Total Maximum Daily Loads of Fecal Bacteria for the Loch Raven Reservoir Basin in Baltimore, Carroll, and Harford Counties, Maryland

FINAL

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List of Abbreviations

ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
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
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
SW	Stormwater
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 Loch Raven Reservoir watershed (Maryland 8-digit assessment unit MD-02130805). 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 tributaries of Loch Raven Reservoir on the State's 303(d) List [Category 5 of the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report)] as impaired by fecal bacteria (listed in 2008) and impacts to biological communities (listed in 2002, 2004 and 2008). The reservoir itself is not listed as impaired by fecal bacteria. The Loch Raven Reservoir and all its tributaries have been designated as Use III-P (Nontidal Cold Water and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08J. This document proposes to establish a TMDL for fecal bacteria in the Loch Raven Reservoir watershed that will allow for attainment of the beneficial use designation of water contact recreation. The listings for impacts to biological communities will be addressed in a separate TMDL document. Listings for the impoundment have already been addressed by TMDLs for phosphorus, sediments and mercury, and a WQA for heavy metals. MDE monitored the Loch Raven Reservoir watershed from 2003-2004 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered. To account for portions of subwatersheds located in Pennsylvania (PA), an upstream load allocation (LA_{PA}), determined to be necessary in order to meet MD water quality standards in the MD portion of the watershed, is also included in this TMDL.

For this TMDL analysis, the Loch Raven Reservoir watershed has been divided into eight subwatersheds. For convenience, seven of these will be referenced by the downstream bacteria monitoring station's name and location: GUN0387 (Gunpowder Falls at Falls Road), LIT0002 (Little Falls), GUN0284 (Gunpowder Falls at Corbett Road), GUN0233 (Gunpowder Falls at Phoenix Road), WGP0050 (Western Run), BEV0005 (Beaverdam Run), and SBH0002 (Spring Branch). The eighth subwatershed encompasses all unmonitored areas downstream of the seven stations, excepting the impoundment, and will be referred to as the Downstream Subwatershed. The pollutant loads set forth in this document are for these eight subwatersheds. To establish baseline and allowable pollutant loads for this TMDL, a flow duration curve approach was employed, using bacteria data from MDE and flow strata estimated from United States Geological Survey (USGS) daily flow monitoring. The sources of fecal bacteria are estimated at seven representative stations in the Loch Raven Reservoir 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 baseline load is estimated from current monitoring data using a long-term geometric mean and weighting factors from the flow duration curve. The TMDL for fecal bacteria entering the Loch Raven Reservoir watershed is established after considering two different hydrological conditions: an average annual condition and an average seasonal dry weather condition (the period between May 1st and September 30th when water contact recreation is more prevalent). The allowable load quantified by the TMDL 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 across the four bacteria source categories. In six of the eight subwatersheds, it was estimated that water quality standards could not be attained with MPRs; thus, higher maximum reductions were applied.

The MD 8-digit Loch Raven Reservoir Total Baseline Load consists of upstream loads generated outside the MD 8-digit watershed assessment unit: a Pennsylvania Upstream Baseline Load (BL_{PA}), plus loads generated within the assessment unit: a MD 8-digit Loch Raven Reservoir Baseline Load (BL_{LR}) Contribution. The baseline loads are summarized in the following table:

MD 8-Digit Loch Raven Reservoir Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)								
Total Baseline Load	=	**Upstream Baseline Load**[1]	+	**MD 8-digit Loch Raven Reservoir Baseline Load Contribution**				
		BL_{PA}		**Nonpoint Source BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**WWTP BL_{LR}**
2,194,308	=	7,106	+	2,033,052	+	152,583	+	1,567

[1] Although the upstream baseline load is reported here as a single value, it could include point and nonpoint sources.

The MD 8-digit Loch Raven Reservoir TMDL of fecal bacteria consists of an annual average allocation attributed to loads generated outside the assessment unit: a Pennsylvania Upstream Load Allocation (LA_{PA}), plus allocations attributed to loads generated within the assessment unit: a MD 8-digit Loch Raven Reservoir TMDL Contribution.

The MD 8-digit Loch Raven Reservoir TMDL Contribution, representing the sum of individual TMDLs for the eight subwatersheds or portions thereof within MD, is distributed between a load allocation (LA_{LR}) for nonpoint sources and waste load allocations (WLA_{LR}) for point sources. Point sources include any National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants (WWTPs) and NPDES regulated stormwater (SW) discharges, including county and municipal separate storm sewer systems (MS4s). 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 MD 8-digit Loch Raven Reservoir TMDL of fecal bacteria is presented in the following table:

MD 8-Digit Loch Raven Reservoir Fecal Bacteria TMDL (Billion MPN *E. coli*/year)

TMDL	=	**LA**			+	**WLA**			+	**MOS**
		LA_{PA}[1]	+	**LA_{LR}**		**SW WLA_{LR}**	+	**WWTP WLA_{LR}**		
513,894	=	6,200	+	487,750	+	18,377	+	1,567	+	Incorpo-rated

Upstream Load Allocation — MD 8-digit Loch Raven Reservoir TMDL Contribution (507,694)

[1] Although the upstream load is reported here as a single value, it could include point and nonpoint sources.

The LA_{PA}, accounting for portions of subwatersheds located in Pennsylvania, is determined to be necessary in order to meet MD water quality standards in the MD 8-digit Loch Raven Reservoir watershed. The LA_{PA} represents a reduction of approximately 13% from the PA baseline load of 7,106 billion MPN *E. coli*/year. The MD 8-digit TMDL Contribution (507,694 billion MPN *E. coli*/year) represents a reduction of approximately 77% from the MD 8-digit Baseline Load Contribution of 2,187,202 billion MPN *E. coli*/year.

Pursuant to recent EPA guidance (US EPA 2006a), maximum daily load (MDL) expressions of the long-term annual average TMDLs are also provided, as shown in the following table:

MD 8-Digit Loch Raven Reservoir Fecal Bacteria MDL Summary (Billion MPN *E. coli*/day)

MDL	=	**LA**			+	**WLA**			+	**MOS**
		LA_{PA}	+	**LA_{LR}**		**SW WLA_{LR}**	+	**WWTP WLA_{LR}**		
17,951	=	243	+	16,876	+	819	+	13	+	Incorpo-rated

Upstream MDL — MD 8-digit Loch Raven Reservoir MDL Contribution (17,708)

Once EPA has approved a TMDL, 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 six of the eight 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 Loch Raven Reservoir watershed (Maryland 8-digit assessment unit MD-02130805). 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 tributaries of Loch Raven Reservoir on the State's 303(d) List [Category 5 of the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report)] as impaired by fecal bacteria (listed in 2008) and impacts to biological communities (listed in 2002, 2004 and 2008). The reservoir itself is not listed as impaired by fecal bacteria. The Loch Raven Reservoir and all its tributaries have been designated as Use III-P (Nontidal Cold Water and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08J. This document proposes to establish a TMDL for fecal bacteria in the Loch Raven Reservoir watershed that will allow for attainment of the beneficial use designation of water contact recreation. The listings for impacts to biological communities will be addressed in a separate TMDL document. Listings for the impoundment have already been addressed by TMDLs for phosphorus, sediments and mercury, and a WQA for heavy metals. MDE monitored the Loch Raven Reservoir watershed from 2003-2004 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered. To account for portions of subwatersheds located in Pennsylvania (PA), an upstream load allocation (LA_{PA}), determined to be necessary in order to meet MD water quality standards in the MD portion of the watershed, is also included in this TMDL.

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 MD's current bacteria water quality criteria, either *E. coli* or enterococci. The indicator organism used in the Loch Raven Reservoir TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Loch Raven Reservoir watershed is located in both Maryland (MD) and Pennsylvania (PA), with a drainage area of 224.4 square miles (143,617 acres). The majority of the watershed is in MD with a portion in York County, PA (see Figure 2.1.1). The MD portion is largely in Baltimore County, with small areas in Carroll and Harford counties.

The watershed includes the towns of Lutherville, Timonium, Cockeysville, Phoenix, Parkton, and Hampstead. The tributaries to the reservoir include Gunpowder Falls, Greene Branch, Beaverdam Run, Royston Branch, Overshot Run, Merryman Branch, Fitzhugh Run, Jenkins Run, Dulaney Branch, Kelly Branch, Spring Branch, Long Quarter Branch and Rush Brook. Gunpowder Falls begins at the outlet of the Prettyboy Reservoir. A major tributary to Gunpowder Falls is Little Falls, which begins near the PA border. See Figure 2.1.1.

Antidegradation Policy and Tier II Waters

Antidegradation is one of three key components required by the Clean Water Act. These three components are: designated uses, water quality criteria, and antidegradation policy. The Clean Water Act's (CWA) Tier II antidegradation policy is found in section 303(d) and its goals are to 1) ensure that no activity will lower water quality to support existing uses, and 2) maintain and protect high quality waters.

Waters of the Loch Raven Reservoir watershed designated as Tier II are listed in Table 2.1.1.

Table 2.1.1: High Quality (Tier II) Waters in the Loch Raven Reservoir Watershed

Tier II Segment	County	Segment Length (miles)	Subwatershed
Beetree Run 1	Baltimore	1.59	LIT0002
First Mine Branch 1	Baltimore, Harford	3.15	LIT0002
Little Falls 1	Baltimore	0.96	LIT0002
Blackrock Run 1	Baltimore	1.41	WGP0050
Delaware Run 1	Baltimore	0.73	WGP0050
Indian Run 1	Baltimore	0.85	WGP0050
Western Run 1	Baltimore	1.64	WGP0050

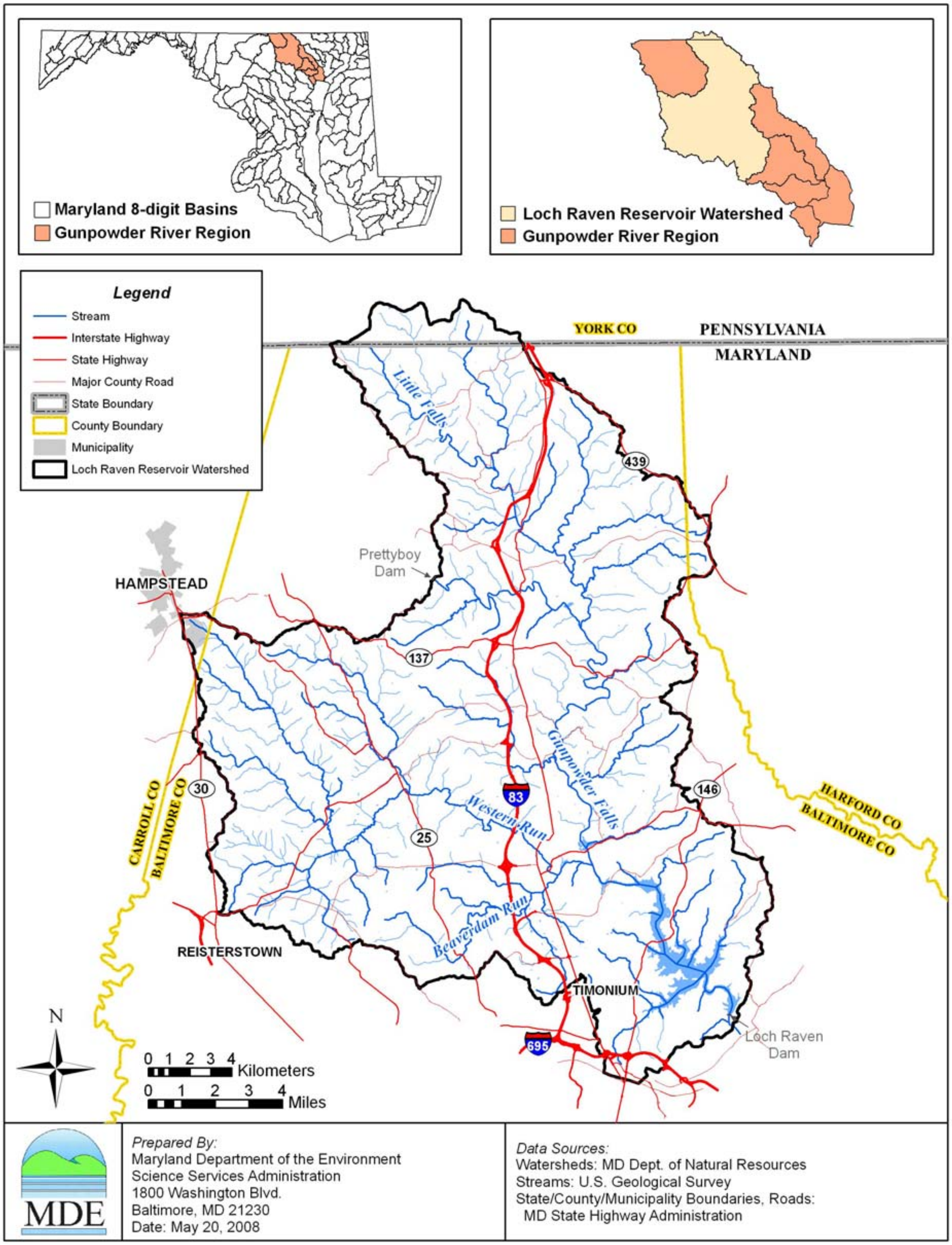


Figure 2.1.1: Location Map of the Loch Raven Reservoir Watershed

Land Use

The Loch Raven Reservoir watershed covers an area of 143,617 acres in MD and PA. Based on the 2002 Maryland Department of Planning (MDP) land use/land cover data, MD's portion of the watershed can be characterized as primarily forest and agricultural land, but with significant urban area as well. The forested areas are mainly along Gunpowder Falls and surrounding the reservoir. The urban areas are mostly in the southern part of the watershed. Regional Earth Science Application Center (RESAC) land use/land cover was used to estimate the land use for the PA portion of the watershed. RESAC shows that the PA portion is largely pasture and agricultural.

The land use acreage and percentage distribution is shown in Table 2.1.1, and spatial distributions for each land use are shown in Figure 2.1.2. Table 2.1.2 shows the land use percentage distribution for each of the eight subwatersheds considered in the analysis. Note that seven of the subwatersheds are identified by the MDE monitoring stations located in the mainstem of the river and its main tributaries, and are listed by flow from upstream to downstream. The eighth subwatershed encompasses all unmonitored areas downstream of the monitoring stations, excepting the impoundment, and is identified as the Downstream Subwatershed.

Table 2.1.2: Land Use Percentage Distribution for the Loch Raven Reservoir Watershed

Land Type	**Maryland Area**		**Pennsylvania Area**		***Total***	
	Acres	**%**	**Acres**	**%**	**Acres**	**%**
Forest	52,000	36.9	515	19.0	52,515	36.6
Agricultural	42,410	30.1	826	30.5	43,236	30.1
Urban	34,201	24.3	333	12.3	34,534	24.0
Pasture	10,201	7.2	1,037	38.3	11,238	7.8
Water	2,093	1.5	1	0.02	2,094	1.5
Total	**140,905**	**100**	**2,712**	**100**	**143,617**	**100**

Table 2.1.3: Land Use Percentage Distribution for the Loch Raven Reservoir Watershed

Station / Subwatershed	Land Use Area (%)				
	Agricultural	Forest	Pasture	Urban	Water
GUN0387 / Gunpowder Falls at Falls Rd.	5.1	78.5	3.0	13.3	0.04
LIT0002 / Little Falls	34.7	38.1	12.9	14.3	0.01
GUN0284 / Gunpowder Falls at Corbett Rd.	23.4	53.1	8.6	14.7	0.1
GUN0233 / Gunpowder Falls at Phoenix Rd.	36.0	35.2	10.8	18.0	0
WGP0050 / Western Run	48.8	32.7	6.7	11.8	0
BEV0005 / Beaverdam Run	12.1	23.7	1.2	62.9	0.1
SBH0002 / Spring Branch	0	2.7	0	97.3	0
Downstream Subwatershed	7.1	39.5	4.4	41.0	7.9

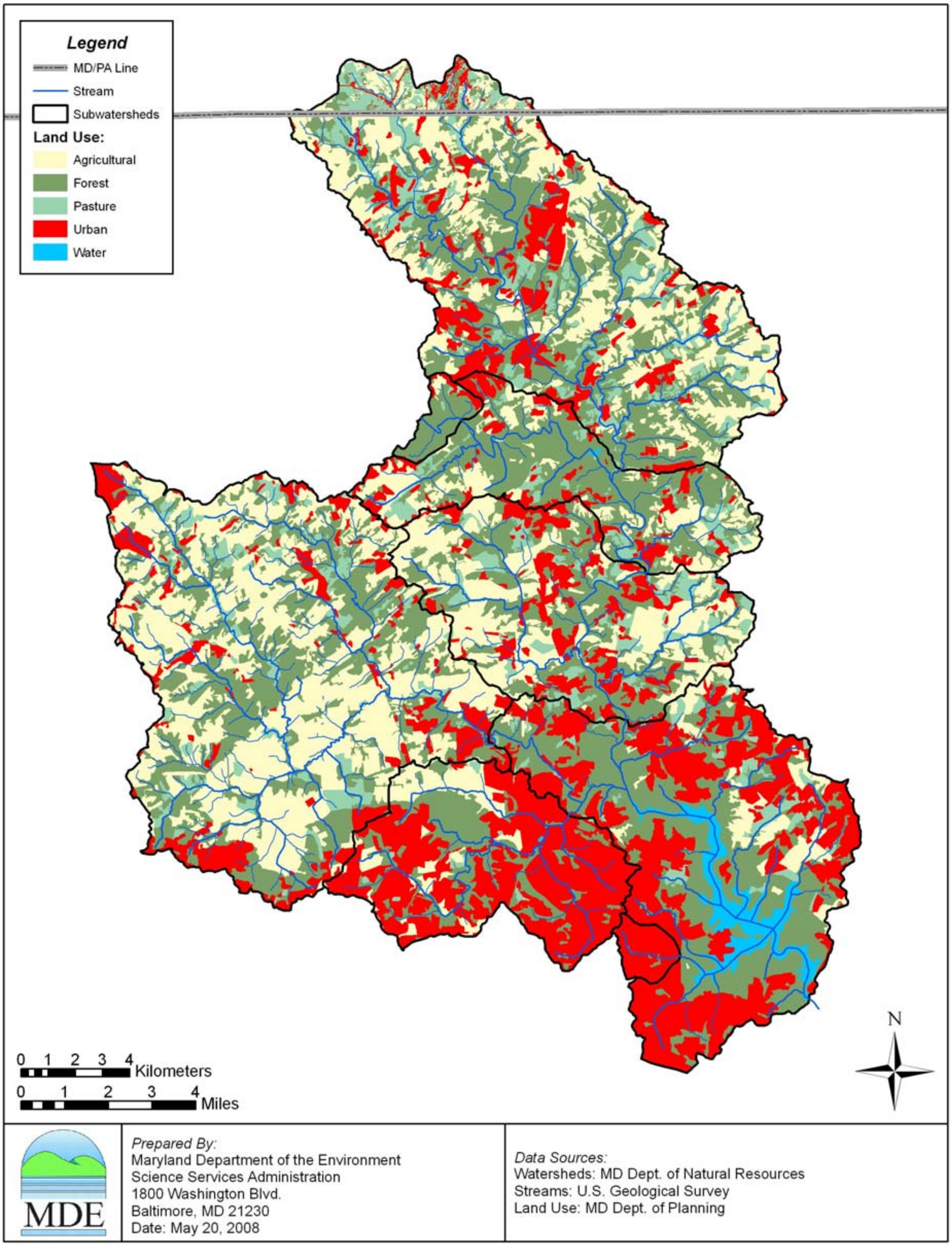


Figure 2.1.2: Land Use of the Loch Raven Reservoir Watershed

Population

The total population in the Loch Raven Reservoir watershed is estimated to be 90,345 people. Figure 2.1.3 illustrates the population density in the watershed. The human population in the Pennsylvania portion of the watershed was estimated based on a weighted average from the 2000 Census GIS Block Groups and the RESAC land cover mapping. Since the boundaries of the watershed differ from the boundaries of the block groups, residential land use data were used to extract the necessary areas of the Census block groups. The residential density designations used for this estimation are shown in Table 2.1.3. The population in the Maryland portion of the watershed was estimated based on a weighted average from the Census block groups and the 2007 MDP Property View. The population for each subwatershed was estimated and is presented in Table 2.1.4.

