the TMDL implementation plan into the appropriate Water Quality Management Plan (WQMP), in accordance with the Clean Water Act's Section 303(e). In response to a Memorandum of Understanding (MOU) between EPA and VADEQ, VADEQ also submitted a draft Continuous Planning Process to EPA in which VADEQ commits to regularly updating the WQMPs. Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

1 Introduction

1.1 Regulatory Guidance

Section 303(d) of the Clean Water Act and the Environmental Protection Agency's (EPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop Total Maximum Daily Loads (TMDLs) for water bodies that are exceeding water quality standards. TMDLs represent the total pollutant loading that a waterbody can receive without exceeding water quality standards. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and instream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources (EPA, 2001).

The main environmental, regulatory agency for Virginia is the Department of Environmental Quality (VADEQ). VADEQ works in coordination with the Virginia Department of Conservation and Recreation (DCR), the Department of Mines, Minerals, and Energy (DMME), and the Virginia Department of Health (VDH) to develop and regulate a more effective TMDL process. VADEQ is the lead agency for the development of TMDLs statewide and focuses its efforts on all aspects of reduction and prevention of pollution to state waters. VADEQ ensures compliance with the Federal Clean Water Act and the Water Quality Planning Regulations, as well as with the Virginia Water Quality Monitoring, Information, and Restoration Act (WQMIRA), passed by the Virginia General Assembly in 1997, and coordinates public participation throughout the TMDL development process.

The role of DCR is to administer the Municipal Separate Storm Sewer System (MS4) permits and General Permits for Construction Stormwater, as well as to initiate nonpoint source pollution control programs statewide through the use of federal grant money. DMME focuses its efforts on issuing surface mining permits and National Pollution Discharge Elimination System (NPDES) permits for industrial and mining operations. Lastly, VDH monitors waters for fecal coliform, classifies waters for shellfish growth and harvesting, and conducts surveys to determine sources of bacterial contamination (VADEQ, 2001).

As required by the Clean Water Act and WQMIRA, VADEQ develops and maintains a listing of all impaired waters in the state that details the pollutant(s) causing each impairment and the potential source(s) of each pollutant. This list is referred to as the 303(d) List of Impaired Waters. In addition to 303(d) List development, WQMIRA directs VADEQ to develop and implement TMDLs for listed waters (VADEQ, 2001a). Once TMDLs have been developed, they are distributed for public comment and then submitted to the EPA for approval.

1.2 Impairment Listing

Segment VAN-A12E-01 of Four Mile Run was listed as impaired for bacteria in Virginia's 2008 305(b)/303(d) Water Quality Assessment Integrated Report (VADEQ, 2008) due to exceedances of the state's water quality criteria for *E. coli* bacteria. The segment was first listed as impaired for fecal coliform bacteria on Virginia's 1996 303(d) List, and was included in Attachment A of the 1999 Consent Decree. The impaired segment is located within the Potomac River basin (USGS Cataloging Unit 02070010) in the City of Alexandria and Arlington County, Virginia (**Figure 1-1**).

The impaired segment of tidal Four Mile Run (VAN-A12E-01) extends from the confluence with the Potomac River at the state boundary, to the upstream limit of tidal waters (covering approximately 0.0516mi^2). During the 2006 assessment period (January 2000 through December 2004), 2 out of 5 *E. coli* samples (40%) collected at listing station 1AFOU000.19 exceeded the *E. coli* maximum criterion of 235 cfu/100 ml. The data collected at this same station during the 2008 assessment period (January 2001 through December 2006) showed an 18% exceedance rate, with 3 of 17 samples exceeding the maximum criterion.

Table 1-1 summarizes the details of the impaired segment.

Table 1-1: Impairment Summary for Four Mile Run (VAN-A12E-01)

TMDL ID	Stream Name	Area (mi^2)	Boundaries	Station ID	Impairment for	Exceedance Rate[1]
VAN-A12E-01	Four Mile Run	0.25	Confluence with the Potomac River at the state boundary to the upstream limit of tidal waters	1AFOU000.19	E. coli	3 of 17 samples (18%)

[1]Based on the 2008 Integrated Assessment Report. Also, it should be noted that in previous Assessments various TMDL IDs have been assigned to this assessment unit, including: A12R-01-BAC (2008) and 00305 (2006).

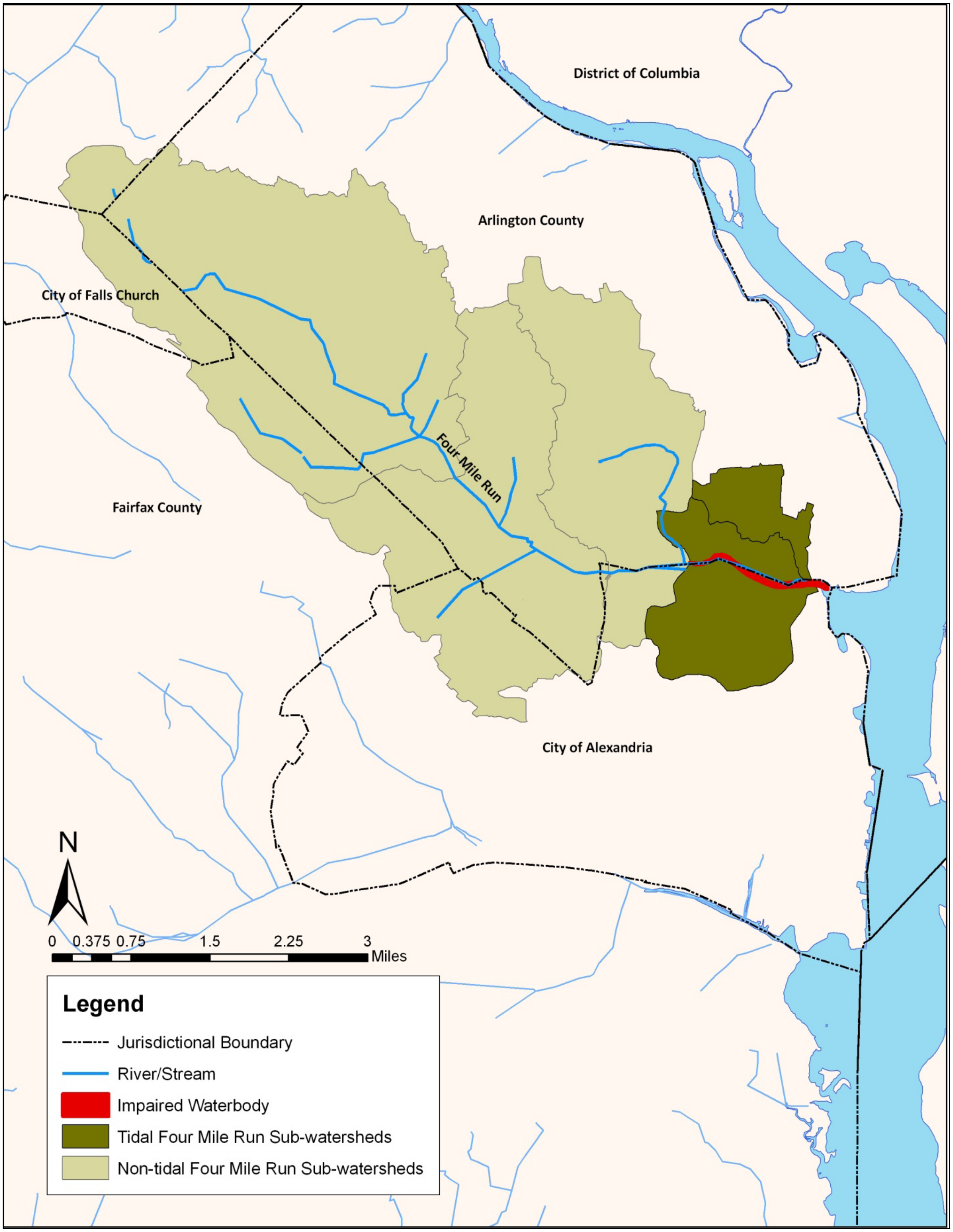

Figure 1-1: Location of the Four Mile Run Watershed

1.3 Applicable Water Quality Standard

Water quality standards consist of designated uses for a waterbody and water quality criteria necessary to support those designated uses. According to Virginia Water Quality Standards (9 VAC 25-260-5), the term "water quality standards means provisions of state or federal law which consist of a designated use or uses for the waters of the Commonwealth and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the State Water Control Law (§62.1-44.2 et seq. of the Code of Virginia) and the federal Clean Water Act (33 USC §1251 et seq.)."

1.3.1 Designated Uses

According to Virginia Water Quality Standards (9 VAC 25-260-10):

"…all state waters 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 be reasonably expected to inhabit them; wildlife; and the production of edible and marketable natural resources (e.g., fish and shellfish)."

1.3.2 Applicable Water Quality Criteria

Effective February 1, 2010, VADEQ specified a new bacteria standard in 9 VAC 25-260-170.A. For a non-shellfish, freshwater waterbody to be in compliance with Virginia bacteria standards for primary contact recreation, the current criteria are as follows:

> *"E. coli bacteria shall not exceed a monthly geometric mean of 126 CFU/100 ml in freshwater...Geometric means shall be calculated using all data collected during any calendar month with a minimum of four weekly samples… 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."*

The previous fecal coliform criteria was phased out because research showed that there is a stronger correlation between the concentration of *E. coli* and the incidence of gastrointestinal illness than with fecal coliform. *E. coli* are bacteriological organisms that can be found in the intestinal tract of warm-blooded animals. Like fecal coliform bacteria, these organisms indicate the presence of fecal contamination.

For bacteria TMDL development after January 15, 2003, *E. coli* is the primary applicable water quality target. However, the loading rates for watershed-based modeling are available only in terms of fecal coliform. Therefore, during the transition from fecal coliform to *E. coli* criteria, DCR, VADEQ and EPA have agreed to apply a translator to instream fecal coliform data to determine whether reductions applied to the fecal coliform load would result in meeting instream *E. coli* criteria. The fecal coliform model and instream translator are used to calculate *E. coli* TMDLs (VADEQ, 2003). The following regression based instream translator is used to calculate *E. coli* concentrations from fecal coliform concentrations:

$$E.\ coli\ conc.\ (cfu/100\ mL) = 2^{-0.0172} \times [fecal\ coliform\ conc.\ (cfu/100mL)]^{0.91905}$$

As of the approval of the latest revisions to Virginia's Water Quality Standards (February 1, 2010), bacteria TMDLs in Virginia are only required to meet the geometric mean criteria. The modeled daily fecal coliform concentrations are converted to daily *E. coli* concentrations using the instream translator. The TMDL development process must also account for seasonal and annual variations in precipitation, flow, land use, and pollutant contributions. Such an approach ensures that TMDLs, when implemented, do not result in exceedances under a wide variety of scenarios that affect fecal coliform loading.

2 TMDL Endpoint Identification

2.1 Selection of TMDL Endpoint and Water Quality Targets

One of the first steps in TMDL development is determining the numeric endpoints, or water quality targets, for each impaired segment. Water quality targets compare the current stream conditions to the expected restored stream conditions after TMDL load reductions are implemented. Numeric endpoints for the Tidal Four Mile Run TMDL are established in the Virginia Water Quality Standards (9 VAC 25-260). These standards state that all waters in Virginia should be free from any substances that can cause the water to exceed the state numeric standards, interfere with its designated uses, or adversely affect human health and aquatic life. Therefore, the current water quality target for this impairment, as stated in 9 VAC 25-260-170, is an *E. coli* geometric mean no greater than 126 colony-forming units (cfu) per 100 ml.

2.2 Critical Condition

The critical condition is considered the "worst case scenario" of environmental conditions in the tidal Four Mile Run watershed. If TMDLs are developed such that water quality targets are met under the critical condition, then these targets would also be met under all other conditions.

EPA regulations, 40 CFR 130.7 (c)(1), require TMDLs to take critical conditions for stream flow, loading, and water quality parameters into account. The intent of this requirement is to ensure that the water quality of the tidal Four Mile Run watershed is protected during times when it is most vulnerable. Critical conditions are important because they describe the combination of factors responsible for exceedances of water quality criteria. They will help in identifying the actions that may have to be undertaken in order to meet water quality standards.

The Four Mile Run watershed is mostly developed. Medium and low-to-medium residential density land uses make up over 50% of the watershed's land area. Less than 10% of the land is comprised of parks, golf courses, or open space. The key potential sources of bacteria are related to a heavy urban land use: pets, wildlife, sanitary sewer overflows (SSOs) and cross-connections between sanitary and storm sewer systems, and facilities like municipal waste water treatment plants (WWTPs) permitted to discharge bacteria.

Fecal coliform loadings result from sources that can contribute during wet weather and dry weather. The critical conditions were determined from the available flow data obtained from USGS and water quality data collected by VADEQ.

Figures Figure 2-1 and **Figure** 2-2 show the concentrations of fecal coliform, in cfu/100 mL, and of *E. coli*, in cfu/100 mL, that were observed at 1AFOU000.19. Station 1AFOU000.19 is VADEQ's water quality monitoring station for the tidal portion of Four Mile Run. The station is located at the George Washington Parkway bridge crossing. The old maximum standard (400 cfu/100 mL for fecal coliform and 235 cfu/100 mL criterion for *E. coli*) is represented in each figure by a red line. The geometric mean standard is 200 cfu/100 mL for fecal coliform and 126 cfu/100 mL for *E. coli*, but is not used here because more than one sample is required per month for this analysis.

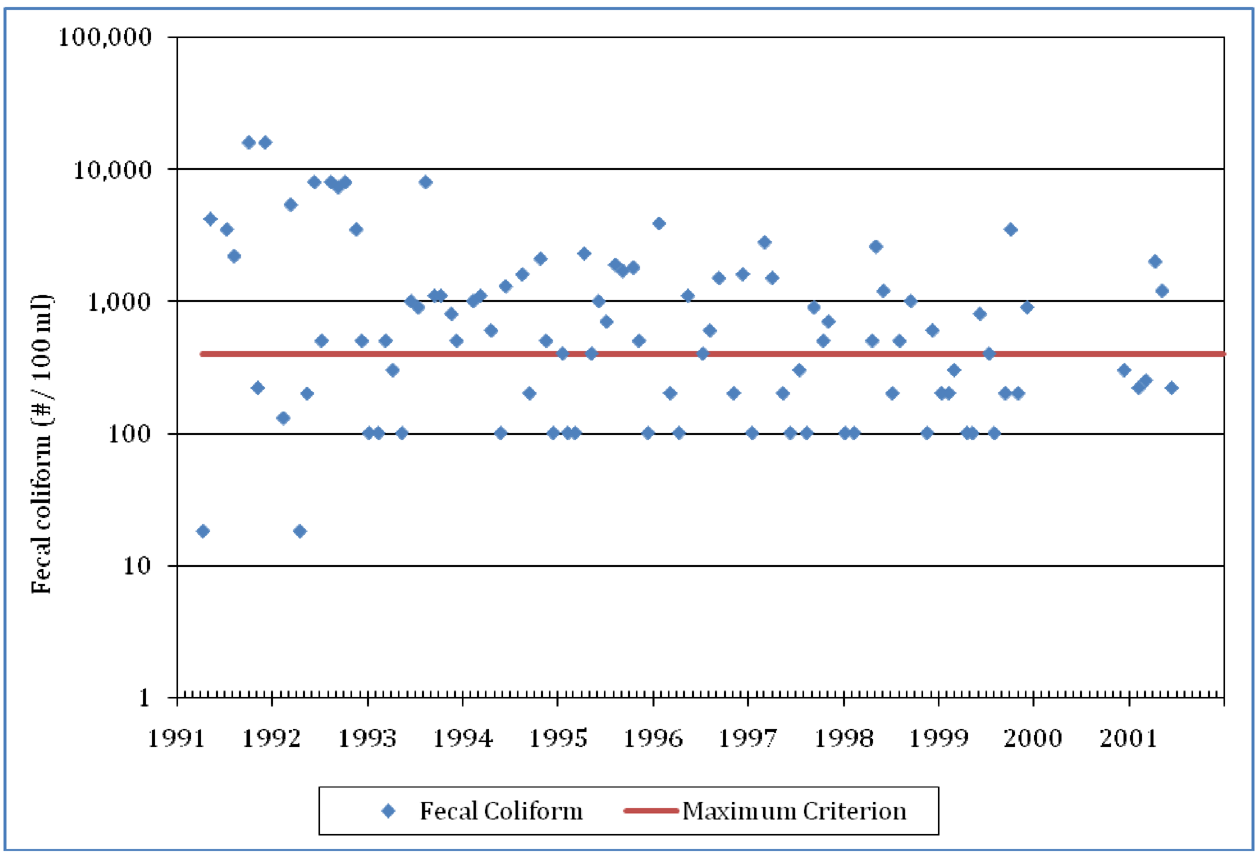

Figure 2-1: Observed Fecal Coliform Concentrations at Station 1AFOU000.19 (1991-2001)

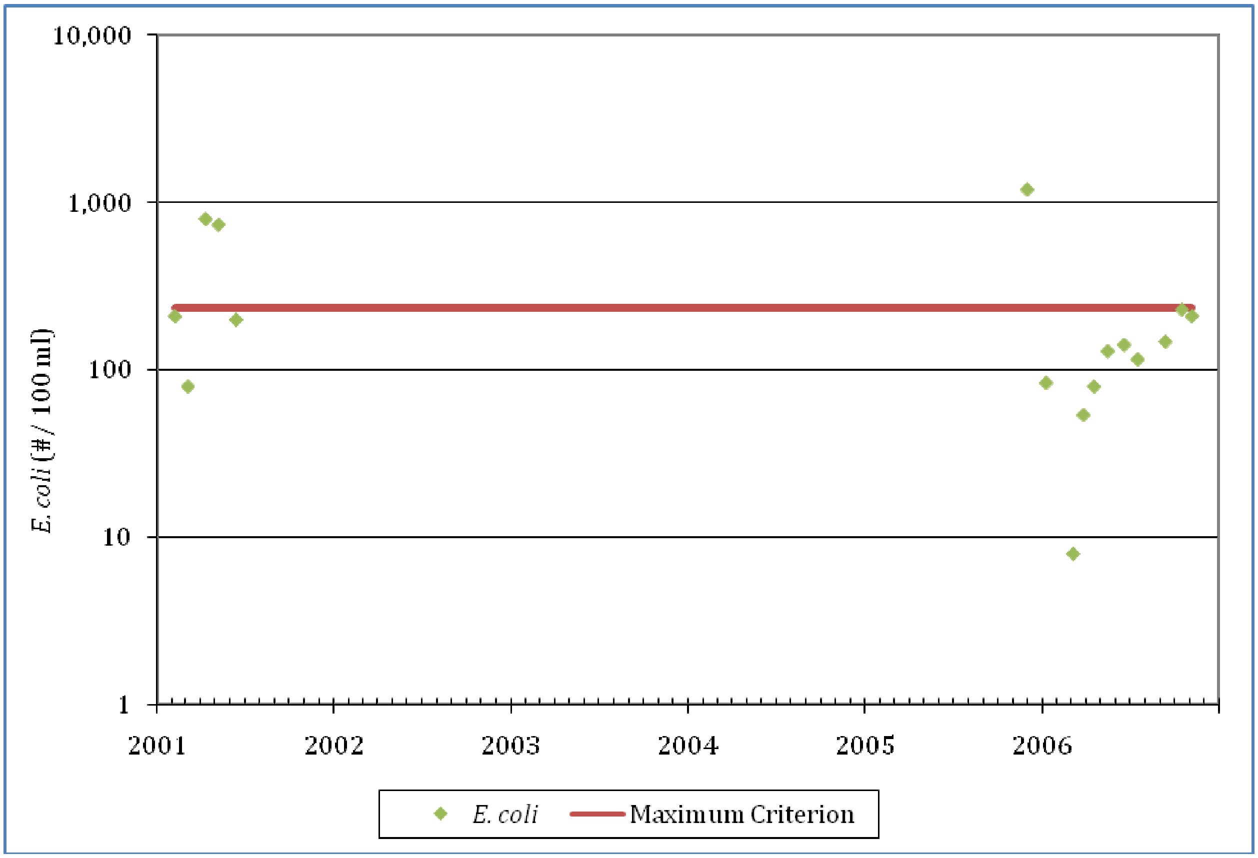

Figure 2-2: Observed *E. coli* Concentrations at Station 1AFOU000.19 (2001–2006)

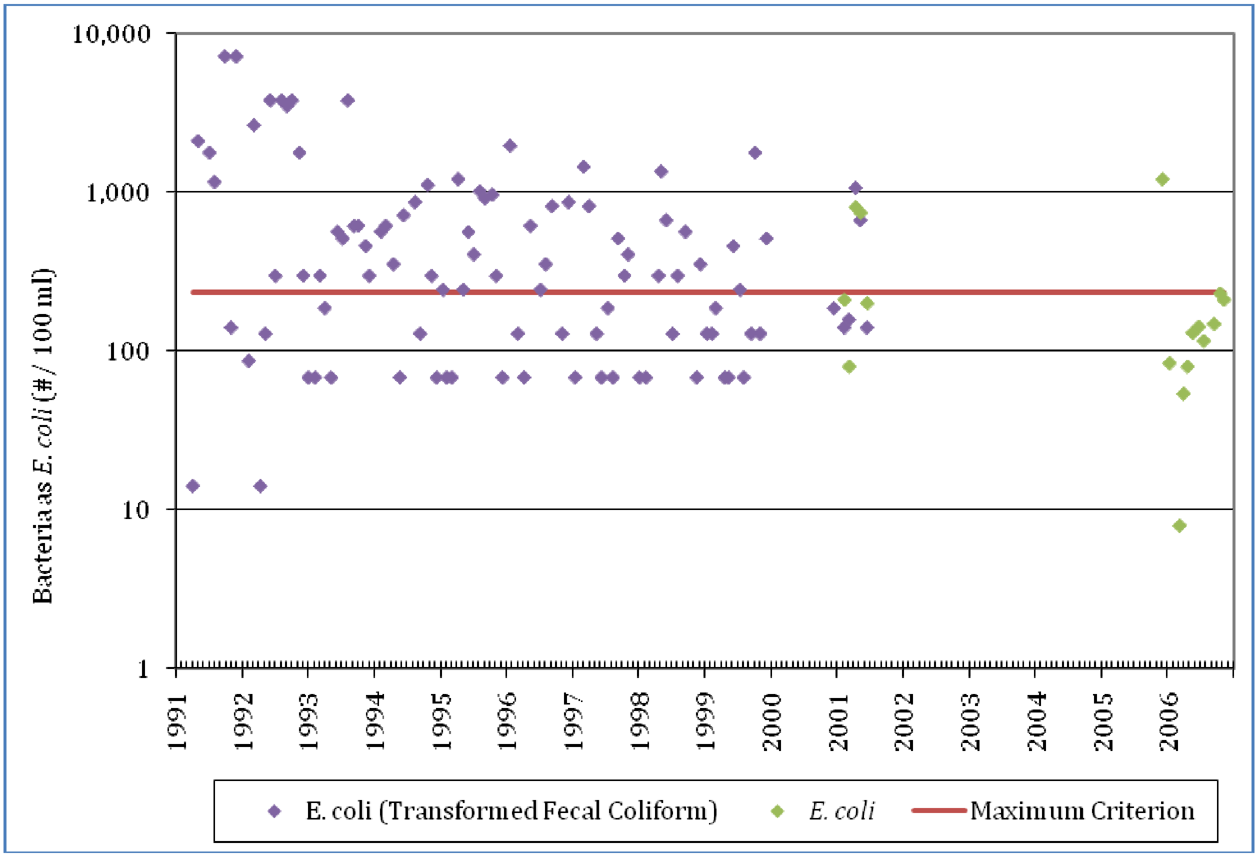

Figure 2-3: Observed *E. coli* Concentrations and Translated Fecal Coliform Concentrations at Station 1AFOU000.19 (1991-2006)

Figure 2-1 shows that the old Fecal Coliform maximum criterion of 400 cfu/100 mL is exceeded throughout the entire period of record at 1AFOU000.19.

