Total Maximum Daily Loads of Fecal Bacteria for the Non-Tidal Rock Creek Basin in Montgomery County, Maryland

FINAL

MARYLAND
DEPARTMENT OF THE ENVIRONMENT

1800 Washington Boulevard, Suite 540
Baltimore MD 21230-1718

Submitted to:

Watershed Protection Division
U.S. Environmental Protection Agency, Region III
1650 Arch Street
Philadelphia, PA 19103-2029

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Table of Contents

List of Figures ..... **i**
List of Tables ..... **ii**
List of Abbreviations ..... **iv**
EXECUTIVE SUMMARY ..... **v**
1.0 INTRODUCTION **1**
2.0 SETTING AND WATER QUALITY DESCRIPTION **2**
2.1 General Setting 2
2.2 Water Quality Characterization 9
2.3 Water Quality Impairment 12
2.4 Source Assessment 17
3.0 TARGETED WATER QUALITY GOAL **23**
4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION **23**
4.1 Overview 23
4.2 Analysis Framework 25
4.3 Estimating Baseline Loads 25
4.4 Critical Condition and Seasonality 31
4.5 Margin of Safety 34
4.6 TMDL Loading Caps 34
4.7 Scenario Descriptions 35
4.8 TMDL Allocation 40
4.9 Summary 41
5.0 ASSURANCE OF IMPLEMENTATION **42**
REFERENCES **45**
Appendix A – Table of Bacteria Concentration Raw Data per Sampling Date with Corresponding Daily Flow Frequency A1
Appendix B - Flow Duration Curve Analysis to Define Strata B1
Appendix C – Rock Creek River Bacterial Source Tracking C1
Appendix D - Assigning Flow Frequency to Ungauged Watersheds D1

List of Figures

Figure 2.1.1: Location Map of the Rock Creek Basin 5
Figure 2.1.2: General Soil Series in the Rock Creek Basin 6
Figure 2.1.3: Land Use of the Rock Creek Watershed 7
Figure 2.1.4: Population Density in Rock Creek Basin 8
Figure 2.2.1: Monitoring Stations in the Rock Creek Basin 11
Figure 2.3.1: Conceptual Diagram of Flow Duration Zones 14
Figure 2.4.1: Sanitary Sewer Service and Septics Areas in the Rock Creek Watershed 19
Figure 2.4.2: Sanitary Sewer Overflows in the Rock Creek Watershed 20
Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analysis Framework 25
Figure 4.3.1: Monitoring Stations and Subwatersheds in the Rock Creek Basin 30
Figure A-1: Enterococci Concentration vs. Time for Rock Creek Monitoring Station NBR0002 .... A3
Figure A-2: Enterococci Concentration vs. Time for Rock Creek Monitoring Station RCM0111 .... A4
Figure A-3: Enterococci Concentration vs. Time for Rock Creek Monitoring Station RCM0235 .... A4
Figure B-1: Rock Creek Flow Duration Curves B2
Figure B-2: Rock Creek: LOESS Smoothing of Hydrograph Separation B3
Figure B-3: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station NBR0002 (Average Annual Condition) B6
Figure B-4: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0235 (Average Annual Condition) B6
Figure B-5: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0111 (Average Annual Condition) B7
Figure B-6: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station NBR0002 (Seasonal Condition) B7
Figure B-7: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0235 (Seasonal Condition) B8
Figure B-8: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0111 (Seasonal Condition) B8
Figure C-1: Classification models for determination of composition of known-source library for identification of Rock Creek water isolates. C5
Figure C-2: Rock Creek Watershed relative contributions by probable sources of Enterococci contamination. C9
Figure D-1: Comparison of Flow Frequency Between 01648000and 01649500 for Rock Creek Bacteria Monitoring Dates D2

List of Tables

Table 2.1.1: Land Use Percentage Distribution for Rock Creek Basin 3
Table 2.1.2: Number of Dwellings Per Acre 4
Table 2.1.3: Total Population Per Subwatershed in Rock Creek Watershed 4
Table 2.2.1: Historical Monitoring Data in the Rock Creek Watershed 10
Table 2.2.2: Locations of DNR (CORE) Monitoring Station in the Rock Creek Watershed 10
Table 2.2.3: Locations of MDE Monitoring Stations in the Rock Creek Watershed 10
Table 2.2.4: Locations of USGS Gauging Stations in Anacostia River Watershed 10
Table 2.3.1: Bacteria Criteria Values from Table 1 COMAR 26.08.02.03-3 Water Quality Criteria Specific to Designated Uses. 12
Table 2.3.2: Weighting factors for Average Hydrology Year Used for Estimation of Geometric Means in the Rock Creek Watershed (Average Hydrology Year) 15
Table 2.3.3: Rock Creek Annual Steady State Geometric Mean by Stratum per Subwatersheds 16
Table 2.3.4: Rock Creek Seasonal (May 1st-September 30th) Period Steady State Geometric Mean by Stratum per Subwatersheds 16
Table 2.3.5: Rock Creek Monitoring Data and Steady State Geometric Mean per Subwatershed for Annual Period 17
Table 2.3.6: Rock Creek Monitoring Data and Steady State Geometric Mean per Subwatershed for the Seasonal Period (May 1st – September 30th) 17
Table 2.4.1: Septic Systems and Households Per Sub-Watershed in Rock Creek Watershed 18
Table 2.4.2: Distribution of Fecal Bacteria Source Loads in the Rock Creek Basin for the Average Annual Period 22
Table 2.4.3: Distribution of Fecal Bacteria Source Loads in the Rock Creek Basin for the Seasonal Period (May 1st – September 30th) 23
Table 4.3.1: Baseline Load Calculations 27
Table 4.4.1: Hydrological Conditions Used to Account for Critical Condition and Seasonality 32
Table 4.4.2: Required Reductions to Meet Water Quality Standards 33
Table 4.6.1: Rock Creek Watershed TMDL Summary 35
Table 4.7.1: Baseline Source Distributions 35
Table 4.7.2: Maximum Practicable Reduction Targets 36
Table 4.7.3: Practicable Reduction Results 38
Table 4.7.4: TMDL Reduction Results: Optimization Model Up to 99% Reduction 39
Table 4.8.1: Potential Source Contributions for Rock Creek TMDL Allocations 40
Table 4.8.2: MS4 Stormwater Allocations 41
Table 4.9.1: Rock Creek Watershed TMDL 41
Table B-1: USGS Gauges in the Rock Creek Watershed B1
Table B-2: Definition of Flow Regimes B3
Table B-3: Weighting Factors for Estimation of Geometric Mean B5
Table C-1: Antibiotics and concentrations used for ARA. C4
Table C-2: Category, total number of isolates and of unique isolate patterns in the Rock Creek known-source library. C6
Table C-3: Percent unknown and percent correct for seven (7) cutoff probabilities for the Rock Creek Watershed used to identify probable sources of Rock Creek water isolates. C7

Table C-4: Actual source categories versus predicted categories of Rock Creek known-source isolate library, with total number of unknown isolates, total isolates, total classified, and rates of correct classification (RCC) for each category. C7
Table C-5: Probable host sources of water isolates by category, number of isolates, percent isolates classified at cutoff probabilities of 50% C8
Table C-6: Enterococci isolates from water collected and analyzed during the fall, winter, spring, and summer seasons for Rock Creek monitoring stations. C9
Table C-7: BST Analysis - Number of Isolates per Station per Date C10
Table C-8: Percentage of Sources per Station per Date..C11
Table C-9: Enterococci Concentration and Percentage of Sources by Stratum (Annual Period) C13
Table C-10: Percentage of Sources per Station by Stratum (Annual Period).............................C15
Table C-11: Overall Percentage of Sources per Station (Annual Period) C15
Table D-1: USGS Gauges in the Rock Creek Watershed..D1
Table D-2: Cross Correlation of Flow Frequency (0-log Model)..D1
Table D-3: Bacteria Monitoring Stations and Reference Flow Gauges D2

List of Abbreviations

ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BPA	Blue Plains Advanced WWTP
BST	Bacteria Source Tracking
CAFO	Confined Animal Feeding Operations
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
CFU	Colony Forming Units
COMAR	Code of Maryland Regulations
CSO	Combined Sewer Overflow
CWA	Clean Water Act
CWP	Center for Watershed Protection
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
GIS	Geographic Information System
LA	Load Allocation
LMM	Long-term Moving Median
MACS	Maryland Agricultural Cost Share Program
MASS	Maryland Agricultural Statistic Service
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
ml	Milliliter(s)
MOS	Margin of Safety
MPN	Most Probable Number
MRLC	Multi-Resolution Land Cover
MPR	Maximum Practicable Reduction
MS4	Municipal Separate Storm Sewer System
MST	Microbial Source Tracking
NPDES	National Pollutant Discharge Elimination System
RCC	Rates of Correct Classification
SSO	Sanitary Sewer Overflows
TARSA	Technical and Regulatory Services Administration
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WSSC	Washington Suburban Sanitary Commission
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WRAS	Watershed Restoration Action Strategy
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria in the non-tidal portion of Rock Creek (basin number 02-14-02-06). Section 303(d) of the federal Clean Water Act (CWA) and the EPA implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is required to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met.

The Maryland Department of the Environment (MDE) has identified the non-tidal portion of Rock Creek, Use I – Water Contact Recreation and Protection of Aquatic Life; Use III – Natural Trout Waters; and Use IV – Recreational Trout Waters [Code of Maryland Regulations (COMAR) 26.08.02.08N] in the State's 303(d) as impaired by nutrients (1996), sediments (1996), fecal bacteria (2002), and impacts to biological communities (2002). Water Quality Analyses for eutrophication in Needwood Lake and Lake Bernard Frank, located in the Rock Creek watershed, were approved by EPA in 2003. The District of Columbia (D.C.) has established a fecal bacteria TMDL for the portion of Rock Creek within D.C.'s boundaries. This document proposes to establish a TMDL of fecal bacteria in the non-tidal portions of Rock Creek to allow for the attainment of beneficial use designation, primary contact recreation. The listings for nutrients, sediments, and impacts to biological communities will be addressed separately at a future date. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered.

To establish baseline and allowable pollutant loads for this TMDL, a flow duration curve approach, using flow strata estimated from United States Geological Survey (USGS) daily flow monitoring data and bacteria monitoring data, was used. The pollutant loads set forth in this document are for the area of the Rock Creek watershed located in Maryland. The sources of fecal bacteria are estimated at three representative stations in the Rock Creek watershed where samples were collected for one year. Multiple antibiotic resistance analysis (ARA) source tracking was used to determine the relative proportion of domestic (pets and human associated animals), human (human waste), livestock (agricultural related animals), and wildlife (mammals and waterfowl) source categories.

The allowable load is determined by estimating a baseline load from current monitoring data. The baseline load is estimated using a long-term geometric mean and weighting factors from the flow duration curve. A reduction in concentration proportional to a reduction in load is assumed and thus the TMDL is equal to the current baseline load with the required reduction applied. The TMDL load for fecal bacteria entering Rock Creek is established after considering six different hydrological conditions: wet and dry annual conditions; wet and dry seasonal conditions (the period between May 1st and September 30th where water contact recreation is more prevalent); and 30-day wet and 30-day dry conditions to be protective of Washington, D.C. waters designated uses (D.C.'s water quality standards are based on a 30-day geometric mean). This allowable load is reported in the units of Most Probable Number (MPN)/day and represents a long-term load estimated over a variety of hydrological conditions and not a literal daily limit.

Two scenarios were developed; the first assessing whether attainment of current water quality standards could be achieved with maximum practicable reductions (MPRs) applied, and the second with the MPR constraints relaxed (*i.e.*, greater reductions than might be feasible). Scenario solutions were based on an optimization method where the objective was to minimize the overall risk to human health, assuming that the risk varies over the four source categories. In all three subwatersheds, it was estimated that water quality standards could not be attained with the MPRs. Thus, for all three watersheds, the second scenario, with relaxed constraints, was used to establish the TMDL.

TMDL allocations in the Rock Creek watershed are based on critical conditions and meet both MD and D.C. bacteria water quality criteria, taking into account a 30-day hydrological condition as specified in D.C.'s water quality standards. The final loads represent loads based on average hydrological conditions. The load reduction scenario results in a load allocation that will achieve water quality standards in MD and D.C.

The fecal bacteria TMDL developed for the Rock Creek non-tidal watershed is 125 billion MPN Enterococci/day. The TMDL is distributed between load allocation (LA) for nonpoint sources and waste load allocations (WLA) for point sources, including National Pollutant Elimination System (NPDES) wastewater treatment plants (WWTPs) and NPDES municipal separate storm sewer systems (MS4). The LA is 65 billion MPN/day. The MS4 WLA is 60 billion MPN/day. The margin of safety (MOS) has been incorporated using a conservative assumption by estimating the loading capacity of the stream based on a more stringent water quality endpoint concentration. The Enterococci water quality criterion concentration was reduced by 5%, from 33 Enterococci MPN/100ml to 31.35 Enterococci MPN/100ml.

Once the EPA has approved a TMDL, and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. MDE intends for the required reduction to be implemented in an iterative process that first addresses those sources with the largest impacts to water quality and risks to human health, with consideration given to ease of implementation and cost of implementation. In addition, follow up monitoring plans will be established to track progress and to assess the implementation efforts. As previously stated, water quality standards cannot be attained in the Rock Creek subwatersheds, based on the maximum practicable reduction rates specified herein. This may occur in subwatersheds where wildlife is a significant component or in subwatersheds that require very high reductions of fecal bacteria loads to meet water quality standards. In these cases, it is expected that the first stage of TMDL implementation will be to implement the MPR scenario.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria in the Rock Creek (basin number 02-14-02-06). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the EPA implementing regulations direct each State to develop a TMDL for each impaired water quality limited segment (WQLS) on the Section 303(d) list, taking into account seasonal variations and a protective margin of safety (MOS) to account for uncertainty. A TMDL reflects the total pollutant loading of the impairing substance a water body can receive and still meet water quality standards.

TMDLs are established to determine the pollution load reduction needed to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

The Maryland Department of the Environment (MDE) has identified Rock Creek, a Use I, Use III and IV waterbody [Code of Maryland Regulations (COMAR) 26.08.02.08N] in the State's 303(d) as impaired by nutrients (1996), sediments (1996), fecal bacteria (2002), and impacts to biological communities (2002). Water Quality Analyses for eutrophication in Needwood Lake and Lake Bernard Frank, located in the Rock Creek watershed, were approved by EPA in 2003. The District of Columbia (D.C.) has established a fecal bacteria TMDL for the portion of Rock Creek within D.C.'s boundaries. D.C.'s fecal bacteria allocation for Maryland's portion of the Rock Creek is 49,000 billion Most Probable Number (MPN) fecal coliform/day. This document proposes to establish a TMDL of fecal bacteria in the non-tidal portions of Rock Creek that will allow for attainment of its designated uses. TMDL allocations in the Rock Creek watershed are based on critical conditions and meet both MD and D.C. bacteria water quality criteria, taking into account a 30-day hydrological condition as specified in D.C.'s water quality standards. The load reduction scenario results in a load allocation that will achieve water quality standards in MD and D.C. All other impairments in the non-tidal portions of Rock Creek will be addressed at a future date. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered in the TMDL analysis.

Fecal bacteria are microscopic single-celled organisms (primarily fecal coliforms and fecal streptococci) found in the wastes of warm-blooded animals. Their presence in water is used to assess the sanitary quality of water for body-contact recreation, for consumption of molluscan bivalves (shellfish), and for drinking water. Excessive amounts of fecal bacteria in surface water used for recreation are known to indicate an increased risk of pathogen-induced illness to humans. Infections due to pathogen-contaminated recreation waters include gastrointestinal, respiratory, eye, ear, nose, throat, and skin diseases (USEPA, 1986).

In 1986, EPA published "Ambient Water Quality Criteria for Bacteria," wherein three indicator organisms were assessed to determine their correlation with swimming-associated illnesses. Fecal coliform, *E. coli* and Enterococci were the indicators used in the analysis. Fecal coliform are a subgroup of total coliform bacteria and *E. coli* are a subgroup of fecal coliform. Most *E. coli* are harmless and are found in great quantities in the intestines of people and warm-blooded animals; however, certain pathogenic strains may cause illness. Enterococci are a subgroup of bacteria in the fecal streptococcus group. Fecal coliform, *E. coli* and Enterococci can all be classified as fecal bacteria. The results of the EPA study (EPA, 1986) demonstrated that fecal coliform showed less correlation to swimming-associated gastroenteritis than either *E. coli* or Enterococci.

The Rock Creek watershed was listed on the Maryland 303(d) list using fecal coliform as the indicator organism. Based on EPA's guidance (EPA, 1986), adopted by Maryland in 2004, the State has revised the bacteria water quality criteria and it is now based on water column limits for either *E. coli* or Enterococci. Because multiple monitoring datasets are available within this watershed for various pathogen indicators, the general term fecal bacteria will be used to refer to the impairing substance throughout this document. The TMDL will be based on the pathogen indicator organisms specified in Maryland's current bacteria water quality criteria, either *E. coli* or Enterococci. The indicator organism used in the Rock Creek TMDL analysis was Enterococci.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Rock Creek watershed comprises approximately 76 square miles (48,640 acres), with approximately 80% of the drainage within Montgomery County, Maryland and the remaining 20% within Washington, D.C. (District of Columbia Rock Creek TMDL, 2004). Rock Creek begins flowing at Laytonsville, Maryland, and continues to flow through Montgomery County, through Washington, D.C. until it reaches the Potomac River. The North Branch of Rock Creek starts flowing at Mount Zion, Maryland and discharges to Rock Creek in Rockville, Maryland. There are two surface impoundments located in the Rock Creek watershed: Needwood Lake and Lake Bernard Frank (Figure 2.1.1).

There are three major drainage areas comprising the Rock Creek watershed: the mainstem of Rock Creek, the North Branch, and the tidal drainage. The mainstem and North Branch are free-flowing (non-tidal) streams. The tidal drainage area consists of the tidal river and its floodplain, as well as small Coastal Plain streams that flow directly to the tidal river. Rock Creek is 33 miles long with the last 9.3 miles (14.96 km) running through the District of Columbia. Only the last quarter mile of the Creek is tidally influenced with the head of tide located approximately where Pennsylvania Avenue crosses the waterway (District of Columbia Rock Creek TMDL, 2004). The river joins the Potomac River approximately 108 miles (174 kilometers) upstream of the Chesapeake Bay.

The free-flowing segments of Rock Creek are primarily within the State of Maryland, specifically Montgomery County. The region this document will address is the free-flowing sections of the Rock Creek watershed, covering a surface area of approximately 60 square miles (37,704 acres).

Geology/Soils

The Rock Creek watershed extends into two physiographic provinces. In Maryland, the Rock Creek watershed is located in the Piedmont Province, where the bedrock consists of metamorphic rocks of Paleozoic age. The Rock Creek portion located in the Washington, D.C. area is located in the Coastal Plain province. The Piedmont province is characterized by relatively narrow and steep-sloped valleys of moderately thin soils, as compared to the undulating Coastal Plain which contains deeper sedimentary soil complexes and supports broader meandering streams (Anacostia watershed network: www.anacostia.net, February 14, 2005).

The North Branch and the mainstem of Rock Creek lie predominantly in the Manor-Glenelg-Chester soil series. Soils in this series are fine-loamy, mixed, mesic Typic Hapludults and are very deep and well drained soils (Montgomery County, Soil Conservation Service, 1995) (Figure 2.1.2).

Land Use

The 2000 Maryland Department of Planning (MDP) land use/land cover data shows that the watershed can be characterized as residential and commercial. These sub-watersheds contain as high as 80% impervious. The land use percentage distribution for Rock Creek Basin is shown in Table 2.1.1, and spatial distributions for each land use are shown in Figure 2.1.3.

Table 2.1.1: Land Use Percentage Distribution for Rock Creek Basin

Land Type	Acreage	Percentage
Residential	22,467	59.6%
Commercial	5,490	14.6%
Forest	6,809	18.1%
Crops	2,032	5.4%
Pasture	746	1.9%
Water	160	0.42%
TOTALS	**37,704**	**100.00%**

Population

The total population in the Rock Creek watershed is estimated to be 196,790 people. Figure 2.1.4 illustrates the population density in the watershed. The human population and the number of households were estimated based on a weighted average from the Geographic Information System (GIS) 2000 Census Block and the MDP Land Use 2002 Cover that includes the Rock Creek watershed. Since the Rock Creek watershed is a sub-area of the Census Block, percentages of each land use within the watershed were used to extract the areas from the 2000 Census Block within the watershed. Table 2.1.2. shows the number of dwellings per acre in the Rock Creek watershed. The number of dwellings per acre was derived from information for residential density (low, medium, high) from the MDP land use cover.

Table 2.1.2: Number of Dwellings Per Acre

Land use Code	Dwellings Per Acre
11 Low Density Residential	1
12 Medium Density Residential	5
13 High Density Residential	8

Based on the number of households from the Total Population from the Census Block and the number of dwellings per acre from the MDP Land Use Cover, population per sub-watershed was calculated (Table 2.1.3).