Table 2.1.4: Number of Dwellings Per Acre

Land Use Code	Dwellings Per Acre
Low Density Residential	1
Medium Density Residential	5
High Density Residential	8

Table 2.1.5: Total Population Per Subwatershed in the Loch Raven Reservoir Watershed

Station / Subwatershed	Population
GUN0387 / Gunpowder Falls at Falls Rd.	219
LIT0002 / Little Falls	8,346
GUN0284 / Gunpowder Falls at Corbett Rd.	2,938
GUN0233 / Gunpowder Falls at Phoenix Rd.	4,854
WGP0050 / Western Run	9,580
BEV0005 / Beaverdam Run	24,541
SBH0002 / Spring Branch	4,940
Downstream Subwatershed	34,927
Total	**90,345**

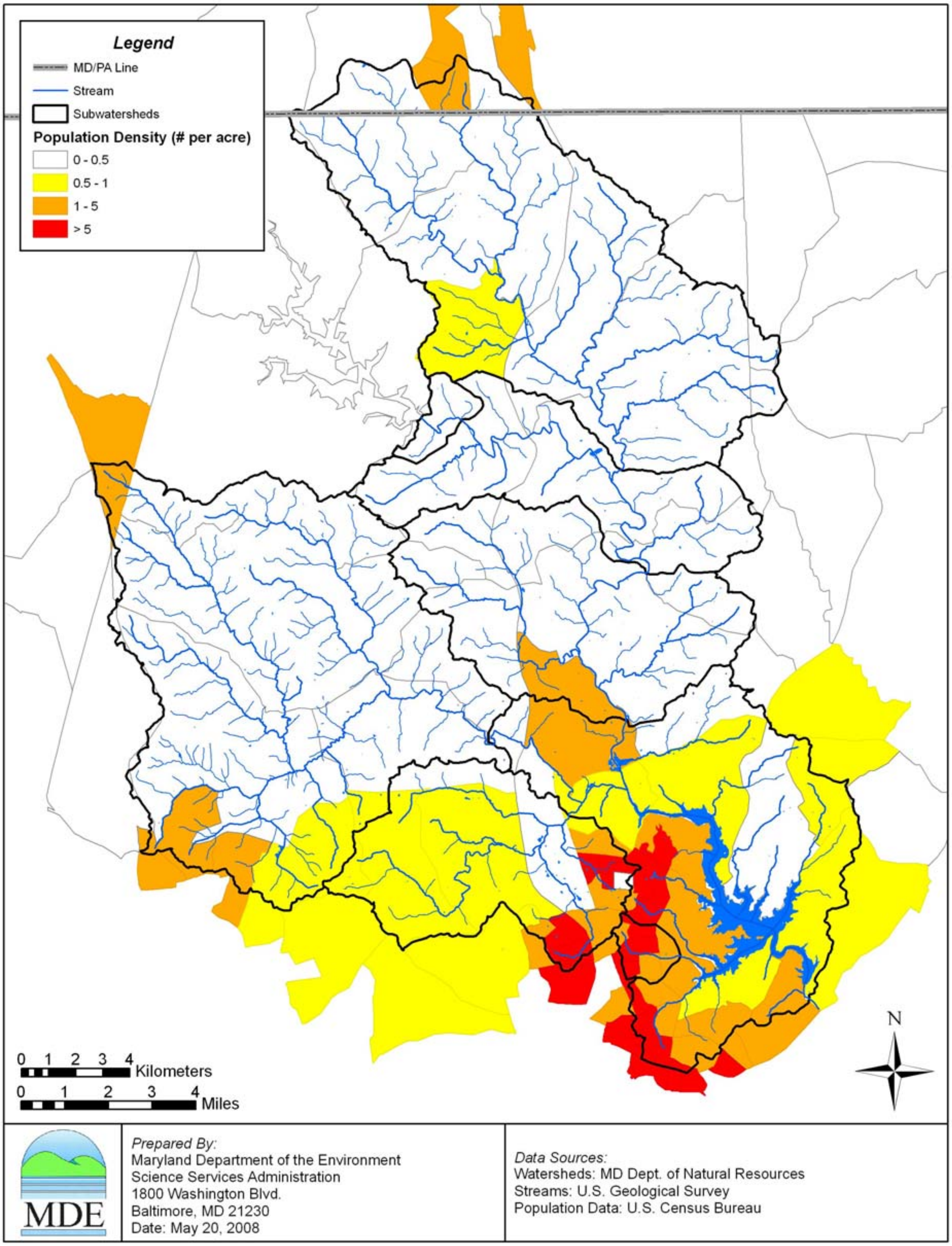


Figure 2.1.3: Population Density in the Loch Raven Reservoir Watershed

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, III 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 Loch Raven Reservoir watershed. MDE conducted monitoring sampling at seven stations in the Loch Raven Reservoir watershed from November 2003 through October 2004. Four United States Geological Survey (USGS) gage stations were used in deriving the surface water flow. The locations of these stations are shown in Tables 2.2.2 to 2.2.4 and in Figure 2.2.1. Observations recorded from the seven MDE monitoring stations are provided in Appendix A.

Bacteria counts are highly variable, which is typical due to the nature of bacteria and their relationship to flow. The E. coli counts for the seven stations ranged between 1 and 14,140 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Loch Raven Reservoir Watershed

Organization	Date	Design	Summary
DNR	01/1986 through 12/2003	Fecal Coliform*	1 station 1 sample per month
MDE	11/2003 through 10/2004	*E. coli*	7 stations 2 samples per month
MDE	11/2003 through 10/2004	BST (*Enterococcus)*	7 stations 1 sample per month

*Only *E. coli* was used for this analysis.

Table 2.2.2: Location of DNR Core Station in the Loch Raven Reservoir Watershed

Station	Tributary	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
GUN0258	Gunpowder Falls	39.550	-76.636

Table 2.2.3: Location of MDE Monitoring Stations in Loch Raven Reservoir Watershed

Tributary	Station	Observation Period	Total Observations	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
Gunpowder Falls	GUN0387	2003 – 2004	24	39.619	-76.690
Little Falls	LIT0002	2003 – 2004	24	39.602	-76.622
Gunpowder Falls	GUN0284	2003 – 2004	24	39.568	-76.611
Gunpowder Falls	GUN0233	2003 – 2004	23	39.519	-76.620
Western Run	WGP0050	2003 – 2004	24	39.511	-76.677
Beaverdam Run	BEV0005	2003 – 2004	24	39.487	-76.645
Spring Branch	SBH0002	2003 – 2004	24	39.440	-76.597

Table 2.2.4: Location of USGS Gauging Stations in Loch Raven Reservoir Watershed

Site Number	Observation Period Used	Total Observations	Latitude	Longitude
01582000	1982-2007	9,131	39.604	-76.620
01582500	1982-2007	9,061	39.550	-76.636
01583500	1982-2007	9,131	39.511	-76.677
01583600	1982-2007	9,131	39.486	-76.646

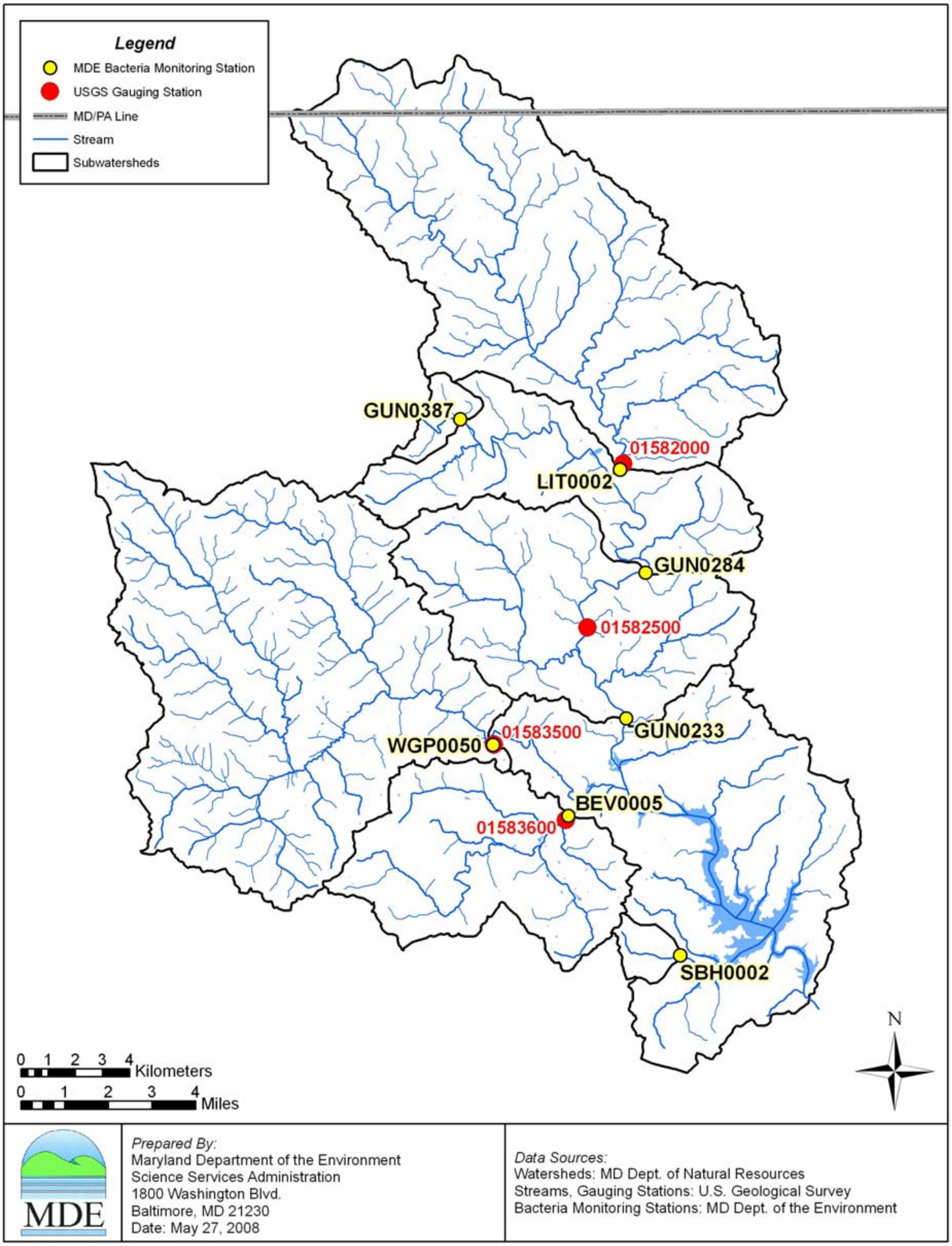


Figure 2.2.1: Monitoring Stations and Subwatersheds in the Loch Raven Reservoir Watershed

2.3 Water Quality Impairment

Designated Uses and Water Quality Standard

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the waters of the MD 8-digit Loch Raven Reservoir watershed is Use III-P (Nontidal Cold Water and Public Water Supply). (COMAR 26.08.02.08J) The waters of the MD 8-digit Loch Raven Reservoir watershed were listed on Maryland's 303(d) List [Category 5 of the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report)] as impaired by fecal bacteria in 2008.

Water Quality Criteria

The State water quality standard for bacteria applicable to freshwater and used in this study is as follows:

Table 2.3.1: Bacteria Criteria Values

(Source: COMAR 26.08.02.03-3 Water Quality Criteria Specific to Designated Uses; Table 1)

Indicator	Steady-State Geometric Mean Indicator Density
Freshwater	
E. coli	126 MPN/100ml

Water Quality Assessment

Interpretation of Bacteria Data for General Recreational Use

Pursuant to the 2008 Integrated Report, the requirements to confirm a Category 5 listing for fecal bacteria impairment in all Use Waters (Water Contact Recreation and Protection of Aquatic Life) are as follows:

A steady-state geometric mean will be calculated with available data from the previous two to five years. The data shall be from samples collected during steady-state, dry weather conditions and during the beach season (Memorial Day through Labor Day), to be representative of the critical condition (highest water contact recreation use). If the resulting steady-state geometric mean is greater than 35 cfu/100 ml enterococci in marine/estuarine waters, 33 cfu/100 ml enterococci in freshwater, or 126 cfu/100 ml *E. coli* in freshwater, the waterbody is confirmed as impaired and a TMDL should be established.

Bacteria water quality impairment in the MD 8-digit Loch Raven Reservoir watershed was assessed as explained above, by comparing the dry weather steady-state geometric means of *E.*

coli concentrations for each subwatershed of the Loch Raven Reservoir with the water quality criterion. The 1986 EPA criteria guidance document assumed steady-state conditions in determining the risk at various bacterial concentrations, and therefore the chosen criterion value of 126 cfu/100 ml *E. coli* also reflects steady-state conditions (EPA 1986).

The dry weather steady-state geometric means are calculated using samples taken during non-rainy days and from May 1st to September 30th, capturing the beach season. Results of these calculations are presented in Table 2.3.2. As shown in the table below, all but one of the seven monitored subwatersheds of the Loch Raven Reservoir had steady-state geometric mean concentrations of *E. coli* above the water quality criterion, supporting the 2008 listing for fecal bacteria and it is therefore concluded that a TMDL is required.

Table 2.3.2: Loch Raven Reservoir Watershed Dry Weather Period Steady-State Geometric Means

Station / Tributary	Number of Samples	Seasonal Steady-State Geometric Mean (MPN/100ml)	Water Quality Criterion (MPN/100ml)
GUN0387 Gunpowder Falls at Falls Rd.	10	18	126
LIT0002 Little Falls	10	139	126
GUN0284 Gunpowder Falls at Corbett Rd.	10	168	126
GUN0233 Gunpowder Falls at Phoenix Rd.	10	224	126
WGP0050 Western Run	10	491	126
BEV0005 Beaverdam Run	9	611	126
SBH0002 Spring Branch	10	1,080	126

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, domestic animals, or wildlife have direct access to the waterbody. Nonpoint source contributions from human sources generally arise from failing septic systems and their associated drain fields or leaking infrastructure (i.e., sewer systems).

Sewer Systems

The MD Loch Raven Reservoir watershed is serviced by both sewer systems and septic systems. Sewer systems are present in the towns of Timonium, Cockeysville, and Hampstead. Wastewater collected by the Hampstead WWTP is treated and discharged into Piney Run, a tributary of Western Run.

Septic Systems

On-site disposal (septic) systems are located throughout the Loch Raven Reservoir watershed. Table 2.4.1 presents the number of septic systems per subwatershed in MD. Figure 2.4.1 displays the areas that are serviced by sewers and the locations of the septic systems in MD.

Table 2.4.1: Septic Systems Per Subwatershed in the Loch Raven Reservoir Watershed in MD

Station / Subwatershed	Septic Systems
GUN0387 / Gunpowder Falls at Falls Rd.	79
LIT0002 / Little Falls	2,407
GUN0284 / Gunpowder Falls at Corbett Rd.	997
GUN0233 / Gunpowder Falls at Phoenix Rd.	1,483
WGP0050 / Western Run	2,379
BEV0005 / Beaverdam Run	3,961
SBH0002 / Spring Branch	6
Downstream Subwatershed	4,331
Total	**15,643**

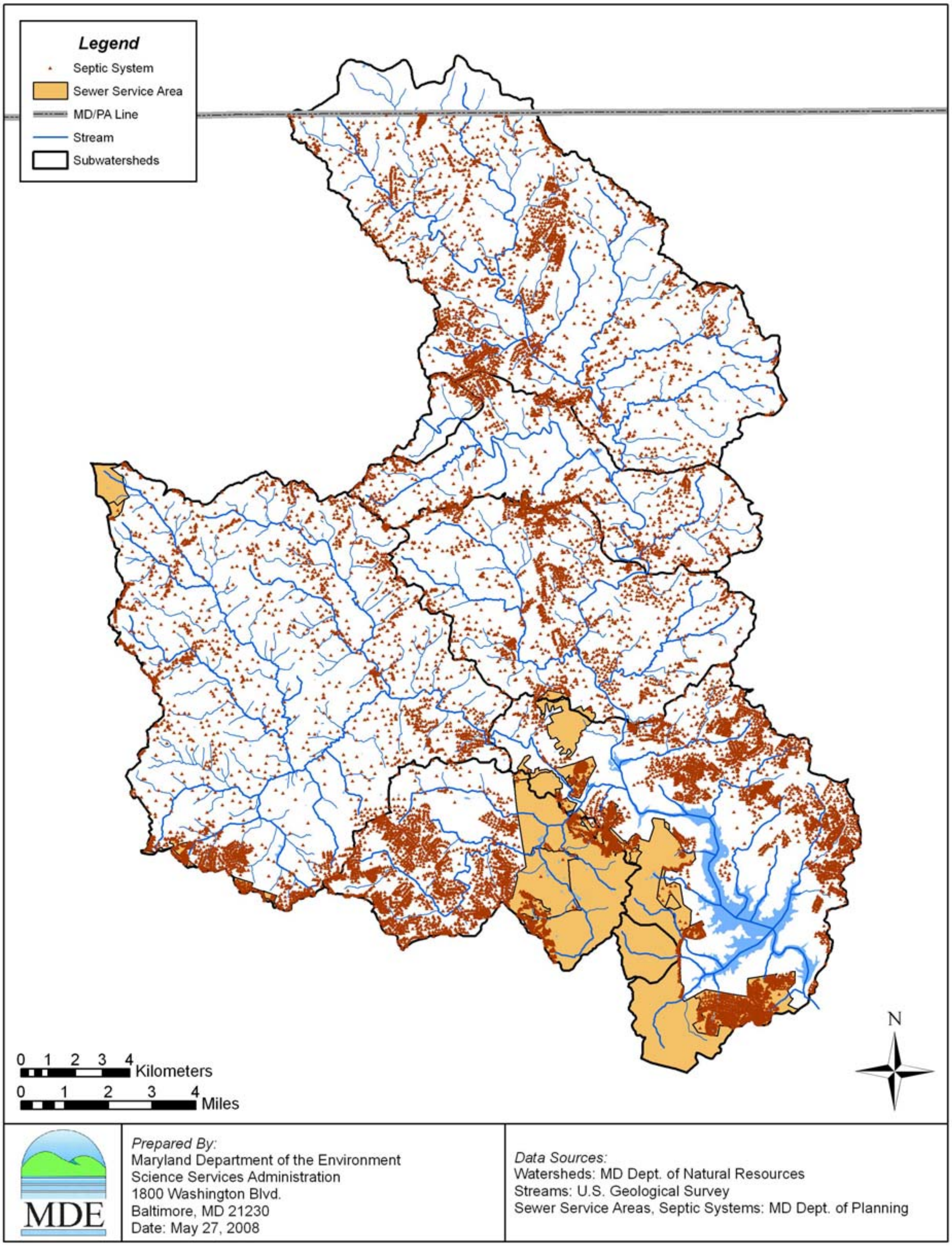


Figure 2.4.1: Sanitary Sewer Service Areas and Septic Locations in MD's Portion of the Loch Raven Reservoir Watershed