Figure 2-2 indicates that when samples were collected in 2001, 2005, and 2006 (none were taken in the intervening years) the maximum criterion (235 cfu/100 mL) for *E. coli* was exceeded three times.

Figure 2-3 shows both the Fecal Coliform data from Figure 2-1 translated into its *E. coli* equivalent and the results from the *E. coli* samples.

It is necessary for the critical condition to consider both wet weather, high flow conditions and dry weather, low flow conditions in order to comply with the geometric mean bacteria standards.

2.3 Consideration of Seasonal Variations

Seasonal variations involve changes in stream flow and water quality because of hydrologic and climatological patterns. Seasonal variations were explicitly included in the modeling approach for this TMDL. The continuous simulation model developed for this TMDL explicitly incorporates the seasonal variations of rainfall, runoff, and fecal coliform wash-off by using an hourly time-step. In addition, fecal coliform accumulation rates for each land use were developed on a monthly basis. This allowed the consideration of temporal variability in fecal coliform loading within the watershed.

3 Watershed Description and Source Assessment

In this section, the types of data available and information collected for the development of the TMDL for Tidal Four Mile Run are presented. This information was used to characterize the impaired segment and its watershed, and to inventory and characterize the potential point and nonpoint sources of fecal coliform in the watershed.

3.1 Data and Information Inventory

A wide range of data and information were used in the development of this TMDL. Categories of data that were used include the following:

- Physiographic data that describe physical conditions (i.e., topography, soils, and land use) within the watershed
- Data that describe physical conditions within the river, such as channel depth, width, slope, and elevation
- Data related to land uses of the watershed, wildlife and pet populations, and information that can be used in the identification of potential fecal coliform sources
- Environmental monitoring data that describe stream flow, tidal elevations, and water quality conditions in the river

Table 3-1 shows the various data types and the data sources used in the TMDL development for the Four Mile Run watershed.

Table 3-1: Inventory of Data and Information Used in the Four Mile Run Bacteria TMDL

Data Category	Description	Source(s)
Watershed physiographic data	Watershed boundary	NVRC
	Land use/land cover	NVRC
	Soil data (SSURGO, STATSGO)	NRCS
	Topographic data (USGS-30 meter DEM, USGS Quads)	USGS
Bathymetric Data	Channel morphology	USACE
Weather data	Hourly meteorological conditions	NCDC
Source Inventory	Population of wildlife and pets Fecal coliform production by species	NVRC
Point sources and direct discharge data and information	Permitted facilities locations and discharge monitoring reports (DMRs)	EPA Permit Compliance System (PCS), VPDES, VADEQ
Environmental monitoring data	Ambient instream monitoring data	VADEQ
	Stream flow data	USGS, VADEQ
	Tidal elevation data	NOAA, USGS

Notes
EPA: Environmental Protection Agency
NCDC: National Climatic Data Center
NOAA: National Oceanic and Atmospheric Administration
NRCS: Natural Resources Conservation Service
NVRC: Northern Virginia Regional Commission
USACE: U. S. Army Corps of Engineers
USGS: U.S. Geological Survey
VADEQ: Virginia Department of Environmental Quality
VPDES: Virginia Pollutant Discharge Elimination System

3.2 Watershed Description and Identification

The Four Mile Run watershed is located in Northern Virginia, crossing the borders of Fairfax County, City of Falls Church, Arlington County, and City of Alexandria. As shown in **Figure 3-1**, the major roadways that run through the watershed include Interstate 395, running from north to south and Interstate 66, running from east to west. Also running east to west are U.S. Highways 29 and 50, and state highways 237 and 244. State highways 7, 27, and 120 run north to south. The watershed is heavily urbanized. The Northern Virginia Regional Commission (NVRC) estimates that according to the 2000 U. S. Census, over 180,000 people live in the watershed (NVRC, 2002). Land use in the watershed is almost completely developed except for open space such as parks or golf courses.

A bacteria TMDL for the non-tidal portion of Four Mile Run was submitted to U.S. EPA in April 2002 and approved by U.S. EPA in May 2002. An implementation plan (IP) was developed for the non-tidal watershed in 2004. The IP was developed to address the bacteria impairment in non-tidal Four Mile Run. The watershed of non-tidal Four Mile Run that is subject to the TMDL and IP is shown in **Figure 3-1**.

The TMDL developed here addresses the bacteria impairment in the tidal portion of Four Mile Run. The impaired segment is located in the Potomac River basin (USGS Cataloging Unit 02070010) and begins at the upstream limit of the tidal portion of Four Mile Run, just downstream of the confluence of Long Branch with Four Mile Run, and ends at the confluence with the Potomac River at the Virginia state line, covering 0.0516 mi^2. The impaired portion of the watershed for which this TMDL is developed covers those sub-watersheds located in Arlington and Alexandria which drain directly into the tidal river downstream of the sub-watersheds addressed in the non-tidal TMDL and IP discussed above. **Figure 3-1** shows the extent of the tidal TMDL drainage. The entire Four Mile Run watershed is approximately 12,440 acres (excluding water), while the bacteria-impaired tidal portion of the watershed is 1,567 acres, or 12.6% of the entire drainage area to tidal Four Mile Run. The TMDL for tidal Four Mile Run will build upon the TMDL and IP for non-tidal Four Mile Run.

Prior to the 1970s, both the tidal portion of Four Mile Run and the lower non-tidal river were frequently subject to floods. In the late 1970s, the Army Corps of Engineers (USACE) developed and implemented a flood control plan for these portions of the river. The implemented plan included lowering the channel of tidal Four Mile Run, constructing levees along the channel, and replacing bridges that cross the tidal river. Currently, USACE is working with Arlington County and the City of Alexandria on a plan for stream restoration for the lower portion of the non-tidal river and the upper tidal sections. The draft Feasibility Report (USACE, 2008) contains a good description of the changes over time in the tidal portion of the river.

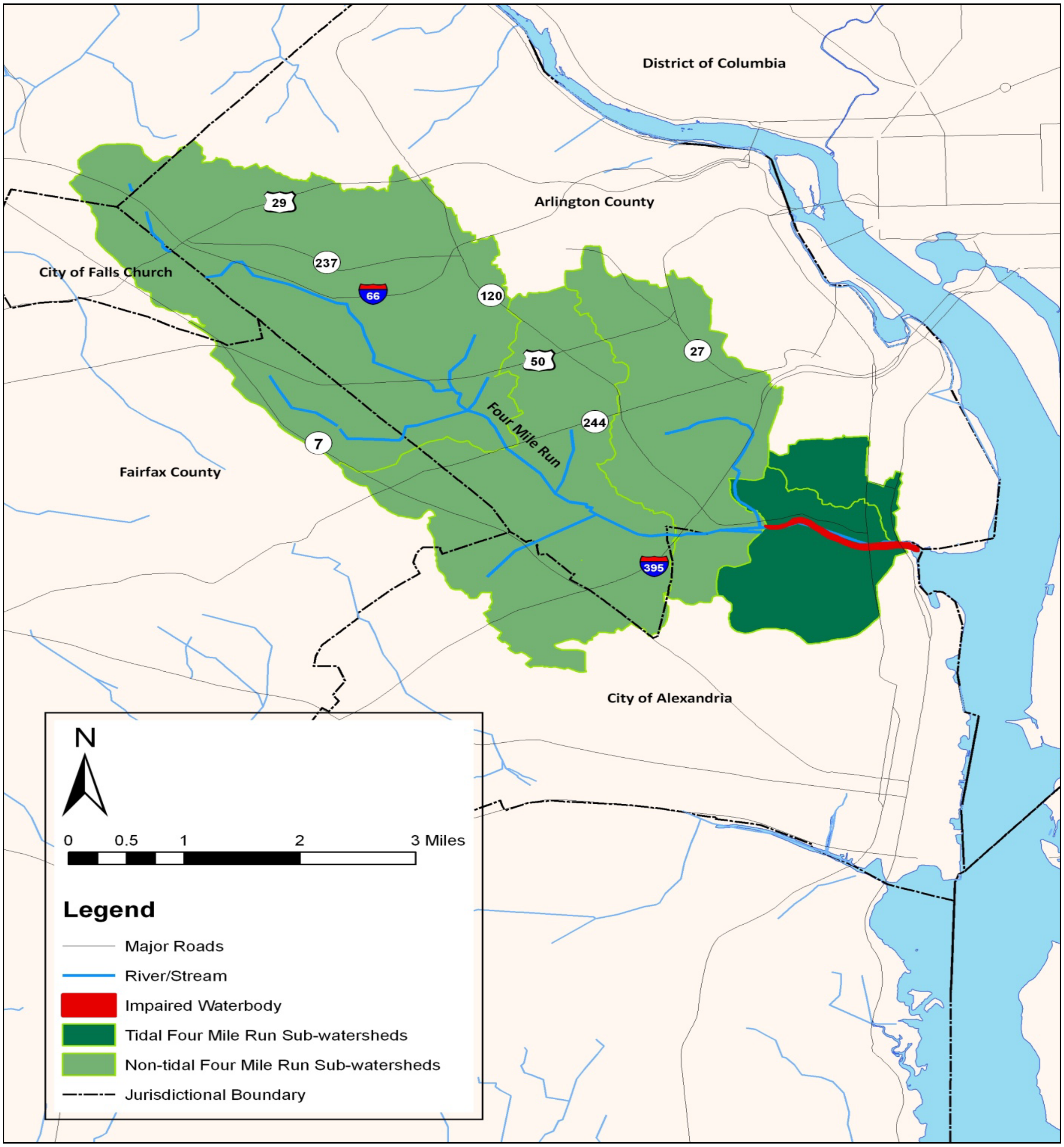

Figure 3-1: Location and Boundary of the Four Mile Run Watershed

3.2.1 Topography

A digital elevation model (DEM) was used to characterize the topography in the watershed. DEM data obtained from USGS show that elevation in the watershed ranges from approximately 3 to 453 feet above mean sea level, with an average elevation of 217 feet above mean sea level.

3.2.2 Soils

The Four Mile Run watershed soil characterization was based on data obtained from the U.S General Soil Map (STATSGO). In the tidal portion of the Four Mile Run watershed the soil is entirely characterized as Quantico-Neabsco-Dumfries (**Table 3-2**).

Table 3-2: Major Soil Associations within the Tidal Four Mile Run Watershed

Soil Name	Acres	Percentage of the Sub-watershed
Quantico-Neabsco-Dumfries (s8285)	1,567	100%

The hydrologic soil group linked with each soil association is also presented in **Table 3-3**. The hydrologic soil groups represent different levels of infiltration capacity of the soils. Hydrologic soil group "A" designates soils that are well to excessively well drained, whereas hydrologic soil group "D" designates soils that are poorly drained. This means that soils in hydrologic group "A" allow a larger portion of the rainfall to infiltrate and become part of the ground water system, while soils in hydrologic group "D" allow a smaller portion of the rainfall to infiltrate and become part of the ground water. Consequently, more rainfall becomes part of the surface water runoff along poorly drained soils. Descriptions of the hydrologic soil groups are presented in **Table 3-4**.

Table 3-3: Soil Hydrologic Groups within the Four Mile Run Watershed

Hydrologic Group	Acres	Percentage of Watershed
B	1,567	100%

Table 3-4: Descriptions of Soil Hydrologic Groups

Soil Hydrologic Group	Description
A	High infiltration rates. Soils are deep, well-drained to excessively-drained sand and gravels.
B	Moderate infiltration rates. Deep and moderately deep, moderately well and well-drained soils with moderately coarse textures.
C	Moderate to slow infiltration rates. Soils with layers impeding downward movement of water or soils with moderately fine or fine textures.
D	Very slow infiltration rates. Soils are clayey, have a high water table, or shallow to impervious cover.

3.2.3 Land Use

Land use information was obtained from the Northern Virginia Regional Commission (NVRC) regional land use GIS layer. This same land use layer was used for the development of the non-tidal TMDL. There are 14 land use categories used in the layer for the tidal drainage, all of them, with the exception of open space, are urban or developed land use categories. The original delineation and land use layer were extended by 6.2 acres to cover the drainage area between the George Washington Parkway and the confluence of Four Mile Run and the Potomac River. **Table 3-5** gives the total number of acres in each land use category in the tidal drainage watershed. **Figure 3-2** shows the land use distribution of the tidal Four Mile Run watershed.

Table 3-5: Land Use in Four Mile Run Tidal Drainage (NRVC, 2002)

Land Use	Percent Impervious	Acres	Percent Watershed
Open Space/Parks	2%	76.1	4.9%
Highway	90%	7.1	0.5%
Medium to High Density Mixed Use	65%	52.9	3.4%
Medium to High Density Industrial	80%	121.4	7.8%
Public/Conservation/Golf	8%	24.2	1.5%
High Density Residential	75%	53.4	3.4%
Medium Density Residential	40%	388.5	24.8%
Medium to High Density Residential	50%	238.3	15.2%
Medium to High Density Commercial	70%	51.3	3.3%
Low to Medium Density Residential	20%	401.6	25.6%
Low Density Commercial	40%	55.5	3.5%
Low Density Industrial	65%	9.8	0.6%
Low Density Mixed Use	30%	86.0	5.5%
Federal	50%	1.0	0.1%
Total (excluding water)	40%	1,566.9	100%

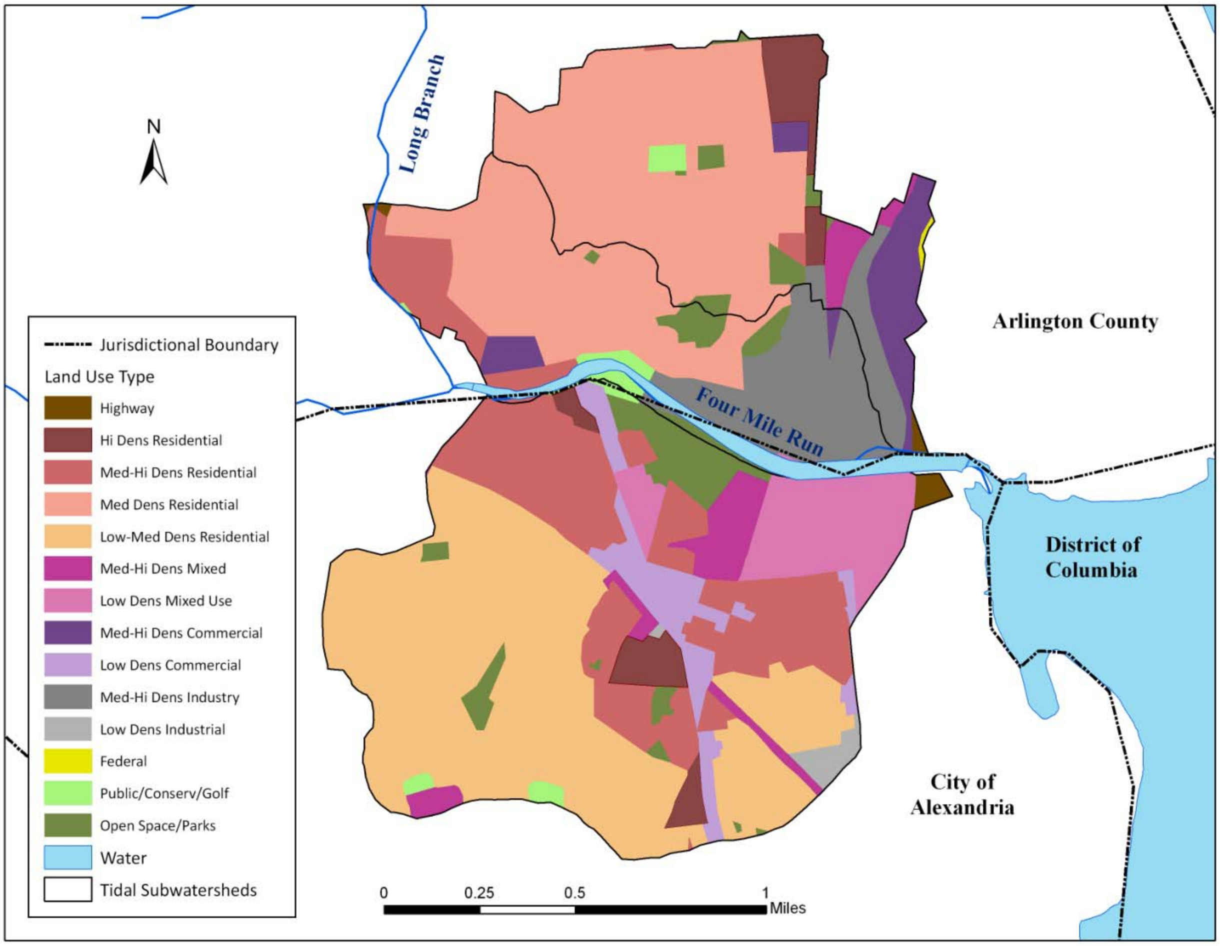

Figure 3-2: NVRC 2002 Land Use in the Four Mile Run Watershed

3.2.4 Tidal River Bathymetry

In 2004, AB Consultants surveyed Four Mile Run, including the tidal portion of the river. Elevations were taken at approximately 12 cross sections. This survey has been incorporated into USACE's feasibility plan for stream restoration on Four Mile Run (Nagoda, 2008). USACE (1969) also documents the designs for the tidal river channel. The use of the bathymetry data in computer simulation model of the tidal river is discussed in more detail in Section 4.2.

3.3 Stream Flow Data and Tidal Elevations

3.3.1 Streamflow Data

Stream flow data were available at one USGS stream flow-gauging station located in the Four Mile Run watershed. The station is located above the impaired stream segment (**Figure 3-3**). Data collected at this station are shown in **Table 3-6**. The station drains 12.6 of the approximately 17 square miles of the non-tidal watershed. Mean average flow over the period of record is 18.4 cubic feet per second (cfs), and the 90th percentile flow is 35 cfs.

Table 3-6: USGS Stream Flow Data located in the Four Mile Run watershed

Station ID	Station Name	Period of Daily-Mean Data	
		Start Date	End Date
01652500	Four Mile Run at Alexandria, VA	May 1951	Present

3.3.2 Tidal Elevations

The National Oceanic and Atmospheric Administration (NOAA) maintains a long-term tidal station at Washington, D.C. (8594900) in the Ship Channel. The period of record for the station is from 1924 to the present. The mean lower low water (MLLW) datum is -1.39 feet and the mean higher high water (MHHW) datum is 1.78 feet, relative to the North American Vertical Datum of 1988 (NAVD88), for a diurnal tidal range of 3.17 feet.

The USGS installed a tidal elevation gage (01652545) on Four Mile Run, 250 feet upstream of the Jefferson Davis Highway (U. S. Highway 1) in July 2006. The maximum and minimum recorded elevations for the period July 2006 through September 2008 are 4.99 feet and -2.53 feet, respectively, relative to the NAVD88 datum. The station has not been in operation long enough to determine a meaningful MLLW or MHHW.

This information is presented in **Table 3-7** and the station locations are shown in **Figure 3-3**. The records for the two stations are compared in Appendix B.

Table 3-7: Tidal Elevation Data located near the Four Mile Run watershed

Station ID	Agency	Station Name	Period of Data	
			Start Date	End Date
8594900	NOAA	Washington, DC	1924	Present
01652545	USGS	Four Mile Run above Highway 1 at Alexandria, VA	July 2006	Present

3.4 VADEQ Ambient Water Quality Data

VADEQ has monitored ambient water quality at one location in the tidal Four Mile Run watershed. Data collection took place between 1991 and 2010. A description of the station is in **Table 3-8** and the location is presented in **Figure 3-3**. Station identification numbers include the abbreviated creek name, and the river mile on that creek where the station is located. The river mile number represents the distance from the mouth of the creek.

Table 3-8: Four Mile Run Water Quality Monitoring Station

Station ID	Station Description	Stream Name
1AFOU000.19	George Washington Parkway	Four Mile Run

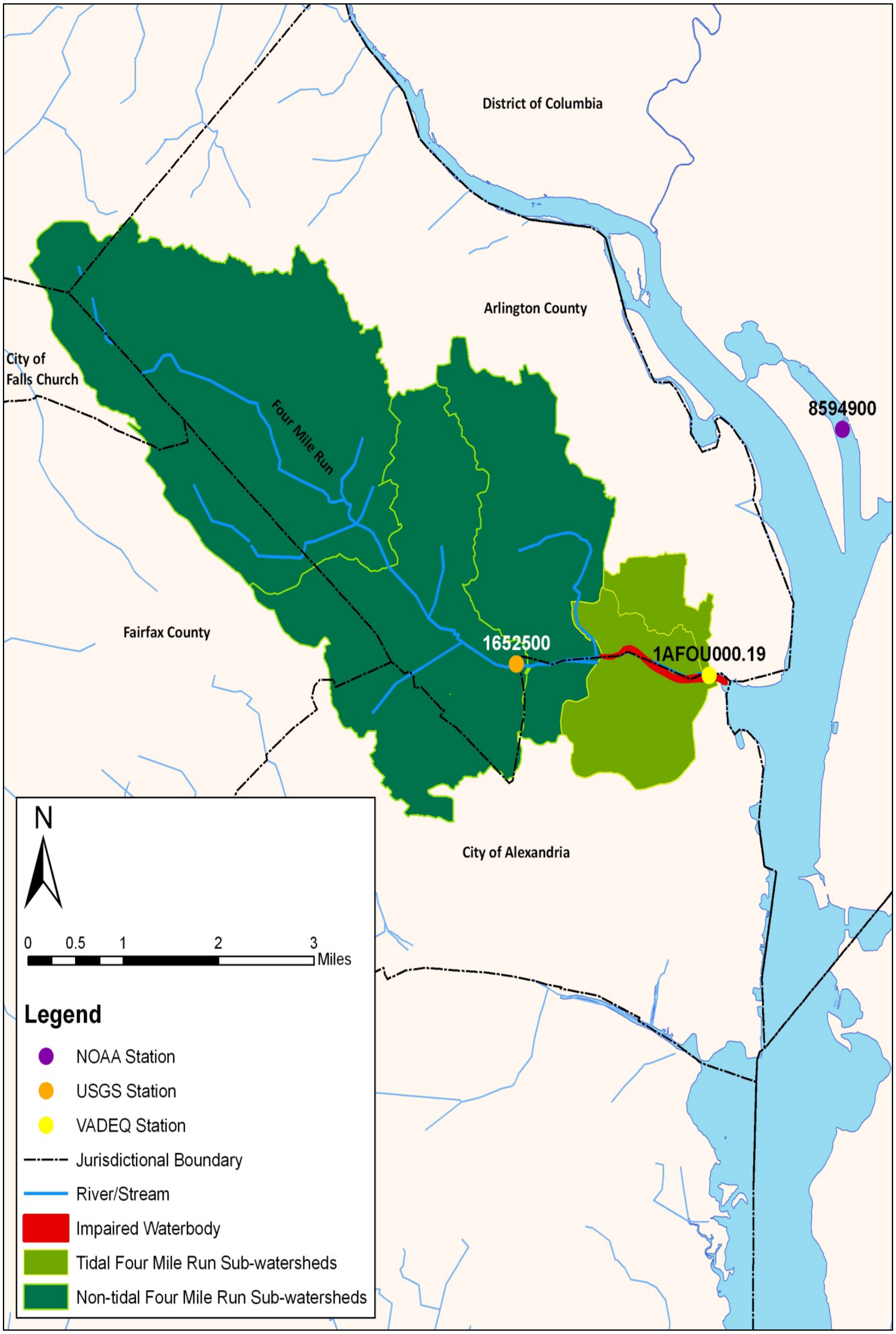

Figure 3-3: Four Mile Run Watershed Monitoring Stations

Table 3-9 shows the fecal coliform data collected at the Four Mile Run monitoring station for the period of record and the number and percentage of samples exceeding water quality standards collected between 1991 and 2001. Analysis of the water quality data indicated that 57% of the samples exceeded the maximum criterion of 400 cfu/100 ml for fecal coliform. Since only one sample was collected per calendar month at these stations, geometric mean exceedances could not be calculated.

