Total Maximum Daily Loads of Fecal Bacteria for the Patapsco River Lower North Branch Basin in Anne Arundel, Baltimore, Carroll, and Howard Counties, and Baltimore City, Maryland

FINAL

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Submitted to:

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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 Patapsco River Lower North Branch (Patapsco LNB) watershed (basin number 02-13-09-06). 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 waters of the Maryland (MD) 8-digit Patapsco LNB watershed on the State's 303(d) List [Category 5 of the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report)] as impaired by nutrients (listed in 1996, revised in 2008 to phosphorus), sediment (1996), metals (1996), fecal bacteria (2008), impacts to biological communities (listed in 2002, 2004 and 2006), and polychlorinated biphenyls (PCBs) (2008). Herbert Run, a tributary of the Patapsco River, was listed in 2006 as impaired by lead and copper. The waters of the MD 8-digit Patapsco LNB watershed have been designated as Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life) See Code of Maryland Regulations (COMAR) 26.08.02.07F(5). Brice Run, also a tributary of the Patapsco River, and its tributaries have been designated as Use III (Nontidal Cold Water). See COMAR 26.08.02.08K(3)(a).

This document proposes to establish a TMDL for fecal bacteria in the Patapsco River LNB watershed that will allow for attainment of the beneficial use designation of water contact recreation. The listings for phosphorus, sediment, PCBs, and impacts to biological communities will be addressed in separate TMDL documents. The listing for metals was addressed in 2002. The Herbert Run listings for lead and copper were addressed in 2008. MDE monitored the Patapsco LNB watershed from 2002-2003 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2007, and all readily available data from the past five years were considered.

For this TMDL analysis, the Patapsco LNB watershed has been divided into five subwatersheds. For convenience, each subwatershed will be referenced by the downstream bacteria monitoring station's name and location. The subwatersheds are PAT0148 (Patapsco River at Hammonds Ferry Rd.), PAT0176 (Patapsco River at Rt. 1), PAT0222 (Patapsco River at Ilchester Rd.), PAT0285 (Patapsco River at Old Frederick Rd.) and PAT0347 (Patapsco River at Old Court Rd.). The pollutant loads set forth in this document are for these five 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 five representative stations in the Patapsco LNB 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 Patapsco LNB 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)/year 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 one of the five subwatersheds, it was estimated that water quality standards could not be attained with MPRs; thus higher maximum reductions were applied.

The MD 8-digit Patapsco LNB Total Baseline Load consists of an upstream load generated outside the MD 8-digit watershed assessment unit: a South Branch Patapsco River Upstream Baseline Load (BL_{SB}), plus loads generated within the assessment unit: a MD 8-digit Patapsco LNB Baseline Load (BL_{LNB}) Contribution. The baseline loads are summarized in the following table:

MD 8-Digit Patapsco River Lower North Branch Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)

Total Baseline Load	=	**Upstream Baseline Load**[1]	+	**MD 8-digit Patapsco River Lower North Branch Baseline Load Contribution**				
		BL_{SB}		**Nonpoint Source BL_{LNB}**	+	**NPDES Stormwater BL_{LNB}**	+	**WWTP BL_{LNB}**
2,365,934	=	933,841	+	976,803	+	452,809	+	2,481

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

The MD 8-digit Patapsco LNB TMDL of fecal bacteria consists of an annual average allocation attributed to loads generated outside the assessment unit: a South Branch Patapsco River Upstream Load Allocation (LA_{SB}), plus allocations attributed to loads generated within the assessment unit: a MD 8-digit Patapsco LNB TMDL Contribution.

The MD 8-digit Patapsco LNB TMDL Contribution, representing the sum of individual TMDLs for the five subwatersheds or portions thereof within the MD 8-digit assessment unit, is distributed between a load allocation (LA_{LNB}) for nonpoint sources and waste load allocations (WLA_{LNB}) 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, i.e., the *E. coli* water quality criterion concentration was reduced by 5%, from 126 MPN/100ml to 119.7 MPN/100ml.

The MD 8-digit Patapsco LNB TMDL of fecal bacteria is presented in the following table:

MD 8-Digit Patapsco River Lower North Branch Fecal Bacteria TMDL (Billion MPN *E. coli*/year)

TMDL	=	LA			+	WLA			+	MOS
		LA_{SB}[1]	+	LA_{LNB}		SW WLA_{LNB}	+	WWTP WLA_{LNB}		
1,987,571	=	813,612	+	783,318	+	388,160	+	2,481	+	Incorporated

Upstream Load Allocation

MD 8-digit Patapsco River Lower North Branch TMDL Contribution (1,173,959)

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

The LA_{SB} accounts for contributions from the South Branch Patapsco River watershed and is determined to be necessary in order to meet water quality standards in the MD 8-digit Patapsco LNB watershed. The LA_{SB} represents a reduction of approximately 13% from the baseline load of 933,841 billion MPN *E. coli*/year. The MD 8-digit Patapsco LNB TMDL Contribution (1,173,959 billion MPN *E. coli*/year) represents a reduction of approximately 18% from the baseline load contribution of 1,432,093 billion MPN *E. coli*/year. The overall average reduction is 16%.

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 Patapsco River Lower North Branch Fecal Bacteria MDL Summary (Billion MPN *E. coli*/day)

MDL	=	LA			+	WLA			+	MOS
		LA_{SB}	+	LA_{LNB}		SW WLA_{LNB}	+	WWTP WLA_{LNB}		
163,537	=	86,817	+	51,384	+	25,315	+	21	+	Incorporated

Upstream MDL

MD 8-digit Patapsco River Lower North Branch MDL Contribution (76,720)

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 one of the five 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 Patapsco River Lower North Branch (Patapsco LNB) watershed (MD basin number 02-13-09-06). 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 state's 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 waters of the MD 8-digit Patapsco LNB watershed on the State's 303(d) List [Category 5 of the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report)] as impaired by nutrients (listed in 1996, revised in 2008 to phosphorus), sediment (1996), metals (1996), fecal bacteria (2008), impacts to biological communities (listed in 2002, 2004 and 2006) and polychlorinated biphenyls (PCBs) (2008). Herbert Run, a tributary of the Patapsco River, was listed in 2006 as impaired by lead and copper. The waters of the MD 8-digit Patapsco LNB watershed have been designated as Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life) See Code of Maryland Regulations (COMAR) 26.08.02.07F(5). Brice Run, also a tributary of the Patapsco River, and its tributaries have been designated as Use III (Nontidal Cold Water). See COMAR 26.08.02.08K(3)(a).

This document proposes to establish a TMDL for fecal bacteria in the Patapsco LNB watershed that will allow for attainment of the beneficial use designation of water contact recreation. The listings for phosphorus, sediment, PCB and impacts to biological communities will be addressed in separate TMDL documents. The listing for metals was addressed in 2002. The Herbert Run listings for lead and copper were addressed in 2008. MDE monitored the Patapsco LNB watershed from 2002-2003 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2007, and all readily available data from the past five years were considered. To account for contributions from the MD 8-digit South Branch Patapsco River watershed, an upstream load allocation (LA_{SB}), determined to be necessary in order to meet water quality standards in the MD 8-digit Patapsco LNB 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 MD 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 Patapsco LNB TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The MD 8-digit Patapsco LNB watershed is located in the Patapsco River region of the Chesapeake Bay watershed within Maryland. The watershed covers portions of Anne Arundel, Baltimore, Carroll and Howard Counties and Baltimore City (see Figure 2.1.1), and includes portions of the towns of Randallstown, Ellicott City, Catonsville, Arbutus, Elkridge, and Hanover. The watershed covers an area of 118.4 square miles (75,755 acres) with an additional 85.8 square miles (54,937 acres) draining from the upstream MD 8-digit South Branch Patapsco River watershed. Water draining into Liberty Reservoir typically does not drain to the Patapsco River LNB because it is retained for drinking water purposes.