Table 2.1.3: Total Population Per Subwatershed in Rock Creek Watershed

Tributary	Station	Population
North Branch	NBR0002	20,270
Rock Creek (Mainstem)	RCM0235	21,580
Rock Creek (Mainstem)	RCM0111	154,940
	TOTAL	**196,790**

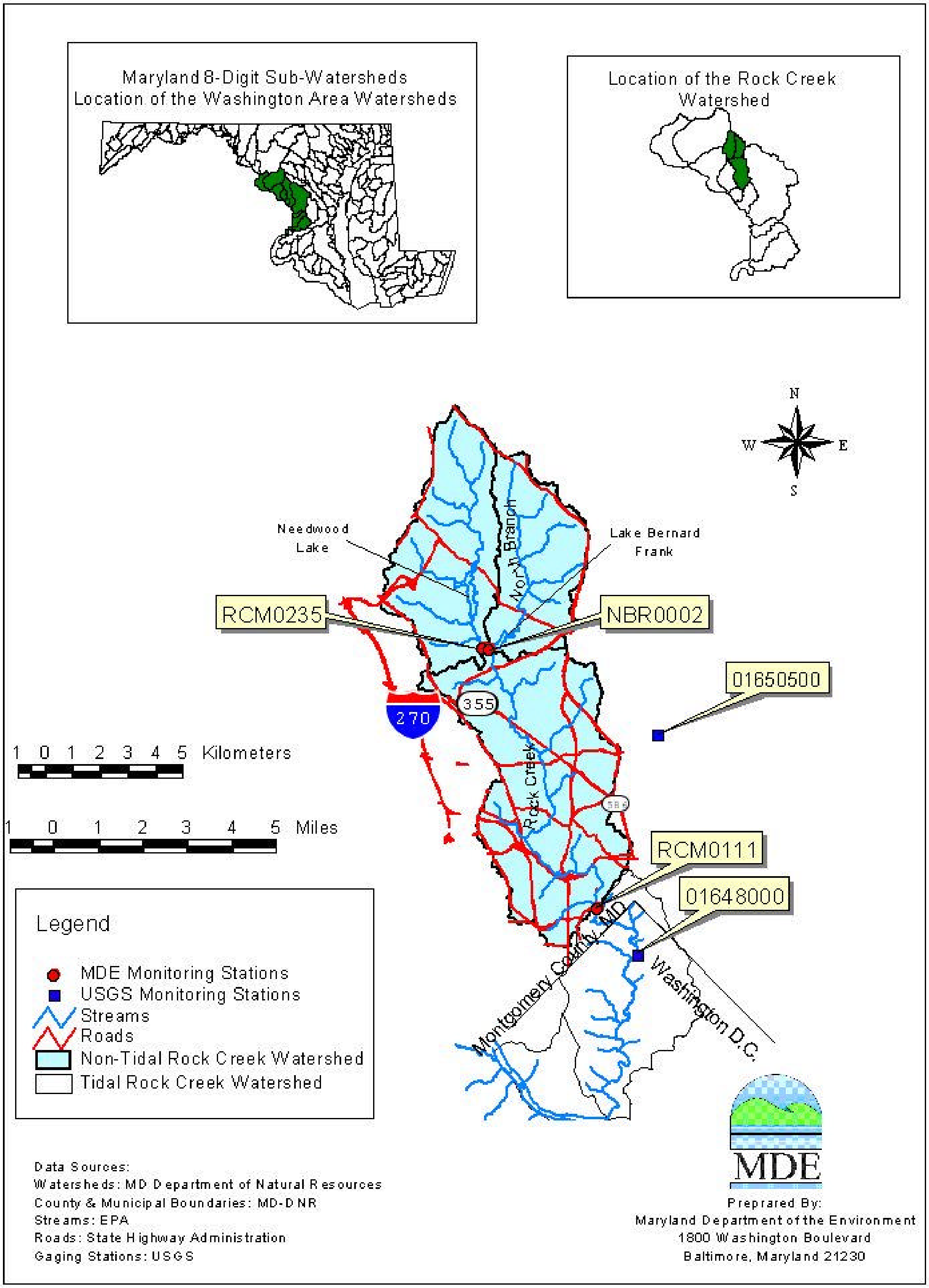

Figure 2.1.1: Location Map of the Rock Creek Basin

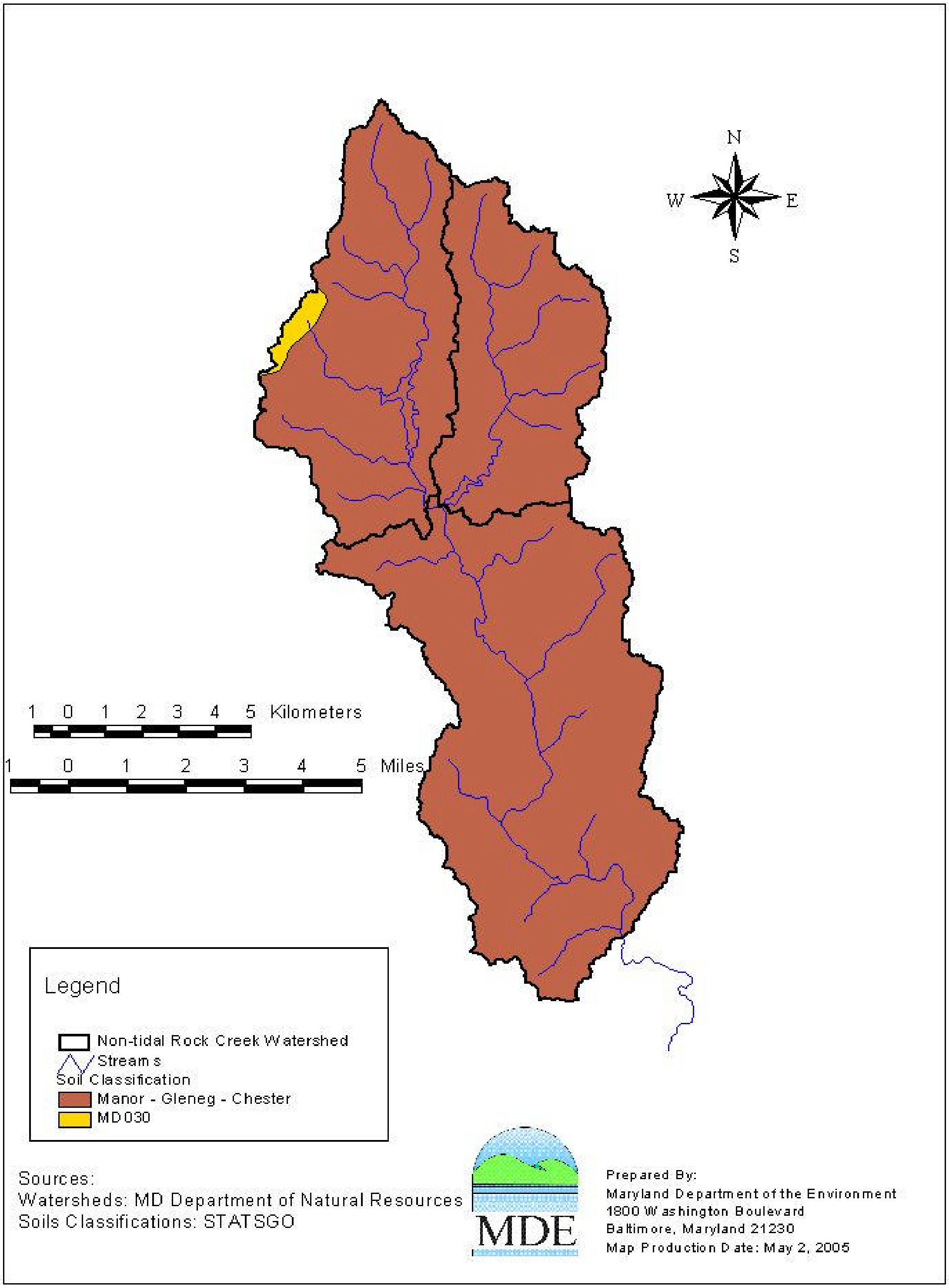

Figure 2.1.2: General Soil Series in the Rock Creek Basin

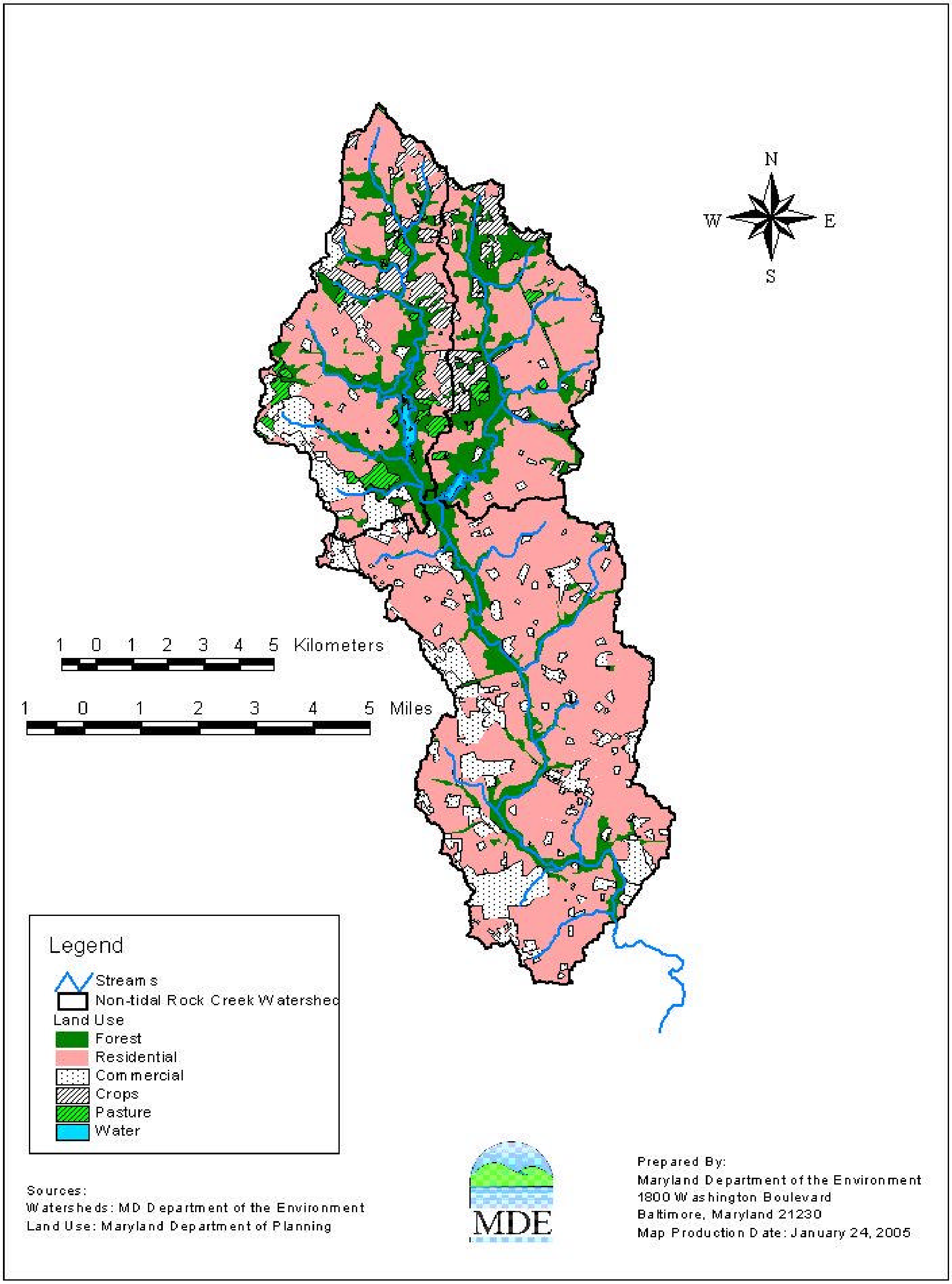

Figure 2.1.3: Land Use of the Rock Creek Watershed

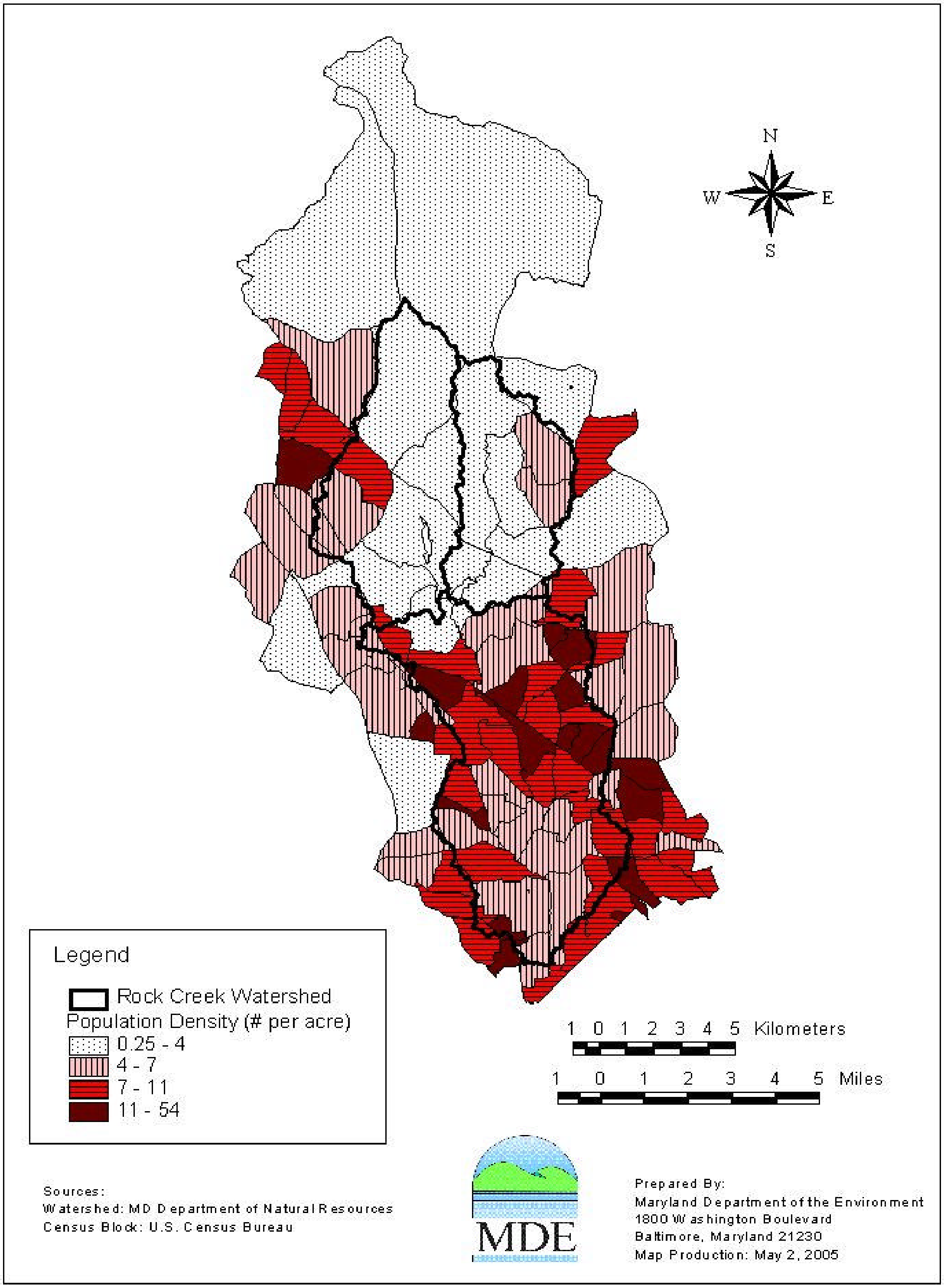

Figure 2.1.4: Population Density in Rock Creek Basin

2.2 Water Quality Characterization

In EPA's guidance document, "Ambient Water Quality Criteria for Bacteria" (1986), fecal bacteria, *E. coli* and Enterococci were assessed as indicator organisms for predicting human health impacts. A statistical analysis found that the highest correlation to gastrointestinal illness was linked to elevated levels of *E. coli* and Enterococci in fresh water (Enterococci in salt water), leading EPA to propose that states use *E. coli* or Enterococci as pathogen indicators. Maryland has adopted the EPA recommended bacterial indicators, *E. coli* and *Enterococcus*. Although the criteria numbers are different, the risk to the recreational bathers at the criteria levels are the same, thus the new indicators can better address this impairment although the impairment was identified using fecal coliform.

Bacteria Monitoring

Table 2.2.1 lists the historical monitoring data for the Rock Creek watershed. Monitoring Station RCM0111 (CORE) was used by the Maryland Department of Natural Resources (DNR) to identify the bacterial impairment. MDE conducted bacteria monitoring at three stations from October 2002 through October 2003. In addition to the bacteria monitoring stations, there is one United States Geological Survey (USGS) gauging station located in the Rock Creek watershed and another USGS station located in the nearby Anacostia River watershed that were used in deriving the surface flow in Rock Creek. The locations of these stations are shown in Table 2.2.2 – Table 2.2.4 and Figure 2.2.1. Observations recorded during 2002-2003 from the three MDE monitoring stations are shown in Appendix A. In general, based on statewide monitoring data, fecal bacteria concentrations are higher in the headwaters. This is also consistent with findings from Wickham, *et al*. (2005), regarding pathogens in Maryland where the likelihood of impairment decreases with watershed size. Appendix A has a table that lists the monitoring results from the Rock Creek watershed.

Bacteria counts are highly variable in Rock Creek. This is typical for all streams due to the nature of bacteria and its relationship to flow. Results of bacteria counts for the three monitoring stations are shown in Appendix A. Data was collected from September 2002 through November 2003. Ranges were typically between 10 and 7,700 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Rock Creek Watershed

Sponsor	Location	Date	Design	Summary
Maryland Department of Natural Resources (DNR) Core Monitoring	MD	1/8/97 – 4/1/98	Fecal Coliform	RCM0111 downstream
Montgomery County Department of Environmental Protection (DEP)	MD	05/08/2000 – 07/24/2000	Fecal Coliform	6 stations with a total of 96 samples collected in the Lower Rock Creek.
Metropolitan Washington Council of Government (MWCOG)	DC	2002 – 2003	Bacterial Source Tracking (BST)	7 monitoring stations in Rock Creek in D.C.
MDE	MD	11/02 to 10/03	Enterococci	3 stations 2x per month
MDE	MD	11/02 to 10/03	BST – Antibiotic Resistance Analysis (ARA) (Enterococci)	3 stations 1x per month

Table 2.2.2: Locations of DNR (CORE) Monitoring Station in the Rock Creek Watershed

Tributary	Monitoring Station	Observation Period	Total Observations.	LONGITUDE Dec-Deg	LATITUDE Dec-Deg
Rock Creek	RCM0111	1997 - 1998	15	38 59.58	77 03.71

Table 2.2.3: Locations of MDE Monitoring Stations in the Rock Creek Watershed

Tributary	Monitoring Station	Observation Period	Total Observations.	LONGITUDE Dec-Deg	LATITUDE Dec-Deg
North Branch	NBR0002	2002 - 2003	25	39 06.11	77 07.22
Rock Creek	RCM0235	2002 - 2003	26	39 06.14	77 07.46
Rock Creek	RCM0111	2002 - 2003	26	38 59.58	77 03.71

Table 2.2.4: Locations of USGS Gauging Stations in Anacostia River Watershed

Monitoring Station	Observation Period Used in TMDL Analysis	Total Observations	LATITUDE Dec-deg	LONGITUDE Dec-deg
01648000	1988 - 2003	5,478	38 58.35	77 02.40
01650500	1988 - 2003	5,508	39 03.60	77 01.80

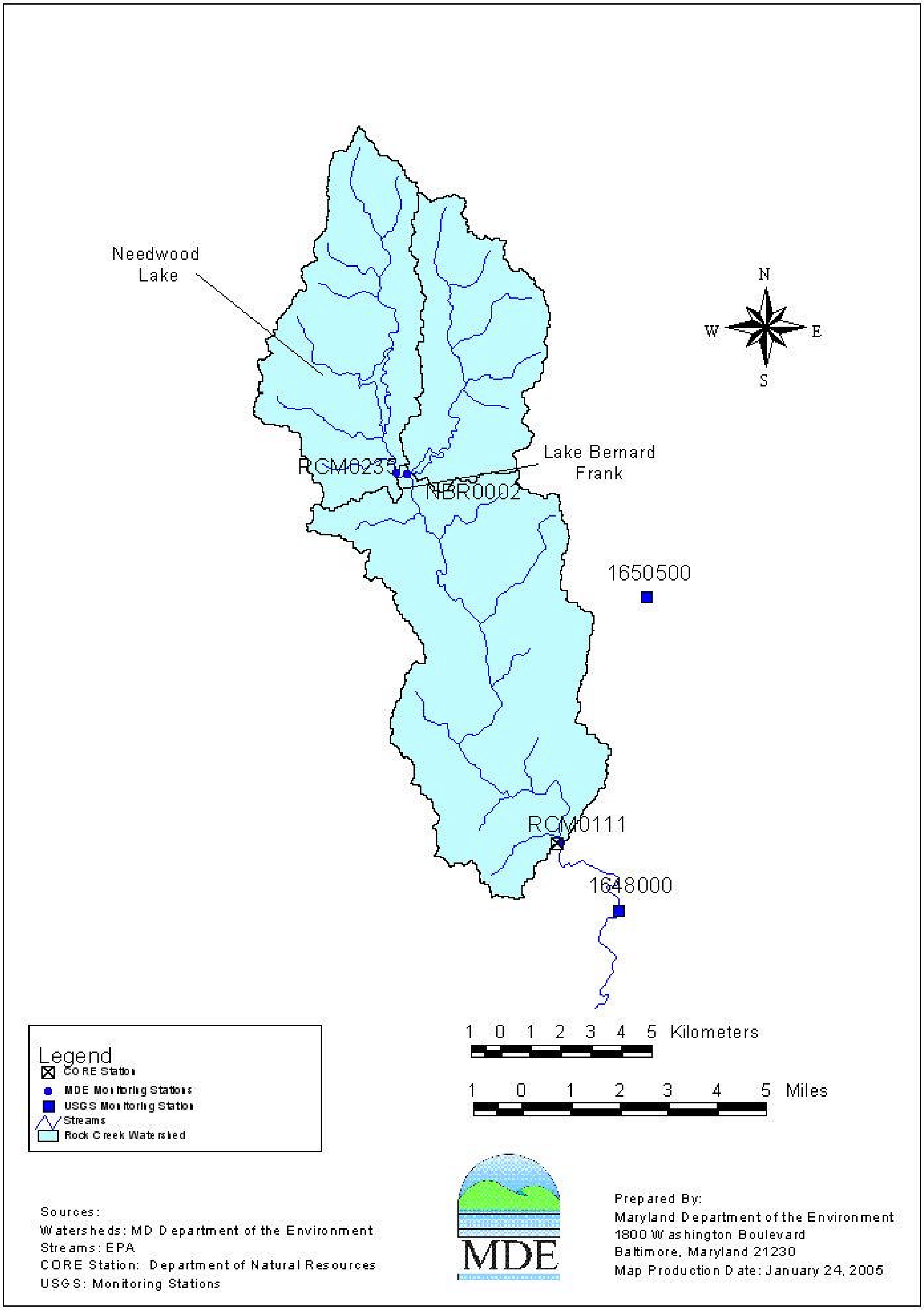

Figure 2.2.1: Monitoring Stations in the Rock Creek Basin

2.3 Water Quality Impairment

Designated Uses and Water Quality Standard

The Maryland water quality standards Surface Water Use Designations for the non-tidal portion of this watershed area are Use I – Water Contact Recreation (below Norbeck Road); Use III – Natural Trout Waters; and Use IV – Recreational Trout Waters (COMAR 26.08.02.08E). Rock Creek has been included on the final 2004 Integrated 303(d) List as impaired by fecal coliform bacteria.

Water Quality Criteria

The State water quality standards for bacteria used for ALL Use waters are as follow (COMAR Section 26.08.02.03-3):

Table 2.3.1: Bacteria Criteria Values from Table 1 COMAR 26.08.02.03-3 Water Quality Criteria Specific to Designated Uses.

Indicator	Steady State Geometric Mean Indicator Density
Freshwater	
E. coli	126 MPN/100ml
Enterococci*	33 MPN/100ml
Marine Water	
Enterococci	35 MPN/100ml

* Used in the Rock Creek analysis

Interpretation of Bacteria Data for General Recreational Use

The listing methodology as per 2006 integrated 303(d) list for all Use Waters - Water Contact Recreation and Protection of Aquatic Life is as follows:

Recreational Waters

A steady state geometric mean will be calculated with available data where there are at least 5 representative sampling events. The data shall be from samples collected during steady state conditions and during the beach season (Memorial Day through Labor Day) to be representative of the critical condition. If the resulting steady state geometric mean is greater than 35 coliform units (cfu)/100 ml Enterococci in marine/estuarine waters, 33 cfu/100 ml Enterococci in freshwater or 126 cfu/100 ml *E. coli* in freshwater, the waterbody will be listed as impaired. If fewer than 5 representative sampling events for an area being assessed are available, data from the previous two years will be evaluated. If the resulting steady state geometric mean of the available data for each year is greater than 35 cfu/100 ml Enterococci in marine/estuarine waters, 33 cfu/100 ml Enterococci in freshwater or 126 cfu/100 ml *E. coli* in freshwater, the water body or beach will be listed as impaired.