Table 3-9: VADEQ Fecal Coliform Data in Four Mile Run

Station	Date Range	No. of Samples	Min (cfu/100mL)	Max (cfu/100mL)	Average (cfu/100mL)	Maximum Criterion Exceedances	
						No.	%
1AFOU000.19	April 1991 – June 2001	99	18	16,000	1,542	56	57

The water was sampled for *E. coli* bacteria at this same station between 2001 and 2010. **Table 3-10** lists the water quality sampling period of record, the number of samples, the minimum, maximum and average concentrations observed, and the number and percentage of samples exceeding the water quality standards. Three samples (19%) exceeded the maximum standard of 235 cfu/100 mL. Since only one sample was collected per calendar month at these stations, geometric mean exceedances could not be calculated.

Table 3-10: VADEQ *E. Coli* Data in the Impaired Segments of Four Mile Run

Station	Date Range	No. of Samples	Min (cfu/100mL)	Max (cfu/100mL)	Avg (cfu/100mL)	Inst. Max (SSM) Exceedances	
						No.	%
1AFOU000.19	February 2001 – January 2010	25	8	1,200	266	8	32

3.4.1 VADEQ Bacterial Source Tracking (BST) Data

As part of the TMDL development, Bacterial Source Tracking (BST) sampling was conducted at one location in the tidal Four Mile Run watershed. The objective of the BST study was to identify the sources of fecal coliform in the listed segment of tidal Four Mile Run.

There are various methodologies used to perform BST, which fall into three major categories: molecular, biochemical and chemical. Molecular (genotype) methods are referred to as "DNA fingerprinting," and are based on the unique genetic makeup of different strains, or subspecies, of fecal coliform bacteria. Biochemical (phenotype) methods are based on detecting biochemical substances produced by bacteria. The type and quantity of these substances are measured to identify the bacteria source. Chemical methods are based on testing for chemical compounds that are associated with human wastewaters, and are restricted to determining if sources of pollution are human or non-human.

For the tidal Four Mile Run TMDL, the Antibiotic Resistance Analysis (ARA) method of BST was used. ARA has been the most widely used and published BST method to date and has been employed in Virginia, Florida, Kansas, Oregon, South Carolina, Tennessee, and Texas. Advantages of ARA include low cost per sample, and fast turnaround times for analyzing samples. The method can also be performed on large numbers of isolates; typically, 48 isolates per unknown source such as an instream water quality sample.

BST was conducted monthly from January 2006 to December 2006 at station 1AFOU000.19, whose location was shown in **Figure 3-3**. Four categories of fecal bacteria sources were considered: wildlife, human, livestock and pet. Results from 12 sampling events at the station, are presented in **Table 3-11** and results are depicted in **Figure 3-4**. Results indicate that bacteria from human, livestock, wildlife, and pet sources are present in tidal Four Mile Run. *E. coli* concentrations exceeded the maximum *E. coli* bacteria criterion of 235 cfu/100mL once in the 12 samples collected at the station. In terms of percentages, the maximum *E .coli* criterion was exceeded 8.3% percent of the time.

Table 3-11: BST Data Collected During 2006 in the Tidal Four Mile Run Watershed							
Station ID	**Date of Sample**	**E. coli (cfu/100 mL)**	**Number of Isolates**	**Wildlife**	**Human**	**Livestock**	**Pet**
1AFOU000.19 1 out of 12 samples (8.3%) exceed 235 cfu/100mL	1/9/2006	84	24	25%	4%	29%	42%
	3/6/2006	8	4	75%	0%	0%	25%
	3/27/2006	54	17	59%	6%	6%	29%
	4/18/2006	80	23	65%	4%	22%	9%
	5/16/2006	130	24	84%	0%	8%	8%
	6/19/2006	142	14	100%	0%	0%	0%
	7/17/2006	116	11	55%	9%	18%	18%
	8/15/2006	410	22	54%	5%	27%	14%
	9/12/2006	148	23	39%	22%	22%	17%
	10/16/2006	230	24	63%	29%	0%	8%
	11/6/2006	210	24	12%	0%	8%	80%
	12/11/2006	142	24	71%	8%	21%	0%

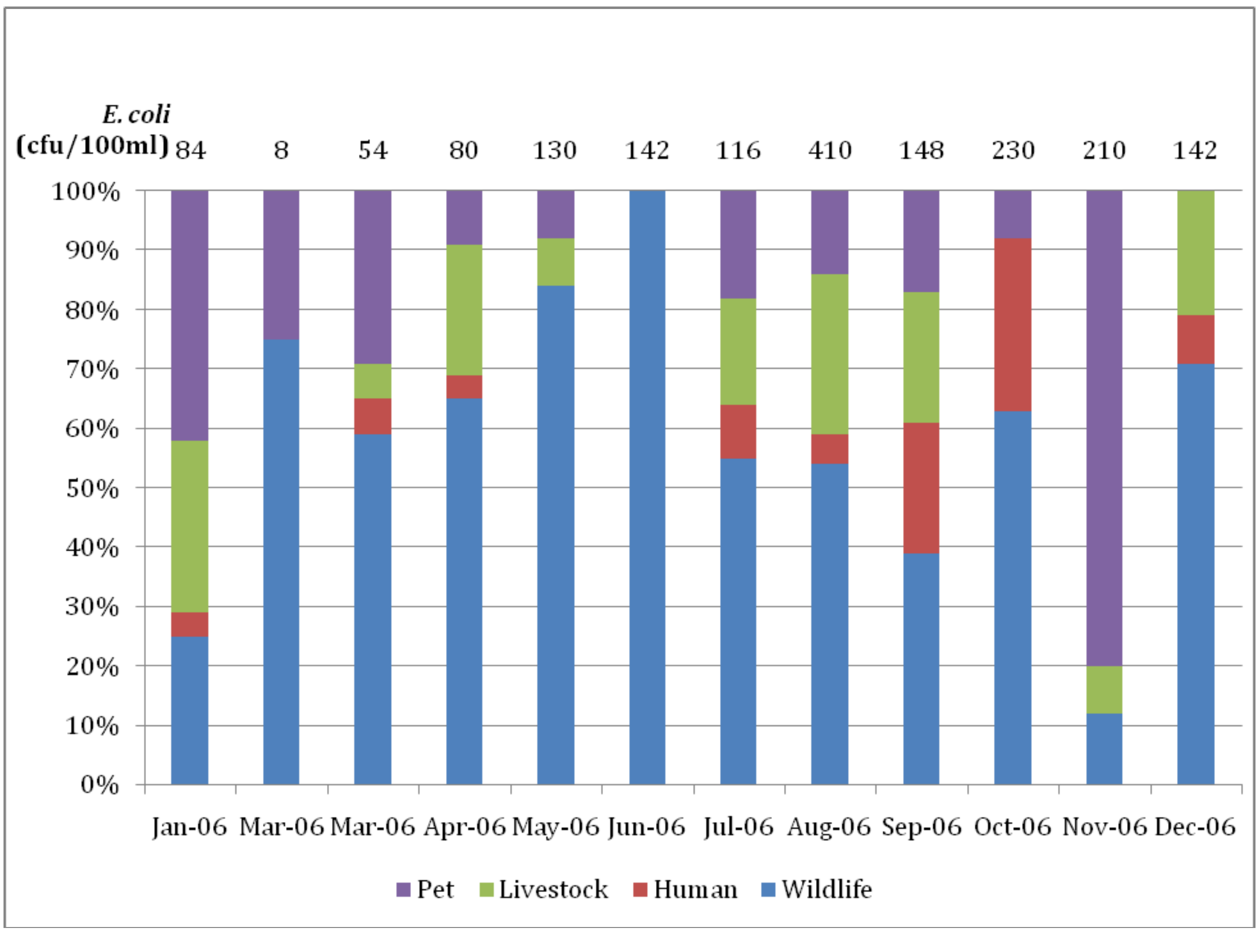

Figure 3-4: BST Source Distributions at 1AFOU000.19

3.5 Bacteria Source Assessment

The entire Four Mile Run watershed is heavily urbanized. The population density is over 9,000 people per square mile (NVRC, 2002). There are no agricultural activities in the watershed, and sanitary sewer systems cover the entire watershed. There are no known septic systems in the tidal drainage to Four Mile Run. The sources of bacteria are limited to those found in urban areas: pets, wildlife, sanitary sewer overflows (SSOs) and cross-connections between sanitary and storm sewer systems, and facilities like municipal waste water treatment plants (WWTPs) permitted to discharge bacteria.

3.5.1 Permitted Facilities

There is only one facility holding an active, individual, municipal Virginia Pollutant Discharge Elimination System (VPDES) permit, issued through the VPDES permitting program, in the tidal drainage of the Four Mile Run Watershed: the Arlington County Water Pollution Control Facility (WPCF). The permit number, design flow, and status are presented in **Table 3-12** and the location is shown in **Figure 3-5**. The WPCF's maximum permitted design flow of 40 million gallons per day (MGD) exceeds the average daily flow of 18.4 cfs (11.9 MGD) on Four Mile Run as measured upstream at USGS gage 01652500 and is comparable to the 90th percentile daily flow of 35 cfs (22.6 MGD) over the gage's period of record. Thus, except for storm flow conditions, flows from WPCF will be the dominant inflow to tidal Four Mile Run.

E. coli concentrations discharged by the WPCF are low, averaging 9.4 cfu/100 ml from 2004 through 2007. Discharged concentrations are thus considerably below the permitted monthly geometric mean concentration limit of 126 cfu/100 ml. Under wet weather conditions, however, stormwater runoff can enter Arlington's sanitary sewer system and result in flows that exceed the WPCF's treatment capacity. Excess flow bypasses one or more of the treatment processes and is discharged through a separate outfall directly into tidal Four Mile Run. These unauthorized discharges are reported to occur an average of four times per year, with an average flow volume of 23 million gallons per year. Major capital improvements are currently being made to WPCF to eliminate these unauthorized flows.

Table 3-12: Individual VPDES Permitted Facilities within the Four Mile Run Watershed

Permit No	Facility Name	Receiving Stream	Size	Category
VA0025143	Arlington County Water Pollution Control Facility	Four Mile Run	Major	Municipal

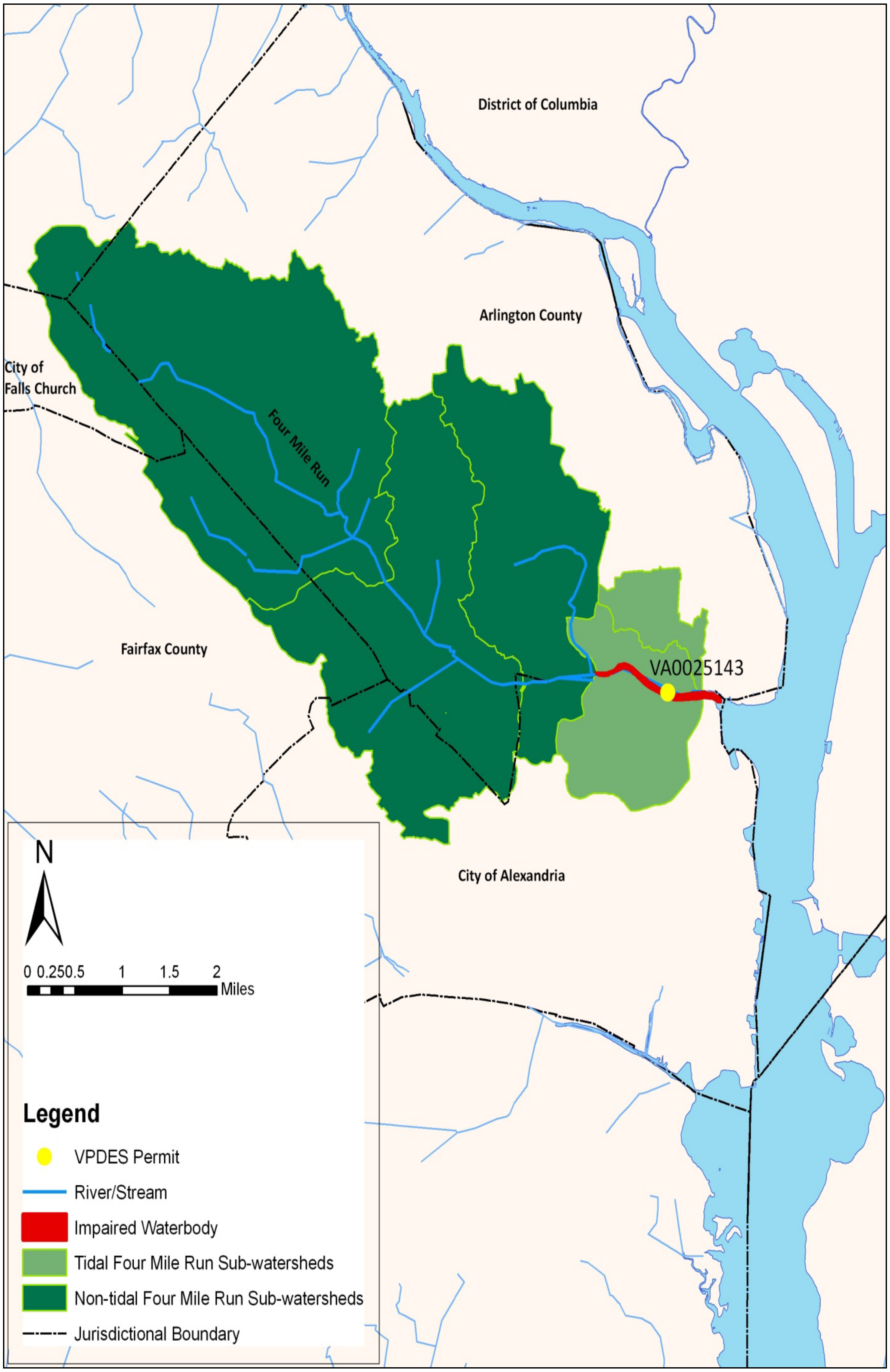

Figure 3-5: Location of Individual VPDES Permitted Facilities in the Tidal Four Mile Run Watershed

Municipal Separate Storm Sewer System (MS4) permits regulate stormwater discharge from counties, municipalities, industrial facilities, and other entities such as state and federal highways. **Table 3-13** gives the MS4 permit holders in the tidal Four Mile Run sub-watersheds.

There are also general VPDES permits issued within the watershed, however, none of these permits are included in TMDL development because they are not permitted to discharge bacteria.

Table 3-13: MS4 Permits within the Tidal Four Mile Run Watershed

Permit Number	MS4 Permit Holder
VA0088579	Arlington County
VAR040057	City of Alexandria
VAR040062	Virginia Department of Transportation—Northern Urban Area
VAR040111	George Washington Memorial Parkway

3.5.2 Wildlife, Human Sources, and Pets

To maintain consistency with the bacteria TMDL for the non-tidal Four Mile Run, the tidal TMDL adopted the source assessment for nonpoint sources used in the previous TMDL. The non-tidal bacteria source assessment developed population densities by land use for wildlife, pets, and human sources from two sources of evidence: (1) an extensive BST study in the Four Mile Run watershed by Dr. George Simmons of Virginia Tech, and (2) best professional judgment of five local naturalists who work in and around the Four Mile Run watershed.

Dr. Simmons BST study was performed from 1998 through 2000. *E. coli* bacteria samples were collected at 31 locations on five separate trips to the watershed across all seasons. Unlike the BST study described in Section 3.4.1 that used the ARA method, Dr. Simmon's study used the "genetic fingerprinting" methodology to identify the source of the *E. coli* bacteria. Genetic fingerprinting attempts to match the DNA found in an unknown sample to DNA from a library of samples with known sources. A successful match typically occurs when the unknown sample matches 80 to 90% of DNA bands with the known sample. **Figure 3-6** shows the percent of isolates identified by source in the non-tidal BST study. The genetic fingerprinting methodology is able to identify sources at a finer taxonomic level than the ARA; however, the fraction of isolates from wildlife, pets, and human sources is comparable to the BST results from the analysis based on samples taken at the GW Parkway in tidal Four Mile Run. This is particularly true given that it is difficult for any BST method to distinguish between pet and human sources. Simmons (2001) summarizes the results of the BST study.

After the BST study was completed, five local naturalists were interviewed: two at Arlington's Long Branch Nature Center (Abugattas, 2001; Zell, 2001), two at Arlington's Gulf Branch Nature Center (Deibler, 2001; Chauvette, 2001), and one at the Northern Virginia Regional Park Authority's Potomac Overlook Regional Park located in Arlington County (Ogle, 2001). The naturalists reviewed the BST results, and estimated the population of species that they reported inhabiting the Four Mile Run watershed. While the naturalists agreed among themselves, there was some disagreement between their best professional judgment and Dr. Simmons' BST study. In their best professional judgment, deer habitat in the Four Mile Run watershed is more limited than the BST study suggests, and some of the species of waterfowl identified by the BST study are known not to inhabit the watershed. Overall, however, the best professional judgment of the naturalists overlapped with the BST results.

The two tracks of evidence were then combined to determine a population density by land use for each source. Population estimates were modified so that bacteria loading rates (fecal coliform bacteria/acre/day) by source matched with the fraction of isolates identified by the BST study on a watershed basis. **Table 3-14** shows the bacteria production rates used to calculate the loading rates. **Table 3-15** shows the resulting source population densities. Human population densities represent the equivalent per capita load from homeless persons and sanitary sewer cross-connections. Dog population densities represent the dog population whose waste is not picked up by their owners.

Table 3-14: Fecal Coliform Production Rates (bacteria/animal/day) (NVRC, 2002)

Host species	Fecal coliform production	Reference
Waterfowl	7.99E+08	Canada Goose values from Accotink Creek TMDL, North River TMDL
Raccoon	4.09E+09	Best professional judgment
Human	1.88E+11	Mara & Oragui, 1981 (septic system equivalent)
Dog	4.09E+09	Long Island Regional Planning Board, 1978
Deer	5.00E+08	Interpolated from Metcalf & Eddy, 1991
Other	1.88E+08	Average of four literature values for chicken

Table 3-15: Estimated Animal Densities by Land Use (NVRC, 2002)

Land Use	Waterfowl	Raccoon	Human	Dog	Deer	Other Wildlife
Open Space/Parks	6	0.45	0.0007	0.12	3	8
Highway	0.5	1	0.008	0.3	0	5
Medium to High Density Mixed Use	3	1	0.03	0.4	0	3.5
Medium to High Density Industrial	2.2	0.9	0.03	0.27	0.2	10
Public/Conservation/Golf	6	0.45	0.0007	0.12	3	8
High Density Residential	4.1	0.5	0.019	0.25	0.2	3
Medium Density Residential	4	0.48	0.0095	0.32	1.2	7
Medium to High Density Residential	3	0.45	0.021	0.2	0.2	2
Medium to High Density Commercial	3	0.45	0.024	0.12	0	2.6
Low to Medium Density Residential	3.3	0.48	0.0028	0.62	1.2	8.4
Low Density Commercial	4.5	0.65	0.016	0.13	0.4	8
Low Density Industrial	4.5	0.52	0.016	0.22	0.6	8
Low Density Mixed Use	4	0.48	0.01	0.32	1.2	7
Federal	4.5	0.65	0.016	0.13	0.4	8

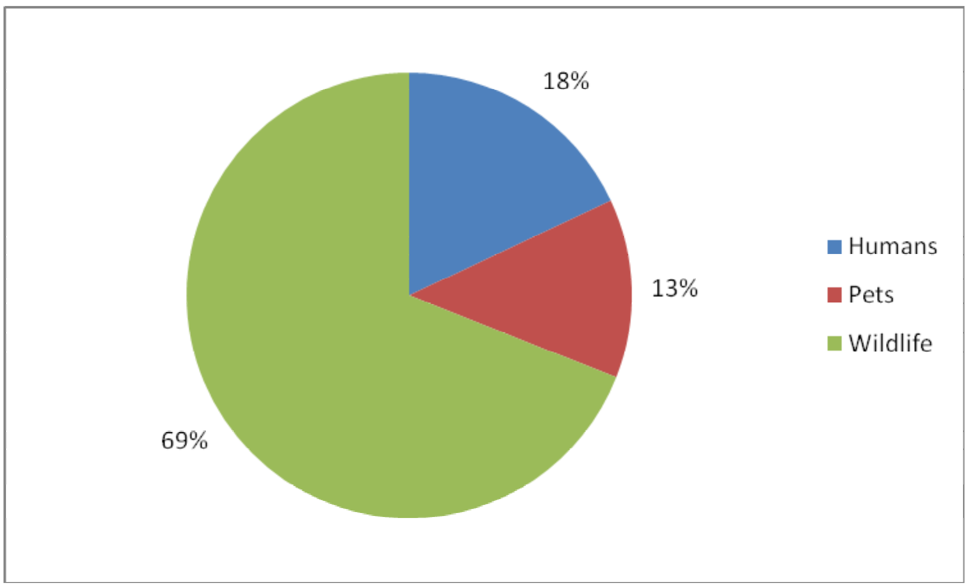

Figure 3-6: Isolate Matches from Virginia Tech BST Study of Four Mile Run (NVRC, 2002)

4 Modeling Approach

Computer simulation modeling plays three roles in bacteria TMDL development. First, computer simulation models are used to determine the loading rates (bacteria per day) to the impaired waterbody from nonpoint sources. The source assessment quantifies how much bacteria is deposited on the land surface by wildlife and pets. The amount of bacteria that enters the waterbody is a function of the runoff or subsurface flow that transports the deposited bacteria into the river or stream. By modeling the fate and transport of bacteria through the hydrological cycle, models can determine the bacteria loads from nonpoint sources.