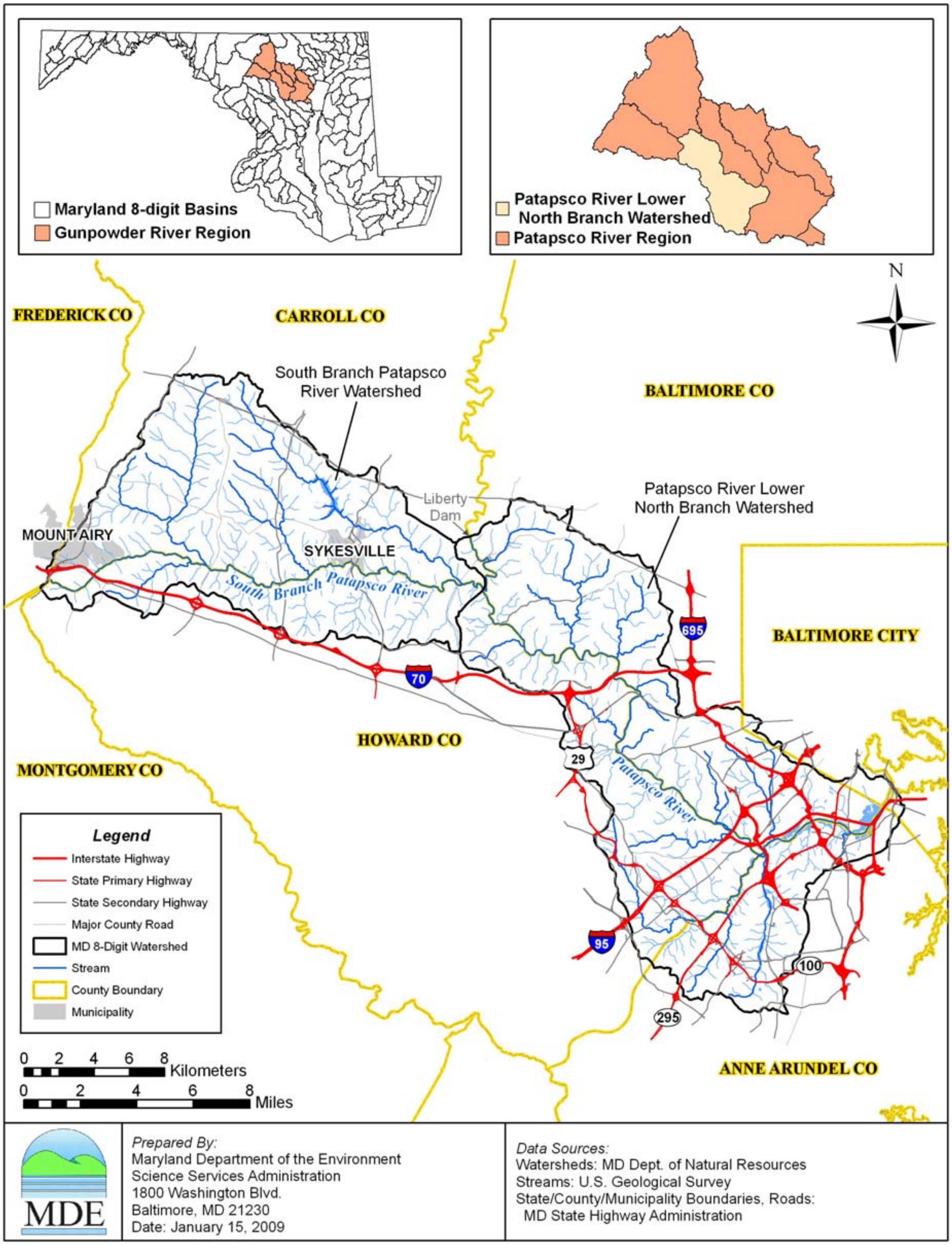


Figure 2.1.1: Location Map of the Patapsco River Lower North Branch Watershed

Land Use

Based on the 2002 Maryland Department of Planning (MDP) land use/land cover data, the Patapsco LNB watershed can be characterized as primarily urban and forest land. The forested areas are mainly along Patapsco River. The urban areas are more prevalent in the downstream portion of the watershed.

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 five subwatersheds considered in the analysis. Note that the subwatersheds are identified by the MDE monitoring stations located in the mainstem of the river, and are listed by flow from upstream to downstream.

Table 2.1.1: Land Use Percentage Distribution for the Patapsco River Lower North Branch Watershed

Land Type	Acres	%
Urban	50,377	40.1
Forest	44,374	35.3
Agricultural	22,472	17.9
Pasture	7,867	6.3
Water	447	0.4
Total	**125,537**	**100**

Table 2.1.2: Land Use Percentage Distribution for the Patapsco River Lower North Branch Watershed

Station / Subwatershed	Land Use Area (%)				
	Urban	Forest	Agricultural	Pasture	Water
PAT0347 / Patapsco River at Old Court Rd.	29.1	31.0	30.8	8.6	0.5
PAT0285 / Pat. R. at Old Frederick Rd.	37.2	41.1	14.5	7.2	0
PAT0222 / Pat. R. at Ilchester Rd.	54.1	41.3	0.6	4.0	0
PAT0176 / Pat. R. at Rt. 1	48.9	45.0	2.8	3.3	0
PAT0148 / Pat. R. at Hammonds Ferry Rd.	57.9	36.0	3.2	2.5	0.4

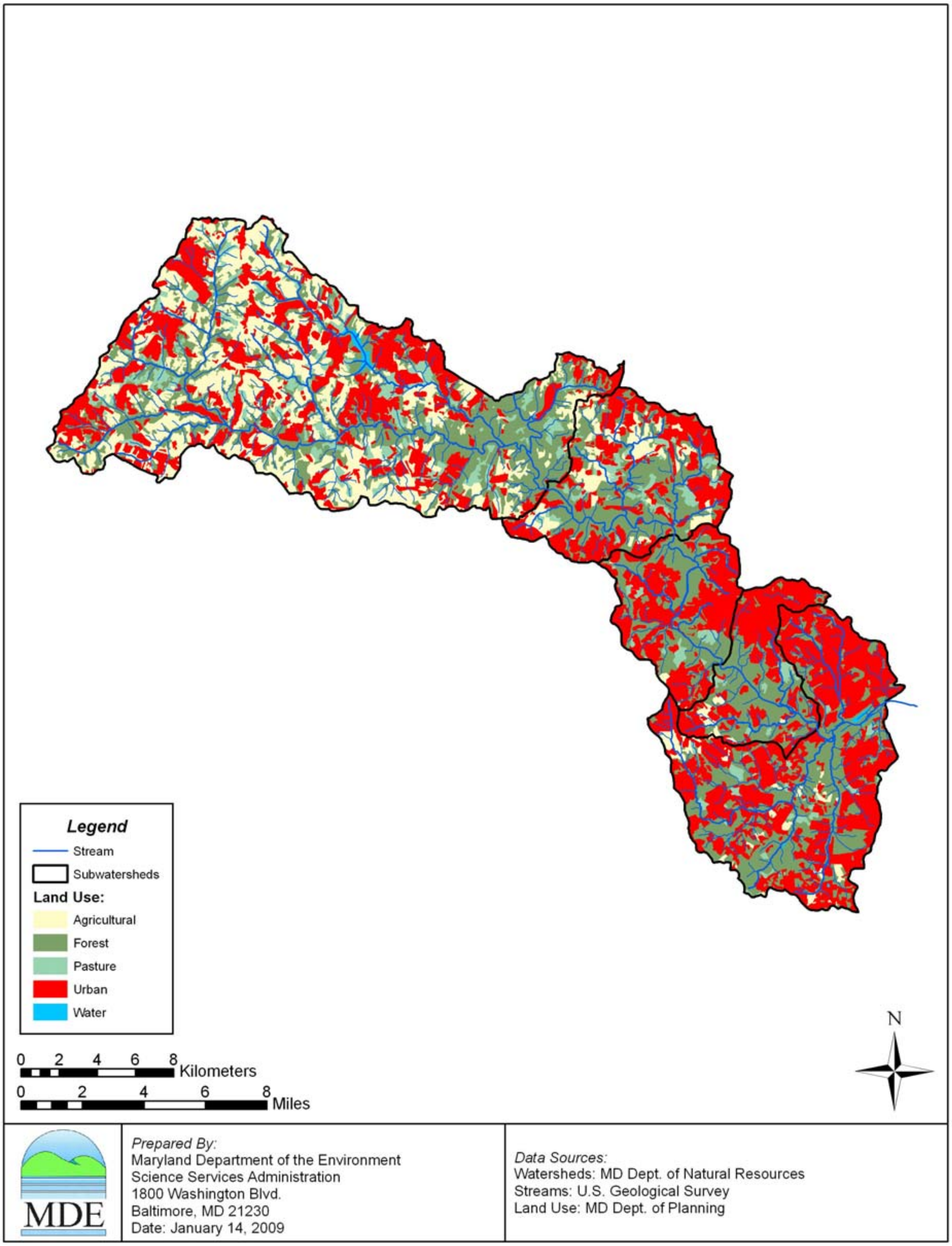


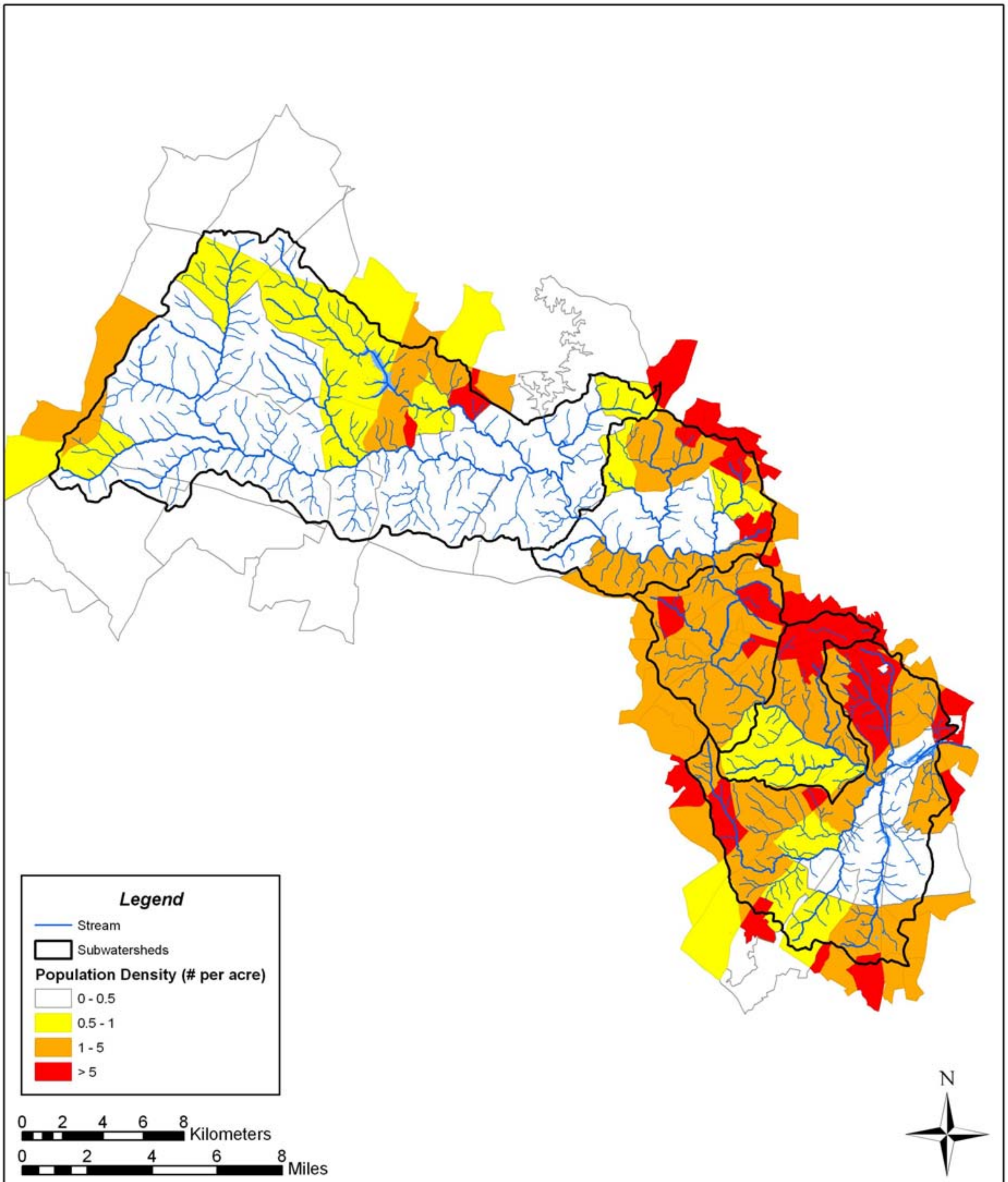
Figure 2.1.2: Land Use of the Patapsco River Lower North Branch Watershed