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 are issued for industrial and municipal WWTPs and Phase I municipal separate storm sewer systems (MS4s). MDE general permits have been established for surface water discharges from: Phase II and other MS4 entities; 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

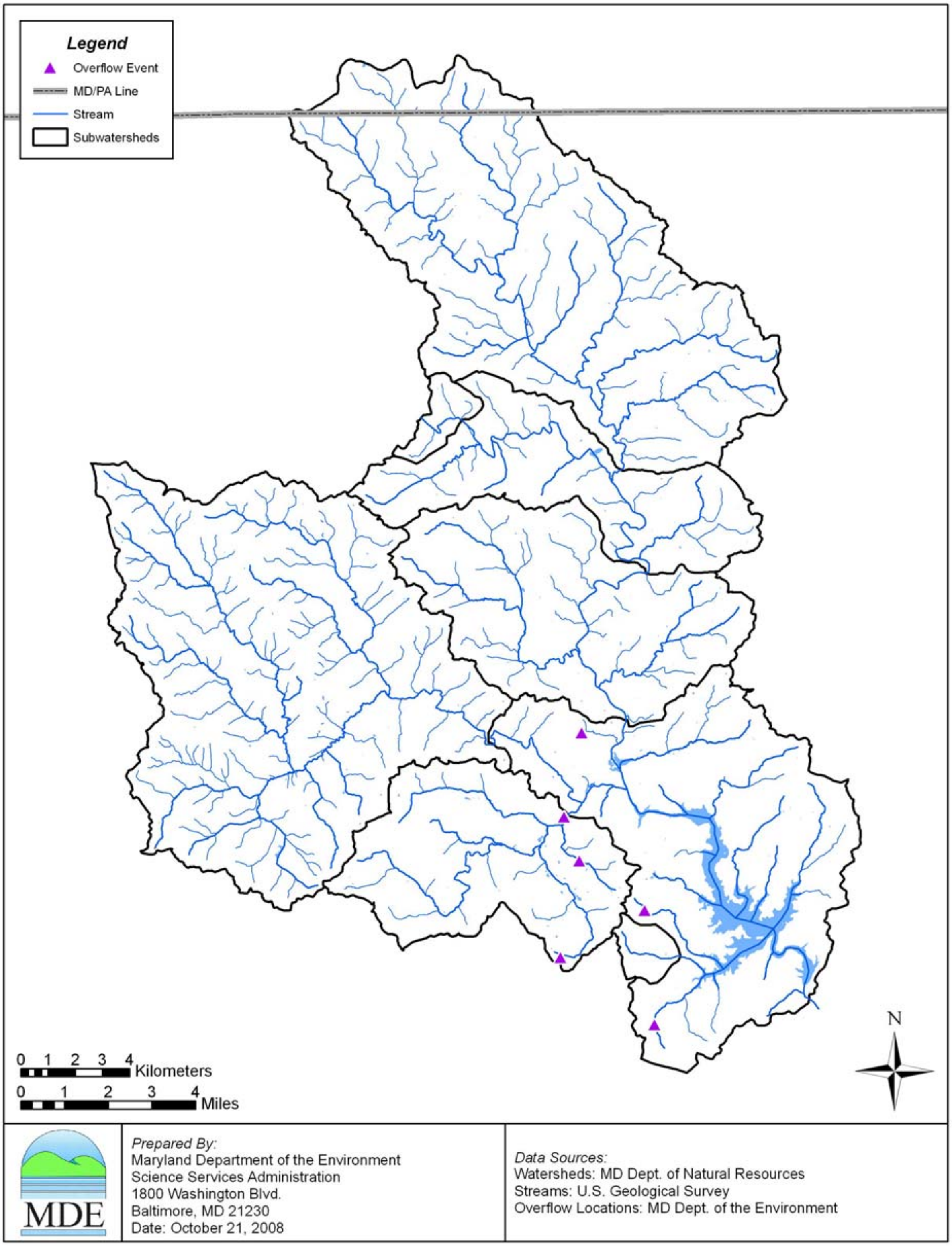
NPDES regulated stormwater discharges are considered point sources subject to assignment to the waste load allocation (WLA). Stormwater runoff is an important source of water pollution, including bacterial pollution. For example, domestic animal and wildlife waste may be transported through an MS4 conveyance or system of conveyances. MS4s may include roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains, best management practices (BMPs), and environmental site design (ESD), designed or used for collecting and conveying, or treating and reducing, stormwater before delivering it to a waterbody. MS4 stormwater management programs are designed to reduce the amount of pollution that enters a waterbody from storm sewer systems to the maximum extent practicable.

MD’s portion of the Loch Raven Reservoir watershed is located in Baltimore, Carroll, and Harford Counties, which all have individual Phase I NPDES MS4 permits. The municipality of Hampstead is covered separately by a general Phase II NPDES MS4 permit. Nonpoint source bacteria loads attributable to these MS4s, and any other Phase I and Phase II NPDES-regulated stormwater entities in the watershed, including the MD State Highway Administration (SHA) Phase I MS4, Phase II State and federal MS4s, and industrial stormwater permittees, are combined in aggregate stormwater waste load allocations (SW-WLAs) in this TMDL.

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 8 SSOs reported to MDE between November 2003 and October 2004 in the Loch Raven Reservoir watershed. Approximately 14,000 gallons of SSOs were discharged through various waterways (surface water, groundwater, sanitary sewers, etc.). Figure 2.4.2 shows the locations where SSOs occurred in the MD portion of the watershed between November 2003 and October 2004.



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Date: October 21, 2008

Data Sources:
Watersheds: MD Dept. of Natural Resources
Streams: U.S. Geological Survey
Overflow Locations: MD Dept. of the Environment

Figure 2.4.2: Sanitary Sewer Overflow Areas in the Loch Raven Reservoir Watershed

Municipal and Industrial Wastewater Treatment Plants (WWTPs)

WWTPs are designed to treat wastewater before it is 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 is one active municipal NPDES permitted point source facility with a permit regulating the discharge of fecal bacteria in the Loch Raven Reservoir watershed. This facility, Hampstead WWTP, treats approximately 0.94 MGD (million gallons per day). There are no industrial facilities in the Loch Raven Reservoir watershed with NPDES permits regulating the discharge of fecal bacteria. Table 2.4.2 lists the Hampstead facility and Figure 2.4.3 shows its location in the watershed.

Table 2.4.2: NPDES Permit Holders Regulated for Fecal Bacteria Discharge in the Loch Raven Reservoir Watershed

Facility	NPDES Permit No.	County	Average Flow (MGD)	Fecal Coliform Concentration Annual AVG (MPN/100ml)	Fecal Coliform Load (Billion MPN/day)
Hampstead WWTP	MD0022446	Carroll	0.944	7.9	0.28

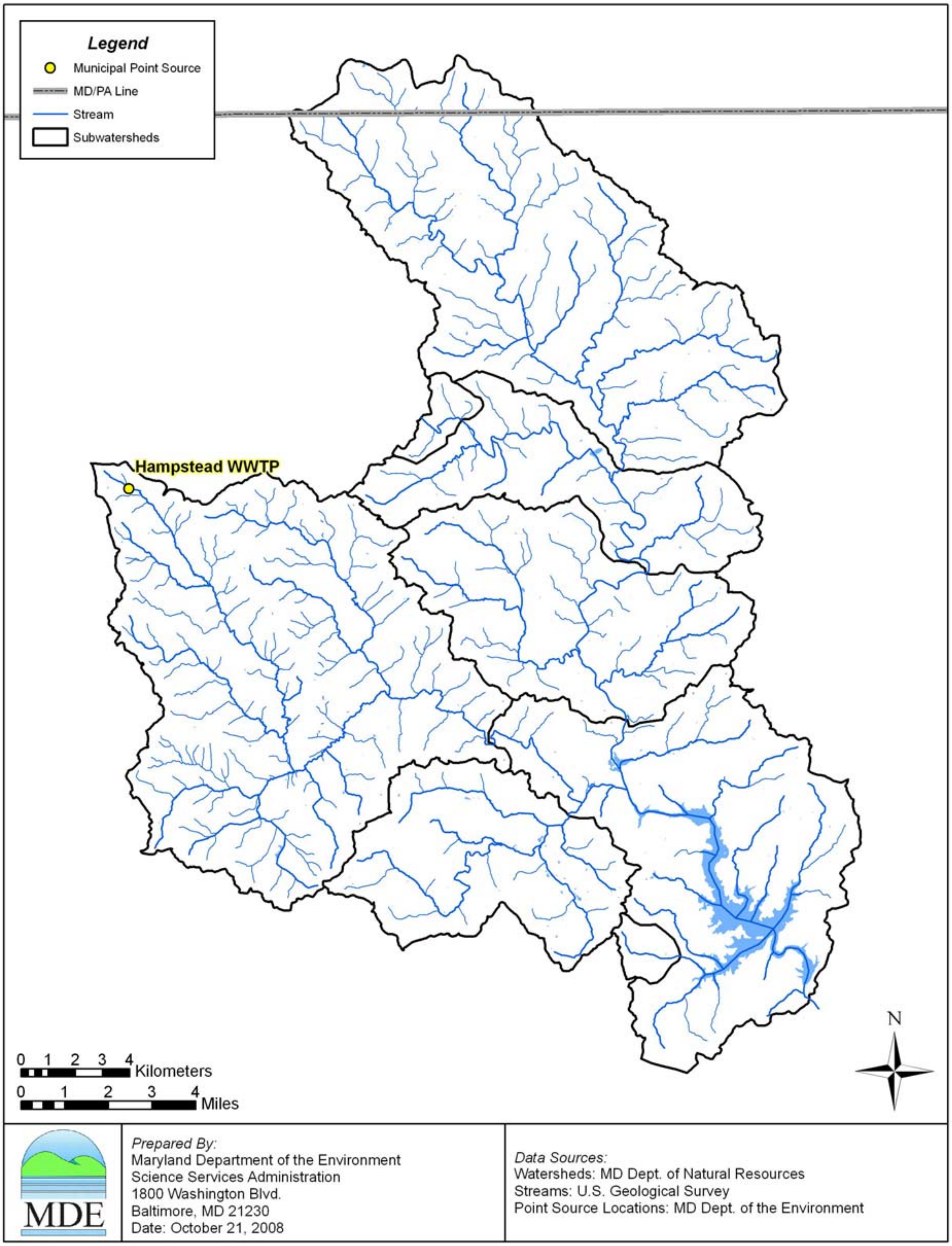

Figure 2.4.3: Permitted Point Sources Discharging Fecal Bacteria in the Loch Raven Reservoir Watershed

Bacteria Source Tracking

Bacteria source tracking (BST) was used to identify the relative contributions of different sources of bacteria to in-stream water samples. BST monitoring was conducted at five stations in the Loch Raven Reservoir watershed, where samples were collected once per month 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). Samples are collected within the watershed from known fecal sources, and a BST technique known as antibiotic resistance analysis (ARA) was used to identify the patterns of antibiotic resistance of these known sources. To identify probable sources, these antibiotic resistance patterns are then compared to isolates of unknown bacteria from ambient water samples. Figure 2.4.4 presents the relative contributions by probable sources of bacteria for the Loch Raven Reservoir Watershed. Details of the BST methodology and data can be found in Appendix C.

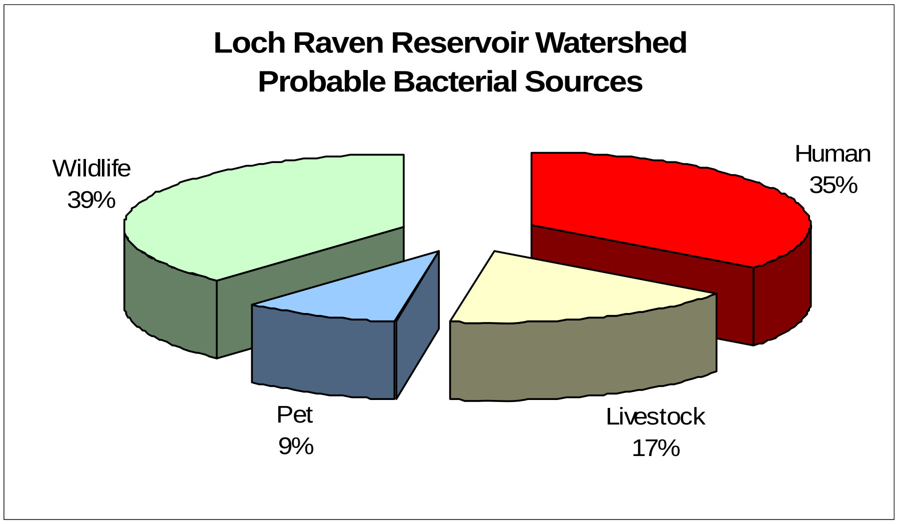

Figure 2.4.4: Loch Raven Reservoir Watershed Relative Contributions by Probable Sources of Fecal Bacteria Contamination

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 Loch Raven Reservoir watershed. 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. Section 4.2 presents the analysis framework and how the hydrological, water quality, and BST data are linked together in the TMDL process. Section 4.3 describes the analysis for estimating a representative geometric mean fecal bacteria concentration and baseline loads. This analysis methodology is based on available monitoring data and is specific to a free-flowing stream system. Section 4.4 shows how the BST analysis results are used to estimate the relative contributions of the different sources of bacteria for each subwatershed of the Loch Raven Reservoir watershed. Section 4.5 addresses the critical condition and seasonality. Section 4.6 presents the margin of safety. Section 4.7 discusses annual average TMDL loading caps and how maximum daily loads are estimated. Section 4.8 presents TMDL scenario descriptions. Section 4.9 presents the load allocations. Finally, in Section 4.10, 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 and 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, as well as 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). The second method 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 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 Analytical Framework

The 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 in each subwatershed is estimated from the observed bacteria concentrations after accounting for critical condition and seasonality. Critical condition and seasonality are determined by assessing annual and dry weather seasonal hydrological conditions. 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.

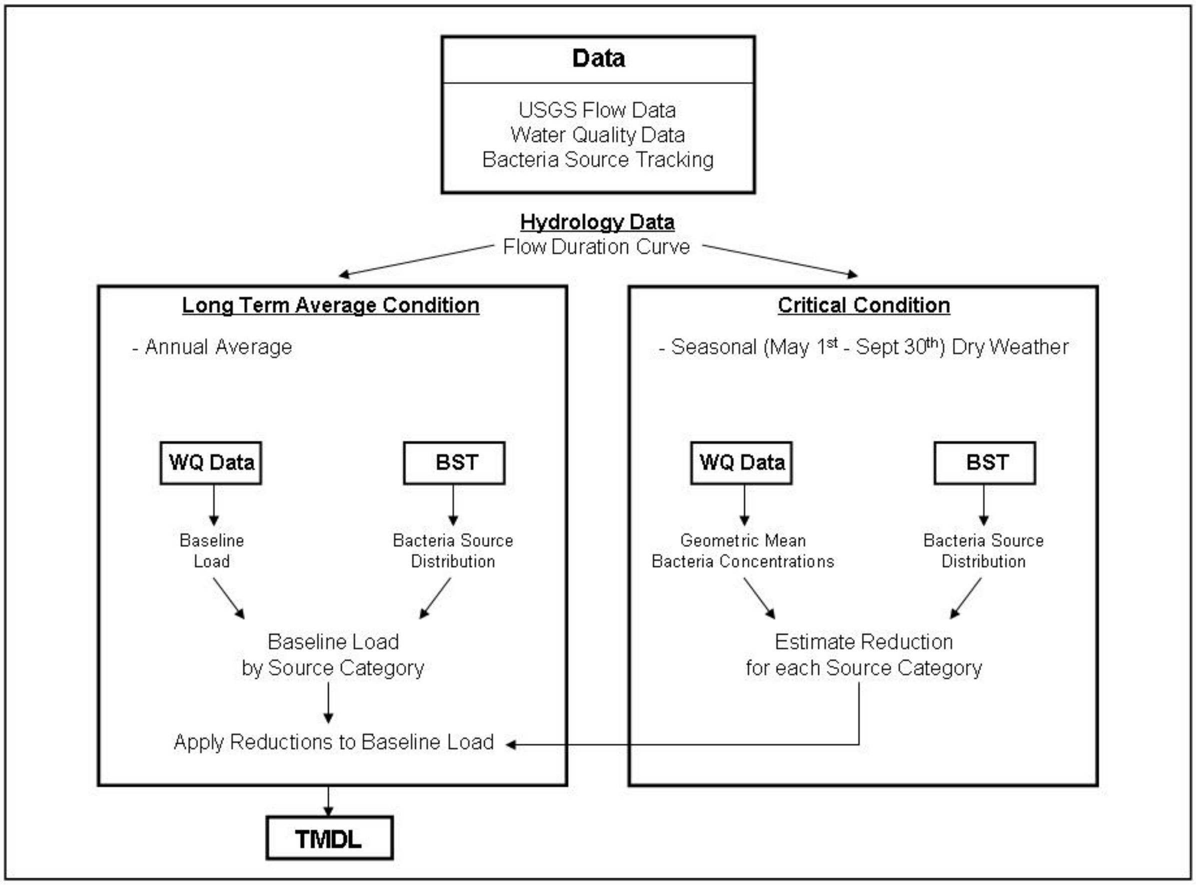

Figure 4.2.1: Diagram of the Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads are estimated for all subwatersheds of the Loch Raven Reservoir watershed. Baseline loads estimated in this TMDL analysis are reported as long-term average annual loads. These loads are estimated using geometric mean concentrations and bias correction factors (calculated from bacteria monitoring data) and daily average flows (estimated from long-term flow data).

Estimating Weighted Annual Average Geometric Mean Concentrations

The weighted annual average geometric mean used in the calculation of baseline loads can be estimated either by monitoring design or 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 data without consideration of the sampling conditions results in a biased estimate of geometric means. The potential bias of these geometric means can be reduced by weighting the sampling 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 geometric mean for the specified period.

A routine monitoring design was used to collect bacteria data in the Loch Raven Reservoir watershed. To estimate the weighted geometric mean, the monitoring data were first reviewed by plotting the sample results versus their corresponding daily flow duration percentile.

To calculate the weighted 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 4.3.1.