Second, models represent the link between bacteria input loads and the bacteria concentrations observed in the impaired waterbody. Model calibration determines how the model represents the fate and transport of bacteria in the waterbody. In the calibration phase, model parameters are adjusted until there is a good fit between the observed and simulated values for flows, temperature, or bacteria concentrations.

Third, the calibrated model is used to predict the bacteria concentrations that would occur under lower loading rates. In particular, the calibrated model is used to determine what input loads from which sources are compatible with water quality standards for bacteria. These input loads form the basis of the TMDL, load allocations (LAs), and wasteload allocations (WLAs).

Consistency with the assumptions of the non-tidal Four Mile Run bacteria TMDL is one of the underlying principles guiding the development of the tidal river bacteria TMDL. This principle has already been used in adopting the land use data (Section 3.2.3), wildlife and pet population estimates, and species bacteria production rates (Section 3.5.2) from the non-tidal TMDL. The computer simulation model used in the non-tidal TMDL was also adopted for the tidal TMDL to determine the bacteria loads to tidal Four Mile Run from nonpoint sources in the tidal drainage and the upstream (non-tidal) watershed.

The computer model used in the development of the non-tidal TMDL is the Hydrological Simulation Program Fortran (HSPF) model. HSPF is the standard model used to develop bacteria TMDLs in Virginia's rivers and streams. It is not capable, however, of simulating tidally-influenced waters. The CE-QUAL-W2 model was chosen to simulate the fate and transport of bacteria in tidal Four Mile Run. CE-QUAL-W2 (or W2) is a laterally-averaged, two-dimensional model capable of simulating both hydrodynamics and the water quality of rivers, lakes and reservoirs, and estuaries. It has been used for many TMDLs for these types of waterbodies in EPA Region III and is currently being used to develop bacteria TMDLs for the tidal portions of the James River.

For consistency with the non-tidal TMDL, the computer simulation period for both the HSPF and W2 models was January 1, 1999 through May 31, 2001. Also for consistency with the non-tidal TMDL and to follow the standard practice of almost all Virginia bacteria TMDLs, fecal coliform bacteria, rather than *E. coli* bacteria, were simulated in both models. As described in Chapter 5, VADEQ's translator equation was used to compare simulated fecal coliform bacteria concentrations to Virginia's *E. coli* water quality standards:

$$\textit{E. coli conc. (cfu/100 mL)} = 2^{-0.0172} \times [\textit{fecal coliform conc. (cfu/100mL)}]^{0.91905}$$

Section 4.3 describes how fecal coliform loads were converted to *E. coli* loads to calculate the TMDL, LAs, and WLAs.

4.1 Determination of Nonpoint Sources and Upstream Loads Using HSPF

4.1.1 HSPF Overview and its Implementation in the Nontidal Four Mile Run Bacteria TMDL

HSPF simulates the fate and transport of pollutants over the entire hydrological cycle. Two distinct sets of processes are represented in HSPF: (1) processes that determine the fate and transport of pollutants at the surface or in the subsurface of a watershed, and (2) in-stream processes. The former will be referred to as land or watershed processes, the latter as in-stream or river reach processes.

Constituents can be represented at various levels of detail and simulated both on land and for in-stream environments. These decisions are made in part by specifying the modules to be used, and thus the choices establish the model structure used for any one problem. In addition to the choice of modules, other types of information must be supplied for the HSPF calculations, including model parameters and the time-series of input data. Input data includes meteorological data, point sources, reservoir information, and other types of continuous data needed for model development.

A watershed is subdivided into model segments, which are defined as areas with similar hydrologic characteristics. Within a model segment, multiple land use types can be simulated, each using different modules and different model parameters. There are two general types of land uses represented in the model: pervious land, which uses the PERLND module, and impervious land, which uses the IMPLND module. More specific land uses, like forest, crop, or developed land, can be implemented using these two general types. In terms of simulation, all land processes are computed for a spatial unit of one acre. The number of acres of each land use in a given model segment is multiplied by the values (fluxes, concentrations, and other processes) computed for the corresponding acre. Although the model simulation is performed on a temporal basis, land use information does not change with time.

Within HSPF, the RCHRES module sections are used to simulate hydraulics of river reaches and the sediment transport, water temperature, and water quality processes that result in the delivery of flow and pollutant loading to a bay, reservoir, ocean, or any other body of water. Flow through a reach is assumed to be unidirectional. In the solution technique of normal advection, it is assumed that simulated constituents are uniformly dispersed throughout the waters of the RCHRES; constituents move at the same horizontal velocity as the water, and the inflow and outflow of materials are based on a mass balance. HSPF primarily uses the "level pool" method of routing flow through a reach. Outflow from a free-flowing reach is a single-valued function of reach volume, specified by the user in an F-Table, although within a time step, the HSPF model uses a convex routing method to move mass flow and mass within the reach. Outflow may leave the reach through as many as five possible exits, which can represent water withdrawals or other diversions.

In the HSPF model developed by NVRC for the non-tidal Four Mile Run bacteria TMDL there are three subwatesheds and three reaches, as shown in **Figure 4-1**. The model simulated area and percent impervious area for the 14 land uses given in **Table 4-1**.

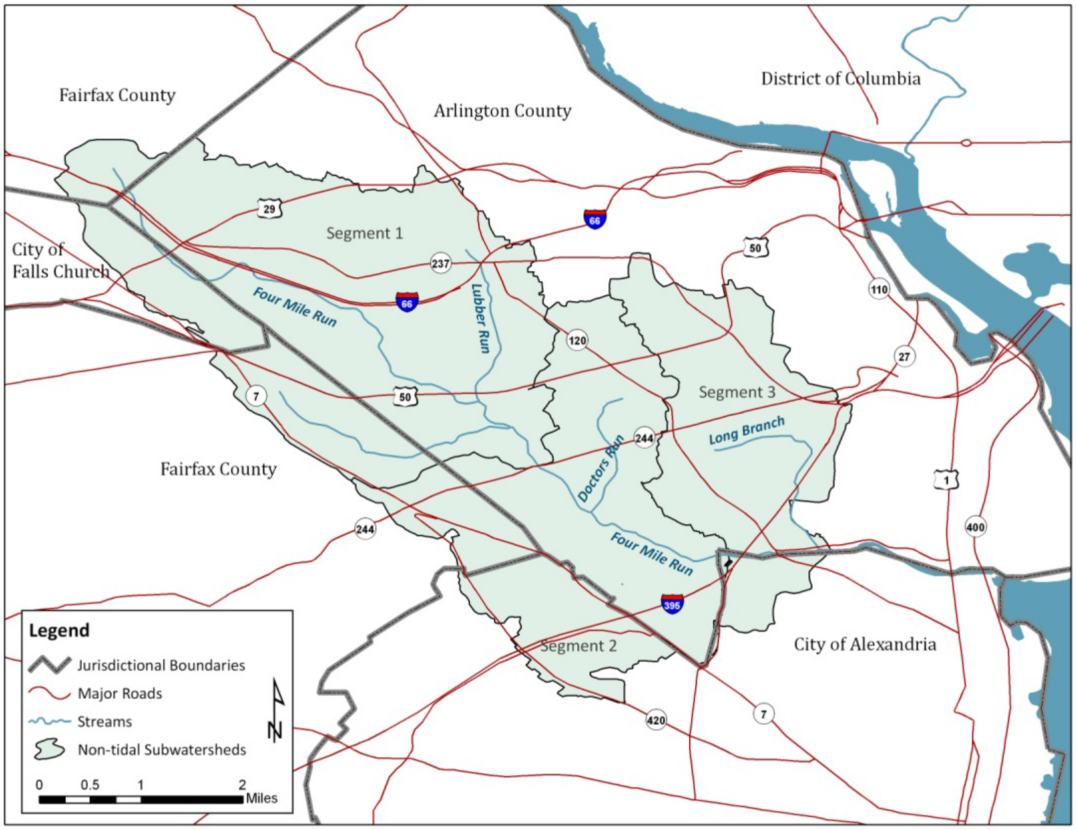

Figure 4-1: Non-tidal Four Mile Run HSPF Model Subwaterheds

Table 4-1: Land Use in Non-tidal Four Mile Run HSPF Model (acres)

Land Use	% Impervious	Segment 1	Segment 2	Segment 3	Total
Open Space/Parks	2%	390	180	40	610
Highway	90%	213	126	130	469
Medium to High Density Mixed Use	65%	241	80	96	417
Medium to High Density Industrial	80%	24	110	20	154
Public/Conservation/Golf	8%	148	102	309	559
High Density Residential	75%	20	179	101	300
Medium Density Residential	40%	2,692	755	804	4,251
Medium to High Density Residential	50%	392	930	414	1,736
Medium to High Density Commercial	70%	86	69	100	255
Low to Medium Density Residential	20%	767	243	33	1,043
Low Density Commercial	40%	260	274	7	541
Low Density Industrial	65%	9	46	5	60
Low Density Mixed Use	30%	12	189	0	201
Federal	50%	0	100	178	278
Total	42%	5,254	3,383	2,237	10,874

Hourly precipitation data from a rain gage in Seven Corners was used for the Segment 1 subwatershed; Segments 2 and 3 used precipitation data from Reagan National Airport. The remainder of the meteorological data—air temperature, wind speed, dew point temperature, cloud cover—were also based on measurements at Reagan National Airport.

The simulation of the hydrological cycle and daily stream flow in the reaches was calibrated against observed daily stream flow (cfs) at the USGS gage on Four Mile Run at Shirlington (01652500). **Table 4-2** gives the calibrated hydrological parameters for the non-tidal model. NVRC (2002) describes the hydrology calibration in more detail.

Fecal coliform bacteria from PERLND land uses were simulated using the PQUAL module. The PQUAL module simulates the buildup, decay, and washoff of constituents from the surface. Subsurface transport is not modeled, although a constituent concentration can be associated with base flow (AOQC) or interflow (IOQC). For bacteria, the buildup rate (ACQOP) is determined from the population per acre and bacteria production rate for each species inhabiting the land use type. The decay rate is input into the model as the maximum amount of bacteria that can be accumulated on the surface (SQOLIM). The washoff rate (WSQOP) determines how much of the bacteria accumulated on the surface is removed by runoff. All of these parameters can vary monthly although only SQOLIM varies monthly in the non-tidal HSPF model. Bacteria are modeled in the same way on impervious surfaces except there is no bacteria concentration associated with interflow or base flow, since only surface flows occur on impervious surfaces. The model was calibrated primarily against observed data at the VADEQ monitoring station on Four Mile Run at Columbia Pike (1AFOU004.22).

Table 4-2: Non-tidal Four Mile Run HSPF Calibration Parameters

Parameter	Definition	Units	Typical		Possible		Final Calibration
			Min	Max	Min	Max	
FOREST	Fraction forest cover	None	0.00	0.5	0	1.0	0.1
LZSN	Lower zone nominal soils moisture	inch	3	8	0.01	100	5
INFILT	Index to infiltration capacity	Inch/hour	0.01	0.25	0.0001	100	0.042
LSUR	Length of overland flow	Feet	200	500	1	None	300 – 2538[1,2]
SLSUR	Slope of overland flowpath	None	0.01	0.15	0.00001	10	0.027 – 0.037[1]
KVARY	Groundwater recession variable	1/inch	0	3	0	None	0
AGWRC	Basic groundwater recession	None	0.92	0.99	0.001	0.999	0.988
PETMAX	Air temp below which ET is reduced	Deg F	35	45	None	None	40
PETMIN	Air temp below which ET is set to zero	Deg F	30	35	None	None	35
INFEXP	Exponent in infiltration equation	None	2	2	0	10	2
INFILD	Ratio of max/mean infiltration capacities	None	2	2	1	2	2
DEEPER	Fraction of groundwater inflow to deep recharge	None	0	0.2	0	1.0	0
BASETP	Fraction of remaining ET from base flow	None	0	0.05	0	1.0	0
AGWETP	Fraction of remaining ET from active groundwater	None	0	0.05	0	1.0	0
CEPSC	Interception storage capacity	Inch	0.03	0.2	0.00	10.0	0.1
UZSN	Upper zone nominal soils moisture	inch	0.10	1	0.01	10.0	0.1
NSUR	Manning's n	None	0.15	0.35	0.001	1.0	0.1 - 0.2
INTFW	Interflow/surface runoff partition parameter	None	1	3	0	None	0.7[2]
IRC	Interflow recession parameter	None	0.5	0.7	0.001	0.999	0.5
LZETP	Lower zone ET parameter	None	0.2	0.7	0.0	0.999	0.4
ACQOP*	Rate of accumulation of constituent	#/day					8.15E9 – 1.44E10[1]
SQOLIM[4]	Maximum accumulation of constituent	#					4 – 9 x ACQOP[1,3]
WSQOP[4]	Wash-off rate	Inch/hour					0.2 - 2.0
IOQC[4]	Constituent concentration in interflow	#/ft³					141,584
AOQC[4]	Constituent concentration in active groundwater	#/ft³					4248
KS[4]	Weighing factor for hydraulic routing		0.5				0.5
FSTDEC[4]	First order decay rate of the constituent	1/day	1.152 (FC)				1
THFST[4]	Temperature correction	none	1.07				2

Table 4-2: Non-tidal Four Mile Run HSPF Calibration Parameters							
	coefficient for FSTDEC						

[1]Varies by individual model segment.
[2]Value is outside suggested range for most HSPF applications, but is acceptable for this urban application.
[3]Varies monthly.
[4]Typical values these parameters are unavailable because they are site-specific and determined through model calibration.

4.1.2 Upstream Loads

Upstream bacteria loads to tidal Four Mile Run under current conditions were determined using the non-tidal Four Mile Run HSPF model described in the previous section. **Figure 4-2** shows the monthly bacteria loads from Segment 3 over the simulation period of January 1999 through May 2001. Over the simulation period, the total load delivered from the non-tidal watershed to tidal Four Mile Run was 9.05E+15 cfus.

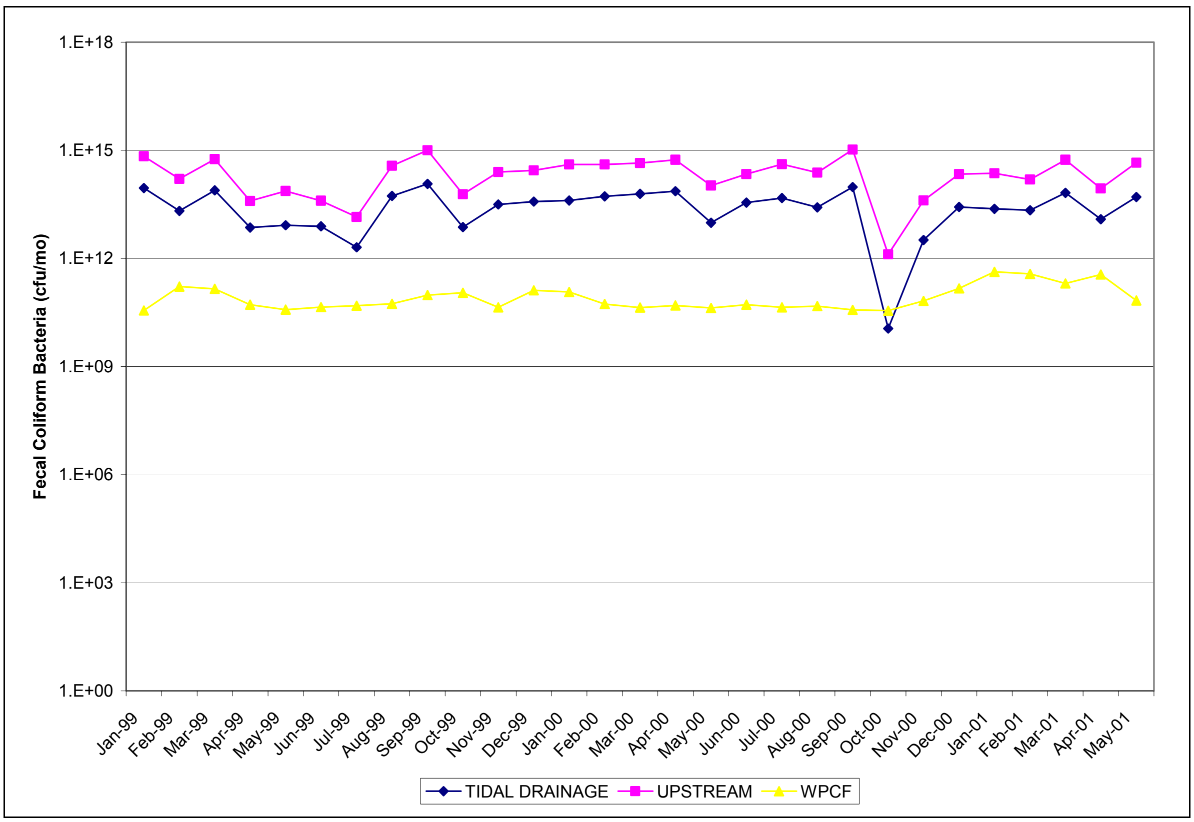

Figure 4-2: Monthly Bacteria Loads, Calibration Period

4.1.3 Extension of the HSPF Model to the Tidal Drainage

The HSPF model was extended to simulate bacteria loads from the tidal drainage. Watershed delineation was taken from the original NVRC land use, but the tidal drainage area was resegmented to make it easier to calculate MS4 loads from Arlington County and the City of Alexandria. **Figure 4-3** shows the segmentation used for the tidal drainage. **Table 4-3** gives the land use in the tidal drainage by segment.

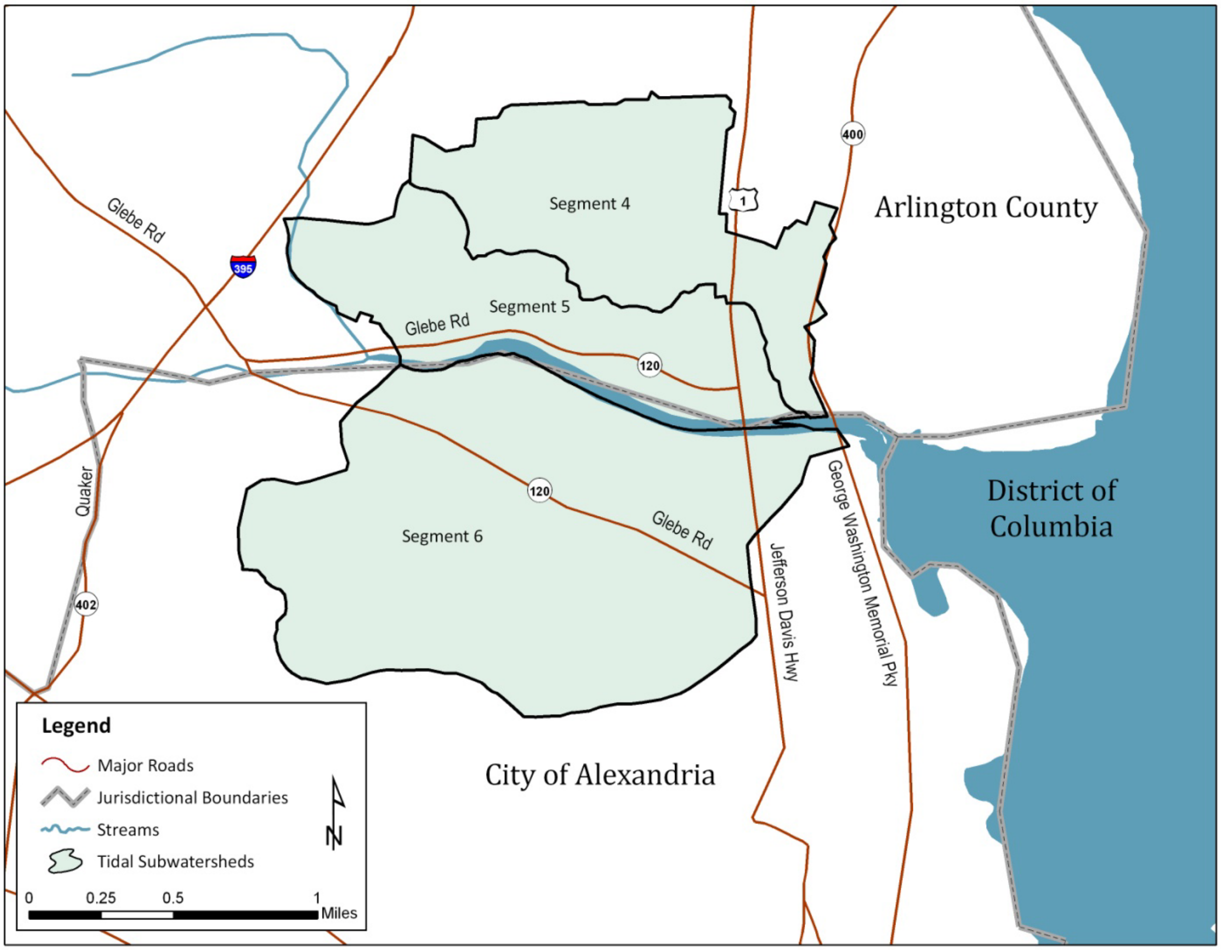

Figure 4-3: HSPF Model Tidal Four Mile Run Subwatersheds

Table 4-3: Tidal Drainage Land Use by HSPF Model Segment (acres)				
Land Use	**Segment 4**	**Segment 5**	**Segment 6**	**Total**
Open Space/Parks	13.1	20.6	42.4	76.1
Highway	1.94	0.9	4.2	7.1
Medium to High Density Mixed Use	13.3	0.0	39.6	52.9
Medium to High Density Industrial	24.4	96.8	0.2	121.4
Public/Conservation/Golf	4.1	12.5	7.6	24.2
High Density Residential	28.2	0.0	25.1	53.4
Medium Density Residential	238.4	150.1	0.0	388.5
Medium to High Density Residential	3.3	42.1	192.8	238.3
Medium to High Density Commercial	40.8	10.5	0.0	51.3
Low to Medium Density Residential	0.0	0.0	401.6	401.6
Low Density Commercial	0.0	0.0	55.5	55.5
Low Density Industrial	0.0	0.0	9.8	9.8
Low Density Mixed Use	0.0	5.2	80.7	86.0
Federal	1.0	0.0	0.0	1.0
Open Space/Parks	366.6	338.9	855.4	1,566.9

Model parameterization and meteorological inputs were taken from Segment 3 in the non-tidal model, which uses hourly precipitation data from Reagan National Airport. Bacteria accumulation rates are the same for each land use, regardless of segment, because the population densities shown in Table 3-15 were determined on a land use basis. **Table 4-4** gives the bacteria accumulation rates for pervious land (ACQOP) by land use. As in the original model, impervious accumulation rates were set at 1/33rd of the pervious accumulation rate. The maximum accumulation of bacteria on impervious surfaces (SQOLIM) was set a four times the impervious accumulation rate. On pervious land, the maximum bacteria accumulation varied by month by the factors shown in **Table 4-5**.