The listing methodology for all general recreational use also applies to beaches. If the steady state geometric mean exceeds 35 cfu/100 ml Enterococci in marine/estuarine waters, 33 cfu/100 ml Enterococci in freshwater or 126 cfu/100 ml *E. coli* in freshwater, the beach area segment, as defined by the endpoint latitudes and longitudes, will be listed as impaired. The single sample maximum criteria applies only to beaches and is to be used for closure and advisory decisions based on short term exceedences of the geometric mean portion of the standard.

Water Quality Assessment

A water quality impairment was assessed by comparing both the annual and the seasonal (May 1st – September 30th) steady state geometric means of Enterococci concentrations with the water quality criterion. Since warm temperatures can occur early in May and last until the end of September or early October, a longer seasonal period than the official beach season (Memorial Day to Labor Day) was used for the water quality assessment, as a conservative assumption in the analysis. The steady state condition is defined as unbiased sampling targeting average flow conditions and/or equally sampling or providing for unbiased sampling of high and low flows. The 1986 EPA criteria document assumed steady state flow in determining the risk at various bacterial concentrations, and therefore the chosen criterion value also reflects steady state conditions (EPA, 1986). The steady state geometric mean condition can be estimated either by monitoring design or more practically by statistical analysis as follows:

1. A stratified monitoring design is used where the number of samples collected is proportional to the duration of high flows, mid flows and low flows within the watershed. This sample design allows a geometric mean to be calculated directly from the monitoring data.

2. Routine monitoring typically results in samples from varying hydrologic conditions (*i.e.*, high flows, mid flows and low flows) where the numbers of samples are not proportional to the duration of those conditions. Averaging these results without consideration of the sampling conditions results in a biased estimate of the steady state geometric mean. The potential bias of the steady state geometric means can be reduced by weighting the samples results collected during high flow, mid flow and low flow regimes by the proportion of time each flow regime is expected to occur. This ensures that the high flow and low flow conditions are proportionally balanced on an annual and seasonal basis.

3. If (1) the monitoring design was not stratified based on flow regime or (2) flow information is not available to weight the samples accordingly, then a geometric mean of sequential monitoring data can be used as an estimate of the steady state geometric mean condition for the specified period.

A routine monitoring design was used to collect bacteria data in the Rock Creek watershed. To estimate the steady state geometric means, the monitoring data was first reviewed by plotting the sample results versus their corresponding daily flow duration percentile. Graphs illustrating these results can be found in Appendix B.

To calculate the steady state geometric means with routine monitoring data, a conceptual model was developed by dividing the daily flow frequency for the stream segment into strata that are representative of hydrologic conditions. A conceptual continuum of flows is illustrated in Figure 2.3.1.

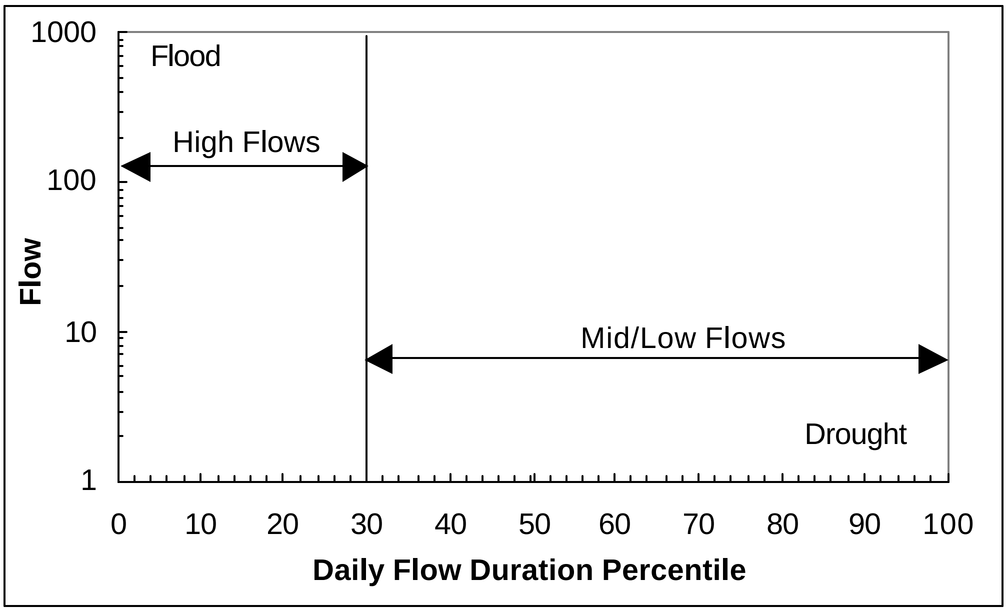

Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

During high flows a significant portion of the total stream flow is from surface flow contributions. Low flow conditions represent periods with minimal rainfall and surface runoff. There is typically a transitional period (mid flows) between the high and low flow durations that is representative of varying contributions of surface flow inputs that result from differing rainfall volumes and antecedent soil moisture conditions. The division of the entire flow regime into strata enables the estimation of a less biased geometric mean from routine monitoring data that more closely approaches steady state. The daily flow duration intervals that define these regions and supporting details of how these zones were developed are presented in Appendix B.

Factors for estimating a steady state geometric mean are based on the frequency of each flow stratum. The weighting factor accounts for the proportion of time that each flow stratum represents. The weighting factors for an average hydrological year used in the Rock Creek TMDL analysis are presented in the following table (Table 2.3.2).

Table 2.3.2: Weighting factors for Average Hydrology Year Used for Estimation of Geometric Means in the Rock Creek Watershed (Average Hydrology Year)

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 30%	0.30
Low Flows	30 – 100%	0.70

Bacteria enumeration results for samples within a specified flow stratum will receive their corresponding weighting factor. The steady state geometric mean is calculated as follows:

$$M_i = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})}{n_i} \qquad (1)$$

where

$$M = \sum_{i=1}^{2} M_i * W_i \qquad (2)$$

Mi = log mean concentration for stratum i
Ci,j = Concentration for sample j in stratum i
ni = number of samples in stratum I
M = weighted mean
Wi= Proportion of stratum i

Finally the weighted log mean is back transformed from log space using the following equation.

$$C_{gm} = 10^{M} \qquad (3)$$

Cgm = Steady state geometric mean concentration

Tables 2.3.3 and 2.3.4 present the geometric means by stratum and the overall steady state geometric mean for the Rock Creek subwatersheds for the annual and the seasonal (May 1st – September 30th) periods.

Table 2.3.3: Rock Creek Annual Steady State Geometric Mean by Stratum per Subwatersheds

Tributary	Station	Stratum	Annual Steady State Geometric Mean	Annual Overall Geometric Mean
North Branch	NBR0002	High Flow	120	34
		Low Flow	20	
Rock Creek	RCM0235	High Flow	123	40
		Low Flow	25	
Rock Creek	RCM0111	High Flow	429	190
		Low Flow	134	

Table 2.3.4: Rock Creek Seasonal (May 1st-September 30th) Period Steady State Geometric Mean by Stratum per Subwatersheds

Tributary	Station	Stratum	Seasonal Steady State Geometric Mean	Seasonal Overall Geometric Mean
North Branch	NBR0002	High Flow	146	47
		Low Flow	28	
Rock Creek	RCM0235	High Flow	131	47
		Low Flow	30	
Rock Creek	RCM0111	High Flow	258	250
		Low Flow	246	

Summary of Water Quality Data

The water quality impairment was assessed by comparing the annual and May 1st - September 30th periods steady state geometric means concentrations at each monitoring station with the water quality criterion. Stations NBR0002 and RCM0235 are located downstream of Lake Bernard Frank and Needwood Lake, respectively. Lakes are typically "sinks" of bacteria. Station RCM0111 is located downstream of stations NBR0002 and RCM0235. Graphs illustrating these results can be found in Appendix B. Steady state geometric means of the monitoring data for both periods assessed and the water quality criterion are shown in Tables 2.3.5 and 2.3.6.

Table 2.3.5: Rock Creek Monitoring Data and Steady State Geometric Mean per Subwatershed for Annual Period

Watershed	Tributary	Station	# Samples	Enterococci Minimum Mean MPN/100ml	Enterococci Maximum Mean MPN/100ml	Enterococci Geometric Mean MPN/100ml	Enterococci Criterion MPN/100ml
02140206	North Branch Rock Creek	NBR0002	25	10	2600	34	33
02140206	Rock Creek	RCM0235	26	10	910	40	33
02140206	Rock Creek	RCM0111	26	10	7700	190	33

Table 2.3.6: Rock Creek Monitoring Data and Steady State Geometric Mean per Subwatershed for the Seasonal Period (May 1st – September 30th)

Watershed	Tributary	Station	# Samples	Enterococci Minimum Mean MPN/100ml	Enterococci Maximum Mean MPN/100ml	Enterococci Geometric Mean MPN/100ml	Enterococci Criterion MPN/100ml
02140206	North Branch Rock Creek	NBR0002	11	10	420	47	33
02140206	Rock Creek	RCM0235	12	10	760	47	33
02140206	Rock Creek	RCM0111	12	10	2910	250	33

2.4 Source Assessment

Nonpoint Source Assessment

Nonpoint sources of fecal bacteria do not have one discharge point but occur over the entire length of a stream or waterbody. Many types of nonpoint sources introduce fecal bacteria to the land surface including the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. As the runoff occurs during rain events, surface runoff transports water and fecal bacteria over the land surface and discharges to the stream system. The deposition of non-human fecal bacteria directly to the stream occurs when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions from human activities generally arise from failing septic systems and their associated drain fields or leaking infrastructure (*i.e.*, sewer systems). In summary, the transport of fecal bacteria from the land surface to the stream system is dictated by the rainfall, soil type, land use, and topography of the watershed.

Sewer and Septic Systems

Wastewater treatment plants are designed to treat wastewater before it can be discharged to a stream or river. The goals of wastewater treatment are to protect the public health, protect aquatic life, and to prevent harmful substances from entering the environment.

The majority of the sanitary sewer mains in the Rock Creek watershed flow to the Blue Plains Advanced Wastewater Treatment Plant (WWTP). The Blue Plains Advanced (BPA) WWTP is located downstream of, and outside, the Rock Creek watershed in Washington, D.C. The BPA WWTP serves the District of Columbia, portions of Maryland, and portions of Virginia, encompassing two to three million people. The BPA WWTP is part of the District of Columbia Waste and Sewer Authority (DCWASA). Washington Suburban Sanitary Commission (WSSC) provides safe drinking water and sewer services to Montgomery and Prince George's Counties and, therefore, shares the cost of maintaining the treatment plant with DCWASA.

There are also on-site disposal (septic) systems in the northern part of the Rock Creek watershed, specifically in the northernmost part of North Branch Rock Creek mainstem around Rockville and north of Rockville. Table 2.4.1 presents the number of septics systems and total households per subwatershed. Figure 2.4.1 depicts the areas that are serviced by sewers and septic systems.

Sanitary Sewer Overflows (SSOs) occur when the capacity of a separate sanitary sewer is exceeded. There are several factors that may contribute to SSOs from a sewerage system, including pipe capacity, operations and maintenance effectiveness, sewer design, age of system, pipe materials, geology and building codes. SSOs are prohibited by the facilities' permit and therefore, must be reported to MDE's Water Management Administration in accordance to COMAR 26.08.10 to be addressed under the State's enforcement program.

There were a total of 36 SSOs in the Rock Creek watershed reported to MDE between November 2002 and October 2003. Approximately 80,219 gallons of SSO discharge was released through various waterways (surface water, groundwater, sanitary sewers, etc.) in the Montgomery County portion of the Rock Creek watershed (MDE, Water Management Administration). Figure 2.4.2 depicts the location of sanitary sewer overflows, from 2002 to 2003 in the Rock Creek watershed.

Table 2.4.1: Septic Systems and Households Per Sub-Watershed in Rock Creek Watershed

Tributary	Station	Septic Systems (units)	Households per Subwatershed
North Branch	NBR0002	1,101	15,657
Rock Creek	RCM0235	1,846	13,112
Rock Creek	RCM0111	0	44,862
	TOTAL	**2,947**	**73,631**

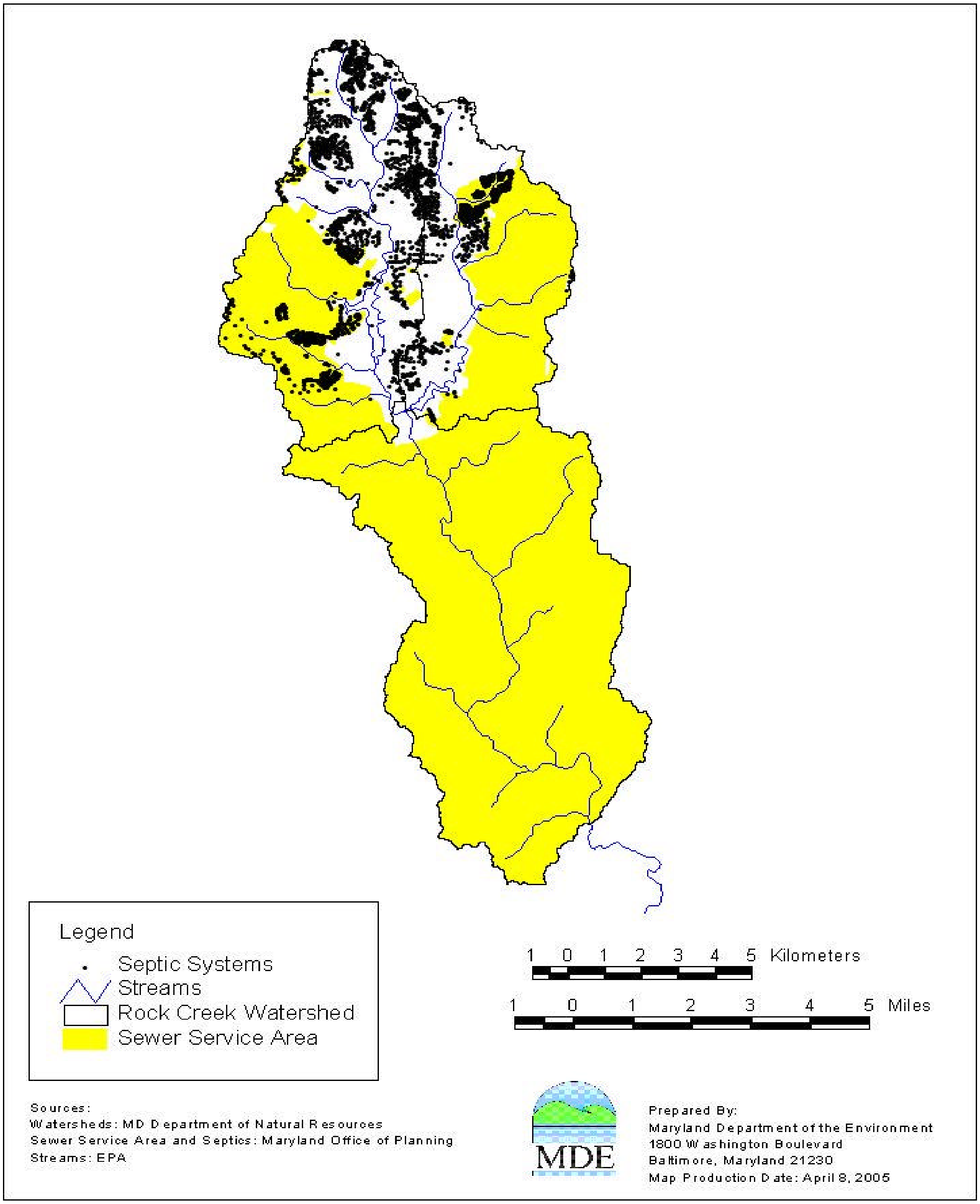

Figure 2.4.1: Sanitary Sewer Service and Septics Areas in the Rock Creek Watershed

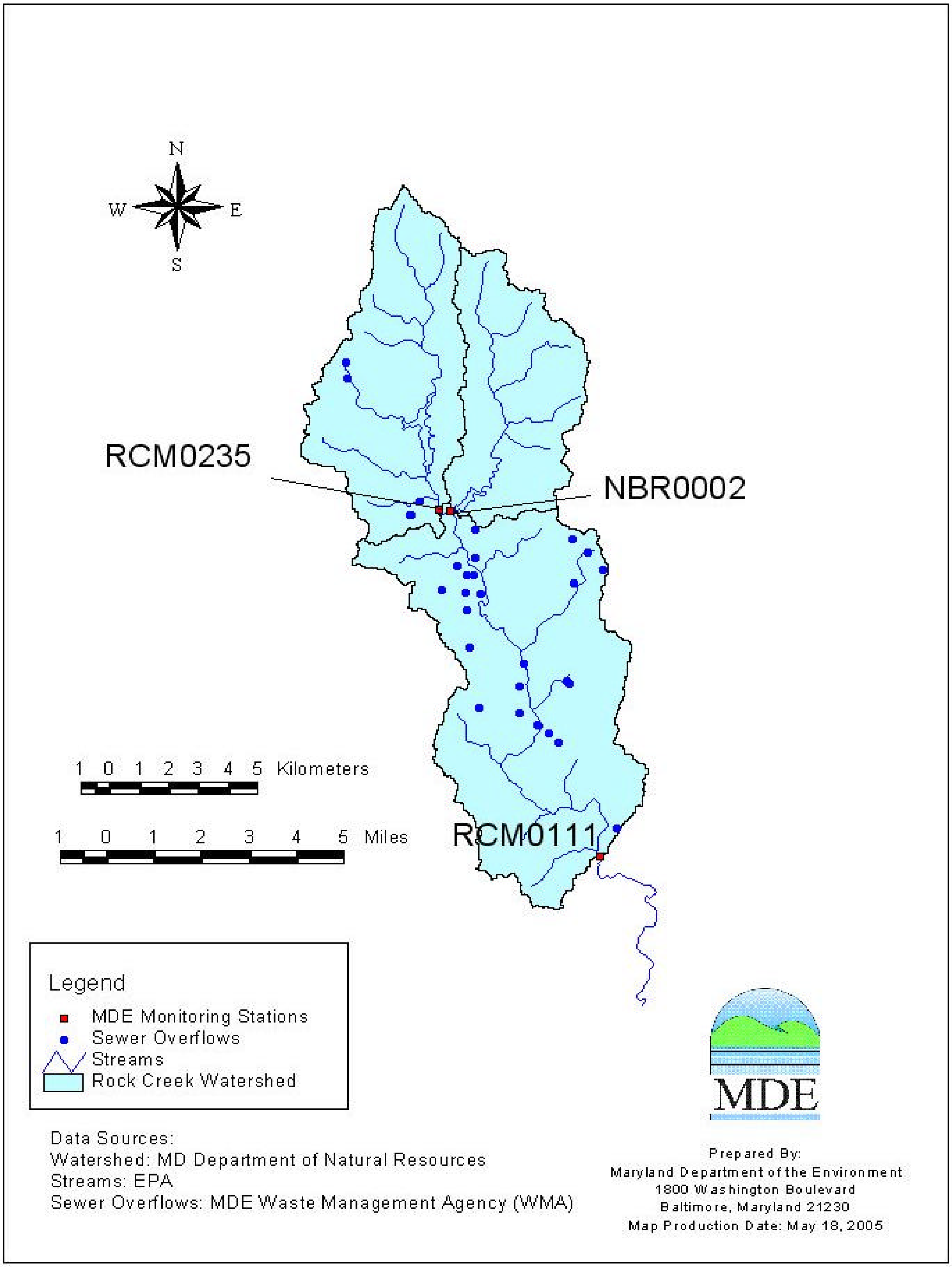

Figure 2.4.2: Sanitary Sewer Overflows in the Rock Creek Watershed

Point Source Assessment

Stormwater

The Rock Creek watershed is located in Montgomery County, a Phase I National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit jurisdiction. The MS4 permit covers stormwater discharges from the municipal separate stormwater sewer system in the County.

Municipal and Industrial WWTPs

Based on the point source permitting information, there are no municipal or industrial NPDES WWTPs with permits regulating the discharge of fecal bacteria directly into the Rock Creek watershed.

Bacteria Source Tracking

Bacteria source tracking (BST) was used to identify the relative contribution of bacteria from different sources in in-stream water samples. BST monitoring was conducted at three stations throughout the Rock Creek watershed with 12 samples (one per month) collected for a one-year duration. Sources are defined as domestic (pets and human associated animals), human (human waste), livestock (agricultural animals), and wildlife (mammals and waterfowl). To identify sources, samples are collected within the watershed from known fecal sources and the patterns of antibiotic resistance of these known sources are compared to isolates of unknown bacteria from ambient samples. Details of the BST methodology and data can be found in Appendix C.

An accurate representation of the expected average source at each station is estimated by using a stratified weighted mean of the identified sample results over the specified period. The weighting factors are based on the log10 of the bacteria concentration and the percent of time that represents the high stream flow or low stream flow (see Appendix B). The procedure for calculating the stratified weighted mean of the sources per monitoring station as follows:

1. Calculate the percentage of isolates per source per each sample date (S).
2. Calculate the weighted percentage (MS) of each source per flow strata (high/low) (see Section 4). The weighting is based on the log10 bacteria concentration for the water sample.
3. The final weighted mean source percentage, for each source category, is based on the proportion of time in each flow duration zone (see Appendix C).

The weighted mean for each source category is calculated using the following equations:

$$MS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{n_i} \qquad (4)$$

where

MSi,k = Weighted mean proportion of isolates for source k in stratum i
i = stratum
j = sample
k = Source category (1 = human, 2 = domestic, 3 = livestock, 4 = wildlife, 5 = unknown)
Ci,j = Concentration for sample j in stratum i
Si,j,k = Proportion of isolates for sample j, of source k in stratum i
ni = number of samples in stratum I

$$M_k = \sum_{i=1}^{2} MS_{i,k} * W_i \qquad (5)$$

M = weighted mean proportion of isolates of source k
Wi= Proportion covered by stratum i

The complete distributions of the annual and seasonal periods source loads are listed in Table 2.4.2 and 2.4.3. Details of the BST data can be found in Appendix C.

Table 2.4.2: Distribution of Fecal Bacteria Source Loads in the Rock Creek Basin for the Average Annual Period

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
NBR0002	High Flow	11	16	34	30	9
	Low Flow	9	6	37	44	4
	Weighted	10	9	36	40	5
RCM0235	High Flow	19	13	23	37	8
	Low Flow	8	7	23	51	11
	Weighted	11	9	23	47	10
RCM0111	High Flow	25	9	20	37	9
	Low Flow	19	10	32	31	8
	Weighted	21	10	28	33	8

Table 2.4.3: Distribution of Fecal Bacteria Source Loads in the Rock Creek Basin for the Seasonal Period (May 1st – September 30th)

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
NBR0002	High Flow	6	26	33	20	15
	Low Flow	4	6	41	45	4
	Weighted	5	12	39	37	7
RCM0235	High Flow	12	25	24	24	15
	Low Flow	2	8	21	55	14
	Weighted	5	13	22	46	15
RCM0111	High Flow	11	20	25	31	13
	Low Flow	10	15	34	35	6
	Weighted	10	17	31	34	8

3.0 TARGETED WATER QUALITY GOAL

The overall objective of the fecal bacteria TMDL set forth in this document is to establish the loading caps needed to assure attainment of water quality standards in Rock Creek watershed area. These standards are described fully in Section 2.3, "Water Quality Impairment."

