Total Maximum Daily Loads of Fecal Bacteria for the Lower Monocacy River Basin in Carroll, Frederick, and Montgomery Counties, Maryland

FINAL

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Submitted to:

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ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
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
CSS	Combined Sewer System
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
MACS	Maryland Agricultural Cost Share Program
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
MGD	Millions of Gallons per Day
ml	Milliliter(s)
MOS	Margin of Safety
MPN	Most Probable Number
MPR	Maximum Practicable Reduction
MS4	Municipal Separate Storm Sewer System
MST	Microbial Source Tracking
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
RCC	Rates of Correct Classification
RESAC	Mid-Atlantic Regional Earth Science Applications Center
SSO	Sanitary Sewer Overflows
STATSGO	State Soil Geographic Database
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
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 Lower Monocacy River watershed (basin number 02-14-03-02). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's 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, states are 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 Lower Monocacy River on the State of Maryland's 303(d) List as impaired by the following (years listed in parentheses): fecal coliform (2002), nutrients (1996), sediments (1996) and impacts to biological communities (2002, 2004, and 2006). Lake Linganore, an impoundment within the Lower Monocacy River basin, was listed for nutrients and sediments in 1996. The Lower Monocacy River, upstream of US Route-40, and its tributary Israel Creek have been designated as Use IV-P waterbodies (Recreational Trout Waters and Public Water Supply). Downstream of Route US-40, the Lower Monocacy River is designated as a Use I-P waterbody (Water Contact Recreation, Protection of Aquatic Life and Public Water Supply). Additional tributaries of the Lower Monocacy River--Carroll Creek, Rocky Fountain Run, Little Bennett Creek, Furnace Branch, Ballenger Creek and Bear Branch--are designated as Use III-P waterbodies (Nontidal Cold Water and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08P. This document proposes to establish a TMDL for fecal bacteria in the Lower Monocacy River that will allow for attainment of the beneficial use designation of primary contact recreation. The listings for nutrients, sediments, and impacts to biological communities will be addressed separately at a future date. Phosphorus and sediment TMDLs for Lake Linganore were approved by EPA on March 13, 2003 to address the nutrient and sediment listings. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered.

A separate fecal bacteria TMDL has been developed for the Upper Monocacy River watershed in another document, pending EPA approval. Because the Upper Monocacy flows into the Lower Monocacy, the Upper Monocacy River TMDL is accounted for herein as an upstream load allocation. Appendix E of this report provides further explanation of the upstream loads.

For this TMDL analysis, the Lower Monocacy River watershed has been divided into nine subwatersheds, which include the tributaries Carroll Creek, Israel Creek, Bush Creek, Ballenger Creek, Bennett Creek, and Linganore Creek (divided into two subwatersheds). The pollutant loads set forth in this document are for these nine subwatersheds. To establish baseline and allowable pollutant loads for this TMDL, a flow duration curve approach was employed, using flow strata estimated from United States Geological Survey (USGS) daily flow monitoring data and bacteria monitoring data. The sources of fecal bacteria are estimated at nine representative stations in the Lower Monocacy River 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 (agriculture-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. The TMDL for fecal bacteria entering the Lower Monocacy River is established after considering three different hydrological conditions: high flow and low flow annual conditions, and an average seasonal condition (the period between May 1st and September 30th when water contact recreation is more prevalent). This allowable load is reported in units of Most Probable Number (MPN)/day and represents a long-term load estimated over a variety of hydrological conditions.

Two scenarios were developed, with the first assessing if attainment of current water quality standards could be achieved by applying maximum practicable reductions (MPRs), and the second applying higher reductions than MPRs. 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 bacteria source categories. In eight of the nine subwatersheds, it was estimated that water quality standards could not be attained with MPRs. Thus, for these subwatersheds, the second scenario with higher maximum reductions was applied. One of the subwatersheds in Linganore Creek could achieve water quality standards with MPRs.

The fecal bacteria long-term annual average TMDL for the Lower Monocacy River watershed, including the Upper Monocacy River upstream load allocation (LA_{UM}), is 2,033,379 billion MPN *E. coli*/year. The TMDL allocation for the Lower Monocacy River MD 8-digit basin is 679,529 billion MPN *E. coli*/year, and represents a reduction of approximately 88.3 % from the baseline load of 5,783,325 billion MPN/year. The maximum daily load for the MD 8-digit basin is 14,048 billion MPN *E. coli*/day. The Lower Monocacy River MD 8-digit portion of the TMDL is distributed between a load allocation (LA_{LM}) for nonpoint sources and waste load allocations (WLA_{LM}) for point sources, including National Pollutant Elimination System (NPDES) wastewater treatment plants (WWTPs) and NPDES regulated stormwater discharges, including municipal separate storm sewer systems (MS4s).

The long-term annual average allocations are as follows: the LA_{LM} is 426,161 billion MPN *E. coli*/year. The WWTP WLA_{LM} is 57,327 billion MPN *E. coli*/year. The Stormwater WLA_{LM} is 196,041 billion MPN *E. coli*/year. In addition to these allocation categories, the TMDL includes an upstream load allocation (LA_{UM}) to account for the load from the Upper Monocacy River, equivalent to the Upper Monocacy River TMDL of 1,353,850 billion MPN *E. coli*/year. The margin of safety (MOS) has been incorporated using a conservative assumption by estimating the loading capacity of the stream based on a water quality endpoint concentration more stringent than the applicable MD water quality standard criterion. The *E. coli* water quality criterion concentration was reduced by 5%, from 126 MPN/100ml to 119.7 MPN/100ml.

The maximum daily loads for the Lower Monocacy MD 8-digit basin, estimated using predicted long-term annual average TMDL concentrations (after source controls), are allocated as follows:

the LA_{LM} is 8,471 billion MPN *E. coli*/day, the Stormwater WLA_{LM} is 5,088 billion MPN *E. coli*/day, and the WWTP WLA_{LM} is 488 billion MPN *E. coli*/day.

Once 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 reductions to be implemented in an iterative process that first addresses those sources with the largest impacts to water quality and creating the greatest risks to human health, with consideration given to ease 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 eight of the nine Lower Monocacy River subwatersheds, using the MPR scenario. MPRs may not be sufficient in subwatersheds where wildlife is a significant component or where very high reductions of fecal bacteria loads are required to meet water quality standards. In these cases, it is expected that the MPR scenario will be the first stage of TMDL implementation. Progress will be made through the iterative implementation process described above, and the situation will be reevaluated in the future.

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 Lower Monocacy River (basin number 02-14-03-02). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (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 waterbody can receive and still meet water quality standards.

TMDLs are established 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 the Lower Monocacy River in the State of Maryland's 303(d) List as impaired by the following (years listed in parentheses): fecal coliform (2002), nutrients (1996), sediments (1996) and impacts to biological communities (2002, 2004, and 2006). Lake Linganore, an impoundment within the Lower Monocacy River basin, was listed for nutrients and sediments in 1996. The Lower Monocacy River, upstream of US Route-40, and its tributary Israel Creek have been designated as Use IV-P waterbodies (Recreational Trout Waters and Public Water Supply). Downstream of Route US-40, the Lower Monocacy River is designated Use I-P waterbody (Water Contact Recreation, Protection of Aquatic Life and Public Water Supply). Additional tributaries of the Lower Monocacy River--Carroll Creek, Rocky Fountain Run, Little Bennett Creek, Furnace Branch, Ballenger Creek and Bear Branch--are designated as Use III-P waterbodies (Nontidal Cold Water and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08P. This document proposes to establish a TMDL for fecal bacteria in the Lower Monocacy River that will allow for attainment of the beneficial use designation of primary contact recreation. The listings for nutrients, sediments, and impacts to biological communities will be addressed separately at a future date. Phosphorus and sediment TMDLs for Lake Linganore were approved by the EPA on March 13, 2003 to address the nutrient and sediment listings. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered.

A separate fecal bacteria TMDL has been developed for the Upper Monocacy River watershed in another document, pending EPA approval. Because the Upper Monocacy flows into the Lower Monocacy, the Upper Monocacy River TMDL is accounted for herein as an upstream load allocation. Appendix E of this report provides further explanation of the upstream loads.

Fecal bacteria are microscopic single-celled organisms (primarily fecal coliform 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 (US EPA 1986).

In 1986, EPA published "Ambient Water Quality Criteria for Bacteria," in which 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 bacteria are a subgroup of total coliform bacteria and *E. coli* bacteria are a subgroup of fecal coliform bacteria. 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 demonstrated that fecal coliform showed less correlation to swimming-associated gastroenteritis than did either *E. coli* or enterococci.

Based on EPA's guidance (US 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 Lower Monocacy River TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Lower Monocacy River watershed is located in Carroll, Frederick, and Montgomery Counties in Maryland (MD) (Figure 2.1.1). The total drainage area of the Lower Monocacy River is approximately 314.2 square miles (201,104 acres). The city of Frederick, MD and several towns including Walkersville, Woodsboro, and Mount Airy are located in the basin. The Lower Monocacy River flows southward through Frederick, eventually emptying into the Middle Potomac River near the town of Dickerson.

There are several major tributaries comprising the Lower Monocacy River watershed: Israel Creek, Carroll Creek, Linganore Creek, Bush Creek, Bennett Creek, and Ballenger Creek. These branches are free-flowing (non-tidal) streams, and flow directly into the Lower Monocacy River.

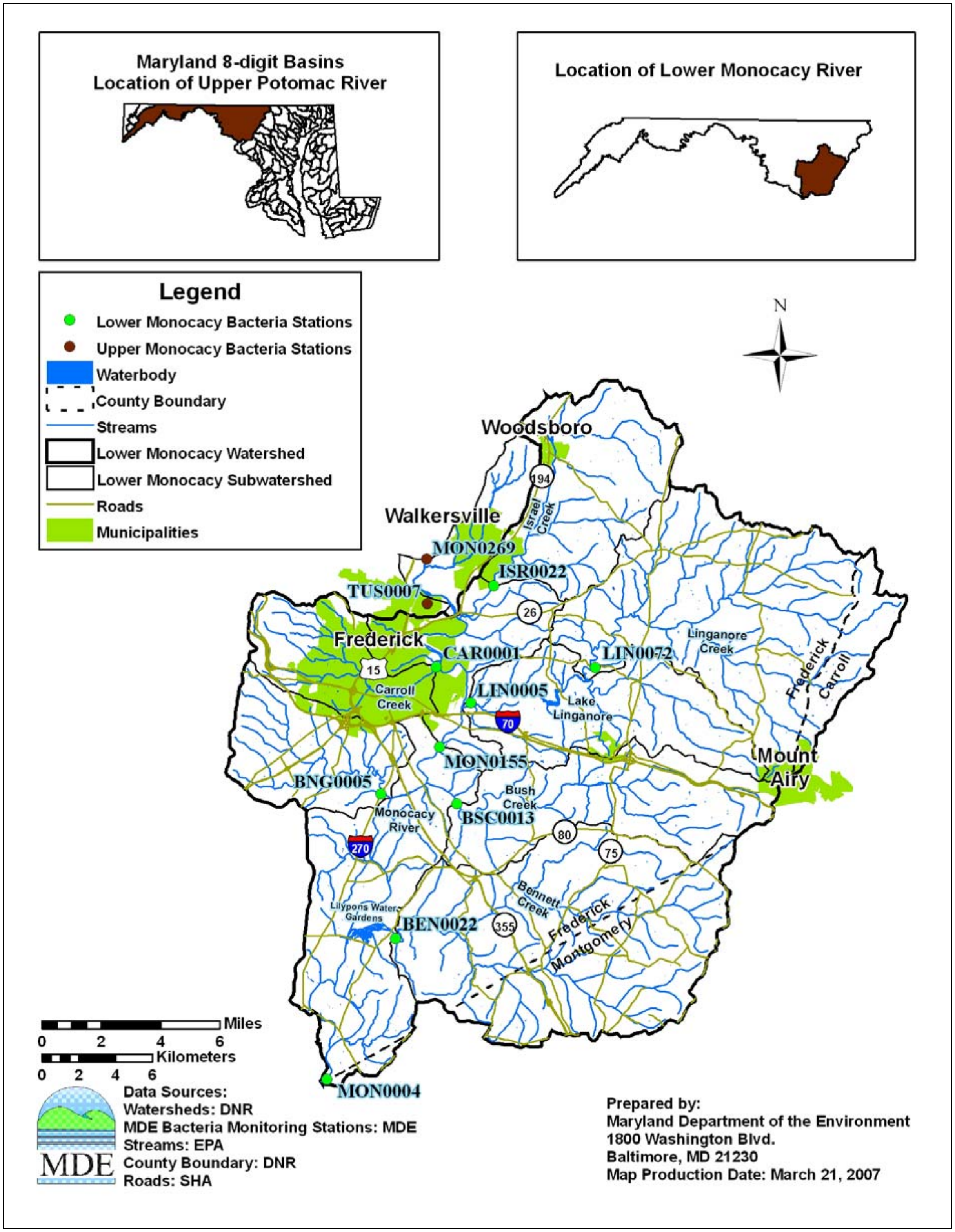

Figure 2.1.1: Location Map of the Lower Monocacy River Basin

Land Use

The 2002 Maryland Department of Planning (MDP) land use/land cover data show that cropland and pastureland account for over 45% of the watershed. The watershed is primarily rural with the exception of Frederick, MD and the smaller communities of Mount Airy, Walkersville, and Woodsboro, which account for the majority of commercial and residential land use.

The land use percentage distribution for the Lower Monocacy River Basin is shown in Table 2.1.1, and spatial distributions for each land use are shown in Figure 2.1.2.

Table 2.1.1: Land Use Percentage Distribution for the Lower Monocacy River Basin

Land Type	Acreage	Percentage
Commercial	10,534	5.2%
Crops	77,831	38.7%
Forest	59,149	29.4%
Pasture	17,616	8.8%
Residential	35,141	17.5%
Water	833	0.4%
Totals	**201,104**	**100%**

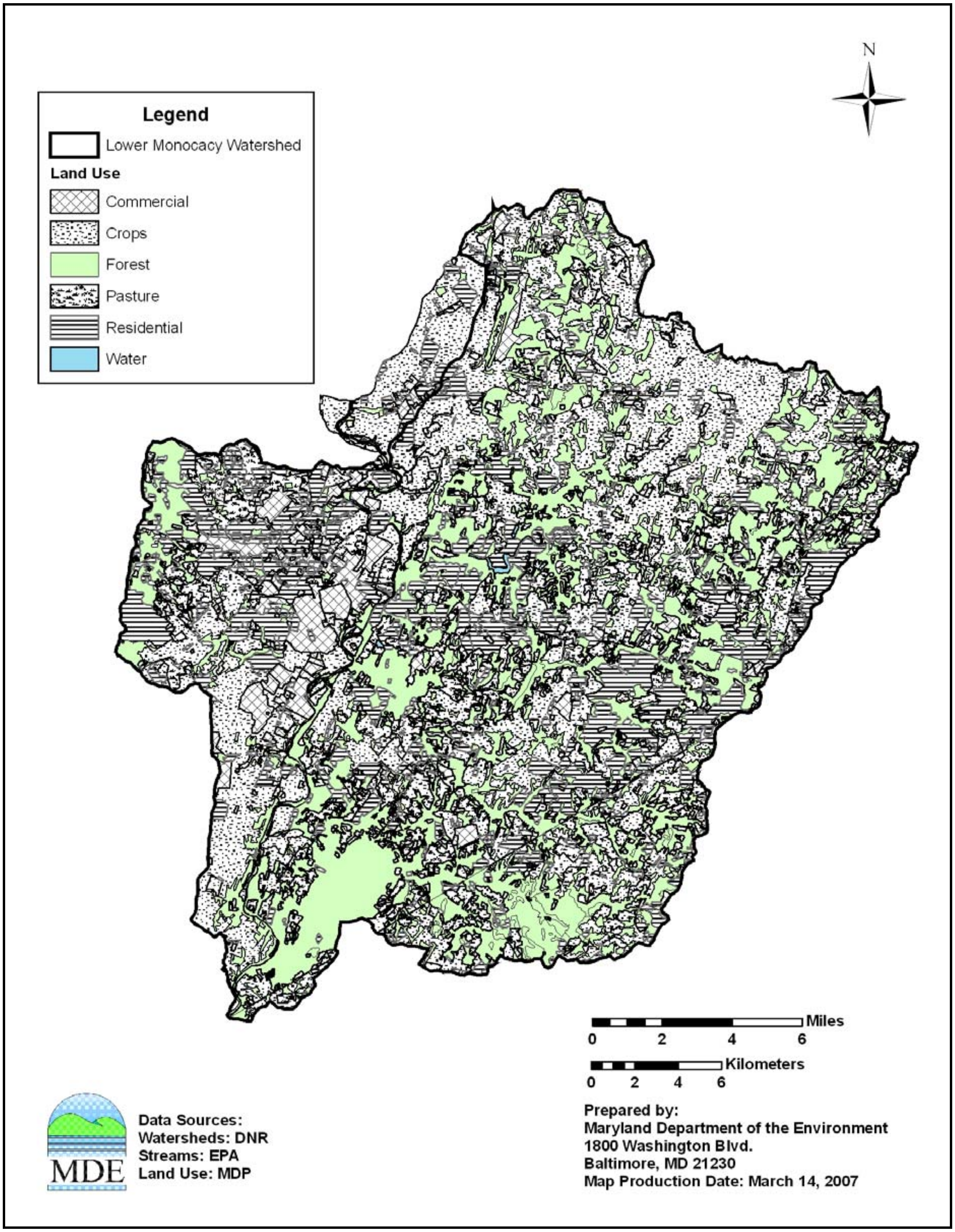

Figure 2.1.2: Land Use of the Lower Monocacy River Watershed

Population

The total population in the Lower Monocacy River watershed is estimated to be 136,079 people. Figure 2.1.3 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 Systems (GIS) 2000 U. S. Census Block and the MDP Land Use 2002 Cover. Since the Lower Monocacy River 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. Table 2.1.2 shows the number of dwellings per acre in the Lower Monocacy River watershed. The number of dwellings per acre was derived from information for residential density (low, medium, high) from the MDP land use cover and the Mid-Atlantic Regional Earth Science Applications Center (RESAC) land use cover.

Table 2.1.2: Number of Dwellings Per Acre

Land use Code	Dwelling Per Acres
Low Density Residential	1
Medium Density Residential	5
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 and RESAC, population per sub-watershed was estimated (see Table 2.1.3). Note that the subwatersheds are identified by the MDE monitoring stations located in the mainstem of the river and in the main tributaries. Monitoring stations are listed by flow from upstream to downstream.

Table 2.1.3: Total Population Per Subwatershed in the Lower Monocacy River Watershed

Station	Dwellings	Population
BEN0022	7,186	12,676
BNG0005	9,088	17,279
BSC0013	5,530	8,595
CAR0001	15,354	38,211
ISR0022	3,377	6,256
LIN0005	12,210	18,342
LIN0072	8,137	11,686
MON0004	2,058	2,953
MON0155	10,521	20,083
Total	**73,461**	**136,079**

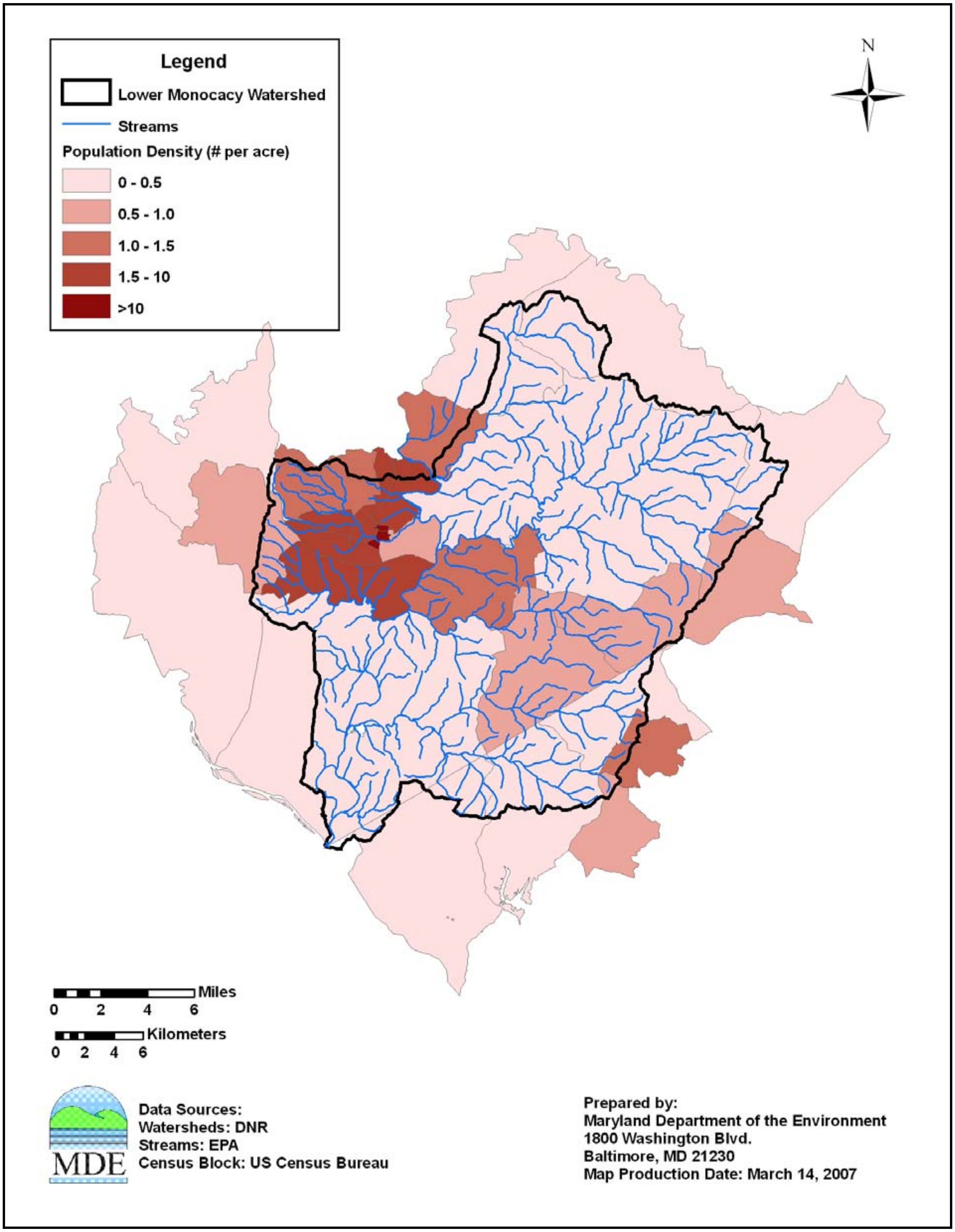

Figure 2.1.3: Population Density in the Lower Monocacy River Basin

2.2 Water Quality Characterization

EPA's guidance document, "Ambient Water Quality Criteria for Bacteria" (1986), recommended that states use *E. coli* (for fresh water) or enterococci (for fresh or salt water) as pathogen indicators. 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).

As per EPA's guidance, Maryland has adopted the new indicator organisms, *E. coli* and enterococci, for the protection of public health in Use I, II, and IV waters. These bacteria listings were originally assessed using fecal coliform bacteria. The analysis was based on a geometric mean of the monitoring data, where the result had to be less than or equal to 200 MPN/100ml. From EPA's analysis (US EPA 1986), this fecal coliform geometric mean target equates to an approximate risk of 8 illnesses per 1,000 swimmers at fresh water beaches and 19 illnesses per 1,000 swimmers at marine beaches (enterococci only), which is consistent with MDE's revised Use I bacteria criteria. Therefore, the original 303(d) List fecal coliform listings can be addressed using the refined bacteria indicator organisms to ensure that risk levels are acceptable.

Bacteria Monitoring

Table 2.2.1 lists the historical monitoring data for the Lower Monocacy River watershed. MDE conducted monitoring from November 2003 through November 2004. There are nine MDE monitoring stations in the Lower Monocacy River watershed. Two stations located in the Upper Monocacy River basin were included in this analysis in order to develop a TMDL for a portion of land not accounted for in the Upper Monocacy River basin TMDL. This area was included in one of the Lower Monocacy River subwatersheds. In addition to the bacteria monitoring stations, there are two United States Geological Survey (USGS) gauge stations used in deriving the surface flow in the Lower Monocacy River. The locations of these stations are shown in Tables 2.2.2 to 2.2.4 and in Figure 2.2.1. Observations recorded during the period 2003-2004 from the MDE monitoring stations are shown in Appendix A. A table listing the monitoring results from the Lower Monocacy River watershed appears in Appendix A.