Table 4-4: Bacteria Accumulation Rates (ACQOP) for Pervious Land	
Land Use	**Bacteria Accumulation Rate (ACQOP) (#/day)**
Open Space/Parks	1.03E+10
Highway	8.16E+09
Medium to High Density Mixed Use	1.44E+10
Medium to High Density Industrial	1.42E+10
Public/Conservation/Golf	1.03E+10
High Density Residential	1.06E+10
Medium Density Residential	1.02E+10
Medium to High Density Residential	9.48E+09
Medium to High Density Commercial	9.73E+09
Low to Medium Density Residential	9.84E+09
Low Density Commercial	1.15E+10
Low Density Industrial	1.14E+10
Low Density Mixed Use	1.03E+10
Federal	1.15E+10

Table 4-5: Maximum Monthly Bacteria Storage Multipliers	
Month	**Maximum Storage Multiplier**
January	6.50
February	6.50
March	7.00
April	7.50
May	8.00
June	8.80
July	9.00
August	9.00
September	8.50
October	8.00
November	7.50
December	7.00

No reaches were represented in the non-tidal drainage. The flows and daily bacteria loads were summed over all land uses, and output from the model without routing them through any river reaches. Figure 4-2 in the previous section shows the monthly loads from the tidal drainage over the simulation period. Over the simulation period, the total load delivered from the tidal drainage to tidal Four Mile Run was 1.10E+15 cfus.

4.2 The CE-QUAL-W2 Model of Tidal Four Mile Run

4.2.1 Overview of CE-QUAL-W2

CE-QUAL-W2 is a laterally-averaged, two-dimensional computer simulation model capable, in its most recent formulations, of representing the hydrodynamics and water quality of rivers, lakes, and estuaries.

Waterbodies represented in CE-QUAL-W2 are divided longitudinally into segments and vertically into layers. A model cell is defined by the intersection of layers and segments. The bottom cell in a segment is fixed by the waterbody's bathymetry. The number of cells in a segment varies with the vertical position of the free surface of the waterbody.

In its simplest form the underlying mathematical structure of CE-QUAL-W2 (or W2) is based on six equations:

1. Navier-Stokes equation for horizontal momentum
2. Equation of continuity

3. Hydrostatic pressure
4. Equation of free surface
5. Equation of state (i.e. water density as a function of temperature and salinity)
6. Constituent transport equation

These six equations are used to solve for six unknowns in each time-step: (1) the location the free surface, (2) the horizontal velocity, (3) the vertical velocity, (4) pressure, (5) water density, and (6) constituent concentration. More details of the CE-QUAL-W2 model structure can be found in Cole and Buchak (1995) and Cole and Wells (2003).

W2 model parameters specify, among other things, the kinetic rates which control how constituents are transformed among themselves. These transformations are counted among the sources and sinks in the constituent transport equation. In addition to model parameters, W2 requires (1) the specification of a time series of inflow volumes, temperatures, and constituent concentrations; (2) meteorological inputs such as wind speed, air temperature, dew point, and cloud cover; and (3) boundary conditions such as inflows, outflows, or water surface elevations.

4.2.2 W2 Model Segmentation and Bathymetry

W2 representation of tidal Four Mile Run has 11 segments and eight layers, but as required in all W2 models the first and last segments and the top and bottom layers are boundary or “dummy” layers used for computational purposes only. **Figure 4-4** shows the model segmentation. **Table 4-6** describes the model segments and gives their length. Model segments average about 240 meters (800 feet) in length. Layers are one meter (3.28 feet) in height.

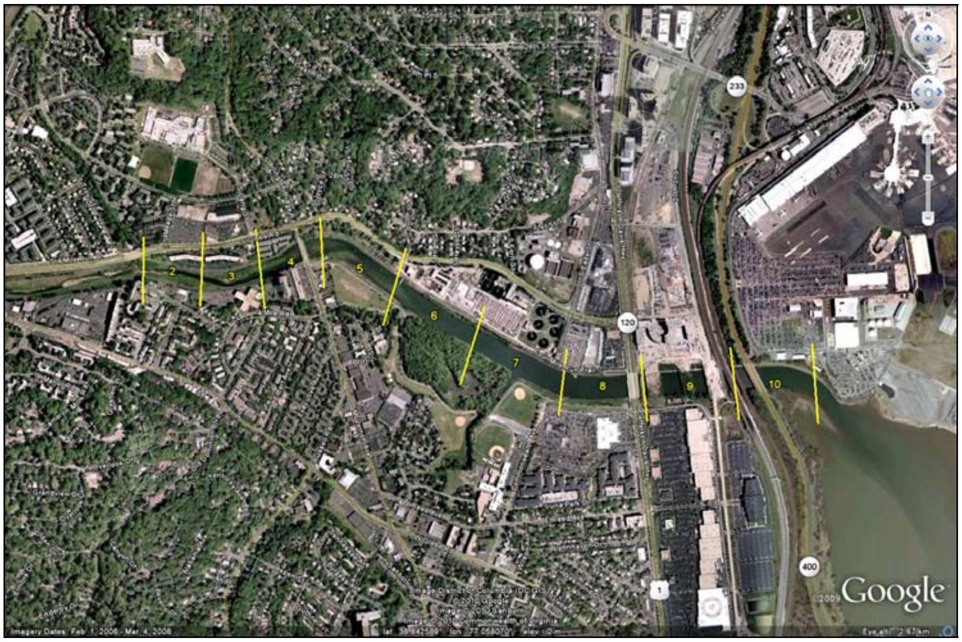

Figure 4-4: Four Mile Run W2 Model Segmentation

Table 4-6: Description of Four Mile Run W2 Model Segments		
Segment	**Distance from Downstream Boundary (ft)**	**Description**
1	NULL	Upstream Boundary Segment
2	6,500-7,200	Downstream of Long Branch
3	5,900-6,500	Vicinity of Lang Street
4	5,300-5,900	Mt. Vernon Avenue Bridge
5	4,500-5,300	Vicinity of Ives Street
6	3,600-4,500	Four Mile Run Park/Arlington WPCF
7	2,700-3,600	Four Mile Run Park/Arlington WPCF
8	1,800-2,700	Route 1 Bridge to Four Mile Run Park
9	900-1,800	Railroad Bridge to Route 1 Bridge
10	0-900	Confluence with Potomac River to Railroad Bridge
11	NULL	Downstream Boundary Segment

Model bathymetry was derived from (1) USACE (1969) designs for channel flood control implemented in the 1970's and (2) 2004 AB Consultants surveys of Four Mile Run used in the USACE Stream Restoration Feasibility Study (UACE, 2008). The 1969 design called for a channel bottom slope of 0.00085 from the confluence with the Potomac River to just above Mount Vernon Avenue, then a slope of 0.00470 upstream past the confluence with Long Branch. There has been both erosion and deposition in the channel since the design was implemented; in particular there is about 0.04 meters of deposited sediment in the lower reaches of the tidal river. Generally, however, the current channel bottom follows the design slope. The W2 model approximates the smooth slope in a "stair-step" fashion shown in **Table 4-7**, which shows the cells in the model and their average width. The average widths of the cells are derived from the cross sections surveyed by AB Consultants in 2004.

Table 4-7: Four Mile Run W2 Model Bathymetry; Cell Widths (ft)

Layer	Segment								
	2	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
2	236	236	328	322	492	492	322	266	266
3	197	197	289	282	443	443	308	259	259
4	177	177	262	256	361	361	282	246	246
5	164	164	236	230	285	285	256	233	233
6	0	0	210	203	226	226	230	220	220
7	0	0	0	0	197	197	203	207	207

4.2.3 W2 Model Inputs and Linkages

W2 requires a time series of meteorological inputs: air temperature, dew point temperature, cloud cover, wind speed, and wind direction. A time series of hourly values of these inputs was taken from measurements made at Reagan National Airport.

W2 also requires that a time series of flow or surface water elevations be set at each upstream or downstream boundary. A time series of temperature and constituent concentrations (in this case bacteria concentrations) must also be set at the boundaries. **Table 4-8** summarizes the inputs used in the W2 model of Four Mile Run for model calibration. In the W2 model of Four Mile Run, flows, temperature, and bacteria concentrations for the upstream boundary were taken from the non-tidal HSPF model and input into Segment 2.

Table 4-8: Four Mile Run W2 Calibration Inputs

Source	Flow (or Tidal Elevation)	Bacteria
Upstream	Non-tidal HSPF Model	Non-tidal HSPF Model
Tidal Drainage	Extended HSPF Model	Extended HSPF Model
WPCF Main Outfall	DMR[1]	DMR[1]
WPCF Bypass	As reported to VADEQ	200,000 cfu/100 ml
Downstream Boundary	Washington DC Tidal Elevations	DC DOE monitoring data

[1] DMR: Discharge Monitoring Report

The downstream boundary is simulated as a time series of fluctuating surface water elevations representing the tidal cycle. The time series of surface water elevations was taken from the NOAA tidal station at Washington, D.C. (8594900).

The time series of temperature and bacteria concentrations were based on the average values from data collected at two District of Columbia monitoring stations in the Potomac River, stations PMS29 and PMS37. The location of these stations is shown in **Figure 4-5**. Data are usually collected monthly at these stations, but for several months during the simulation period data were not collected at either station. For these months, the long-term average monthly values from these stations were used as model inputs. **Table 4-9** and **Table** 4-10 show the temperature and bacteria concentrations, respectively, from these stations over the simulation period, as well as their average values and the long-term monthly averages used as inputs to the model. The model was set to interpolate between the monthly values at each time step. Appendix A contains the results of sensitivity analyses performed to determine the impact of boundary conditions on model calibration.

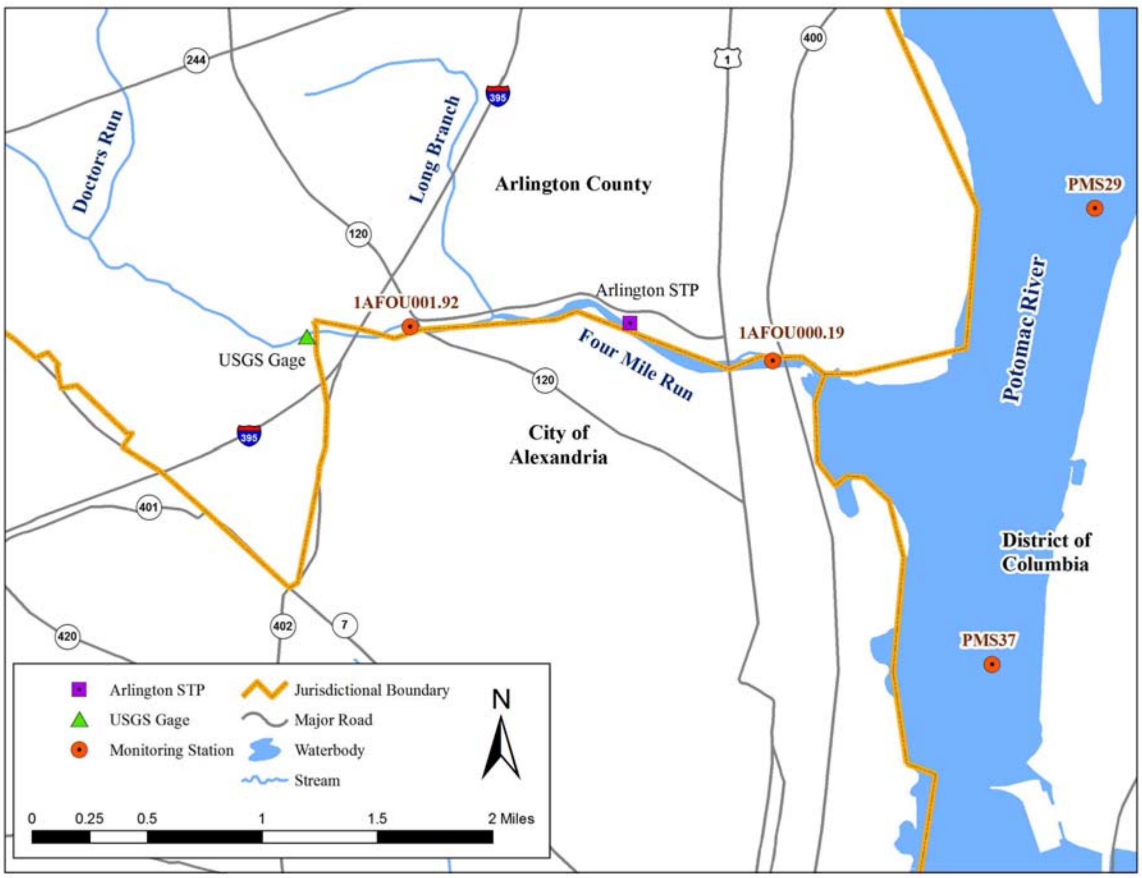

Figure 4-5: Monitoring Stations Used in Four Mile Run W2 Model Development

Table 4-9: Monthly Temperature (ºF) at Potomac Monitoring Stations

Sample Date	PMS29	PMS37	Average
12/14/1998	50	50	50
1/11/1999	32	34	34
2/8/1999	42	43	43
3/1/1999	40	41	40
3/16/1999	40	32	40
4/12/1999	58	59	58
4/26/1999	58	32	58
5/10/1999	69	69	69
5/24/1999	74	32	74
6/7/1999	78	78	78
6/21/1999	74	32	74
7/6/1999	86	90	88
7/19/1999	87	32	87
8/2/1999	85	86	86
8/16/1999	83	32	83
9/7/1999	76	77	76
9/20/1999	69	32	69
10/4/1999	67	66	67
10/18/1999	62	32	62
11/1/1999	58	62	60
12/6/1999	46	47	46
1/18/2000	35	35	35
2/14/2000	37	48	43
3/13/2000	53	53	53
3/27/2000	55	32	55
4/10/2000	55	55	55
4/24/2000	58	32	58
5/8/2000	74	74	74
6/12/2000	80	79	80
6/26/2000	83	32	83
7/10/2000	82	86	84
7/24/2000	78	32	78
8/7/2000	79	80	80
8/21/2000	76	32	76
9/11/2000	76	77	77
9/25/2000	70	32	70
10/10/2000	61	62	61
10/23/2000	63	32	63
11/13/2000	54	55	55
12/11/2000	38	39	38
1/8/2001	32	35	35
2/12/2001	42	43	43
3/5/2001	32	44	44
3/19/2001	48	32	48

4/2/2001	46	46	46
4/16/2001	60	32	60
5/7/2001	73	71	72
5/21/2001	67	32	67
6/11/2001	73	74	73

Table 4-10: Monthly Fecal Coliform Bacteria Concentrations (#/100 ml) at Potomac Monitoring Stations

Sample Date	PMS29	PMS37	Average
12/14/1998		80	80
1/13/1999			529*
2/12/1999			243*
3/11/1999			283*
4/10/1999			136*
5/9/1999			89*
6/8/1999			201*
7/7/1999			194*
8/2/1999	80	20	50
9/7/1999	230	500	365
10/7/1999			331*
11/7/1999			307*
12/6/1999	90	230	160
1/18/2000	80	130	105
2/14/2000	500	320	410
3/13/2000	80	300	190
4/10/2000	500	230	365
5/8/2000		20	20
6/12/2000	20	20	20
7/10/2000	40	20	30
8/7/2000		800	800
9/11/2000	20	80	50
10/10/2000	80	80	80
11/13/2000	1700	1700	1700
12/11/2000	500	140	320
1/8/2001		800	800
2/12/2001	500	80	290
3/5/2001		500	500
4/2/2001	800	260	530
5/7/2001	20	20	20
6/11/2001	500	40	270

* long-term monthly average

The time series of flow and bacteria concentrations from the tidal drainage were taken from the extended HSPF model described in Section 4.3.1. Temperature values were taken from the upstream HSPF model. Inputs from the tidal drainage were entered as a distributed tributary, which means they were distributed over segments in proportion to segment surface areas.

Flows and bacteria from Arlington WPCF were entered as a tributary to Four Mile Run in Segment 7. The data for these time series were taken from the monthly Discharge Monitoring Reports (DMRs) which WPCF is required to file under its permit. Because of their relative importance, these inputs are discussed in more detail in Section 4.2.4.

4.2.4 Flows and Bacteria Concentrations from Arlington County Water Pollution Control Facility

There are two types of discharges associated with Arlington WPCF: the daily discharge from normal plant operations and the unauthorized bypass flows that occur when flow exceeds plant capacity or there is some other malfunction in the treatment system. Both were represented in the calibration simulation.

Arlington WPCF is required to report average monthly flow and fecal coliform bacteria concentrations in their monthly discharge monitoring reports. This data formed the basis of the monthly time series of loads and bacteria concentrations that represent normal discharge from the plant. **Table 4-11** shows the monthly values for flows and concentrations during the simulation period that were used in the W2 model. The average monthly values were applied each time step within the month. Temperature data was unavailable so the temperatures used in the HSPF model were also used for WPCF flows.

Table 4-11: Arlington WPCF Monthly Flow and Bacteria Concentrations		
Month	**Average Flow (MGD)**	**Average Fecal Coliform (#/100 ml)**
Jan-99	27.2	1.1
Feb-99	26.1	6.0
Mar-99	30.4	4.0
Apr-99	27.1	1.7
May-99	27.0	1.2
Jun-99	27.7	1.4
Jul-99	27.6	1.5
Aug-99	27.3	1.7
Sep-99	28.9	2.9
Oct-99	24.3	3.9
Nov-99	25.7	1.5
Dec-99	25.1	4.4
Jan-00	25.4	3.9
Feb-00	27.2	1.8
Mar-00	28.4	1.3
Apr-00	28.9	1.5
May-00	27.5	1.3
Jun-00	28.5	1.6
Jul-00	28.5	1.3
Aug-00	28.7	1.4
Sep-00	27.5	1.2
Oct-00	27.3	1.1
Nov-00	26.6	2.2
Dec-00	25.1	5.0
Jan-01	28.1	12.9
Feb-01	27.3	12.8
Mar-01	30.2	5.7
Apr-01	30.1	10.4
May-01	30.5	1.9

Arlington WPCF is also required to report bypass discharges and estimate discharge volumes. Reported discharges and volumes are listed in **Table 4-12**. Only five events occurred during the simulation period. A concentration of 200,000 bacteria/100 mL was associated with each bypass event. This concentration is within the range of combined sewer overflows (CSOs) reported nationally and is comparable to the concentrations in CSOs reported by the District of Columbia and the City of Alexandria. A sensitivity analysis was performed to test the sensitivity of the W2 model calibration to bypass concentration. The results from this analysis are reported in Appendix A.

Table 4-12: Arlington WPFC Bypass Flows	
Date	**Bypass Flow (Million Gallons)**
1/24/1999	5.1
3/15/1999	4.8
9/16/1999	23.8
4/17/2000	0.6
3/30/2001	3.7

4.2.5 W2 Model Hydrodynamic Simulation

The standard procedure for calibrating the hydrodynamic simulation of W2 is to compare simulated and observed surface water elevations or velocities and adjust Manning's n coefficient, which controls channel friction, until there is agreement between observed and simulated values. In addition, if there are observations on a conservative constituent like salt or observed concentrations of a tracer or dye study, the parameters that control longitudinal dispersion can be calibrated.

There is no data available for Four Mile Run to calibrate the hydrodynamic simulation during the calibration period. Except for the USGS tidal elevation data collected after 2006, which is probably collected too close to the confluence of Four Mile Run with the Potomac to be useful for calibration, there are no data collected in Four Mile Run that could be used for calibrating hydrodynamic parameters. For this reason no calibration of the hydrodynamic parameters was attempted, though as part of the geomorphic survey of Four Mile Run, USACE (2008) did estimate that Manning's n for the upper portion of the tidal river was 0.035.

In lieu of calibrating the hydrodynamic parameters, default values were used in W2. **Table 4-13** gives the values of key hydrodynamic parameters used in the model of Four Mile Run. Appendix A describes the results of sensitivity tests to determine if the uncertainty in hydrodynamic parameters impacted the TMDL scenarios.

Table 4-13: Four Mile Run W2 Model Hydrodynamic Parameters		
Parameter	**Value**	**Description**
EBOT	-1.37	Bottom elevation, m[1]
THETA	0.55	Time-weighing for vertical advection
AX	1.0	Longitudinal eddy viscosity, m^2 sec^{-1}
DX	1.0	Longitudinal eddy diffusivity, m^2 sec^{-1}
FI	0.035	Manning's n
AZMAX	0.001	Maximum vertical eddy viscosity, m^2 sec^{-1}

[1]Relative to mean lower low water elevation (MLLW) for NOAA station 8594900.

4.2.6 W2 Temperature Simulation

Figure 4-6 compares observed and simulated temperatures for Four Mile Run at the GW Parkway gage site. Overall, W2 captures the seasonal trend in temperature, though some low temperature observations in 1999 are underpredicted.

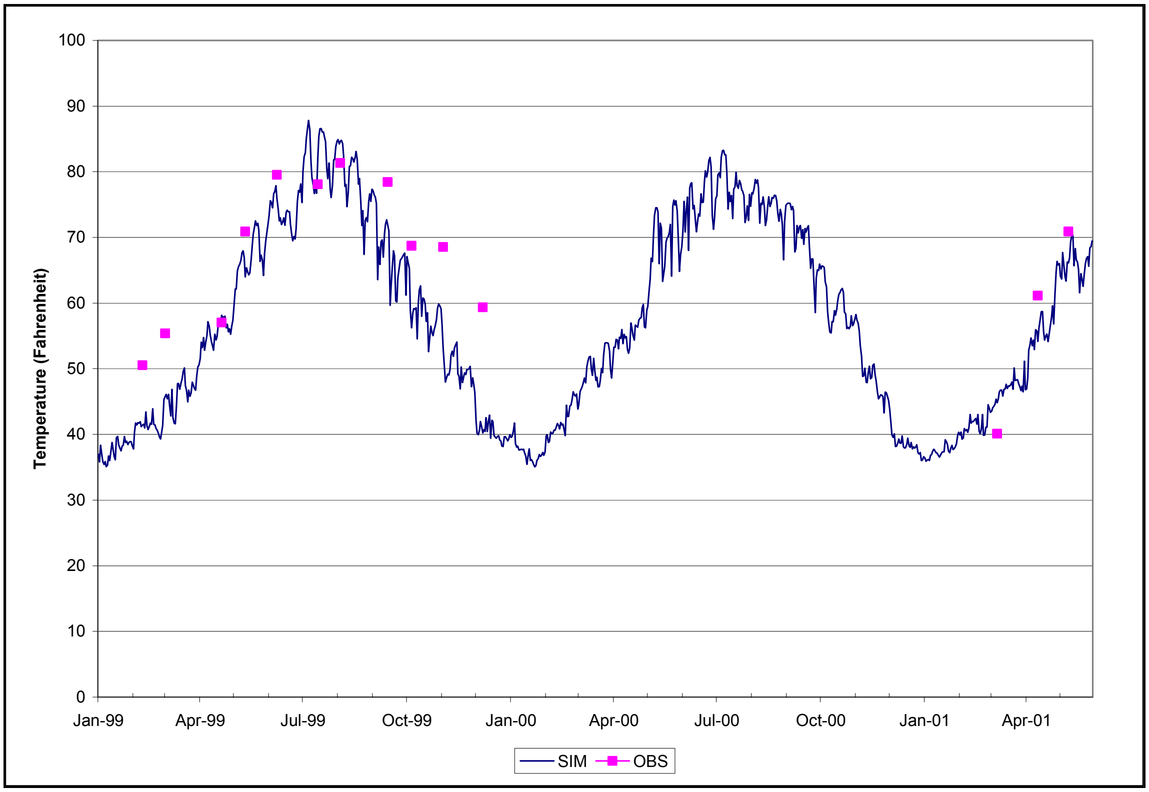

Figure 4-6: Observed and Simulated Temperature, Four Mile Run at George Washington Parkway

Water temperature in W2 is primarily calibrated by adjusting wind fetch with a wind sheltering coefficient, which controls evaporation from the water surface, or by adjusting a shading coefficient which controls the percent of solar radiation reaching the water surface. Water temperature in the Four Mile Run model was not sensitive to either of these two adjustments. The temperature is primarily determined by the input temperatures from HSPF and WPCF and the downstream boundary temperature.