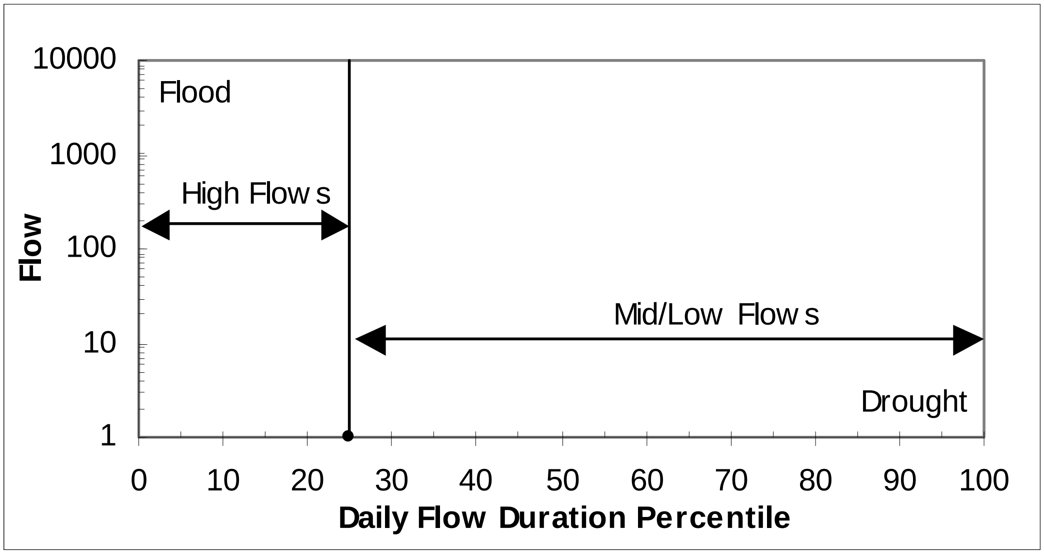

Figure 4.3.1: Conceptual Diagram of Flow Duration Zones

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. Because the bacteria samples were taken during a routine monitoring design and not a stratified monitoring design, the division of the entire flow regime into strata enables the estimation of a less flow-biased geometric mean.

Based on flow data of USGS gages 01582000, 01582500, 01583500 and 01583600 it was determined that the long-term average daily flow corresponds to a daily flow duration of 34.3%. Hence for this analysis it is defined that flows greater than the 34.3 percentile flow represent high flows, and flows lesser than the 34.3 percentile flow represent mid/low flows. A detailed method of how the flow strata were defined is presented in Appendix B.

Factors for estimating a weighted 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 Loch Raven Reservoir watershed TMDL analysis are presented in Table 4.3.1.

Table 4.3.1: Weighting Factors for Average Hydrology Year Used for Estimation of Geometric Means in the Loch Raven Reservoir Watershed

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 34.3%	0.343
Mid/Low Flows	34.3 – 100%	0.657

Bacteria enumeration results for samples within a specified stratum will receive their corresponding weighting factor. The 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 weighted geometric mean concentration is estimated using the following equation:

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

where,

C_{gm} = Steady-state geometric mean concentration

For both the annual and seasonal analysis only the overall geometric mean for the period was applied due to an insufficient number of samples in both hydrological conditions. Table 4.3.2 presents the annual maximum and minimum concentrations and the overall annual geometric means for each subwatershed of the Loch Raven Reservoir. Table 4.3.3 presents the seasonal dry weather steady-state (May 1st –September 30th) maximum and minimum concentrations and the overall geometric mean concentrations for each subwatershed. Graphs illustration these results can be found in Appendix B. For the downstream subwatershed the average geometric mean concentrations of the three upstream watersheds, GUN0233, WGP0050 and BEV0005, were applied to account for the unmonitored streams. The watershed of SBH0002 was not used in this calculation due to its unique land use (highly urbanized) conditions and extreme concentrations.

Table 4.3.2: Loch Raven Reservoir Watershed Annual Geometric Means

Station / Tributary	**Number of Samples**	***E. coli* Minimum Concentration** (MPN/100ml)	***E. coli* Maximum Concentration** (MPN/100ml)	**Annual* Average Geometric Mean** (MPN/100ml)
GUN0387 Gunpowder Falls at Falls Rd.	24	1	120	14
LIT0002 Little Falls	24	10	770	96
GUN0284 Gunpowder Falls at Corbett Rd.	24	10	770	75
GUN0233 Gunpowder Falls at Phoenix Rd.	23	10	14,140	142
WGP0050 Western Run	24	10	2,910	233
BEV0005 Beaverdam Run	24	20	2,500	213
SBH0002 Spring Branch	24	30	9,210	300
Downstream Subwatershed	N/A			196

*** Used for estimating average annual baseline loads**

Table 4.3.3: Loch Raven Reservoir Watershed Seasonal (May 1 - September 30) Dry Weather Steady-State Geometric Means

Station / Tributary	Number of Samples	*E. coli* Minimum Concentration (MPN/100ml)	*E. coli* Maximum Concentration (MPN/100ml)	Dry Weather* Steady-State Geometric Mean (MPN/100ml)
GUN0387 Gunpowder Falls at Falls Rd.	10	10	120	18
LIT0002 Little Falls	10	10	770	139
GUN0284 Gunpowder Falls at Corbett Rd.	10	50	770	168
GUN0233 Gunpowder Falls at Phoenix Rd.	10	60	3,800	224
WGP0050 Western Run	10	190	1,400	491
BEV0005 Beaverdam Run	9	140	2,500	611
SBH0002 Spring Branch	10	260	9,210	1,080
Downstream Subwatershed	N/A			442

***Used for estimating reductions needed to meet water quality standards**

As stated previously, for both the annual and seasonal analysis an overall geometric mean was calculated, rather than by flow stratum, due to an insufficient number of samples in the two flow conditions. 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.

With calculated geometric means and arithmetic means for each subwatershed, the bias correction factors are estimated as follows:

$$F_1 = A/C \qquad (6)$$

where,

F_1 = bias correction factor
A = long term annual arithmetic mean
C = long term annual geometric mean

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

For each subwatershed, the baseline loads are then estimated as follows:

$$L = Q * C * F_1 * F_2 \qquad (7)$$

where,

L = daily average load (Billion MPN/day) at monitoring station
Q = daily average flow (cfs)
C = geometric mean (MPN/100ml)
F_1 = bias correction factor
F_2 = unit conversion factor (0.0245)

Estimating Subwatershed Loads

Subwatersheds with more than one monitoring station are subdivided into unique watershed segments, thus allowing individual load and reduction targets to be determined for each. In the Loch Raven Reservoir watershed two stations have upstream monitoring stations, as listed in Table 4.3.4. In these two cases the subwatershed is differentiated by adding the extension “sub” to the name of the downstream monitoring station. For example, GUN0233sub signifies only the area and load between stations GUN0233 and GUN0284 while GUN0233 refers to the cumulative area draining to that station. The portion of the watershed downstream of stations, GUN0233, WGP0050, BEV0005 and SBH0002, is referred to as the Downstream Subwatershed. This identification represents only the area and load downstream of those four stations. There are a total of eight subwatersheds considered in this analysis, corresponding to the seven monitoring stations and the unmonitored downstream portion.

Table 4.3.4: Subdivided Watersheds in the Loch Raven Reservoir Watershed

Subwatershed	Upstream Station(s)
GUN0284sub	GUN0387, LIT0002
GUN0233sub	GUN0284
Downstream Subwatershed	GUN0233, WGP0050, BEV0005, SBH0002

Bacteria loads from these subwatersheds are joined by loads from their upstream subwatersheds to result in the concentration measured at the downstream monitoring station. 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:

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

where,

Q_{us} = upstream flow (cfs)
Q_{sub} = subwatershed flow (cfs)
Q_{ds} = downstream flow (cfs)

And the general equation for the bacteria loading mass balance is:

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

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 subwatershed load, expressed as $Q_{sub}C_{sub}$ in equation (9), and the average flow are used to estimate the geometric mean concentration of the subwatershed.

As explained above, to estimate the load from subwatershed GUN0284sub, the transported load from stations GUN0387 and LIT0002 is subtracted from the load measured at station GUN0284. The difference is assigned to subwatershed GUN0284sub. To estimate the load from subwatershed GUN0233sub, the transported load from stations GUN0284 is subtracted from the load measured at station GUN0233. The difference is assigned to subwatershed GUN0233sub.

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 GUN0284sub and GUN0233sub were assigned from the analysis for GUN0284 and GUN0233, respectively.

The bacteria concentration for the watershed referred to as the Downstream Subwatershed, is assigned as the average of the concentrations at the three upstream stations, GUN0233, WGP0050 and BEV0005, and is assumed to be representative of that subwatershed. The bacteria source distribution for the downstream subwatershed is also assigned as the average of the BST analysis results of the three specified upstream stations.

Results of the baseline load calculations, including subwatersheds partially located in PA, are presented in Table 4.3.5.

Table 4.3.5: Baseline Loads Calculations

Subwatershed	Area (mi^2)	Daily Average Flow (cfs)	*E. coli* Concentration (MPN/100ml)	Baseline *E. coli* Load (Billion MPN/year)
GUN0387	1.8	2.3	14	460
LIT0002[1]	53.8	70.3	96	97,368
GUN0284sub	18.6	24.3	343	142,466
GUN0233sub	26.9	35.2	572	1,177,287
WGP0050	60.1	69.7	233	307,744
BEV0005	20.9	30.3	213	115,900
SBH0002	1.5	2.2	300	21,893
Downstream Subwatershed	40.7	53.2	196	331,190

[1] Subwatershed partially located in Pennsylvania

Baseline loads for subwatersheds located in both MD and PA were estimated using the ratios of the areas of the MD and PA portions to the total area of the subwatershed. The total baseline load for all subwatersheds or portions thereof located in MD is estimated as 2,187,202 billion MPN *E.coli*/year. The total baseline load for the portions of subwatersheds located in PA is 7,106 billion MPN E. coli/year. A summary of the baseline loads is given in Table 4.3.6.

Table 4.3.6: Baseline Loads Summary

MD 8-Digit Loch Raven Reservoir Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)								
Total Baseline Load	=	**Upstream Baseline Load**[1]	+	**MD 8-digit Loch Raven Reservoir Baseline Load Contribution**				
		BL_{PA}		**Nonpoint Source BL_{LR}**	+	**NPDES Stormwater BL_{LR}**	+	**WWTP BL_{LR}**
2,194,308	=	7,106	+	2,033,052	+	152,583	+	1,567

[1] Although the upstream baseline load is reported here as a single value, it could include point and nonpoint sources.

4.4 Bacteria Source Tracking

As explained above in the Source Assessment Section, ARA was used to identify probable bacterial sources in the Loch Raven watershed. An accurate representation of the expected contribution of each source (human, pets, livestock and wildlife) at each station is estimated by using a weighted mean of the identified sample results. The weighting factors are based on the $\log_{10}$ of the bacteria concentration. The procedure for calculating the 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 an initial weighted percentage (IMS) of each source. The weighting is based on the $\log_{10}$ bacteria concentration for the water sample.
3. Adjust the weighted percentage based on the classification of known sources.

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

$$MS_l = \sum_{k=1}^{5} \frac{A_{l,k} * IMS_k}{P_k} \qquad (4)$$

where,

$$IMS_k = \frac{\sum_{j=1}^{n} \log_{10}(C_j) * S_{j,k}}{\sum_{j=1}^{n} \log_{10}(C_j)} \qquad (5)$$

and where,

MS_l = weighted mean proportion of isolates of source l

IMS_k = initial weighted mean proportion of isolates for source k

$A_{l,k}$ = number of known source l isolates initially predicted as source k
P_k = number of total known isolates initially predicted as source k
j = sample
k = source category (1=human, 2=domestic, 3=livestock, 4=wildlife, 5=unknown)
l = final source category (1=human, 2=domestic, 3=livestock, 4=wildlife)
C_j = concentration for sample j
$S_{j,k}$ = proportion of isolates for sample j, of source k
n = number of samples

The complete distributions of the annual and seasonal period source loads are listed in Tables 4.4.1 and 4.4.2. Details of the BST data and tables with the BST analysis results can be found in Appendix C. For the downstream subwatershed, averages of the three upstream (GUN0233, WGP0050 and BEV0005) source percentages were used.

Table 4.4.1: Distribution of Fecal Bacteria Source Loads in the Loch Raven Reservoir Watershed for the Average Annual Period

Station	% Domestic Animals	% Human	% Livestock	% Wildlife
GUN0387	7.9	41.4	4.7	46.0
LIT0002	5.0	53.8	10.6	30.7
GUN0284	15.1	26.0	13.4	45.5
GUN0233	6.4	26.2	13.7	53.7
WGP0050	5.4	28.1	14.3	52.2
BEV0005	7.6	37.4	12.4	42.6
SBH0002	5.4	33.1	13.9	47.6
Downstream Subwatershed	6.5	30.6	13.5	49.5

Table 4.4.2: Distribution of Fecal Bacteria Source Loads in the Loch Raven Reservoir Watershed for the Seasonal (May 1 – September 30) Dry Weather Period

Station	% Domestic Animals	% Human	% Livestock	% Wildlife
GUN0387	15.8	46.7	4.4	33.2
LIT0002	9.6	58.7	6.7	25.0
GUN0284	23.8	28.6	8.2	39.4
GUN0233	11.2	30.2	9.3	49.2
WGP0050	8.3	33.0	10.1	48.6
BEV0005	7.9	38.0	12.0	42.1
SBH0002	4.6	29.0	14.0	52.4
Downstream Subwatershed	9.2	33.7	10.5	46.6

4.5 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 both the annual and dry weather seasonal conditions. Seasonality is assessed as the time period when water contact recreation is expected, specifically dry weather days during May 1st through September 30th. The critical condition requirement is met by determining the maximum reduction per bacteria source that satisfies both conditions and meets the water quality standard, thereby minimizing the risk to water contact recreation. It is assumed that the reduction applied to a bacteria source category will be constant through both conditions.

The reductions of fecal bacteria required to meet water quality standards in each subwatershed of the Loch Raven Reservoir watershed are shown in Table 4.4.1. For computational purposes, the calculations include those subwatersheds partially located in PA.

Table 4.5.1: Required Fecal Bacteria Reductions (by Condition) to Meet Water Quality Standards

Station	Condition	Domestic Animals %	Human %	Livestock %	Wildlife %
GUN0387	Annual	0.0	0.0	0.0	0.0
	Seasonal	0.0	0.0	0.0	0.0
	Maximum Source Reduction	**0.0**	**0.0**	**0.0**	**0.0**
LIT0002[1]	Annual	0.0	0.0	0.0	0.0
	Seasonal	0.0	23.7	0.0	0.0
	Maximum Source Reduction	**0.0**	**23.7**	**0.0**	**0.0**
GUN0284sub	Annual	98.0	98.0	98.0	25.7
	Seasonal	98.0	98.0	98.0	76.1
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**76.1**
GUN0233sub	Annual	98.0	98.0	98.0	62.8
	Seasonal	98.0	98.0	98.0	68.3
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**68.3**
WGP0050	Annual	98.0	98.0	98.0	3.4
	Seasonal	98.0	98.0	98.0	51.9
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**51.9**
BEV0005	Annual	29.8	95.0	48.9	0.0
	Seasonal	98.0	98.0	98.0	56.2
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**56.2**
SBH0002	Annual	98.0	98.0	98.0	18.3
	Seasonal	98.0	98.0	98.0	80.7
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**80.7**
Downstream Subwatershed	Annual	28.8	95.0	59.9	0.0
	Seasonal	98.0	98.0	98.0	44.2
	Maximum Source Reduction	**98.0**	**98.0**	**98.0**	**44.2**

[1] Subwatersheds partially located in Pennsylvania

4.6 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.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA 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. The second approach was used for this TMDL 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.

4.7 Scenario Descriptions

Source Distribution

The final bacteria source distribution and corresponding baseline loads are derived from the source proportions listed in Table 4.4.1. The source distribution and baseline loads used in the TMDL scenarios are presented in Table 4.67.1. As stated in Section 4.3, the source distributions for subwatersheds GUN0284sub and GUN0233sub were based on the sources identified at stations GUN0284 and GUN0233 respectively.

Table 4.7.1: Bacteria Source Distributions and Corresponding Baseline Loads Used in the Annual Average TMDL Analysis

Subwatershed	Domestic		Human		Livestock		Wildlife		Total Load (Billion *E. coli* MPN/year)
	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	
GUN0387	7.9	36	41.4	190	4.7	22	46.0	212	460
LIT0002[1]	5.0	4,835	53.8	52,396	10.6	10,275	30.7	29,862	97,368
GUN0284sub	15.1	21,497	26.0	37,092	13.4	19,028	45.5	64,849	142,466
GUN0233sub	6.4	75,552	26.2	308,913	13.7	160,834	53.7	631,988	1,177,287
WGP0050	5.4	16,654	28.1	86,556	14.3	43,975	52.2	160,559	307,744
BEV0005	7.6	8,765	37.4	43,373	12.4	14,377	42.6	49,385	115,900
SBH0002	5.4	1,184	33.1	7,254	13.9	3,032	47.6	10,423	21,893
Downstream Subwatershed	6.5	21,408	30.6	101,331	13.5	44,551	49.5	163,900	331,190

[1] Subwatersheds partially located in Pennsylvania

First Scenario: Fecal Bacteria Practicable Reduction Targets

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.7.2. These values are based on 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 4.7.2: 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 4.7.2). The model was defined as follows:

$$\text{Risk Score} = \text{Min} \sum_{i=1}^{4} P_j * W_j \qquad (10)$$

where,

$$P_j = \frac{(1 - R_i) * Pb_j}{1 - TR} \qquad (11)$$

and,

$$TR = \frac{C - C_{cr}}{C} \tag{12}$$

Therefore the risk score can be represented as:

$$Risk\ Score = Min \sum_{i=1}^{4} \left[\frac{(1 - R_j) * Pb_j}{(1 - \frac{C - Ccr}{C})} * W_j \right] \tag{13}$$

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 = weight 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:

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

In six of the eight 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 4.7.3.

Table 4.7.3: Practicable Reduction Scenario Results

Subwatershed	Applied Reductions				Total Reduction %	Target Reduction %
	Domestic %	Human %	Livestock %	Wildlife %		
GUN0387	0.0	0.0	0.0	0.0	0.0	0.0
LIT0002[1]	0.0	23.7	0.0	0.0	12.7	12.7
GUN0284sub	75.0	95.0	75.0	0.0	46.1	88.0
GUN0233sub	75.0	95.0	75.0	0.0	40.0	82.1
WGP0050	75.0	95.0	75.0	0.0	41.5	73.9
BEV0005	75.0	95.0	75.0	0.0	50.5	80.2
SBH0002	75.0	95.0	75.0	0.0	45.9	89.8
Downstream Subwatershed	75.0	95.0	75.0	0.0	44.0	71.4

[1] Subwatersheds partially located in Pennsylvania

Second Scenario: Fecal Bacteria Reductions Higher than MPRs

The TMDL must specify load allocations that will meet the water quality standards. In the practicable reduction targets scenario, six of the eight subwatersheds could not 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 these subwatersheds, the maximum allowable reduction was increased to 98% for all sources, including wildlife. A similar optimization procedure as before 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 considered in the practicable reduction scenario but subject to the following constraints:

$$\begin{aligned}
C &= Ccr \\
0 \leq R_{human} &\leq 98\% \\
0 \leq R_{pets} &\leq 98\% \\
0 \leq R_{livestock} &\leq 98\% \\
0 \leq R_{wildlife} &\leq 98\% \\
P_j &\geq 1\%
\end{aligned}$$

A summary of the results of this second scenario analysis is presented in Table 4.7.4.