Bacteria counts are highly variable and results are presented on a log scale for the seven monitoring stations for data collected for November 2003 through November 2004. Bacteria counts ranged between 10 and 11,200 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Lower Monocacy River Watershed

Sponsor	Location	Date	Design	Summary
Maryland Department of Natural Resources (DNR) Core Monitoring	MD	2/1/95 to 4/1/98	Fecal Coliform	MON0155: Monocacy River south of Frederick
MDE	MD	11/03 to 10/04	*E. coli*	9 stations; Enumeration 2x per month
MDE	MD	11/03 to 10/04	BST (*E. coli*)	9 stations; ARA/BST 1x per month

Table 2.2.2: Location of DNR (CORE) Monitoring Station in the Lower Monocacy River Watershed

Monitoring Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
MON0155	2/1/95 - 4/1/98	38	39.38788	-77.38110

Table 2.2.3: Locations of MDE Monitoring Stations in the Lower Monocacy River Watershed

Monitoring Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
BEN0022	2003-2004	24	39.294	-77.407
BNG0005	2003-2004	24	39.365	-77.416
BSC0013	2003-2004	23	39.360	-77.369
CAR0001	2003-2004	23	39.427	-77.382
ISR0022	2003-2004	23	39.467	-77.346
LIN0005	2003-2004	24	39.410	-77.360
LIN0072	2003-2004	24	39.427	-77.282
MON0004	2003-2004	23	39.225	-77.450
MON0155	2003-2004	24	39.386	-77.381
MON0269	2003-2004	24	39.480	-77.388
TUS0007	2003-2004	24	39.458	-77.388

Table 2.2.4: Locations of USGS Gauging Stations in the Lower Monocacy River Watershed

Monitoring Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
01643000	1998-2007	6701	39.403	-77.366
01643500	1998-2007	6689	39.294	-77.407

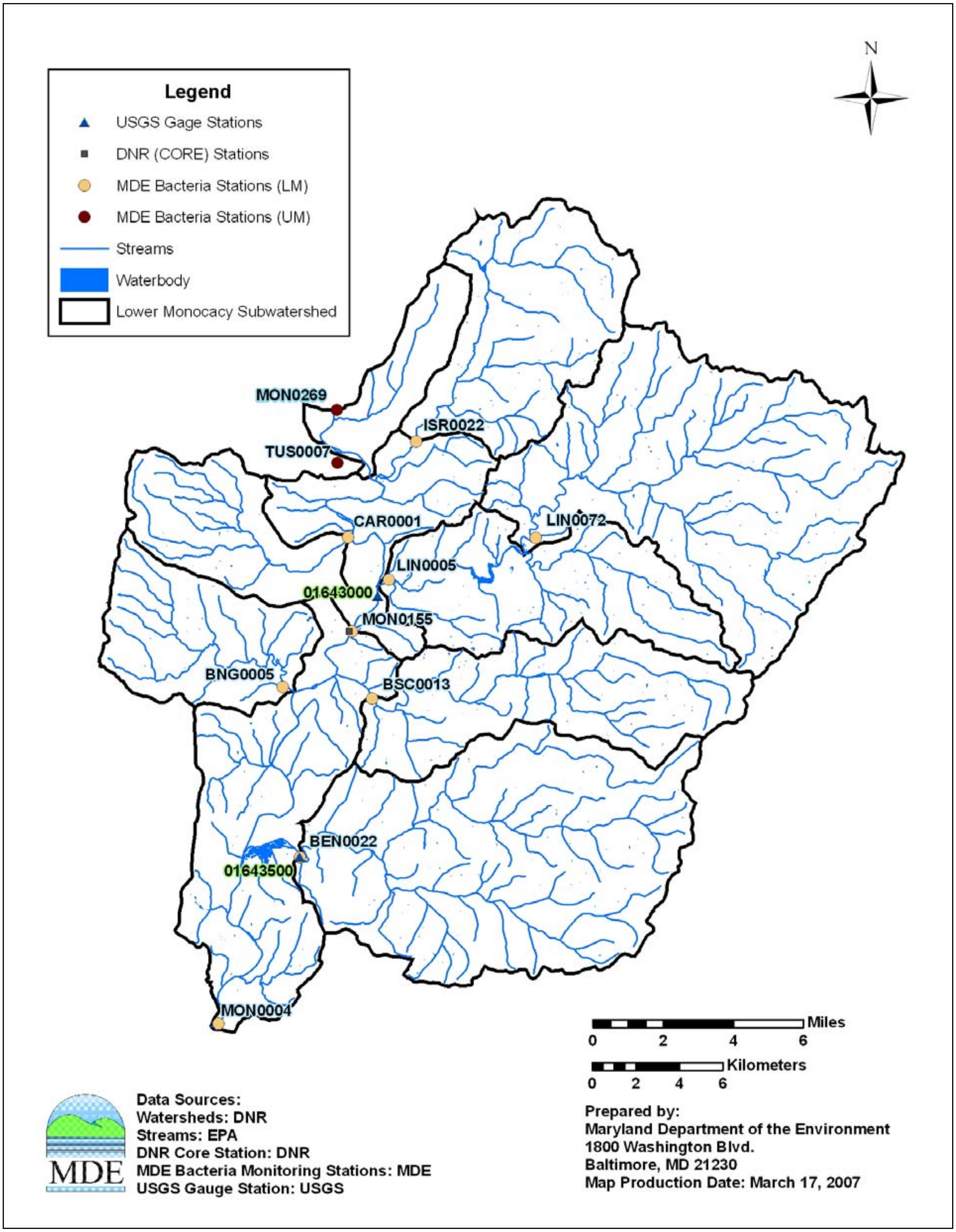

Figure 2.2.1: Monitoring Stations and Subwatersheds in the Lower Monocacy River Basin

2.3 Water Quality Impairment

Designated Uses and Water Quality Standard

The Maryland water quality standards Surface Water Use Designation for the Lower Monocacy River, upstream of US Route-40, and its tributary Israel Creek is Use IV-P (Recreational Trout Waters and Public Water Supply). Downstream of Route US-40, the Lower Monocacy River is designated as Use I-P (Water Contact Recreation, Protection of Aquatic Live and Public Water Supply). Its tributaries Carroll Creek, Rocky Fountain Run, Little Bennett Creek, Furnace Branch, Ballenger Creek, and Bear Branch are designated as Use III-P (Water Contact Recreation, Protection of Aquatic Life, Non-tidal Cold Water and Public Water Supply) (COMAR 26.08.02.08P). The Lower Monocacy River was listed in the State of Maryland's 303(d) List as impaired by fecal bacteria in 2002.

Water Quality Criteria

The State water quality standard for bacteria (*E. coli*) used in this study is as follows (COMAR 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/100 ml

Interpretation of Bacteria Data for General Recreational Use

The relevant portion (for freshwater) of the listing methodology pursuant to the 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 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 the resulting steady-state geometric mean is greater than 126 *E. coli* MPN/100 ml in freshwater, the waterbody will be listed as impaired. If fewer than five representative sampling events for an area being assessed are available, data from the previous two years will be evaluated in the same way. The single sample maximum criterion applies only to beaches and is to be used for closure and advisory decisions based on short term exceedances of the geometric mean portion of the standard.

Water Quality Assessment

Bacteria water quality impairment in the Lower Monocacy River was assessed by comparing both the annual and the seasonal (May 1st –September 30th) steady-state geometric means of *E. coli* concentrations with the water quality criterion. Graphs illustrating these results can be found in Appendix B.

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 without bias.

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.

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 Lower Monocacy River watershed. To estimate the steady-state geometric mean, the monitoring data were 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 mean 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.

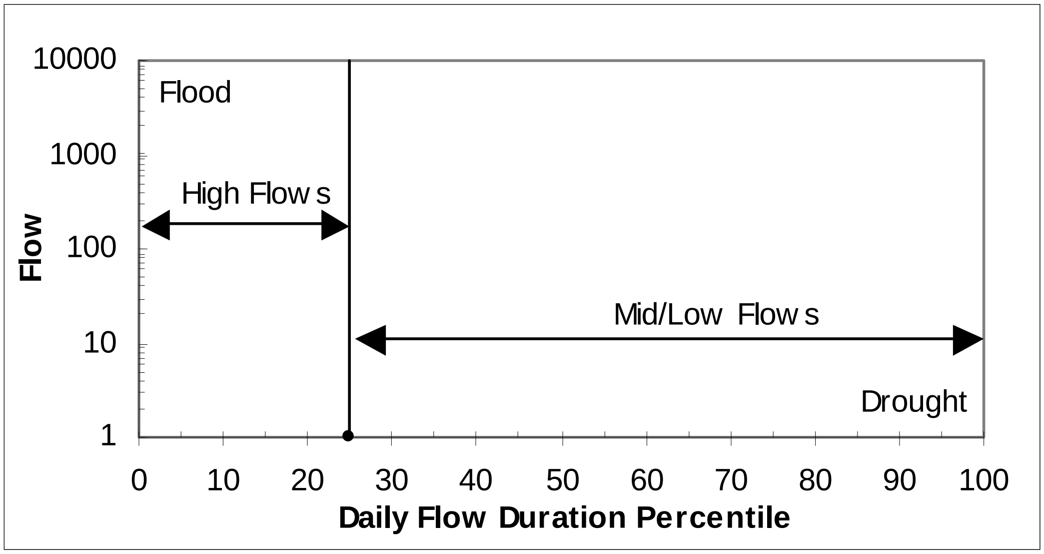

Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

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 mid flow period between the high and low flow durations, 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. Based on a flow analysis of several watersheds throughout Maryland, it was determined that flows within the 25^{th} to 30^{th} daily flow duration percentiles were representative of average daily flows. It is assumed for this analysis that flows higher than the 25^{th} percentile flow represent high flows, and flows lower than the 25^{th} percentile represent mid/low flows. A detailed method of how the flow strata were defined is 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 Lower Monocacy River TMDL analysis are presented in Table 2.3.2.

Table 2.3.2: Weighting Factors for Average Hydrology Year Used for Estimation of Geometric Means in the Lower Monocacy River Watershed

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 25%	0.25
Mid/Low Flows	25 – 100%	0.75

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

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

where

$$M_i = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})}{n_i} \qquad (2)$$

M = log weighted mean
M_i = log mean concentration for stratum i
W_i= Proportion of stratum i
$C_{i,j}$ = Concentration for sample j in stratum i
n_i = number of samples in stratum

Finally, the steady-state geometric mean concentration is estimated using the following equation:

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

C_{gm} = Steady-state geometric mean concentration

Tables 2.3.3 and 2.3.4 present the maximum and minimum concentrations and the geometric means by stratum, and the overall steady-state geometric mean for the Lower Monocacy River subwatersheds for the annual and the seasonal (May 1st –September 30th) periods. Monitoring stations are listed by flow from upstream to downstream. For the seasonal period, only one sample in each subwatershed fell in the high flow category; therefore, a geometric mean by flow stratum could not be calculated due to an insufficient number of samples. In the seasonal analysis, only the overall geometric mean was applied.

Table 2.3.3: Lower Monocacy River Annual Steady-State Geometric Means by Stratum per Subwatersheds

Station	Flow Stratum	# Samples	*E. coli* Minimum (MPN/100ml)	*E. coli* Maximum (MPN/100ml)	Annual Steady State Geometric Mean (MPN/100ml)	Annual Overall Geometric Mean (MPN/100ml)
BEN0022	**High**	12	20	1,400	206	163
	Low	12	10	700	150	
BNG0005	**High**	9	50	1,190	265	243
	Low	15	50	1,240	237	
BSC0013	**High**	8	50	2,140	640	310
	Low	15	40	930	244	
CAR0001	**High**	9	350	1,720	738	918
	Low	14	74	5,170	986	
ISR0022	**High**	9	130	2,280	445	959
	Low	14	20	11,200	1,238	
LIN0005	**High**	9	10	5,170	189	118
	Low	15	10	840	101	
LIN0072	**High**	9	190	3,260	846	644
	Low	15	60	2,040	587	
MON0004	**High**	8	30	1,580	319	143
	Low	15	10	880	110	
MON0155	**High**	9	30	1,380	378	184
	Low	15	10	830	144	

Table 2.3.4: Lower Monocacy River Seasonal (May 1st-September 30th) Period Steady-State Geometric Means by Stratum per Subwatersheds

Station	# Samples	*E. coli* Minimum (MPN/100ml)	*E. coli* Maximum (MPN/100ml)	Seasonal Overall Geometric Mean (MPN/100ml)
BEN0022	10	100	1,400	249
BNG0005	10	190	1,240	435
BSC0013	10	230	1,070	434
CAR0001	9	74	5,170	1,142
ISR0022	10	276	11,200	3,067
LIN0005	10	30	670	126
LIN0072	10	148	2,490	1,102
MON0004	10	30	1,580	223
MON0155	10	120	1,020	294

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. During rain events, surface runoff transports water and fecal bacteria over the land surface and discharges to the stream system. This transport is dictated by rainfall, soil type, land use, and topography of the watershed. 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. 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). The Lower Monocacy River watershed is covered by three National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) individual permits, which are technically point sources subject to waste load allocation (WLA_{LM}); therefore, nonpoint source contributions from domestic animal and human sources will be categorized as point sources and assigned to the Stormwater WLA_{LM}. The presence of agricultural land use is significant in the watershed, and sources associated with it (i.e., livestock) contribute to the load allocation (LA_{LM}) in this analysis. Wildlife contributions will be distributed between WLAs and LAs due to the presence of wildlife in both developed and undeveloped areas of the watershed.

Sewer Systems

The Lower Monocacy River watershed is serviced by both sewer systems and septic systems. Sewer systems are present in the city of Frederick and several towns including Mount Airy, Woodsboro, and Walkersville. Wastewater collected by these systems is treated at several Wastewater Treatment Plants (WWTPs) throughout the watershed. A list of these facilities is found in Table 2.4.2.

Septic Systems

On-site disposal (septic) systems are located throughout the Lower Monocacy River watershed. Table 2.4.1 presents the total households and the number of septic systems per subwatershed. Figure 2.4.1 depicts the areas that are serviced by sewers and septic systems.

Table 2.4.1: Septic Systems and Households Per Subwatershed in the Lower Monocacy River Watershed

Subwatershed Station	Septics Systems (units)	Households per Subwatershed
BEN0022	4,064	7,186
BNG0005	2,582	9,088
BSC0013	2,992	5,530
CAR0001	1,199	15,354
ISR0022	1,379	3,377
LIN0005	4,256	12,210
LIN0072	3,329	8,137
MON0004	1,117	2,058
MON0155	1,423	10,521
Total	**23,764**	**83,982**

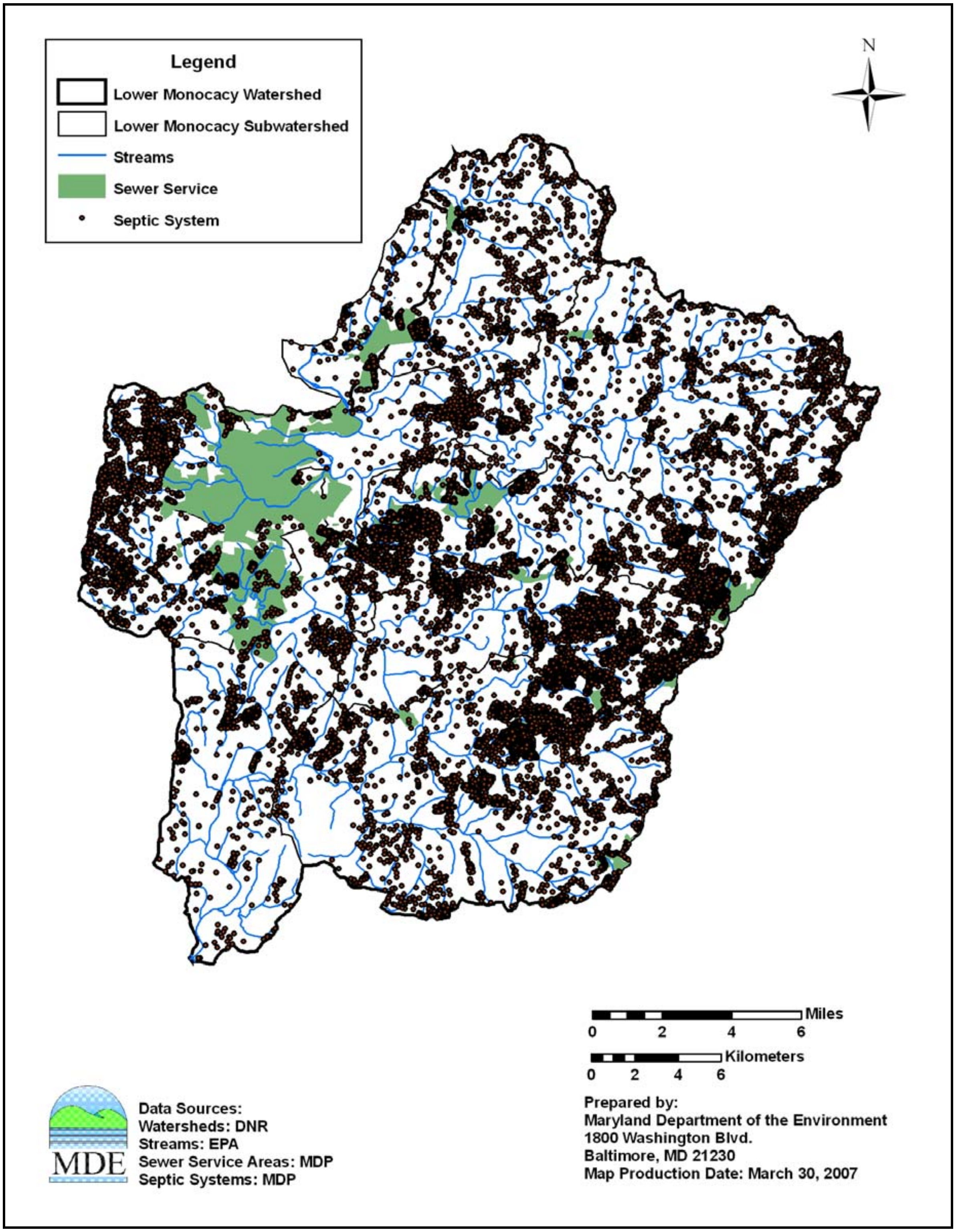

Figure 2.4.1: Sanitary Sewer Service Areas and Septics in the Lower Monocacy River Watershed

Point Source Assessment

There are two broad types of National Pollutant Discharge Elimination System (NPDES) permits considered in this analysis: individual and general. Both types of permits include industrial and municipal categories. Individual permits can include industrial and municipal WWTPs and Phase I municipal separate storm sewer systems (MS4s). MDE general permits have been established for surface water discharges that include: Phase II and other MS4 permits, surface coal mines, mineral mines, quarries, borrow pits, ready-mix concrete, asphalt plants, seafood processors, hydrostatic testing of tanks and pipelines, marinas, concentrated animal feeding operations, and stormwater associated with industrial activities.

NPDES Regulated Stormwater

Bacteria sources associated with MS4s and other NPDES regulated stormwater entities are considered point sources. Stormwater runoff is an important source of water pollution, including bacterial pollution. A MS4 is a conveyance or system of conveyances (roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains) designed or used for collecting or conveying stormwater and delivering it to a waterbody. MS4 programs are designed to reduce the amount of pollution that enters a waterbody from storm sewer systems to the maximum extent practicable.

The Lower Monocacy River watershed is located in Carroll, Frederick, and Montgomery Counties, which are all individual Phase I National Pollutant Discharge Elimination System (NPDES) MS4 permit jurisdictions. Stormwater in the watershed is conveyed through storm sewers covered by NPDES MS4 permits. Bacteria loads associated with these MS4s are therefore included in the Stormwater WLA_{LM} of this TMDL, which also encompasses any other NPDES regulated Phase I and Phase II stormwater entities in the watershed, including State and federal permittees.

Sanitary Sewer Overflows

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' permits, and must be reported to MDE's Water Management Administration in accordance with COMAR 26.08.10 to be addressed under the State's enforcement program.

There were a total of 15 SSOs reported to MDE between September 2003 and November 2004 in the Lower Monocacy River watershed. Approximately 424,415 gallons of SSOs were discharged through various waterways (surface water, groundwater, sanitary sewers, etc.) in the Frederick and Montgomery County portion of the watershed. No SSOs were reported in the Carroll County portion of the watershed. Figure 2.4.2 depicts the locations where SSOs occurred in the watershed between September 2003 and November 2004.

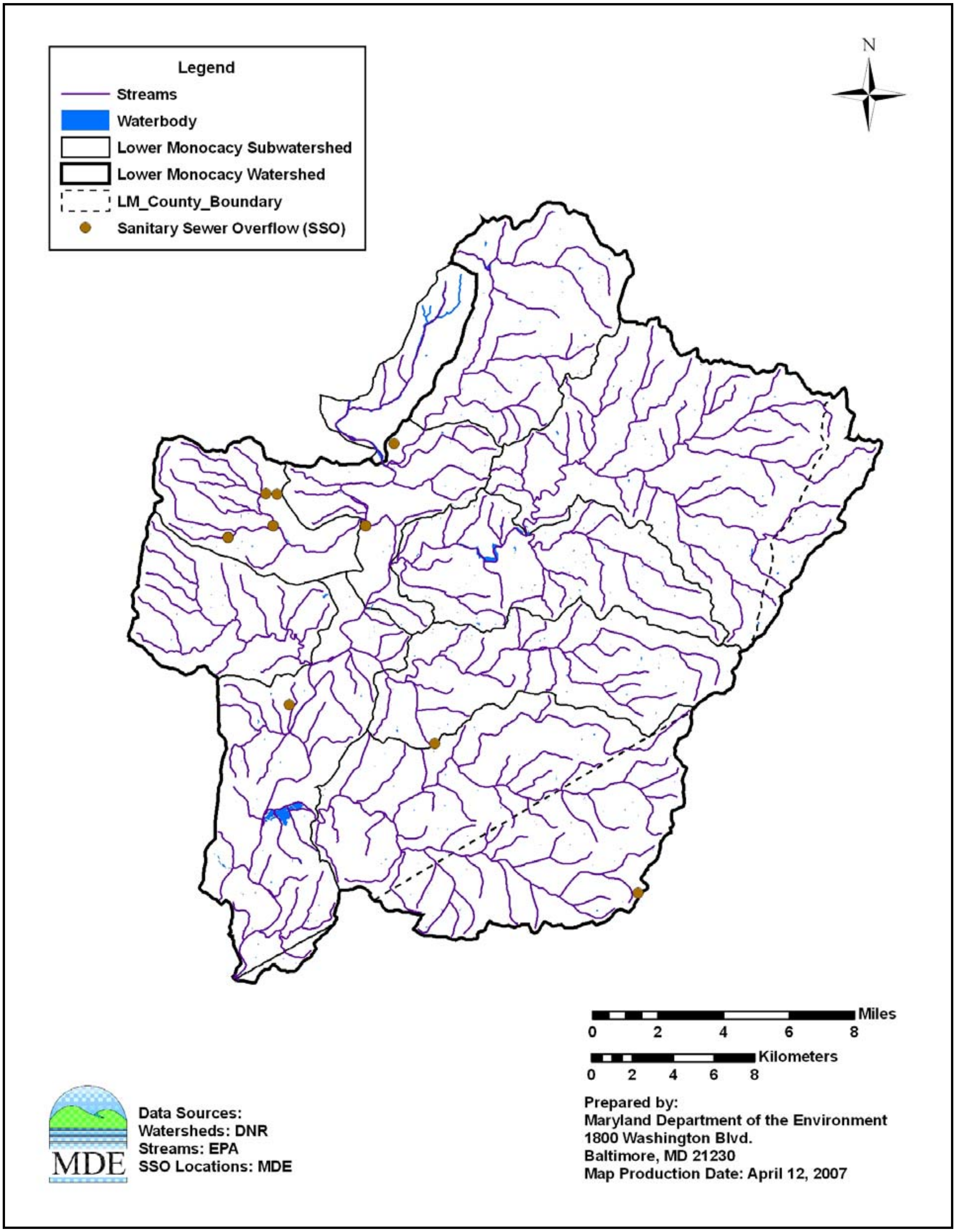

Figure 2.4.2: Sanitary Sewer Overflows Areas in the Lower Monocacy River Watershed

Municipal and Industrial Wastewater Treatment Plants (WWTPs)

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.

Based on MDE's point source permitting information, there are 17 NPDES permitted point source facilities with permits regulating the discharge of fecal bacteria directly into the Lower Monocacy River watershed (Table 2.4.2 and Figure 2.4.3). Table 2.4.2 lists all active facilities. The McKinney WWTP is currently under construction and is located adjacent to the Ballenger Creek WWTP. The effluent from the McKinney WWTP will be combined with the Ballenger Creek WWTP and discharged through the existing Ballenger Creek outfall.

Table 2.4.2: NPDES Permit Holders with Permits Regulating Fecal Bacteria Discharge in the Lower Monocacy River Watershed

Facility	Map ID	NPDES Permit	Subwatershed	Average Annual Flow* (MGD)	Fecal Coliform Average Annual Concentrations* (MPN/100ml)	Fecal Coliform Load Per Day (Billion MPN/day)
Reichs Ford Sanitary Landfill	ps-1	MD0061093	MON0004	0.075	**32**	0.094
Woodsboro WWTP	ps-2	MD0058661	ISR0022	0.084	21	0.105
Kemptown School WWTP	ps-3	MD0056481	BEN0022	0.002	34	0.002
Monrovia WWTP	ps-4	MD0059609	BSC0013	0.082	32	0.103
New Life Foursquare Church/School WWTP	ps-5	MD0057100	BNG0005	0.002	21	0.003
Concord Trailer Park WWTP	ps-6	MD0023060	BNG0005	0.008	2	0.010
Libertytown WWTP	ps-7	MD0060577	LIN0072	0.039	27	0.048
Hyattstown WWTP	ps-8	MD0067768	BEN0022	0.004	13	0.005
New Market WWTP	ps-9	MD0020729	BSC0013	0.075	35	0.094
Cracked Claw WWTP	ps-10	MD0024244	BSC0013	**0.012**	13	0.015
Mill Bottom WWTP	ps-11	MD0065439	BSC0013	0.062	25	0.078
Springview Mobile Home WWTP	ps-12	MD0022870	BNG0005	0.007	2	0.008
Pleasant Branch WWTP	ps-13	MD0065269	BEN0022	0.044	22.421	0.055
Dan-Dee Motel and Country Inn WWTP	ps-14	MD0023710	CAR0001	0.001	3.400	0.001
Frederick City WWTP	ps-15	MD0021610	MON0155	7.176	7.532	8.964
Fort Detrick WWTP	ps-16	MD0020877	MON0155	0.685	2.000	0.855
Ballenger Creek WWTP	ps-17	MD0021822	MON0004	4.751	21.769	5.935
Future McKinney Creek WWTP		-	MON0004	-	-	-

*Values in bold are maximum concentration or flow

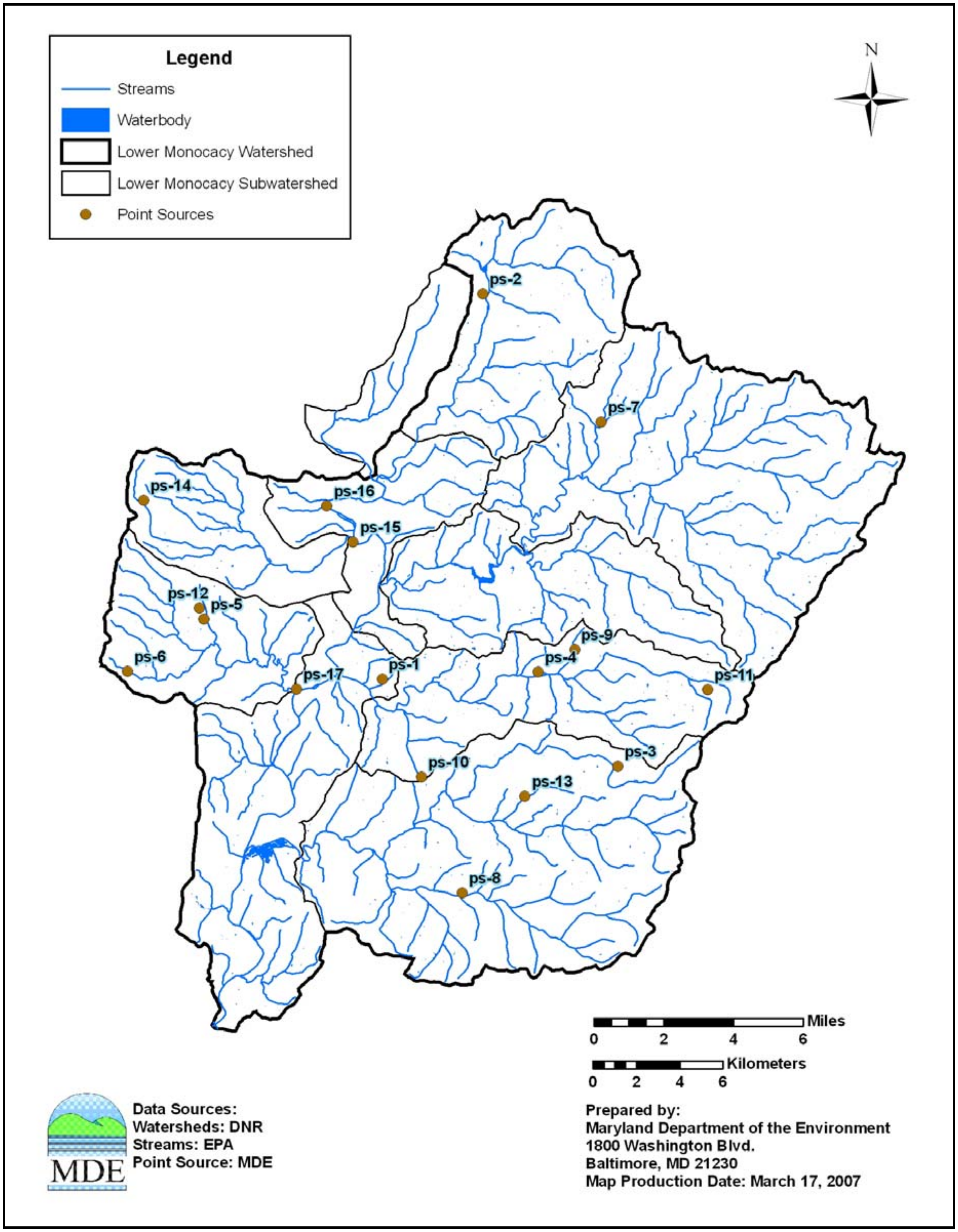

Figure 2.4.3: Permitted Point Sources Discharging Fecal Bacteria in the Lower Monocacy River Watershed

Bacteria Source Tracking

Bacteria source tracking (BST) was used to identify the relative contributions from various sources of bacteria to in-stream water samples. BST monitoring was conducted at nine stations throughout the Lower Monocacy River watershed, where 12 samples (one per month) were 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 water 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. The weighting factors are based on the $\log_{10}$ 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 is 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). The weighting is based on the $\log_{10}$ 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 (i.e., high flow=0.3, low flow=0.7).