4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION

4.1 Overview

This section provides an overview of the non-tidal fecal bacteria TMDL development, with a discussion on the many complexities involved with the estimation of bacteria concentrations, loads and sources. The second section presents the analysis framework and how the hydrological, water quality and BST data are linked together in the TMDL process. The third section describes the analysis for estimating a representative geometric mean fecal bacteria concentration and baseline loads. The analysis methodology is based on available monitoring data and specific to a free flowing stream system. The fourth section addresses the critical condition and seasonality. The fifth section presents the margin of safety. The sixth section discusses TMDL loading caps. The seventh section presents TMDL scenario descriptions. The eighth section presents the load allocations. Finally, in section nine, the TMDL equation is summarized.

To be most effective, the TMDL provides a basis for allocating loads among the known pollutant sources in the watershed so that appropriate control measures can be implemented and water quality standards achieved. By definition, the TMDL is the sum of the individual waste load allocations (WLA) for point sources, load allocations (LA) for nonpoint sources and natural background sources. A margin of safety (MOS) is also included and accounts for the uncertainty in the analytical procedures used for water quality modeling, and the limits in scientific and technical understanding of water quality in natural systems. Although this formulation suggests that the TMDL be expressed as a load, the Code of Federal Regulations (40 CFR 130.2(i)) states that the TMDL can be expressed in terms of “mass per time, toxicity or other appropriate measure.”

For many reasons, bacteria are difficult to simulate in water quality models. They reproduce and die off in a non-linear fashion as a function of many environmental factors, including temperature, pH, turbidity (UV light penetration), and settling. They occur in concentrations that vary widely (*i.e.*, over orders of magnitude) and accurate estimation of source inputs are difficult to develop. Finally, limited data are available to characterize the effectiveness of any program or practice at reducing bacteria loads (Schueler, 1999).

Bacteria concentrations, determined through laboratory analysis of in-stream water samples for bacteria indicators (*e.g.*, Enterococci), are expressed in either colony forming units (CFU) or most probable number (MPN) of colonies. The first method (Method 1600) is a direct estimate of the bacteria colonies (EPA, 1985), and the second (Method 9223B) is a statistical estimate of the number of colonies (APHA, 1998). Enumeration results indicate the extreme variability in the total bacteria counts. The distribution of the enumeration results from water samples tends to be lognormal, with a strong positive skew of the data. Estimating loads of constituents that vary by orders of magnitude can introduce much uncertainty and result in large confidence intervals around the final results.

Estimating bacteria sources can be problematic due to the many assumptions required and the limited available data. For example, when considering septic systems, information is required on spatial location of failing septic systems, consideration of transport to in-stream assessment location and estimation of the load from the septic system (degree of failure). Secondary sources, such as illicit discharges, also add to the uncertainty in a bacteria water quality model.

Estimating domestic animal sources requires information regarding the pet population in a watershed, how often the owners clean up after them, and the spatial location of the pet waste relative to the stream (near-field for upland transport). Livestock sources are limited by spatial resolution of Agricultural Census information (available at the county level), site-specific issues relating to animals’ confinement, and confidentiality of data related to the development of Nutrient Management Plans. The most uncertain source category is wildlife. In an urban environment, this can result from the increased deer populations near streams to rat populations in storm sewers. In rural areas, estimation of wildlife populations and habitat locations in a watershed is required.

MDE recognizes the inherent uncertainty in developing traditional water quality models for the calculation of bacteria TMDLs. In this TMDL, MDE applies an analytical method which, when combined with BST, provides reasonable results (Cleland, 2003); and allows impaired streams to be addressed expeditiously.

4.2 Analysis Framework

This TMDL analysis uses flow duration curves to identify flow intervals that are used as indicator hydrological conditions (*i.e.* annual average, critical conditions). As explained previously, this analytical method combined with water quality monitoring data and BST provides a better description of water quality and meets TMDL requirements.

Figure 4.2.1 illustrates how the hydrological (flow duration curve), water quality and BST data are linked together for the TMDL development.

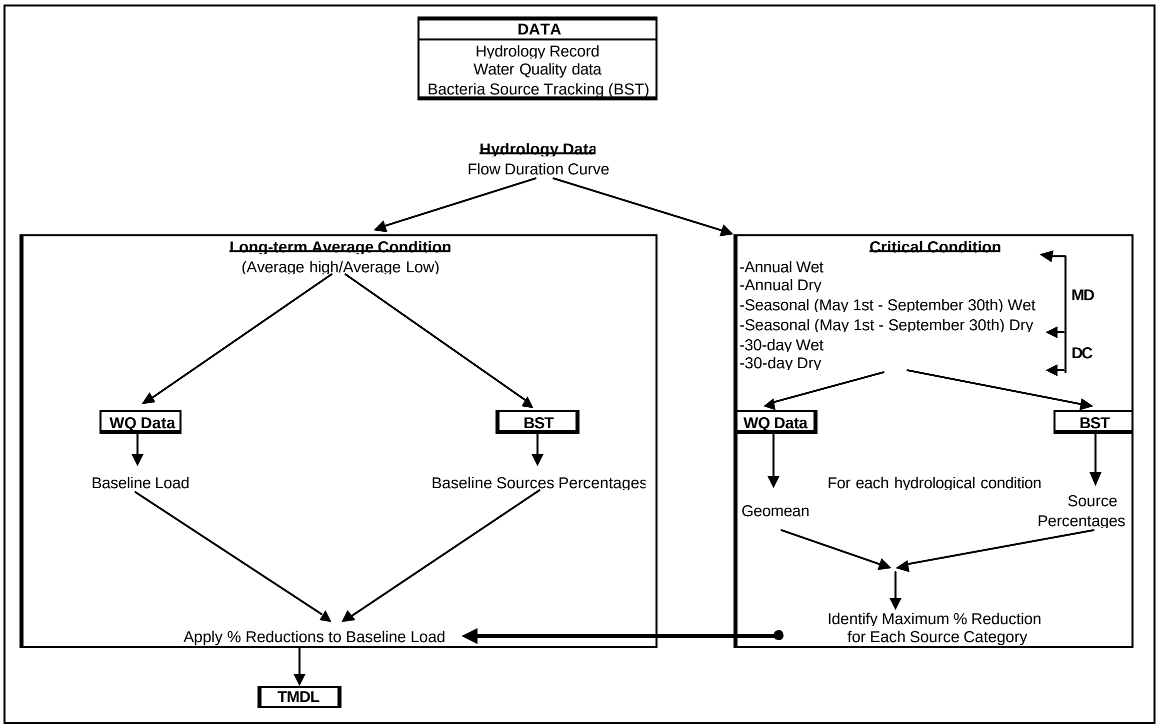

Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads estimated in this TMDL analysis are reported in long-term average loads. The geometric mean concentration is calculated from the log transformation of the raw data. Statistical theory tells us that when back transformed values are used to calculate average daily loads or total annual loads, the loads will be biased low (Richards, 1998). To avoid this bias, a factor should be added to the log-concentration before it is back transformed. There are several methods of determining this bias correction factor ranging from parametric estimates resulting from the theory of the log-normal distribution to non-parametric estimates using a smearing factor. [Ferguson, 1986; Cohn *et al*., 1989; Duan, 1983]. There is much literature on the applicability and results from these various methods, with a summary provided in Richards

(1998). Each has advantages and conditions of applicability. A non-parametric estimate of the bias correction factor (Duan, 1983) was used in this TMDL analysis.

Daily average flows are estimated for each flow stratum using the watershed area ratio approach, since nearby long-term flow monitoring data are available.

The loads for each stratum are estimated as follows:

$$L_i = Q_i * C_i * F_1 * F_2 \qquad (6)$$

where

Li = Daily average load (MPN/day) at each station for stratum i
Qi = Daily average flow (cfs) for stratum i
Ci = long term annual geometric mean for stratum i
F1= Unit conversion factor from cfs*MPN/100ml to MPN/day (2.4466×10^7)
F2= Bias correction factor

To total baseline load is estimated as follows:

$$L_t = \sum_{i=1}^{2} L_i * W_i \qquad (7)$$

Lt = Daily average load at station (MPN/day)
Wi= Proportion or weighting factor of stratum i

In the Rock Creek watershed, a weighting factor of 0.3 for high flow and 0.7 for low flow were used to estimate the annual baseline load expressed as billion MPN Enterococci/day. Results are as follows:

Table 4.3.1: Baseline Load Calculations

Station	Area (sq. miles)	USGS Reference Gauge	High Flow			Low Flow			Baseline Load (billion MPN/day	Steady State Geometric Mean Conc. MPN/100ml
			Unit flow (cfs/sq. mile)	Q (cfs)	Enterococci Concentration (MPN/100ml)	Unit flow (cfs/sq mile)	Q (cfs)	Enterococci Concentration (MPN/100ml)		
NBR0002us	12.4	1650500	3.079	38	1,676	0.4192	5.2	281	1,786	480
RCM0235us	16.9	1650500	3.079	52	544	0.4192	7.1	110	497	178
NBR0002	12.4	1650500	3.079	38	120	0.4192	5.2	20	128	34
RCM0235	16.9	1650500	3.079	52	123	0.4192	7.1	25	113	40
RCM0111	58.9	1648000	2.660	157	429	0.4770	28.1	134	1,901	190
RCM0111sub	29.6			66	885		15.8	218	1,676	332

To treat each subwatershed as a separate entity, thus allowing separate load and reduction targets for watersheds that have one or more upstream monitored subwatersheds, they were subdivided into unique watershed segments. Rock Creek has two monitoring stations located upstream of RCM0111 (Figure 4.3.1).

The subwatershed upstream of station RCM0111 and downstream of stations NBR0002 and RCM235 was defined with the extension “sub” added to the station name (*e.g.*, RCM0111sub, see Table 4.5.1). The load for subwatershed RCM0111sub was estimated using a steady state mass balance model with first order decay. The loads from the upstream watersheds, estimated from monitoring data at stations NBR0002 and RCM0235, were multiplied by a transport factor derived from first order decay. These transported loads were then subtracted from the downstream cumulative load to estimate the adjacent subwatershed load. The general equation for the flow mass balance is:

$$\sum Q_{us} + Q_{sub} = Q_{ds} \qquad (8)$$

where

Qus = Upstream flow
Qsub = Subwatershed flow
Qds = Downstream flow

and the general equations for bacteria loading mass balance:

$$\sum (e^{-kt} Q_{us} C_{us}) + Q_{sub} C_{sub} = Q_{ds} C_{ds} \qquad (9)$$

where

Cus = Upstream flow
k = Bacteria decay coefficient (1/day)
t = travel time from upstream watershed to outlet
Csub = Subwatershed flow
Cds = Downstream flow

There are two impoundments in the Rock Creek watershed: Needwood Lake and Lake Bernard Frank located in subwatersheds NRB0002 and RCM235, respectively. Ponds and lakes are excellent sinks for bacteria because they are fairly enclosed systems. Compared to streams, water entering a pond has a longer residence time before leaving the system. Because of this, bacteria loads entering a lake can be significantly reduced by natural decay, loss due to solar radiation and settling. Therefore, loads upstream of the ponds should be used to better estimate the reductions in these subwatersheds, if needed, to meet water quality criteria. The subwatersheds upstream of stations NRB0002 and RCM235 were defined with the extension “us”. The loads from subwatersheds NBR0002us and RCM235us represent the loads entering the ponds.

Water quality samples were collected downstream of the pond. A steady-state mass balance equation with first order decay was used to estimate the bacterial loading from the watershed before entering the ponds. A median decay rate of 0.1/day from different literature values (Easton *et al.*, 2001 and 1999) and estimates based on *in situ* measurements of Enterococci, was selected based on the pond's average retention time (Maryland Water Resources Administration, 1985). The average retention time used for Needwood Lake was 14.8 days (1,281,176 seconds). The average retention time used for Lake Bernard Frank was 26.4 days (2,277,969 seconds). These loadings were calculated for the high flow and the low flow stratums. The following equation was used for calculating the bacteria loadings upstream of the two ponds:

$$C_{i,in} e^{-kt} = C_{i,out} \tag{10}$$

$$C_{i,in} = \frac{C_{i,out}}{e^{-kt}} \tag{11}$$

Where:
Ci, in = Enterococci concentrations inflow to pond/lake in stratum i
Ci, out = Enterococci concentrations outflow to pond/lake in stratum i
k = Bacteria decay coefficient (1/day)
t = average travel time from upstream watershed to outlet

Source estimates from the BST analysis were completed for each station and are based on the contribution from the upstream watershed. Given the uncertainty of in-stream bacteria processes and the complexity involved in estimating an accurate source transport factor, the sources for NBR0002us, RCM0235us, and RCM0111sub were assigned from the analysis for NBR0002, RCM0235, and RCM0111, respectively.

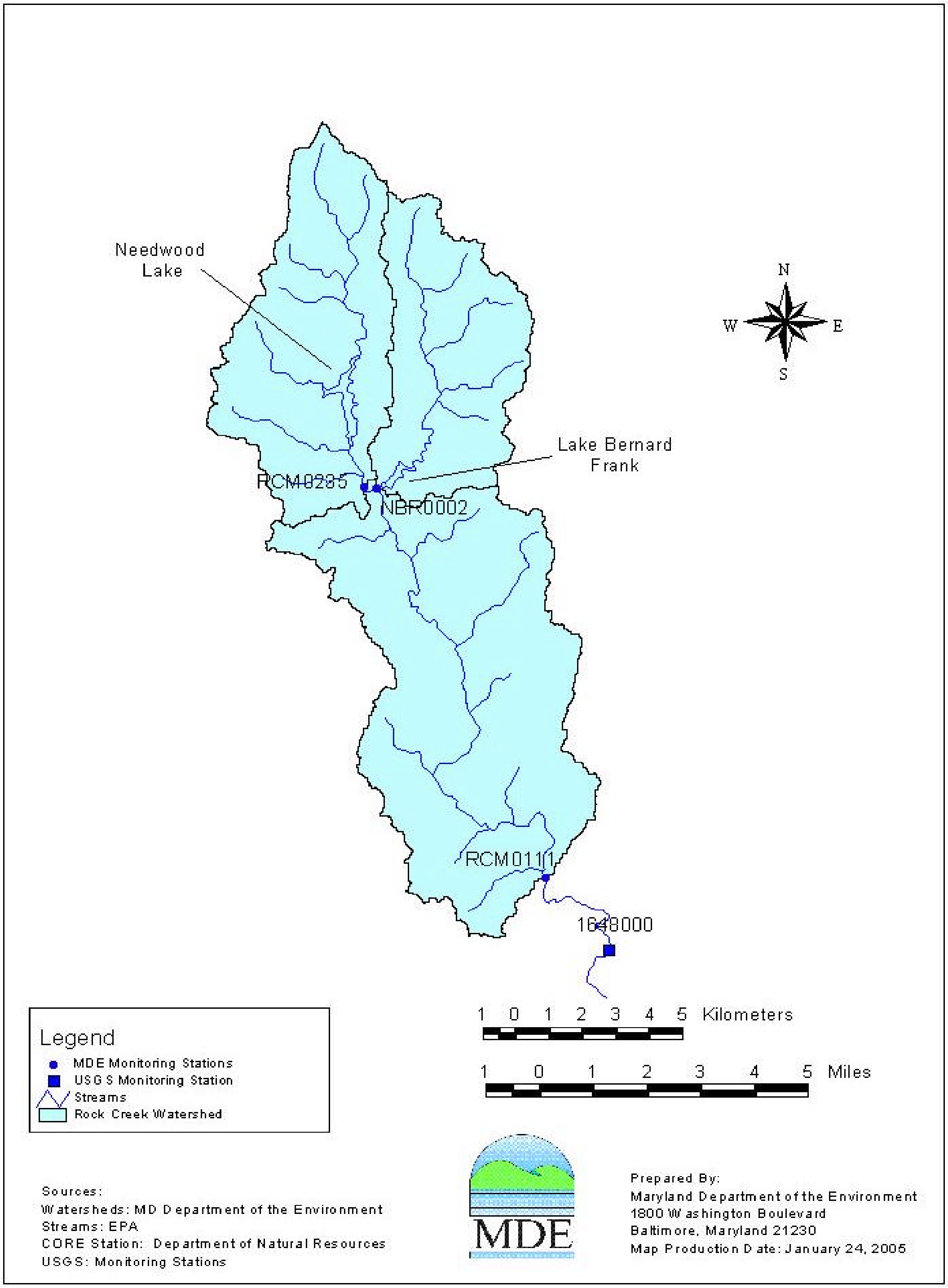

Figure 4.3.1: Monitoring Stations and Subwatersheds in the Rock Creek Basin

4.4 Critical Condition and Seasonality

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

For this TMDL the critical condition is determined by assessing various hydrological conditions (wet/dry) including 30-day wet and 30-day dry conditions to be protective of the District of Columbia (D.C.) waters designated uses. D.C.'s water quality standards are based on a 30-day geometric mean.

Seasonality is captured by assessing the time period when water contact recreation is expected (May 1st - September 30th). The average hydrological condition over a 15-year period is approximately 30% high flow and 70% low flow as defined in Appendix B. Using the definition of a high flow condition occurring when the daily flow duration interval is less than 30% and a low flow condition occurring when the daily flow duration interval is greater than 70%, critical hydrological condition can be estimated by the percent of high or low flows during a specific period.

D.C. has established a fecal bacteria TMDL for the portion of Rock Creek within D.C.'s boundaries. D.C.'s fecal bacteria TMDL was approved by EPA in February 2004. Comparing the upstream loads reported in the Washington, D.C. fecal coliform TMDL to MD's proposed TMDL for Rock Creek is complicated due to several factors: First, MD's loads are estimated as the loads upstream from Rock Creek and North Branch, and are not simply the sum of the subwatersheds' loads, since bacteria are not conservative. Second, MD and D.C. use different pathogen indicator organisms in their water quality standards. Third, the frequency of sampling and data assessment methodology are different. Finally, the baseline conditions for the D. C. TMDL and MD's TMDL are different.

As stated above, Maryland's proposed fecal bacteria TMDL for Rock Creek has been determined by assessing various hydrological conditions to account for critical conditions and seasonality. Furthermore, both MD and D.C. fecal bacteria water quality standards, independent of the bacteriological densities and/or indicator organism used in their corresponding analysis, are based on EPA's recommendations in "Quality Criteria for Water" of an accepted illness rate of 8 illnesses/1,000 swimmers. Therefore, MD's proposed TMDL loads have been established to meet D.C.'s water quality standards, and will be protective of downstream designated uses under any hydrological condition.

The following seven conditions were used to account for the critical condition and include the effects of seasonality.

Table 4.4.1: Hydrological Conditions Used to Account for Critical Condition and Seasonality

Hydrological Condition		Averaging Period	Water Quality Data Used	Sub-watershed	Fraction High Flow	Fraction Low Flow	Period
Annual	Average Condition	365 days	All	NBR0002us; RCM0235us	0.30	0.70	Long Term Average
				RCM0111subNE B0002	0.30	0.70	Long Term Average
	Wet	365 days	All	NBR0002us; RCM0235us	0.55	0.45	April 8th, 1996 – March 23rd, 1997
				RCM0111subNE B0002	0.58	0.42	April 1st, 1996 - March 31st, 1997
	Dry	365 days	All	NBR0002us; RCM0235us	0.07	0.93	October 1st, 2002 – Sept 30th, 2003
				RCM0111subNE B0002	0.10	0.90	Sept 1st, 2001 - August 31st, 2002
Season	Wet	May 1st – Sept 30th	May 1st – Sept 30th	NBR0002us; RCM0235us	0.51	0.49	May 1st – Sept 30th, 2003
				RCM0111sub NEB0002	0.62	0.38	May 1st – Sept 30th, 2003
	Dry	May 1st – Sept 30th	May 1st – Sept 30th	NBR0002us; RCM0235us	0.09	0.91	May 1st – Sept 30th, 2002
				RCM0111subNE B0002	0.10	0.90	May 1st – Sept 30th, 1991
30-day	Wet	30 days	All	NBR0002us; RCM0235us	1.00	0.00	Several occurrences during both Winter and Summer
				RCM0111subNE B0002	1.00	0.00	Several occurrences during both Winter and Summer
	Dry	30 days	All	NBR0002us; RCM0235us	0.00	1.00	Several occurrences during both Winter and Summer
				RCM0111subNE B0002	0.00	1.00	Several occurrences during both Winter and Summer

The critical condition is determined by the maximum reduction per source that satisfy all seven conditions and is required to meet the water quality standard while minimizing the risk to water contact recreation. It is assumed that the reduction that can be implemented to a bacteria source category will be constant through all conditions (*e.g.*, pets waste can be reduced to 75%).

The monitoring data for all stations located in the Rock Creek watershed cover a sufficient temporal span (at least one year), to estimate annual and seasonal conditions.

Table 4.4.2: Required Reductions to Meet Water Quality Standards

Subwatershed	Hydrological Condition		Domestic %	Human %	Livestock %	Wildlife %
NBR0002us	Annual	Average	99	99	99	91
		Wet	99	99	99	79
		Dry	99	99	99	92
	Seasonal	Wet	99	99	99	86
		Dry	99	99	99	96
	30-day	Wet	99	98	99	77
		Dry	99	99	99	91
	Maximum Source Reduction		**99**	**99**	**99**	**96**
RCM0235us	Annual	Average	98	98	98	78
		Wet	97	97	98	5
		Dry	98	98	98	78
	Seasonal	Wet	94	98	98	68
		Dry	98	98	98	89
	30-day	Wet	97	97	98	52
		Dry	98	98	98	78
	Maximum Source Reduction		**98**	**98**	**98**	**89**
RCM0111sub	Annual	Average	98	98	98	86
		Wet	98	98	98	67
		Dry	98	98	98	78
	Seasonal	Wet	98	98	98	50
		Dry	98	98	98	94
	30-day	Wet	98	98	98	61
		Dry	98	98	98	86
	Maximum Source Reduction		**98**	**98**	**98**	**94**

4.5 Margin of Safety

A Margin of Safety (MOS) is required as part of this TMDL in recognition of the many uncertainties in the understanding and simulation of bacteriological water quality in natural systems and in statistical estimates of indicators. As mentioned in Section 4.1, it is difficult to estimate stream loadings for fecal bacteria due to the variation in loadings across sample locations and time. Load estimation methods should be both precise and accurate to obtain the true estimate of the mean load. Refined precision in the load estimation is due to using a stratified approach along the flow duration intervals thus reducing the variation in the estimates. Moreover, Richards (1998) reports that averaging methods are generally biased, and the bias increases as the size of the averaging window increases. Finally, accuracy in the load estimation is based on minimal bias in the final result when compared to the true value.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA, April 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (*i.e.*, TMDL = LA + WLA + MOS). The second approach is to incorporate the MOS as conservative assumptions used in the TMDL analysis. For this TMDL, the second approach was used by estimating the loading capacity of the stream based on a more stringent water quality criterion concentration. The Enterococci water quality criterion concentration was reduced by 5%, from 33 Enterococci MPN/100ml to 31.35 Enterococci MPN/100ml.