4.2.7 W2 Bacteria Calibration

The standard VADEQ methodology for bacteria TMDLs recommends that the observed geometric mean of bacteria monitoring data and the percent exceedance of the *E. coli* maximum criterion of 235 cfu/100 ml be used as calibration targets. Simulated bacteria concentrations over the entire simulation period at locations corresponding to monitoring stations should match their observed values. The bacteria decay rate in W2 was adjusted until bacteria concentration in Segment 9 were within approximately 10% of both the geometric mean and exceedance frequency observed at station 1AFOU000.19 at the George Washington Parkway. Simulated concentrations below the 100 cfu/100 ml detection limit for the observed data were set at 100 cfu/100 ml. **Table 4-14** compares the observed and simulated geometric mean and exceedance rates. The calibrated decay rate was 0.45. The temperature correction coefficient was set at its default value of 1.04.

Table 4-14: Four Mile Run W2 Model Bacteria Calibration

	Geometric Mean Fecal Coliform Concentration	**Exceedance Rate of Maximum *E. Coli* Criterion (235 cfu/100 ml)**
Observed	352	0.35
Simulated	375	0.36

Figure 4-7 shows a time series of observed and simulated fecal coliform bacteria concentrations at the GW Parkway over the simulation period. **Figure 4-8** shows box plots of the distribution of observed and simulated bacteria concentrations, which compare the quartiles of the distributions. As the figure shows, the quartiles and median concentration values match reasonably well. Simulated minimum concentrations are below the observed values because observed values are set at their detection limit.

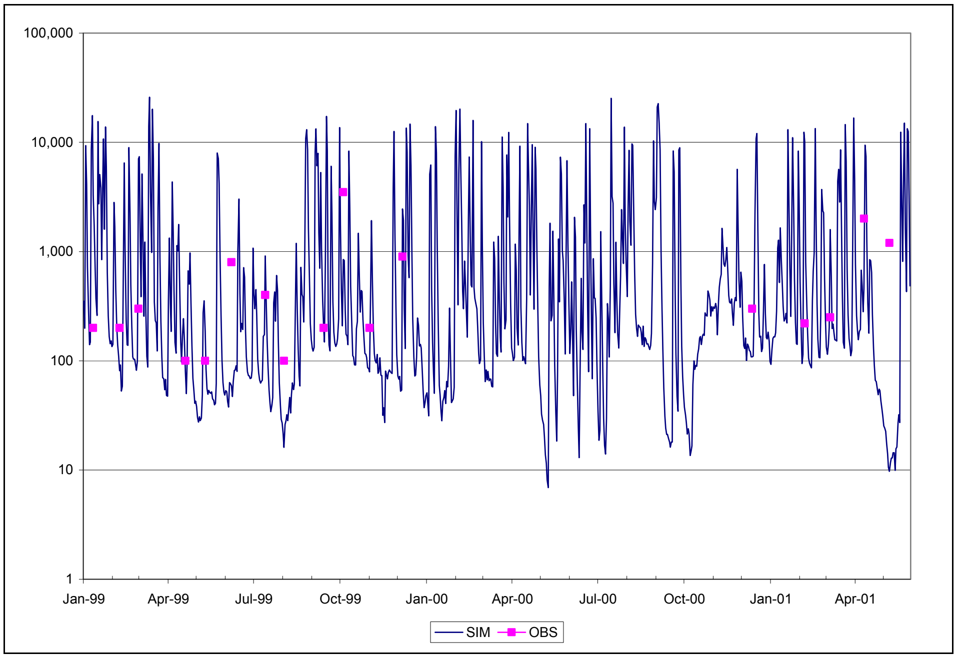

Figure 4-7: Observed and Simulated Fecal Coliform Concentrations, Four Mile Run at George Washington Parkway

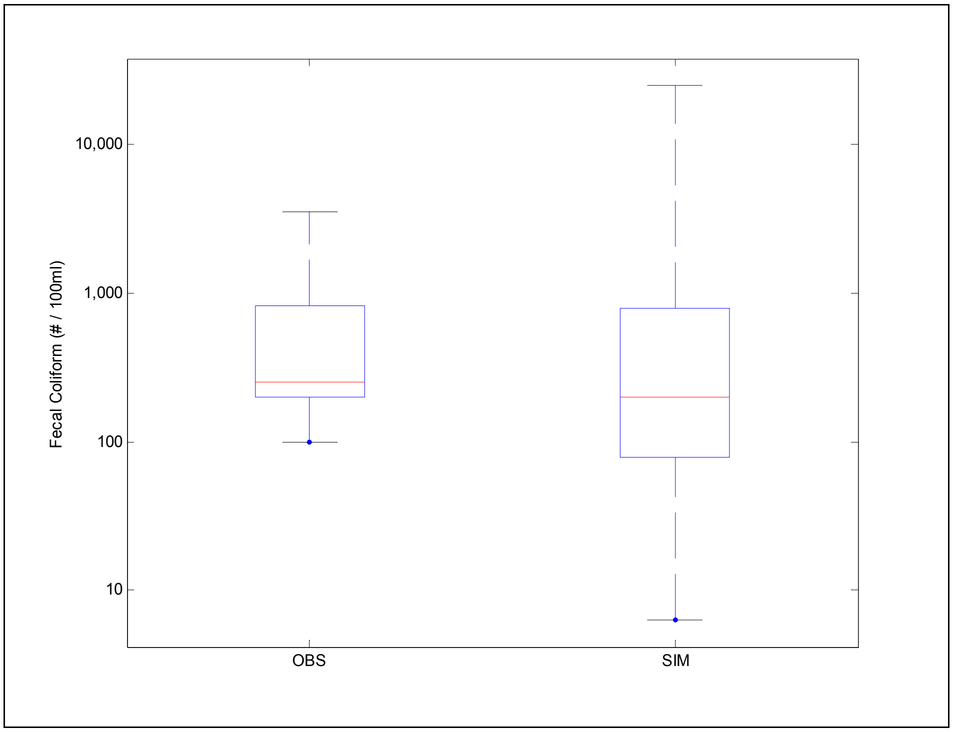

Figure 4-8: Distribution of Observed and Simulated Fecal Coliform Concentrations, Four Mile Run at George Washington Parkway

4.3 Existing Fecal Coliform and *E. Coli* Bacteria Loads

The first subsection presents the fecal coliform bacteria loads by source delivered to tidal Four Mile Run. Source loads are presented as average annual values. These were calculated by dividing the total loads for the simulation period by the number of days in the simulation period (882 days) and multiplying this figure by 365 days in a year.

The second subsection converts those loads into their *E. coli* bacteria equivalents using VADEQ's translator equation.

4.3.1 Existing Fecal Coliform Bacteria Loads

Table 4-15 gives the average annual delivered fecal coliform bacteria loads from the tidal drainage by land use and segment. The average annual loads from upstream, the Arlington WPCF, and its bypass are also given. The tidal drainage accounts for only 11% of the load, while the upstream non-tidal river accounts for 87% of the load. Bypass loads are about 3% of the total average annual load, while the load from WPCF's main outfall is less than 0.1% of the total annual load.

Table 4-15: Average Annual Fecal Coliform Loads (cfu/yr) by Source, Current Conditions				
Land Use	**Segment 4**	**Segment 5**	**Segment 6**	**Total**
Open Space/Parks	6.09E+12	9.59E+12	1.98E+13	3.55E+13
Highway	4.79E+11	6.90E+10	1.04E+12	1.59E+12
Medium to High Density Mixed Use	3.77E+12	0.00	1.13E+13	1.50E+13
Medium to High Density Industrial	4.63E+12	1.83E+13	2.91E+10	2.30E+13
Public/Conservation/Golf	1.86E+12	5.63E+12	3.40E+12	1.09E+13
High Density Residential	4.63E+12	0.00	4.13E+12	8.76E+12
Medium Density Residential	7.36E+13	4.63E+13	0.00	1.20E+14
Medium to High Density Residential	8.11E+11	1.04E+13	4.77E+13	5.89E+13
Medium to High Density Commercial	7.00E+12	1.81E+12	0.00	8.80E+12
Low to Medium Density Residential	0.00	0.00	1.93E+13	1.93E+13
Low Density Commercial	0.00	0.00	1.53E+14	1.53E+14
Low Density Industrial	0.00	0.00	2.21E+12	2.21E+12
Low Density Mixed Use	1.21E+07	8.40E+10	1.30E+12	1.38E+12
Federal	2.88E+11	0.00	0.00	2.88E+11
Total Tidal Drainage	1.03E+14	9.22E+13	2.62E+14	4.57E+14
Upstream	-	-	-	3.75E+15
Arlington WPCF	-	-	-	1.29E+12
WPCF Bypass	-	-	-	1.19E+14
Total All Sources				4.32E+15

4.3.2 Existing *E. Coli* Bacteria Loads

Table 4-16 gives the average annual delivered *E. coli* bacteria loads from the tidal drainage and land use segments. The average annual loads from upstream, the Arlington WPCF, and its bypass are also given.

The *E. coli* loads from the tidal drainage sources were obtained from their flows and fecal coliform loads as follows:

1. A daily fecal coliform concentration was calculated from the total flow and daily fecal coliform load , i.e. the daily sum of the flows and loads from all land uses in all tidal drainage segments
2. The fraction of the total daily fecal coliform load from each land use and segment was calculated on a daily basis
3. The daily fecal coliform concentration calculated in step (1) was converted to an *E. coli* concentration using the VADEQ translator equation
4. The daily *E. coli* concentration was converted to a daily load by multiplying by the total daily flow
5. The total daily *E. coli* load was partitioned among the land uses and segments in proportion to their share of the total fecal coliform load calculated in step (2)

The *E. coli* loads for upstream, WPCF, and bypass flows were calculated based on a straightforward use of the translator equation on their daily fecal coliform concentrations and the flows from these sources. The share of the average annual *E. coli* load from bypass flows dropped slightly, from about 3% to 2%, but otherwise the share of the load from each source is approximately the same as their share of the total average annual fecal coliform load.

Table 4-16: Average Annual *E. coli* Loads (cfu/yr) by Source, Current Conditions

Land Use	Segment 4	Segment 5	Segment 6	Total
Open Space/Parks	2.72E+12	4.28E+12	8.83E+12	1.58E+13
Highway	2.14E+11	3.23E+10	4.67E+11	7.14E+11
Medium to High Density Mixed Use	1.70E+12	0.00	5.10E+12	6.80E+12
Medium to High Density Industrial	2.12E+12	8.40E+12	1.34E+10	1.05E+13
Public/Conservation/Golf	8.28E+11	2.50E+12	1.51E+12	4.84E+12
High Density Residential	2.11E+12	0.00	1.88E+12	3.99E+12
Medium Density Residential	3.29E+13	2.07E+13	0.00	5.36E+13
Medium to High Density Residential	3.64E+11	4.68E+12	2.14E+13	2.65E+13
Medium to High Density Commercial	3.17E+12	8.19E+11	0.00	3.99E+12
Low to Medium Density Residential	0.00	0.00	8.65E+12	8.65E+12
Low Density Commercial	0.00	0.00	6.83E+13	6.83E+13
Low Density Industrial	0.00	0.00	9.97E+11	9.97E+11
Low Density Mixed Use	6.74E+06	4.16E+10	6.41E+11	6.83E+11
Federal	1.29E+11	0.00	0.00	1.29E+11
Total Tidal Drainage	4.61E+13	4.15E+13	1.17E+14	2.05E+14
Upstream	-	-	-	1.66E+15
Arlington WPCF	-	-	-	1.12E+12
WPCF Bypass	-	-	-	4.38E+13
Total All Sources	-	-	-	1.91E+15

5 Allocation

Allocation analysis was the third stage in the development of the tidal Four Mile Run bacteria TMDL. The purpose of this third stage was to develop the framework for reducing bacteria loading under the existing watershed conditions so that water quality standards can be met. The TMDL represents the maximum amount of pollution that the stream can receive without exceeding the water quality criteria. The load allocations for the selected scenarios were calculated using the following equation:

$$TMDL = \sum WLA + \sum LA + MOS$$

Where:

WLA = waste load allocation (point source contributions)
LA = load allocation (nonpoint source allocation)
MOS = margin of safety

Typically, several potential allocation strategies would achieve the TMDL endpoint and water quality criteria. Available control options depend on the number, location, and character of pollutant sources.

5.1 Incorporation of Margin of Safety

The margin of safety (MOS) is a required component of the TMDL to account for any lack of knowledge concerning the relationship between effluent limitations and water quality. According to EPA guidance (*Guidance for Water Quality-Based Decisions: The TMDL Process, 1991*), the MOS can be incorporated into the TMDL using two methods:

- implicitly incorporating the MOS using conservative model assumptions to develop allocations
- explicitly specifying a portion of the TMDL as the MOS and using the remainder for allocations

The bacteria TMDL for tidal Four Mile Run uses an implicit MOS, based on four factors. First, as will be explained in more detail in the following sections, TMDL scenarios were developed based on the principle that the tidal drainage to Four Mile Run had to meet water quality standards without the assistance of dilution from the upstream tidal river or the downstream boundary with the Potomac

River. For all potential TMDL scenarios, the concentrations upstream and downstream of tidal Four Mile Run were set at the fecal coliform equivalent of the *E. coli* geometric mean standard of 126 cfu/100 ml (195 cfu/100 ml fecal coliform equivalent). Second, it was assumed that there were no losses in transport between the tidal drainage and the tidal river. Third, the concentration of the source responsible for the largest volume of water entering tidal Four Mile Run, Arlington WPCF, was set at its permit limit, which is also the geometric mean standard. Fourth, as shown in Appendix A, the W2 model of Four Mile Run is relatively insensitive to the bacteria decay coefficient, which was calibrated conservatively for this TMDL.

5.2 Allocation Scenario Development

Table 5-1 summarizes the general assumptions of the potential TMDL scenario simulations. In all scenario simulations, the bacteria concentration from Arlington WPCF was set at its permit limit. The flow was increased to 150% of the current design capacity to provide additional wasteload allocation for future growth. The flows and bacteria loads from the plant's bypass were eliminated, since these discharges are not permitted. The non-tidal river flow concentration was set at 195 cfu/100 ml, the fecal coliform equivalent of the monthly geometric mean *E. coli* standard. The downstream concentration at the Potomac confluence was set at 195 cfu/100 ml; tidal elevations at the downstream boundary were not changed for the TMDL scenarios.

Table 5-1: Four Mile Run W2 Scenario Input Assumptions

Source	Flow (or Tidal Elevation)	Bacteria
Upstream	Non-tidal HSPF Model	195 cfu/100 ml
Tidal Drainage	Extended HSPF Model	HSPF Model Scenario
WPCF Main Outfall	60 MGD	195 cfu/100 ml
WPCF Bypass	none	Not applicable
Downstream Boundary	Washington DC Tidal Elevations	195 cfu/100 ml

The tidal drainage to Four Mile Run is modeled using the same hydrology and bacteria loading rates as used for the non-tidal Four Mile Run TMDL. Given the guiding principle that the sources to tidal Four Mile Run must meet water quality standards without relying on dilution from either the non-tidal river or the Potomac River boundary, it was anticipated but not assumed, that, subject to the conservative constraints described in Section 5.1, tidal Four Mile Run would respond in a similar fashion to reduction in bacteria loading rates as the non-tidal portion of the watershed. To develop consistent baselines for comparison and to facilitate TMDL implementation for the entire Four Mile Run watershed, the same four potential TMDL scenarios were simulated for the tidal drainage as were simulated for the non-tidal bacteria TMDL. Those four scenarios were defined by reducing bacteria loading rates to the land surface by the following sources: human (SSOs, cross-connections, and homeless persons), pet, raccoon, waterfowl, and other wildlife (primarily deer). **Table 5-2** shows reduction rates for the four scenarios. Scenario 0 represents a simulation which implements the general assumptions for TMDL scenarios given in Table 5-1, but with no reductions from the tidal drainage.

Table 5-2 also shows the frequency of exceedances of the monthly geometric mean *E. coli* water quality standard. Scenarios were required to meet water quality standards in all predominately tidal segments (Segments 4 through 10). Just as in the non-tidal TMDL, only Scenario 4, which calls for a 98% reduction from human and pet sources, had stringent enough reductions to meet water quality standards throughout the simulation period (January 1999 through May 2001). Scenario 3, which calls for the same level of reduction from human and pet sources but only an 80% reduction from wildlife, had an approximately 10% exceedance rate.

Table 5-2: Scenario Source Application Rate Reductions (in % reduction) and *E. coli* Geometric Mean Exceedance Rates

Scenario	Waterfowl	Raccoon	Human	Pet	Other Wildlife	Exceedance Rate
Base (calibration)	0%	0%	0%	0%	0%	83%
0[1]	0%	0%	0%	0%	0%	69%
1	0%	0%	95%	95%	0%	59%
2	50%	50%	95%	95%	0%	34%
3	80%	80%	98%	98%	80%	10%
4	95%	95%	98%	98%	95%	0%

[1] Scenario 0 has all Scenario assumptions in Table 5-1 but no reduction from tidal drainage sources

Fecal coliform input loads for the tidal drainage and the WPCF were translated into *E. coli* load and wasteload allocations using the method described in Section 4.3. The TMDL was determined as the sum of all input loads. **Table 5-3** shows the average annual *E. coli* loads and the allocated loads by land use, as given by Scenario 4. The long-term average *E. coli* loads and coefficient of variations were determined to implement the final allocation scenarios and to express the TMDL on a daily basis. Assuming a log-normal distribution of data and a probability of occurrence of 95%, the maximum daily loads were determined using the following equation (*USEPA OWOW 2007 Options for Expressing Daily Loads in TMDLs*):

$$MDL = LTA \times Exp[z\sigma - 0.5\sigma^2]$$

where;

MDL = maximum daily limit (cfu/day)
LTA = long-term average (cfu/day)
z = z statistic of the probability of occurrence
$\sigma^2 = \ln(CV^2+1)$
CV = coefficient of variation

Table 5-3: Scenario 4 Average Annual *E. Coli* Loads (cfu/year) By Source				
Land Use	**Segment 4**	**Segment 5**	**Segment 6**	**Total**
Open Space/Parks	1.83E+11	2.76E+11	5.70E+11	1.03E+12
Highway	2.89E+10	1.63E+09	2.54E+10	5.60E+10
Medium to High Density Mixed Use	4.16E+11	0.00	2.33E+11	6.49E+11
Medium to High Density Industrial	8.48E+11	3.86E+11	6.12E+08	1.23E+12
Public/Conservation/Golf	6.24E+10	1.61E+11	9.76E+10	3.21E+11
High Density Residential	7.09E+11	0.00	9.11E+10	8.01E+11
Medium Density Residential	4.43E+12	1.14E+12	0.00	5.56E+12
Medium to High Density Residential	5.96E+10	2.21E+11	1.01E+12	1.29E+12
Medium to High Density Commercial	9.02E+11	3.77E+10	0.00	9.40E+11
Low to Medium Density Residential	0.00	0.00	4.71E+11	4.71E+11
Low Density Commercial	0.00	0.00	3.76E+12	3.76E+12
Low Density Industrial	0.00	0.00	5.21E+10	5.21E+10
Low Density Mixed Use	1.19E+08	4.53E+10	7.00E+11	7.45E+11
Federal	2.19E+10	0.00	0.00	2.19E+10
Total Tidal Drainage	7.66E+12	2.27E+12	7.01E+12	1.69E+13
Upstream	-	-	-	3.43E+13
Arlington WPCF	-	-	-	1.04E+14
WPCF Bypass	-	-	-	0.00
Total All Sources	-	-	-	1.56E+14

The following sections present the waste load allocation and load allocations for the impaired segment.

5.3 Wasteload Allocation

This section outlines the wasteload allocations (WLA) for the impaired segment. It presents the existing and allocated loads for each permitted (VPDES and MS4) facility contributing to the impaired segment.

5.3.1 Arlington Water Pollution Control Facility

The only individual municipal VPDES permit in the tidal Four Mile Run drainage is the Arlington WPCF. As described in Section 5.2, it is given a wasteload allocation based on its *E. coli* permit limit of 126 cfu/100 ml and its current design flow of 40 MGD. An allocation equivalent to 20 MGD of flow discharging at the *E. coli* geometric mean criterion was also included in the WLA to accommodate potential growth and expansion of VPDES point sources in the watershed. **Table 5-4** shows the wasteload allocation for VPDES point sources in the tidal Four Mile Run watershed.

<table>
<tr><th colspan="5">Table 5-4: E. Coli Wasteload Allocation for VPDES Permitted Point Sources</th></tr>
<tr><th>Permit Number</th><th>Permit Type</th><th>Design Flow (MGD)</th><th>Permit Concentration (cfu/100 ml)</th><th>Wasteload Allocation (cfu/year)</th></tr>
<tr><td>VA0025143</td><td>Municipal</td><td>40</td><td>126</td><td>6.96E+13</td></tr>
<tr><td colspan="4">Allocation for Future Growth of Point Sources</td><td>3.48E+13</td></tr>
<tr><td colspan="4">Total WLA</td><td>1.04E+14</td></tr>
</table>

5.3.2 MS4 Allocation

As discussed earlier, loads associated with MS4 permits are considered part of the wasteload allocations. Four MS4 permits have been issued in the tidal drainage to Four Mile Run, including a Phase I permit for Arlington County and Phase II permits for the City of Alexandria, VDOT, and the George Washington Memorial Parkway.

All land-based loadings except the loadings from the open space and public land use categories were allocated to the MS4s. Due to the spatial overlap between MS4 entities and the resulting uncertainty of the appropriate operator of the system, the MS4 loads are aggregated by jurisdiction (Arlington County, the City of Alexandria) in the TMDL.

Table 5-5 shows the aggregated wasteload allocation and the percent reduction from current loads.