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

$$MS_k = \sum_{i=1}^{2} MS_{i,k} * W_i \qquad (4)$$

where

$$MS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})} \qquad (5)$$

where

$MS_{i,k}$ = Weighted mean proportion of isolates for source k in stratum i
MS_k = weighted mean proportion of isolates of source k
W_i= Proportion covered by stratum i
i = stratum
j = sample
k = Source category (1 = human, 2 = domestic, 3 = livestock, 4 = wildlife, 5 = unknown)
$C_{i,j}$ = Concentration for sample j in stratum i
$S_{i,j,k}$ = Proportion of isolates for sample j, of source k in stratum i
n_i = number of samples in stratum I

The complete distributions of the annual and seasonal periods source loads are listed in Tables 2.4.3 and 2.4.4. Details of the BST data and tables with the BST analysis results can be found in Appendix C. For the seasonal period, only one sample in each subwatershed fell in the high flow category; therefore, a distribution by flow stratum was not calculated due to an insufficient number of samples. In the seasonal analysis, a distribution of all samples was calculated and applied.

Table 2.4.3: Distribution of Fecal Bacteria Source Loads in the Lower Monocacy River Basin for the Annual Period

Station	Flow Stratum	% domestic animals	% human	% livestock	% wildlife	% unknown
BEN0022	High	17.1	18.9	21.6	26.0	16.4
	Low	17.6	15.9	22.7	17.5	26.3
	Weighted	17.5	16.7	22.4	19.6	23.8
BNG0005	High	22.0	13.9	24.8	23.4	16.0
	Low	34.3	8.6	27.8	11.4	17.9
	Weighted	31.2	9.9	27.1	14.4	17.4
BSC0013	High	17.0	13.6	21.5	20.6	27.3
	Low	23.3	29.6	21.4	9.8	16.0
	Weighted	21.7	25.6	21.4	12.5	18.8
CAR0001	High	30.5	23.6	19.2	15.2	11.6
	Low	19.5	12.7	32.0	15.0	20.7
	Weighted	22.3	15.4	28.8	15.1	18.4
ISR0022	High	36.2	18.3	21.8	12.4	11.2
	Low	25.6	8.8	30.5	18.2	17.0
	Weighted	28.3	11.1	28.3	16.7	15.5
LIN0005	High	25.7	29.9	22.4	7.3	14.7
	Low	24.9	5.7	27.4	19.7	22.3
	Weighted	25.1	11.8	26.1	16.6	20.4
LIN0072	High	34.7	22.9	11.9	14.0	16.6
	Low	12.8	7.7	30.1	21.5	27.9
	Weighted	18.2	11.5	25.6	19.6	25.1
MON0004	High	23.4	21.9	22.0	18.4	14.3
	Low	16.2	15.1	28.8	14.1	25.8
	Weighted	18.0	16.8	27.1	15.1	23.0
MON0155	High	24.0	22.3	23.6	16.2	13.9
	Low	14.0	8.1	29.9	23.9	24.1
	Weighted	16.5	11.7	28.3	22.0	21.5

Table 2.4.4: Distribution of Fecal Bacteria Source Loads in the Lower Monocacy River Basin for the Seasonal Period (May 1st – September 30th)

Station	% domestic animals	% human	% livestock	% wildlife	% unknown
BEN0022	7.7	20.6	23.5	20.0	28.2
BNG0005	14.9	15.4	39.8	11.8	18.0
BSC0013	9.6	26.0	25.1	18.8	20.4
CAR0001	16.6	11.6	36.3	20.4	15.1
ISR0022	20.2	11.5	36.1	13.9	18.3
LIN0005	7.6	10.8	25.8	21.9	33.9
LIN0072	8.2	14.3	31.0	18.9	27.5
MON0004	11.6	15.9	23.7	20.6	28.2
MON0155	14.4	2.4	28.9	22.2	32.1

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 the Lower Monocacy River 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 of the many complexities involved in estimating bacteria concentrations, loads and sources. The second section presents the analysis for estimating a representative geometric mean fecal bacteria concentration and baseline loads. The third section describes the analysis framework and how the hydrological, water quality and BST data are linked together in the TMDL process. This analysis methodology is based on available monitoring data and is 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 annual average TMDL loading caps and how maximum daily loads are estimated. The seventh section presents TMDL scenario descriptions. The eighth section presents the load allocations. Finally, in Section 4.9, 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 (WLAs) for point sources, load allocations (LAs) for non point 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 an accurate estimation of source inputs is 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 (US EPA 1985) is a direct estimate of the bacteria colonies (Method 1600), and the second is a statistical estimate of the number of colonies (ONPG MUG Standard Method 9223B, AOAC 991.15). Sample results indicate the extreme variability in the total bacteria counts (see Appendix A). The distribution of the sample results 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 also be problematic, due to the many assumptions required and to limited available data. Lack of specific numeric and spatial location data for several source categories, from failing septic systems to domestic animals, livestock, and wildlife populations, can create many potential uncertainties in traditional water quality modeling. For this reason, MDE applies an analytical method combined with the bacteria source tracking described above for the calculation of this TMDL.

4.2 Analysis Framework

This TMDL analysis uses flow duration curves to identify flow intervals that are used as indicators of hydrological conditions (i.e., annual average and critical conditions). This analytical method, combined with water quality monitoring data and BST, provides reasonable results (Cleland 2003), a better description of water quality than traditional water quality modeling, and also meets TMDL requirements.

In brief, baseline loads are estimated first for each subwatershed by using bacteria monitoring data and long-term flow data. These baseline loads are divided into four bacteria source categories using the results of BST analysis. Next, the percent reduction required to meet the water quality criterion is estimated from the observed bacteria concentrations after determining the critical condition and accounting for seasonality. Critical condition and seasonality are determined by assessing annual and seasonal hydrological conditions for high flow and low flow periods. Finally, TMDLs for each subwatershed are estimated by applying these percent reductions.

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

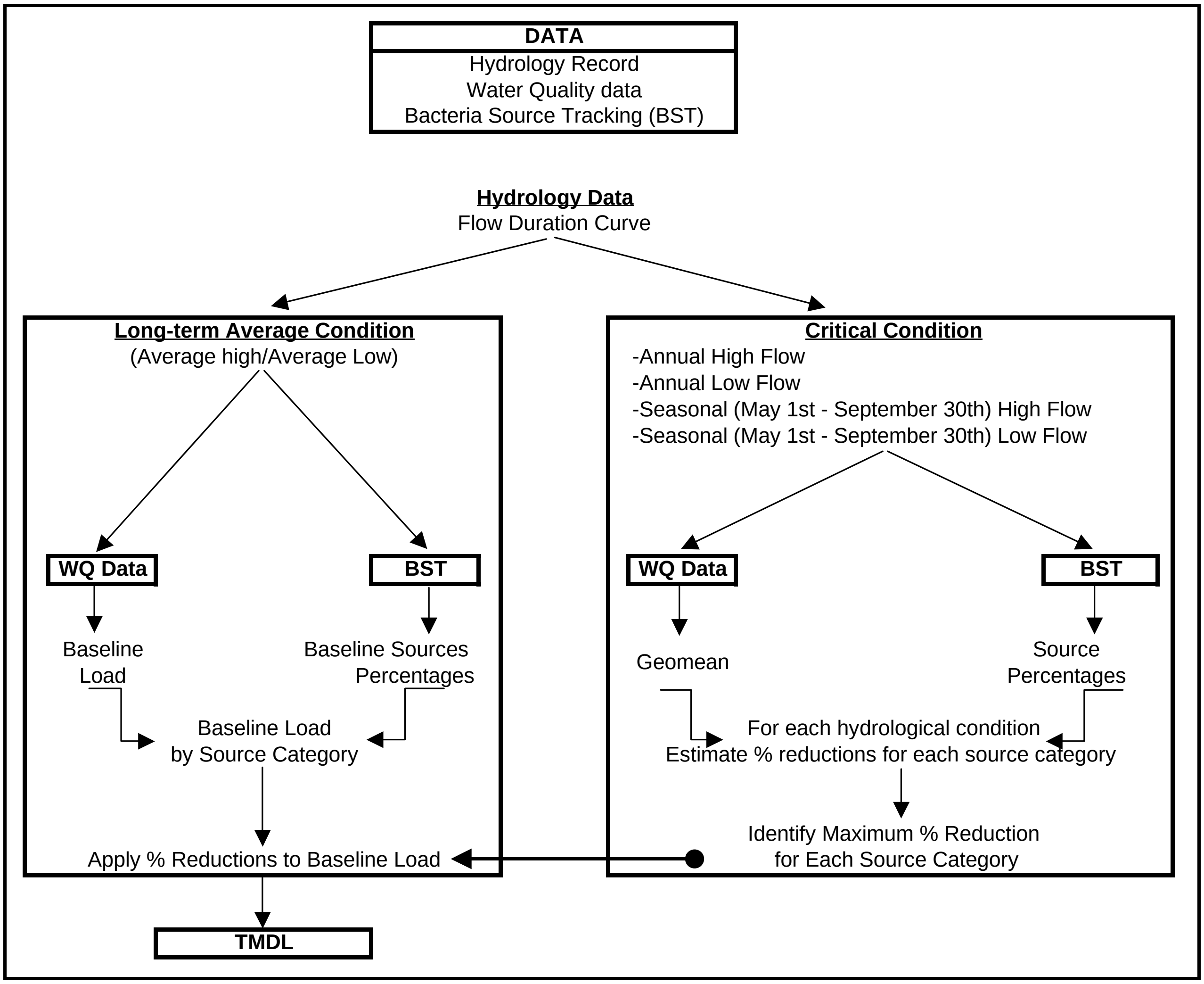

Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads estimated in this TMDL analysis are reported in long-term average loads, using bacteria monitoring data and long-term flow data.

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 bias correction 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.

To estimate baseline loads for each subwatershed of the Lower Monocacy River, bias correction factors, daily average flows and geometric mean concentrations for each stratum are first estimated.

The bias correction factor for each stratum is estimated as follows:

$$F1_i = A_i/C_i \qquad (6)$$

where

$F1_i$ = Bias correction factor for stratum *i*
A_i = Long term annual arithmetic mean for stratum *i*
C_i = Long term annual geometric mean for stratum *i*

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

The loads for each stratum are estimated as follows:

$$L_i = Q_i * C_i * F_1 * F_2 \qquad (7)$$

where

L_i = Daily average load (Billion MPN/day) at monitoring station for stratum i
Q_i = Daily average flow (cfs) for stratum i
C_i = Geometric mean for stratum i
F_1 = Bias correction factor
F_2 = Unit conversion factor (0.0245)

Finally, for each subwatershed, the baseline load is estimated as follows:

$$L = \sum_{i=1}^{2} L_i * W_i \qquad (8)$$

L = Daily average load at station (MPN/day)
W_i= Proportion of stratum i

In the Lower Monocacy River watershed, a weighting factor of 0.25 for high flow and 0.75 for low/mid flows were used to estimate the annual baseline load expressed as Billion MPN *E. coli*/day.

Estimating Subwatersheds Loads

Subwatersheds with more than one monitoring station were subdivided into unique watershed segments, thus allowing individual load and reduction targets to be determined for each. In the Lower Monocacy River watershed, three subwatersheds have both upstream and downstream monitoring stations. The downstream segments of each are monitored at stations LIN0005, MON0004, and MON0155, respectively (see Figure 2.2.1), and identified as subwatersheds by adding the extension "sub" to their station names (LIN0005sub, MON0004sub, and MON0155sub). Thus, there are a total of nine subwatersheds defined in this analysis. The upstream stations for subwatershed MON0004sub, TUS0007 and MON0269, are located in the Upper Monocacy River basin. A portion of the Upper Monocacy River basin was not accounted for in the Upper Monocacy River TMDL and therefore was included as a part of this subwatershed. The baseline loads for these stations were required to calculate the subwatershed load for MON0004sub.

The total baseline loads from the upstream watersheds, estimated from the monitoring data, were multiplied by a transport factor derived from first order decay. The decay factor for *E. coli* used in the analysis was obtained from the study "Pathogen Decay in Urban Waters" by Easton et al. (2001), and was estimated by linear regression of counts of microorganisms versus time (die-off plots). The estimated 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:

$$\sum Q_{us} + Q_{sub} = Q_{ds} \tag{9}$$

where

Q_{us} = Upstream flow (cfs)
Q_{sub} = Subwatershed flow (cfs)
Q_{ds} = Downstream flow (cfs)

and the general equations for bacteria loading mass balance:

$$\sum (e^{-kt} Q_{us} C_{us}) + Q_{sub} C_{sub} = Q_{ds} C_{ds} \tag{10}$$

where

C_{us} = Upstream bacteria concentration (MPN/100ml)
k = Bacteria (*E. coli*) decay coefficient (1/day) = 0.762 day^{-1}
t = travel time from upstream watershed to outlet (days)
C_{sub} = Subwatershed bacteria concentration (MPN/100ml)
C_{ds} = Downstream bacteria concentration (MPN/100ml)

The concentrations in the subwatersheds were estimated by considering the ratio of high flow concentration to low flow concentrations in the upstream watersheds. If the total load and average flow were used to estimate the geometric mean concentration, this estimated concentration would be biased if there was a correlation with flow and concentration. For example, in two strata, the steady-state geometric mean is estimated as follows:

$$L = Q_{high}W_{high}C_{high} + Q_{low}W_{low}C_{low} \tag{11}$$

where

L = Average Load (MPN/day)
Q_i = Average flow for stratum i
W_i= Proportion of stratum i
C_i = Concentration for stratum i
n_i = number of samples in stratum I

Notice that the load in equation (10) is based on two concentrations and therefore, when using the mass balance approach and the total load, this results in two unknowns, C_{high} and C_{low}, with one equation. Thus a relationship between C_{high} and C_{low}, must be estimated to solve for the concentration in both strata. This relationship is estimated using the average of the ratios estimated from the monitoring data in the upstream watersheds. Using this relationship, the following two equations result:

$$C_{low} = \frac{L}{Q_{high}R*W_{high} + Q_{low}W_{low}} \tag{12}$$

where

$$R = \frac{C_{high}}{C_{low}} \tag{13}$$

and the final geometric mean concentration is estimated as follows:

$$GM = 10^{W_{high}\log_{10}(C_{high}) + W_{low}\log_{10}(C_{low})} \tag{14}$$

To estimate the load from subwatershed MON0155sub, the transported load from stations TUS0007, MON0269, LIN0005sub, ISR0022, and CAR0001, estimated as explained above, is subtracted from the load measured at station MON0155. The difference is assigned to subwatershed MON0155sub. To estimate the load from subwatershed MON0004sub, the transported load from stations MON0155, BNG0005, BSC0013, and BEN0022 is subtracted from the load measured at station MON0004. The difference is assigned to subwatershed MON0004sub. To estimate the load from subwatershed LIN0005sub, the transported load from station LIN0072LL, determined from the lake discharge equation explained below, is subtracted from the load measured at station LIN0005. The difference is assigned to subwatershed LIN0005sub.

Source estimates from the BST analysis are 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 back-calculating an accurate source transport factor, the sources for MON0155sub, MON0004sub, and LIN0005sub were assigned from the analysis for MON0155, MON0004, and LIN0005, respectively.

Station LIN0072 is located directly above an impoundment, Linganore Lake. 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. In order to estimate the correct subwatershed load for the downstream station LIN0005, the flow and concentration downstream of Lake Linganore must be determined and substituted for the flow and concentration at station LIN0072 in the calculation. The location of the outlet from the Lake will be defined as LIN0072LL. The load from subwatershed LIN0007LL represents the load exiting the lake.

A steady-state mass balance equation with first order decay was used to estimate the bacterial loading from the watershed exiting the lake. 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 *E. coli*, was selected based on the pond's average retention time (Maryland Water Resources Administration, 1985). The average retention time used for Linganore Lake was 16.2 days (1,400,000 seconds). The average discharge from the lake of 83.8 cfs was assigned as the outlet flow for low and high flow conditions. Data was not available for the high and low flow strata. These loadings were calculated for the high flow and the low flow stratums. The following equation was used for calculating the bacteria loadings discharge from the lake:

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

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

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

Results of the baseline load calculations are presented in Table 4.3.1.

Table 4.3.1: Baseline Loads Calculations

Station	Area (mi^2)	High Flow Q (cfs)	High Flow *E. coli* Concentration (MPN/100ml)	High Flow Smearing Factor	Low Flow Q (cfs)	Low Flow *E. coli* Concentration (MPN/100ml)	Low Flow Smearing Factor	Baseline Load (Billion MPN *E. coli*/year)
TUS0007 Upper Monocacy River	18.2	59.7	126.5	1.4	11.0	368.4	1.4	62,687
MON0269 Upper Monocacy River	647.7	2639.7	298.5	2.0	281.7	139.0	2.1	4,081,709
LIN0072	61.0	212.1	845.6	1.4	32.9	5,87.5	1.6	761,160
LIN0072LL	N/A	83.8	421.5	1.4	83.8	44.2	1.6	148,871
LIN0005sub	28.1	97.6	269.1	5.7	15.1	162.7	2.2	370,480
ISR0022	29.0	100.8	444.9	1.5	15.6	1,238.3	2.6	489,398
CAR0001	17.0	59.2	738.4	1.1	9.2	986.5	1.6	208,746
MON0155sub	28.4	118.9	3,545.1	1.6	10.9	2,709.1	1.7	1,857,541
BNG0005	20.0	69.5	264.7	1.6	10.8	236.7	1.4	90,861
BSC0013	29.9	104.0	640.2	1.5	16.1	243.5	1.3	261,330
BEN0022	62.9	190.5	206.1	1.9	35.2	150.2	1.5	218,897
MON0004sub	38.0	132.3	2,234.9	1.9	20.5	852.4	2.1	1,524,912

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 annual and seasonal hydrological conditions for wet and dry periods. 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 25% high flow and 75% low flow as defined in Appendix B. Using the definition of a high flow condition as occurring when the daily flow duration interval is less than 25% and a low flow condition as occurring when the daily flow duration interval is greater than 25%, critical hydrological condition can be estimated by the percent of high or low flows during a specific period.

As stated above, Maryland's proposed fecal bacteria TMDL for the Lower Monocacy River has been determined by assessing various hydrological conditions to account for seasonal and annual averaging periods. The five conditions listed in Table 4.4.1were used to account for the critical condition.

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

USGS Gage	Hydrological Condition		Averaging Period	Water Quality Data Used	Fraction High Flow	Fraction Low Flow	Condition Period
01643000	Annual	Average	365 days	All	0.25	0.75	Long Term Average
		Wet	365 days	All	0.602	0.398	Jan 1997 - Jan 1998
		Dry	365 days	All	0.014	0.986	May 2002 - May 2003
	Seasonal	Wet	May 1st – Sept 30th	May 1st – Sept 30th	0.520	0.480	May 1996 - Sep 1996
		Dry	May 1st – Sept 30th	May 1st – Sept 30th	0.000	1.000	May 2002 - Sep 2002
01643500	Annual	Average	365 days	All	0.25	0.75	Long Term Average
		Wet	365 days	All	0.764	0.236	Jan 1997 - Jan 1998
		Dry	365 days	All	0.019	0.981	May 2002 - May 2003
	Seasonal	Wet	May 1st – Sept 30th	May 1st – Sept 30th	0.579	0.421	May 1996 - Sep 1996
		Dry	May 1st – Sept 30th	May 1st – Sept 30th	0.007	0.993	May 1997 - Sep 1997

The critical condition requirement is met by determining the maximum reduction per bacteria source that satisfies all hydrological conditions, and that is required to meet the water quality standard while minimizing the risk to water contact recreation. It is assumed that the reduction applied to a bacteria source category will be constant through all conditions.

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

Table 4.4.2 shows the reductions of fecal bacteria required in each subwatershed of the Lower Monocacy River to meet water quality standards for designated uses.

Table 4.4.2: Required Reductions of Fecal Bacteria to Meet Water Quality Standards

Station	Time Period		Domestic %	Human %	Livestock %	Wildlife %
LIN0072	Annual	Wet	98%	98%	98%	33%
		Dry	98%	98%	98%	36%
	Seasonal	Wet / Dry	98%	98%	98%	64%
	Maximum Source Reduction		**98%**	**98%**	**98%**	**64%**
LIN0005sub	Annual	Wet	46%	72%	47%	0%
		Dry	34%	68%	30%	0%
	Seasonal	Wet / Dry	0%	0%	0%	0%
	Maximum Source Reduction		**46%**	**72%**	**47%**	**0%**
ISR0022	Annual	Wet	98%	98%	98%	5%
		Dry	98%	98%	98%	62%
	Seasonal	Wet / Dry	98%	98%	98%	87%
	Maximum Source Reduction		**98%**	**98%**	**98%**	**87%**
CAR0001	Annual	Wet	98%	98%	98%	28%
		Dry	98%	98%	98%	44%
	Seasonal	Wet / Dry	98%	98%	98%	63%
	Maximum Source Reduction		**98%**	**98%**	**98%**	**63%**
MON0155sub	Annual	Wet	98%	90%	98%	97%
		Dry	98%	90%	98%	93%
	Seasonal	Wet / Dry	98%	90%	98%	88%
	Maximum Source Reduction		**98%**	**90%**	**98%**	**97%**
BNG0005	Annual	Wet	66%	97%	57%	0%
		Dry	53%	95%	52%	0%
	Seasonal	Wet / Dry	92%	98%	77%	0%
	Maximum Source Reduction		**92%**	**98%**	**77%**	**0%**
BSC0013	Annual	Wet	86%	98%	93%	0%
		Dry	32%	98%	33%	0%
	Seasonal	Wet / Dry	96%	98%	91%	0%
	Maximum Source Reduction		**96%**	**98%**	**93%**	**0%**
BEN0022	Annual	Wet	74%	97%	0%	0%
		Dry	0%	96%	0%	0%
	Seasonal	Wet / Dry	0%	98%	73%	0%
	Maximum Source Reduction		**74%**	**98%**	**73%**	**0%**
MON0004sub	Annual	Wet	98%	88%	98%	80%
		Dry	98%	88%	98%	46%
	Seasonal	Wet / Dry	98%	88%	98%	81%
	Maximum Source Reduction		**98%**	**88%**	**98%**	**81%**

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 reduced (more stringent) water quality criterion concentration. The *E. coli* water quality criterion concentration was reduced by 5%, from 126 *E. coli* MPN/100ml to 119.7 *E. coli* MPN/100ml.

4.6 Scenario Descriptions

Source Distribution

The final bacteria source distribution and corresponding baseline loads are derived from the source proportions listed in Table 2.4.3. 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 and baseline loads used in the TMDL scenarios are presented in Table 4.6.1. The source distributions for subwatersheds MON0155sub, LIN0005sub and MON0004sub, were based on the sources identified at stations MON0155, LIN0005, and MON0004, respectively.