Population

The total population in the Patapsco LNB watershed is estimated to be 206,330. Figure 2.1.3 illustrates the population density in the watershed. The population 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 2.1.3.

Table 2.1.3: Total Population Per Subwatershed in the Patapsco River Lower North Branch Watershed

Station / Subwatershed	Population
PAT0347 / Pat. R. at Old Court Rd.	37,606
PAT0285 / Pat. R. at Old Frederick Rd.	28,928
PAT0222 / Pat. R. at Ilchester Rd.	37,015
PAT0176 / Pat. R. at Rt. 1	27,450
PAT0148 / Pat. R. at Hammonds Ferry Rd.	75,331
Total	**206,330**



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Date: January 20, 2009

Data Sources:
Watersheds: MD Dept. of Natural Resources
Streams: U.S. Geological Survey
Population Data: U.S. Census Bureau

Figure 2.1.3: Population Density in the Patapsco River Lower North Branch 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. That 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 Patapsco LNB watershed. MDE conducted monitoring sampling at five stations in the Patapsco LNB watershed from October 2002 through October 2003. One United States Geological Survey (USGS) gage station was 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 five 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 five stations ranged between 2 and 46,100 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the MD 8-digit Patapsco River Lower North Branch Watershed

Organization	Date	Design	Summary
DNR	01/1986 through 12/2003	Fecal Coliform*	2 station 1 sample per month
MDE	10/2002 through 10/2003	*E. coli*	5 stations 2 samples per month
MDE	10/2002 through 10/2003	BST (*Enterococcus)*	5 stations 1 sample per month

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

Table 2.2.2: Location of DNR Core Stations in the MD 8-digit Patapsco River Lower North Branch Watershed

Station	Tributary	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
PAT0285	Patapsco River	39.312	-76.792
PAT0176	Patapsco River	39.218	-76.705

Table 2.2.3: Location of MDE Monitoring Stations in the MD 8-digit Patapsco River Lower North Branch Watershed

Tributary	Station	Observation Period	Total Observations	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
Patapsco River	PAT0347	2002 – 2003	26	39.332	-76.870
Patapsco River	PAT0285	2002 – 2003	26	39.310	-76.792
Patapsco River	PAT0222	2002 – 2003	26	39.251	-76.764
Patapsco River	PAT0176	2002 – 2003	26	39.218	-76.707
Patapsco River	PAT0148	2002 – 2003	26	39.231	-76.665

Table 2.2.4: Location of USGS Gauging Stations in the MD 8-digit Patapsco River Lower North Branch Watershed

Site Number	Observation Period Used	Total Observations	Latitude	Longitude
01589000	1979-2004	9,132	39.310	-76.792

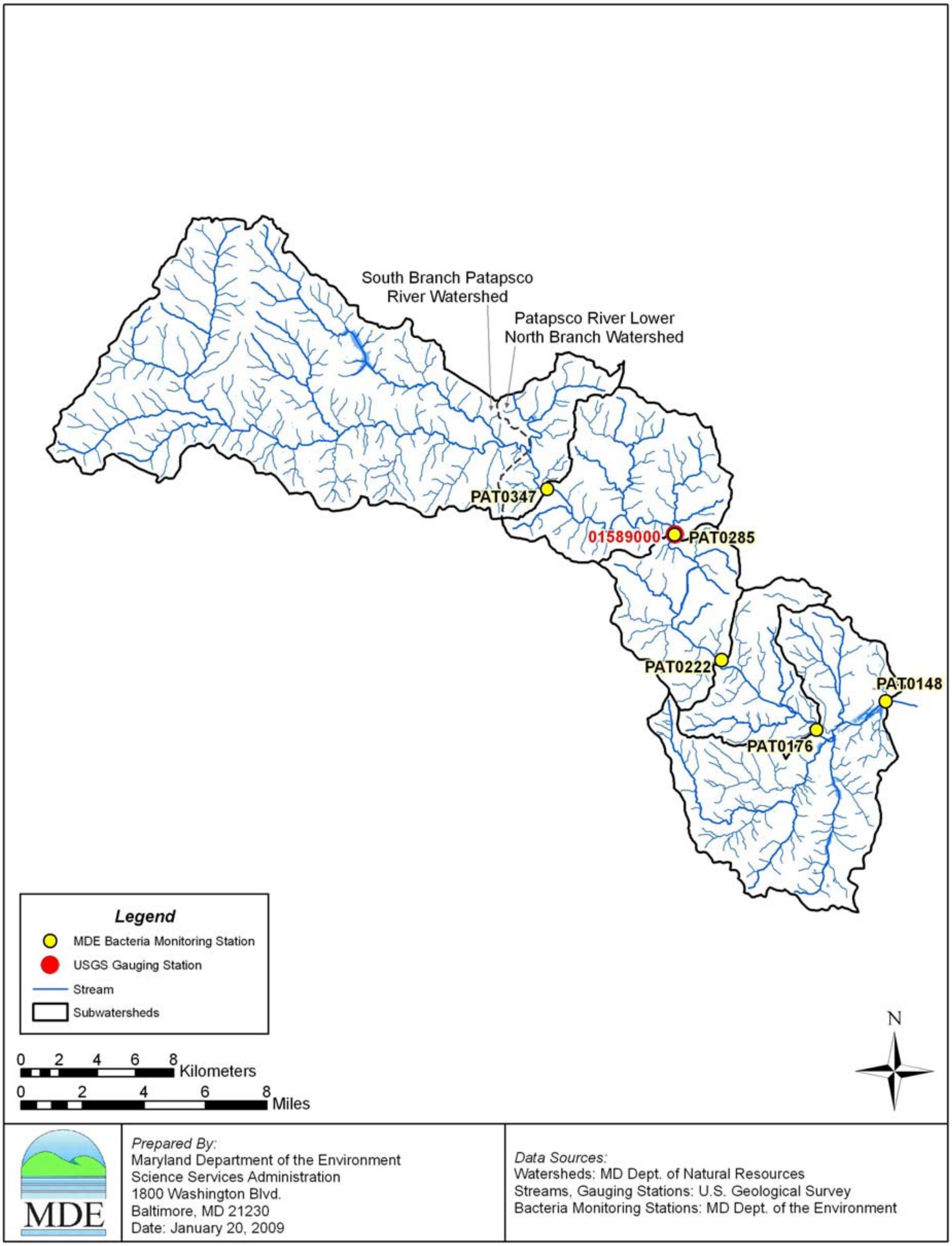

Figure 2.2.1: Monitoring Stations and Subwatersheds in the Patapsco River Lower North Branch Watershed

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 Patapsco LNB watershed is Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life). See COMAR 26.08.02.07F(5). Brice Run and its tributaries have been designated as Use III (Nontidal Cold Water). See COMAR 26.08.02.08K(3)(a). The MD 8-digit Patapsco LNB watershed was 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 year two (2) to five (5) 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 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 Patapsco LNB watershed was assessed as explained above, by comparing the dry weather steady-state geometric means of *E. coli* concentrations for each subwatershed of the Patapsco LNB 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, two of the five subwatersheds of the Patapsco LNB 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: Patapsco River Lower North Branch Watershed Dry Weather Steady-State Geometric Means

Station / Tributary	Number of Samples	Dry weather Steady-State Geometric Mean (MPN/100ml)	Water Quality Criterion (MPN/100ml)
PAT0347 Pat. R. at Old Court Rd.	8	134	126
PAT0285 Pat. R. at Old Frederick Rd.	8	93	126
PAT0222 Pat. R. at Ilchester Rd.	7	119	126
PAT0176 Pat. R. at Rt. 1	7	117	126
PAT0148 Pat. R. at Hammonds Ferry Rd.	7	231	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 8-digit Patapsco LNB watershed is serviced by both sewer systems and septic systems. Sewer systems are present in the areas of Arbutus, Catonsville, Elkridge, Ellicott City, Halethorpe, Randallstown, and Severn. Wastewater from most of these areas is collected by the Patapsco WWTP and treated and discharged into the Patapsco River in the Baltimore Harbor watershed.

Septic Systems

On-site disposal (septic) systems are located throughout the Patapsco LNB watershed. Table 2.4.1 presents the number of septic systems per subwatershed including the South Branch Patapsco River watershed. Figure 2.4.1 displays the areas that are serviced by sewers and the locations of the septic systems.