4.6 TMDL Loading Caps

The TMDL loading cap is an estimate of the assimilative capacity of the monitored watershed and is provided in MPN/day. This loading is for the watershed upstream of monitoring stations RCM0111, located on the mainstem of Rock Creek.

The TMDL is based on a long-term average hydrological condition, and therefore the loads are not literal daily limits. Estimation of the TMDL requires knowledge of how the bacteria concentrations vary with flow rate or the flow duration interval. This concentration versus flow relationship is accounted for by using the strata defined on the flow duration curve.

The TMDL loading cap is estimated by first determining the baseline or current condition load and the associated geometric mean from the available monitoring data. The baseline load is estimated using the geometric mean concentration and average daily flow for each flow stratum. The loads from these two strata are then weighted to represent average conditions (see Table 4.3.1), based on the proportion of each stratum, to estimate the total long-term loading rate.

Next, the percent reduction (based on the critical condition) required to meet the water quality criterion is estimated from the observed bacteria concentrations accounting for the critical conditions. It is assumed that a reduction in concentration is proportional to a reduction in load and thus the TMDL is equal to the current baseline load multiplied by one minus the required reduction.

$$TMDL = L_b * (1 - R) \quad (12)$$

where

Lb = Current or baseline load estimated from monitoring data
R = Reduction required from baseline to meet water quality criterion

The bacteria TMDL for the watershed upstream of monitoring stations RCM0111 is:

Table 4.6.1: Rock Creek Watershed TMDL Summary

Station	**Baseline Load Enterococci (billion MPN/day)**	**TMDL Load Enterococci (billions MPN/day)**	**Target Reduction %**
NBR0002us	1,786	37	97.9
RCM0235us	497	32	93.6
RCM0111sub	1,672	56	96.7
Total	3,955	125	96.8

4.7 Scenario Descriptions

Source Distribution

The final source distribution is derived from the source proportions listed in Table 2.4.2. For the purposes of the TMDL analysis and allocations, the percentage of sources identified as "unknown" were removed and the known sources were then scaled up proportionally so that they totaled 100%. The source distribution used in this scenario is presented in Table 4.7.1. As stated in Section 4.3, the source distribution for stations NBR0002us, RCM0235us and RCM0111sub, was based on the sources identified at stations NBR0002, RCM0235 and RCM0111, respectively.

Table 4.7.1: Baseline Source Distributions

Station	**% Domestic**	**% Human**	**% Livestock**	**% Wildlife**	**% Total**
NBR0002us	10.1	9.7	38.2	42.0	100
RCM0235us	13.9	11.4	28.7	46.1	100
RCM0111sub	23.6	10.4	30.6	35.4	100

Practicable Reduction Targets

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.7.2. These values are based on best professional judgment and a review of the available literature. It is assumed that human sources would potentially confer the highest risk of gastrointestinal illness and therefore should have the highest reduction. If a domestic WWTP is located in the upstream watershed, this is considered in the MPR so as to not violate the permitted loads. The domestic animal category includes sources from pets (*e.g.*, dogs) and the MPR is based on an estimated success of education and outreach programs.

Table 4.7.2: Maximum Practicable Reduction Targets

	Human	**Domestic**	**Livestock**	**Wildlife**
Max Practical Reduction per Source	95%	75%	75%	0%
Rationale	(a) Direct source inputs (b) Human pathogens more prevalent in humans than animals. (c) Enteric viral diseases spread from human to human	Target goal reflects uncertainty in effectiveness of urban BMPs[1] and is also based on best professional judgment	Target goal based on sediment reductions from BMPs[2] and best professional judgment	No programmatic approaches for wildlife reduction to meet water quality standards Waters contaminated by wild animal waste offer a public health risk that is orders of magnitude less than that associated with human waste.[4]

[1]USEPA. 1984. Health Effects Criteria for Fresh Recreational Waters. EPA-600/1-84-004. U.S. Environmental Protection Agency, Washington, DC.
[2]USEPA. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. U.S. Environmental Protection Agency, Washington, DC.
[3]USEPA. 2004. Agricultural BMP Descriptions as Defined for The Chesapeake Bay Program Watershed Model. Nutrient Subcommittee Agricultural Nutrient Reduction Workshop.
[4]Environmental Indicators and Shellfish Safety. 1994. Edited by Cameron, R., Mackeney and Merle D. Pierson, Chapman & Hall.

As previously stated, these practicable reduction targets are based on the available literature and best professional judgment. There is much uncertainty with estimated reductions from best management practices (BMPs). The BMP efficiency for bacteria reduction ranged from –6% to +99% based on a total of 10 observations (USEPA, 1999). The MPR to agricultural lands was based on sediment reductions identified by the EPA (EPA, 2004).

The practicable reduction scenario was developed based on an optimization analysis whereby a subjective estimate of risk was minimized and constraints were set on maximum reduction and allowable background conditions. Risk was defined on a scale of one to five, where it was assumed that human sources had the highest risk (5), domestic animal and livestock next (3) and wildlife the lowest (1) (see Table 4.7.2). The objective is to minimize the sum of the risk for all conditions while meeting the maximum practicable reduction constraints. The model was defined as follows:

$$\text{Min} \sum_{i=1}^{7} (Ph*5 + Pd*3 + Pl*3 + Pw*1) \qquad i = \text{hydrological condition}$$

Subject to

C = Ccr
0 <= Rh <= 95%
0 <= Rl <= 75%
0 <= Rd <= 75%
Rw = 0
Ph ,Pl, Pd, Pw >= 1%

Where

Ph = % human source in final allocation
Pd = % domestic animal source in final allocation
Pl = % livestock source in final allocation
Pw = % wildlife source in final allocation
C = In-stream concentration
Ccr = Water quality criterion
Rh = Reduction applied to human sources
Rl = Reduction applied to livestock sources
Rd = Reduction applied to domestic animal sources

In all three watersheds, the constraints of this scenario could not be satisfied indicating there was not a practicable solution. A summary of the analysis is presented in Table 4.7.3.

Table 4.7.3: Practicable Reduction Results

Station	Applied Reductions				Achievable?
	Domestic %	Human %	Livestock %	Wildlife %	
NBR0002us	75%	95%	75%	0%	No
RCM0235us	75%	95%	75%	0%	No
RCM0111sub	75%	95%	75%	0%	No

The TMDL must specify load allocations that will meet the water quality standards. In the practicable reduction targets scenario all three subwatersheds could not meet water quality standards based on MPRs.

To further develop the TMDL, the constraints on the MPRs were relaxed in one of the three subwatersheds where the water quality attainment was not achievable with the MPRs. In this subwatershed, the maximum allowable reduction was increased to 99% for all sources, including wildlife. A similar optimization procedure was used to minimize risk. Again, the objective is to minimize the sum of the risk for all conditions while meeting the maximum practicable reduction constraints. The model was defined as follows:

$$\text{Min} \sum_{i=1}^{7} (Ph*5 + Pd*3 + Pl*3 + Pw*1) \qquad i = \text{hydrological condition}$$

Subject to

C = Ccr
0 <= Rh <= 99%
0 <= Rl <= 99%
0 <= Rd <= 99%
0 <= Rw <= 99%
Ph , Pl, Pd, Pw >= 1%

Where

Ph = % human source in final allocation
Pd = % domestic animal source in final allocation
Pl = % livestock source in final allocation
Pw = % wildlife source in final allocation
C = In-stream concentration
Ccr = Water quality criterion
Rh = Reduction applied to human sources
Rl = Reduction applied to livestock sources
Rd = Reduction applied to domestic animal sources

The summary of the analysis is presented in Table 4.7.4.

Table 4.7.4: TMDL Reduction Results: Optimization Model Up to 99% Reduction

Station	Domestic %	Human %	Livestock %	Wildlife %	Target Reduction
NBR0002us	99.0%	99.0%	99.0%	96.4%	97.9%
RCM0235us	98.0%	98.0%	98.0%	88.7%	93.7%
RCM0111sub	98.0%	98.0%	98.0%	94.3%	96.7%

4.8 TMDL Allocation

The TMDL allocation includes waste load allocations (WLA) for point sources, for stormwater (where MS4 permits are required), and the load allocation (LA) for nonpoint sources. The margin of safety is explicit and is expressed as a 5% reduction of the Enterococci water quality criterion concentration, from 33 Enterococci MPN/100ml to 31.35 Enterococci MPN/100ml. TMDL allocations in the Rock Creek watershed are based on critical conditions and meet both MD and D.C. bacteria water quality criteria, taking into account a 30-day hydrological condition as specified in D.C.'s water quality standards. The final loads represent loads based on average hydrological conditions. The load reduction scenario results in a load allocation that will achieve water quality standards in MD and D.C. The State reserves the right to revise these allocations provided such allocations are consistent with the achievement of water quality standards.

The bacteria sources are grouped into four categories that are also consistent with divisions for various management strategies. The categories are human, domestic animal, livestock and wildlife. TMDL allocation rules are presented in Table 4.8.1. This table identifies how the TMDL will be allocated among WWTPs, MS4 permits and the LA.

Table 4.8.1: Potential Source Contributions for Rock Creek TMDL Allocations

Allocation Category	Human	Domestic	Livestock	Wildlife
WWTP				
MS4		X		X
LA	X		X	X

There are no point sources in the Rock Creek basin, therefore, the human source load is assigned entirely to the LA. As explained below, where the entire watershed is covered by an MS4 permit(s), the domestic pet allocation is assigned to the MS4 WLA. Livestock is not covered by MS4 permits and will, therefore, be part of the LA when it is not included as part of a Confined Animal Feeding Operation (CAFO). Wildlife sources will be distributed between the LA and the WLA-MS4, based on a ratio of the amount of urban land compared to pasture and forest land in the watershed.

<u>Municipal Separate Stormwater Systems (MS4)</u>

Both individual and general NPDES MS4 Phase I and Phase II permits are point sources subject to WLA assignment in the TMDL. Quantification of rainfall-driven nonpoint source loads is uncertain. EPA recognized this in its guidance document entitled "Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs" (November 2002), which states that available data and information usually are not detailed enough to determine WLAs for NPDES-regulated stormwater discharges on an outfall-specific basis. Therefore, in watersheds with an existing

MS4 permit, domestic animal bacteria loads will be lumped into a single WLA-MS4 load. In watersheds with no existing individual MS4 permits, these loads will be included in the LA.

The jurisdiction within the Rock Creek watershed, Montgomery County, is covered by individual Phase I MS4 program regulations. Based on EPA's guidance, the MS4 WLA is presented as one combined load for the entire land area of each county. In the future, when more detailed data and information become available, it is anticipated that MDE will revise the WLA into appropriate WLAs and LAs, and may also revise the LA accordingly. Note that the overall reductions in the TMDL will not change. The WLA-MS4 distribution in the Rock Creek watershed is presented in Table 4.8.2.

Table 4.8.2: MS4 Stormwater Allocations

Station	WLA – MS4 Load (billions MPN/day)
NBR0002us	13
RCM0235us	12
RCM0111sub	35
Total	60

<u>Municipal and Industrial WWTPs</u>

There are no municipal or industrial NPDES WWTPs with permits regulating the discharge of fecal bacteria directly into the Rock Creek watershed.

4.9 Summary

The TMDL for the Rock Creek watershed is presented below.

Table 4.9.1: Rock Creek Watershed TMDL

<u>Station</u>	TMDL Load Enterococci (billion MPN/day)	LA Load Enterococci (billion MPN/day)	WLA-PS Load Enterococci (billion MPN/day)	WLA-MS-4 Load Enterococci (billion MPN/day)
NBR0002us	37	24	0	13
RCM0235us	32	20	0	12
RCM0111sub	56	21	0	35
Total	125	65	0	60

In all three subwatersheds, based on the practicable reduction rates specified, water quality standards cannot be achieved. This may occur in watersheds where wildlife is a significant component or watersheds that require very high reductions to meet water quality standards. However, if there is no feasible TMDL scenario, then MPRs are increased to provide estimates of the reductions required to meet water quality standards. For these watersheds, it is noted that the reductions may be beyond practical limits. In this case, it is expected that the first stage of implementation will be to implement the MPR scenario.

5.0 ASSURANCE OF IMPLEMENTATION

Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and wasteload allocations can and will be implemented. In the Rock Creek watershed, the TMDL analysis indicates that reduction of fecal bacteria loads from all sources including wildlife are beyond the MPR targets. Rock Creek and its tributary North Branch may not be able to attain water quality standards. The extent of the fecal bacteria load reductions required to meet water quality criteria in the three subwatersheds of the non-tidal Rock Creek and in downstream waters are not feasible by effluent limitations (there are no point sources) and also by implementing cost-effective and reasonable best management practices to nonpoint sources. Therefore, MDE proposes a staged approach of implementation beginning with the MPR scenario, with regularly scheduled follow-up monitoring to assess the effectiveness of the implementation plan.

Based on the above, the final scenario for all three subwatersheds is based on reductions that are beyond the MPR targets. These MPR targets were defined based on a literature review of BMPs effectiveness and assuming a zero reduction for wildlife sources. The uncertainty of BMPs effectiveness for bacteria, reported within the literature, is quite large. As an example, pet waste education programs have varying results based on stakeholder involvement. Additionally, the extent of wildlife reduction associated with various BMPs methods (*e.g.,* structural, non-structural, etc) is uncertain. Therefore, MDE intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality and human health risk, with consideration given to ease of implementation and cost. The iterative implementation of BMPs in the watershed has several benefits: tracking of water quality improvements following BMP implementation through follow-up stream monitoring; providing a mechanism for developing public support through periodic updates on BMP implementation; and helping to ensure that the most cost-effective practices are implemented first.

In 1983, the EPA Nationwide Urban Runoff Program found that stormwater runoff from urban areas contains the same general types of pollutants found in wastewater, and that 30% of identified cases of water quality impairment were attributable to stormwater discharges. In November 1990, EPA required jurisdictions with a population greater than 100,000 to apply for NPDES Permits for stormwater discharges. The jurisdiction where the Rock Creek watershed is located, Montgomery County, is required to participate in the stormwater NPDES program, and has to comply with the NPDES Permit regulations for stormwater discharges. The permit-required management programs are being implemented in the County to meet locally established watershed protection and restoration goals and to control stormwater discharges to the maximum extent practicable. These jurisdiction-wide programs are designed to control stormwater discharges to the maximum extent practical. Funding sources for implementation include the State Water Quality Revolving Loan Fund and the Stormwater Pollution Cost Share Program. Details of this program and additional funding sources can be found at http://www.dnr.state.md.us/bay/services/summaries.html.

Additional potential funding sources for implementation include the Maryland's Agricultural Cost Share Program (MACS) which provides grants to farmers to help protect natural resources and the Environmental Quality and Incentives Program which focuses on implementing conservation practices and BMPs on land involved with livestock and production.

Though not directly linked, it is assumed that the nutrient management plans from the Water Quality Improvement Act of 1998 (WQIA) will have some reduction of bacteria from manure application practices.

In 2000, the Maryland DNR initiated the Watershed Restoration Action Strategy (WRAS) Program as one of several new approaches to implementing water quality and habitat restoration and protection. The WRAS Program encourages local governments to focus on priority watersheds for restoration and protection. Since the program's inception, local governments have received grants and technical assistance from DNR for 20 WRAS projects in which local people identify local watershed priorities for restoration, protection and implementation. WRAS information provides a potential targeting tool to direct future efforts in implementation. (DNR-WRAS Program, 2005).

Additionally, MDE's "Managing Maryland for Results" (MDE, 2005) document states the following related to sewage overflows:

> Objective 4.5: Reduce the quantity in gallons of sewage overflows [total for Combined Sewer System Overflows (CSO) and Separate Sewer System Overflows (SSO)] equivalent to a 50% reduction of 2001 amounts (50, 821,102 gallons) by the year 2010 through implementation of EPA's minimum control strategies, long term control plans (LTCP), and collection system improvements in capacity, inflow and infiltration reduction, operation and maintenance.
>
> Strategy 4.5.1: MDE will implement regulations adopted in FY 2004 to ensure that all jurisdictions are reporting all sewage overflows to the Department, notifying the public about significant overflows, and are taking appropriate steps to address the cause(s) of the overflows.
>
> Strategy 4.5.2: MDE will inspect and take enforcement actions against those CSO jurisdictions that have not developed long-term control plans with schedules for completion and require that enforceable schedules are incorporated in consent decrees or judicial orders.

> Strategy 4.5.3: MDE will take enforcement actions to require that jurisdictions experiencing significant or repeated SSOs take appropriate steps to eliminate overflows, and will fulfill the commitment in the EPA 106 grant for NPDES enforcement regarding the initiation of formal enforcement actions against 20% of jurisdictions in Maryland with CSOs and significant SSO problems annually.

In 2004, the United States and the State of Maryland brought suit against Washington Suburban Sanitary Commission (WSSC) in the U.S. District Court for the District of Maryland to remedy recurrent SSOs from the WSSC system, *United States et al. v. Washington Suburban Sanitary Commission*, C.A. A consent decree was negotiated among the United States, Maryland, several intervenor citizen groups and WSSC and lodged on July 26, 2005. The consent decree case No. PJM 04-3679 (Greenbelt Division) was approved and entered in December, 2005. WSSC already reports overflows to MDE as required by Environment Article, Section 9-331.1, Annotated Code of Maryland and COMAR 26.08.10.

Implementation and Wildlife Sources

It is expected that in some waters for which TMDLs will be developed, the bacteria source analysis indicates that after controls are in place for all anthropogenic sources, the waterbody will not meet water quality standards. However, while neither the Maryland, nor EPA is proposing the management of wildlife to allow for the attainment of water quality standards, managing the overpopulation of wildlife remains an option for state and local stakeholders.

After developing and implementing to the maximum extent possible a reduction goal based on the anthropogenic sources identified in the TMDL, Maryland anticipates that implementation to reduce the controllable nonpoint sources may also reduce some wildlife inputs to the waters. As explained before, implementation plans will include tracking of water quality improvements following BMP implementation through follow-up stream monitoring.

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Appendix A – Table of Bacteria Concentration Raw Data per Sampling Date with Corresponding Daily Flow Frequency

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	Enterococci MPN/100ml
NBR0002	10/07/2002	97.8372	160
NBR0002	10/21/2002	87.2410	10
NBR0002	11/06/2002	7.9789	10
NBR0002	11/18/2002	6.0705	2600
NBR0002	12/02/2002	70.0109	10
NBR0002	12/16/2002	28.6441	1010
NBR0002	01/06/2003	20.7743	510
NBR0002	01/21/2003	50.5998	10
NBR0002	02/03/2003	47.0738	10
NBR0002	03/03/2003	5.1981	50
NBR0002	03/17/2003	24.1912	10
NBR0002	04/21/2003	26.9357	20
NBR0002	05/05/2003	32.9335	10
NBR0002	05/19/2003	17.9026	420
NBR0002	06/02/2003	25.4998	200
NBR0002	06/16/2003	25.4998	20
NBR0002	06/23/2003	18.7023	100
NBR0002	07/07/2003	11.2323	400
NBR0002	07/21/2003	50.5998	50
NBR0002	08/04/2003	39.7492	20
NBR0002	08/18/2003	43.8023	90
NBR0002	08/25/2003	70.1927	20
NBR0002	09/08/2003	66.1032	30
NBR0002	10/06/2003	55.1618	10
NBR0002	10/20/2003	51.9447	10
RCM0111	10/07/2002	99.0323	550
RCM0111	10/21/2002	81.9427	120
RCM0111	11/06/2002	7.7415	7700
RCM0111	11/18/2002	3.1221	5170
RCM0111	12/02/2002	74.3108	380
RCM0111	12/16/2002	16.4871	630

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	Enterococci MPN/100ml
RCM0111	01/06/2003	13.3102	530
RCM0111	01/21/2003	57.2394	10
RCM0111	02/03/2003	51.7254	30
RCM0111	03/03/2003	4.7106	110
RCM0111	03/17/2003	29.8156	90
RCM0111	04/21/2003	35.7130	20
RCM0111	05/05/2003	37.9587	10
RCM0111	05/19/2003	22.5306	310
RCM0111	06/02/2003	18.9520	70
RCM0111	06/16/2003	16.6697	160
RCM0111	06/23/2003	9.2934	270
RCM0111	07/07/2003	6.1895	2100
RCM0111	07/21/2003	53.9529	210
RCM0111	08/04/2003	38.8899	1520
RCM0111	08/18/2003	34.9644	2910
RCM0111	08/25/2003	65.2547	120
RCM0111	09/08/2003	63.6115	200
RCM0111	09/22/2003	12.5616	150
RCM0235	10/07/2002	97.8372	150
RCM0235	10/21/2002	87.2410	40
RCM0235	11/06/2002	7.9789	910
RCM0235	11/18/2002	6.0705	400
RCM0235	12/02/2002	70.0109	10
RCM0235	12/16/2002	28.6441	360
RCM0235	01/06/2003	20.7743	460
RCM0235	01/21/2003	50.5998	10
RCM0235	02/03/2003	47.0738	10
RCM0235	03/03/2003	5.1981	50
RCM0235	03/17/2003	24.1912	10
RCM0235	04/21/2003	26.9357	10
RCM0235	05/05/2003	32.9335	10
RCM0235	05/19/2003	17.9026	270
RCM0235	06/02/2003	25.4998	250

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	Enterococci MPN/100ml
RCM0235	06/16/2003	25.4998	20
RCM0235	06/23/2003	18.7023	100
RCM0235	07/07/2003	11.2323	760
RCM0235	07/21/2003	50.5998	50
RCM0235	08/04/2003	39.7492	160
RCM0235	08/18/2003	43.8023	100
RCM0235	08/25/2003	70.1927	10
RCM0235	09/08/2003	66.1032	10
RCM0235	09/22/2003	22.7190	50
RCM0235	10/06/2003	55.1618	10
RCM0235	10/20/2003	51.9447	30