Table 4.7.4: Reduction Results Based on Optimization Model Allowing Up to 98% Reduction

Subwatershed	Applied Reductions				Total Reduction %	Target Reduction %
	Domestic %	Human %	Livestock %	Wildlife %		
GUN0387	0.0	0.0	0.0	0.0	0.0	0.0
LIT0002[1]	0.0	23.7	0.0	0.0	12.7	12.7
GUN0284sub	98.0	98.0	98.0	76.1	88.0	88.0
GUN0233sub	98.0	98.0	98.0	68.3	82.1	82.1
WGP0050	98.0	98.0	98.0	51.9	73.9	73.9
BEV0005	98.0	98.0	98.0	56.2	80.2	80.2
SBH0002	98.0	98.0	98.0	80.7	89.8	89.8
Downstream Subwatershed	98.0	98.0	98.0	44.2	71.4	71.4

[1]Subwatersheds partially located in Pennsylvania

4.8 TMDL Loading Caps

The TMDL loading cap is an estimate of the assimilative capacity of the monitored watershed. The TMDL loading caps are provided in billion MPN *E. coli*/day. These loading caps are for the seven subwatersheds located upstream of their respective monitoring stations as well as the one downstream watershed. Loading caps for subwatersheds of Loch Raven Reservoir partially located in PA were included in the TMDL scenario. A TMDL summary for the entire Loch Raven Reservoir watershed will include an upstream load allocation for the portion of the watershed located in PA to indicate estimated loads necessary to meet MD water quality standards in the MD 8-digit assessment unit for the Loch Raven Reservoir watershed.

Annual Average TMDL

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 the long-term annual average daily flow.

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 4.5). 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 4.5, represents the maximum reduction per source that satisfies the two hydrological conditions in each subwatershed, and that is required to meet water quality standards.

$$\text{TMDL Loading Cap} = L_b * (1 - R) \qquad (14)$$

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, including those partially located in PA, are shown in Tables 4.8.1 and 4.8.2.

Table 4.8.1: Annual Average TMDL Loading Caps

Subwatershed	*E. coli* Baseline Load (Billion MPN/year)	Long-Term Average *E. coli* TMDL Load (Billion MPN/year)	% Target Reduction
GUN0387	460	460	0.0
LIT0002[1]	97,368	84,958	12.7
GUN0284sub	142,466	17,029	88.0
GUN0233sub	1,177,287	211,228	82.1
WGP0050	307,744	80,168	73.9
BEV0005	115,900	22,967	80.2
SBH0002	21,893	2,244	89.8
Downstream Subwatershed	331,190	94,840	71.4
Total	**2,194,308**	**513,894**	**76.6**

[1] Subwatersheds partially located in Pennsylvania

Table 4.8.2: Annual Average TMDL Loading Caps by Source Category

Subwatershed	Domestic		Human		Livestock		Wildlife		Total Load (Billion *E. coli* MPN/year)
	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	
GUN0387	7.9	36	41.4	190	4.7	22	46.0	212	460
LIT0002[1]	5.7	4,835	47.1	39,986	12.1	10,275	35.1	29,862	84,958
GUN0284sub	2.5	430	4.4	742	2.2	381	90.9	15,476	17,029
GUN0233sub	0.7	1,511	2.9	6,178	1.5	3,217	94.8	200,322	211,228
WGP0050	0.4	333	2.2	1,731	1.1	879	96.3	77,225	80,168
BEV0005	0.8	175	3.8	868	1.3	288	94.2	21,636	22,967
SBH0002	1.1	24	6.5	145	2.7	61	89.8	2,014	2,244
Downstream Subwatershed	0.5	428	2.1	2,027	0.9	891	96.5	91,494	94,840

[1] Subwatersheds partially located in Pennsylvania

Maximum Daily Loads

Recent EPA guidance (US EPA 2006a) recommends that maximum daily load (MDL) expressions of long-term annual average TMDLs should also be provided as part of the TMDL analysis and report. 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 (MDL) is expected to be exceeded. Draft EPA/TetraTech 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 Loch Raven Reservoir watershed MDLs, 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 MDLs have an upper bound percentile that accounts for the variability of daily loads. The upper bound percentile and the MDLs 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 MDLs. First, all the data available from each monitoring station are examined and the percentile rank of the highest observed concentration (at each station) is computed. The highest computed percentile rank is the upper bound percentile to be used in estimating the MDLs.

Secondly, the long-term annual average TMDL (see Table 4.8.1) concentrations are estimated. 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 MDL at each station is estimated using the upper boundary percentile computed in the first step above. Finally, MDLs are computed from these MDL concentrations and their corresponding flows.

Results of the fecal bacteria MDL analysis for the Loch Raven Reservoir subwatersheds, including for computational purposes those partially located in PA, are shown in Table 4.8.3. The downstream subwatershed is assigned the average MDL of the upstream subwatersheds (GUN0233, WGP0050 and BEV0005).

Table 4.8.3: Loch Raven Reservoir Watershed Maximum Daily Loads Summary

Subwatershed	**Maximum Daily Load (Billion *E. coli* MPN/day)**
GUN0387	11
LIT0002[1]	3,327
GUN0284sub	157
GUN0233sub	2,186
WGP0050	5,251
BEV0005	1,194
SBH0002	212
Downstream Subwatershed	5,613

[1] Subwatersheds partially located in Pennsylvania

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

4.9 TMDL Allocations

The Loch Raven Reservoir watershed fecal bacteria TMDL is composed of the following components:

$$TMDL = LA_{LR} + WLA_{LR} + LA_{PA} + MOS \qquad (15)$$

where,

LA_{LR} = MD Loch Raven Reservoir Watershed Load Allocation
WLA_{LR} = MD Loch Raven Reservoir Watershed Waste Load Allocation
LA_{PA} = Pennsylvania Load Allocation
MOS = Margin of Safety

The TMDL allocation for the Loch Raven Reservoir MD 8-digit basin includes load allocations (LA_{LR}) for nonpoint sources and waste load allocations (WLA_{LR}) for point sources including WWTPs and NPDES-regulated stormwater discharges. The Stormwater (SW) WLA_{LR} includes any nonpoint source loads determined 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_{LR} and to the SW-WLA_{LR} and WWTP-WLA_{LR} is provided in the subsections that follow.

In addition to these allocation categories for the MD 8-digit watershed, the Loch Raven Reservoir watershed TMDL includes an upstream load allocation for the portion of the watershed located in PA (LA_{PA}). The LA_{PA} was calculated using the ratios of the areas of the watershed in MD and in PA to the total area of the watershed, and is presented as a "lump-sum" upstream load comprising all bacteria source categories. The LA_{PA}, determined to be necessary in order to meet MD water quality standards in the Loch Raven Reservoir MD 8-digit basin, will not be distributed between nonpoint sources (LA) and point sources (WLA).

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_{LR} (those nonpoint sources or portions thereof not transported and discharged by stormwater systems) and the WLA_{LR} (point sources including WWTPs, and NPDES regulated stormwater discharges). Only the final LA_{LR} or WLA_{LR} is reported in this TMDL. Note that the assignment of an allowable human load to the LA_{LR} 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 4.9.1: Potential Source Contributions for TMDL Allocation Categories in the Loch Raven Reservoir Watershed in MD

Source Category	**TMDL Allocation Categories**		
	LA_{LR}	**WLA_{LR}**	
		WWTP	**Stormwater**
Human	X	X	
Domestic	X		X
Livestock	X		
Wildlife	X		X

* These allocations apply only to the portion of the watershed in MD. The TMDL allocation scenario load attributed to PA includes all four bacteria source categories in one single load.

LA_{LR}

All four bacteria source categories could potentially contribute to nonpoint source loads. For human sources, the nonpoint source contribution is estimated by subtracting any WWTP loads from the TMDL human load, and is then assigned to the LA_{LR}. Livestock loads are also assigned to the LA_{LR}. Since the entire Loch Raven Reservoir watershed is covered by NPDES MS4 permits, bacteria loads from domestic animal and wildlife sources are distributed between the SW-WLA_{LR} and LA_{LR}.

WLA_{LR}

NPDES Regulated Stormwater

EPA’s guidance document, "Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs" (November 2002), advises that all individual and general NPDES Phase I and Phase II stormwater permits are point sources subject to WLA assignment in the TMDL. The document acknowledges that quantification of rainfall-driven nonpoint source loads is uncertain, stating that available data and information usually are not detailed enough to determine WLAs for NPDES-regulated stormwater discharges on an outfall-specific basis; therefore, the EPA guidance allows the stormwater WLA to be expressed as an aggregate allotment.

Bacteria loads from domestic animal sources are distributed between the $SW\text{-}WLA_{LR}$ and the LA_{LR} based on a ratio of the population in urban land use areas to the population in non-urban areas. The bacteria load from wildlife sources is distributed between the $SW\text{-}WLA_{LR}$ and LA_{LR} based on a ratio of the per capita acreage in urban areas to the per capita acreage in non-urban areas. This weighting allows for a greater domestic animal source allocation in urban areas, and a greater wildlife source allocation to non-urban areas. In watersheds with no existing NPDES-regulated stormwater permits, these loads will be included entirely in the LA.

Within the MD portion of the Loch Raven Reservoir watershed, the jurisdictions of Baltimore County, Carroll County, and Harford County have individual Phase I MS4 permits. The municipality of Hampstead is also covered by a general Phase II MS4 permit. Based on EPA's guidance, the SW-WLA is presented as one combined load for the entire land area of each jurisdiction in each subwatershed. In addition to the county and municipal MS4s, the SW-WLA category includes any other Phase I and Phase II NPDES regulated stormwater entities in the watershed, including the MD SHA Phase I MS4, Phase II State and federal MS4s, and industrial stormwater permittees. In the future, when more detailed data and information become available, it is anticipated that the SW-WLA may be disaggregated into more specific allocations by permit type.

The NPDES regulated stormwater baseline loads of fecal bacteria for the MD portion of the Loch Raven Reservoir watershed are presented by jurisdiction and subwatershed in Table 4.9.2. The corresponding $SW\text{-}WLA_{LR}$ distribution is presented in Table 4.9.3. It is important to note that these apportioned loads are still aggregate SW-WLAs within each jurisdiction. The average annual allocations represent overall reductions in fecal bacteria loads from regulated stormwater sources of 88% from Baltimore County, 95% from Carroll County, 98% from the municipality of Hampstead, and 0% from Harford County. Upon approval of the TMDL, "NPDES-regulated municipal stormwater and small construction storm water discharges effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002a).

Table 4.9.2: Stormwater Baseline Loads in MD

Subwatershed	Baltimore County $SW\text{-}BL_{LR}$	Carroll County $SW\text{-}BL_{LR}$	Hampstead $SW\text{-}BL_{LR}$	Harford County $SW\text{-}BL_{LR}$
	(Billion MPN *E. coli*/year)			
GUN0387	33	N/A	N/A	N/A
LIT0002[1]	3,234	N/A	N/A	35
GUN0284sub	15,284	N/A	N/A	N/A
GUN0233sub	66,357	N/A	N/A	N/A
WGP0050	10,332	426	4,714	N/A
BEV0005	17,961	N/A	N/A	N/A
SBH0002	10,750	N/A	N/A	N/A
Downstream Subwatershed	23,457	N/A	N/A	N/A

[1] MD portion of the subwatershed only.

Table 4.9.3: Annual Average Stormwater Allocations in MD

Subwatershed	Baltimore County $SW\text{-}WLA_{LR}$	Carroll County $SW\text{-}WLA_{LR}$	Hampstead $SW\text{-}WLA_{LR}$	Harford County $SW\text{-}WLA_{LR}$
	(Billion MPN *E. coli*/year)			
GUN0387	33	N/A	N/A	N/A
LIT0002[1]	3,234	N/A	N/A	35
GUN0284sub	512	N/A	N/A	N/A
GUN0233sub	4,538	N/A	N/A	N/A
WGP0050	1,556	21	104	N/A
BEV0005	4,498	N/A	N/A	N/A
SBH0002	1,874	N/A	N/A	N/A
Downstream Subwatershed	1,972	N/A	N/A	N/A

[1] MD portion of the subwatershed only.

Municipal and Industrial WWTPs

As explained in the source assessment section above, there is one NPDES permitted point source facility with a permit regulating the discharge of fecal bacteria in the Loch Raven Reservoir watershed. This facility discharges into the subwatershed of WGP0050 (Western Run). The WLA for the WWTP is estimated using the design flow of the plant stated in the facility's

NPDES permit and the *E. coli* criterion concentration of 126 MPN/100ml. Bacteria loads assigned to the WWTP are allocated as the WWTP-WLA$_{LR}$.

4.10 Summary

The long-term annual average TMDL and TMDL allocations are presented in Table 4.10.1. Table 4.10.2 presents the maximum daily loads for the subwatersheds or portions thereof within the Loch Raven Reservoir MD 8-digit basin.

Table 4.10.1: Loch Reservoir Watershed Annual Average TMDL

Subwatershed	**Total Allocation**	**LA$_{LR}$**	**SW-WLA$_{LR}$**	**WWTP-WLA$_{LR}$**
	(Billion MPN *E. coli* /year)			
GUN0387	460	427	33	0
LIT0002[1]	78,758	75,490	3,268	0
GUN0284sub	17,029	16,517	512	0
GUN0233sub	211,228	206,690	4,538	0
WGP0050	80,168	76,920	1,681	1,567
BEV0005	22,967	18,469	4,498	0
SBH0002	2,244	369	1,875	0
Downstream Subwatershed	94,840	92,868	1,972	0
MD Total	507,694	487,750	18,377	1,567
PA Upstream Load	6,200			
***TMDL*[2]**	**513,894**			

[1] MD portion of the subwatershed only.
[2] The MOS is incorporated.

Table 4.10.2: Loch Raven Reservoir Watershed Maximum Daily Loads

Subwatershed	Total Allocation	LA_{LR}	$SW\text{-}WLA_{LR}$	$WWTP\text{-}WLA_{LR}$
	(Billion MPN *E. coli* /day)			
GUN0387	11	10	1	0
LIT0002[1]	3,084	2,956	128	0
GUN0284sub	157	152	5	0
GUN0233sub	2,186	2,139	47	0
WGP0050	5,251	5,128	110	13
BEV0005	1,194	960	234	0
SBH0002	212	35	177	0
Downstream Subwatershed	5,613	5,496	117	0
MD Total	17,708	16,876	819	13
PA Upstream Load	243			
***TMDL*[2]**	**17,951**			

[1] MD portion of the subwatershed only.
[2] The MOS is incorporated.

The long-term annual average fecal bacteria TMDL summary for the entire Loch Raven Reservoir watershed is presented in Table 4.10.3.

Table 4.10.3: MD 8-Digit Loch Raven Reservoir Watershed Annual Average TMDL Summary

(Billion MPN *E. coli*/year)										
TMDL	=	**LA**			+	**WLA**			+	**MOS**
		LA$_{PA}$[1]	+	**LA$_{LR}$**		**SW WLA$_{LR}$**	+	**WWTP WLA$_{LR}$**		
513,894	=	6,200	+	487,750	+	18,377	+	1,567	+	Incorpo-rated

Upstream Load Allocation

MD 8-digit Loch Raven Reservoir TMDL Contribution (507,694)

[1] This upstream PA load allocation is determined to be necessary in order to meet MD water quality standards in the MD portion of the Loch Raven Reservoir watershed. Although the upstream load is reported here as a single value, it could include point and nonpoint sources.

The maximum daily loads of fecal bacteria for the MD 8-digit Loch Raven Reservoir watershed, including the PA upstream load, are summarized in Table 4.10.4.

Table 4.10.4: MD 8-Digit Loch Raven Reservoir Watershed MDL Summary

(Billion MPN *E. coli*/day)										
MDL	=	**LA**			+	**WLA**			+	**MOS**
		LA$_{PA}$	+	**LA$_{LR}$**		**SW WLA$_{LR}$**	+	**WWTP WLA$_{LR}$**		
17,951	=	243	+	16,876	+	819	+	13	+	Incorpo-rated

Upstream MDL

MD 8-digit Loch Raven Reservoir MDL Contribution (17,708)

In certain watersheds, the goal of meeting water quality standards may require very high reductions that are not achievable with current technologies and management practices. In this situation, where there is no feasible TMDL scenario, MPRs are increased to provide estimates of the reductions required to meet water quality standards. In six of the eight Loch Raven Reservoir subwatersheds, water quality standards cannot be achieved with the maximum practicable reduction rates specified in Table 4.7.3. For these six subwatersheds the TMDLs shown in Tables 4.10.1 and 4.10.2 represent reductions from current bacteria loadings that are beyond practical reductions. In cases where such high reductions are required to meet standards, it is expected that the first stage of implementation will be to carry out 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 Loch Raven Reservoir watershed, the TMDL analysis indicates that, for six of the eight subwatersheds, the reductions of fecal bacteria loads 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 tributaries of Loch Raven Reservoir may not be able to attain water quality standards. The fecal bacteria load reductions required to meet water quality criteria in six of the eight Loch Raven Reservoir subwatersheds 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.

Low interest loans are available to property owners with failing septic systems through MDE's Linked Deposit Program, for assistance in correction of such systems through replacement or connection to public sewer systems. In addition, Maryland’s Bay Restoration Fund provides funding to upgrade onsite sewage disposal systems. These upgrades, which enhance nitrogen removal, will also help reduce human source fecal bacteria loads from failing septic systems in the watershed.

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.

The Loch Raven Reservoir watershed is managed under NPDES MS4 permits for Baltimore, Carroll, and Harford Counties, and for the municipality of Hampstead, as well as all other Phase I MS4s in the watershed, including the MD State Highway Administration, Phase II State and federal MS4s, and industrial stormwater permittees. This provides regulatory assurances that urban stormwater sources will be managed to the maximum extent practicable. The State's NPDES stormwater permits use a watershed approach for improving the water quality of stormwater runoff because it is comprehensive and efficient. By examining all stormwater pollutants including physical and biological impairments at the same time, cost effective control strategies can be developed. This approach is based upon detailed stormwater assessments regarding: water quality conditions, identifying and ranking water quality problems, identifying all structural and nonstructural BMP opportunities, conducting visual watershed inspections, specifying how restoration efforts are monitored, and providing estimated costs and detailed implementation schedules for restoration work. Stormwater BMPs and programs implemented as required by MS4 permits shall be consistent with available WLAs developed under the TMDL. Where fecal bacteria are transported through an MS4 conveyance system, stormwater BMPs implemented to control urban runoff should help in reducing fecal bacteria loads in the Loch Raven Reservoir watershed.

Baltimore County is under a Consent Decree regarding its sanitary sewer overflows. Implementation of the conditions of the Consent Decree should assist in addressing the bacteria sources, particularly the human sources, in the sewered portion of the watershed.