Table 2.4.1: Septic Systems Per Subwatershed in the Patapsco River Lower North Branch Watershed

Station / Subwatershed	Septic Systems
PAT0347 / Pat. R. at Old Court Rd.	7,578
PAT0285 / Pat. R. at Old Frederick Rd.	2,733
PAT0222 / Pat. R. at Ilchester Rd.	2,481
PAT0176 / Pat. R. at Rt. 1	868
PAT0148 / Pat. R. at Hammonds Ferry Rd.	3,321
Total	**16,981**

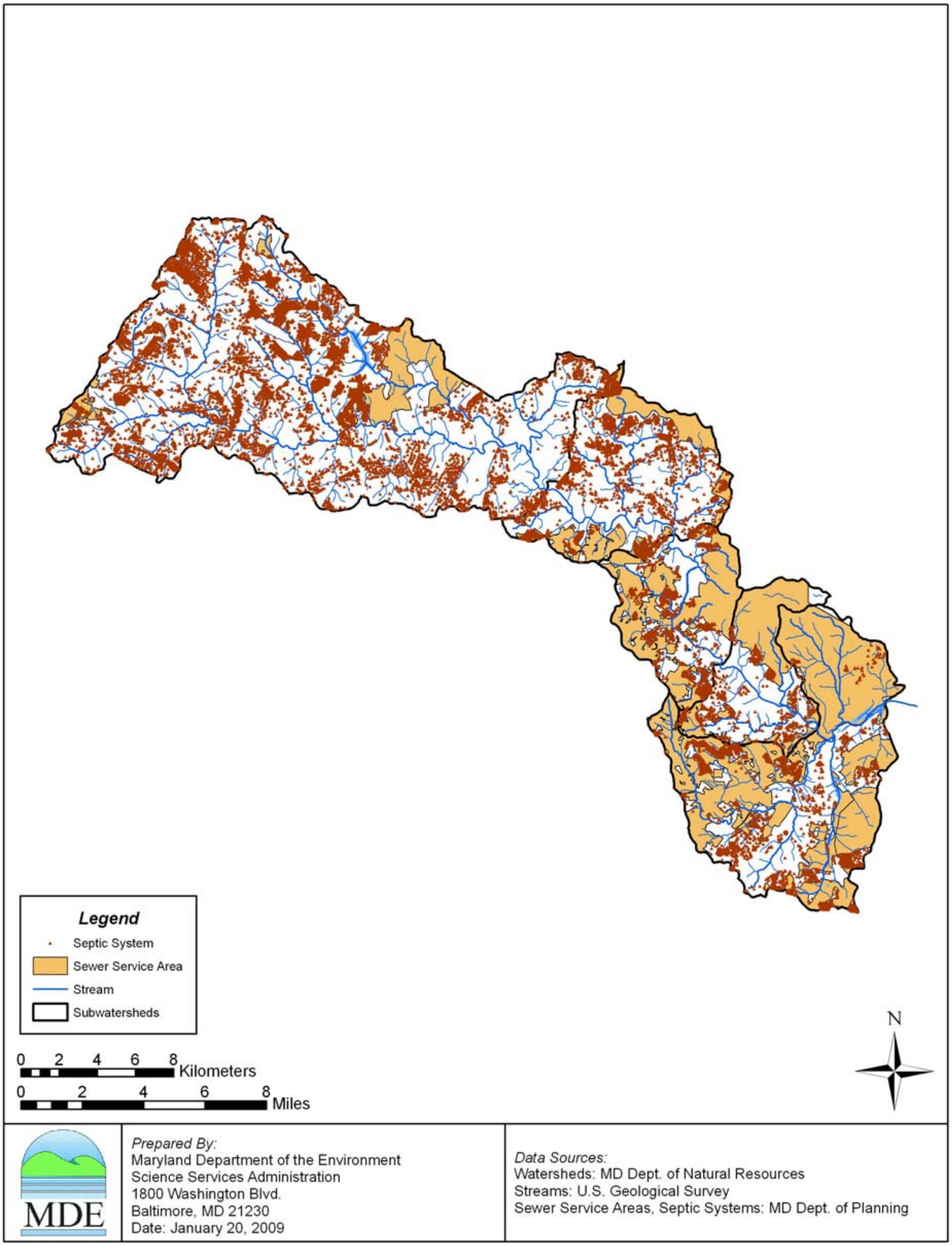

Figure 2.4.1: Sanitary Sewer Service Areas and Septic Locations in the Patapsco River Lower North Branch Watershed

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.

The MD 8-digit Patapsco LNB watershed is located in Anne Arundel, Baltimore, Carroll, and Howard Counties, and Baltimore City, all of which have individual Phase I NPDES MS4 permits. 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 33 SSOs reported to MDE between October 2002 and October 2003 in the MD 8-digit Patapsco LNB watershed. Approximately 2,376,000 gallons of SSOs were discharged through various waterways (surface water, groundwater, sanitary sewers, etc.). Figure 2.4.2 shows the locations where these SSOs occurred.

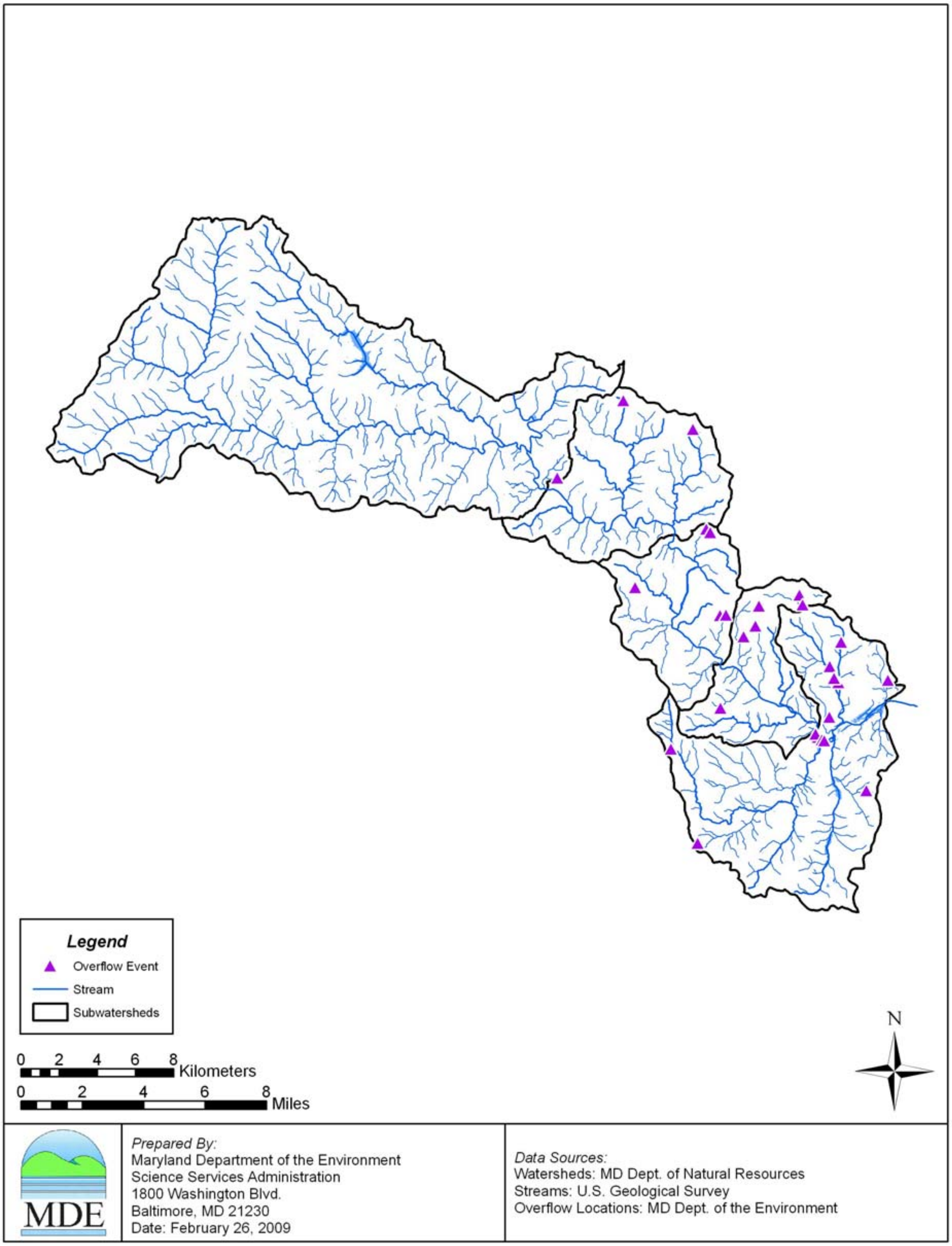

Figure 2.4.2: Sanitary Sewer Overflow Areas in the MD 8-digit Patapsco River Lower North Branch Watershed

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 are three municipal NPDES permitted point source facilities with permits regulating the discharge of fecal bacteria in the MD 8-digit Patapsco LNB watershed. Two of the facilities, Holiday Mobile Estates WWTP and Woodstock Job Corps WWTP, combined, treat approximately 0.13 million gallons per day (MGD). Deep Run WWTP has not been discharging but is included in the analysis because it maintains a discharge permit. There are no industrial facilities in the MD 8-digit Patapsco LNB watershed with NPDES permits regulating the discharge of fecal bacteria. Table 2.4.2 lists these facilities and Figure 2.4.3 shows their location in the watershed.