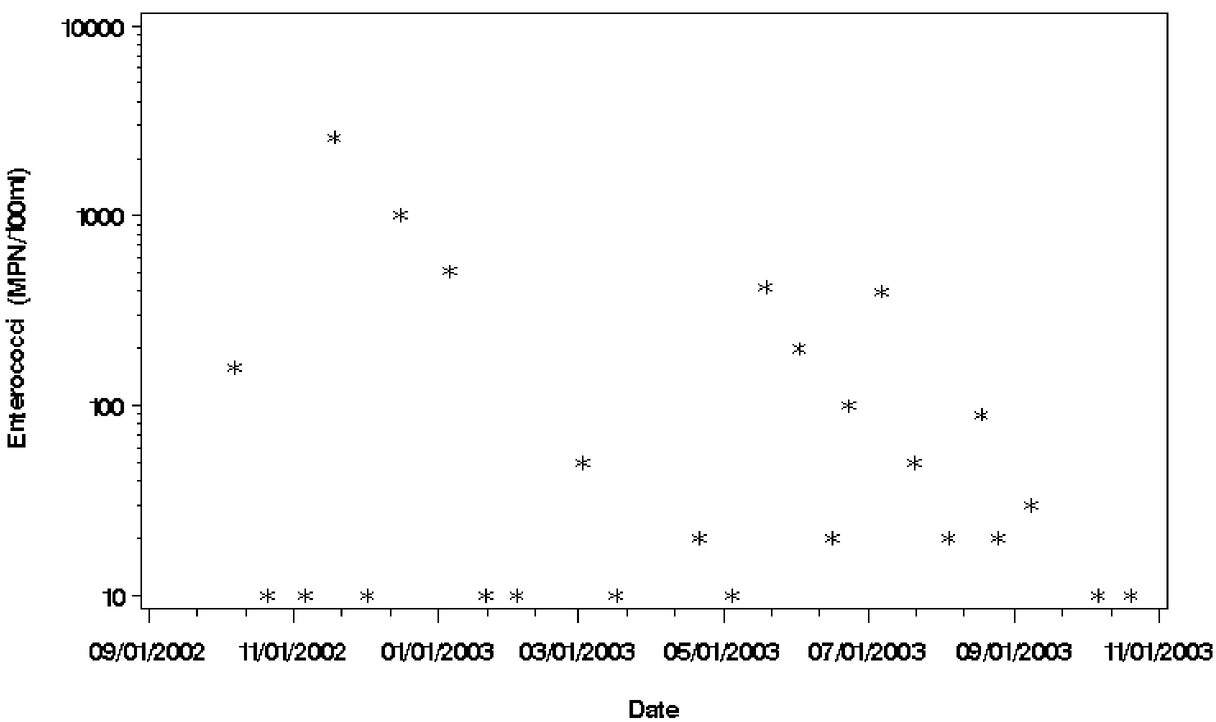

Figure A-1: Enterococci Concentration vs. Time for Rock Creek Monitoring Station NBR0002

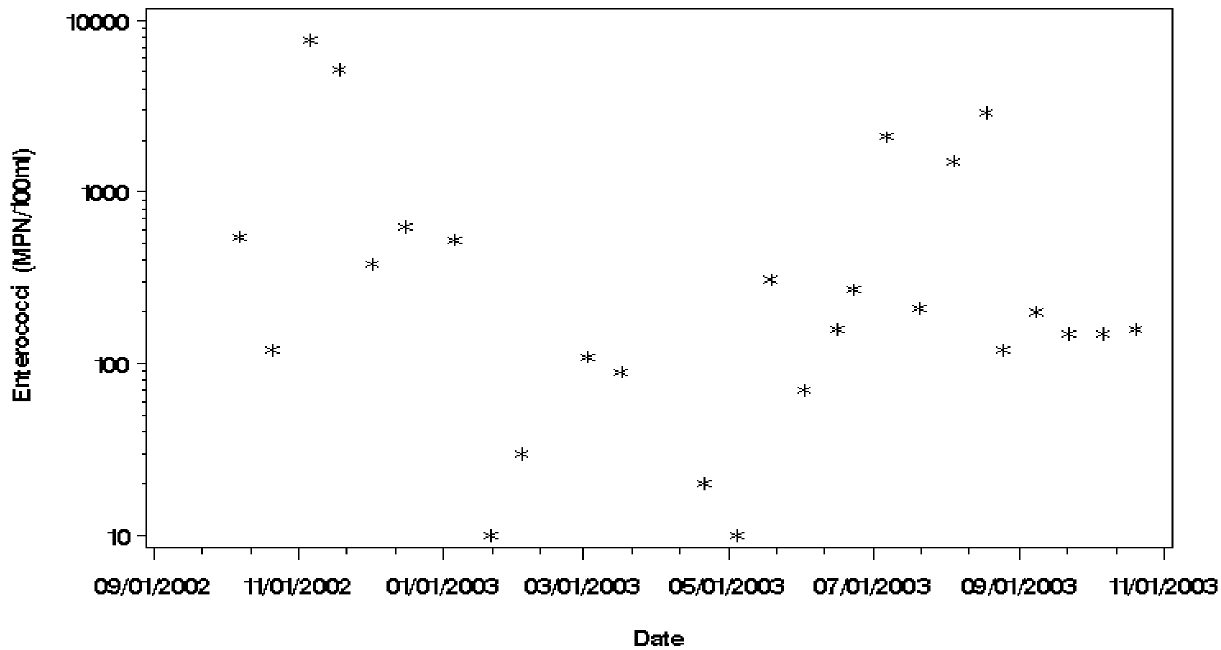

Figure A-2: Enterococci Concentration vs. Time for Rock Creek Monitoring Station RCM0111

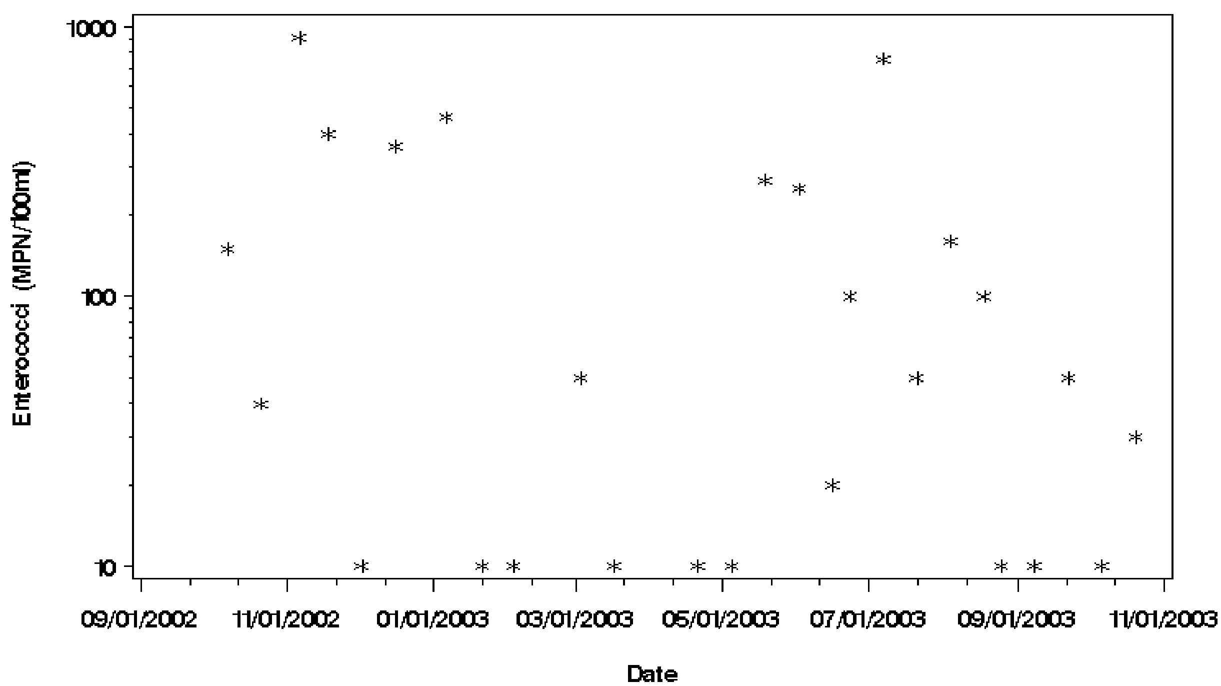

Figure A-3: Enterococci Concentration vs. Time for Rock Creek Monitoring Station RCM0235

Appendix B - Flow Duration Curve Analysis to Define Strata

The Rock Creek and Anacostia River watersheds were assessed to determine hydrologically significant strata. The purpose of these strata is to apply weights to monitoring data and thus (1) reduce bias associated with the monitoring design and (2) approximate a critical condition for TMDL development. The strata group hydrologically similar water quality samples and provide a better estimate of the mean concentration at the monitoring station.

The flow duration curve for a watershed is a plot of all possible daily flows, ranked from highest to lowest, versus their probability of exceedence. In general, the higher flows will tend to be dominated by excess runoff from rain events and the lower flows will result from drought type conditions. The mid range flows are a combination of high base flow with limited runoff and lower base flow with excess runoff. The range of these mid level flows will vary with soil antecedent conditions. The purpose of the following analysis is to identify hydrologically significant groups, based on the previously described flow regimes, within the flow duration curve.

Flow Analysis

The Rock Creek Watershed has one active (01648000) USGS flow gauge. One inactive gauge (01650500), located in the Anacostia River watershed, was used for subwatersheds NBR0002 and RCM0235, respectively. The gauges and dates of information used are as follows:

Table B-1: USGS Gauges in the Rock Creek Watershed

USGS Gauge #	Dates used	Description
01648000	Oct 1, 1988 to Sep 30, 2003	
01650500	Nov 27, 1997 to Sep 30, 2003	
01650500 (estimate)	Oct 1, 1988 to Sep 30, 2003	Estimated flow based on USGS Gauge 0165100 using MOVE.1 (Hirsch, 1982)

Flow duration curves for these two gauges are presented in Figure B-1.

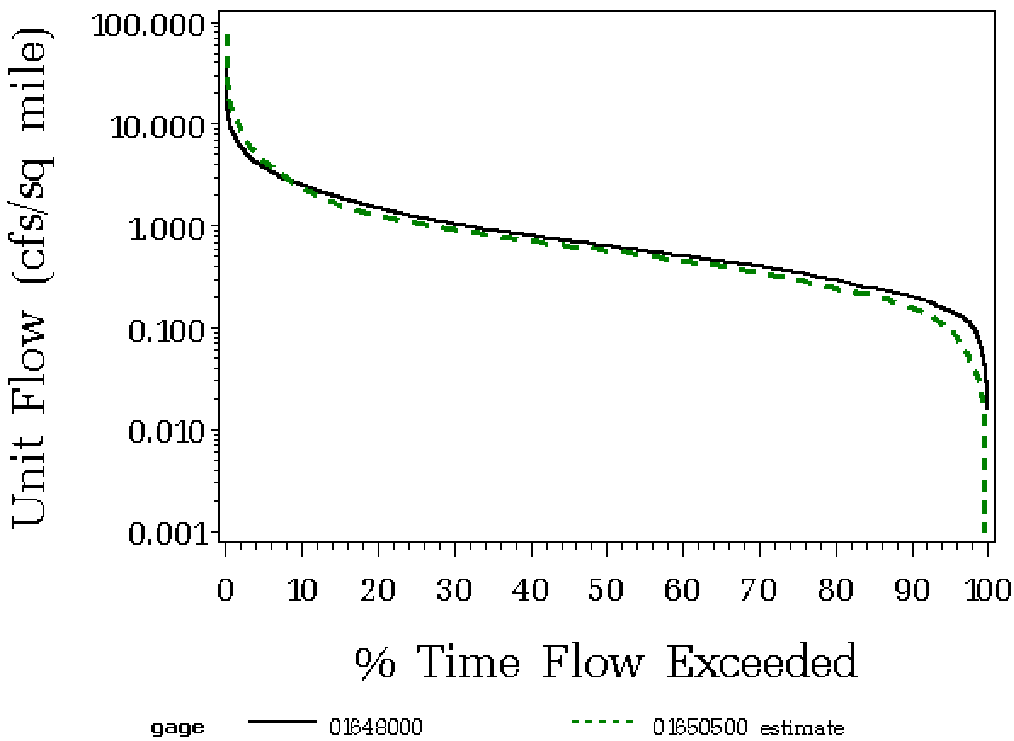

Figure B-1: Rock Creek Flow Duration Curves

The separation of high flow and low flow was based on the analysis of flow data for the referenced USGS gauges located in the Rock Creek and the Anacostia River watersheds. The hydrograph separation technique is equivalent to the sliding interval technique use in the USGS HYSEP program (USGS, 1996) and the interval is based on the duration of surface runoff estimated from Linsley et al. (1982) and Pettyjohn and Henning (1979). Following hydrograph separation, the percent of surface runoff vs. the daily flow duration interval is plotted and a non-parametric smoothing method (LOESS) was used to identify general patterns.

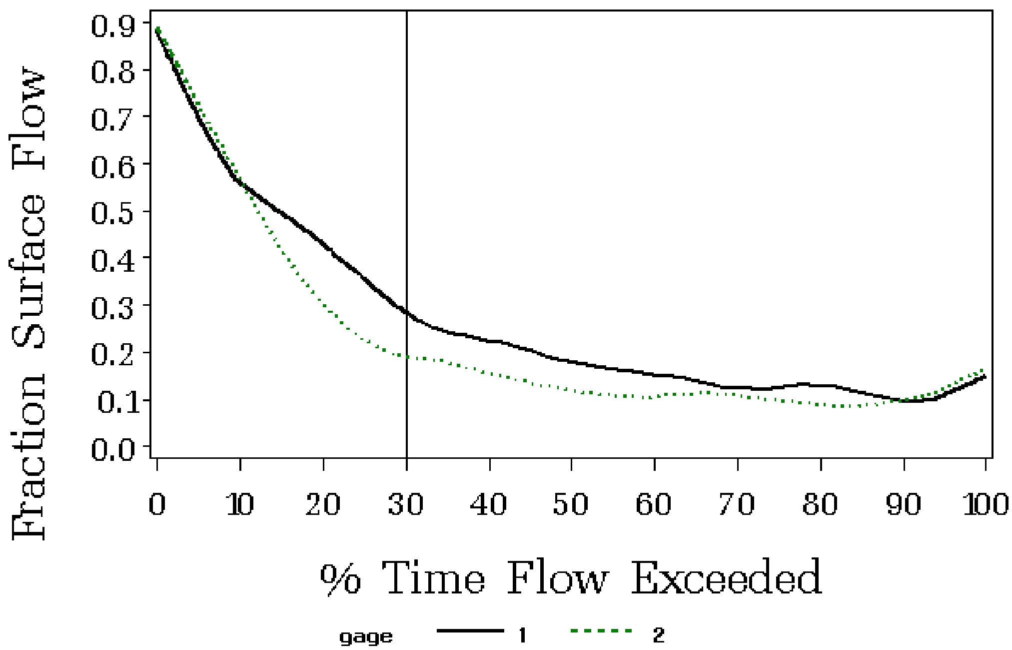

Figure B-2: Rock Creek: LOESS Smoothing of Hydrograph Separation

These patterns are illustrated in Figure B-2. From this figure it can be seen that a significant change in slope occurs at approximately the 30 percent daily flow interval for the gauge located at Rock Creek (01648000) of the Rock Creek watershed. The predominant inflection point for the station located on the upstream section of the Northwest Branch of the Anacostia River (01650500) occurs near the 25th percentile. For consistency among the stations, the inflection point was based on the station with the most monitoring data, station 01648000 (Rock Creek).

It was observed that no significant change in slope or mean fraction of surface runoff occurs in the Rock Creek below the 30 percent daily flow interval and that this area is representative of a region of significant and increasing surface flow contribution to the stream. Above the 30th percentile, a small change of slope was observed at the 90th percentile, however, given the similarity in the mean fraction of surface flow for the 30 – 100 percentile stratum, an additional stratum was not defined. Therefore, the 30th percentile threshold was used to define the limits between high flow and low flows as appropriate. Using these thresholds, definitions of high and low range flows are presented in Table B-2.

Table B-2: Definition of Flow Regimes

High flow	Represents conditions where stream flow tends to be dominated by surface runoff.
Low flow	Represents conditions where stream flow tends to be more dominated by groundwater flow.

Flow-Data Analysis

The final analysis to define the daily flow duration intervals (flow regions, strata) includes the bacteria monitoring data. Bacteria (Enterococci or *E. coli*) monitoring data are “placed” within the regions (stratum) based on the daily flow duration percentile of the date of sampling. Figures B-3 to B-5 show the Rock Creek Enterococci monitoring data with corresponding flow frequency for the annual average and the seasonal conditions.

Maryland’s water quality standards for bacteria state that a steady-state geometric mean will be calculated with available data where there are at least five representative sampling events. The data shall be from samples collected during steady state conditions and during the beach season (Memorial Day through Labor Day) to be representative of the critical condition. If fewer than five representative sampling events for an area being assessed are available, data from the previous two years will be evaluated. In Rock Creek, there are sufficient samples in both the high and low flow strata to estimate the geometric means.

Weighting factors for estimating a weighted geometric mean are based on the frequency of each flow stratum during the averaging period. The weighting factors for the averaging periods and hydrological conditions are presented in Table B-3. Averaging periods are defined in this report as:

(1) Annual Average Hydrological Condition
(2) Annual High Flow Condition
(3) Annual Low Flow Condition
(4) Seasonal (May 1st – September 30th) High Flow Condition
(5) Seasonal (May 1st – September 30th) Low Flow Condition
(6) 30-day High Flow Condition
(7) 30-day Low Flow Condition

Weighted geometric means for the average annual and the seasonal conditions are plotted with the monitoring data on Figures B-3 to B-8.

Table B-3: Weighting Factors for Estimation of Geometric Mean

Condition	Regime	Subwatershed	Weighting Factor High Flow	Weighting Factor Low Flow
Annual	Average Flow	NBR0002us; RCM0235us	0.30	0.70
		RCM0111sub	0.30	0.70
	High Flow	NBR0002us; RCM0235us	0.55	0.45
		RCM0111sub	0.58	0.42
	Low Flow	NBR0002us; RCM0235us	0.07	0.93
		RCM0111sub	0.10	0.90
Season	High Flow	NBR0002us; RCM0235us	0.51	0.49
		RCM0111sub	0.62	0.38
	Low Flow	NBR0002us; RCM0235up	0.09	0.91
		RCM0111sub	0.10	0.90
30-day	High Flow	NBR0002us; RCM0235us	1.00	0.00
		RCM0111sub	1.00	0.00
	Low Flow	NBR0002us; RCM0235us	0.00	1.00
		RCM0111sub	0.00	1.00

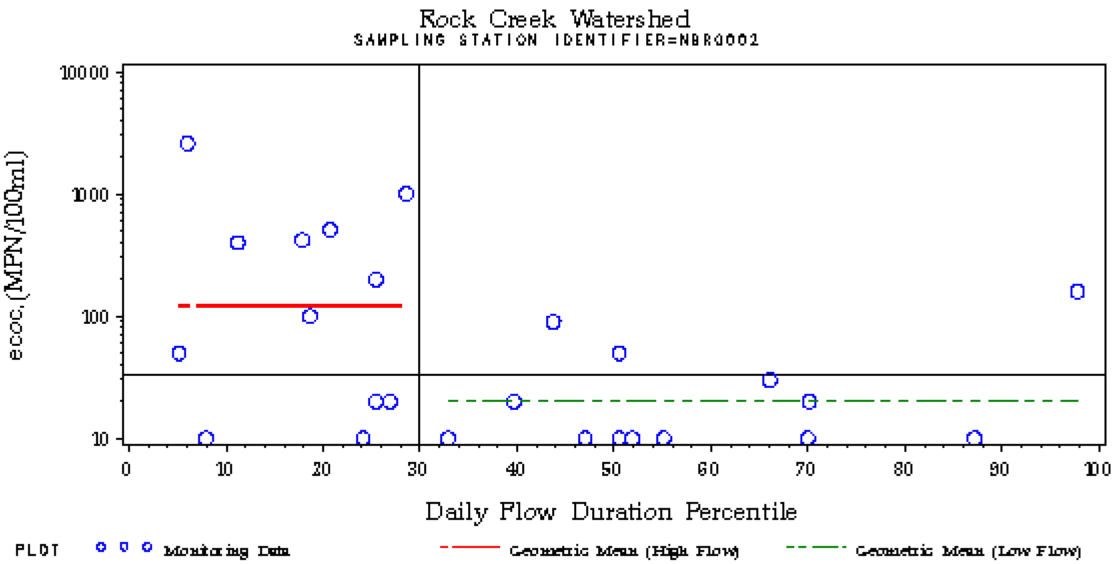

Figure B-3: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station NBR0002 (Average Annual Condition)

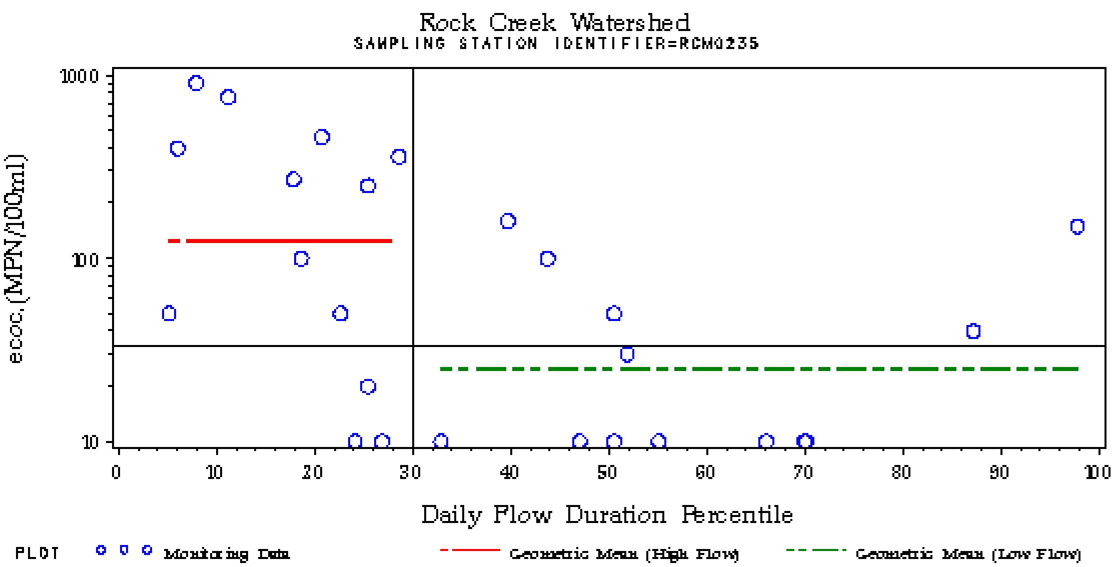

Figure B-4: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0235 (Average Annual Condition)

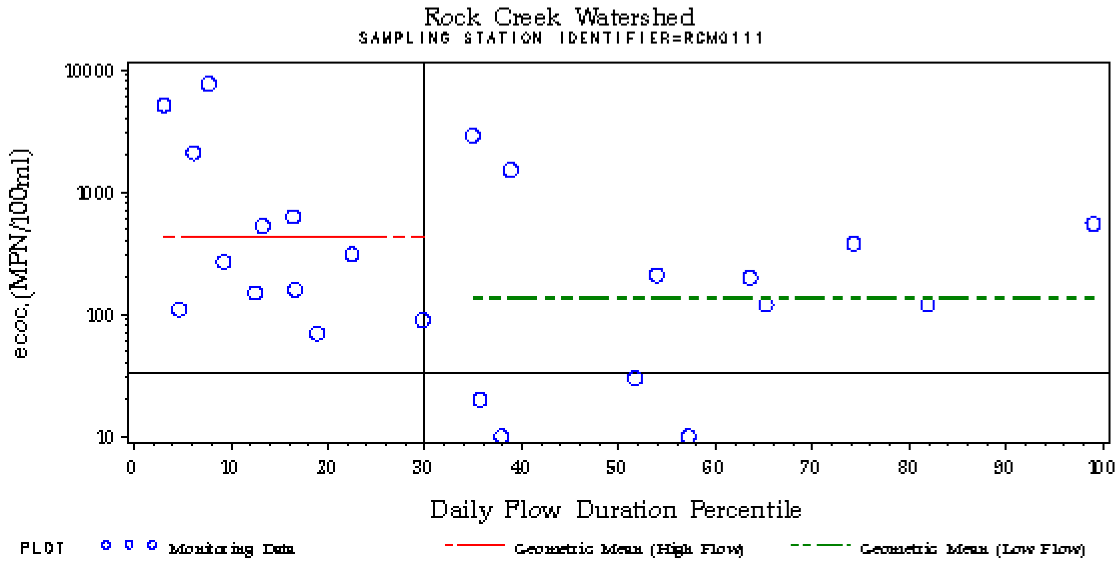

Figure B-5: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0111 (Average Annual Condition)