Table 4.6.1: Bacteria Source Distributions and Corresponding Baseline Loads Used in the TMDL Analysis

Station	Domestic		Human		Livestock		Wildlife		Total Load (Billion MPN *E. coli*/year)
	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	
BEN0022	22.9%	50,154	21.9%	47,924	29.5%	64,481	25.7%	56,338	218,897
BNG0005	37.8%	34,312	12.0%	10,901	32.8%	29,790	17.5%	15,858	90,861
BSC0013	26.8%	69,928	31.5%	82,276	26.3%	68,836	15.4%	40,290	261,330
CAR0001	27.3%	56,983	18.9%	39,497	35.3%	73,697	18.5%	38,569	208,746
ISR0022	33.4%	163,692	13.2%	64,586	33.6%	164,227	19.8%	96,892	489,398
LIN0005sub	31.5%	116,842	14.8%	54,716	32.8%	121,546	20.9%	77,377	370,480
LIN0072	24.4%	185,346	15.4%	116,967	34.1%	259,687	26.2%	199,160	761,160
MON0004sub	23.3%	356,040	21.8%	332,461	35.2%	536,735	19.7%	299,676	1,524,912
MON0155sub	21.0%	390,349	14.9%	276,127	36.1%	670,397	28.0%	520,668	1,857,541

First Scenario: Fecal Bacteria Practicable Reduction Targets

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.6.2. These values are based on review of the available literature and best professional judgment. It is assumed that human sources would potentially have the highest risk of causing 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 4.6.2: Maximum Practicable Reduction Targets

Max Practicable Reduction per Source	**Human**	**Domestic**	**Livestock**	**Wildlife**
	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.[1]	Target goal reflects uncertainty in effectiveness of urban BMPs[2] and is also based on best professional judgment	Target goal based on sediment reductions from BMPs[3] and best professional judgment	No programmatic approaches for wildlife reduction to meet water quality standards. Waters contaminated by wild animal wastes offer a public health risk that is orders of magnitude less than that associated with human waste.[4]

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

As previously stated, these maximum practicable reduction targets are based on the available literature and best professional judgment. There is much uncertainty with estimated reductions from best management practices (BMP). The BMP efficiency for bacteria reduction ranged from –6% to +99% based on a total of 10 observations (US EPA 1999). The MPR to agricultural lands was based on sediment reductions identified by EPA (US 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 animals and livestock next (3), and wildlife the lowest (1) (See Table 4.6.2). The model was defined as follows:

$$\text{Risk Score} = \text{Min} \sum_{i=1}^{4} P_j * W_j \qquad (15)$$

Where

$$P_j = \frac{(1-R_i) * Pb_j}{1-TR} \qquad (16)$$

and

$$TR = \frac{C - C_{cr}}{C} \tag{17}$$

Therefore the risk score can be represented as:

$$Risk\ Score = Min\sum_{i=1}^{4}\left[\frac{(1-R_j)*Pb_j}{(1-\frac{C-Ccr}{C})}*W_j\right] \tag{18}$$

where
i = hydrological condition
j = bacteria source category =human, domestic animal, livestock and wildlife
P_j = % of each source category (human, domestic animals, livestock and wildlife) in final allocation
W_j = Weigh of risk per source category = 5, 3 or 1
R_j= percent reduction applied by source category (human, domestic animals, livestock and wildlife) for the specified hydrological condition (variable)
Pb_j = original (baseline) percent distribution by source category (variable)
TR = total reduction (constant within each hydrological condition) = Target reduction
C = In-stream concentration
Ccr = Water quality criterion

The model is subject to the following constraints:

C = Ccr
$0 <= R_{human} <= 95\%$
$0 <= R_{pets} <= 75\%$
$0 <= R_{livestock} <= 75\%$
$R_{wildlife} = 0$
$P_j >= 1\%$

In eight of nine subwatersheds, the constraints of this scenario could not be satisfied, indicating there was not a practicable solution. A summary of the first scenario analysis results is presented in Table 4.6.3.

Table 4.6.3: Practicable Reduction Scenario Results

Station	Applied Reductions				Achievable
	Domestic %	Human %	Livestock %	Wildlife %	
BEN0022	75.0%	95.0%	75.0%	0.0%	No
BNG0005	75.0%	95.0%	75.0%	0.0%	No
BSC0013	75.0%	95.0%	75.0%	0.0%	No
CAR0001	75.0%	95.0%	75.0%	0.0%	No
ISR0022	75.0%	95.0%	75.0%	0.0%	No
LIN0005sub	46%	72%	47%	0.0%	Yes
LIN0072	75.0%	95.0%	75.0%	0.0%	No
MON0004sub	75.0%	95.0%	75.0%	0.0%	No
MON0155sub	75.0%	95.0%	75.0%	0.0%	No

Second Scenario: Fecal Bacteria Reductions Higher than Maximum Practicable Reductions

The TMDL must specify load allocations that will meet the water quality standards. In the practicable reduction targets scenario, only one of the subwatersheds of Lower Monocacy River could meet water quality standards based on MPRs.

To further develop the TMDL, a second scenario was analyzed in which the constraints on the MPRs were relaxed in the subwatersheds where water quality attainment was not achievable with MPRs. In these subwatersheds, the maximum allowable reduction was increased to 98% 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 scenario reduction constraints. The model was defined in the same manner as shown in the practicable reduction scenario but subject to the following constraints:

$C = Ccr$
$0 <= R_i <= 98\%$
$P_j >= 1\%$

The summary of the analysis is presented in Table 4.6.4.

Table 4.6.4: TMDL Scenario Results: Percent Reductions Based on Optimization Model Allowing Up to 98% Reduction

Station	Domestic (%)	Human (%)	Livestock (%)	Wildlife (%)	Target Reduction
BEN0022	73.7%	98.0%	72.9%	0.0%	59.8%
BNG0005	92.1%	98.0%	76.9%	0.0%	71.7%
BSC0013	95.6%	98.0%	93.4%	0.0%	81.0%
CAR0001	98.0%	98.0%	98.0%	62.6%	91.5%
ISR0022	98.0%	98.0%	98.0%	86.8%	95.8%
LIN0005sub	46.0%	72.5%	47.1%	0.0%	40.7%
LIN0072	98.0%	98.0%	98.0%	64.1%	89.1%
MON0004sub	98.0%	88.5%	98.0%	81.3%	92.6%
MON0155sub	98.0%	90.0%	98.0%	97.3%	96.6%

4.7 TMDL Loading Caps

The TMDL loading cap is an estimate of the assimilative capacity of the monitored watershed. Estimation of the TMDL requires knowledge of how bacteria concentrations vary with flow rate or the flow duration interval. This relationship between concentration and flow is established using the strata defined by the flow duration curve.

The TMDL loading caps are provided in billion MPN *E. coli*/day. These loading caps are for the nine subwatersheds located upstream of their respective monitoring stations: BEN0022, BNG0055, BSC0013, CAR0001, ISR0022, LIN0005sub, LIN0072, MON0004sub, and MON0155sub.

Annual Average TMDL Loading Caps

As explained in the sections above, the annual average TMDL loading caps are estimated by first determining the baseline or current condition loads for each subwatershed and the associated geometric mean from the available monitoring data. This annual average 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 required to meet the water quality criterion is estimated from the observed bacteria concentrations accounting for the critical conditions (See Section 4.4). A reduction in concentration is proportional to a reduction in load; thus the TMDL is equal to the current baseline load multiplied by one minus the required reduction. This reduction, estimated as explained in Section 4.4, represents the maximum reduction per source that satisfies all hydrological conditions in each subwatershed, and is required to meet water quality standards.

$$TMDL = L_b * (1 - R) \qquad (19)$$

where

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

The annual average bacteria TMDL loading caps for the subwatersheds are shown in Tables 4.7.1 and 4.7.2.

Table 4.7.1: Lower Monocacy River Subwatersheds Annual Average TMDL Loading Caps

Station	Baseline Load (Billion MPN *E. coli*/year)	TMDL Loading Caps (Billion MPN *E. coli*/year)	% Target Reduction
BEN0022	218,897	87,950	59.8%
BNG0005	90,861	25,679	71.7%
BSC0013	261,330	49,585	81.0%
CAR0001	208,746	17,811	91.5%
ISR0022	489,398	20,656	95.8%
LIN0005sub	370,480	219,857	40.7%
LIN0072	761,160	82,739	89.1%
MON0004sub	1,524,912	112,257	92.6%
MON0155sub	1,857,541	62,995	96.6%
Total	**5,783,325**	**679,529**	**88.3%**

Table 4.7.2: TMDL Loading Caps by Source Category - Annual Average Conditions

Station	Domestic		Human		Livestock		Wildlife		Total Load (Billion MPN *E. coli*/year)
	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	%	Load (Billion MPN *E. coli*/year)	
BEN0022	15.0%	13,198	1.1%	958	19.8%	17,457	64.1%	56,338	87,950
BNG0005	10.6%	2,725	0.8%	218	26.8%	6,878	61.8%	15,858	25,679
BSC0013	6.2%	3,092	3.3%	1,646	9.2%	4,557	81.3%	40,290	49,585
CAR0001	6.4%	1,140	4.4%	790	8.3%	1,474	80.9%	14,407	17,811
ISR0022	15.8%	3,274	6.3%	1,292	15.9%	3,285	62.0%	12,806	20,656
LIN0005sub	28.7%	63,071	6.8%	15,052	29.3%	64,358	35.2%	77,377	219,857
LIN0072	4.5%	3,707	2.8%	2,339	6.3%	5,194	86.4%	71,499	82,739
MON0004sub	6.3%	7,121	29.6%	38,379	9.6%	10,735	54.5%	56,023	112,257
MON0155sub	12.4%	7,807	43.8%	27,613	21.3%	13,408	22.5%	14,167	62,995

Maximum Daily Loads

Selection of an appropriate method for translating a TMDL based on a longer time period into one using a daily time period requires decisions regarding 1) the level of resolution, and 2) the level of protection. The level of resolution pertains to the amount of detail used in specifying the maximum daily load. The level of protection represents how often the maximum daily load is expected to be exceeded. Draft EPA/Tetra Tech guidance on daily loads (Limno-Tech 2007) provides three categories of options for both level of resolution and level of protection, and discusses these categories in detail.

For the Lower Monocacy River daily TMDL, a "representative daily load" option was selected as the level of resolution, and a value "that will be exceeded with a pre-defined probability" was selected as the level of protection. In these options, the maximum daily loads are two single daily loads that correspond to the two flow strata, with an upper bound percentile that accounts for the variability of daily loads. The upper bound percentile and the maximum daily loads were estimated following EPA's "*Technical Support Document for Water Quality-Based Toxics Control*" (1991 TSD) (EPA 1991); and "*Approaches For Developing a Daily Load Expression for TMDLs Computed for Longer Term Averages*" (EPA 2006).

There are three steps to the overall process of estimating these maximum daily loads. First, all the data available from each monitoring station are examined together by stratum. The percentile rank of the highest observed concentration (for each stratum at each station) is computed. The highest computed percentile rank is the upper boundary to be used in estimating the maximum daily loads.

Secondly, the long-term annual average TMDL (see Table 4.7.1) concentrations are estimated for both high-flow and low-flow strata. This is conducted for each station using a statistical methodology (the "Statistical Theory of Rollback," or "STR," described more fully in Appendix D).

Third, based on the estimated long-term average (LTA) TMDL concentrations, the maximum daily load (MDL) for each flow stratum at each station is estimated using the upper boundary percentile computed in the first step above. Finally, maximum daily loads are computed from these MDL concentrations and their corresponding flows.

Results of the fecal bacteria MDL analysis for the Lower Monocacy River subwatersheds are shown in Table 4.7.3

Table 4.7.3: Lower Monocacy River Watershed Maximum Daily Loads Summary

Station	Stratum	Maximum Daily Load by Stratum (Billion *E. coli* MPN/day)	Maximum Daily Load (Weighted) (Billion *E. coli* MPN/day)
BEN0022	High Flow	3,590	1,163
	Low Flow	354	
BNG0005	High Flow	904	295
	Low Flow	92	
BSC0013	High Flow	2,947	800
	Low Flow	84	
CAR0001	High Flow	239	182
	Low Flow	164	
ISR0022	High Flow	265	505
	Low Flow	585	
LIN0005sub	High Flow	26,688	6,982
	Low Flow	414	
LIN0072	High Flow	2,402	921
	Low Flow	427	
MON0004sub	High Flow	7,609	2,170
	Low Flow	357	
MON0155sub	High Flow	3,420	1,029
	Low Flow	232	

See Appendix D for a more detailed explanation of the procedure for obtaining these daily loads.

4.8 TMDL Allocations

The Lower Monocacy River fecal bacteria TMDL is composed of the following components:

$$TMDL = LA_{LM} + WLA_{LM} + LA_{UM} + MOS \qquad (20)$$

LA_{LM} – Lower Monocacy Load Allocation
WLA_{LM} – Lower Monocacy Waste Load Allocation
LA_{UM} – Upper Monocacy Load Allocation
MOS – Margin of Safety

The TMDL allocations for the Lower Monocacy River MD 8-digit basin include a load allocation (LA_{LM}) for certain nonpoint sources, and waste load allocations (WLA_{LM}) for point sources including WWTPs and NPDES-regulated stormwater discharges. The Stormwater (SW) WLA_{LM} includes any nonpoint source loads deemed to be transported and discharged by regulated stormwater systems. An explanation of the distribution of nonpoint source loads and point source loads to the LA_{LM} and to the SW-WLA_{LM} and WWTP-WLA_{LM} is provided in the subsections that follow.

In addition to these allocation categories for the MD 8-digit watershed, the Lower Monocacy River TMDL includes an upstream load allocation to account for the load from the Upper Monocacy River watershed (LA_{UM}). The final Upper Monocacy River TMDL, determined in a separate TMDL document, constitutes the LA_{UM} to the Lower Monocacy River. See Appendix E for further information on the upstream loads.

The margin of safety (MOS) is explicit and is incorporated in the analysis using a conservative assumption; it is not specified as a separate term. The assumption is that a 5% reduction of the criterion concentration established by MD to meet the applicable water quality standard will result in more conservative allowable loads of fecal bacteria, and thus provide the MOS. The final loads are based on average hydrological conditions, with reductions estimated based on critical hydrological conditions. The load reduction scenario results in load allocations that will achieve water quality standards. The State reserves the right to revise these allocations provided such revisions are consistent with the achievement of water quality standards.

Bacteria Source Categories and Allocation Distributions

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 the LA_{LM} (those nonpoint sources or portions thereof not transported and discharged by stormwater systems) and the WLA_{LM} (point sources including WWTPs, and NPDES regulated stormwater entities). Only the final LA_{LM} or WLA_{LM} is reported in this TMDL. Note that the assignment of a small allowable human load to the SW WLA_{LM} is in consideration of the possible presence of such loads in the watershed beyond the reach of the sanitary sewer systems. The term “allowable load” means the load that the waterbody can assimilate and still meet water quality standards.

Table 4.8.1: Potential Source Contributions for TMDL Allocations

Allocation Category	LA	WLA	
		WWTPs	Stormwater
Human		X	X
Domestic			X
Livestock	X		
Wildlife	X		X

Load Allocation (LA_{LM})

All four bacteria source categories could potentially contribute to nonpoint source loads. For human sources, if the watershed has no MS4s or other NPDES-regulated stormwater entities, the nonpoint source contribution is estimated by subtracting any WWTP and CSO loads from the TMDL human load, and is then assigned to the LA_{LM}. However, in watersheds covered by NPDES-regulated stormwater permits, any such nonpoint sources of human bacteria (i.e., beyond the reach of the sanitary sewer systems) are assigned to the SW WLA_{LM}. There are 17 NPDES WWTPs with permits regulating the discharge of bacteria in the Lower Monocacy River watershed. There are no subwatersheds with assigned NPDES CSO WLA.

Livestock loads are all assigned to the LA_{LM}. Domestic animals (pets) loads are assigned to the LA in watersheds with no MS4s or other NPDES-regulated stormwater systems. Since the entire Lower Monocacy River watershed is covered by NPDES MS4 permits, bacteria loads from domestic animal sources are assigned to the SW WLA_{LM} in all nine subwatersheds of the Lower Monocacy River. However, wildlife sources will be distributed between the LA_{LM} and the SW WLA_{LM}, based on a ratio of the amount of pervious non-urban and pervious urban land.

Waste Load Allocation (WLA_{LM})

NPDES Regulated Stormwater

Both individual and general NPDES Phase I and Phase II stormwater permits are point sources subject to WLA assignment in the TMDL. Quantification of rainfall-driven nonpoint source loads, such as those transported by stormwater through MS4s, 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 are grouped together into a single SW WLA along with other potential nonpoint source loads such as human and wildlife loads. This allowable human load in the $SWWLA_{LM}$ is estimated by subtracting any WWTP and CSO loads from the total allowable (TMDL) human load. There are 17 NPDES WWTPs with permits regulating the discharge of bacteria in the Lower Monocacy River watershed. There are no NPDES CSO permits in the watershed. The SW WLA_{LM} wildlife load is estimated as explained above. In watersheds with no existing NPDES-regulated stormwater permits, these loads will be included in the LA.

The jurisdictions within the Lower Monocacy River watershed, Carroll, Frederick, and Montgomery Counties, are covered by individual Phase I MS4 program regulations. Based on EPA's guidance, the Stormwater WLA_{LM} 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. In addition to the counties' MS4s, the Stormwater WLA_{LM} category encompasses any other NPDES regulated Phase I and Phase II stormwater discharges in the watershed, including State and federal entities. The Stormwater WLA_{LM} distribution between Carroll, Frederick, and Montgomery Counties is presented in Table 4.8.2.

Table 4.8.2: Annual Average Stormwater Allocations

Station	Stormwater WLA Loads (Billion MPN *E. Coli*/year)						
	Carroll	%	Frederick	%	Montgomery	%	Total
BEN0022	0	0%	10,639	52%	9,947	48%	20,586
BNG0005	0	0%	7,662	100%	0	0%	7,662
BSC0013	0	0%	12,155	100%	1	0%	12,157
CAR0001	0	0%	8,715	100%	0	0%	8,715
ISR0022	0	0%	5,755	100%	0	0%	5,755
LIN0005sub	0	0%	95,216	100%	0	0%	95,216
LIN0072	1,855	14%	11,543	86%	0	0%	13,398
MON0004sub	0	0%	11,157	97%	344	3%	11,502
MON0155sub	0	0%	21,050	100%	0	0%	21,050
Total	**1,856**		**183,893**		**10,293**		**196,041**

Municipal and Industrial WWTP

As explained in the source assessment section above, there are seventeen municipal WWTP with permits regulating the discharge of bacteria into the Lower Monocacy River. The WLA for each WWTP is estimated using the design flow of the plant stated in the facility NPDES permit and the *E. coli* criterion of 126 MPN/100ml. Bacteria loads assigned to these WWTPs are allocated as the WWTP WLA.

4.9 Summary

The long-term annual average TMDL and TMDL allocations are presented in Table 4.9.1. Table 4.9.2 presents the maximum daily loads for the subwatersheds in the Lower Monocacy River MD 8-digit basin. Table 4.9.3 presents a summary of the final long-term annual average Lower Monocacy River fecal bacteria TMDL and Table 4.9.4 provides a summary of the maximum daily loads.

Table 4.9.1: Lower Monocacy River Watershed TMDL

Subwatershed	Total Allocation	LA	Stormwater WLA	WWTP WLA
	Billion MPN *E. Coli*/year			
BEN0022	87,950	67,147	20,586	218
BNG0005	25,679	17,970	7,662	47
BSC0013	49,585	36,435	12,157	992
CAR0001	17,811	9,075	8,715	21
ISR0022	20,656	14,728	5,755	174
LIN0005sub	219,857	124,641	95,216	N/A
LIN0072	82,739	69,253	13,398	87
MON0004sub	112,257	62,377	11,502	38,379
MON0155sub	62,995	24,535	21,050	17,409
Lower Monocacy 8-Digit Total	**679,529**	**426,161**	**196,041**	**57,327**
Upper Monocacy Upstream Load	**1,353,850**			
TMDL[1]	**2,033,379**			

[1]The MOS is incorporated.

Table 4.9.2: Lower Monocacy River Watershed Maximum Daily Loads

Station	MDL	LA	Stormwater WLA	WWTP WLA
	Billion MPN *E. Coli*/day			
BEN0022	1,163	888	273	1.85
BNG0005	295	207	88	0.40
BSC0013	800	588	204	8.46
CAR0001	182	93	89	0.18
ISR0022	505	360	144	1.48
LIN0005sub	6,982	3,958	3,024	N/A
LIN0072	921	771	149	0.74
MON0004sub	2,170	1,206	637	327.01
MON0155sub	1,029	401	480	148.34
Lower Monocacy 8-Digit Total*	**14,048**	**8,471**	**5,088**	**488**
Upper Monocacy Upstream Load	**105,797**			
Total	**119,845**			

*This total load represents the sum of the individual MDLs of the subwatersheds presented above.

Table 4.9.3: Lower Monocacy River Watershed Annual Average TMDL Summary

TMDL Billion MPN *E. coli*/year	=	LA_{LM}	+	WLA_{LM}	+	LA_{UM}	+	MOS
		Billion MPN *E. coli*/year						
2,033,379	=	426,161	+	253,368	+	1,353,850[1]	+	Incorporated

[1]This upstream load is equivalent to the Upper Monocacy River TMDL.

Table 4.9.4: Lower Monocacy River Watershed Annual Average MDL Summary

MDL Billion MPN *E. coli*/day	=	LA_{LM}	+	WLA_{LM}	+	LA_{UM}	+	MOS
		Billion MPN *E. coli*/year						
119,845	=	8,471	+	5,577	+	105,797[1]	+	Incorporated

[1]This upstream load is equivalent to the total Upper Monocacy River MDL.

In eight of the nine Lower Monocacy River subwatersheds, water quality standards cannot be achieved with the maximum practicable reduction rates specified. This occurs in 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 these cases, 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 Lower Monocacy River watershed, the TMDL analysis indicates that, for eight of nine subwatersheds, the reduction of fecal bacteria loads from all sources including wildlife 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 Lower Monocacy River may not be able to attain water quality standards. The fecal bacteria load reductions required to meet water quality criteria in eight of nine subwatersheds of the Lower Monocacy River are not feasible by implementing effluent limitations and cost-effective, reasonable BMPs to nonpoint sources. Therefore, MDE proposes a staged approach to implementation beginning with the MPR scenario, with regularly scheduled follow-up monitoring to assess the effectiveness of the implementation plan.

Additional reductions will be achieved through the implementation of BMPs; however, the literature reports considerable uncertainty concerning the effectiveness of BMPs in treating bacteria. 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.

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.

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. Neither Maryland nor EPA is proposing the elimination of wildlife to allow for the attainment of water quality standards, although 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.

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Appendix A – Bacteria Data

Table A-1: Measured Bacteria Concentration with Daily Flow Frequency

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
BEN0022	11/03/2003	12.4215	350
BEN0022	11/17/2003	20.2093	110
BEN0022	12/01/2003	8.7892	300
BEN0022	12/15/2003	2.6756	1330
BEN0022	01/06/2004	15.3064	500
BEN0022	01/21/2004	40.9865	10
BEN0022	02/04/2004	16.3079	230
BEN0022	02/18/2004	20.5082	20
BEN0022	03/02/2004	24.7982	60
BEN0022	03/16/2004	23.9013	100
BEN0022	04/06/2004	12.4215	110
BEN0022	04/20/2004	16.3079	180
BEN0022	05/11/2004	32.7952	100
BEN0022	05/25/2004	29.8356	220
BEN0022	06/08/2004	33.2735	600
BEN0022	06/22/2004	46.9656	160
BEN0022	07/07/2004	58.8640	170
BEN0022	07/20/2004	65.3363	200
BEN0022	08/10/2004	98.4155	110
BEN0022	08/24/2004	96.3378	120
BEN0022	09/08/2004	21.0463	1400
BEN0022	09/21/2004	68.9985	700
BEN0022	10/05/2004	61.0463	180
BEN0022	10/19/2004	61.0463	110
BNG0005	11/03/2003	21.3668	200
BNG0005	11/17/2003	27.4097	60

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
BNG0005	12/01/2003	13.0856	230
BNG0005	12/15/2003	4.5807	1190
BNG0005	01/06/2004	12.9961	300
BNG0005	01/21/2004	61.5339	60
BNG0005	02/04/2004	20.8744	600
BNG0005	02/18/2004	30.1850	50
BNG0005	03/02/2004	20.8744	50
BNG0005	03/16/2004	31.7816	120
BNG0005	04/06/2004	16.0400	120
BNG0005	04/20/2004	21.0534	100
BNG0005	05/11/2004	36.4369	450
BNG0005	05/25/2004	43.0916	370
BNG0005	06/08/2004	18.0842	1080
BNG0005	06/22/2004	41.1668	500
BNG0005	07/07/2004	63.2199	560
BNG0005	07/20/2004	68.5915	310
BNG0005	08/10/2004	71.5309	230
BNG0005	08/24/2004	63.9958	190
BNG0005	09/08/2004	79.7523	1240
BNG0005	09/21/2004	50.8953	290
BNG0005	10/05/2004	41.1221	380
BNG0005	10/19/2004	60.4745	220
BSC0013	11/03/2003	21.3668	200
BSC0013	11/17/2003	27.4097	300
BSC0013	12/01/2003	13.0856	880
BSC0013	12/15/2003	4.5807	2140
BSC0013	01/06/2004	12.9961	1270
BSC0013	01/21/2004	61.5339	40
BSC0013	02/18/2004	30.1850	170
BSC0013	03/02/2004	20.8744	50

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
BSC0013	03/16/2004	31.7816	90
BSC0013	04/06/2004	16.0400	760
BSC0013	04/20/2004	21.0534	1450
BSC0013	05/11/2004	36.4369	420
BSC0013	05/25/2004	43.0916	240
BSC0013	06/08/2004	18.0842	1070
BSC0013	06/22/2004	41.1668	230
BSC0013	07/07/2004	63.2199	400
BSC0013	07/20/2004	68.5915	300
BSC0013	08/10/2004	71.5309	490
BSC0013	08/24/2004	63.9958	320
BSC0013	09/08/2004	79.7523	930
BSC0013	09/21/2004	50.8953	540
BSC0013	10/05/2004	41.1221	260
BSC0013	10/19/2004	60.4745	60
CAR0001	11/03/2003	21.3668	820
CAR0001	11/17/2003	27.4097	360
CAR0001	12/01/2003	13.0856	350
CAR0001	12/15/2003	4.5807	740
CAR0001	01/06/2004	12.9961	420
CAR0001	01/21/2004	61.5339	130
CAR0001	02/04/2004	20.8744	1260
CAR0001	02/18/2004	30.1850	820
CAR0001	03/02/2004	20.8744	440
CAR0001	03/16/2004	31.7816	4110
CAR0001	04/06/2004	16.0400	1010
CAR0001	04/20/2004	21.0534	760
CAR0001	05/11/2004	36.4369	860
CAR0001	05/25/2004	43.0916	1500
CAR0001	06/08/2004	18.0842	1720

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
CAR0001	06/22/2004	41.1668	74
CAR0001	07/07/2004	63.2199	2250
CAR0001	07/20/2004	68.5915	1080
CAR0001	08/24/2004	63.9958	1200
CAR0001	09/08/2004	79.7523	5170
CAR0001	09/21/2004	50.8953	1330
CAR0001	10/05/2004	41.1221	1150
CAR0001	10/19/2004	60.4745	2380
ISR0022	11/03/2003	21.3668	430
ISR0022	11/17/2003	27.4097	110
ISR0022	12/01/2003	13.0856	570
ISR0022	12/15/2003	4.5807	2280
ISR0022	01/06/2004	12.9961	130
ISR0022	02/04/2004	20.8744	560
ISR0022	02/18/2004	30.1850	20
ISR0022	03/02/2004	20.8744	160
ISR0022	03/16/2004	31.7816	170
ISR0022	04/06/2004	16.0400	340
ISR0022	04/20/2004	21.0534	210
ISR0022	05/11/2004	36.4369	4350
ISR0022	05/25/2004	43.0916	2900
ISR0022	06/08/2004	18.0842	1470
ISR0022	06/22/2004	41.1668	276
ISR0022	07/07/2004	63.2199	11200
ISR0022	07/20/2004	68.5915	7700
ISR0022	08/10/2004	71.5309	3870
ISR0022	08/24/2004	63.9958	2380
ISR0022	09/08/2004	79.7523	2490
ISR0022	09/21/2004	50.8953	7270
ISR0022	10/05/2004	41.1221	1400