Table 2.4.2: NPDES Permit Holders Regulated for Fecal Bacteria Discharge in the MD 8-digit Patapsco River Lower North Branch Watershed

Facility	NPDES Permit No.	County	Average Flow (MGD)	Average Fecal Coliform Concentration (MPN/100ml)	Fecal Coliform Load (Billion MPN/day)
Woodstock Job Corps WWTP	MD0023906	Baltimore	0.025	25.8[1]	0.02
Holiday Mobile Estates WWTP	MD0053082	Anne Arundel	0.108	3.0[2]	0.01
Deep Run WWTP	MD0056618	Howard	N/A		

[1] Average of reported monthly maximum concentrations
[2] Average of reported monthly average concentrations

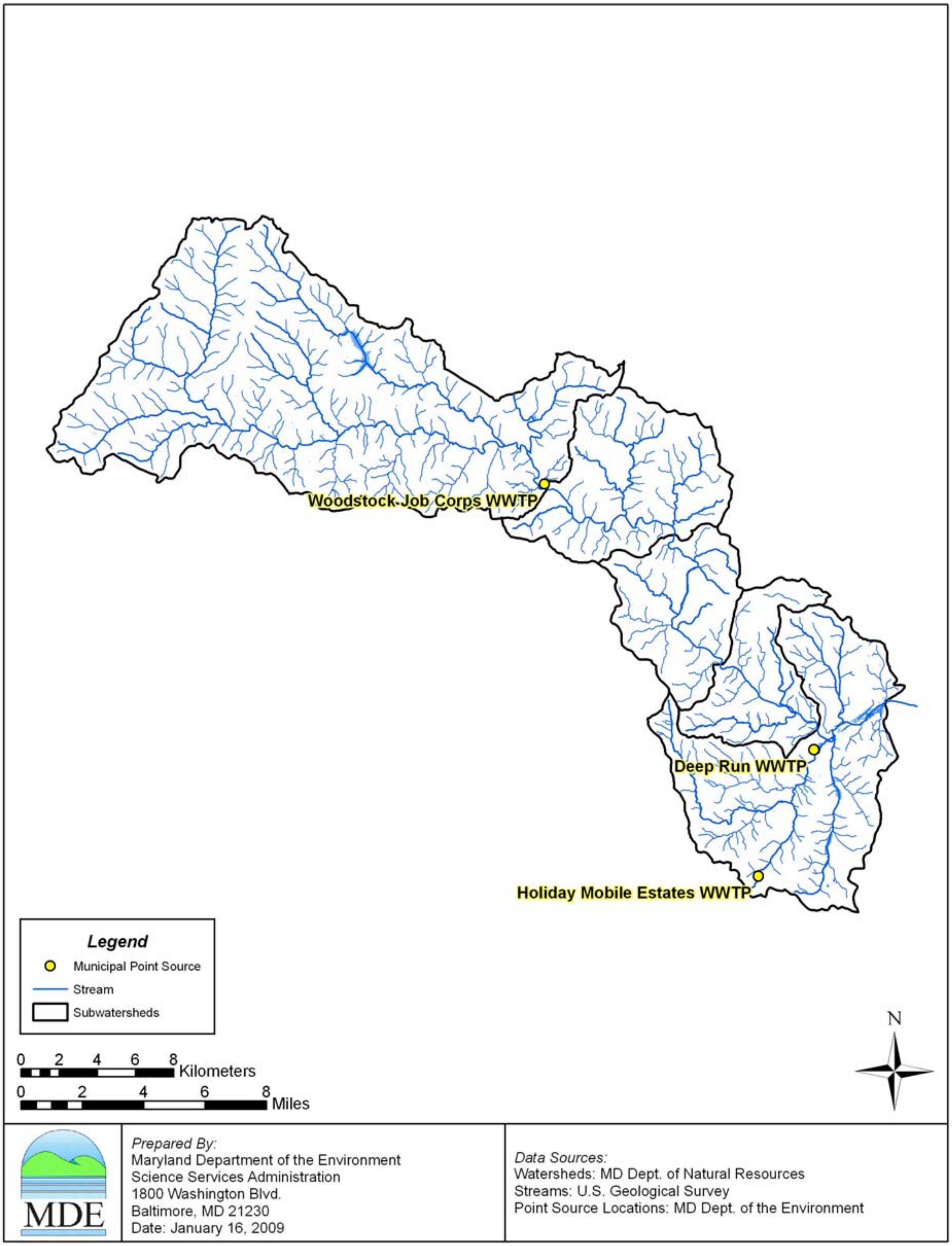

Figure 2.4.3: Permitted Point Sources Discharging Fecal Bacteria in the MD 8-Digit Patapsco Lower North Branch Watershed

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 Patapsco LNB 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 entire Patapsco River watershed. Details of the BST methodology and data can be found in Appendix C.

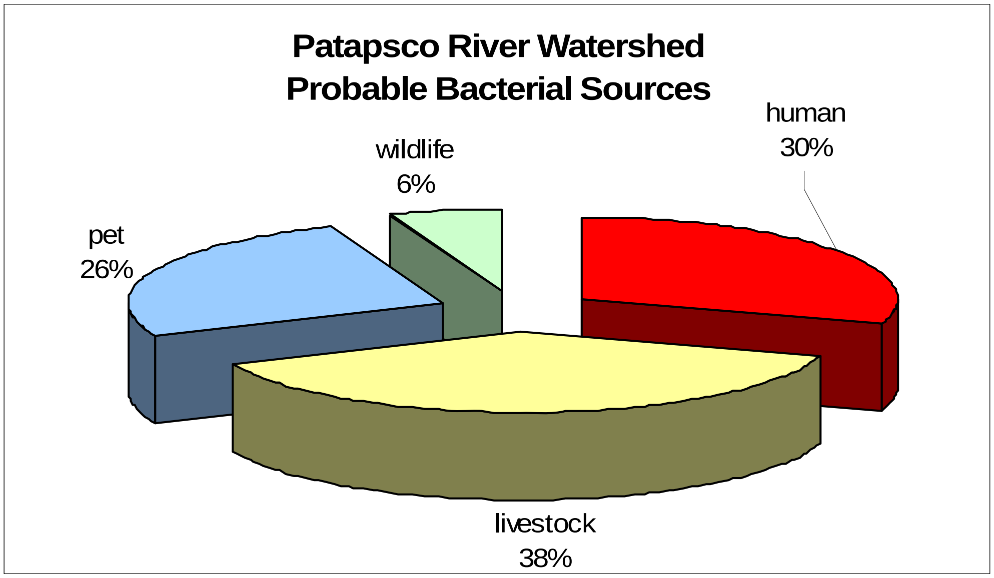

Figure 2.4.4: Patapsco River Watershed Relative Contributions by Probable Sources of Fecal Bacteria Contamination

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 MD 8-digit Patapsco LNB 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 Patapsco LNB. 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 TMDL can be expressed in terms of “mass per time, toxicity or other appropriate measure.” See 40 C.F.R. 1310.2(i).

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.

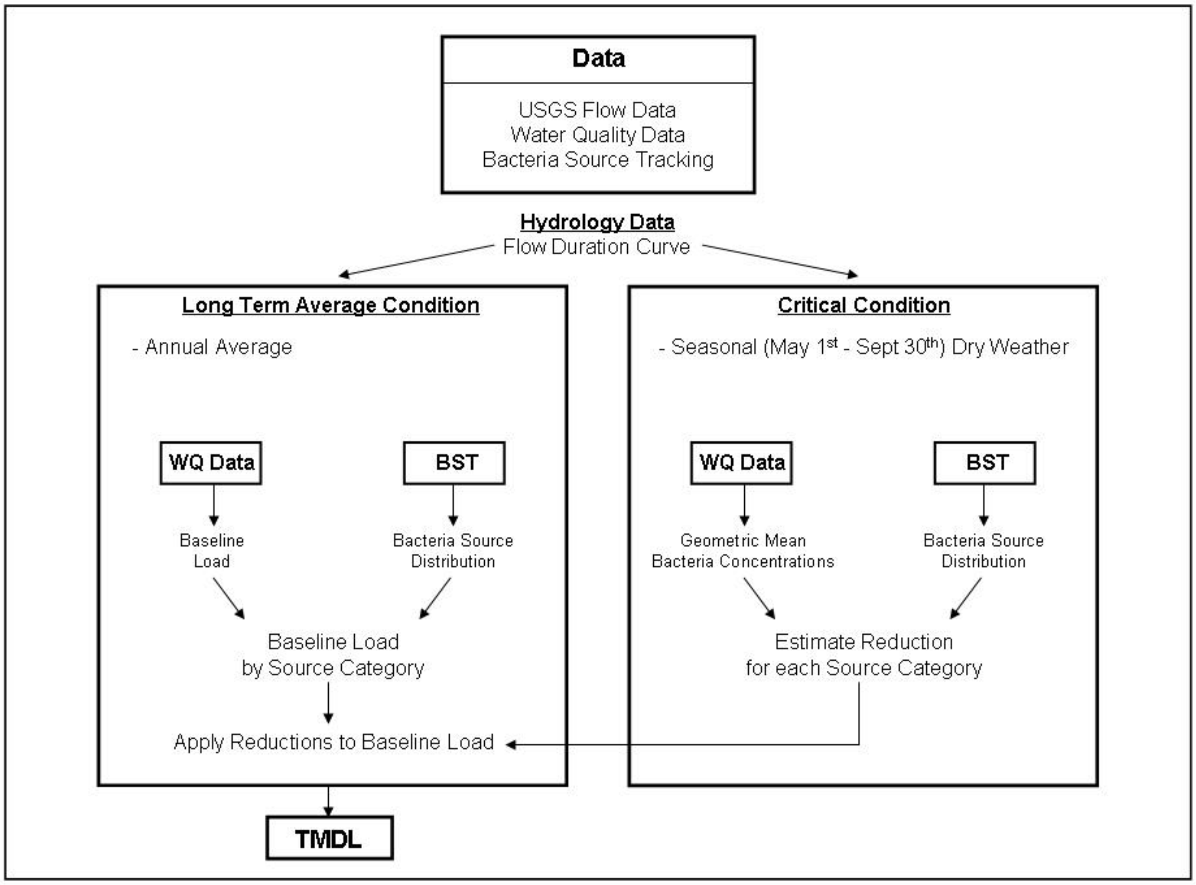

Figure 4.2.1: Diagram of the Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads are estimated for all subwatersheds of the Patapsco LNB watershed, including, for computational purposes, one partially located in MD 8-digit South Branch Patapsco River 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 Patapsco River Lower North Branch LNB 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.