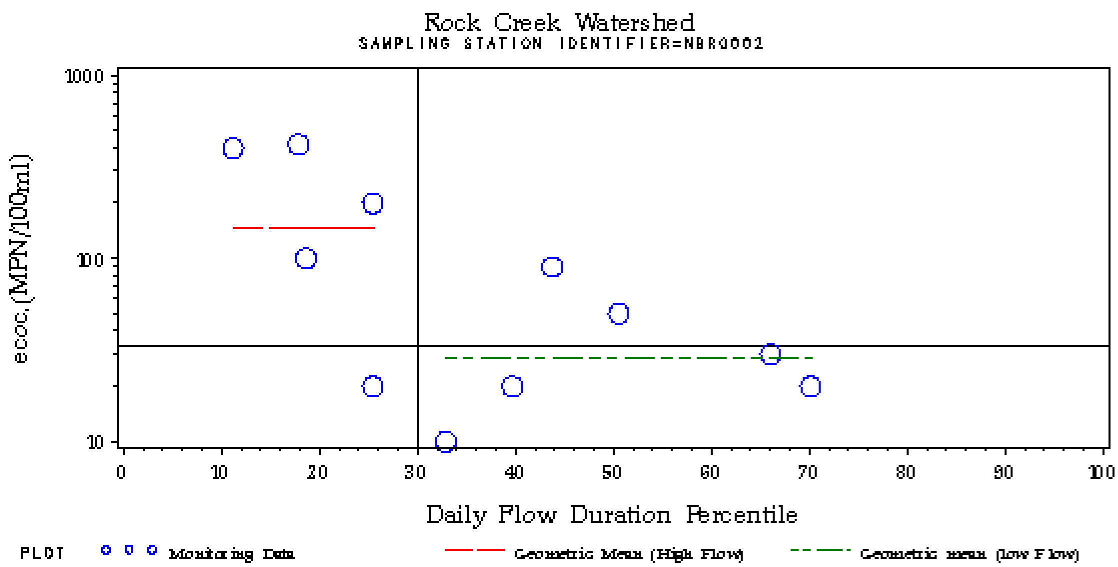

Figure B-6: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station NBR0002 (Seasonal Condition)

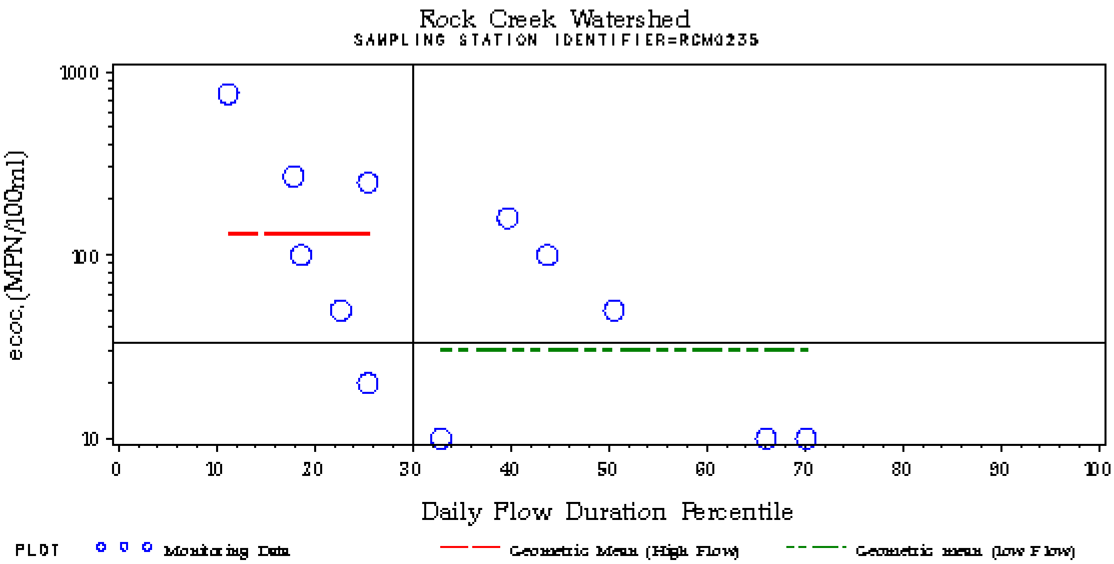

Figure B-7: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0235 (Seasonal Condition)

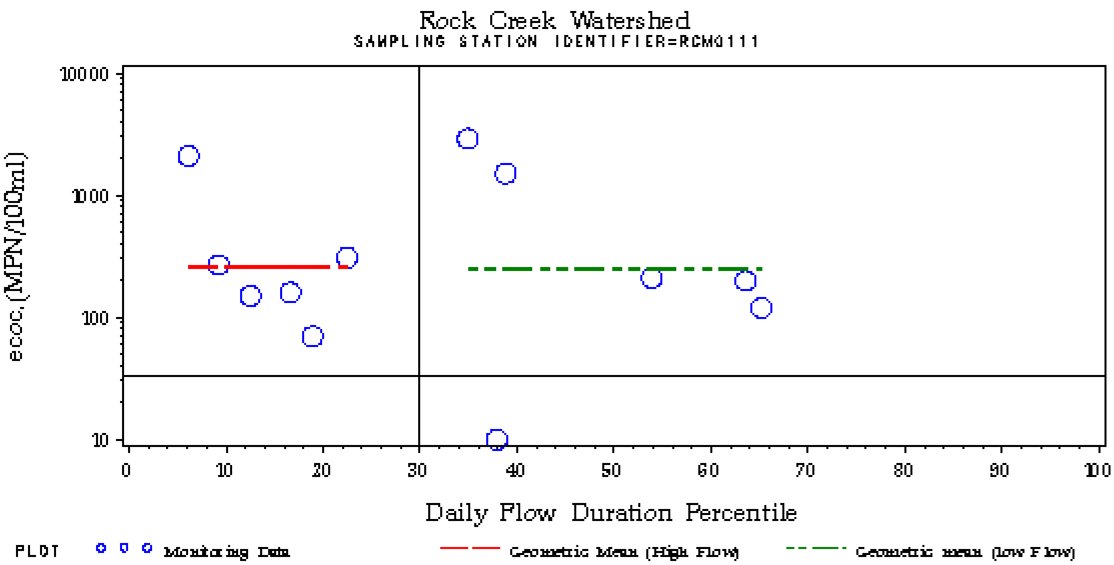

Figure B-8: Enterococci Concentration vs. Flow Duration for Rock Creek Monitoring Station RCM0111 (Seasonal Condition)

Appendix C – Rock Creek River Bacterial Source Tracking

Probable Sources of Enterococci Contamination
November 2002 – October 2003

Identifying Sources of Fecal Pollution in the
Rock Creek Watershed, Maryland

Mark F. Frana, Ph.D. and Elichia A. Venso, Ph.D.
Department of Biological Sciences and Environmental Health Science
Salisbury University, Salisbury, MD

May 17, 2005

INTRODUCTION

Microbial Source Tracking. Microbial Source Tracking (MST) is a relatively recent scientific and technological innovation designed to distinguish the origins of enteric microorganisms found in environmental waters. Several different methods and a variety of different indicator organisms (both bacteria and viruses) have successfully been used for MST, as described in recent reviews (Scott et al., 2002; Simpson et al., 2002). When the indicator organism is bacteria, the term Bacterial Source Tracking (BST) is often used. Some common bacterial indicators for BST analysis include: *E. coli*, *Enterococcus* spp., Bacteroides-Prevotella, and Bifidobacterium spp.

Techniques for MST can be grouped into one of the following three categories: molecular (genotypic) methods, biochemical (phenotypic) methods, or chemical methods. Ribotyping, Pulsed-Field Gel Electrophoresis (PFGE), and Randomly-Amplified Polymorphic DNA (RAPD) are examples of molecular techniques. Biochemical methods include Antibiotic Resistance Analysis (ARA), F-specific coliphage typing, and Carbon Source Utilization (CSU) analysis. Chemical techniques detect chemical compounds associated with human activities, but do not provide any information regarding nonhuman sources. Examples of this type of technology include detection of optical brighteners from laundry detergents or caffeine (Simpson et al., 2002).

Many of the molecular and biochemical methods of MST are "library-based," requiring the collection of a database of fingerprints or patterns obtained from indicator organisms isolated from known sources. Statistical analysis determines fingerprints/patterns of known-source species or categories of species (*i.e.*, human, livestock, pets, wildlife). Indicator isolates collected from water samples are analyzed using the same MST method to obtain their fingerprints or patterns, which are then statistically compared to those in the library. Based upon this comparison, the final results are expressed in terms of the "statistical probability" that the water isolates came from a given source (Simpson et al. 2002).
In this BST study of the Rock Creek Watershed, we used the ARA method with *Enterococcus* spp. as the indicator organism. Previous BST publications have demonstrated the predictive value of using this particular technique and indicator organism (Hagedorn, 1999; Wiggins, 1999).

Antibiotic Resistance Analysis. A variety of different host species can potentially contribute to the fecal contamination found in natural waters. Many years ago, scientists speculated on the possibility of using resistance to antibiotics as a way of determining the sources of this fecal contamination (Bell et al., 1983; Krumperman, 1983). In ARA, the premise is that bacteria isolated from different hosts can be discriminated based upon differences in the selective pressure of microbial populations found in the gastrointestinal tract of those hosts (humans, livestock, pets, wildlife) (Wiggins, 1996). Microorganisms isolated from the fecal material of wildlife would be expected to have a much lower level of resistance to antibiotics than isolates collected from the fecal material of humans, livestock and pets. In addition, depending upon the specific antibiotics used in the analysis, isolates from humans, livestock and pets could be differentiated from each other.

In ARA, isolates from known sources are tested for resistance or sensitivity against a panel of antibiotics and antibiotic concentrations. This information is then used to construct a library of antibiotic resistance patterns from known-source bacterial isolates. Microbial isolates collected from water samples are then tested and their resistance results are recorded. Based upon a comparison of resistance patterns of water and library isolates, a statistical analysis can predict the likely host source of the water isolates. (Hagedorn 1999; Wiggins 1999).

LABORATORY METHODS

Isolation of Enterococci from Known-Source Samples. Fecal samples, identified to source, were delivered to the Salisbury University (SU) BST lab by Maryland Department of the Environment (MDE) personnel. Fecal material suspended in phosphate buffered saline was plated onto selective m-*Enterococcus* agar. After incubation at 37o C, up to 10 Enterococci isolates were randomly selected from each fecal sample for ARA testing.

Isolation of Enterococci from Water Samples. Water samples were collected by MDE staff and shipped overnight to MapTech Inc, Blacksburg, Va. Bacterial isolates were collected by membrane filtration. Up to 24 randomly selected Enterococci isolates were collected from each water sample and all isolates were then shipped to the SU BST lab.

Antibiotic Resistance Analysis. Each bacterial isolate from both water and scat were grown in Enterococcosel® broth (Becton Dickinson, Sparks, MD) prior to ARA testing. Enterococci are capable of hydrolyzing esculin, turning this broth black. Only esculin-positive isolates were tested for antibiotic resistance.

Bacterial isolates were plated onto tryptic soy agar plates, each containing a different concentration of a given antibiotic. Plates were incubated overnight at 37o C and isolates then scored for growth (resistance) or no growth (sensitivity). Data consisting of a “1” for resistance or “0” for sensitivity for each isolate at each concentration of each antibiotic was then entered into a spread-sheet for statistical analysis.

The following includes the antibiotics and concentrations used for isolates in the Rock Creek Watershed analysis.

Table C-1: Antibiotics and concentrations used for ARA.

Antibiotic	Concentration ($\mu g\ ml^{-1}$)
Amoxicillin	0.625
Cephalothin	10, 15, 30, 50
Chloramphenicol	1, 2.5, 5, 10
Chlortetracycline	60, 80, 100
Erythromycin	10, 15, 30, 50
Gentamycin	5, 10, 15, 20
Neomycin	40, 60, 80
Oxytetracycline	20, 40, 60, 80, 100
Salinomycin	1, 2.5, 5, 10
Streptomycin	40, 60, 80, 100
Tetracycline	10, 15, 30, 50, 100
Vancomycin	2.5

KNOWN-SOURCE LIBRARY

Construction and Use. Fecal samples (scat) from known sources in the watershed were collected during the study period by MDE personnel and delivered to the BST Laboratory at SU. Enterococci isolates were obtained from known sources, which included human, dog, horse, deer, rabbit, fox, raccoon, opossum, and birds, including goose. A library of patterns of *Enterococcus* isolate responses to the panel of antibiotics was analyzed using the statistical software CART® (Salford Systems, San Diego, CA). The library consisted of response patterns of 774 *Enterococcus* isolates from the Rock Creek Watershed. The Rock Creek watershed isolate library was not paired with another watershed after examination of possible library combinations (Figure C-1). The classification models in Figure C-1 show the percent correct classification of isolates for various combinations of libraries versus the percent unknown (unclassified) isolates for those combinations. The watersheds in those models were Rock Creek (RC), Anacostia (Ana), Cabin John (CJ), and Piscataway (Pis). “All Inland” was the combination of all four, RC, Ana, CJ, and Pis.

Enterococci isolate response patterns were also obtained from bacteria in water samples collected at the three (3) monitoring stations in the Rock Creek basin. Using statistical techniques, these patterns were then compared to those in the combined library to identify the probable source of each water isolate.

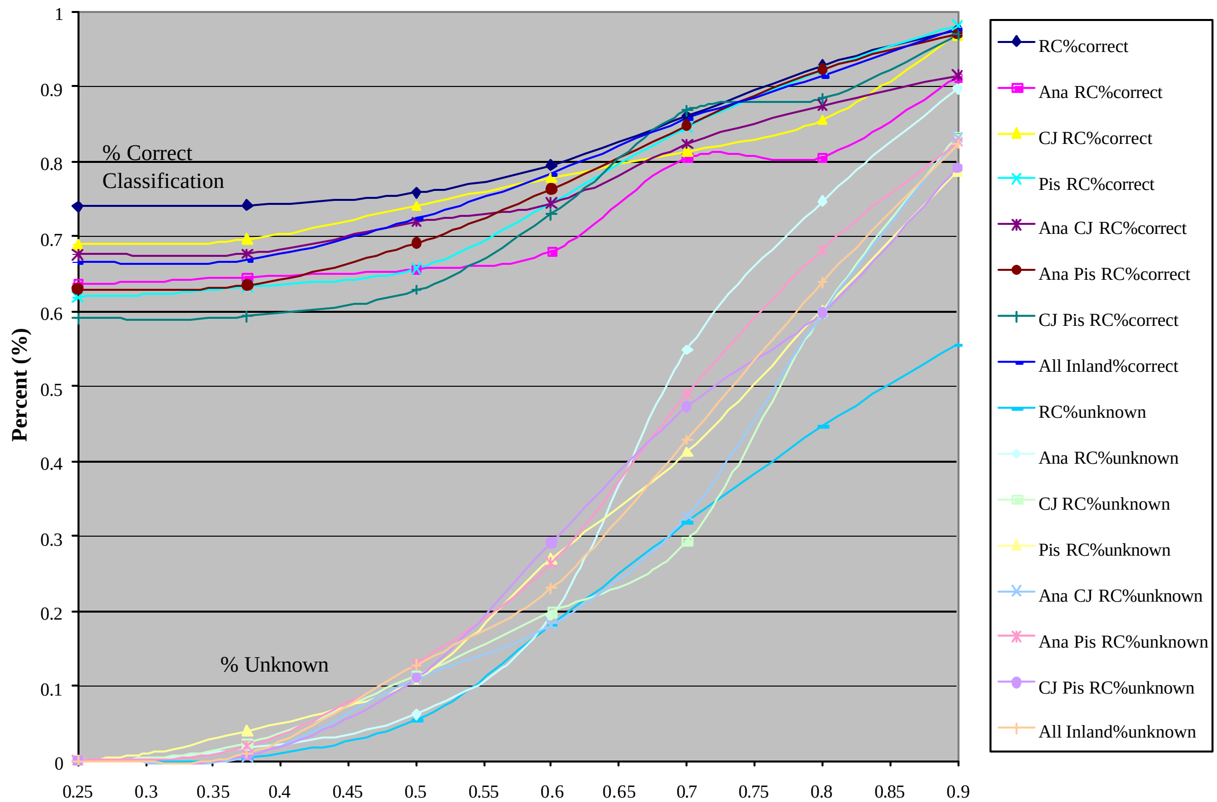

Figure C-1: Classification models for determination of composition of known-source library for identification of Rock Creek water isolates.

STATISTICAL ANALYSIS

We applied a tree classification method, [1]CART®, to build a model that classifies isolates into source categories based on ARA data. CART® builds a classification tree by recursively splitting the library of isolates into two nodes. Each split is determined by the antibiotic variables (antibiotic resistance measured for a collection of antibiotics at varying concentrations). The first step in the tree-building process splits the library into two nodes by considering every binary split associated with every variable. The split is chosen that maximizes a specified index of homogeneity for isolate sources within each of the nodes. In subsequent steps, the same process is applied to each resulting node until a *stopping* criterion is satisfied. Nodes where an additional split would lead to only an insignificant increase in the *homogeneity* index relative to the *stopping* criterion are referred to as *terminal* nodes.[2] The collection of *terminal* nodes defines the classification model. Each *terminal* node is associated with one source, the source that is most populous among the library isolates in the node. Each water sample isolate (*i.e.*, an

[2] An ideal split, *i.e.*, a split that achieves the theoretical maximum for homogeneity, would produce two nodes each containing library isolates from only one source.

isolate with an unknown source), based on its antibiotic resistance pattern, is identified with one specific *terminal* node and is assigned the source of the majority of library isolates in that *terminal* node.[3]

We imposed an additional requirement in our classification method for determining the sources of water sample isolates. We interpreted the proportion of the majority source among the library isolates in a *terminal* node as a probability. This proportion is an estimate of the probability that an isolate with unknown source, but with the same antibiotic resistance pattern as the library isolates in the *terminal* node, came from the source of the majority of the library isolates in the *terminal* node. If that probability was less than a specified *acceptable source identification probability*, we did not assign a source to the water sample isolates identified with that *terminal* node. Instead we assigned "Unknown" as the source for that node and "Unknown" for the source of all water sample isolates identified with that node. For the Rock Creek Watershed tree-classification model, *the acceptable source identification probability* was set at 0.50 (50%).

RESULTS: LIBRARY

Known-Source Library. The known-source isolates in the Rock Creek Watershed known-source library were grouped into four categories: pet (specifically dog), human, livestock, and wildlife (Table C-2).

Table C-2: Category, total number of isolates and of unique isolate patterns in the Rock Creek known-source library.

Category	Total Isolates	Unique Patterns
Pet	52	24
Human	56	38
Livestock	167	76
Wildlife	499	237
Total	774	375

The library was analyzed for its ability to take a subset of the library isolates and correctly predict the identity of their host sources when they were treated as unknowns. Average rates of correct classification (ARCC) for the combined library were found by repeating this analysis using several probability cutoff points, as described above. From these results, the percent unknown and percent correct classification (ARCC) was calculated (Table C-3).

[3] The CART® tree-classification method we employed includes various features to ensure the development of an optimal classification model. For brevity in exposition, we have chosen not to present details of those features, but suggest the following sources: Breiman L, *et al. Classification and Regression Trees*. Pacific Grove: Wadsworth, 1984; and Steinberg D and Colla P. *CART—Classification and Regression Trees*. San Diego, CA: Salford Systems, 1997.

Table C-3: Percent unknown and percent correct for seven (7) cutoff probabilities for the Rock Creek Watershed used to identify probable sources of Rock Creek water isolates.

Cutoff Probability	(ARCC) Percent Unknown	Percent Correct
0.25	0.0%	74.0%
0.375	0.4%	74.2%
0.50	5.4%	75.8%
0.60	18.1%	79.5%
0.70	31.8%	86.0%
0.80	74.7%	92.8%
0.90	89.7%	97.7%

A cutoff probability of 0.50 (50%) was shown to yield an acceptable ARCC of 76%. The percent correct using no cutoff was 74%. Using a cutoff probability of 0.50 (50%), the library isolates that were not classified and thus were unknown were removed. The library containing the remaining isolates was then used to test the ability of the library to correctly predict the known-source isolates obtained from the Rock Creek Watershed. The rates of correction classification for the four categories of sources in Rock Creek known-source isolate library are shown in Table C-4 below. The library was then used in the statistical prediction of probable sources of bacteria in water samples collected from Rock Creek.

Table C-4: Actual source categories versus predicted categories of Rock Creek known-source isolate library, with total number of unknown isolates, total isolates, total classified, and rates of correct classification (RCC) for each category.

	Predicted ?							
Actual ?	Pet	Human	Livestock	Wildlife	Unknown	Total	Total Classified	RCC[1]
Pet	**42**	0	3	0	7	52	45	93%
Human	2	**48**	1	0	5	56	51	94%
Livestock	2	1	**134**	17	13	167	154	87%
Wildlife	35	39	77	**331**	17	499	482	69%
Sum	80	88	215	348	42	774	732	

[1]RCC = Number of correctly predicted species category / Total number classified (predicted).
Example: One hundred seven (42) Pet correctly predicted / 45 total number classified for Pet = 42/45 = 93% RCC.

RESULTS: WATER

Rock Creek Watershed Water Samples. Monthly monitoring from the Rock Creek monitoring stations was the source of water samples. If weather conditions prevented sampling at a station, a second collection(s) in a later month was performed. The maximum number of Enterococci isolates per water sample was 24, although the number of isolates that actually grew was sometimes fewer than 24. A total of 691 Enterococci isolates were analyzed by statistical analysis. The BST results by category, Table C-5 below shows the number of isolates and percent isolates classified at the 0.50 (50%) cutoff probability, as well as the percent classified overall.

Table C-5: Probable host sources of water isolates by category, number of isolates, percent isolates classified at cutoff probabilities of 50%

Category	No.	% Isolates Classified 50% Prob.
Pet	119	17.2%
Human	68	9.8%
Livestock	195	28.2%
Wildlife	253	36.6%
Unknown	56	8.1%
Missing Data	0	
Total w/ Complete Data	691	
Total	691	
% Classified		91.9%

The relative contributions of probable sources of Enterococci contamination in the watershed is shown below in Figure C-2.