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
ISR0022	10/19/2004	60.4745	760
LIN0005	11/03/2003	21.3668	170
LIN0005	11/17/2003	27.4097	620
LIN0005	12/01/2003	13.0856	5170
LIN0005	12/15/2003	4.5807	1190
LIN0005	01/06/2004	12.9961	10
LIN0005	01/21/2004	61.5339	10
LIN0005	02/04/2004	20.8744	20
LIN0005	02/18/2004	30.1850	30
LIN0005	03/02/2004	20.8744	10
LIN0005	03/16/2004	31.7816	20
LIN0005	04/06/2004	16.0400	2610
LIN0005	04/20/2004	21.0534	160
LIN0005	05/11/2004	36.4369	40
LIN0005	05/25/2004	43.0916	70
LIN0005	06/08/2004	18.0842	350
LIN0005	06/22/2004	41.1668	30
LIN0005	07/07/2004	63.2199	120
LIN0005	07/20/2004	68.5915	90
LIN0005	08/10/2004	71.5309	90
LIN0005	08/24/2004	63.9958	120
LIN0005	09/08/2004	79.7523	670
LIN0005	09/21/2004	50.8953	440
LIN0005	10/05/2004	41.1221	840
LIN0005	10/19/2004	60.4745	130
LIN0072	11/03/2003	21.3668	910
LIN0072	11/17/2003	27.4097	420
LIN0072	12/01/2003	13.0856	700
LIN0072	12/15/2003	4.5807	3260
LIN0072	01/06/2004	12.9961	770

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
LIN0072	01/21/2004	61.5339	60
LIN0072	02/04/2004	20.8744	1150
LIN0072	02/18/2004	30.1850	90
LIN0072	03/02/2004	20.8744	190
LIN0072	03/16/2004	31.7816	160
LIN0072	04/06/2004	16.0400	310
LIN0072	04/20/2004	21.0534	820
LIN0072	05/11/2004	36.4369	750
LIN0072	05/25/2004	43.0916	1500
LIN0072	06/08/2004	18.0842	2490
LIN0072	06/22/2004	41.1668	148
LIN0072	07/07/2004	63.2199	1520
LIN0072	07/20/2004	68.5915	1990
LIN0072	08/10/2004	71.5309	1720
LIN0072	08/24/2004	63.9958	700
LIN0072	09/08/2004	79.7523	2040
LIN0072	09/21/2004	50.8953	860
LIN0072	10/05/2004	41.1221	1110
LIN0072	10/19/2004	60.4745	800
MON0004	11/03/2003	21.3668	210
MON0004	11/17/2003	27.4097	70
MON0004	12/01/2003	13.0856	1050
MON0004	12/15/2003	4.5807	1140
MON0004	01/06/2004	12.9961	540
MON0004	01/21/2004	61.5339	20
MON0004	02/18/2004	30.1850	10
MON0004	03/02/2004	20.8744	30
MON0004	03/16/2004	31.7816	30
MON0004	04/06/2004	16.0400	330
MON0004	04/20/2004	21.0534	50

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
MON0004	05/11/2004	36.4369	250
MON0004	05/25/2004	43.0916	100
MON0004	06/08/2004	18.0842	1580
MON0004	06/22/2004	41.1668	200
MON0004	07/07/2004	63.2199	880
MON0004	07/20/2004	68.5915	30
MON0004	08/10/2004	71.5309	90
MON0004	08/24/2004	63.9958	120
MON0004	09/08/2004	79.7523	190
MON0004	09/21/2004	50.8953	720
MON0004	10/05/2004	41.1221	710
MON0004	10/19/2004	60.4745	70
MON0155	11/03/2003	21.3668	350
MON0155	11/17/2003	27.4097	310
MON0155	12/01/2003	13.0856	1380
MON0155	12/15/2003	4.5807	1110
MON0155	01/06/2004	12.9961	520
MON0155	01/21/2004	61.5339	20
MON0155	02/04/2004	20.8744	220
MON0155	02/18/2004	30.1850	30
MON0155	03/02/2004	20.8744	30
MON0155	03/16/2004	31.7816	10
MON0155	04/06/2004	16.0400	770
MON0155	04/20/2004	21.0534	110
MON0155	05/11/2004	36.4369	160
MON0155	05/25/2004	43.0916	240
MON0155	06/08/2004	18.0842	1020
MON0155	06/22/2004	41.1668	280
MON0155	07/07/2004	63.2199	830
MON0155	07/20/2004	68.5915	120

Sampling Station Identifier	Date	Daily flow frequency	*E. coli* MPN/100ml
MON0155	08/10/2004	71.5309	150
MON0155	08/24/2004	63.9958	280
MON0155	09/08/2004	79.7523	150
MON0155	09/21/2004	50.8953	700
MON0155	10/05/2004	41.1221	310
MON0155	10/19/2004	60.4745	90

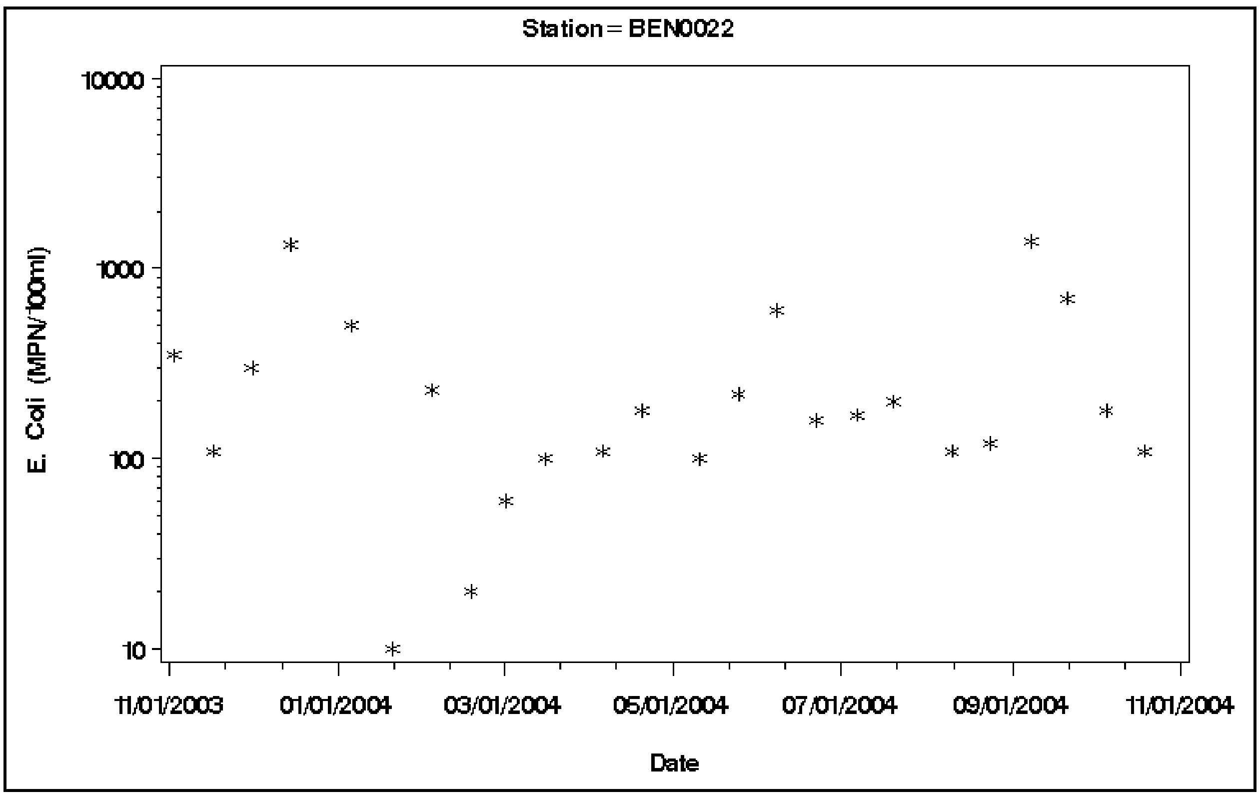

Figure A-1: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station BEN0022

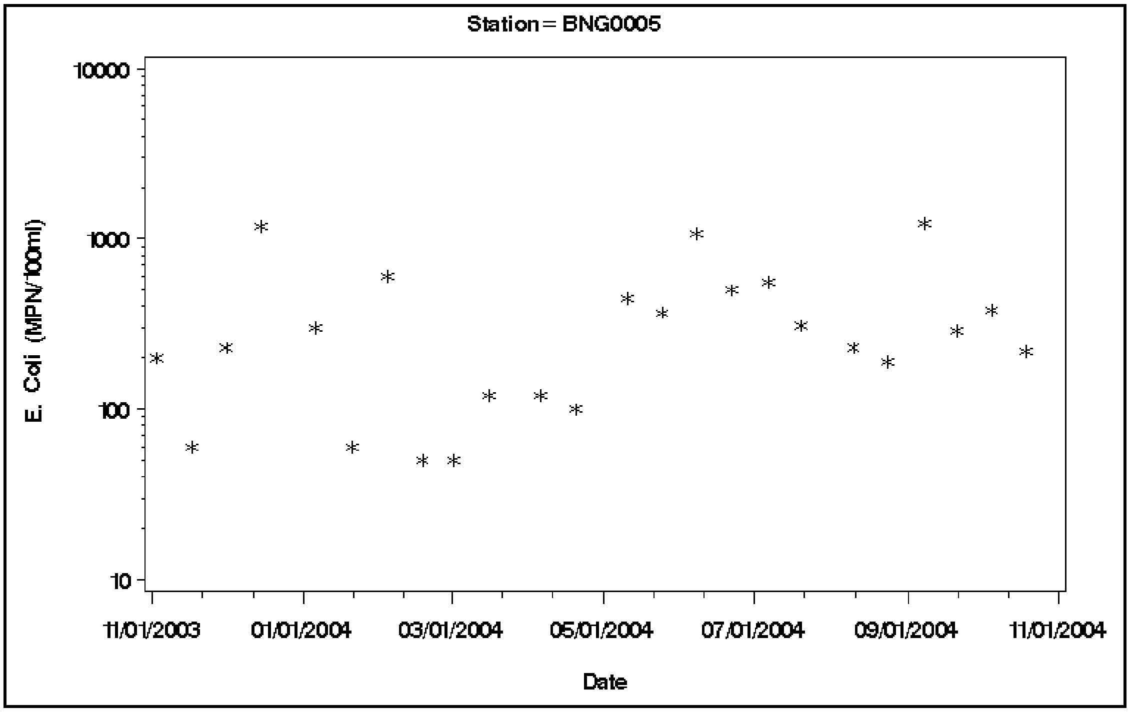

Figure A-2: ***E. coli*** **Concentration vs. Time for the Lower Monocacy River Monitoring Station BNG0005**

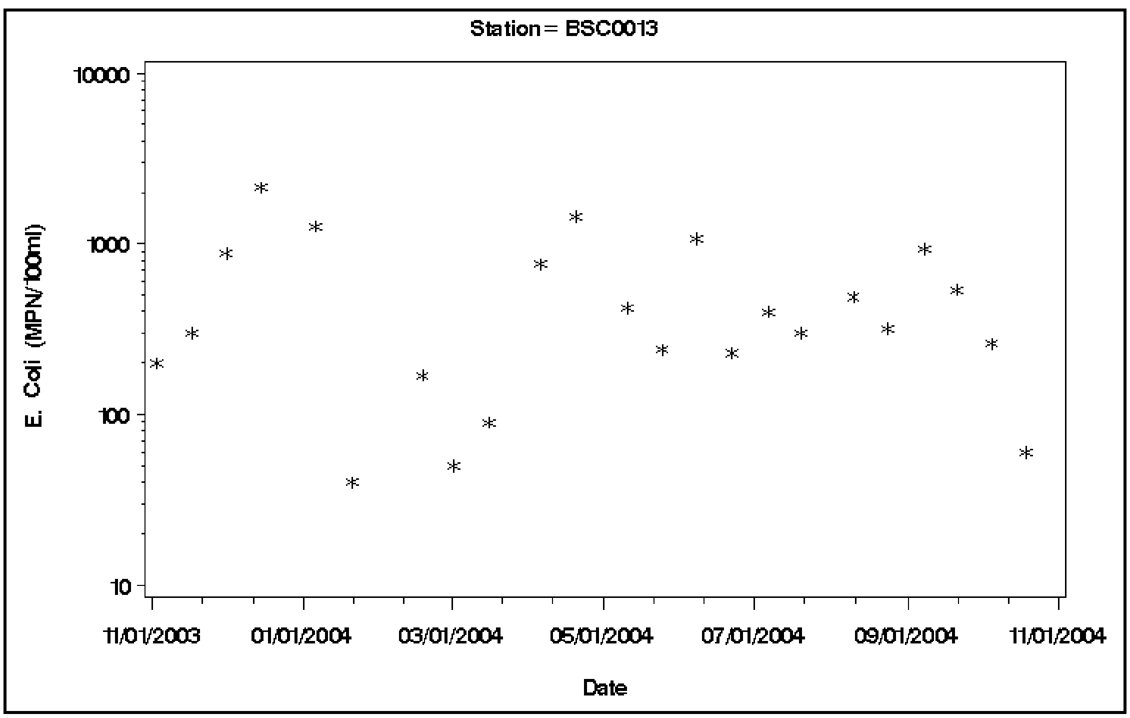

Figure A-3: ***E. coli*** **Concentration vs. Time for the Lower Monocacy River Monitoring Station BSC0013**

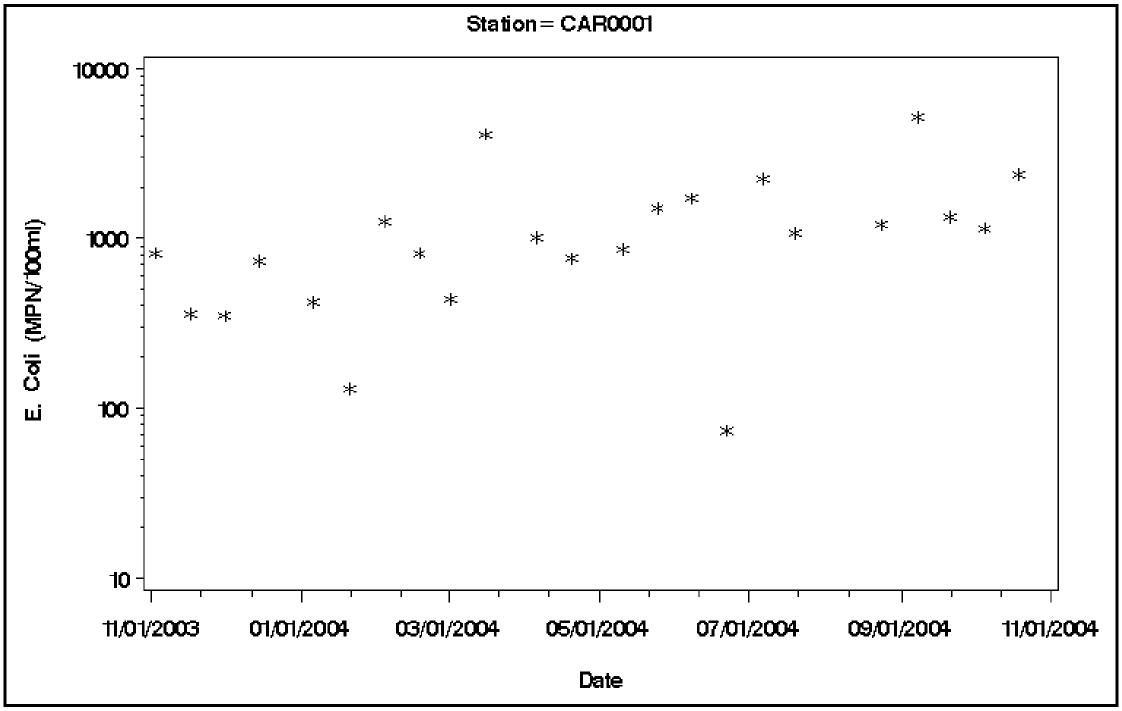

Figure A-4: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station CAR0001

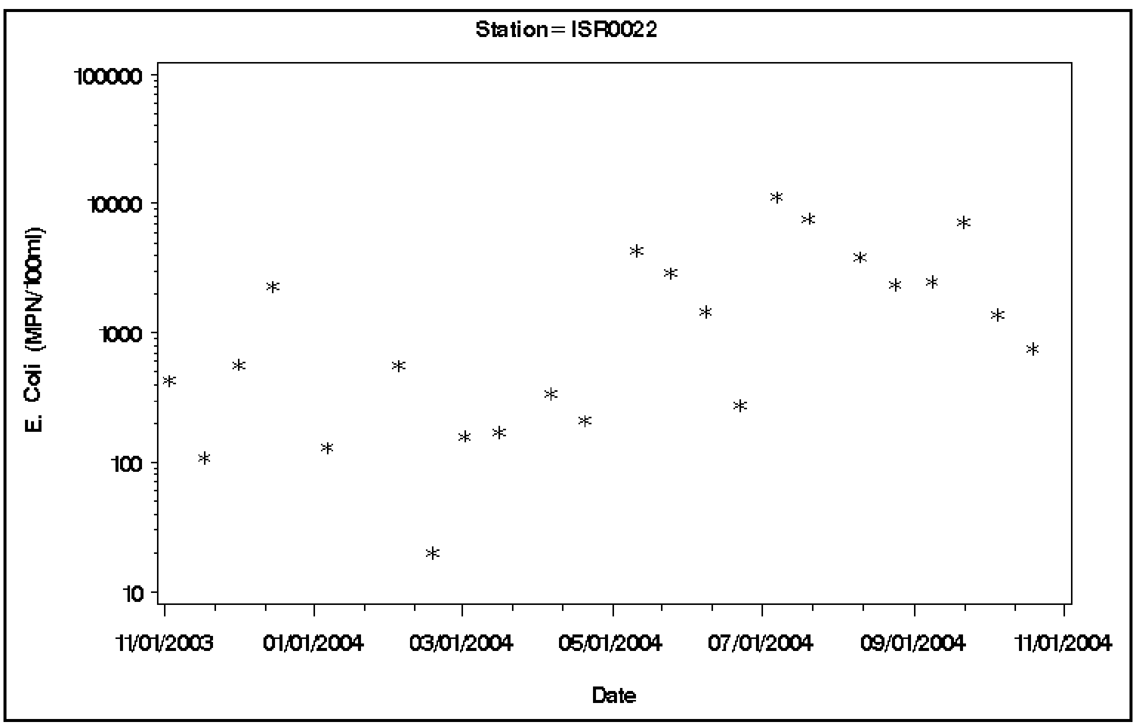

Figure A-5: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station ISR0022

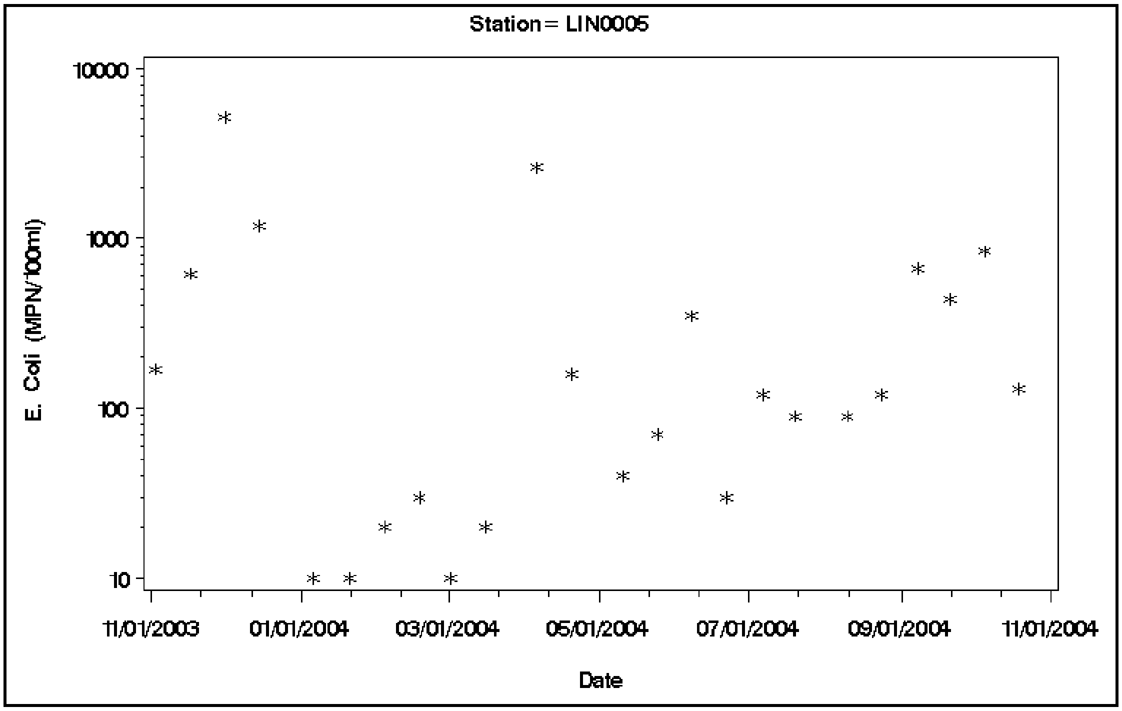

Figure A-6: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station LIN0005

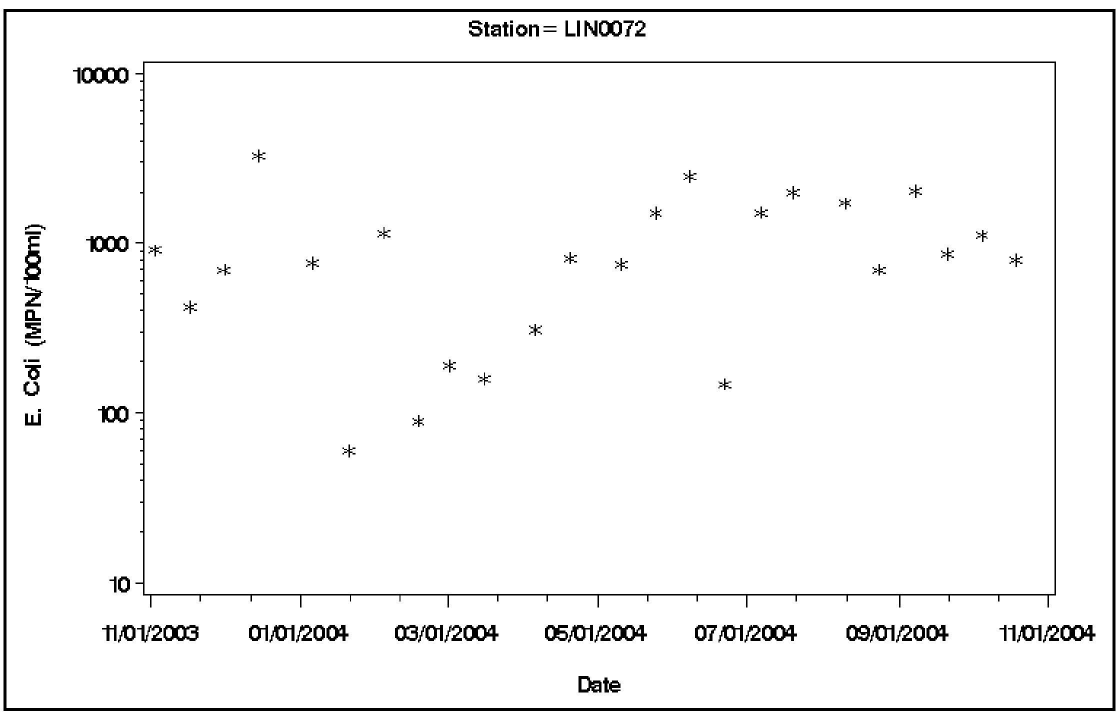

Figure A-7: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station LIN0072

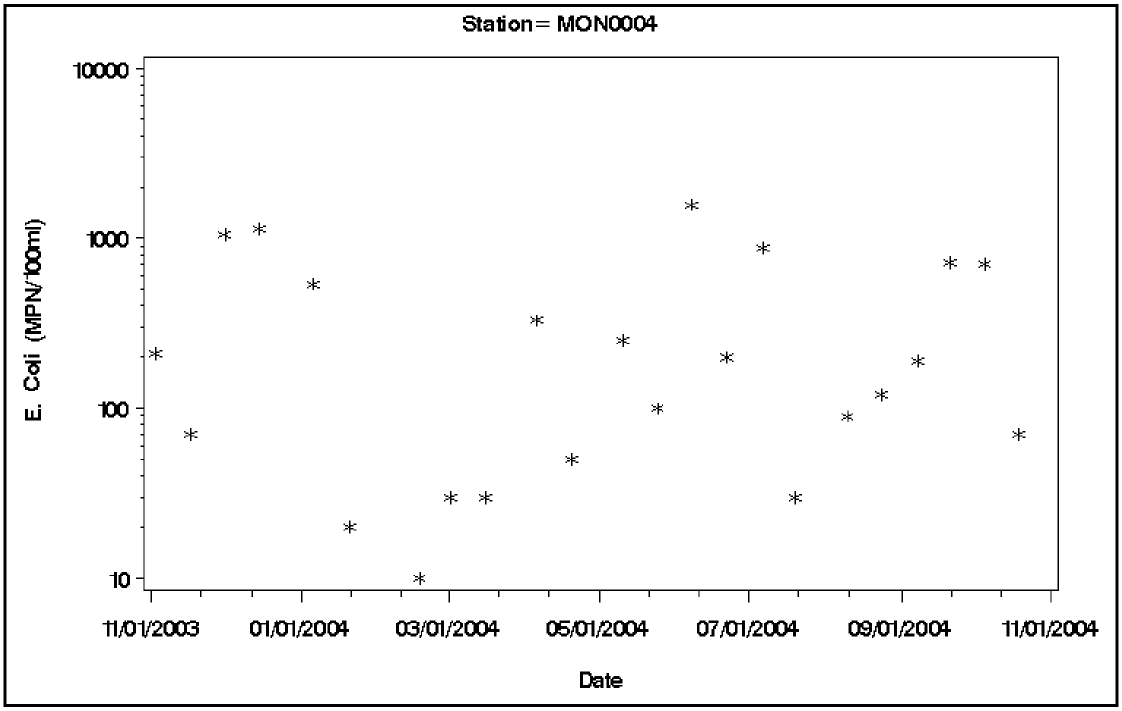

Figure A-7: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station MON0004

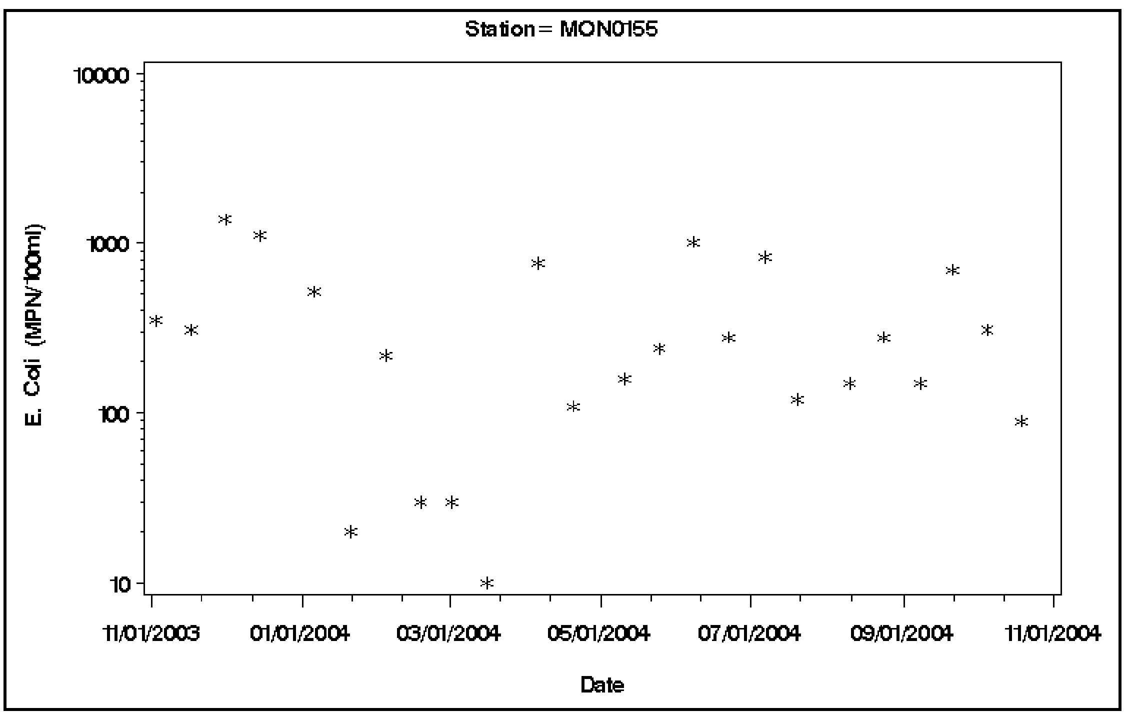

Figure A-7: *E. coli* Concentration vs. Time for the Lower Monocacy River Monitoring Station MON0155