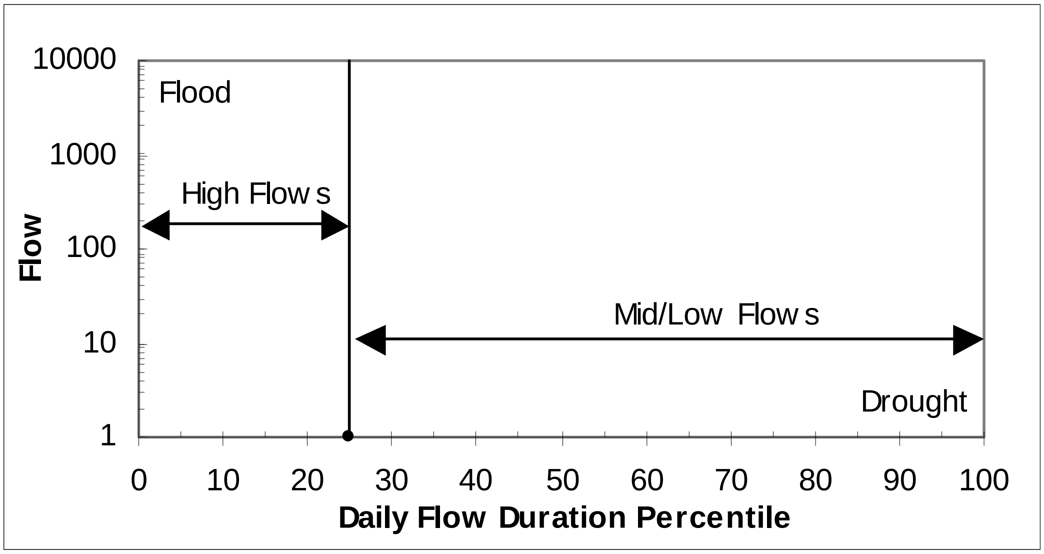

Figure 4.3.1: Conceptual Diagram of Flow Duration Zones

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 gage 01589000 it was determined that the long-term average daily flow corresponds to a daily flow duration of 27.2%. Hence, for this analysis flows greater than the 27.2 percentile flow represent high flows, and flows less than the 27.2 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 Patapsco LNB 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 Patapsco River Lower North Branch Watershed

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 27.2%	0.272
Mid/Low Flows	27.2 – 100%	0.728

Bacteria enumeration results for samples within a specified stratum will receive their corresponding weighting factor. The weighted 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} = Weighted geometric mean concentration

For the seasonal analysis only, the overall geometric mean for the period was applied due to an insufficient number of samples during low flow conditions. Table 4.3.2 presents the annual maximum and minimum concentrations, the annual average geometric means by stratum, and the annual average weighted geometric means for each subwatershed of the Patapsco LNB. Table 4.3.3 presents the seasonal dry weather steady-state maximum and minimum concentrations and the geometric mean concentrations for each subwatershed. Graphs illustrating these results can be found in Appendix B.

Table 4.3.2: Patapsco River Lower North Branch Watershed Annual Weighted Geometric Means

Station / Tributary	**Flow Stratum**	**Number of Samples**	***E. coli* Minimum Concentration** (MPN/100ml)	***E. coli* Maximum Concentration** (MPN/100ml)	**Annual Geometric Mean by Stratum** (MPN/100ml)	**Annual * Weighted Geometric Mean** (MPN/100ml)
PAT0347 Pat. R. at Old Court Rd.	**High**	18	20	21,900	148	74
	Low	8	5	190	57	
PAT0285 Pat. R. at Old Frederick Rd.	**High**	18	10	32,600	128	54
	Low	8	2	200	39	
PAT0222 Pat. R. at Ilchester Rd.	**High**	18	40	46,100	171	96
	Low	8	3	440	77	
PAT0176 Pat. R. at Rt. 1	**High**	18	10	29,900	128	57
	Low	8	7	230	42	
PAT0148 Pat. R. at Hammonds Ferry Rd.	**High**	18	10	20,100	203	129
	Low	8	7	960	109	

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

Table 4.3.3: Patapsco River Lower North Branch Watershed Seasonal (May 1 - September 30) Dry Weather Period 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)
PAT0347 Pat. R. at Old Court Rd.	8	60	190	134
PAT0285 Pat. R. at Old Frederick Rd.	8	40	150	93
PAT0222 Pat. R. at Ilchester Rd.	7	50	250	119
PAT0176 Pat. R. at Rt. 1	7	40	190	117
PAT0148 Pat. R. at Hammonds Ferry Rd.	7	160	380	231

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

The weighted annual average 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 flow stratum, the bias correction factors are estimated as follows:

$$F_{1i} = A_i/C_i \qquad (4)$$

where,

F_{1i} = bias correction factor for stratum i
A_i = long term annual arithmetic mean for stratum i
C_i = long term annual geometric mean for stratum i

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

The loads for each stratum are estimated as follows:

$$L_i = Q_i * C_i * F_{1i} * F_2 \qquad (5)$$

where,

L_i = daily average load (Billion MPN/day) at monitoring station for stratum *i*
Q_i = daily average flow (cfs) for stratum *i*
C_i = geometric mean for stratum *i*
F_{1i} = bias correction factor for stratum *i*
F_2 = unit conversion factor (0.0245)

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

$$L = \sum_{i=1}^{2} L_i * W_i \qquad (6)$$

where,

L = daily average load at station (MPN/day)
W_i = proportion of stratum *i*

In the Patapsco LNB watershed, weighting factors of 0.272 for high flow and 0.728 for low/mid flows were used to estimate the annual baseline load expressed as Billion MPN *E. coli*/year.

Estimating Subwatershed Loads

Subwatersheds with more than one monitoring station were subdivided into unique watershed segments, thus allowing individual load and reduction targets to be determined for each. In the Patapsco LNB watershed four stations have upstream monitoring stations, as listed in Table 4.3.4. In these four cases the subwatershed is differentiated by adding the extension “sub” to the name of the downstream monitoring station. For example, PAT0148sub signifies only the area and load between stations PAT0148 and PAT0176 while PAT0148 refers to the cumulative area draining to that station. There are a total of five subwatersheds considered in this analysis, corresponding to the five monitoring stations.

Table 4.3.4: Subdivided Watersheds in the Patapsco River Lower North Branch Watershed

Subwatershed	Upstream Station(s)
PAT0285sub	PAT0347
PAT0222sub	PAT0285
PAT0176sub	PAT0222
PAT0148sub	PAT0176

Bacteria loads from these subwatersheds are joined by loads from their upstream subwatersheds to result in the concentration measured at the downstream monitoring station. However, for the purposes of this TMDL, the bacteria concentration measured at each monitoring station is assumed to be representative of that corresponding subwatershed and independent of flow from upstream subwatersheds. For example, the load transported from upstream station PAT0176 is not considered in the estimation of the load from subwatershed PAT0148sub. Instead the bacteria concentration measured at station PAT0148 is assigned to that subwatershed.

This assumption is used due to a special scenario seen in the subwatershed of PAT0176sub. For this subwatershed, bacteria loadings from upstream subwatersheds are significantly greater than the cumulative load measured at the downstream station. This occurrence indicates that the bacteria loads are not carried on as they are transported downstream. Attributing the measured concentration solely to the immediate subwatershed will result in a slightly conservative estimate of bacteria loads but will also allow a more consistent methodology throughout the watershed than applying unpredictable upstream loads.

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 the subwatersheds defined in Table 4.3.4 were assigned from the analysis of their downstream stations.

Results of the baseline load calculations, including subwatersheds partially located in the MD 8-digit South Branch Patapsco River watershed, are presented in Table 4.3.5.

Table 4.3.5: Baseline Loads Calculations

Subwatershed	Area (mi^2)	High Flow		Low Flow		Baseline *E. coli* Load (Billion MPN/year)
		Average Flow (cfs)	*E. coli* Concentration. (MPN/100ml)	Average Flow (cfs)	*E. coli* Concentration (MPN/100ml)	
PAT0347[1]	95.8	276.8	148	60.1	57	1,041,673
PAT0285sub	25.7	74.4	128	16.1	39	358,827
PAT0222sub	17.5	50.5	171	11.0	77	344,864
PAT0176sub	14.4	41.7	128	9.1	42	185,573
PAT0148sub	42.8	123.6	203	26.9	109	434,997

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

Baseline loads for subwatersheds located in both the MD 8-digit Patapsco LNB watershed and the MD 8-digit South Branch Patapsco River watershed were estimated using the ratios of the areas of the two portions to the total area of the subwatershed. The total baseline load for all subwatersheds or portions thereof located in the MD 8-digit Patapsco LNB watershed is estimated as 1,432,093 billion MPN *E. coli*/year. The total baseline load for the portions of subwatersheds located in the MD 8-digit South Branch Patapsco River watershed is 933,841 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 Patapsco River Lower North Branch Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)								
Total Baseline Load	=	Upstream Baseline Load[1]	+	MD 8-digit Patapsco River Lower North Branch Baseline Load Contribution				
		BL_{SB}		Nonpoint Source BL_{LNB}	+	NPDES Stormwater BL_{LNB}	+	WWTP BL_{LNB}
2,365,934	=	933,841	+	976,803	+	452,809	+	2,481

[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 Section 2.4, Source Assessment, ARA was used to identify probable bacterial sources in the Patapsco River watershed. An accurate representation of the expected contribution of each source (human, pets, livestock, or wildlife) at each station is estimated by using a stratified weighted mean of the identified sample results. The weighting factors are based on the $\log_{10}$ of the bacteria concentration and the percent of time that represents the high stream flow or low stream flow (see Appendix B). The procedure for calculating the stratified weighted mean of the sources per monitoring station is as follows:

1. Calculate the percentage of isolates per source per each sample date (S).
2. Calculate an initial weighted percentage (IMS) of each source per flow strata (high/low). 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.
4. The final weighted mean source percentage for each source category is based on the proportion of time in each flow duration zone.