<table>
<tr><th colspan="4">Table 5-5: E. Coli Wasteload Allocation for MS4 Permits</th></tr>
<tr><th>Permit Number</th><th>MS4 Permit Holder</th><th>Wasteload Allocation (cfu/year)</th><th>Percent Reduction (%)</th></tr>
<tr><td>VA0088579</td><td>Arlington County</td><td rowspan="3">2.23E+13</td><td rowspan="3">88%</td></tr>
<tr><td>VAR040062</td><td>VDOT</td></tr>
<tr><td>VAR040111</td><td>George Washington Memorial Parkway</td></tr>
<tr><td>VAR040057</td><td>City of Alexandria</td><td rowspan="3">1.53E+13</td><td rowspan="3">94%</td></tr>
<tr><td>VAR040062</td><td>VDOT</td></tr>
<tr><td>VAR040111</td><td>George Washington Memorial Parkway</td></tr>
</table>

5.4 Load Allocation

The load allocation represents the land-based loads from the open space and public land use categories. **Table 5-6** summarizes the load allocation and percent reduction from current loads.

Table 5-6: *E. Coli* Load Allocation

Load Allocation (cfu/year)	Percent Reduction (%)
3.26 E+12	93%

5.5 TMDL Allocation Summary

The daily bacteria TMDL for tidal Four Mile Run is shown in **Table 5-7**. The average annual bacteria TMDL is shown in **Table 5-8**. **Figure 5-1** shows the calendar-month geometric mean *E. coli* concentrations under existing conditions and after the reductions specified in Scenario 4, the TMDL Scenario, are applied at the GW Parkway. As shown by Figure 5-1, the reduction of pet and human sources by 98% and wildlife sources by 95% results in bacteria concentrations that are below the geometric mean standard for *E. coli.*

Table 5-7: Tidal Four Mile Run TMDL (cfu/day) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
1.52E+12	1.08E+11	Implicit	1.63E+12

Table 5-8: Tidal Four Mile Run TMDL (cfu/year) for *E. coli* Bacteria

WLA	LA	MOS	TMDL
1.42E+14	3.26 E+12	Implicit	1.45E+14

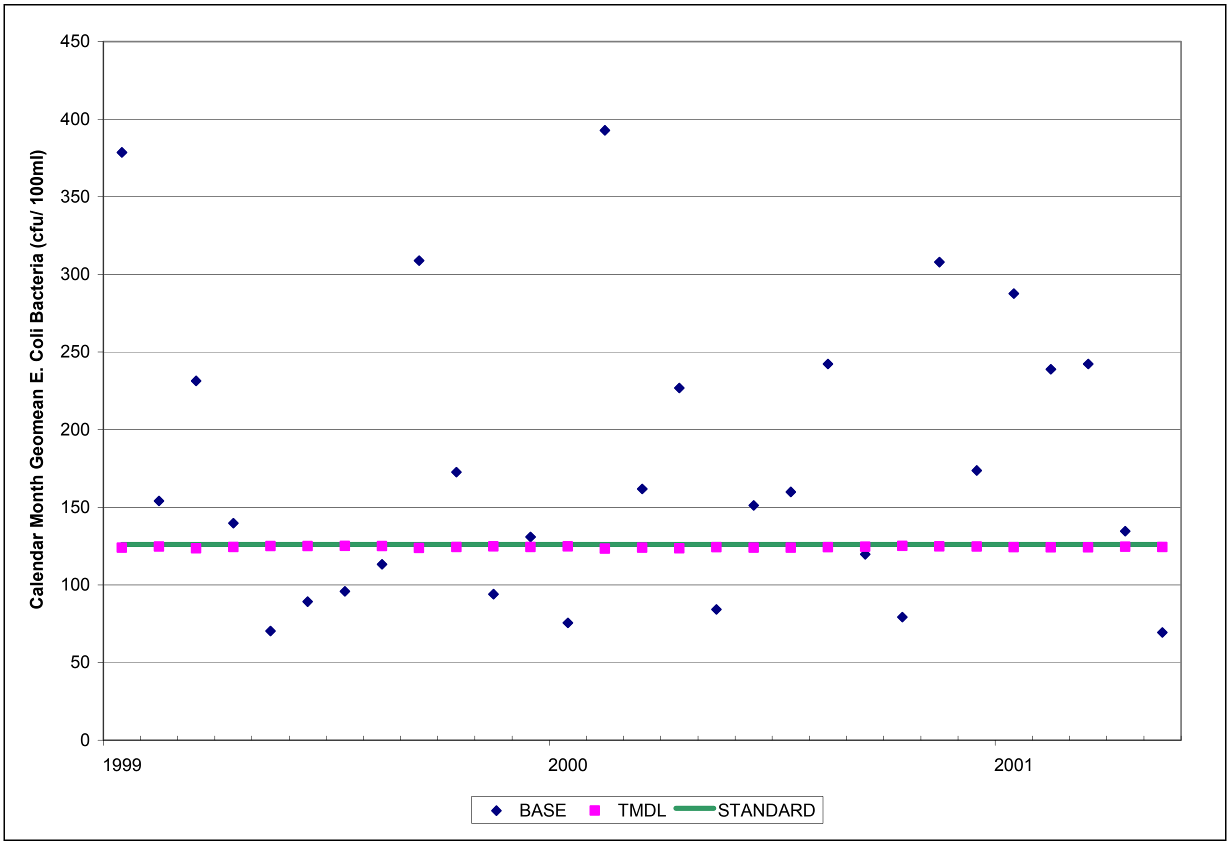

Figure 5-1: Tidal Four Mile Run Calendar-Month Geometric Mean *E. Coli* Bacteria Concentrations (cfu/100 ml) under Existing Conditions and TMDL Scenario

6 TMDL Implementation

Once a TMDL has been approved by EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources. The following sections outline the framework used in Virginia to provide reasonable assurance that the required pollutant reductions can be achieved.

6.1 Continuing Planning Process and Water Quality Management Planning

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

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

6.2 Staged Implementation

In general, Virginia intends for the required control actions, including Best Management Practices (BMPs), to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. The iterative implementation of pollution control actions in the watershed has several benefits:

1. enables tracking of water quality improvements following implementation through follow-up stream monitoring;
2. provides a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. provides a mechanism for developing public support through periodic updates on implementation levels and water quality improvements;
4. helps ensure that the most cost effective practices are implemented first; and

5. allows for the evaluation of the adequacy of the TMDL in achieving water quality standards.

6.3 Implementation of Wasteload Allocations

Federal regulations require that all new or revised National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the assumptions and requirements of any applicable TMDL WLA (40 CFR §122.44 (d)(1)(vii)(B)). All such permits should be submitted to EPA for review.

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

6.3.1 Treatment Plants

This TMDL does not require reductions from municipal or industrial treatment plants.

6.3.2 Stormwater

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

<u>Municipal Separate Storm Sewer Systems – MS4s</u>

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

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

Additional information on Virginia's Stormwater Phase 2 program and a downloadable menu of Best Management Practices and Measurable Goals Guidance can be found at http://www.dcr.virginia.gov/sw/vsmp.htm.

6.3.3 TMDL Modifications for New or Expanding Dischargers

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

6.4 Implementation of Load Allocations

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

6.4.1 Implementation Plan development

For the implementation of the TMDL's LA component, a TMDL implementation plan will be developed that addresses, at a minimum, the requirements specified in the Code of Virginia, Section 62.1-44.19.7. State law directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters." The implementation plan "shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments." EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain water quality standards, monitoring plans, and milestones for attaining water quality standards.

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

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

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

6.4.2 Staged Implementation Scenarios

The purpose of the staged implementation scenarios is to identify one or more combinations of implementation actions that will result in the reduction of controllable sources to the maximum extent practicable using cost-effective, reasonable BMPs for nonpoint source control. Among the most efficient sediment BMPs for both urban and rural watersheds are infiltration and retention basins, riparian buffer zones, grassed waterways, streambank protection and stabilization, and wetland development or enhancement.

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

A useful goal for a staged implementation approach would be to achieve an exceedance rate of 10 % or less of the maximum *E. coli* criterion (235 cfu/100 ml). Under VADEQ's current monitoring and assessment protocols, an exceedance rate of the maximum standard less than 10% would be sufficient to remove tidal Four Mile Run from the list of impaired waters. **Table 6-1** shows the exceedance rates for the four TMDL scenarios. Scenarios 1 through 4 all have exceedance rates less than 10%. In the bacteria TMDL for the non-tidal Four Mile Run, NVRC (2002) estimated that an exceedance rate of less than 10% would be achieved with reductions somewhere between Scenarios 2 and 3. The tidal river requires less reduction to meet the maximum criterion than the non-tidal river, because under the tidal TMDL storm concentrations higher than the 235 cfu/100 ml maximum criterion in *E. coli* bacteria concentrations are diluted by upstream flows and WPCF discharges with bacteria concentrations equivalent to the 126 *E. coli* geometric mean standard. Since the Stage 1 goals of the non-tidal TMDL are more stringent, when applied to the tidal drainage, they are compatible with the tidal river meeting the maximum *E. coli* standard.

Table 6-1: Potential Stage 1 Scenario Source Application Rate Reductions (in % reduction) and Exceedance Rates of the Maximum *E. Coli* Criterion (235 cfu/100 ml)

Scenario	Waterfowl	Raccoon	Human	Pet	Other Wildlife	Exceedance Rate
Base (calibration)	0%	0%	0%	0%	0%	36%
0[1]	0%	0%	0%	0%	0%	11%
1	0%	0%	95%	95%	0%	9%
2	50%	50%	95%	95%	0%	4%
3	80%	80%	98%	98%	80%	1%
4	95%	95%	98%	98%	95%	0%

[1] Scenario 0 has all Scenario assumptions in Table 5-1 but no reduction from tidal drainage sources.

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

6.4.3 Link to Ongoing Restoration Efforts

Implementation of this TMDL will contribute to on-going water quality improvement efforts aimed at restoring water quality in the watershed. An implementation plan (IP) for the fecal coliform TMDL developed for non-tidal Four Mile Run was completed in 2004. This plan, "Implementation Plan for the Fecal Coliform (TMDL) for Four Mile Run, Virginia" reflects the current efforts of Alexandria, Arlington, Fairfax County, and the City of Falls Church to reduce bacteria pollutant loads in the watershed. The IP covers the non-tidal extent of the watershed.

The IP outlines three basic tactics for limiting the anthropogenic contributions of bacteria to Four Mile Run:

1. Pollution Prevention
2. Mitigation Measures
3. Indirect Measures

The 2004 report discusses in detail the commitments that the City of Alexandria, Arlington County, Fairfax County, and the City of Falls Church have each made to reducing bacteria inputs into the watershed. The commitments are detailed by agency, scope, and timeframe. Additional commitments from agencies such as the Virginia Department of Transportation and the Northern Virginia Regional Commission are also listed in the report.

In general, each jurisdiction plans to work to reduce bacteria inputs by addressing the following categories of challenges:

1. sanitary sewer overflows
2. inappropriate (illicit) connections to the storm drain system
3. faulty septic systems
4. improper pet waste disposal
5. street and storm drain infrastructure
6. stream corridor degradation
7. stormwater reduction and reuse
8. stormwater treatment

Arlington County and the City of Alexandria are working with the U.S. Army Corps of Engineers to develop a stream restoration plan for Four Mile Run, including sections of the tidal river. Stream corridor restoration potentially may lower bacteria concentrations by restoring an ecological balance to riparian areas.

Additionally, each jurisdiction is working to affect the behaviors and attitudes of the basin's citizens to nonpoint source pollution. For instance, outreach campaigns have been launched to address illegal dumping in storm drains. While some of these programs address broad water quality issues, some jurisdictions are also conducting directed outreach efforts relating to bacteria reduction. The City of Alexandria and Arlington County have placed emphasis on proper dog walking habits. These two jurisdictions have also coordinated the development of a set of educational signs for parks in the watershed that explain Four Mile Run's relation to the Chesapeake Bay, the history of the watershed, and how we all live downstream of someone else.

6.4.4 Implementation Funding Sources

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

Some of the major potential sources of funding for non-regulated implementation actions include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, Virginia State Revolving Loan Program (also available for permitted activities), Virginia Agricultural Best Management Practices Cost-Share Programs, Virginia Water Quality Improvement Fund (available for both point and nonpoint source pollution), tax credits and landowner contributions. Information on WQIF projects and allocations can be found at http://www.deq.virginia.gov/bay/wqif.html and at http://www.dcr.virginia.gov/sw/wqia.htm.

6.5 Follow-Up Monitoring

Following the development of the TMDL, VADEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. VADEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study. The purpose, location, parameters, frequency, and duration of the monitoring will be determined by VADEQ 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 VADEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the VADEQ regional TMDL coordinator by September 30 of each year. **Table 6-2** provides a summary of the water quality monitoring stations in the tidal Four Mile Run bacteria-impaired watershed.

Table 6-2: Active VADEQ Water Quality Monitoring Stations in Four Mile Run		
Station ID	**Station Description**	**Stream Name**
1AFOU000.19	George Washington Parkway	Four Mile Run

[1]Note: The last 5 digits of the VADEQ station number corresponds to stream mile.

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

In some cases, watersheds will require monitoring above and beyond what is included in VADEQ's standard monitoring plan. Ancillary monitoring by citizens' or watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established QA/QC guidelines in order to maximize compatibility with VADEQ monitoring data. In instances where citizens' monitoring data is not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bimonthly single station monitoring will be contingent on staff resources and available laboratory budget. More information on citizen monitoring in Virginia and QA/QC guidelines is available at http://www.deq.virginia.gov/cmonitor/.

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

6.6 Attainability of Designated Uses

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

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

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

1. naturally occurring pollutant concentration prevents the attainment of the use;
2. natural, ephemeral, intermittent, or low flow conditions prevent the attainment of the use unless these conditions may be compensated for by the discharge of sufficient volume of effluent discharges without violating state water conservation
3. human-caused conditions or sources of pollution prevent the attainment of the use and cannot be remedied or would cause more environmental damage to correct than to leave in place
4. dams, diversions, or other types of hydrologic modifications preclude the attainment of the use, and it is not feasible to restore the waterbody to its original condition or to operate the modification in such a way that would result in the attainment of the use;
5. physical conditions related to natural features of the waterbody, such as the lack of proper substrate, cover, flow, depth, pools, riffles, and the like, unrelated to water quality, preclude attainment of aquatic life use protection; or
6. controls more stringent than those required by §301b and §306 of the Clean Water Act would result in substantial and widespread economic and social impact.

This and other information is collected through a special study called a UAA. All site-specific criteria or designated use changes must be adopted by the SWCB as amendments to the water quality standards regulations. During the regulatory process, watershed stakeholders and other interested citizens, as well as the EPA, are able to provide comment. Additional information can be obtained at http://www.deq.virginia.gov/wqs/documents/WQS_eff_1FEB2010.pdf.

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

As a first step, measures targeted at the controllable, anthropogenic sources identified in the TMDL's staged implementation scenarios will be implemented. The expectation would be for the reductions of all controllable sources to the maximum extent practicable using the implementation approaches described above. VADEQ will continue to monitor biological health and water quality in the stream during and subsequent to the implementation of these measures to determine if water quality standard is attained. This effort will also help to evaluate if the modeling assumptions were correct. In the best-case scenario, water quality goals will be met and the stream's uses fully restored using effluent controls and BMPs. If, however, water quality standards are not being met, and no additional effluent controls and BMPs can be identified, a UAA would then be initiated with the goal of re-designating the stream for a more appropriate use or subcategory of a use.

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

7 Public Participation

The development of the tidal Four Mile Run bacteria TMDL would not have been possible without public participation. Three technical advisory committee (TAC) meetings and two public meetings were held. The following is a summary of the meetings.

7.1 Technical Advisory Committee Meetings

TAC Meeting No. 1 – The first TAC meeting was held on October 30, 2008 at the Central Public Library in Arlington, Virginia to present and review the steps and the data used in the development of the bacteria TMDL for the tidal Four Mile Run listed segment.

TAC Meeting No. 2 – The second TAC meeting was held on June 15, 2009 at the Shirlington Public Library in Arlington, Virginia to discuss the bacteria source assessment and progress made in developing the bacteria TMDL for the tidal Four Mile Run.

TAC Meeting No. 3 – The third TAC meeting was held on January 21, 2010 at the Shirlington Public Library in Arlington, Virginia to review the results of the model calibration and potential TMDL scenarios, and to discuss the levels of bacteria reductions required to meet water quality standards.

7.2 Public Meetings

Public Meeting No. 1 – The first public meeting was held on November 19, 2008 at the Fairlington Community Center in Arlington, Virginia to present the TMDL development process, the tidal Four Mile Run bacteria-impaired segment, data that caused the segment to be on the 303(d) list, and the data and information needed for TMDL development. Nineteen people attended this meeting. Copies of the presentation were made available for public distribution. This meeting was publicly announced in the Virginia Register.

Public Meeting No. 2 – The second public meeting was held on March 8, 2010 at the Shirlington Public Library in Arlington, Virginia to review TMDL development and discuss the required TMDL reductions. Copies of the presentation and the draft TMDL report executive summary were available for public distribution. The meeting was announced publicly in The Virginia Register of Regulations. Twelve people attended this meeting.

The following groups and agencies participated in the development of the bacteria TMDL for tidal Four Mile Run:

- Alexandria Sanitation Authority
- Arlington County Department of Environmental Services
- Arlington Water Pollution Control Facility
- City of Alexandria Department of Transportation and Environmental Services
- City of Falls Church, Environmental Services
- Fairfax County Stormwater Planning Division, Department of Public Works and Environmental Services
- Greeley and Hanson
- LimnoTech
- National Park Service, George Washington Memorial Parkway
- Northern Virginia Community College
- Northern Virginia Regional Commission
- Northern Virginia Soil and Water Conservation District
- Virginia Department of Conservation and Recreation
- Virginia Department of Forestry
- Virginia Department of Transportation

Appendix A: Sensitivity Analysis

In Chapter 5, it was shown that the load reductions specified by Scenario 4 are necessary to meet water quality standards. The CE-QUAL-W2 model was used to determine that the bacteria loads under Scenario 4 do meet water quality standards, whereas the load reductions under Scenarios 1, 2, and 3 do not meet water quality standards. The goal of this sensitivity analysis is to address potential sources of uncertainly in model simulation results. More specifically, the sensitivity analysis addresses whether there are uncertainties in model specification or calibration that would call into question the main conclusions of the TMDL development: (1) Scenario 4 meets water quality standards, and (2) Scenarios 1, 2, and 3 do not.

There are four sources of uncertainty addressed by this sensitivity analysis. The first source of uncertainty stems from the fact that data was not available to calibrate the hydrodynamics of the W2 model. Default parameters were used to specify the hydrodynamic simulation. It is possible that another set of parameters would better represent hydrodynamics in tidal Four Mile Run and lead to a different simulation of the fate and transport of bacteria in the tidal river.

The second source of uncertainty is the uncertainty associated with the calibration of the simulation of bacteria in tidal Four Mile Run. The primary purpose of calibrating the W2 model against observed bacteria concentrations is to determine the decay rate of bacteria in the tidal river. A range of decay rates may be compatible with the calibration targets of (1) matching the observed geometric mean of the observed fecal coliform bacteria concentrations during the simulation period and (2) matching the exceedance rate of the *E. coli* maximum criterion (235 cfu/100 ml, equivalent to 385 cfu/100 ml of fecal coliform bacteria based on the VADEQ translator equation). It is possible that there is a decay coefficient that is compatible with the observed data but would lead to the conclusion either (1) that Scenario 4 does not meet water quality standards, or (2) that Scenario 1, 2, or 3 does meet water quality standards.

The third and fourth sources of uncertainty concern the estimated bacteria inputs used in the calibration. There was no data available on the bacteria concentrations associated with bypasses from Arlington WPCF. The concentration used in the model, 200,000 cfu/100 ml, was a conservative choice with respect to load estimation. It is representative of CSO concentrations from the City of Alexandria's combined sewer system. The choice of bypass concentration could have influenced the decay rate, and therefore may have impacted the scenario results. Similarly, monitoring data from DCDOE's ambient monitoring program was used to set the boundary bacteria concentrations at the simulation of the confluence of Four Mile Run and the Potomac River. There are no explicit observations of bacteria concentrations during storm events when bacteria concentrations tend to be higher that average. Therefore, bacteria concentrations at the downstream boundary of the W2 model may be underestimated in the calibration, and this may in turn influenced the determination of the decay rate.

The sensitivity analysis answers the question "How would the calibrated W2 model change if these hydrodynamic parameters or loading rates had been specified differently?" The bacteria decay rate determined in the W2 model calibration is the link between the sources of uncertainty and the scenario results. Therefore, the sensitivity of model calibration and scenario results to the bacteria decay coefficient will be discussed first to provide the context for the rest of the sensitivity analysis.

A.1 Sensitivity of the Calibration and Scenarios to the Bacteria Decay Coefficient

Table A-1 shows the values of the simulated geometric mean fecal coliform concentration and exceedance rate of the fecal coliform equivalent of the *E. coli* maximum exceedance rate. Assuming that the model is calibrated if the geometric mean and exceedance rate are within 10% of their observed values, bacteria decay coefficients in the range between 0.35 and 1.0 are in agreement with the observed calibration. If the simulated geometric mean or the simulated exceedance rate is below their observed counterparts, the model is not calibrated conservatively, and is open to the charge that the model cannot demonstrate that the water quality standard is met because it under predicts observed concentrations. The most appropriate range for the decay coefficient is therefore between about 0.5 and 0.35. The model was calibrated conservatively by choosing a value for the decay coefficient of 0.45, which results in simulated geometric mean bacteria concentrations and exceedance rates somewhat greater than their observed counterparts. This conservative choice of decay coefficient supports the adoption of an implicit margin of safety (MOS), especially when it is recognized that the decay coefficient is a logarithmic measure of decay (on the natural log scale), so that if one decay rate is twice the rate of another, it will result in a bacteria concentration more than five times lower over the same period of time.

Table A-1: Sensitivity of Bacteria Calibration to Bacteria Decay Rate		
Bacteria Decay Rate (1/d)	**Geometric Mean**	**Exceedance Rate**
1.0	313	0.31
0.9	322	0.32
0.8	332	0.33
0.7	343	0.33
0.6	355	0.34
0.55	361	0.34
0.5	368	0.35
0.45	375	0.36
0.4	383	0.36
0.35	391	0.37
0.3	400	0.38
Observed	352	0.35
± 10% Observed	316-387	0.31-0.39

Table A-2 shows the approximate minimum decay rates compatible with Scenarios 2, 3, and 4 meeting water quality standards. Higher decay rates imply lower bacteria concentrations, so it can be assumed that these scenarios will meet water quality standards with decay rates above their minimum values. The minimum rate for Scenario 4 is below the acceptable calibration range for the decay coefficient. This means that, all other considerations fixed, Scenario 4 meets water quality standards under all possible values of the decay rate compatible with the observed data. The minimum rate for Scenario 2 is above the acceptable calibration range. This means that there is no decay rate consistent with the observed data under which Scenario 2 meets water quality standards. Scenario 3 is compatible with the observed data in the broadest sense but not compatible with a conservative calibration.