Appendix B – Flow Duration Curve Analysis to Define Strata

The Lower Monocacy River watershed was 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 exceedance. 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 Lower Monocacy River watershed has two active USGS flow gauges. The gauges and dates of information used are as follows:

Table B-1: USGS Gauges in the Lower Monocacy River Watershed

USGS Gauge #	Dates used	Description
01643000	October 1, 1988 to September 30, 2004	Monocacy River at Jug Bridge Near Frederick, Md
01643500	October 1, 1988 to September 30, 2004	Bennett Creek at Park Mills, Md

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

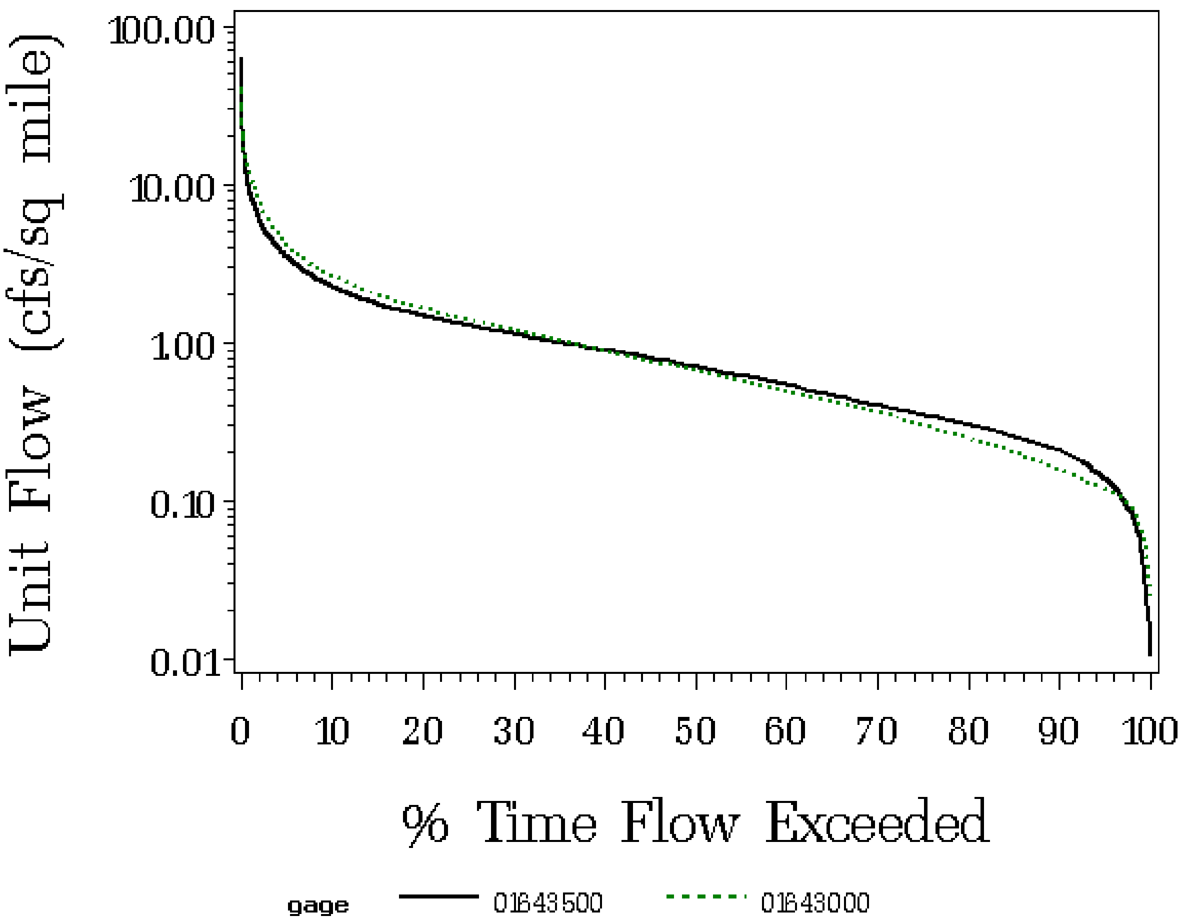

Figure B-1: Lower Monocacy River Flow Duration Curves

Based on the long-term flow data for the Lower Monocacy River watershed and other watersheds in the region (*i.e.* Double Pipe Creek and the Upper Monocacy River), the long term average daily unit flows range between 1.2 to 1.4 cfs/sq. mile, which corresponds to a range of 21^{st} to 28^{th} flow frequency based on the flow duration curves of these watersheds. Using the definition of a high flow condition as occurring when flows are higher than the long-term average flow and a low flow condition as occurring when flows are lower than the long-term average flow, the 25^{th} percentile threshold was selected to define the limits between high flows and low flows in this watershed. Therefore, a high flow condition will be defined as occurring when the daily flow duration percentile is less than 25% and a low flow condition will be defined as occurring when the daily flow duration percentile is greater than 25%. 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 (*E. coli*) monitoring data are "placed" within the regions (strata) based on the daily flow duration percentile of the date of sampling. Figures B-2 to B-8 show the Lower Monocacy River *E. coli* monitoring data with corresponding flow frequency for the average annual condition.

Maryland's water quality standards for bacteria state that, when available, the geometric mean indicator should be based on at least five samples taken representatively over 30 days. Therefore, in situations in which fewer than five samples "fall" within a particular flow regime interval, the interval and the adjacent interval will be joined. In the Lower Monocacy River, for the annual average flow condition, there are sufficient samples in both the high flow strata to estimate the geometric means. However, in the seasonal (May 1st – September 30th) flow condition, there are no sufficient samples within the high flow strata to estimate geometric means; therefore, for this condition an average seasonal geometric mean will be calculated.

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

Weighted geometric means for the average annual condition are plotted with the monitoring data on Figures B-2 to B-10.

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

USGS Gage	Hydrological Condition		Subwatershed	Weighting Factor High Flow	Weighting Factor Low Flow
01643000	Annual	Average	All	0.25	0.75
		Wet	All	0.602	0.398
		Dry	All	0.014	0.986
	Seasonal	Wet	All	0.520	0.480
		Dry	All	0.000	1.000
01643500	Annual	Average	All	0.25	0.75
		Wet	All	0.764	0.236
		Dry	All	0.019	0.981
	Seasonal	Wet	All	0.579	0.421
		Dry	All	0.007	0.993

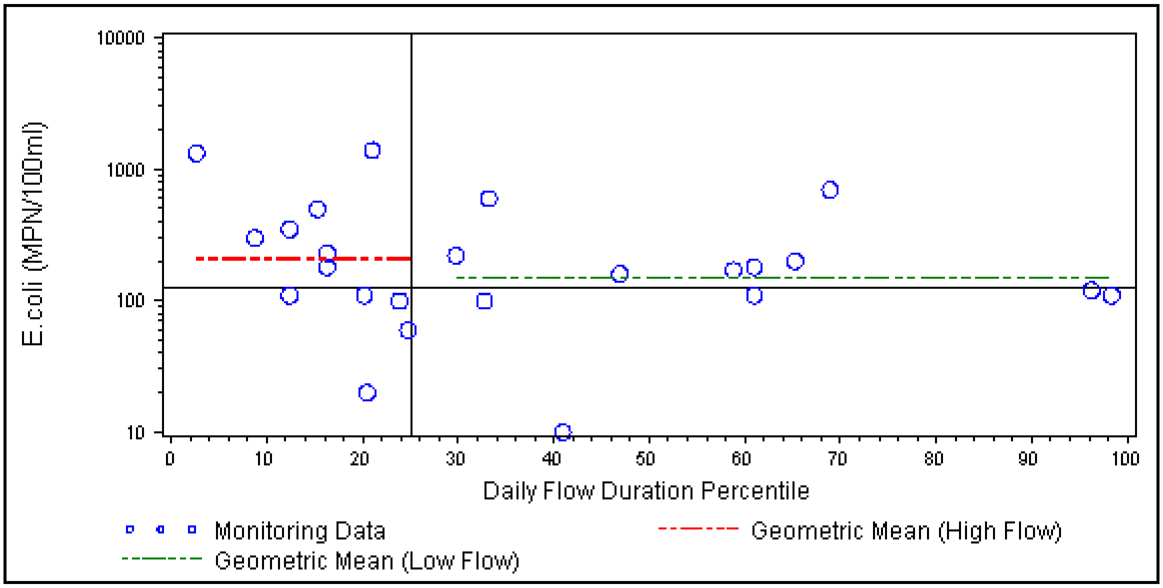

Figure B-2: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station BEN0022

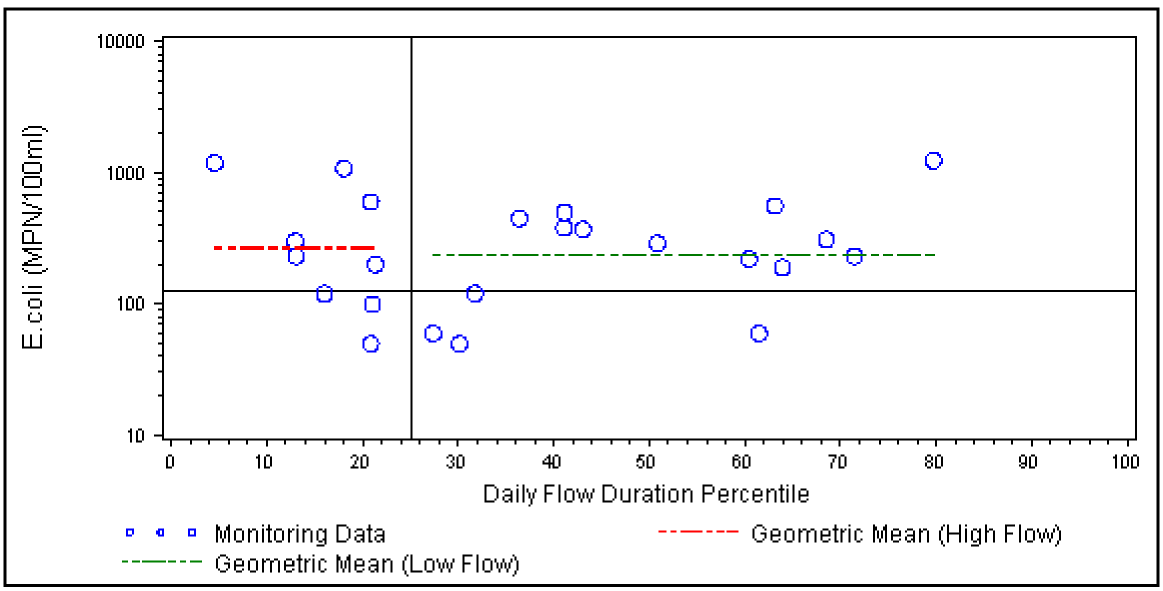

Figure B-3: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station BNG0005

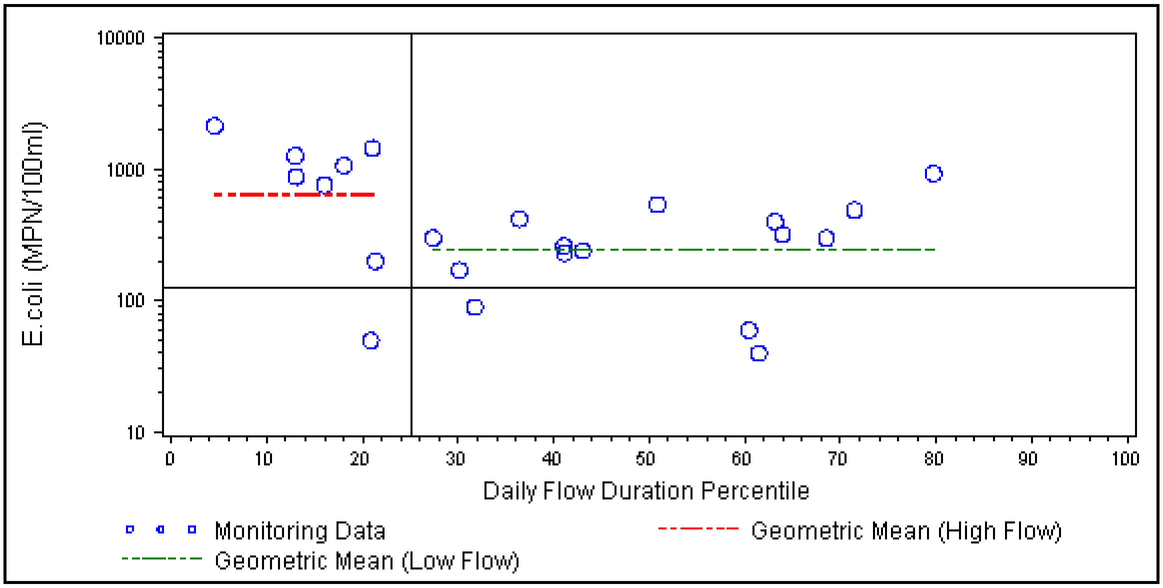

Figure B-4: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station BSC0013

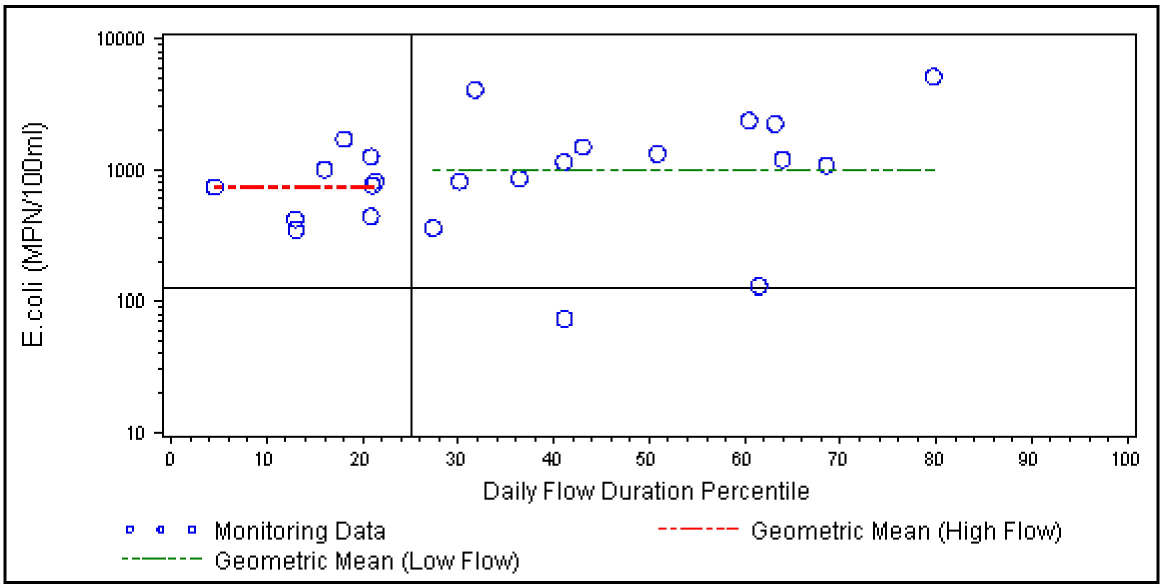

Figure B-5: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station CAR0001

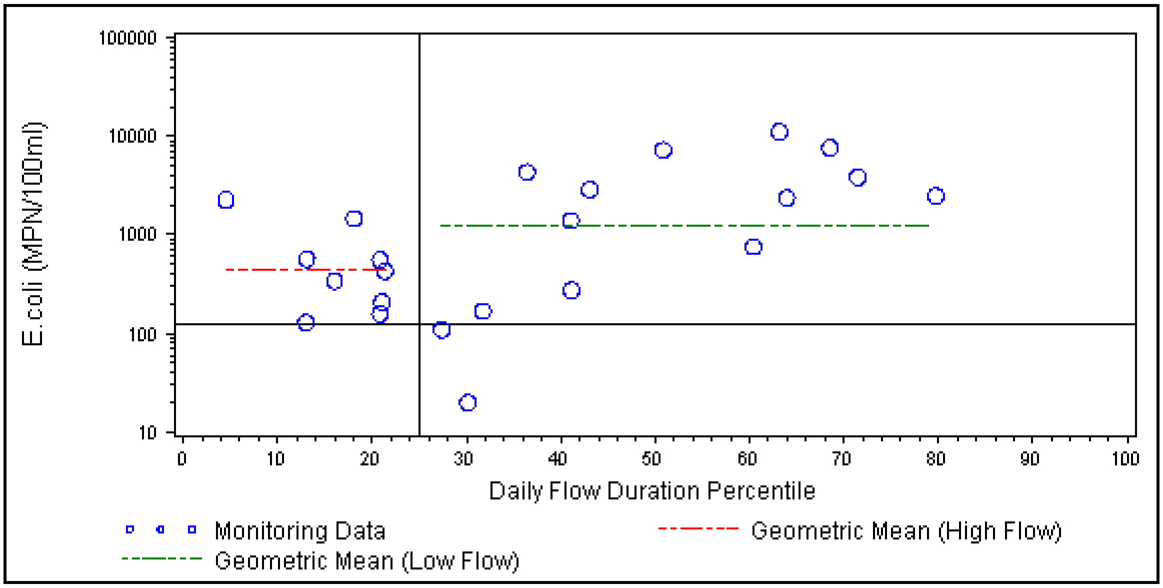

Figure B-6: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station ISR0022

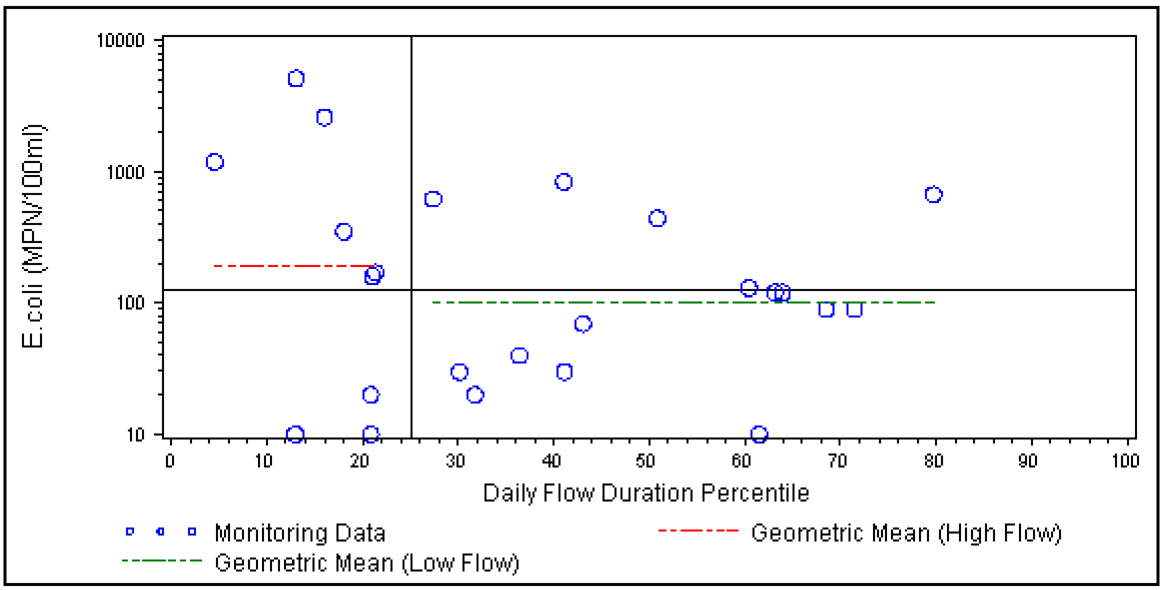

Figure B-7: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station LIN0005

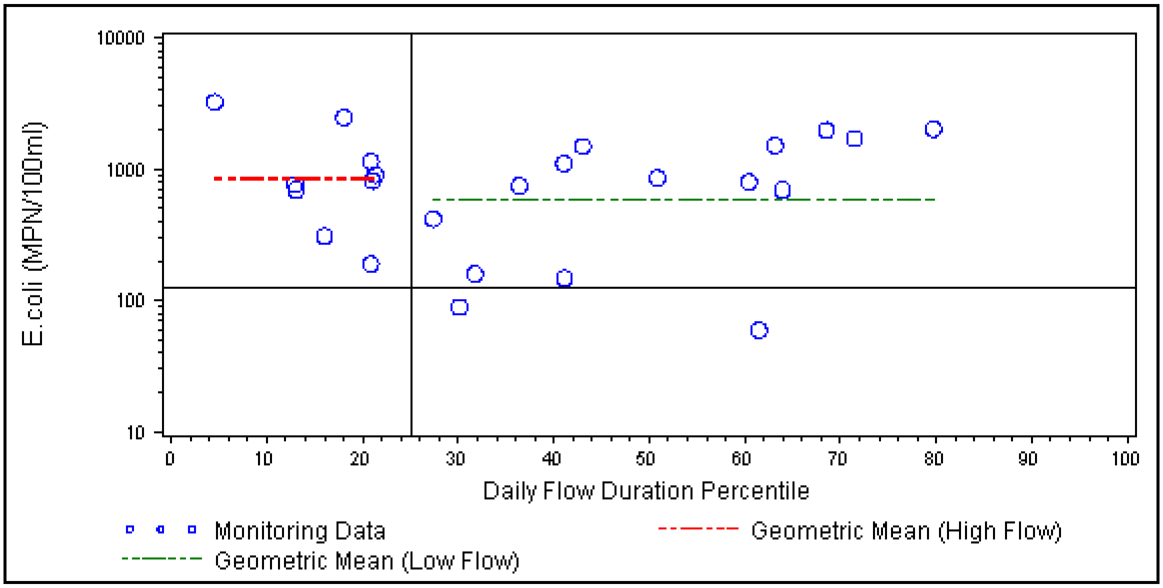

Figure B-8: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station LIN0072

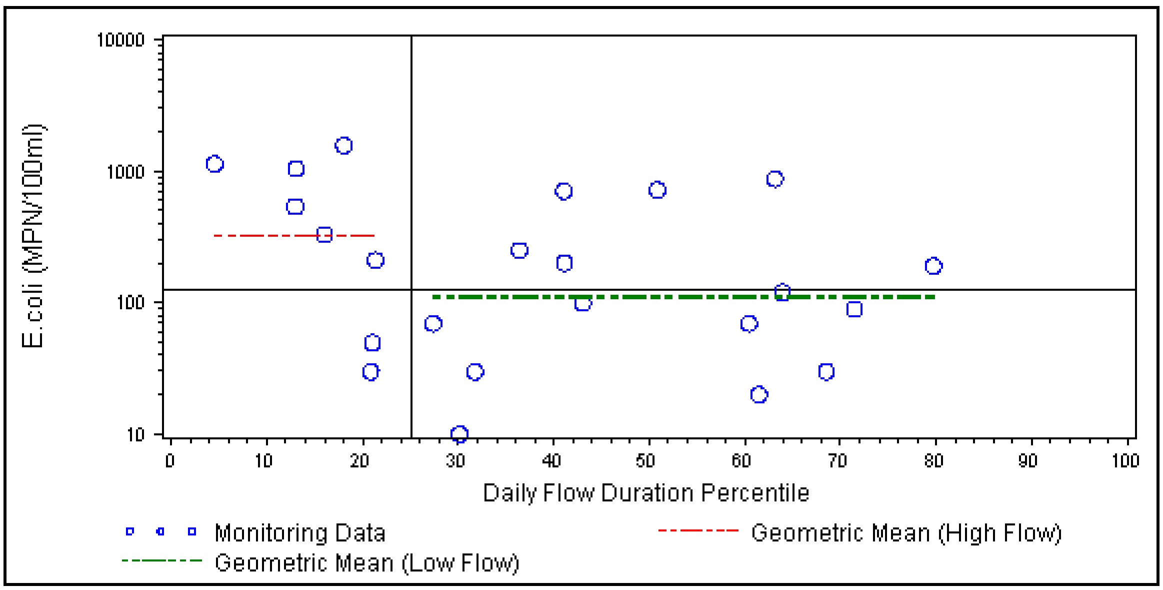

Figure B-9: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station MON0005

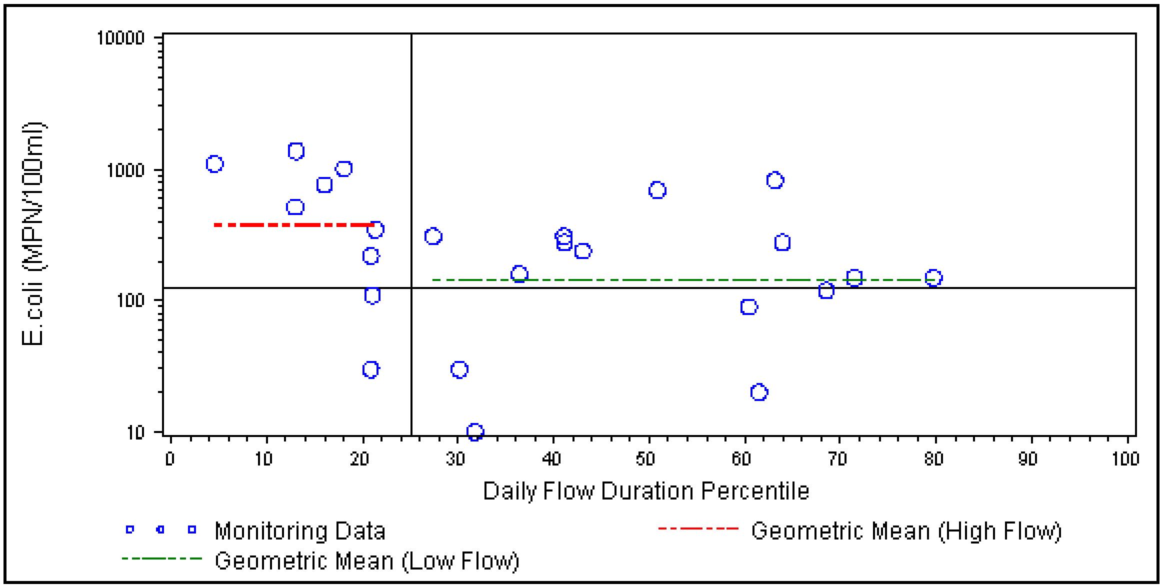

Figure B-10: *E. coli* Concentration vs. Flow Duration for the Lower Monocacy River Monitoring Station MON0155

Appendix C – BST Report

Identifying Sources of Fecal Pollution in Lower Monocacy River Watershed, Maryland

June 2004 – October 2006

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Department of Biological Sciences and Environmental Health Science
Salisbury University, Salisbury, MD

October 31, 2006

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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 sources 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 project, we studied the following Maryland nontidal watersheds: Antietam Creek, Concoheague Creek, Lower Monocacy River, Lower Monocacy River, and Upper Monocacy River. Also included in the study was the Potomac River Watershed shellfish harvesting area. The methodology used was the ARA 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). A pilot study using PFGE, a genotypic BST method, was used on a subset of known-source isolates collected from the Potomac River Watershed.