If a hydrological condition (i. e., dry weather seasonal condition) does not have enough samples in each flow duration zone, then the final weighted mean source percentage is not stratified based on flow duration zones and an overall seasonal source pencentage is calculated, weighted only by the concentration of the water sample (See Appendix B).

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

$$MS_l = \sum_{i=1}^{2} MS_{i,l} * W_i \qquad (7)$$

where,

$$MS_{i,l} = \sum_{k=1}^{5} \frac{A_{l,k} * IMS_{i,k}}{P_k} \qquad (8)$$

where,

$$IMS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})} \qquad (9)$$

and where,

MS_l = weighted mean proportion of isolates of source *l*
$MS_{i,l}$ = adjusted weighted mean proportion of isolates for source *l* in stratum *i*
$IMS_{i,k}$ = initial weighted mean proportion of isolates for source *k* in stratum *i*
W_i = proportion covered by stratum *i*
$A_{l,k}$ = number of known source *l* isolates initially predicted as source *k*
P_k = number of total known isolates initially predicted as source *k*

i = stratum
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)
$C_{i,j}$ = concentration for sample j in stratum i
$S_{i,j,k}$ = proportion of isolates for sample j, of source k in stratum i
n_i = number of samples in stratum i

The complete distributions of the annual and seasonal 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.

Table 4.4.1: Distribution of Fecal Bacteria Source Loads in the Patapsco River Lower North Branch Watershed for the Average Annual Period

Station	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife
PAT0347	**High**	18.8	23.8	15.0	42.5
	Low	20.6	11.3	11.1	57.0
	Weighted	20.1	14.7	12.2	53.0
PAT0285	**High**	18.0	24.9	16.3	40.8
	Low	26.4	19.1	7.5	47.0
	Weighted	24.1	20.7	9.9	45.4
PAT0222	**High**	15.9	26.5	17.8	39.8
	Low	31.1	20.4	8.0	40.5
	Weighted	27.0	22.1	10.7	40.3
PAT0176	**High**	14.0	29.1	17.6	39.2
	Low	21.9	17.0	14.9	46.3
	Weighted	19.7	20.3	15.6	44.4
PAT0148	**High**	17.6	30.9	13.5	38.0
	Low	21.8	33.7	8.2	36.3
	Weighted	20.7	32.9	9.7	36.7

Table 4.4.2: Distribution of Fecal Bacteria Source Loads in the Patapsco River Lower North Branch Watershed for the Seasonal (May 1 – September 30) Dry Weather Period

Station	% Domestic Animals	% Human	% Livestock	% Wildlife
PAT0347	27.3	12.2	11.4	49.1
PAT0285	17.5	17.8	16.4	48.3
PAT0222	27.7	9.6	10.0	52.7
PAT0176	18.1	12.0	18.0	51.9
PAT0148	17.7	25.4	12.3	44.7

4.5 Critical Condition and Seasonality

Federal regulations require TMDLs to take into account critical conditions for stream flow, loading, and water quality parameters. See 40 CFR 130.7(c)(1)). 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 from 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 bacteria monitoring data for all stations located in the Patapsco LNB watershed cover a sufficient temporal span (at least one year) to estimate annual conditions. However, sufficient data were not available for the seasonal period to consider high flow and low flow conditions. Since only two samples were taken during low flow conditions, a geometric mean cannot be established for that condition. Therefore an overall average geometric mean and average flow were used for the seasonal analysis.

The reductions of fecal bacteria required to meet water quality standards in each subwatershed of the Patapsco LNB watershed are shown in Table 4.5.1. For computational purposes, the calculations include those subwatersheds partially located in the MD 8-digit South Branch Patapsco River watershed.

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

Station	Condition	Domestic Animals %	Human %	Livestock %	Wildlife %
PAT0347[1]	Annual	0.0	0.0	0.0	0.0
	Seasonal	0.0	87.4	0.0	0.0
	Maximum Source Reduction	**0.0**	**87.4**	**0.0**	**0.0**
PAT0285sub	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**
PAT0222sub	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**
PAT0176sub	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**
PAT0148sub	Annual	0.0	21.6	0.0	0.0
	Seasonal	80.5	98.0	75.0	0.0
	Maximum Source Reduction	**80.5**	**98.0**	**75.0**	**0.0**

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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. Refined precision in the load estimation is due to using a stratified approach along the flow duration intervals, thus reducing the variation in the estimates. Moreover, Richards (1998) reports that averaging methods are generally biased, and the bias increases as the size of the averaging window increases. Finally, accuracy in the load estimation is based on minimal bias in the final result when compared to the true value.

Based on EPA guidance, the MOS can be achieved through two approaches (EPA 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 4.7.1. As stated in Section 4.3, the source distributions for subwatersheds PAT0285sub, PAT0222sub, PAT0176sub, and PAT0148sub were based on the sources identified at stations PAT0285, PAT0222, PAT0176, and PAT0148 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)	
PAT0347[1]	20.1	209,080	14.7	153,371	12.2	126,719	53.0	552,503	1,041,673
PAT0285sub	24.1	86,526	20.7	74,154	9.9	35,401	45.4	162,746	358,827
PAT0222sub	27.0	93,102	22.1	76,095	10.7	36,756	40.3	138,911	344,864
PAT0176sub	19.7	36,596	20.3	37,625	15.6	28,997	44.4	82,355	185,573
PAT0148sub	20.7	89,836	32.9	143,286	9.7	42,047	36.7	159,828	434,997

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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 4.6.2). 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 one of the five subwatersheds (PAT0148sub), 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 %		
PAT0347[1]	0.0	87.4	0.0	0.0	12.9	12.9
PAT0285sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0222sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0176sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0148sub	75.0	95.0	75.0	0.0	54.0	56.1

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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, one of the five subwatersheds (PAT0148sub) 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 %		
PAT0347[1]	0.0	87.4	0.0	0.0	12.9	12.9
PAT0285sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0222sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0176sub	0.0	0.0	0.0	0.0	0.0	0.0
PAT0148sub	80.5	98.0	75.0	0.0	56.1	56.1

[1]Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

4.8 TMDL Loading Caps

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

The TMDL loading caps are provided in billion MPN *E. coli*/year. These loading caps are for the five subwatersheds located upstream of their respective monitoring stations. A loading cap for one subwatershed of the MD 8-digit Patapsco LNB watershed partially located in the MD 8-digit South Branch Patapsco River watershed was included in the TMDL scenario. A TMDL summary for the entire Patapsco LNB watershed will include an upstream load allocation for the portion of the watershed located in the MD 8-digit South Branch Patapsco River watershed to indicate estimated loads necessary to meet water quality standards in the MD 8-digit Patapsco River Lower North Branch 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 for each flow stratum. The loads from these two strata are then weighted to represent average conditions (see Table 4.3.1), based on the proportion of each stratum, to estimate the total long-term loading rate.

Next, the percent reduction required to meet the water quality criterion is estimated from the observed bacteria concentrations accounting for the critical conditions (See Section 4.5). 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 the MD 8-digit South Branch Patapsco River watershed, 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**
PAT0347[1]	1,041,673	907,561	12.9
PAT0285sub	358,827	358,827	0.0
PAT0222sub	344,864	344,864	0.0
PAT0176sub	185,573	185,573	0.0
PAT0148sub	434,997	190,746	56.1
Total	**2,365,934**	**1,987,571**	**16.0**

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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)	
PAT0347[1]	23.0	209,080	2.1	19,259	14.0	126,719	60.9	552,503	907,561
PAT0285sub	24.1	86,526	20.7	74,154	9.9	35,401	45.4	162,746	358,827
PAT0222sub	27.0	93,102	22.1	76,095	10.7	36,756	40.3	138,911	344,864
PAT0176sub	19.7	36,596	20.3	37,625	15.6	28,997	44.4	82,355	185,573
PAT0148sub	9.2	17,541	1.5	2,866	5.5	10,511	83.8	159,828	190,746

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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 Patapsco LNB 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 EPA’s *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 together by stratum, and the percentile rank of the highest observed concentration (for each stratum 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 for both high-flow and low-flow strata. This is conducted for each station using a statistical methodology (the "Statistical Theory of Rollback," or "STR," described more fully in Appendix D).

Third, based on the estimated long-term average (LTA) TMDL concentrations, the MDL for each flow stratum 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 Patapsco LNB subwatersheds, including for computational purposes those partially located in the MD 8-digit South Branch Patapsco River, are shown in Table 4.8.3.