Table A-2: Sensitivity of Scenario Results to Bacteria Decay Rate	
Scenario	**Minimum Decay Rate to Meet Water Quality Standards (/day)**
2	1.3
3	.82
4	.32

A.2 Sensitivity of Bacteria Simulation to Hydrodynamic Parameters

As reported in Section 4.2, hydrodynamic parameters in the Four Mile Run W2 model were not calibrated because there was not appropriate observed data, such as velocity measurements, tracer studies, or surface elevation measurements, to use in a calibration during the simulation period, although more recently, starting in 2006, the USGS has measured surface water elevations in Four Mile Run at the Route 1 bridge.

The hydrodynamic simulation is a product of bathymetry and forcing functions such as tidal elevations at the boundary or inflows from non-tidal tributaries. Bathymetric data was available for Four Mile Run from USACE's (2008) Feasibility Study for stream restoration in Four Mile Run. The calibrated HSPF model for the non-tidal river was used to determine input flows from upstream river and the tidal drainage.

Surface water elevations were taken from the NOAA station at Washington, D.C. in the Ship Channel across the river from Four Mile Run. Those elevations should be reasonably representative of the surface water elevations in the Potomac in the vicinity of Four Mile Run. Surface water elevations at the USGS station in Four Mile Run were compared to those from the Washington Ship Channel over their overlapping period of record to estimate potential uncertainty in the surface water elevations at the downstream boundary of the model domain. Section A.2.1 discusses that comparison. Section A.2.2 Impact of Hydrodynamic Parameters on Bacteria Calibration presents a sensitivity study of the impact of the uncertainty in hydrodynamic parameters on the calibration of the W2 model.

A.2.1 Comparison of Surface Water Elevations in Four Mile Run and the Washington Ship Channel

Measured surface water elevations at the Washington Ship Channel (NOAA 8594900) and Four Mile Run (USGS 01652545) were compared over the period of July 2006 through September 2008. **Figure A-1** shows the difference between daily maximum surface elevations and daily minimum surface water elevations at the two stations over that period. Surface water elevations at the two stations generally are highly correlated, but the daily maximum surface water elevation in Four Mile Run seems to be on average about 0.27 feet less than at Washington Ship Channel and the minimum elevation seems to be on average about 0.16 feet less than Washington Ship Channel. It must be added that the differences between the two stations show significant drift and may be related to the provisional nature of the USGS data.

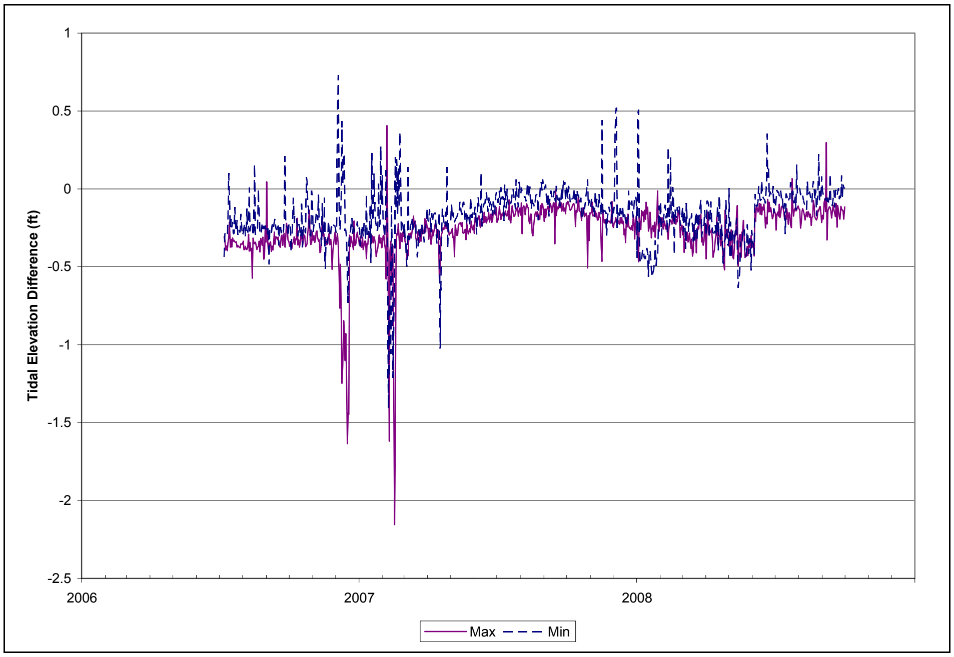

Figure A-1: Difference in Daily Maximum and Minimum Tidal Elevations (ft) between Four Mile Run and Washington Ship Channel

Tidal harmonic constituents were calculated for each station using least-squares linear multiple regression based on the data from the period July 2006 through September 2008. The formula for the regression equation model is

$$E = \sum a_i * \cos(f_i*t) + b_i * \sin(f_i*t) + \varepsilon$$

where

E = tidal elevation (ft)
a_i , b_i = amplitudes of harmonic coefficients
f_i = angular frequency of harmonic coefficient (radians/hr)
t = time (hrs)
ε = error term

Table A-3 gives the values of the harmonic constituents. Although the values of the coefficients are not similar, the resulting predicted or synthetic time series for the two stations are very similar. Synthetic tidal elevations were calculated from the harmonic constituents for the two stations over the W2 model's simulation period, January 1999 through May 2001 (**Figure A-2**and **Figure** A-3). As might be expected, since the astronomical forcing functions are almost identical, the synthetic tidal elevations are highly correlated. The daily maximum and minimum tidal elevations at Four Mile Run are only a few percent smaller than those at the Washington Ship Channel.

Table A-3: Harmonic Constituents Based on Surface Water Elevations (ft) July 2006 –September 2008

Harmonic (ft)	Frequency (radians/hr)	Washington Ship Channel		Four Mile Run	
		Cos	Sin	Cos	Sin
Const.		2.37E-01		6.98E-02	
M2	1.41E-04	1.24E-01	-1.28E+00	8.39E-02	-1.25E+00
S2	1.45E-04	1.16E-02	-1.83E-01	-4.00E-03	-1.72E-01
N2	1.38E-04	-2.44E-01	-4.45E-02	-2.45E-01	-3.51E-02
K2	1.46E-04	2.63E-02	6.11E-02	2.74E-02	5.01E-02
K1	7.29E-05	-9.40E-03	-1.62E-01	-9.24E-03	-1.63E-01
O1	6.76E-05	1.28E-01	5.20E-03	1.26E-01	5.56E-03
P1	7.25E-05	1.61E-02	-2.70E-02	8.53E-03	-2.97E-02
Q1	6.50E-05	1.59E-02	-1.86E-02	8.08E-03	-2.42E-02
M4	2.81E-04	-3.92E-02	1.10E-01	-4.31E-02	9.46E-02

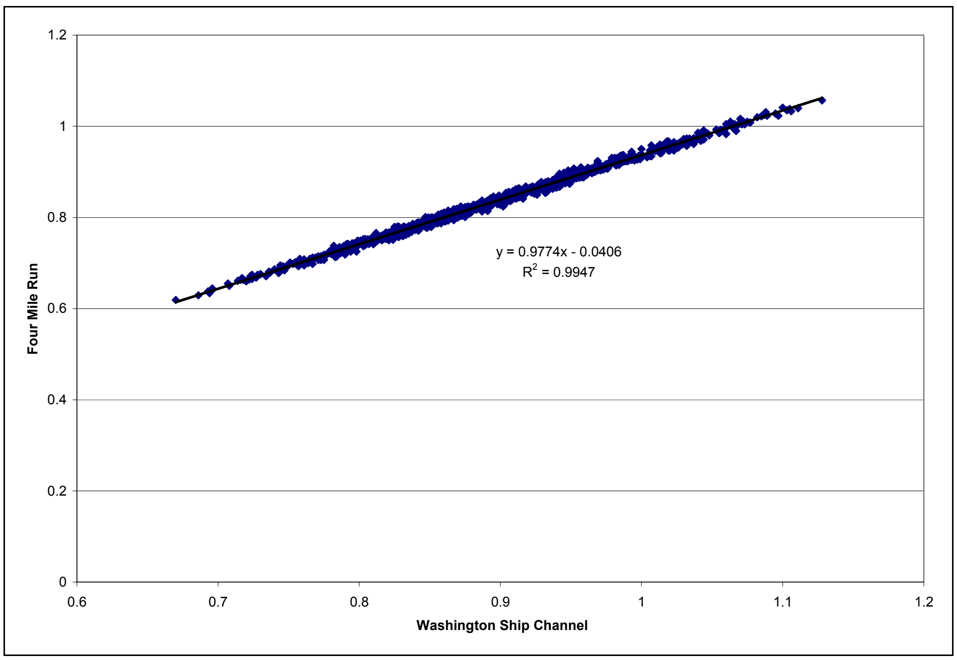

Figure A-2: Maximum Daily Synthetic Tide Elevations, 1999-2001

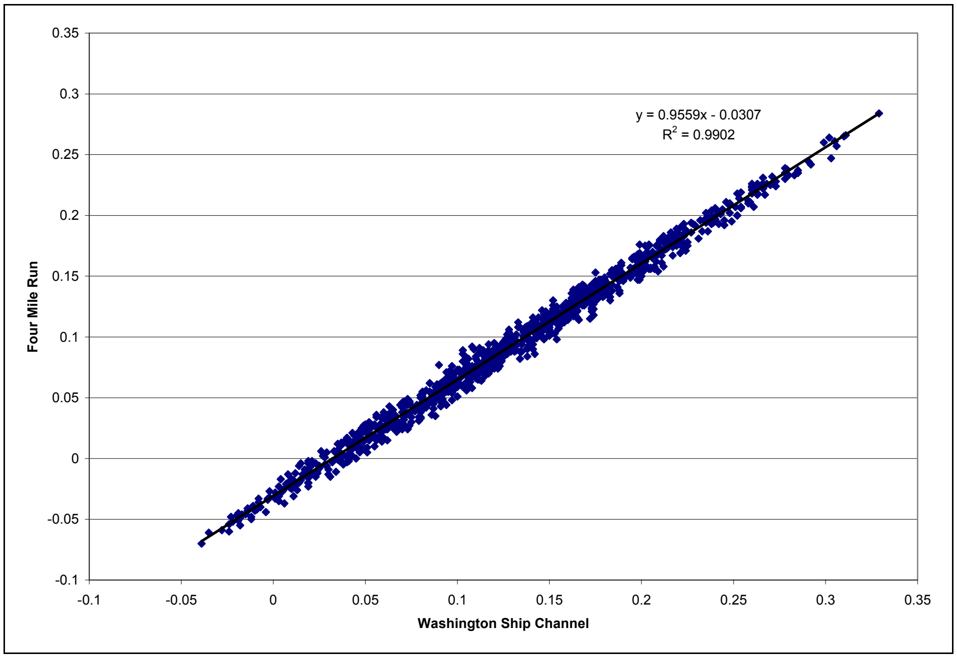

Figure A-3: Minimum Daily Synthetic Tide Elevations, 1999-2001

Synthetic tidal elevations were calculated initially with the hope that they could either be used in model calibration or to set the downstream boundary conditions. The USGS station on Four Mile Run is only approximately 1,800 feet upstream of the downstream boundary. The significance of the difference in surface water elevations is not clear, and given the relative coarseness of the W2 segmentation and the small size of the difference in the synthetic tidal data, it is not feasible to use the synthetic tide data from the USGS station on Route 1 in a hydrodynamic calibration. It does provide evidence, however, that the surface water elevations from the Washington Ship Channel are an adequate representation of the surface elevations at the model boundary, since the synthetic time series are very similar to each other.

A.2.2 Impact of Hydrodynamic Parameters on Bacteria Calibration

The Four Mile Run W2 model was simulated with a range of values for hydrodynamic parameters. The impact of the variation in these parameters on the bacteria calibration was determined through the change in the geometric mean and exceedance rate. Four parameters were varied: (1) manning's n (FI) or the bottom roughness coefficient; (2) horizontal (longitudinal) diffusivity (AX); (3) horizontal (longitudinal) diffusivity (DX); (4) the bottom elevation (EBOT). Three values were used for each parameter, and all possible combinations of parameter levels were simulated for a total of 81 simulations. The software utility SENSAN (Dougherty, 2000) was used to facilitate managing the simulations and recording their output.

Table A-4 shows the levels of the parameters simulated and the resulting percent change in geometric mean concentrations and exceedance rates. AX and DX were set at half and twice their default value of 1.0. The value of FI used in the calibration, 0.035, was determined by USACE field reconnaissance of Four Mile Run (USACE, 2008). In the sensitivity study, the high and low levels were chosen to cover the potential range of values of Manning's n. As Table A-4 shows, the bacteria simulation is not sensitive to the values of these parameters. The geometric mean varies by about 1% and the exceedance rate varies by 2%.

Table A-4: Sensitivity Analysis for Hydrodynamic Parameters

Parameters				Geometric Mean	Exceedance Rate
EBOT	**AX**	**DX**	**FI**		
-1.34	1	1	0.035	375	0.36
-1.34	1	1	0.100	375	0.36
-1.34	1	1	0.010	375	0.36
-1.34	1	0.5	0.035	374	0.36
-1.34	1	0.5	0.100	374	0.36
-1.34	1	0.5	0.010	374	0.36
-1.34	1	2	0.035	379	0.37
-1.34	1	2	0.100	379	0.37
-1.34	1	2	0.010	379	0.37
-1.34	0.5	1	0.035	375	0.36
-1.34	0.5	1	0.100	375	0.36
-1.34	0.5	1	0.010	375	0.36
-1.34	0.5	0.5	0.035	374	0.36
-1.34	0.5	0.5	0.100	374	0.36
-1.34	0.5	0.5	0.010	374	0.36
-1.34	0.5	2	0.035	379	0.37
-1.34	0.5	2	0.100	379	0.37
-1.34	0.5	2	0.010	379	0.37
-1.34	2	1	0.035	375	0.36
-1.34	2	1	0.100	375	0.36
-1.34	2	1	0.010	375	0.36
-1.34	2	0.5	0.035	374	0.36
-1.34	2	0.5	0.100	374	0.36
-1.34	2	0.5	0.010	374	0.36
-1.34	2	2	0.035	379	0.37
-1.34	2	2	0.100	379	0.37
-1.34	2	2	0.010	379	0.37
-1.2	1	1	0.035	359	0.36
-1.2	1	1	0.100	359	0.36
-1.2	1	1	0.010	359	0.36
-1.2	1	0.5	0.035	359	0.36
-1.2	1	0.5	0.100	359	0.36
-1.2	1	0.5	0.010	359	0.36
-1.2	1	2	0.035	361	0.36
-1.2	1	2	0.100	361	0.36
-1.2	1	2	0.010	361	0.36
-1.2	0.5	1	0.035	359	0.36
-1.2	0.5	1	0.100	359	0.36
-1.2	0.5	1	0.010	359	0.36
-1.2	0.5	0.5	0.035	359	0.36
-1.2	0.5	0.5	0.100	359	0.36

Table A-4: Sensitivity Analysis for Hydrodynamic Parameters					
Parameters				**Geometric Mean**	**Exceedance Rate**
EBOT	**AX**	**DX**	**FI**		
-1.2	0.5	0.5	0.010	359	0.36
-1.2	0.5	2	0.035	361	0.36
-1.2	0.5	2	0.100	361	0.36
-1.2	0.5	2	0.010	361	0.36
-1.2	2	1	0.035	359	0.36
-1.2	2	1	0.100	359	0.36
-1.2	2	1	0.010	359	0.36
-1.2	2	0.5	0.035	359	0.36
-1.2	2	0.5	0.100	359	0.36
-1.2	2	0.5	0.010	359	0.36
-1.2	2	2	0.035	361	0.36
-1.2	2	2	0.100	361	0.36
-1.2	2	2	0.010	361	0.36
-1.5	1	1	0.035	391	0.37
-1.5	1	1	0.100	391	0.37
-1.5	1	1	0.010	391	0.37
-1.5	1	0.5	0.035	388	0.37
-1.5	1	0.5	0.100	388	0.37
-1.5	1	0.5	0.010	388	0.37
-1.5	1	2	0.035	396	0.37
-1.5	1	2	0.100	396	0.37
-1.5	1	2	0.010	396	0.37
-1.5	0.5	1	0.035	390	0.37
-1.5	0.5	1	0.100	390	0.37
-1.5	0.5	1	0.010	390	0.37
-1.5	0.5	0.5	0.035	388	0.37
-1.5	0.5	0.5	0.100	388	0.37
-1.5	0.5	0.5	0.010	388	0.37
-1.5	0.5	2	0.035	396	0.37
-1.5	0.5	2	0.100	396	0.37
-1.5	0.5	2	0.010	396	0.37
-1.5	2	1	0.035	391	0.37
-1.5	2	1	0.100	391	0.37
-1.5	2	1	0.010	391	0.37
-1.5	2	0.5	0.035	388	0.37
-1.5	2	0.5	0.100	388	0.37
-1.5	2	0.5	0.010	388	0.37
-1.5	2	2	0.035	396	0.37
-1.5	2	2	0.100	396	0.37
-1.5	2	2	0.010	396	0.37

Raising the bottom elevation decreases tidal heights with respect to the bottom of the channel, so there is less flux of water and bacteria from the Potomac to Four Mile Run. Lowering the bottom increase the flux from the Potomac. The high and low values for EBOT were set at ± 0.4 feet from the calibration, which is greater than the range of the average difference between observed maximum and minimum surface elevations at the Four Mile Run and Washington Ship Channel stations. The bacteria calibration was sensitive to changes in EBOT. Changes in the level of EBOT changed the simulated geometric mean by about 5% and the exceedance rate by about 4%. The maximum deviation of the exceedance rate was 0.38, which is still within the bounds of agreement with the observed data, but the maximum deviation of geometric mean was 391, which is outside the range for an acceptable calibration. Raising the decay rate to 0.475 returned the model to agreement with the observed data. Scenario 4 met water quality standards with EBOT set to -1.5 without adjusting the decay rate.

A.3 Uncertainty in Bypass Bacteria Concentration

Since bypass flows are sometimes treated with chlorination it was assumed that concentrations are more likely to be lower than the 200,000 cfu/100 ml than higher than that concentration. The W2 model was run with four additional values of the bypass concentration. The concentration values and the resulting geometric mean concentrations and exceedance rates are shown in **Table A-5**. As the table shows, the bacteria concentration of the bypass has little impact on the bacteria simulation.

Table A-5: Sensitivity of Bacteria Calibration to Bypass Concentrations

Bypass Concentration (cfu/100 ml)	Geometric Mean	Exceedance Rate
5,000	371	0.36
20,000	372	0.36
50,000	373	0.36
200,000	375	0.36

A.4 Uncertainty in the Downstream Boundary Bacteria Concentration

The element of the W2 model that is most likely to be represented inaccurately is the assumption that under storm conditions bacteria concentrations at the Potomac confluence remain at their ambient levels. It is generally assumed that bacteria concentrations are elevated in the Potomac River during storm events, when stormwater and CSOs known to have high bacteria concentrations enter the river in the metropolitan region.

There was not sufficient monitoring data available to directly estimate bacteria concentrations at Four Mile Run's confluence with the Potomac River during storm events, so the conservative assumption was to assume that concentrations remained at the ambient levels determined by the DCDOE monitoring data. This assumption is conservative because if downstream boundary concentrations were increased during storm events, the calibrated decay constant might have to be greater than under the current calibration, and therefore it would be easier to meet water quality standards in tidal Four Mile Run under potential TMDL scenarios. Another way to look at this is that increasing concentrations at the Potomac boundary during storm events may increase the flux of bacteria from the Potomac River to Four Mile Run and therefore increase the percent the load from sources outside the watershed. On the other hand, since simulated concentrations are already at high levels during storm events, increasing bacteria concentrations at the boundary may not greatly increase either the simulated geometric mean concentration or the simulated exceedance rate.

To determine the impact of increasing bacteria concentrations during storm events at the downstream model boundary, an artificial time series of bacteria concentrations was constructed from information available from the District of Columbia Water and Sewer Authority's (DCWASA) Long-Term Control Plan (LTCP) Dynamic Estuary Model (DEM), which was also used by DCDOE to develop the bacteria TMDL for the Potomac River. Greeley and Hansen, who developed the LTCP on behalf of DCWASA, documented the calibration and application of the DEM model (Greeley and Hansen, 2001). DCDOE graciously made available the DEM TMDL scenarios, but was unable to provide the model simulations for the current conditions (Chowdhury, 2009). From the DEM TMDL scenarios, it was determined that storm events elevate bacteria concentrations for about two days. Greeley and Hansen (2001) indicate that the maximum simulated bacteria concentrations are around 10,000 cfu/100 ml; these concentrations only occur when approximately two inches of rain fall; otherwise, 1,000 cfu/100 ml is approximately the largest concentrations seen during storm events.

The artificial boundary time series was constructed by setting a first day and second day concentration according precipitation as shown in **Table A-6**. The concentrations were deliberately set at high levels to over simulate the impact of storm concentrations at the boundary and thereby set an upper bound to their potential impact. Using the artificial boundary time series with the current calibrated bacteria decay rate of 0.45/day, the simulated exceedance rate is compatible with the observed exceedance rate, but the simulated geometric mean concentration is not in agreement with the observed data, as shown in **Table A-7**. A decay rate of 0.65 represents a conservative calibration compatible with the observed data. The simulation ceases to be conservative at a decay rate of 0.75, below the threshold at which Scenario 3 would satisfy water quality standards. Therefore, while increasing the bacteria concentrations at the downstream boundary would have an impact on the bacteria calibration and could lead to a higher calibrated decay rate, it is very unlikely that the decay rate would be increased enough to meet water quality standards under Scenario 3, and thereby change the TMDL allocations for tidal Four Mile Run.

Table A-6: Bacteria Concentrations for Artificial Boundary Conditions (cfu/100 ml)

Precipitation (in.)	1st Day	2nd Day
>1.0	10,000	5,000
0.5 -1.0	1,000	500

Table A-7: Sensitivity of Bacteria Calibration to Artificial Boundary Condition Concentration

Decay Rate (/day)	Geometric Mean	Violation Rate
0.75	367	0.35
0.65	379	0.36
0.55	393	0.37
0.45	408	0.38

A.5 Summary of the Results of the Sensitivity Analysis

The central conclusion of the tidal Four Mile Run bacteria TMDL, that the load reductions specified by Scenario 4 are both necessary and sufficient to meet the calendar-month geometric mean *E. coli* water quality criterion, has been tested by sensitivity analysis and has been found to be “robust” with respect to the assumptions of TMDL development. That is to say, the sensitivity analysis has shown that the uncertainty in some key assumptions does not affect the determination of the TMDL allocations. If the bacteria concentrations at the Potomac boundary had been set higher, if a hydrodynamic calibration had resulted in a different value for Manning’s n, or if observed tidal elevations had been available at the confluence of Four Mile Run and the Potomac River, it is very unlikely that TMDL allocations would be different.

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