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 *Enterococcus* 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 37^{o} C, up to eight (8) *Enterococcus* isolates were randomly selected from each fecal sample for ARA testing.

Isolation of Enterococcus 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 *Enterococcus* 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 37^{o} 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 table includes the antibiotics and concentrations used for isolates in analyses for all the study watersheds.

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

Antibiotic	Concentration (µg/ml)
Amoxicillin	0.625
Cephalothin	10, 15, 30, 50
Chloramphenicol	10
Chlortetracycline	60, 80, 100
Erythromycin	10
Gentamycin	5, 10, 15
Neomycin	40, 60, 80
Oxytetracycline	20, 40, 60, 80, 100
Salinomycin	10
Streptomycin	40, 60, 80, 100
Tetracycline	10, 30, 50, 100
Vancomycin	2.5

KNOWN-SOURCE LIBRARY

Construction and Use. Fecal samples (scat) from known sources in each watershed were collected during the study period by MDE personnel and delivered to the BST Laboratory at SU. *Enterococcus* isolates were obtained from known sources (e.g., human, dog, cow, horse, deer, fox, rabbit, and goose). For each watershed, 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). *Enterococcus* isolate response patterns were also obtained from bacteria in water samples collected at the monitoring stations in each basin. Using statistical techniques, these patterns were then compared to those in the appropriate library to identify the probable source of each water isolate. A combined library of known sources was used for Antietam Creek and Concocheaque Creek Watersheds using patterns from scat obtained from both watersheds, and the water isolate patterns of each were compared to the combined library. A combined known-source library was also used for Lower Monocacy River, Lower Monocacy River, and Upper Monocacy River, with water isolate patterns of each compared to this combined library.

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 isolate with an unknown source), based that is most populous among the library isolates in the node. Each water sample isolate (i.e., an 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]

Lower Monocacy River Watershed ARA Results

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1 The Elements of Statistical Learning: Data Mining, Inference, and Prediction. Hastie T, Tibshirani R, and Friedman J. Springer 2001.

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.

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.

Known-Source Library. A 1,684 known-source isolate library was constructed that included 554 isolates from the Lower Monocacy River Watershed (LMO), 559 isolates from the Upper Monocacy River Watershed (UMO), combined with 571 isolates from sources in the Double Pipe Creek Watershed (DOP). The known sources in the combined library were grouped into four categories: humans, livestock (cows and horses), pets (specifically dogs), and wildlife (deer, fox, goose, muskrat, and raccoon) (see Table C-2). 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 library were found by repeating this analysis using several probability cutoff points, as described above. The number-not-classified for each probability was determined. From these results, the percent unknown and percent correct classification (RCCs) were calculated (Table C-3).

Table C-2: Lower Monocacy River. Category, total number, and number of unique patterns in the Lower Monocacy portion and in the combined DOP-LMO UMO known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
Lower Monocacy River Library:			
human	human	126	103
livestock	horse, cow	179	57
pet	dog	56	37
wildlife	deer, fox, goose, raccoon	193	44
Total		554	241
Double Pipe Creek Library:			
human	human	96	69
livestock	horse, cow	156	53
pet	dog	80	41
wildlife	deer, fox, goose, raccoon	239	78
Total		571	241
Upper Monocacy River Library:			
human	human	135	92
livestock	horse, cow	175	70
pet	dog	86	52
wildlife	deer, fox, goose, muskrat, raccoon	163	47
Total		559	261
Combined DOP-LMO-UMO Library:			
human	human	357	264
livestock	cow, horse	510	180
pet	dog	222	130
wildlife	deer, fox, goose, muskrat, raccoon	595	169
Total		1684	743

Table C-3: Lower Monocacy Creek. Number of isolates not classified, percent unknown, and percent correct for eight (8) threshold probabilities for LMO known source isolates using the combined DOP-LMO-UMO known-source library.

Threshold	0	0.25	0.375	0.5	0.6	0.7	0.8	0.9
% correct	65.5%	65.5%	67.7%	73.2%	76.1%	82.9%	91.6%	96.8%
% unknown	0.0%	0.0%	4.5%	26.5%	52.3%	72.6%	85.0%	88.6%
# not classified	0	0	25	147	290	402	471	491

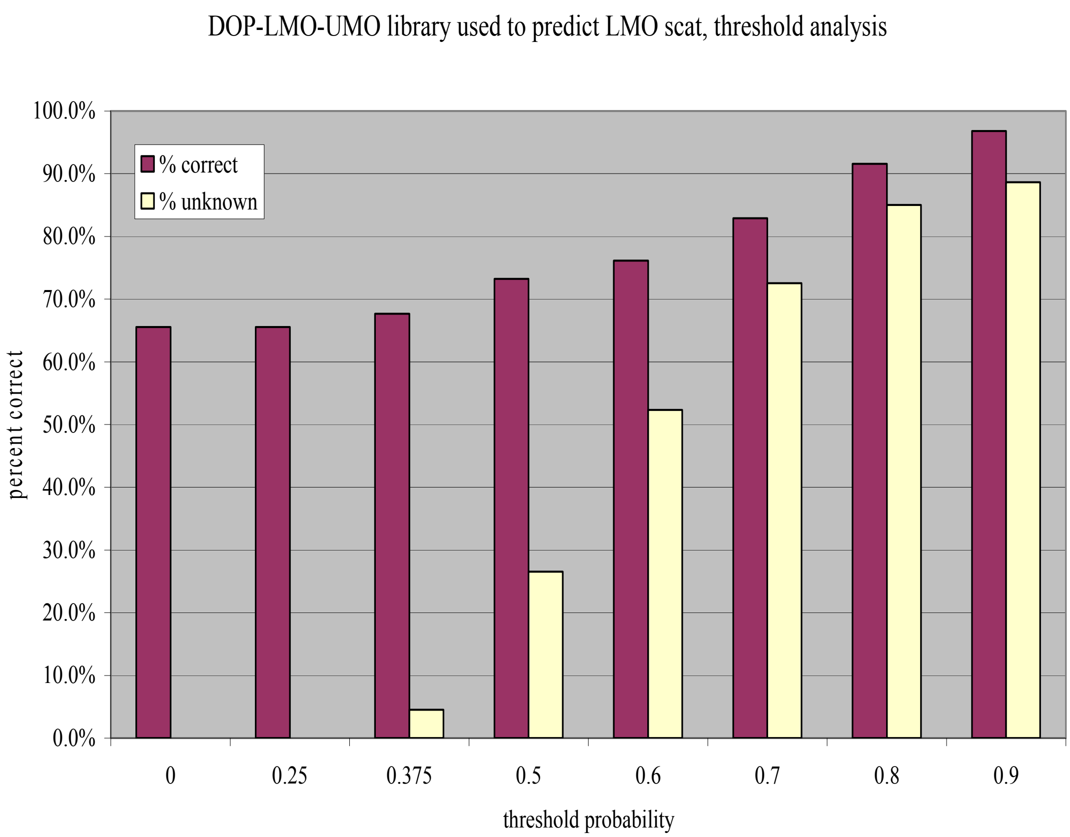

Figure C-1: Lower Monocacy Classification Model: Percent Correct versus Percent Unknown using a combined DOP-LMO-UMO library.

For the Lower Monocacy River Watershed, a cutoff probability of 0.50 (50%) was shown to yield an ARCC of 73 % (Table C-3). The rates of correction classification for the four categories of sources in the Lower Monocacy River portion of the library, using the cutoff probability of 0.50 (50%), are shown in Table C-4 below. The RCCs for human and pet are 74% and 88%, respectively, with 79% for wildlife, and 61% for livestock.

Table |C-4: Lower Monocacy River. Actual species categories versus predicted categories, at 50% probability cutoff, with rates of correct classification (RCC) for each category.

	Predicted						
Actual	human	livestock	pet	wildlife	Unknown	Total	RCC*
human	75	5	20	2	24	126	73.5%
livestock	8	78	4	37	52	179	61.4%
pet	5	1	43	0	7	56	87.8%
wildlife	5	17	5	102	64	193	79.1%
Total	93	101	72	141	147	554	

*RCC = Actual number of predicted species category / Total number predicted.
Example: 163 pet correctly predicted / 175 total number predicted for pet = 163/175 = 93%.

Lower Monocacy River Water Samples. Monthly monitoring from nine (9) monitoring stations on Lower Monocacy River was the source of water samples. The maximum number of *Enterococcus* isolates per water sample was 24, although the number of isolates that actually grew was sometimes fewer than 24. A total of 2,161 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicates that 80% of the water isolates were assigned to a probable host source when using a 0.50 (60%) probability cutoff.

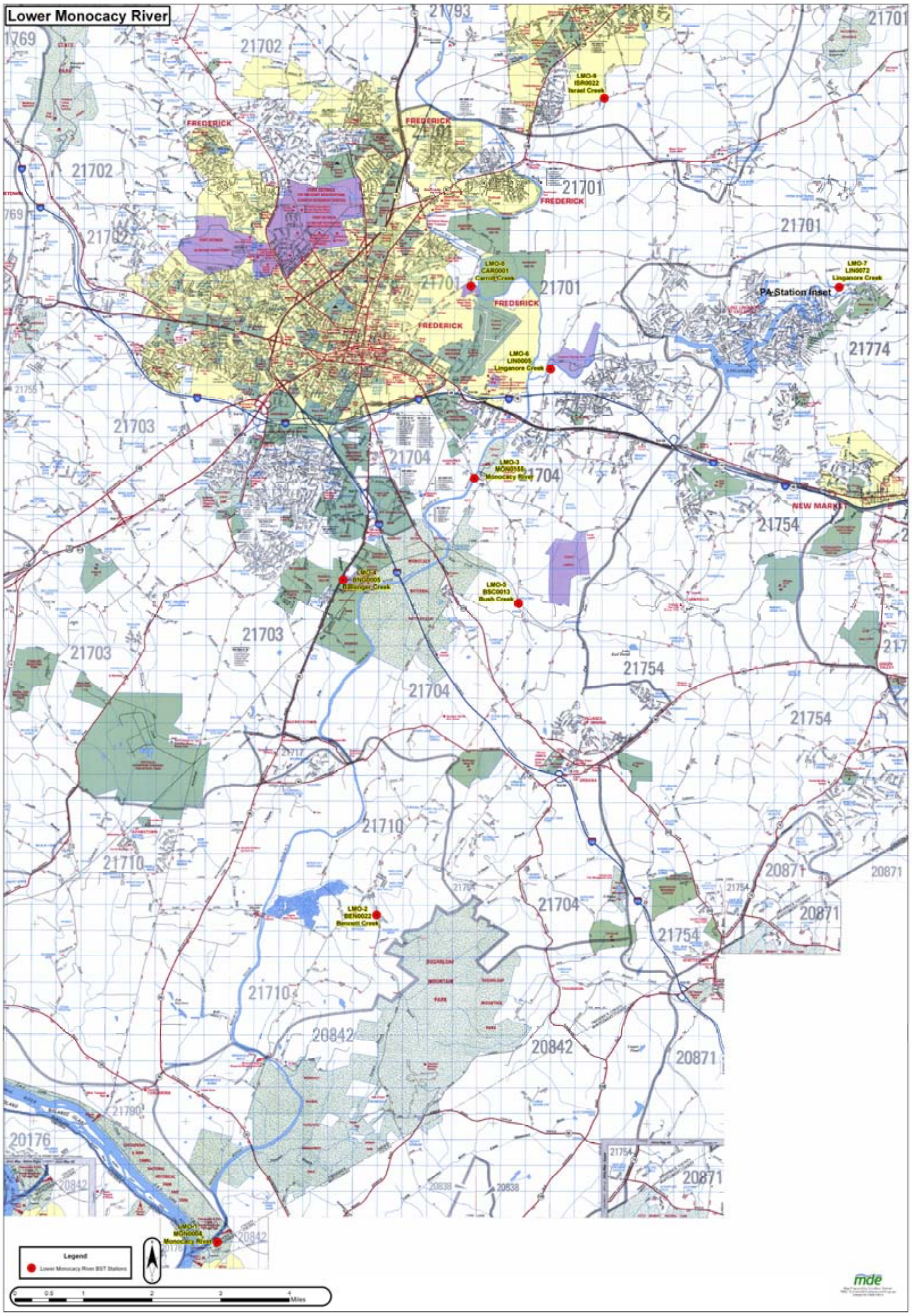

Figure C-2: Map of Lower Monocacy River Watershed. Red dots indicate water monitoring sites

Table C-5: Probable host source distribution of water isolates by species category, based on DOP-LMO-UMO combination library model with a 50% threshold probability.

Category	Number	% assigned to category 50% Prob.	% assigned to category (excluding unknowns)
human	340	15.7%	19.6%
livestock	522	24.2%	30.1%
pet	502	23.2%	29.0%
wildlife	369	17.1%	21.3%
unknown	428	19.8%	
Total	2161	100.0%	100.0%
% Classified	**80.2%**		

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

Table C-6: Lower Monocacy River. *Enterococcus* isolates obtained from water collected during the spring, summer, fall, and winter seasons, by monitoring station.

	Season				
Station	Spring	Summer	Fall	Winter	Total
BEN0022	57	59	63	50	229
BNG0005	68	72	65	45	250
BSC0013	63	71	72	22	228
CAR0001	63	72	63	72	270
ISR0022	72	72	62	45	251
LIN0005	63	72	67	16	218
LIN0072	62	70	58	47	237
MON0004	58	71	70	27	226
MON0155	72	57	71	52	252
Total	578	616	591	376	2161

Tables C-7 and C-8 (below) show the number and percent of the probable sources for each monitoring station by month.

Table C-7: Lower Monocacy River. BST Analysis: Number of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEN0022	11/17/03	0	3	0	13	0	16
BEN0022	12/01/03	1	12	2	3	5	23
BEN0022	01/06/04	2	4	6	4	5	21
BEN0022	02/04/04	8	1	10	2	2	23
BEN0022	03/02/04	1	0	1	1	3	6
BEN0022	04/06/04	3	2	4	2	2	13
BEN0022	05/11/04	1	3	3	6	9	22
BEN0022	06/08/04	6	9	1	3	3	22
BEN0022	07/07/04	1	5	6	5	18	35
BEN0022	09/08/04	9	5	0	6	4	24
BEN0022	10/05/04	6	4	9	4	1	24
BNG0005	11/17/03	1	0	4	4	11	20
BNG0005	12/01/03	2	6	7	6	0	21
BNG0005	01/06/04	3	3	4	5	4	19
BNG0005	02/04/04	1	5	8	7	1	22
BNG0005	03/02/04	0	0	2	1	1	4
BNG0005	04/06/04	3	5	0	5	7	20
BNG0005	05/11/04	4	11	5	1	3	24
BNG0005	06/08/04	6	8	2	2	6	24
BNG0005	07/07/04	1	12	16	4	15	48
BNG0005	09/08/04	4	13	0	6	1	24
BNG0005	10/05/04	0	0	24	0	0	24
BSC0013	11/17/03	8	1	12	2	1	24
BSC0013	12/01/03	5	4	5	2	8	24
BSC0013	01/06/04	0	5	4	4	6	19
BSC0013	03/02/04	0	0	1	0	2	3
BSC0013	04/06/04	5	4	1	2	3	15
BSC0013	05/11/04	7	7	0	2	8	24
BSC0013	06/08/04	3	5	3	9	4	24
BSC0013	07/07/04	3	19	6	7	12	47
BSC0013	09/08/04	13	3	3	3	2	24
BSC0013	10/05/04	5	5	11	1	2	24
CAR0001	11/17/03	3	4	3	4	3	17
CAR0001	12/01/03	4	8	6	4	1	23
CAR0001	01/06/04	6	5	5	2	6	24
CAR0001	02/04/04	10	1	12	0	1	24
CAR0001	03/02/04	3	1	20	0	0	24
CAR0001	04/06/04	5	6	1	0	3	15
CAR0001	05/11/04	7	4	7	5	1	24
CAR0001	06/08/04	3	5	1	11	4	24
CAR0001	07/07/04	2	15	2	1	4	24

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
CAR0001	08/10/04	1	1	2	8	12	24
CAR0001	09/08/04	0	10	6	3	5	24
CAR0001	10/05/04	3	2	4	4	10	23
ISR0022	11/17/03	4	1	2	7	3	17
ISR0022	12/01/03	3	1	10	2	6	22
ISR0022	01/06/04	2	7	6	4	1	20
ISR0022	02/04/04	6	3	10	2	1	22
ISR0022	03/02/04	3	0	0	0	0	3
ISR0022	04/06/04	0	5	16	2	1	24
ISR0022	05/11/04	4	5	6	5	4	24
ISR0022	06/08/04	6	9	2	4	3	24
ISR0022	07/07/04	3	11	4	2	4	24
ISR0022	08/10/04	1	12	7	0	4	24
ISR0022	09/08/04	0	6	5	6	7	24
ISR0022	10/05/04	0	5	11	6	1	23
LIN0005	11/17/03	1	10	5	3	3	22
LIN0005	12/01/03	9	2	10	0	0	21
LIN0005	01/06/04	0	1	1	0	1	3
LIN0005	02/04/04	4	5	0	3	1	13
LIN0005	04/06/04	8	5	6	2	3	24
LIN0005	05/11/04	3	2	0	3	7	15
LIN0005	06/08/04	5	7	1	3	8	24
LIN0005	07/07/04	3	10	8	12	15	48
LIN0005	09/08/04	0	8	2	7	7	24
LIN0005	10/05/04	1	4	15	3	1	24
LIN0072	11/17/03	0	2	0	5	5	12
LIN0072	12/01/03	3	5	8	5	1	22
LIN0072	01/06/04	5	2	9	4	3	23
LIN0072	02/04/04	4	3	16	0	1	24
LIN0072	04/06/04	4	1	5	1	3	14
LIN0072	05/11/04	5	12	3	2	2	24
LIN0072	06/08/04	8	2	0	5	9	24
LIN0072	07/07/04	1	12	0	6	3	22
LIN0072	08/10/04	0	3	3	8	10	24
LIN0072	09/08/04	3	8	4	1	8	24
LIN0072	10/05/04	2	3	8	4	7	24
MON0004	11/17/03	5	3	6	1	7	22
MON0004	12/01/03	10	4	8	1	1	24
MON0004	01/06/04	2	4	12	4	2	24
MON0004	03/02/04	1	0	0	2	0	3
MON0004	04/06/04	5	6	1	4	3	19
MON0004	05/11/04	3	3	4	2	3	15
MON0004	06/08/04	3	7	0	7	7	24

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
MON0004	09/08/04	6	3	0	3	11	23
MON0004	10/05/04	1	14	2	3	4	24
MON0155	11/17/03	5	9	1	7	1	23
MON0155	12/01/03	7	3	7	6	1	24
MON0155	01/06/04	2	6	7	2	4	21
MON0155	02/04/04	13	4	5	2	0	24
MON0155	03/02/04	3	2	0	0	2	7
MON0155	04/06/04	5	7	5	4	3	24
MON0155	05/11/04	1	5	3	1	14	24
MON0155	06/08/04	0	8	4	5	7	24
MON0155	07/07/04	2	4	9	13	9	37
MON0155	09/08/04	0	11	0	5	4	20
MON0155	10/05/04	2	7	6	5	4	24

Table C-8: Lower Monocacy River. BST Analysis: Percentage of Sources per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEN0022	11/17/03	0%	19%	0%	81%	0%	100%
BEN0022	12/01/03	4%	52%	9%	13%	22%	100%
BEN0022	01/06/04	10%	19%	29%	19%	24%	100%
BEN0022	02/04/04	35%	4%	43%	9%	9%	100%
BEN0022	03/02/04	17%	0%	17%	17%	50%	100%
BEN0022	04/06/04	23%	15%	31%	15%	15%	100%
BEN0022	05/11/04	5%	14%	14%	27%	41%	100%
BEN0022	06/08/04	27%	41%	5%	14%	14%	100%
BEN0022	07/07/04	3%	14%	17%	14%	51%	100%
BEN0022	09/08/04	38%	21%	0%	25%	17%	100%
BEN0022	10/05/04	25%	17%	38%	17%	4%	100%
BNG0005	11/17/03	5%	0%	20%	20%	55%	100%
BNG0005	12/01/03	10%	29%	33%	29%	0%	100%
BNG0005	01/06/04	16%	16%	21%	26%	21%	100%
BNG0005	02/04/04	5%	23%	36%	32%	5%	100%
BNG0005	03/02/04	0%	0%	50%	25%	25%	100%
BNG0005	04/06/04	15%	25%	0%	25%	35%	100%
BNG0005	05/11/04	17%	46%	21%	4%	13%	100%
BNG0005	06/08/04	25%	33%	8%	8%	25%	100%
BNG0005	07/07/04	2%	25%	33%	8%	31%	100%
BNG0005	09/08/04	17%	54%	0%	25%	4%	100%
BNG0005	10/05/04	0%	0%	100%	0%	0%	100%
BSC0013	11/17/03	33%	4%	50%	8%	4%	100%
BSC0013	12/01/03	21%	17%	21%	8%	33%	100%

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BSC0013	01/06/04	0%	26%	21%	21%	32%	100%
BSC0013	03/02/04	0%	0%	33%	0%	67%	100%
BSC0013	04/06/04	33%	27%	7%	13%	20%	100%
BSC0013	05/11/04	29%	29%	0%	8%	33%	100%
BSC0013	06/08/04	13%	21%	13%	38%	17%	100%
BSC0013	07/07/04	6%	40%	13%	15%	26%	100%
BSC0013	09/08/04	54%	13%	13%	13%	8%	100%
BSC0013	10/05/04	21%	21%	46%	4%	8%	100%
CAR0001	11/17/03	18%	24%	18%	24%	18%	100%
CAR0001	12/01/03	17%	35%	26%	17%	4%	100%
CAR0001	01/06/04	25%	21%	21%	8%	25%	100%
CAR0001	02/04/04	42%	4%	50%	0%	4%	100%
CAR0001	03/02/04	13%	4%	83%	0%	0%	100%
CAR0001	04/06/04	33%	40%	7%	0%	20%	100%
CAR0001	05/11/04	29%	17%	29%	21%	4%	100%
CAR0001	06/08/04	13%	21%	4%	46%	17%	100%
CAR0001	07/07/04	8%	63%	8%	4%	17%	100%
CAR0001	08/10/04	4%	4%	8%	33%	50%	100%
CAR0001	09/08/04	0%	42%	25%	13%	21%	100%
CAR0001	10/05/04	13%	9%	17%	17%	43%	100%
ISR0022	11/17/03	24%	6%	12%	41%	18%	100%
ISR0022	12/01/03	14%	5%	45%	9%	27%	100%
ISR0022	01/06/04	10%	35%	30%	20%	5%	100%
ISR0022	02/04/04	27%	14%	45%	9%	5%	100%
ISR0022	03/02/04	100%	0%	0%	0%	0%	100%
ISR0022	04/06/04	0%	21%	67%	8%	4%	100%
ISR0022	05/11/04	17%	21%	25%	21%	17%	100%
ISR0022	06/08/04	25%	38%	8%	17%	13%	100%
ISR0022	07/07/04	13%	46%	17%	8%	17%	100%
ISR0022	08/10/04	4%	50%	29%	0%	17%	100%
ISR0022	09/08/04	0%	25%	21%	25%	29%	100%
ISR0022	10/05/04	0%	22%	48%	26%	4%	100%
LIN0005	11/17/03	5%	45%	23%	14%	14%	100%
LIN0005	12/01/03	43%	10%	48%	0%	0%	100%
LIN0005	01/06/04	0%	33%	33%	0%	33%	100%
LIN0005	02/04/04	31%	38%	0%	23%	8%	100%
LIN0005	04/06/04	33%	21%	25%	8%	13%	100%
LIN0005	05/11/04	20%	13%	0%	20%	47%	100%
LIN0005	06/08/04	21%	29%	4%	13%	33%	100%
LIN0005	07/07/04	6%	21%	17%	25%	31%	100%
LIN0005	09/08/04	0%	33%	8%	29%	29%	100%
LIN0005	10/05/04	4%	17%	63%	13%	4%	100%
LIN0072	11/17/03	0%	17%	0%	42%	42%	100%
LIN0072	12/01/03	14%	23%	36%	23%	5%	100%

			Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
LIN0072	01/06/04	22%	9%	39%	17%	13%	100%
LIN0072	02/04/04	17%	13%	67%	0%	4%	100%
LIN0072	04/06/04	29%	7%	36%	7%	21%	100%
LIN0072	05/11/04	21%	50%	13%	8%	8%	100%
LIN0072	06/08/04	33%	8%	0%	21%	38%	100%
LIN0072	07/07/04	5%	55%	0%	27%	14%	100%
LIN0072	08/10/04	0%	13%	13%	33%	42%	100%
LIN0072	09/08/04	13%	33%	17%	4%	33%	100%
LIN0072	10/05/04	8%	13%	33%	17%	29%	100%
MON0004	11/17/03	23%	14%	27%	5%	32%	100%
MON0004	12/01/03	42%	17%	33%	4%	4%	100%
MON0004	01/06/04	8%	17%	50%	17%	8%	100%
MON0004	03/02/04	33%	0%	0%	67%	0%	100%
MON0004	04/06/04	26%	32%	5%	21%	16%	100%
MON0004	05/11/04	20%	20%	27%	13%	20%	100%
MON0004	06/08/04	13%	29%	0%	29%	29%	100%
MON0004	07/07/04	8%	29%	21%	23%	19%	100%
MON0004	09/08/04	26%	13%	0%	13%	48%	100%
MON0004	10/05/04	4%	58%	8%	13%	17%	100%
MON0155	11/17/03	22%	39%	4%	30%	4%	100%
MON0155	12/01/03	29%	13%	29%	25%	4%	100%
MON0155	01/06/04	10%	29%	33%	10%	19%	100%
MON0155	02/04/04	54%	17%	21%	8%	0%	100%
MON0155	03/02/04	43%	29%	0%	0%	29%	100%
MON0155	04/06/04	21%	29%	21%	17%	13%	100%
MON0155	05/11/04	4%	21%	13%	4%	58%	100%
MON0155	06/08/04	0%	33%	17%	21%	29%	100%
MON0155	07/07/04	5%	11%	24%	35%	24%	100%
MON0155	09/08/04	0%	55%	0%	25%	20%	100%
MON0155	10/05/04	8%	29%	25%	21%	17%	100%

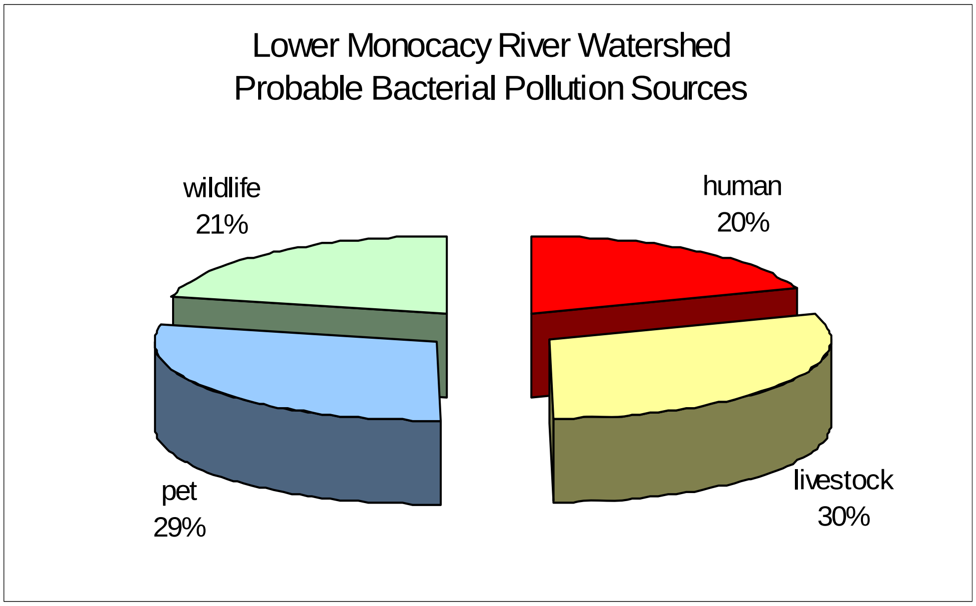

Figure C-3: Lower Monocacy River Watershed relative contribution by probable sources of *Enterococcus* contamination

Lower Monocacy River Summary

The use of ARA allowed the identification of probable bacterial sources in the Lower Monocacy River Watershed for source categories in the library. When water isolates were compared to the library and potential sources predicted, 80% of the isolates were classified by statistical analysis. The largest category of potential sources in the watershed as a whole was livestock (30%), pet (29%), followed by wildlife (21%), and human (20%).

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Appendix D – Estimating Maximum Daily Loads

This appendix documents the technical approach used to define maximum daily loads of fecal bacteria consistent with the annual average TMDL which, when met, are protective of water quality standards in Lower Monocacy River. The approach builds upon the TMDL analysis that was conducted to ensure that compliance with the annual average target will result in compliance with the applicable water quality standards. The annual average loading target was converted into allowable *daily* values by using the loadings developed from the TMDL analysis. The approach is consistent with available EPA guidance on generating daily loads for TMDLs.

The available guidance for developing daily loads does not specify a single allowable approach; it contains a range of options. Selection of a specific method for translating a time-series of allowable loads into expression of a TMDL requires decisions regarding both the level of resolution (e.g., single daily load for all conditions vs. loads that vary with environmental conditions) and level of probability associated with the TMDL.

Level of Resolution

The level of resolution pertains to the amount of detail used in specifying the maximum daily load. The draft EPA guidance on daily loads provides three categories of options for level of resolution.

1. **Representative daily load:** In this option, a single daily load (or multiple representative daily loads) is specified that covers all time periods and environmental conditions.
2. **Flow-variable daily load:** This option allows the maximum daily load to vary based upon the observed flow condition.
3. **Temporally-variable daily load:** This option allows the maximum daily load to vary based upon seasons or times of varying source or water body behavior.

Probability Level

Essentially all TMDLs have some probability of being exceeded, with the specific probability being either explicitly specified or implicitly assumed. This level of probability reflects, directly or indirectly, two separate phenomena:

1. Water quality criteria consist of components describing acceptable magnitude, duration, and frequency. The frequency component addresses how often conditions can allowably surpass the combined magnitude and duration components.
2. Pollutant loads, especially from wet weather sources, typically exhibit a large degree of variability over time. It is rarely practical to specify a "never to be exceeded value" for a daily load, as essentially any loading value has some finite probability of being exceeded.

The draft daily load guidance states that the probability component of the maximum daily load should be "based on a representative statistical measure" that is dependent upon the specific TMDL and best professional judgment of the developers. This statistical measure represents how often the maximum daily load is expected/allowed to be exceeded. The primary options for selecting this level of protection would be:

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

Se***lected Approach for Defining Maximum Daily Loads for Nonpoint Sources and MS4***

To calculate the Lower Monocacy River MDL for nonpoint sources and MS4, a "representative daily load" option was selected as the level of resolution, and a value "that will be exceeded with a pre-defined probability" was selected as the level of protection. In these options, the maximum daily load is one single daily load that covers to the two flow strata, with an upper bound percentile that accounts for the variability of daily loads. The upper bound percentile and the maximum daily loads were estimated following EPA's "*Technical Support Document for Water Quality-Based Toxics Control*" (1991 TSD) (EPA 1991); and "*Approaches For Developing a Daily Load Expression for TMDLs Computed for Longer Term Averages*" (EPA 2006).

The 1991 TSD illustrates a way to identify a target maximum daily concentration from a long-term average concentration (LTA) based on a coefficient of variation (CV) and the assumption of a log-normal distribution of the data. The equations for determining both the upper boundary percentile and corresponding maximum daily load described in the TSD are as follows:

$$MDLC = LTA * e^{[Z\sigma - 0.5\sigma^2]} \qquad \text{(D1)}$$

$$\text{and} \quad MDL = MDLC*Q*F \qquad \text{(D2)}$$

where

MDLC = Maximum daily load concentration (MPN/100ml)

LTAC = Long-term average TMDL concentration (MPN/100ml)

MDL = Maximum Daily Load (MPN/day)

Z = z-score associated with upper bound percentile (unitless)

$\sigma^2 = \ln(CV^2 + 1)$

CV = Coefficient of variation

Q = Flow (cfs)

F = conversion factor

The first step is to use the bacteria monitoring data to estimate the upper bound percentile as the percentile of the highest observed bacteria concentration in each of the three monitoring stations of Lower Monocacy River. Using the maximum value of *E. coli* observed in each monitoring station, and solving for the z-score using the above formula, the value of "z" and its corresponding percentile is found as shown below. The percentile associated with the particular value of z can be found in tables in statistics books or using the function NORMSINV(%) in EXCEL©.

$Z = [\log_{10}(MOC) - \log(AM) + 0.5\sigma^2]/\sigma$

Where

Z = z-score associated with upper bound percentile

MOC = Maximum observed bacteria concentration (MPN/100ml)

AM = Arithmetic mean observed bacteria concentrations (MPN/100ml)

$\sigma^2 = \ln(CV^2 + 1)$

CV = Coefficient of variation (arithmetic)

Note that these equations use arithmetic parameters, not geometric parameters as used in the calculations of the long-term annual average TMDL. Therefore, bias correction factors are not necessary to estimate the loads as will be explained below.

The highest percentile of all the stations analyzed by stratum will define the upper bound percentile to be used in estimating the maximum daily limits. In the case of Lower Monocacy River, a value measured during low-flow conditions at the BNG0005 station resulted in the highest percentile of all nine stations and strata. This value translates to the 96.5th percentile, which is the upper boundary percentile to be used in the computation of the maximum daily limits (MDLs) throughout this analysis. Results of the analysis to estimate the recurrence or upper boundary percentile are shown in Table D-1.

Table D-1: Percentiles of Maximum Observed Bacteria Concentrations in the Lower Monocacy River Subwatersheds

Station	Strata	Maximum Observed *E. coli* Concentration (MPN/100ml)	Percentile
BEN0022	High Flow	1400	94.02%
	Low Flow	700	92.71%
BNG0005	High Flow	1190	91.75%
	Low Flow	1240	96.50%
BSC0013	High Flow	2140	83.39%
	Low Flow	930	94.38%
CAR0001	High Flow	1720	94.44%
	Low Flow	5170	91.78%
ISR0022	High Flow	2280	95.52%
	Low Flow	11200	88.13%
LIN0005	High Flow	5170	92.10%
	Low Flow	840	94.14%
LIN0072	High Flow	3260	93.48%
	Low Flow	2040	85.65%
MON0004	High Flow	1580	86.24%
	Low Flow	880	93.97%
MON0155	High Flow	1380	84.80%
	Low Flow	830	92.04%

As seen in Table D-1, the highest percentile value obtained from all nine stations and strata is 96.5%, therefore, the upper boundary percentile to be used to estimate MDLs in this analysis will equal 96.5%. This 96.5th percentile value results in a maximum daily load that would not be exceeded 96.5% of the time, as, in a similar manner, a TMDL that represents the long term average condition would be expected to be exceeded half the time even after all required controls were implemented.

The MDLCs are estimated based on a statistical methodology referred to as “Statistical Theory of Rollback (STR)”. This method predicts concentrations of a pollutant after its sources have been controlled (post-control concentrations), in this case after annual average TMDL implementation. Using STR, the daily TMDLs are calculated as presented below.

First, the long-term average TMDL concentrations (C_{LTA}) by stratum are estimated by applying the required percent reduction to the baseline (monitoring data) concentrations (C_b) by stratum as follows:

From Section 4.3, equations (8) and (9):

$L_b = L_{b-H} + L_{b-L}$

$L_b = Q_H * C_{bH} * F_{1H} * W_H + Q_L * C_{bL} * F_{1L} * W_L$

And from equation (10)

$Annual\ Average\ TMDL = L_b * (1 - R)$

Therefore, $L_b*(1-R) = Q_H*C_H*F_{1H}*W_H*(1-R) + Q_L*C_L*F_{1L}*W_L*(1-R)$

As explained before, a reduction in concentration is proportional to a reduction in load, thus the bacteria concentrations expected after reductions are applied are equal to the baseline concentrations multiplied by one minus the required reduction:

$$C_{LTA-H} = C_{b-H}*(1-R_H)$$

$$C_{LTA-L} = C_{b-L}*(1-R_L)$$

The TMDL concentrations estimated as explained above are shown in Table D-2.

Table D-2: Long-term Annual Average (LTA) TMDL Bacteria Concentrations

Station	Strata	LTA Geometric Mean Concentrations (MPN/100ml)	LTA Arithmetic Mean* Concentrations (MPN/100ml)
BEN0022	High Flow	83	177
	Low Flow	60	106
BNG0005	High Flow	75	134
	Low Flow	67	102
BSC0013	High Flow	121	264
	Low Flow	46	66
CAR0001	High Flow	63	73
	Low Flow	84	171
ISR0022	High Flow	19	30
	Low Flow	52	297
LIN0005	High Flow	167	2,609
	Low Flow	89	223
LIN0072	High Flow	92	137
	Low Flow	64	127
MON0004	High Flow	160	471
	Low Flow	55	136
MON0155	High Flow	136	299
	Low Flow	52	112

*Only arithmetic parameters are used in the daily loads analysis.

The next step is to calculate the 96.5th percentile (the MDL concentrations) of these expected concentrations (LTA concentrations) using the coefficient of variation of the baseline concentrations. Based on a general rule for coefficient of variations, the coefficient of variation of the distribution of the concentrations of a pollutant does not change after these concentrations have been reduced or controlled by a fixed proportion (Ott 1995).

Therefore, the coefficient of variation estimated using the monitoring data concentrations does not change, and it can be used to estimate the 96.5th percentile of the long-term average TMDL concentrations (LTAC) using equation (D1). These values are shown in Table D-3.

Table D-3: Maximum Daily Load (MDL) Concentrations

Station	Stratum	CV	MDL Concentrations (MPN/100ml)
BEN0022	High Flow	1.9	770
	Low Flow	1.4	410
BNG0005	High Flow	1.5	532
	Low Flow	1.1	350
BSC0013	High Flow	1.9	1,158
	Low Flow	1.0	213
CAR0001	High Flow	0.6	165
	Low Flow	1.8	729
ISR0022	High Flow	1.2	107
	Low Flow	5.6	1,531
LIN0005sub	High Flow	15.6	11,172
	Low Flow	2.3	1,118
LIN0072	High Flow	1.1	463
	Low Flow	1.7	531
MON0004sub	High Flow	2.8	2,350
	Low Flow	2.2	712
MON0155sub	High Flow	2.0	1,176
	Low Flow	1.9	874

With the 96.5th percentiles of LTA TMDL bacteria concentrations estimated for both high flow and low flow strata as explained above, the maximum daily load for MS4 and nonpoint sources for each subwatershed can be now estimated as:

$$\text{Daily TMDL (MPN/day)} = Q_H*(96.5^{th}C_{LTA\text{-}H})*F_{1H}*W_H + Q_L*(96.5^{th}C_{LTA\text{-}L})*F_{1L}*W_L$$

Selected Approach for Defining Maximum Daily Loads for Other Point Sources

The TMDL also considers contributions from other point sources (i.e., municipal and industrial WWTP) in watersheds that have NPDES permits with fecal bacteria limits. The TMDL analysis that defined the average annual TMDL held each of these sources constant at their existing NPDES permit limit (daily or monthly) for the entire year. The approach used to determine maximum daily loads was dependent upon whether a maximum daily load was specified within the permit. If a maximum daily load was specified within the permit, then the maximum design flow is multiplied by the maximum daily limit to obtain a maximum daily load. If a maximum daily limit was not specified in the permit, then the maximum daily loads are calculated from guidance in the TSD for Water Quality-based Toxics Control (EPA 1991). The long-term average annual TMDL was converted to maximum daily limits using Table 5-2 of the TSD assuming a coefficient of variation of 0.6 and a 99^{th} percentile probability. This results in a dimensionless multiplication factor of 3.11. The average annual bacteria loads for WWTPs are reported in billion MPN/year. In Lower Monocacy River, to estimate the maximum daily loads for WWTPs, the annual average loads are multiplied by the multiplication factor as follows:

WLA-WWTP MDL (bill MPN/day) = [WLA-WWTP bill MPN/year)]*(3.11/365)

The Maximum Daily Loads for the Lower Monocacy River subwatersheds are presented in Table D-4 below.

Table D-4: Maximum Daily Loads (MDL)

Station	Stratum	Maximum Daily Load by Stratum (Billion *E. coli* MPN/day)	Maximum Daily Load (Weighted) (Billion *E. coli* MPN/day)
BEN0022	High Flow	3,590	1,163
	Low Flow	354	
BNG0005	High Flow	904	295
	Low Flow	92	
BSC0013	High Flow	2,947	800
	Low Flow	84	
CAR0001	High Flow	239	182
	Low Flow	164	
ISR0022	High Flow	265	505
	Low Flow	585	
LIN0005sub	High Flow	26,688	6,982
	Low Flow	414	
LIN0072	High Flow	2,402	921
	Low Flow	427	
MON0004sub	High Flow	7,609	2,170
	Low Flow	357	
MON0155sub	High Flow	3,420	1,029
	Low Flow	232	

Maximum Daily Loads Allocations

Using the MDLs estimated as explained above, loads are allocated following the same methodology as the annual average TMDL (See section 4.8). A summary of maximum daily loads for the Lower Monocacy River watershed is presented in Table D-5.

Table D-5: Lower Monocacy River Watershed Maximum Daily Loads

Station	**MDL**	**LA**	**Stormwater WLA**	**WWTP-WLA**
	Billion MPN *E. Coli*/day			
BEN0022	1,163	888	273	1.85
BNG0005	295	207	88	0.40
BSC0013	800	588	204	8.46
CAR0001	182	93	89	0.18
ISR0022	505	360	144	1.48
LIN0005sub	6,982	3,958	3,024	N/A
LIN0072	921	771	149	0.74
MON0004sub	2,170	1,206	637	327.01
MON0155sub	1,029	401	480	148.34
Total	**14,048**	**8,471**	**5,088**	**488**

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Appendix E – Relationship of Fecal Bacteria TMDLs for the Double Pipe Creek, Upper Monocacy River, and Lower Monocacy River Watersheds

The purpose of this appendix is to explain the hydrologic relationship between the Double Pipe Creek, Upper Monocacy River, and Lower Monocacy River watersheds and how this affects the fecal bacteria TMDLs for each of the respective watersheds. As illustrated in Figure E-1, the three watersheds are hydrologically connected, beginning with the Double Pipe Creek watershed to the east. The Double Pipe Creek watershed flows into the Upper Monocacy River watershed, near the small town of Rocky Ridge. It is also shown in Figure E-1 that the Upper Monocacy River watershed includes land in Pennsylvania and Maryland. The combined flow from the Upper Monocacy River watershed and the Double Pipe Creek watershed flows into the Lower Monocacy River watershed. The hydrologic connectivity of the watersheds is illustrated in Figure E-2.

The baseline fecal bacteria loads for the watersheds are shown in Table E-1. The TMDL calculations are shown in Tables E-2 through E-4. Further information can be found in the individual TMDL documents for each watershed.

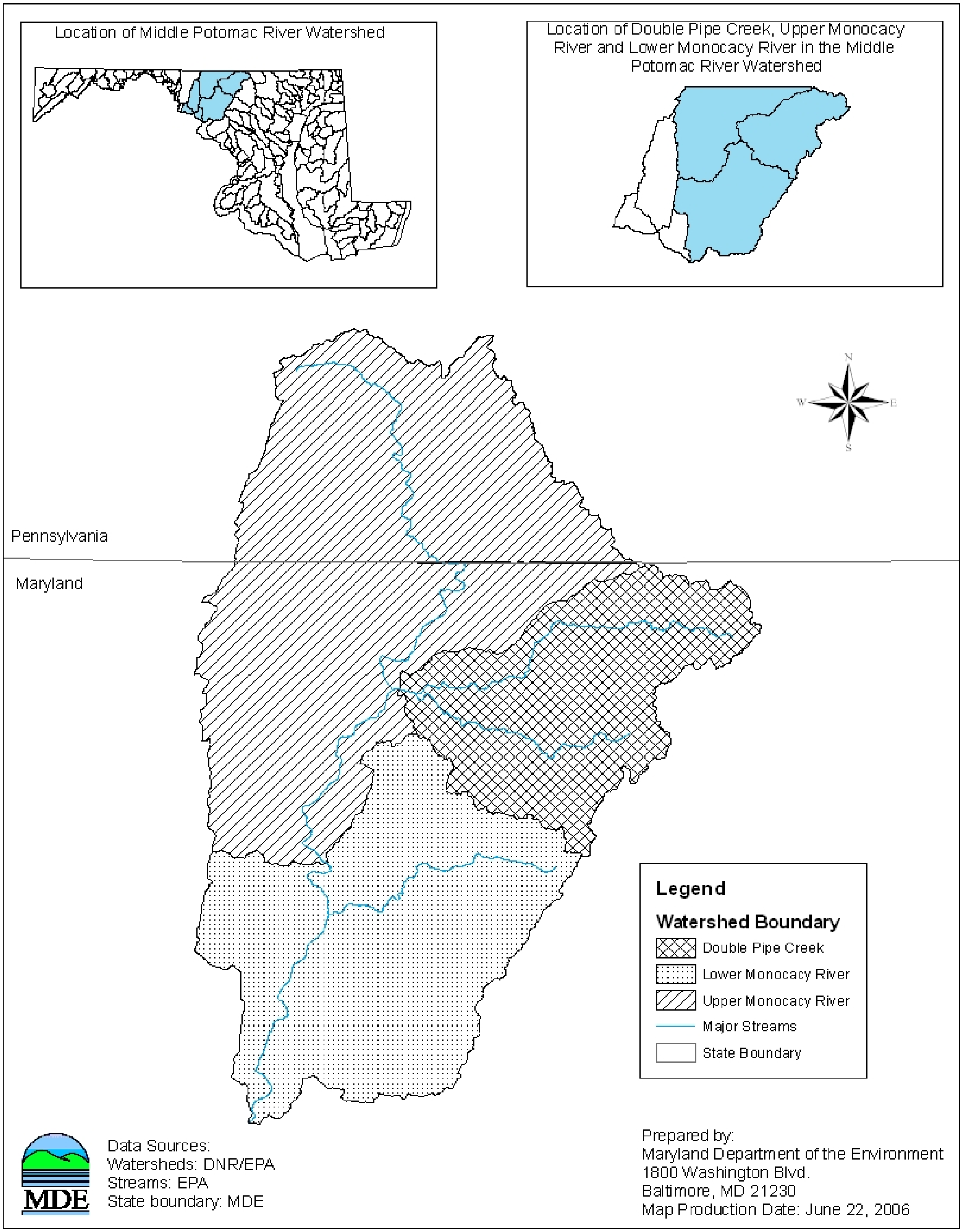

Figure E-1: Location of the Double Pipe Creek, Upper Monocacy River, and Lower Monocacy River Watersheds

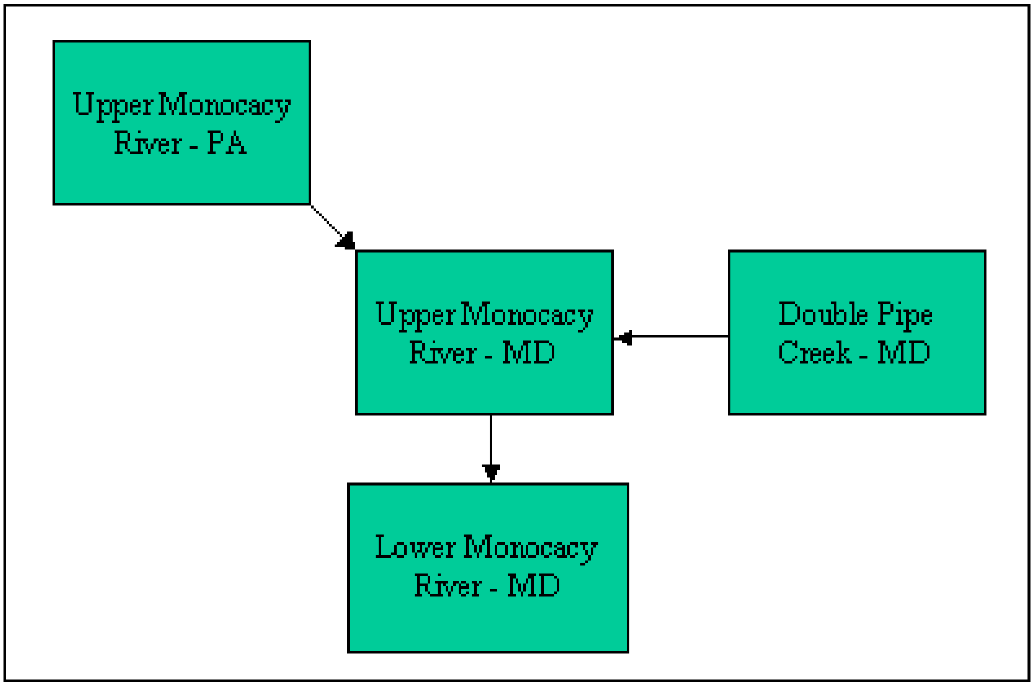

Figure E-2: Flow Schematic of the Double Pipe Creek, Upper Monocacy River, and Lower Monocacy River Watersheds

Table E-1: Fecal Bacteria Baseline Loads

Watershed	Total Baseline Load	=	MD 8-digit Basin Load	+	Upstream Load
	Billion MPN *E. coli*/year				
Double Pipe Creek	11,614,269	=	11,614,269	+	N/A
Upper Monocacy River	15,073,485	=	1,985,054	+	13,088,431[1]
Lower Monocacy River	20,856,810	=	5,783,325	+	15,073,485[2]

[1]The upstream load is equivalent to the Double Pipe Creek baseline load (11,614,269 billion MPN *E. coli*/year) plus the PA baseline load (1,474,162 billion MPN *E. coli*/year).
[2]The upstream load is equivalent to the Upper Monocacy River baseline load.

Table E-2: Double Pipe Creek TMDL

TMDL Billion MPN *E. coli*/year	=	MD LA	+	MD Stormwater WLA +	+	MD WWTP WLA	+	MOS
		Billion MPN *E. coli*/year						
282,168	=	181,528	+	91,249	+	9,391	+	Incorporated

Table E-3: Upper Monocacy River TMDL Summary

TMDL Billion MPN *E. coli*/year	=	LA_{UM}	+	WLA_{UM}	+	LA_{DP}	+	LA_{PA}	+	MOS
		Billion MPN *E. coli*/year								
1,353,850	=	483,751	+	57,483	+	282,168[1]	+	575,448[2]	+	Incorporated

[1] This upstream load allocation is equivalent to the Double Pipe Creek TMDL.
[2] This upstream PA load allocation is determined to be necessary in order to meet MD water quality standards in the MD portion of the Upper Monocacy River watershed.

Table E-4: Lower Monocacy River TMDL Summary

TMDL Billion MPN *E. coli*/year	=	LA_{LM}	+	WLA_{LM}	+	LA_{UM}	+	MOS
		Billion MPN *E. coli*/year						
2,033,379	=	426,161	+	253,368	+	1,353,850[1]	+	Incorporated

[1]The upstream load is equivalent to the Upper Monocacy River TMDL Summary.