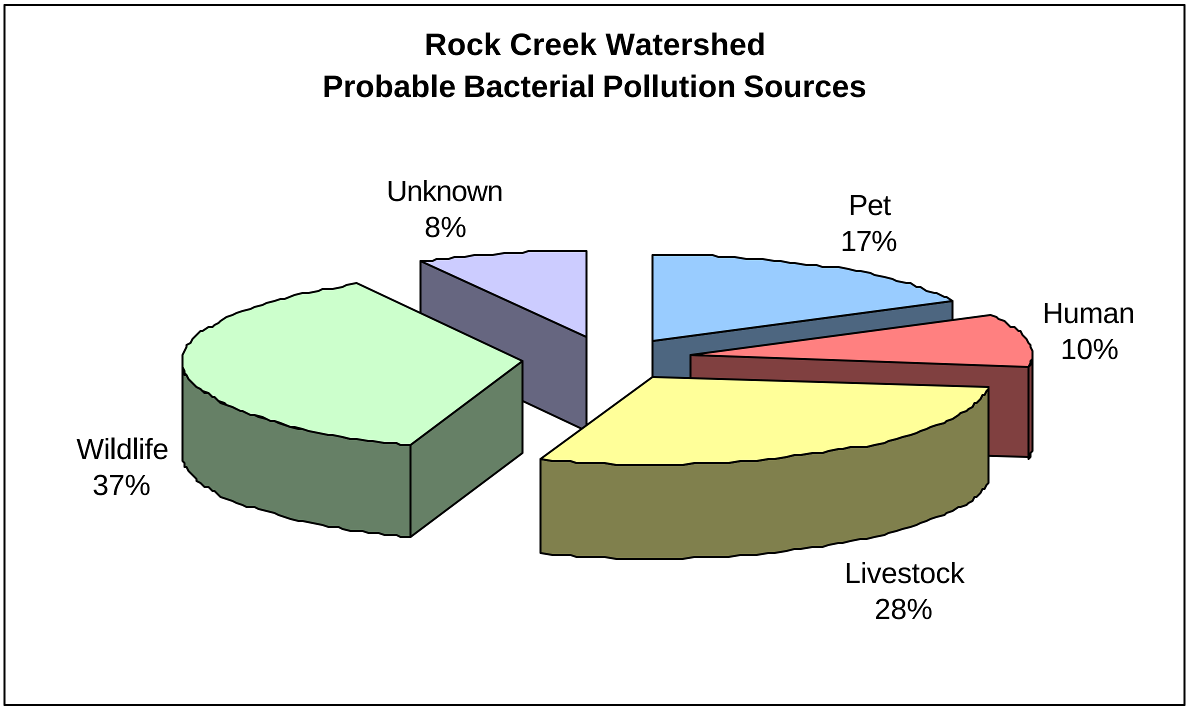

Figure C-2: Rock Creek Watershed relative contributions by probable sources of Enterococci contamination.

The seasonal distribution of water isolates from samples collected at each sampling station is shown below on Table C-6.

Table C-6: Enterococci isolates from water collected and analyzed during the fall, winter, spring, and summer seasons for Rock Creek monitoring stations.

Station	Fall	Winter	Spring	Summer	Total
RCM0111	87	44	72	70	273
RCM0235	61	28	52	70	211
NBR0002	91	18	29	69	207
Total	239	90	153	209	691

Tables C-7 through C-11 on the following pages show the results of BST analysis from the estimation of number of isolates per station per date to the final estimation of the overall percentage of bacteria sources by subwatershed.

Table C-7: BST Analysis - Number of Isolates per Station per Date

Station	date	domestic animals	human	livestock	wildlife	unknown
NBR0002	11/18/2002	1	0	15	7	1
NBR0002	12/02/2002	4	2	7	7	0
NBR0002	01/06/2003	3	3	7	9	2
NBR0002	03/03/2003	9	2	2	4	1
NBR0002	04/21/2003	0	1	0	2	0
NBR0002	05/05/2003	0	0	1	1	0
NBR0002	06/02/2003	2	12	9	1	0
NBR0002	07/07/2003	1	1	7	8	7
NBR0002	08/04/2003	3	4	7	9	0
NBR0002	09/08/2003	0	0	10	10	2
NBR0002	10/06/2003	3	1	5	11	2
RCM0111	11/18/2002	4	1	3	10	2
RCM0111	12/02/2002	11	0	9	4	0
RCM0111	01/06/2003	9	0	7	6	2
RCM0111	02/03/2003	1	1	8	8	2
RCM0111	03/03/2003	13	0	0	11	0
RCM0111	04/21/2003	7	2	1	7	7
RCM0111	05/05/2003	2	3	10	8	1
RCM0111	06/02/2003	4	1	6	10	3
RCM0111	07/07/2003	2	7	6	6	3
RCM0111	08/04/2003	4	5	8	6	1
RCM0111	09/08/2003	0	2	7	11	2
RCM0111	10/06/2003	0	1	11	5	2
RCM0235	11/18/2002	1	1	9	7	1
RCM0235	12/02/2002	6	0	5	2	0
RCM0235	01/06/2003	6	2	1	15	0
RCM0235	02/03/2003	0	0	0	5	0
RCM0235	03/03/2003	14	1	1	7	0
RCM0235	04/21/2003	1	0	7	12	1
RCM0235	05/05/2003	0	2	1	3	1
RCM0235	06/02/2003	5	1	8	9	1
RCM0235	07/07/2003	1	10	4	3	6

Station	date	domestic animals	human	livestock	wildlife	unknown
RCM0235	08/04/2003	0	0	6	13	5
RCM0235	09/08/2003	2	1	4	15	0
RCM0235	10/06/2003	0	1	2	1	1

Table C-8: Percentage of Sources per Station per Date

Station	date	% domestic animals	% human	% livestock	% wildlife	% unknown
NBR0002	11/18/2002	4.1667	0.0000	62.5000	29.167	4.1667
NBR0002	12/02/2002	20.0000	10.0000	35.0000	35.000	0.0000
NBR0002	01/06/2003	12.5000	12.5000	29.1667	37.500	8.3333
NBR0002	03/03/2003	50.0000	11.1111	11.1111	22.222	5.5556
NBR0002	04/21/2003	0.0000	33.3333	0.0000	66.667	0.0000
NBR0002	05/05/2003	0.0000	0.0000	50.0000	50.000	0.0000
NBR0002	06/02/2003	8.3333	50.0000	37.5000	4.167	0.0000
NBR0002	07/07/2003	4.1667	4.1667	29.1667	33.333	29.1667
NBR0002	08/04/2003	13.0435	17.3913	30.4348	39.130	0.0000
NBR0002	09/08/2003	0.0000	0.0000	45.4545	45.455	9.0909
NBR0002	10/06/2003	13.6364	4.5455	22.7273	50.000	9.0909
RCM0111	11/18/2002	20.0000	5.0000	15.0000	50.000	10.0000
RCM0111	12/02/2002	45.8333	0.0000	37.5000	16.667	0.0000
RCM0111	01/06/2003	37.5000	0.0000	29.1667	25.000	8.3333
RCM0111	02/03/2003	5.0000	5.0000	40.0000	40.000	10.0000
RCM0111	03/03/2003	54.1667	0.0000	0.0000	45.833	0.0000
RCM0111	04/21/2003	29.1667	8.3333	4.1667	29.167	29.1667
RCM0111	05/05/2003	8.3333	12.5000	41.6667	33.333	4.1667
RCM0111	06/02/2003	16.6667	4.1667	25.0000	41.667	12.5000
RCM0111	07/07/2003	8.3333	29.1667	25.0000	25.000	12.5000
RCM0111	08/04/2003	16.6667	20.8333	33.3333	25.000	4.1667
RCM0111	09/08/2003	0.0000	9.0909	31.8182	50.000	9.0909
RCM0111	10/06/2003	0.0000	5.2632	57.8947	26.316	10.5263
RCM0235	11/18/2002	5.2632	5.2632	47.3684	36.842	5.2632
RCM0235	12/02/2002	46.1538	0.0000	38.4615	15.385	0.0000

Station	date	% domestic animals	% human	% livestock	% wildlife	% unknown
RCM0235	01/06/2003	25.0000	8.3333	4.1667	62.500	0.0000
RCM0235	02/03/2003	0.0000	0.0000	0.0000	100.000	0.0000
RCM0235	03/03/2003	60.8696	4.3478	4.3478	30.435	0.0000
RCM0235	04/21/2003	4.7619	0.0000	33.3333	57.143	4.7619
RCM0235	05/05/2003	0.0000	28.5714	14.2857	42.857	14.2857
RCM0235	06/02/2003	20.8333	4.1667	33.3333	37.500	4.1667
RCM0235	07/07/2003	4.1667	41.6667	16.6667	12.500	25.0000
RCM0235	08/04/2003	0.0000	0.0000	25.0000	54.167	20.8333
RCM0235	09/08/2003	9.0909	4.5455	18.1818	68.182	0.0000
RCM0235	10/06/2003	0.0000	20.0000	40.0000	20.000	20.0000

Table C-9: Enterococci Concentration and Percentage of Sources by Stratum (Annual Period)

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	flow regime (1=high/2=low)	Enterococci conc MPN/100ml	log mean conc.	% domestic animals	% human	% livestock	% wildlife	% unknown
NBR0002	10/07/2002	2	160	2.20412	.	.	.	.	.
NBR0002	10/21/2002	2	10	1.00000	.	.	.	.	.
NBR0002	11/06/2002	1	10	1.00000	.	.	.	.	.
NBR0002	11/18/2002	1	2600	3.41497	4.1667	0.0000	62.5000	29.167	4.1667
NBR0002	12/02/2002	2	10	1.00000	20.0000	10.0000	35.0000	35.000	0.0000
NBR0002	12/16/2002	1	1010	3.00432	.	.	.	.	.
NBR0002	01/06/2003	1	510	2.70757	12.5000	12.5000	29.1667	37.500	8.3333
NBR0002	01/21/2003	2	10	1.00000	.	.	.	.	.
NBR0002	02/03/2003	2	10	1.00000	.	.	.	.	.
NBR0002	03/03/2003	1	50	1.69897	50.0000	11.1111	11.1111	22.222	5.5556
NBR0002	03/17/2003	1	10	1.00000	.	.	.	.	.
NBR0002	04/21/2003	1	20	1.30103	0.0000	33.3333	0.0000	66.667	0.0000
NBR0002	05/05/2003	2	10	1.00000	0.0000	0.0000	50.0000	50.000	0.0000
NBR0002	05/19/2003	1	420	2.62325	.	.	.	.	.
NBR0002	06/02/2003	1	200	2.30103	8.3333	50.0000	37.5000	4.167	0.0000
NBR0002	06/16/2003	1	20	1.30103	.	.	.	.	.
NBR0002	06/23/2003	1	100	2.00000	.	.	.	.	.
NBR0002	07/07/2003	1	400	2.60206	4.1667	4.1667	29.1667	33.333	29.1667
NBR0002	07/21/2003	2	50	1.69897	.	.	.	.	.
NBR0002	08/04/2003	2	20	1.30103	13.0435	17.3913	30.4348	39.130	0.0000
NBR0002	08/18/2003	2	90	1.95424	.	.	.	.	.
NBR0002	08/25/2003	2	20	1.30103	.	.	.	.	.
NBR0002	09/08/2003	2	30	1.47712	0.0000	0.0000	45.4545	45.455	9.0909
NBR0002	10/06/2003	2	10	1.00000	13.6364	4.5455	22.7273	50.000	9.0909
NBR0002	10/20/2003	2	10	1.00000	.	.	.	.	.
RCM0111	10/07/2002	2	550	2.74036	.	.	.	.	.
RCM0111	10/21/2002	2	120	2.07918	.	.	.	.	.
RCM0111	11/06/2002	1	7700	3.88649	.	.	.	.	.
RCM0111	11/18/2002	1	5170	3.71349	20.0000	5.0000	15.0000	50.000	10.0000
RCM0111	12/02/2002	2	380	2.57978	45.8333	0.0000	37.5000	16.667	0.0000

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	flow regime (1=high/2=low)	Enterococci conc MPN/100ml	log mean conc.	% domestic animals	% human	% livestock	% wildlife	% unknown
RCM0111	12/16/2002	1	630	2.79934	.	.	.	.	.
RCM0111	01/06/2003	1	530	2.72428	37.5000	0.0000	29.1667	25.000	8.3333
RCM0111	01/21/2003	2	10	1.00000	.	.	.	.	.
RCM0111	02/03/2003	2	30	1.47712	5.0000	5.0000	40.0000	40.000	10.0000
RCM0111	03/03/2003	1	110	2.04139	54.1667	0.0000	0.0000	45.833	0.0000
RCM0111	03/17/2003	1	90	1.95424	.	.	.	.	.
RCM0111	04/21/2003	2	20	1.30103	29.1667	8.3333	4.1667	29.167	29.1667
RCM0111	05/05/2003	2	10	1.00000	8.3333	12.5000	41.6667	33.333	4.1667
RCM0111	05/19/2003	1	310	2.49136	.	.	.	.	.
RCM0111	06/02/2003	1	70	1.84510	16.6667	4.1667	25.0000	41.667	12.5000
RCM0111	06/16/2003	1	160	2.20412	.	.	.	.	.
RCM0111	06/23/2003	1	270	2.43136	.	.	.	.	.
RCM0111	07/07/2003	1	2100	3.32222	8.3333	29.1667	25.0000	25.000	12.5000
RCM0111	07/21/2003	2	210	2.32222	.	.	.	.	.
RCM0111	08/04/2003	2	1520	3.18184	16.6667	20.8333	33.3333	25.000	4.1667
RCM0111	08/18/2003	2	2910	3.46389	.	.	.	.	.
RCM0111	08/25/2003	2	120	2.07918	.	.	.	.	.
RCM0111	09/08/2003	2	200	2.30103	0.0000	9.0909	31.8182	50.000	9.0909
RCM0111	09/22/2003	1	150	2.17609	.	.	.	.	.
RCM0111	10/06/2003	.	.	.	0.0000	5.2632	57.8947	26.316	10.5263
RCM0235	10/07/2002	2	150	2.17609	.	.	.	.	.
RCM0235	10/21/2002	2	40	1.60206	.	.	.	.	.
RCM0235	11/06/2002	1	910	2.95904	.	.	.	.	.
RCM0235	11/18/2002	1	400	2.60206	5.2632	5.2632	47.3684	36.842	5.2632
RCM0235	12/02/2002	2	10	1.00000	46.1538	0.0000	38.4615	15.385	0.0000
RCM0235	12/16/2002	1	360	2.55630	.	.	.	.	.
RCM0235	01/06/2003	1	460	2.66276	25.0000	8.3333	4.1667	62.500	0.0000
RCM0235	01/21/2003	2	10	1.00000	.	.	.	.	.
RCM0235	02/03/2003	2	10	1.00000	0.0000	0.0000	0.0000	100.000	0.0000
RCM0235	03/03/2003	1	50	1.69897	60.8696	4.3478	4.3478	30.435	0.0000
RCM0235	03/17/2003	1	10	1.00000	.	.	.	.	.
RCM0235	04/21/2003	1	10	1.00000	4.7619	0.0000	33.3333	57.143	4.7619
RCM0235	05/05/2003	2	10	1.00000	0.0000	28.5714	14.2857	42.857	14.2857

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	flow regime (1=high/2=low)	Enterococci conc MPN/100ml	log mean conc.	% domestic animals	% human	% livestock	% wildlife	% unknown
RCM0235	05/19/2003	1	270	2.43136	.	.	.	.	.
RCM0235	06/02/2003	1	250	2.39794	20.8333	4.1667	33.3333	37.500	4.1667
RCM0235	06/16/2003	1	20	1.30103	.	.	.	.	.
RCM0235	06/23/2003	1	100	2.00000	.	.	.	.	.
RCM0235	07/07/2003	1	760	2.88081	4.1667	41.6667	16.6667	12.500	25.0000
RCM0235	07/21/2003	2	50	1.69897	.	.	.	.	.
RCM0235	08/04/2003	2	160	2.20412	0.0000	0.0000	25.0000	54.167	20.8333
RCM0235	08/18/2003	2	100	2.00000	.	.	.	.	.
RCM0235	08/25/2003	2	10	1.00000	.	.	.	.	.
RCM0235	09/08/2003	2	10	1.00000	9.0909	4.5455	18.1818	68.182	0.0000
RCM0235	09/22/2003	1	50	1.69897	.	.	.	.	.
RCM0235	10/06/2003	2	10	1.00000	0.0000	20.0000	40.0000	20.000	20.0000
RCM0235	10/20/2003	2	30	1.47712	.	.	.	.	.

Table C-10: Percentage of Sources per Station by Stratum (Annual Period)

SAMPLING STATION IDENTIFIER	flow regime (1=high/2=low)	% domestic animals	% human	% livestock	% wildlife	% unknown
NBR0002	1	11.6244	15.8270	33.7572	30.0842	8.7072
NBR0002	2	8.7582	6.4332	37.1167	43.7946	3.8973
RCM0111	1	25.3137	9.0246	19.3708	37.1730	9.1180
RCM0111	2	18.9967	9.9600	32.2774	31.0755	7.6904
RCM0235	1	18.9089	13.0864	22.8820	37.5359	7.5868
RCM0235	2	7.6685	7.3731	23.0468	50.7784	11.1332

Table C-11: Overall Percentage of Sources per Station (Annual Period)

SAMPLING STATION IDENTIFIER	% domestic animals	% human	% livestock	% wildlife	% unknown	total
NBR0002	9.6181	9.25134	36.1088	39.6815	5.3403	100
RCM0111	20.8918	9.67936	28.4054	32.9047	8.1187	100
RCM0235	11.0406	9.08710	22.9974	46.8056	10.0693	100

SUMMARY

The use of ARA was successful for identification of probable bacterial sources in the Rock Creek Watershed as evidenced by the RCCs in the library (a range of from a usable 69% for wildlife to a high of 87% for livestock, 93% for pet, and 94% for human. When water isolates were compared to the library and probable sources predicted, 92% the water isolates were classified by statistical analysis. The largest category of probable sources in the watershed was wildlife (37%). Less than 10% of the water isolates were from unknown (unclassified) probable sources. The remaining probable sources included livestock (28%), pets (17%), and human (10%). Horses are found within Rock Creek Park, both at the police stables and for trail-riding within the park by the public. These horses may contribute to the probable sources due to livestock found in this urban watershed.

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Appendix D - Assigning Flow Frequency to Ungauged Watersheds

The Rock Creek Watershed has one USGS gauge within the watershed boundary downstream from station RCM0111 (01648000) (see Table D-1). One USGS gauge that is located in the Anacostia River (01650500) was also used because it best reflected the Rock Creek subwatersheds NBR0002 and RCM0235, based on land use, watershed size and proximity. As noted in Table D-1, USGS station 01650500 located in the Northwest Branch of the Anacostia near Colesville only has a partial record with the time series beginning on November 27, 1997 and ending on September 30, 2003. Therefore, this record was extended using the station with the highest cross correlation results, station 0165100 located downstream on Northwest Branch (DRAFT Anacostia River Bacteria TMDL, 2005).

Table D-1: USGS Gauges in the Rock Creek Watershed

USGS Gauge #	Dates used	Description
01648000	Oct 1, 1988 to Sep 30, 2003	
01650500	Nov 27, 1997 to Sep 30, 2003	
01650500 (estimate)	Oct 1, 1988 to Sep 30, 2003	Estimated flow based on USGS Gauge 0165100 using MOVE.1 (Hirsch, 1982)

To plot the bacteria monitoring data in a flow duration curve format, flow frequencies must be estimated for monitoring dates at these three stations. Typical methods for estimating flows at ungauged location include using regional regression equations or a drainage area ratio approach with a gauged basin.

Previous regression studies for predicting flows in Maryland are by Dillow (1995), Moglen et al. (2002) and Versar (2004). All of these studies identify that the most statistically significant watershed characteristic for predicting flow is the watershed area. Soil and landuse characteristics, when added to the equations, add some predictive power. Results from Versar (2004) indicated that the flow regression equations described more of the variability found in high flows than for low flows. Reis et al. (2000) provides a summary of recent literature and notes that when using the drainage area ratio approach, evidence suggests that the ratio of the ungauged basin to gauged basin should be between 0.33 and 3.0.

The cross correlation of daily flow frequency and daily flow rate were analyzed using an n-lag model. The purpose of this was to identify if two watersheds will have similar flows and frequencies for the same day. Results for three stations indicated the highest correlation occurred with the 0-lag model suggesting that daily flows and frequencies are similar for the same days. Results for the zero lag correlations are as follows:

Table D-2: Cross Correlation of Flow Frequency (0-log Model)

	01648000	01650500
01648000	1	
01650500	0.944	1

Using primarily watershed area ratio as the criterion, gauges were assigned as follows:

Table D-3: Bacteria Monitoring Stations and Reference Flow Gauges

Station	Watershed Area (sq. miles)	USGS Reference Gauge	USGS Gauge Area (sq. miles)	Area Ratio
NBR0002	12.4	1650500	21.1	0.59
RCM0235	16.8	1650500	21.1	0.80
RCM0111	29.6	1648000	62.2	0.48

A visual comparison among the USGS flow gauges is presented in Figure D-1. Note that the separation of the flow strata is added to identify potential misclassification of a sample. The four quadrants of the graph are defined and labels identify zones based on consistent and inconsistent placement of stations in flow strata between gauges. These figures support that the flow frequency between the two gauges, especially for bacteria sample dates, is very similar.

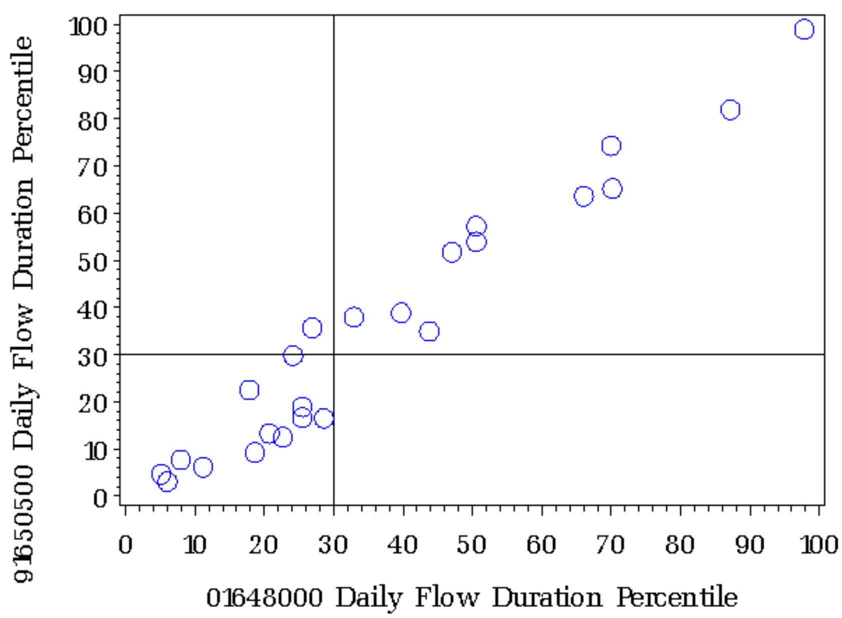

Figure D-1: Comparison of Flow Frequency Between 01648000and 01649500 for Rock Creek Bacteria Monitoring Dates

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