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. 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

Station	Date	Daily flow frequency	*E. coli* Concentration (MPN/100ml)
BEV0005	11/05/2003	14.1371	200
	11/19/2003	0.8979	140
	12/03/2003	41.8528	50
	12/17/2003	0.8760	960
	01/05/2004	10.2825	150
	01/20/2004	31.9755	60
	02/02/2004	36.1805	20
	02/17/2004	26.5112	50
	03/01/2004	36.1805	480
	03/15/2004	36.1805	30
	04/05/2004	13.5567	40
	04/19/2004	23.4341	110
	05/10/2004	44.8861	140
	05/24/2004	51.5659	380
	06/07/2004	29.9058	790
	06/21/2004	71.3973	370
	07/06/2004	78.9860	2500
	07/19/2004	48.3574	910
	08/09/2004	85.9396	830
	08/23/2004	90.9220	420
	09/07/2004	91.9076	120
	09/20/2004	71.3973	960
	10/04/2004	71.3973	380
	10/18/2004	82.8625	190

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
GUN0233	11/05/2003	15.7360	130
	11/19/2003	3.8733	100
	12/03/2003	13.0545	70
	12/17/2003	1.2249	14140
	01/05/2004	7.2832	50
	01/20/2004	15.7360	30
	02/17/2004	15.7360	40
	03/01/2004	19.8742	30
	03/15/2004	21.7833	10
	04/05/2004	7.5811	470
	04/19/2004	14.7650	60
	05/10/2004	25.7559	60
	05/24/2004	28.4816	270
	06/07/2004	4.9327	350
	06/21/2004	17.4465	270
	07/06/2004	38.0049	3800
	07/19/2004	31.7921	260
	08/09/2004	29.4968	70
	08/23/2004	38.0049	60
	09/07/2004	47.2633	70
	09/20/2004	20.9777	710
	10/04/2004	24.7848	260
	10/18/2004	37.1993	60

Station	**Date**	**Daily flow frequency**	***E. coli* Concentration (MPN/100ml)**
GUN0284	11/05/2003	15.7360	50
	11/19/2003	3.8733	40
	12/03/2003	13.0545	30
	12/17/2003	1.2249	250
	01/05/2004	7.2832	40
	01/20/2004	15.7360	30
	02/02/2004	19.6866	30
	02/17/2004	15.7360	30
	03/01/2004	19.8742	10
	03/15/2004	21.7833	10
	04/05/2004	7.5811	320
	04/19/2004	14.7650	30
	05/10/2004	25.7559	50
	05/24/2004	28.4816	210
	06/07/2004	4.9327	300
	06/21/2004	17.4465	230
	07/06/2004	38.0049	770
	07/19/2004	31.7921	70
	08/09/2004	29.4968	90
	08/23/2004	38.0049	170
	09/07/2004	47.2633	70
	09/20/2004	20.9777	420
	10/04/2004	24.7848	160
	10/18/2004	37.1993	20

Station	Date	Daily flow frequency	*E. coli* Concentration (MPN/100ml)
GUN0387	11/05/2003	12.5602	30
	11/19/2003	1.4455	10
	12/03/2003	12.1770	30
	12/17/2003	1.3250	40
	01/05/2004	7.5011	10
	01/20/2004	15.5278	10
	02/02/2004	17.9698	10
	02/17/2004	15.8563	10
	03/01/2004	19.0101	10
	03/15/2004	21.8791	20
	04/05/2004	12.1770	1
	04/19/2004	19.3714	10
	05/10/2004	25.2957	10
	05/24/2004	32.2711	10
	06/07/2004	14.8270	10
	06/21/2004	16.8309	10
	07/06/2004	36.5747	120
	07/19/2004	22.9851	10
	08/09/2004	24.7919	20
	08/23/2004	34.7678	20
	09/07/2004	50.2081	10
	09/20/2004	27.5186	90
	10/04/2004	25.2957	20
	10/18/2004	40.3198	10

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
LIT0002	11/05/2003	12.5602	160
	11/19/2003	1.4455	40
	12/03/2003	12.1770	120
	12/17/2003	1.3250	220
	01/05/2004	7.5011	70
	01/20/2004	15.5278	40
	02/02/2004	17.9698	20
	02/17/2004	15.8563	10
	03/01/2004	19.0101	100
	03/15/2004	21.8791	20
	04/05/2004	12.1770	260
	04/19/2004	19.3714	90
	05/10/2004	25.2957	80
	05/24/2004	32.2711	260
	06/07/2004	14.8270	10
	06/21/2004	16.8309	320
	07/06/2004	36.5747	130
	07/19/2004	22.9851	250
	08/09/2004	24.7919	150
	08/23/2004	34.7678	120
	09/07/2004	50.2081	90
	09/20/2004	27.5186	770
	10/04/2004	25.2957	280
	10/18/2004	40.3198	110

Station	Date	Daily flow frequency	*E. coli* Concentration (MPN/100ml)
SBH0002	11/05/2003	14.1371	100
	11/19/2003	0.8979	1310
	12/03/2003	41.8528	70
	12/17/2003	0.8760	3650
	01/05/2004	10.2825	120
	01/20/2004	31.9755	40
	02/02/2004	36.1805	180
	02/17/2004	26.5112	50
	03/01/2004	36.1805	30
	03/15/2004	36.1805	30
	04/05/2004	13.5567	30
	04/19/2004	23.4341	50
	05/10/2004	44.8861	990
	05/24/2004	51.5659	1440
	06/07/2004	29.9058	720
	06/21/2004	71.3973	770
	07/06/2004	78.9860	4600
	07/19/2004	48.3574	9210
	08/09/2004	85.9396	610
	08/23/2004	90.9220	380
	09/07/2004	91.9076	260
	09/20/2004	71.3973	1070
	10/04/2004	71.3973	170
	10/18/2004	82.8625	380

Station	Date	Daily flow frequency	*E. coli* Concentration (MPN/100ml)
WGP0050	11/05/2003	22.7332	130
	11/19/2003	2.7705	110
	12/03/2003	21.4849	140
	12/17/2003	1.4126	2910
	01/05/2004	10.1621	90
	01/20/2004	21.4849	120
	02/02/2004	17.9260	10
	02/17/2004	20.4008	50
	03/01/2004	25.2738	40
	03/15/2004	23.4012	20
	04/05/2004	7.9720	930
	04/19/2004	15.1226	220
	05/10/2004	21.4849	280
	05/24/2004	32.1507	700
	06/07/2004	17.0061	1100
	06/21/2004	44.8204	430
	07/06/2004	50.1533	200
	07/19/2004	47.3390	910
	08/09/2004	57.9829	400
	08/23/2004	65.8892	190
	09/07/2004	74.4306	450
	09/20/2004	59.3408	1400
	10/04/2004	56.6908	840
	10/18/2004	65.8892	190

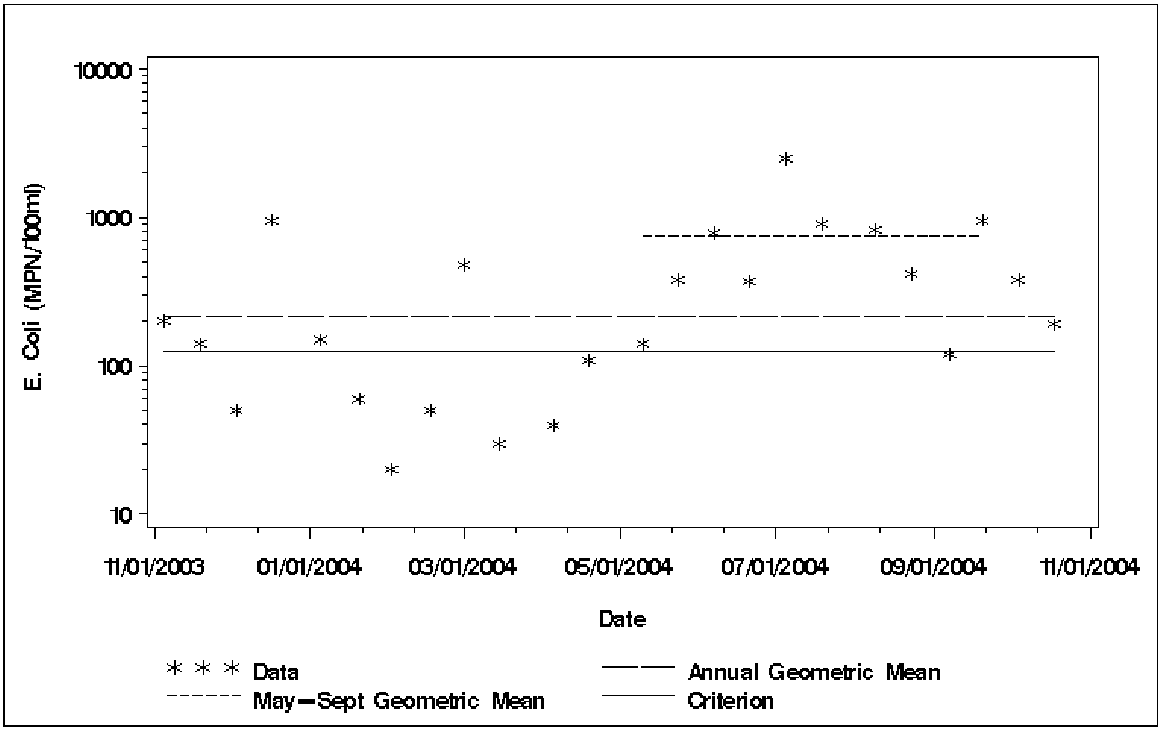

Figure A-1: *E. coli* Concentration vs. Time for MDE Monitoring Station BEV0005

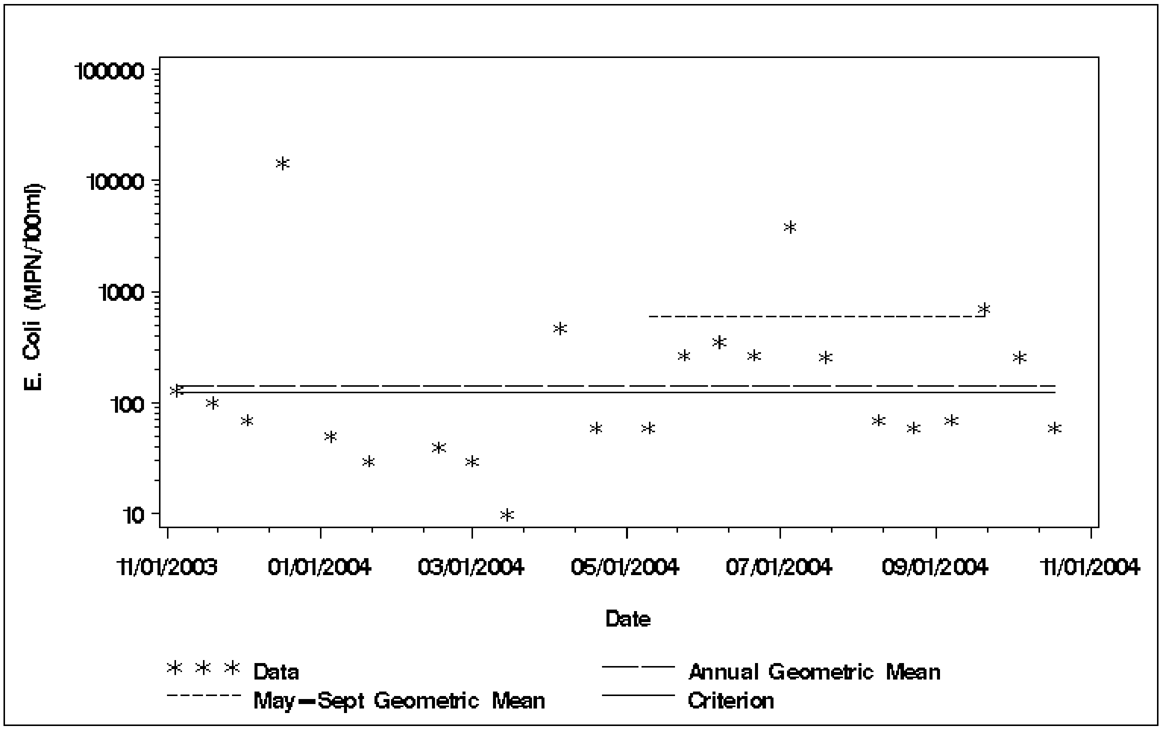

Figure A-2: *E. coli* Concentration vs. Time for MDE Monitoring Station GUN0233

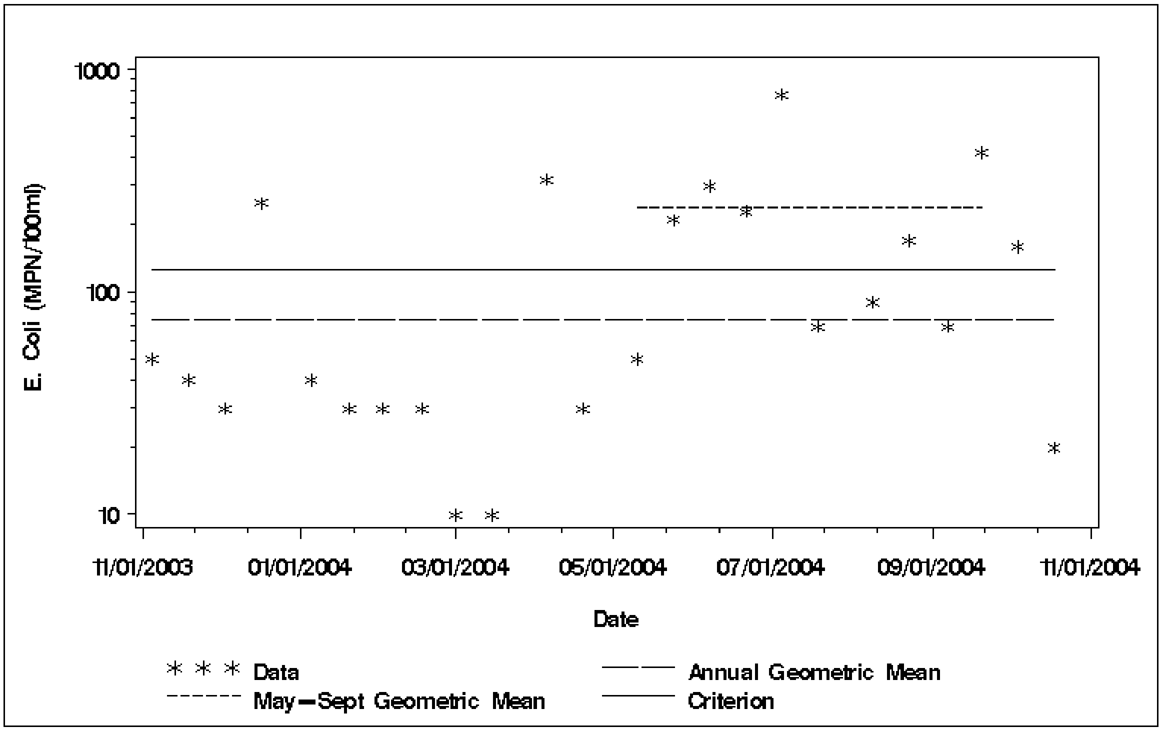

Figure A-3: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station GUN0284**

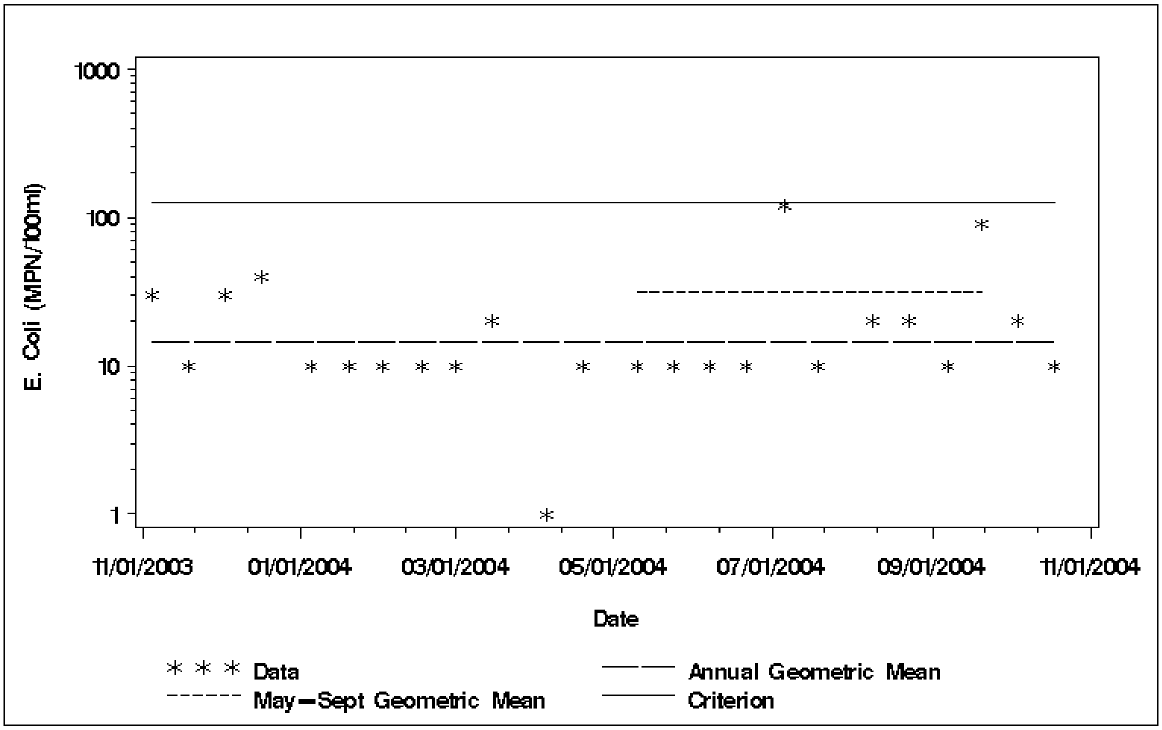

Figure A-4: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station GUN0387**

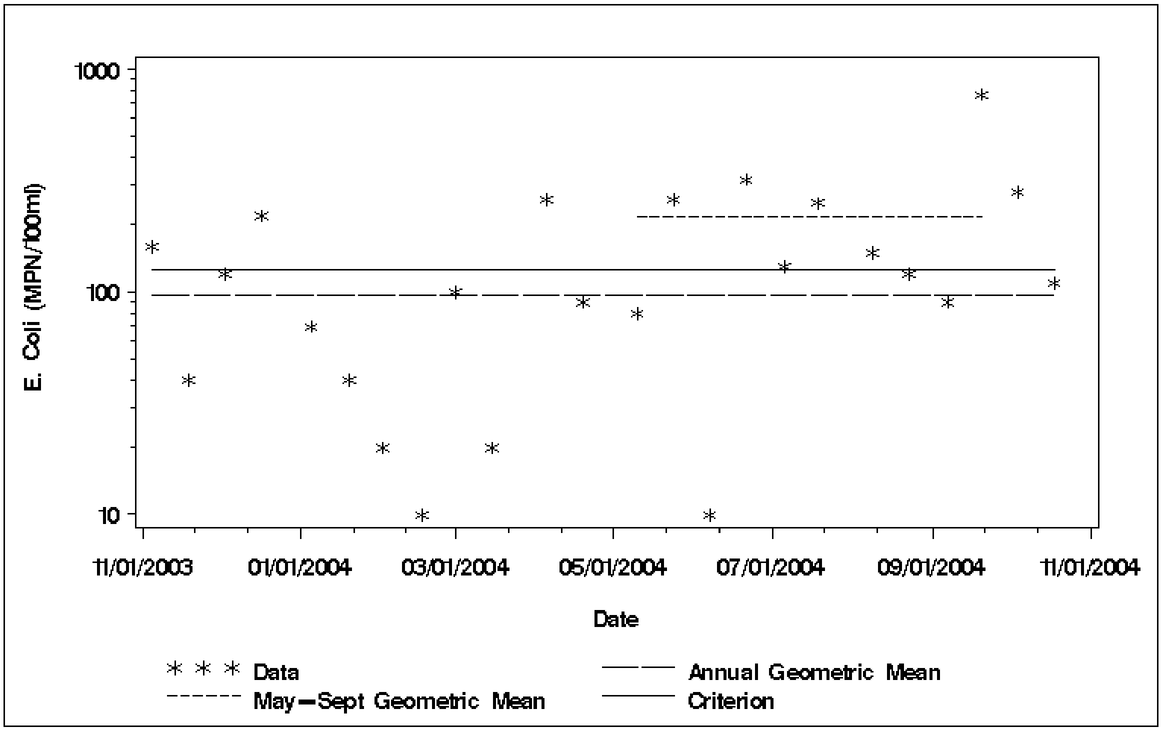

Figure A-5: *E. coli* Concentration vs. Time for MDE Monitoring Station LIT0002

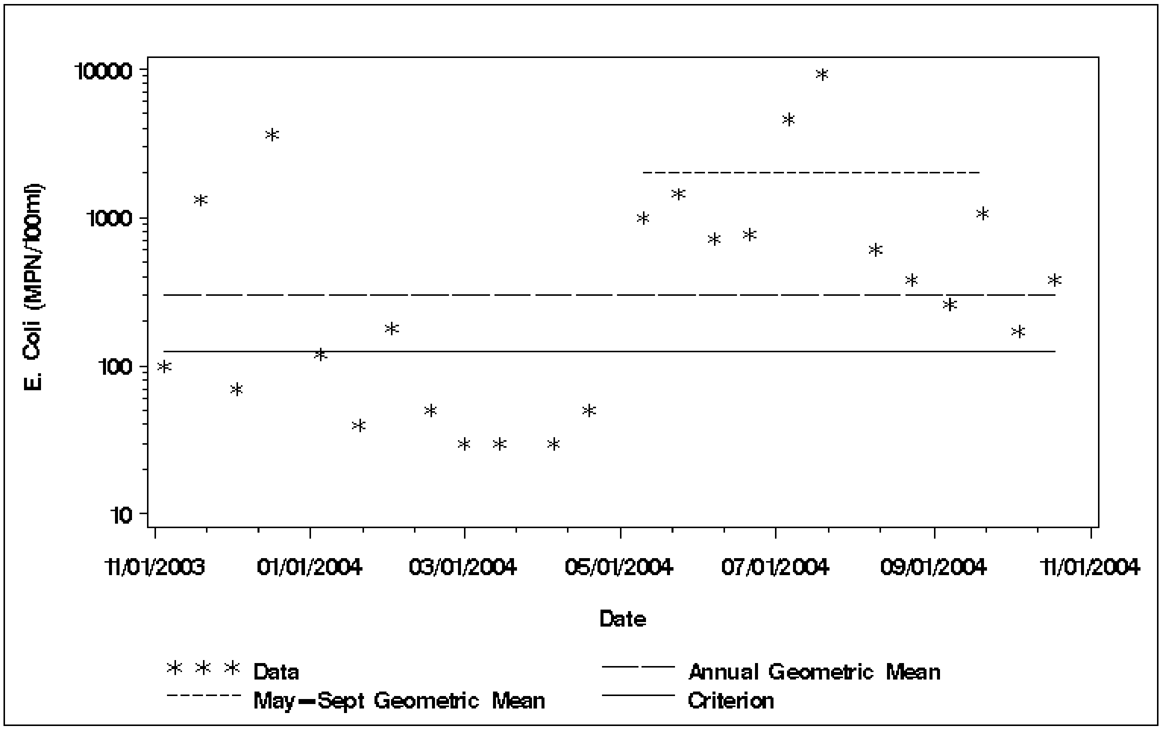

Figure A-6: *E. coli* Concentration vs. Time for MDE Monitoring Station SBH0002

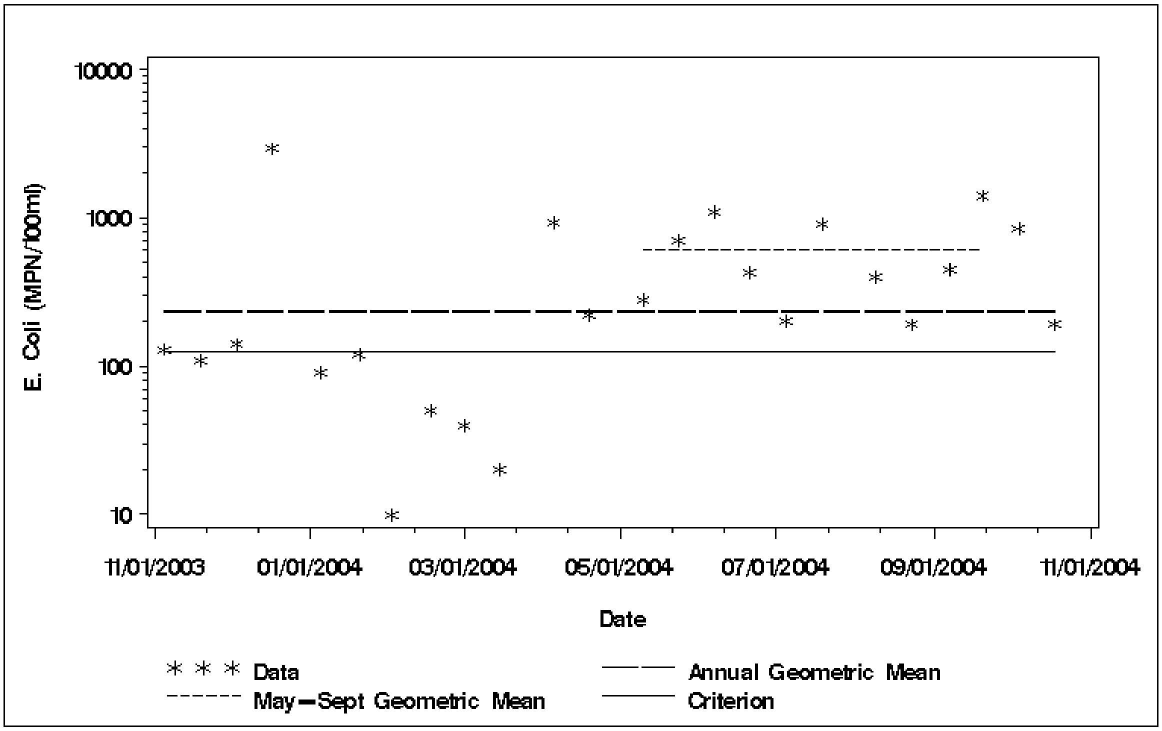

Figure A-7: *E. coli* Concentration vs. Time for MDE Monitoring Station WGP0050

Appendix B - Flow Duration Curve Analysis to Define Strata

The Loch Raven Reservoir watershed was assessed to determine hydrologically significant strata. The purpose of these strata is to apply weights to monitoring data and thus reduce bias associated with the monitoring design. 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 antecedent soil moisture 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

There are four USGS gage stations in the Loch Raven Reservoir watershed used for the analysis. These sites are listed in Table B-1. Flow duration curves for these sites are presented in Figure B-1.

Table B-1: USGS Sites in the Loch Raven Reservoir Watershed

USGS Site #	Dates Used	Location
01582000	10/01/1982 – 9/30/2007	Little Falls at Blue Mount, MD
01582500	12/10/1982 – 9/30/2007	Gunpowder Falls at Glencoe, MD
01583500	10/01/1982 – 9/30/2007	Western Run at Western Run, MD
01583600	10/01/1982 – 9/30/2007	Beaverdam Run at Cockeysville, MD

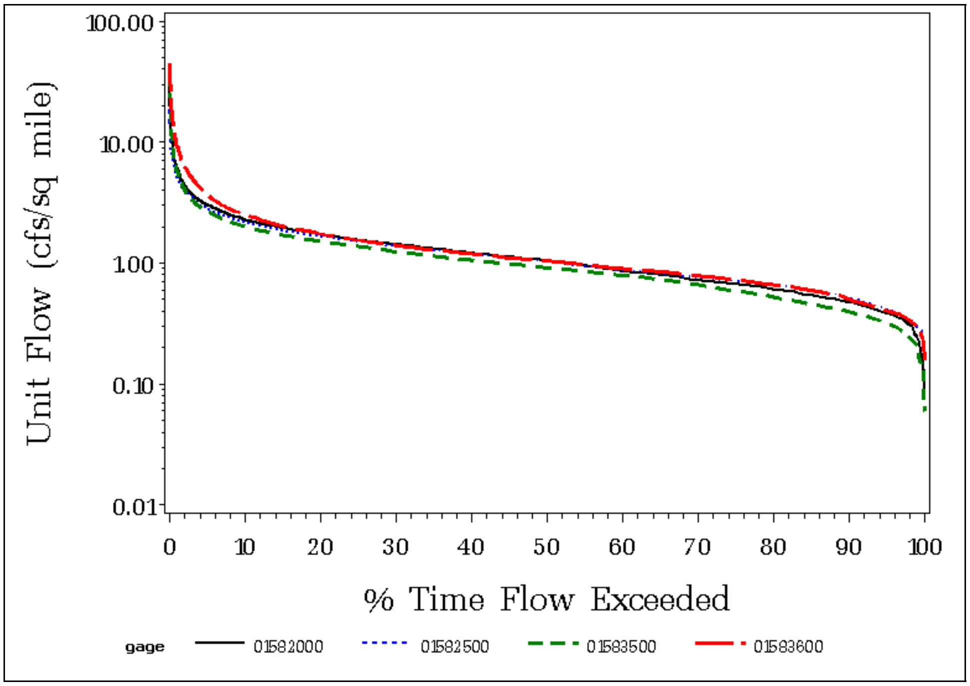

Figure B-1: Flow Duration Curve for Loch Raven Reservoir Watershed USGS Sites

The long-term average daily unit flows at the four stations correspond to a weighted average flow frequency of 34.3%. 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 34.3 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 34.3% and a low flow condition will be defined as occurring when the daily flow duration percentile is greater than 34.3%. 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.

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.

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 Loch Raven Reservoir watershed there are not sufficient samples in both flow regimes to estimate the geometric means by stratum. Therefore an overall geometric mean will be calculated for both the annual and seasonal conditions.

Appendix C – BST Report

Final Report

Maryland Department of the Environment

MOU U00P7200322

Identifying Sources of Fecal Pollution in Shellfish and Nontidal Waters in Maryland Watersheds

November 2006 – June 2008

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Salisbury University, Salisbury, MD

June 30, 2008

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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: Liberty Reservoir, Loch Raven Reservoir, and the Upper Patuxent River Also included in the study were the following tidal shellfish harvesting areas: Honga River, Hunting Creek and Leeds Creek, Little Choptank River, Little Creek, Miles River, Shipping Creek, and Wells Cove watersheds . 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 (Price *et al*., 2006; Hagedorn, 1999; Wiggins, 1999). A pilot study using PFGE, a genotypic BST method, was used on a subset of deer scat isolates collected from watersheds across Maryland.

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; Price *et al*., 2006; 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, cow, goat, horse, dog, bear, beaver, deer, duck, fox, goose, heron, opossum, rabbit, raccoon, and squirrel). 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. For both the nontidal and tidal watersheds, no combined known-source libraries were used for any shellfish harvesting area; a known-source isolate library collected from each area was used for the particular watershed.

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]

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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.

Loch Raven Reservoir Watershed ARA Results

Known-Source Library. A 620 known-source isolate library was constructed from sources in the Loch Raven Reservoir Watershed. The number of unique antibiotic resistance patterns was calculated, and the known sources in the combined library were grouped into four categories: human, livestock (cow, horse), pet (dog), and wildlife (deer, duck, goose, fox, rabbit, raccoon) (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 in the "Statistical Analysis" section of this document. The number-not-classified for each probability was determined. From these results, the percent unknown and percent correct classification (RCCs) was calculated (Table C-3).

Table C-2: Category, total number, and number of unique patterns in the Loch Raven Reservoir known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
Human	human	187	101
Livestock	cow, horse	96	24
Pet	dog	56	22
Wildlife	deer, duck, goose, fox, rabbit, raccoon	281	65
Total		620	212

For Loch Raven Reservoir Watershed, a cutoff probability of 0.50 (50%) was shown to yield an overall rate of correct classification of 76% (Figure C-1; Table C-3). The resulting rates of correction classification (RCCs) for the four categories of sources in the Loch Raven Reservoir library are shown in Table C-4.

Table C-3: Number of isolates not classified, percent unknown, and percent correct for seven (7) cutoff probabilities for Loch Raven Reservoir known-source isolates using the Loch Raven Reservoir known-source library.

Threshold	0	0.375	**0.5**	0.6	0.7	0.8	0.9
% correct	67.1%	71.6%	**76.3%**	76.9%	81.7%	86.9%	92.2%
% unknown	0.0%	9.2%	**27.7%**	35.8%	49.8%	61.8%	73.2%
# not classified	0	57	**172**	222	309	383	454

Figure C-1: Loch Raven Reservoir Classification Model: Percent Correct versus Percent Unknown using the Loch Raven Reservoir library.

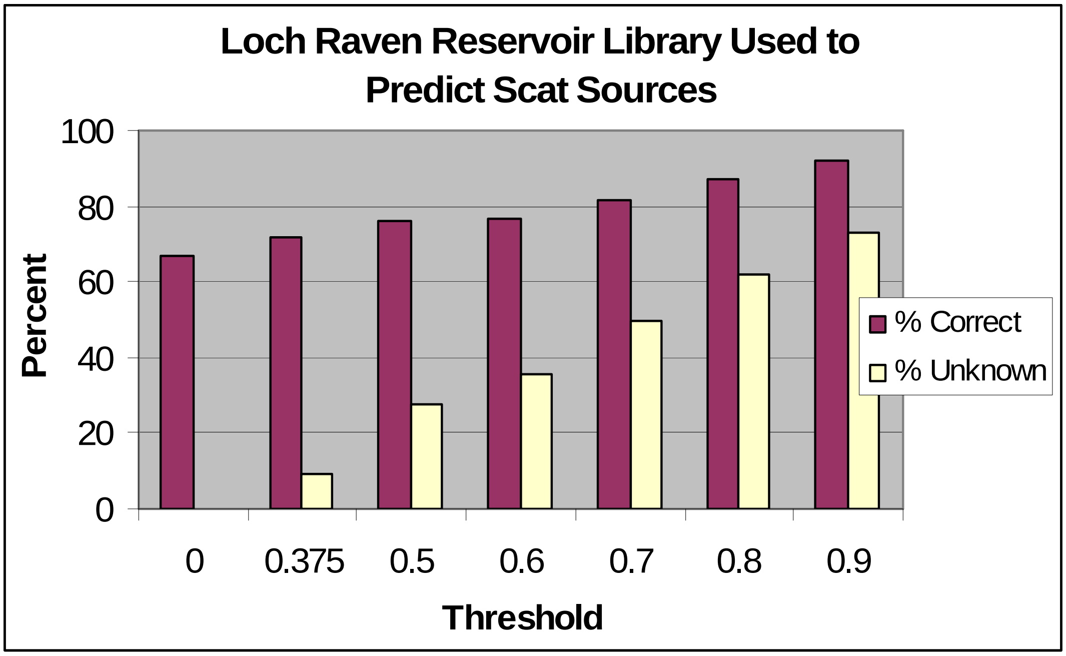


Table C-4: Actual species categories versus predicted categories, at 50% probability cutoff, with rates of correct classification (RCC) for each category.

	Predicted						
Actual	Human	Livestock	Pet	Wildlife	Unknown	Total	RCC*
Human	122	1	8	16	40	187	83.0%
Livestock	1	41	5	12	37	96	69.5%
Pet	1	1	40	1	13	56	93.0%
Wildlife	20	35	5	139	82	281	69.8%
Total	144	78	58	168	172	620	76.3%

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

Loch Raven Reservoir Water Samples. Monthly monitoring from seven (7) monitoring stations on Loch Raven Reservoir was the source of water samples. The maximum number of *Enterococcus* isolates obtained per water sample was 24, although the number of isolates that actually grew was sometimes less than 24. A total of 1,447 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicate that 97% of the water isolates were able to be classified to a probable host source when using a 0.50 (50%) probability threshold.

Table C-5: Probable host sources of water isolates by species category, number of isolates, and percent isolates classified at a cutoff probability of 50%.

Source	Count	Percent	Percent Without Unknowns
Human	498	34.4%	35.4%
Livestock	238	16.4%	16.9%
Pet	132	9.1%	9.4%
Wildlife	538	37.2%	38.3%
Unknown	41	2.8%	
Total	1447	100.0%	100.0%
% classified	**97.2%**		

*Percentages may not add up to 100% due to rounding.

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

Table C-6: *Enterococcu*s isolates obtained from water collected during the spring, summer, fall, and winter seasons for Loch Raven Reservoir's seven (7) monitoring stations.

	Season				
Station	Spring	Summer	Fall	Winter	Total
BEV0005	68	71	60	58	257
GUN0233	61	67	60	17	205
GUN0284	58	58	62	32	210
GUN0387	13	8	35	9	65
LIT0002	56	68	49	29	202
SBH0002	60	72	68	51	251
WGP0050	66	68	69	54	257

Tables C-7 and C-8 on the following pages show the number and percent of the probable sources for each monitoring station by month.

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

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEV0005	11/19/03	5	13	0	4	0	22
BEV0005	12/03/03	2	2	2	7	7	20
BEV0005	01/05/04	15	2	1	5	1	24
BEV0005	02/17/04	6	5	2	9	2	24
BEV0005	03/01/04	2	2	3	3	0	10
BEV0005	04/05/04	18	0	0	0	2	20
BEV0005	05/10/04	3	9	0	12	0	24
BEV0005	06/07/04	9	1	5	9	0	24
BEV0005	07/06/04	6	1	4	12	0	23
BEV0005	08/09/04	18	6	0	0	0	24
BEV0005	09/07/04	11	0	0	12	1	24
BEV0005	10/04/04	5	0	2	11	0	18
GUN0233	11/19/03	7	4	0	11	2	24
GUN0233	12/03/03	4	9	0	3	0	16
GUN0233	01/05/04	0	0	0	4	2	6
GUN0233	02/17/04	5	3	0	1	0	9
GUN0233	03/01/04	0	0	0	2	0	2
GUN0233	04/05/04	5	6	0	12	0	23
GUN0233	05/10/04	3	4	3	5	0	15
GUN0233	06/07/04	11	3	4	5	0	23
GUN0233	07/06/04	7	1	2	14	0	24
GUN0233	08/09/04	5	0	9	10	0	24
GUN0233	09/07/04	2	0	0	17	0	19
GUN0233	10/04/04	1	5	2	12	0	20
GUN0284	11/19/03	0	2	3	13	0	18
GUN0284	12/03/03	5	14	0	5	0	24
GUN0284	01/05/04	3	13	0	8	0	24
GUN0284	02/17/04	0	3	0	3	0	6
GUN0284	03/01/04	0	0	1	1	0	2
GUN0284	04/05/04	13	4	0	7	0	24
GUN0284	05/10/04	7	0	1	1	1	10
GUN0284	06/07/04	3	1	17	3	0	24
GUN0284	07/06/04	2	0	7	13	0	22
GUN0284	08/09/04	7	0	6	7	0	20
GUN0284	09/07/04	1	3	2	10	0	16

Table C-7 (continued): BST Analysis: Number of Isolates per Station per Date.

		Predicted	Source				
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
GUN0284	10/04/04	6	1	3	10	0	20
GUN0387	11/19/03	0	0	0	1	0	1
GUN0387	12/03/03	6	0	0	14	1	21
GUN0387	01/05/04	4	0	0	0	0	4
GUN0387	02/17/04	0	0	0	5	0	5
GUN0387	06/07/04	12	0	1	0	0	13
GUN0387	07/06/04	4	0	3	0	0	7
GUN0387	08/09/04	0	0	0	1	0	1
GUN0387	10/04/04	7	0	1	5	0	13
LIT0002	11/19/03	2	2	0	0	0	4
LIT0002	12/03/03	15	1	1	3	1	21
LIT0002	01/05/04	0	16	0	8	0	24
LIT0002	02/17/04	2	0	0	0	0	2
LIT0002	03/01/04	2	0	0	0	1	3
LIT0002	04/05/04	5	1	0	7	0	13
LIT0002	05/10/04	8	0	5	6	0	19
LIT0002	06/07/04	21	1	2	0	0	24
LIT0002	07/06/04	19	0	3	2	0	24
LIT0002	08/09/04	15	2	3	0	0	20
LIT0002	09/07/04	12	5	0	5	2	24
LIT0002	10/04/04	18	2	0	2	2	24
SBH0002	11/19/03	9	11	2	2	0	24
SBH0002	12/03/03	7	0	3	10	1	21
SBH0002	01/05/04	13	3	0	7	0	23
SBH0002	02/17/04	10	7	2	3	0	22
SBH0002	03/01/04	1	0	0	4	1	6
SBH0002	04/05/04	6	1	0	4	1	12
SBH0002	05/10/04	7	5	1	11	0	24
SBH0002	06/07/04	7	9	2	6	0	24
SBH0002	07/06/04	9	1	1	13	0	24
SBH0002	08/09/04	4	5	0	15	0	24
SBH0002	09/07/04	5	3	3	12	1	24
SBH0002	10/04/04	6	2	4	10	1	23
WGP0050	11/19/03	5	0	1	14	3	23
WGP0050	12/03/03	1	9	0	11	1	22
WGP0050	01/05/04	1	3	0	12	1	17
WGP0050	02/17/04	6	2	1	12	0	21

Table C-7 (continued): BST Analysis: Number of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
WGP0050	03/01/04	2	3	1	6	4	16
WGP0050	04/05/04	7	11	0	6	0	24
WGP0050	05/10/04	5	4	0	8	1	18
WGP0050	06/07/04	9	3	7	5	0	24
WGP0050	07/06/04	9	0	0	15	0	24
WGP0050	08/09/04	8	1	5	10	0	24
WGP0050	09/07/04	4	2	0	13	1	20
WGP0050	10/04/04	8	6	1	9	0	24
Total		498	238	132	538	41	1447

Table C-8: BST Analysis: Percent of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEV0005	11/19/03	23%	59%	0%	18%	0%	100%
BEV0005	12/03/03	10%	10%	10%	35%	35%	100%
BEV0005	01/05/04	63%	8%	4%	21%	4%	100%
BEV0005	02/17/04	25%	21%	8%	38%	8%	100%
BEV0005	03/01/04	20%	20%	30%	30%	0%	100%
BEV0005	04/05/04	90%	0%	0%	0%	10%	100%
BEV0005	05/10/04	13%	38%	0%	50%	0%	100%
BEV0005	06/07/04	38%	4%	21%	38%	0%	100%
BEV0005	07/06/04	26%	4%	17%	52%	0%	100%
BEV0005	08/09/04	75%	25%	0%	0%	0%	100%
BEV0005	09/07/04	46%	0%	0%	50%	4%	100%
BEV0005	10/04/04	28%	0%	11%	61%	0%	100%
GUN0233	11/19/03	29%	17%	0%	46%	8%	100%
GUN0233	12/03/03	25%	56%	0%	19%	0%	100%
GUN0233	01/05/04	0%	0%	0%	67%	33%	100%
GUN0233	02/17/04	56%	33%	0%	11%	0%	100%
GUN0233	03/01/04	0%	0%	0%	100%	0%	100%
GUN0233	04/05/04	22%	26%	0%	52%	0%	100%
GUN0233	05/10/04	20%	27%	20%	33%	0%	100%
GUN0233	06/07/04	48%	13%	17%	22%	0%	100%
GUN0233	07/06/04	29%	4%	8%	58%	0%	100%
GUN0233	08/09/04	21%	0%	38%	42%	0%	100%
GUN0233	09/07/04	11%	0%	0%	89%	0%	100%
GUN0233	10/04/04	5%	25%	10%	60%	0%	100%
GUN0284	11/19/03	0%	11%	17%	72%	0%	100%
GUN0284	12/03/03	21%	58%	0%	21%	0%	100%
GUN0284	01/05/04	13%	54%	0%	33%	0%	100%

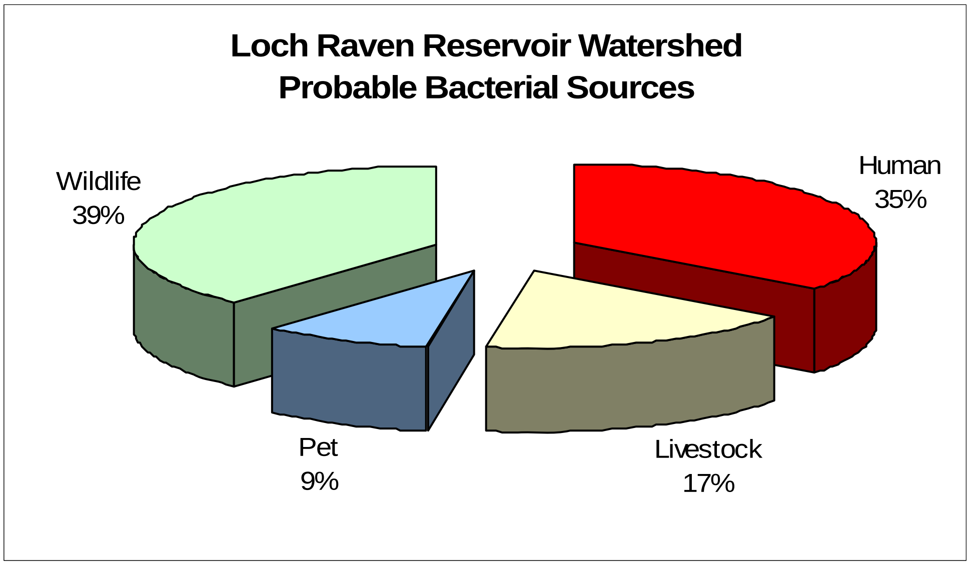
Table C-8 (continued): BST Analysis: Percent of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
GUN0284	02/17/04	0%	50%	0%	50%	0%	100%
GUN0284	03/01/04	0%	0%	50%	50%	0%	100%
GUN0284	04/05/04	54%	17%	0%	29%	0%	100%
GUN0284	05/10/04	70%	0%	10%	10%	10%	100%
GUN0284	06/07/04	13%	4%	71%	13%	0%	100%
GUN0284	07/06/04	9%	0%	32%	59%	0%	100%
GUN0284	08/09/04	35%	0%	30%	35%	0%	100%
GUN0284	09/07/04	6%	19%	13%	63%	0%	100%
GUN0284	10/04/04	30%	5%	15%	50%	0%	100%
GUN0387	11/19/03	0%	0%	0%	100%	0%	100%
GUN0387	12/03/03	29%	0%	0%	67%	5%	100%
GUN0387	01/05/04	100%	0%	0%	0%	0%	100%
GUN0387	02/17/04	0%	0%	0%	100%	0%	100%
GUN0387	06/07/04	92%	0%	8%	0%	0%	100%
GUN0387	07/06/04	57%	0%	43%	0%	0%	100%
GUN0387	08/09/04	0%	0%	0%	100%	0%	100%
GUN0387	10/04/04	54%	0%	8%	38%	0%	100%
LIT0002	11/19/03	50%	50%	0%	0%	0%	100%
LIT0002	12/03/03	71%	5%	5%	14%	5%	100%
LIT0002	01/05/04	0%	67%	0%	33%	0%	100%
LIT0002	02/17/04	100%	0%	0%	0%	0%	100%
LIT0002	03/01/04	67%	0%	0%	0%	33%	100%
LIT0002	04/05/04	38%	8%	0%	54%	0%	100%
LIT0002	05/10/04	42%	0%	26%	32%	0%	100%
LIT0002	06/07/04	88%	4%	8%	0%	0%	100%
LIT0002	07/06/04	79%	0%	13%	8%	0%	100%
LIT0002	08/09/04	75%	10%	15%	0%	0%	100%
LIT0002	09/07/04	50%	21%	0%	21%	8%	100%
LIT0002	10/04/04	75%	8%	0%	8%	8%	100%
SBH0002	11/19/03	38%	46%	8%	8%	0%	100%
SBH0002	12/03/03	33%	0%	14%	48%	5%	100%
SBH0002	01/05/04	57%	13%	0%	30%	0%	100%
SBH0002	02/17/04	45%	32%	9%	14%	0%	100%
SBH0002	03/01/04	17%	0%	0%	67%	17%	100%
SBH0002	04/05/04	50%	8%	0%	33%	8%	100%
SBH0002	05/10/04	29%	21%	4%	46%	0%	100%
SBH0002	06/07/04	29%	38%	8%	25%	0%	100%
SBH0002	07/06/04	38%	4%	4%	54%	0%	100%

Table C-8 (continued): BST Analysis: Percent of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
SBH0002	08/09/04	17%	21%	0%	63%	0%	100%
SBH0002	09/07/04	21%	13%	13%	50%	4%	100%
SBH0002	10/04/04	26%	9%	17%	43%	4%	100%
WGP0050	11/19/03	22%	0%	4%	61%	13%	100%
WGP0050	12/03/03	5%	41%	0%	50%	5%	100%
WGP0050	01/05/04	6%	18%	0%	71%	6%	100%
WGP0050	02/17/04	29%	10%	5%	57%	0%	100%
WGP0050	03/01/04	13%	19%	6%	38%	25%	100%
WGP0050	04/05/04	29%	46%	0%	25%	0%	100%
WGP0050	05/10/04	28%	22%	0%	44%	6%	100%
WGP0050	06/07/04	38%	13%	29%	21%	0%	100%
WGP0050	07/06/04	38%	0%	0%	63%	0%	100%
WGP0050	08/09/04	33%	4%	21%	42%	0%	100%
WGP0050	09/07/04	20%	10%	0%	65%	5%	100%
WGP0050	10/04/04	33%	25%	4%	38%	0%	100%
Total		34%	16%	9%	37%	3%	100%

Figure C-2: Loch Raven Reservoir Watershed relative contributions by probable sources of *Enterococcus* contamination.



Loch Raven Reservoir Summary

The use of ARA was successful for identification of probable bacterial sources in the Loch Raven Reservoir Watershed. When water isolates were compared to the library and potential sources predicted, 97% of the isolates were classified as to category by statistical analysis. The highest RCC for the library was 93% (for pet), with 70% for livestock and wildlife. Human sources had a RCC of 83%.

The largest category of potential sources in the watershed as a whole was wildlife (39% of classified water isolates), followed by human and livestock (35% and 17%, respectively). The lowest potential source contribution was for pet (9%) (Fig. C-2).

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Adjustment of BST Results

As explained in the BST Summary for the Loch Raven Reservoir, the percent of correct classification (RCC) for bacteria sources can introduce a potential misclassification of the more probable sources in the watershed. This is seen in Table C-4, which shows results of the analysis of samples from known sources. For example, out of 620, 96 isolates were known to be of livestock source but only 41 were classified by the analysis as being of livestock source. Of those 96, 1 was classified as human, 5 as pet, 12 as wildlife and 37 as unknown. Similarly, of the other three categories, 1 isolates known to be human, 1 isolates known to be pet, and 35 known wildlife isolates were classified as livestock, resulting in a total of 78 of all 620 isolates classified as livestock of which only 41 were known to be of livestock source.

The results provided by the BST methodology can be adjusted based on the known source percent of correct classification results provided in Table C-4.

Example:

The current BST methodology provides the following source percentages for station GUN0284 during annual conditions:

Source Category	**Original Percentage**
Pets	20.93 %
Human	22.38 %
Livestock	15.94 %
Wildlife	40.00 %
Unknown	0.75 %

To get the correct human source percentage we redistributed the above percentages based on the % of correct classification as follows.

From Table C-4:

Source Category	**Isolates known to be from Human Source**	**Total Isolates Predicted for Each category**	**Percentage**
Pets	8	58	13.8 %
Human	122	144	84.7 %
Livestock	1	78	1.3 %
Wildlife	16	168	9.5 %
Unknown	40	172	23.3 %

Applying those percentages to the original estimated source distribution presented above will result in the adjusted percentage for human sources:

= (13.8 x 20.93) + (84.7 x 22.38) + (1.3 x 15.94) + (9.5 x 40.00) + (23.3 x 0.75) = 26.04 %

Thus the correct human source percentage, the value used in the TMDL analysis, is 26.04% and not 22.38%. Corrected percentages are also calculated as above for domestic animal (pet), livestock and wildlife sources. The classification of unknown is eliminated in the process as all known isolates are of known source. For station GUN0284 the annual corrected source percentages are as follows:

Source Category	Adjusted Percentage
Pets	15.1 %
Human	26.0 %
Livestock	13.4 %
Wildlife	45.5 %

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 the Loch Raven Reservoir watershed. 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.

Selected Approach for Defining Maximum Daily Loads for Nonpoint Sources and MS4

To calculate the Loch Raven Reservoir watershed MDL for non-point sources and MS4s, 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 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:

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

and,

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

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)

σ^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 seven monitoring stations of the Loch Raven Reservoir watershed. 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©.

$$Z = [\log_{10}(MOC) - \log(AM) + 0.5\sigma^2]/\sigma \qquad \text{(D3)}$$

where,

Z = z-score associated with upper bound percentile
MOC = maximum observed bacteria concentration (MPN/100ml)
AM = arithmetic mean observed bacteria concentrations (MPN/100ml)
σ^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 will define the upper bound percentile to be used in estimating the maximum daily limits. In the case of the Loch Raven Reservoir watershed, a value measured at the GUN0233 station resulted in the highest percentile of the seven stations. This value translates to the 99.8th 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

Subwatershed	Maximum Observed *E. coli* Concentration (MPN/100ml)	Percentile (%)
GUN0387	120	99.0
LIT0002[1]	770	97.0
GUN0284	770	97.5
GUN0233	14,140	99.8
WGP0050	2,910	96.6
BEV0005	2,500	97.3
SBH0002	9,210	97.8

[1] Subwatersheds partially located in Pennsylvania

The 99.8th percentile value results in a maximum daily load that would not be exceeded 99.8% 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}) are estimated by applying the required percent reduction to the baseline (monitoring data) concentrations (C_b):

From Section 4.3, equations (7):

$$L_b = Q*C_b*F_1$$

And from equation (14):

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

Therefore,

$$L_b*(1-R) = Q*C*F_1*(1-R) \qquad \text{(D4)}$$

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:

$$C_{LTA} = C_b * (1-R) \qquad \text{(D5)}$$

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

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

Subwatershed	**LTA Geometric Mean *E. coli* Concentration** (MPN/100ml)	**LTA Arithmetic Mean* *E. coli* Concentration** (MPN/100ml)
GUN0387	14	22
LIT0002[1]	84	154
GUN0284	55	112
GUN0233	83	307
WGP0050	61	157
BEV0005	42	96
SBH0002	31	130

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

[1] Subwatersheds partially located in Pennsylvania

The next step is to calculate the 99.8th 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 pollutant concentrations 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 99.8th 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

Subwatershed	Coefficient of Variation	MDL *E. coli* Concentration (MPN/100ml)
GUN0387	1.15	196
LIT0002[1]	1.54	1,933
GUN0284	1.77	1,640
GUN0233	3.56	8,255
WGP0050	2.39	3,077
BEV0005	2.04	1,611
SBH0002	4.13	3,875

[1] Subwatersheds partially located in Pennsylvania

With the 99.8th percentiles of LTA TMDL bacteria concentrations estimated as explained above, the maximum daily load for MS4 and non-point sources for each subwatershed can be now estimated as:

$$Daily\ TMDL\ (MPN/day) = Q^*(99.8^{th}C_{LTA})^*F_1 \qquad (D6)$$

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 99th 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 the Loch Raven Reservoir watershed, to estimate the maximum daily loads for WWTPs, the annual average loads are multiplied by the multiplication factor as follows:

$$WWTP\text{-}WLA\ MDL\ _{(billion\ MPN/day)} = [WWTP\text{-}WLA\ _{(billion\ MPN/year)}]^*(3.11/365) \qquad (D7)$$

The Maximum Daily Loads for the Loch Raven Reservoir subwatersheds, including those partially located in PA, are presented in Table D-4 below. For the unmonitored downstream subwatershed an average load of the upstream stations, GUN0233, WGP0050 and BEV0005, is used.

Table D-4: Maximum Daily Loads Summary

Subwatershed	**Maximum Daily Load** (Billion *E.* coli MPN/day)
GUN0387	11
LIT0002[1]	3,327
GUN0284sub	157
GUN0233	2,186
WGP0050	5,251
BEV0005	1,194
SBH0002	212
Downstream Subwatershed	5,613

[1] Subwatersheds partially located in Pennsylvania

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). The maximum daily load allocations for the Loch Raven Reservoir watershed are presented in Table D-5.

Table D-5: Loch Raven Reservoir Watershed Maximum Daily Loads in MD

Subwatershed	**Total Allocation**	**LA_{LR}**	**$SW\text{-}WLA_{LR}$**	**$WWTP\text{-}WLA_{LR}$**
	(Billion MPN *E. coli* /day)			
GUN0387	11	10	1	0
LIT0002[1]	3,084	2,956	128	0
GUN0284sub	157	152	5	0
GUN0233	2,186	2,139	47	0
WGP0050	5,251	5,128	110	13
BEV0005	1,194	960	234	0
SBH0002	212	35	177	0
Downstream Subwatershed	5,613	5,496	117	0
Total	**17,708**	**16,876**	**819**	**13**

[1] MD portion of the subwatershed only.

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