Table 4.8.3: Patapsco River Lower North Branch Watershed Maximum Daily Loads Summary

Subwatershed	**Flow Stratum**	**Maximum Daily Load (Billion *E. coli* MPN/day)**	
		by Stratum	**Weighted by Stratum**
PAT0347[1]	High Low	331,703 9,902	96,842
PAT0285sub	High Low	66,503 3,576	20,692
PAT0222sub	High Low	56,950 4,419	18,708
PAT0176sub	High Low	39,313 1,030	11,443
PAT0148sub	High Low	41,658 6,211	15,852

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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

4.9 TMDL Allocations

The Patapsco LNB watershed fecal bacteria TMDL is composed of the following components:

$$TMDL = LA_{LNB} + WLA_{LNB} + LA_{SB} + MOS \qquad (15)$$

where,

LA_{LNB} = MD 8-digit Patapsco LNB Watershed Load Allocation
WLA_{LNB} = MD 8-digit Patapsco LNB Watershed Waste Load Allocation
LA_{SB} = MD 8-digit South Branch Patapsco River Watershed Load Allocation
MOS = Margin of Safety

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

In addition to these allocation categories for the MD 8-digit Patapsco LNB watershed, the TMDL includes an upstream load allocation for the portion of the watershed located in the MD 8-digit South Branch Patapsco River watershed (LA_{SB}). The LA_{SB} was calculated using the ratios of the areas of the watershed in the two 8-digit basins to the total area of the watershed, and is presented as a "lump-sum" upstream load comprising all bacteria source categories. The LA_{SB}, determined to be necessary in order to meet water quality standards in the MD 8-digit Patapsco LNB watershed, 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 4.9.1. This table identifies how the TMDL will be allocated among the LA_{LNB} (those nonpoint sources or portions thereof not transported and discharged by stormwater systems) and the WLA_{LNB} (point sources including WWTPs, and NPDES regulated stormwater discharges). Only the final LA_{LNB} or WLA_{LNB} is reported in this TMDL. Note that the assignment of an allowable human load to the LA_{LNB} 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 MD 8-digit Patapsco River Lower North Branch Watershed

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

* These allocations apply only to the MD 8-digit Patapsco River Lower North Branch watershed. The TMDL allocation scenario load attributed to the MD 8-digit South Branch Patapsco River watershed includes all four bacteria source categories in one single load.

LA_{LNB}

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_{LNB}. Livestock loads are also assigned to the LA_{LNB}. Since the entire Patapsco LNB watershed is covered by NPDES MS4 permits, bacteria loads from domestic animal and wildlife sources are distributed between the SW-WLA_{LNB} and LA_{LNB}.

WLA_{LNB}

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, EPA guidance allows the stormwater WLA to be expressed as an aggregate allotment.

Bacteria loads from domestic animal sources are distributed between the SW-WLA$_{LNB}$ and the LA$_{LNB}$ 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-WLA$_{LNB}$ and LA$_{LNB}$ 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, 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 8-digit Patapsco LNB watershed, the jurisdictions of Anne Arundel, Baltimore, Carroll, and Howard Counties and Baltimore City have individual Phase I MS4 permits. 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 8-digit Patapsco LNB watershed are presented by jurisdiction and subwatershed in Table 4.9.2. The corresponding SW-WLA$_{LNB}$ 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 21% from Anne Arundel County, 25% from Baltimore City, 13% from Baltimore County, 0% from Carroll County, and 13% from Howard 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

Subwatershed	Anne Arundel County SW-BL$_{LNB}$	Baltimore City SW-BL$_{LNB}$	Baltimore County SW-BL$_{LNB}$	Carroll County SW-BL$_{LNB}$	Howard County SW-BL$_{LNB}$
	(Billion MPN E. coli/year)				
PAT0347[1]	0	0	16,605	255	2,546
PAT0285sub	0	0	69,872	0	26,533
PAT0222sub	0	0	55,239	0	72,422
PAT0176sub	0	3,490	32,811	0	22,701
PAT0148sub	60,361	1,703	47,016	0	41,255

[1] MD 8-digit Patapsco River Lower North Branch portion of the subwatershed only.

Table 4.9.3: Annual Average Stormwater Allocations

Subwatershed	Anne Arundel County SW-WLA$_{LNB}$	Baltimore City SW-WLA$_{LNB}$	Baltimore County SW-WLA$_{LNB}$	Carroll County SW-WLA$_{LNB}$	Howard County SW-WLA$_{LNB}$
	(Billion MPN E. coli/year)				
PAT0347[1]	0	0	16,605	255	2,546
PAT0285sub	0	0	69,872	0	26,533
PAT0222sub	0	0	55,239	0	72,422
PAT0176sub	0	3,490	32,811	0	22,701
PAT0148sub	47,814	412	18,444	0	19,016

[1] MD 8-digit Patapsco River Lower North Branch portion of the subwatershed only.

Municipal and Industrial WWTPs

As explained in the source assessment section above, there are three NPDES permitted point source facilities with permits regulating the discharge of fecal bacteria in the MD 8-digit Patapsco LNB watershed. The WLA for each WWTP is estimated using the design flow of the plant stated in the facility's NPDES permit and the *E. coli* criterion of 126 MPN/100ml. Bacteria loads assigned to the WWTPs are allocated as the WWTP-WLA$_{LNB}$ and are presented in Table 4.9.4.

Table 4.9.4: WWTP Allocations in the MD 8-digit Patapsco River Lower North Branch Watershed

Facility	NPDES Permit No.	Permit Flow (MGD)	Annual Average TMDL WWTP-WLA$_{LNB}$ (Billion MPN/year)	Maximum Daily Load WWTP-WLA$_{LNB}$ (Billion MPN/day)
Woodstock Job Corps WWTP	MD0023906	0.050	87	0.7
Holiday Mobile Estates WWTP	MD0053082	0.125	218	1.9
Deep Run WWTP	MD0056618	1.250	2,176	18.5

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 MD 8-digit Patapsco LNB basin.

Table 4.10.1: Patapsco River Lower North Branch Watershed Annual Average TMDL

Subwatershed	**Total Allocation**	**LA_{LNB}**	**$SW\text{-}WLA_{LNB}$**	**$WWTP\text{-}WLA_{LNB}$**
	(Billion MPN *E. coli* /year)			
PAT0347[1]	93,949	74,456	19,406	87
PAT0285sub	358,827	262,422	96,405	0
PAT0222sub	344,864	217,203	127,661	0
PAT0176sub	185,573	126,571	59,002	0
PAT0148sub	190,746	102,666	85,686	2,394
MD 8-digit Patapsco River Lower North Branch Total	1,173,959	783,318	388,160	2,481
MD 8-digit South Branch Patapsco River Upstream Load	813,612			
***TMDL*[2]**	**1,987,571**			

[1] MD 8-digit Patapsco River Lower North Branch portion of the subwatershed only.
[2] The MOS is incorporated.

Table 4.10.2: Patapsco River Lower North Branch Watershed Maximum Daily Loads

Subwatershed	**Total Allocation**	**LA_{LNB}**	**$SW\text{-}WLA_{LNB}$**	**$WWTP\text{-}WLA_{LNB}$**
	(Billion MPN *E. coli* /day)			
PAT0347[1]	10,025	7,953	2,071	1
PAT0285sub	20,692	15,133	5,559	0
PAT0222sub	18,708	11,783	6,925	0
PAT0176sub	11,443	7,805	3,638	0
PAT0148sub	15,852	8,711	7,121	20
MD Total	76,720	51,384	25,315	21
MD 8-digit South Branch Patapsco River Upstream Load	86,817			
***MDL*[2]**	**163,537**			

[1] MD 8-digit Patapsco River Lower North Branch portion of the subwatershed only.
[2] The MOS is incorporated.

The long-term annual average fecal bacteria TMDL summary for the Patapsco LNB watershed is presented in Table 4.10.3. Note that the upstream MD 8-digit South Branch Patapsco River watershed load allocation (LA$_{SB}$) is determined to be necessary in order to meet water quality standards in the MD 8-digit Patapsco LNB watershed.

Table 4.10.3: MD 8-Digit Patapsco River Lower North Branch Watershed Annual Average TMDL Summary

(Billion MPN *E. coli*/year)										
TMDL	=	**LA**			+	**WLA**			+	**MOS**
		LA$_{SB}$[1]	+	**LA$_{LNB}$**		**SW WLA$_{LNB}$**	+	**WWTP WLA$_{LNB}$**		
1,987,571	=	813,612	+	783,318	+	388,160	+	2,481	+	Incorporated

Upstream Load Allocation

MD 8-digit Patapsco River Lower North Branch TMDL Contribution (1,173,959)

[1] 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 Patapsco LNB watershed are summarized in Table 4.10.4.

Table 4.10.4: MD 8-Digit Patapsco River Lower North Branch Watershed MDL Summary

(Billion MPN *E. coli*/day)										
MDL	=	**LA**			+	**WLA**			+	**MOS**
		LA$_{SB}$	+	**LA$_{LNB}$**		**SW WLA$_{LNB}$**	+	**WWTP WLA$_{LNB}$**		
163,537	=	86,817	+	51,384	+	25,315	+	21	+	Incorporated

Upstream MDL

MD 8-digit Patapsco River Lower North Branch MDL Contribution (76,720)

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 one of the five Patapsco LNB subwatersheds (PAT0148sub), water quality standards cannot be achieved with the maximum practicable reduction rates specified in Table 4.7.3. For this subwatershed 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 Patapsco LNB watershed, the TMDL analysis indicates that, for one of the five 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. Patapsco River and its tributaries may not be able to attain water quality standards. The fecal bacteria load reductions required to meet water quality criteria in one of the five Patapsco LNB 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 Patapsco LNB watershed is managed under NPDES MS4 permits for Anne Arundel, Baltimore, Carroll, and Howard Counties, and Baltimore City, 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 the following: 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 Patapsco LNB 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 non-point 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)
PAT0148	10/02/2002	97.9056	230
	10/22/2002	85.8407	20
	11/13/2002	22.0059	380
	12/03/2002	72.2419	7
	12/17/2002	25.3982	100
	01/07/2003	18.2448	70
	01/22/2003	41.6519	110
	02/04/2003	27.1386	200
	03/04/2003	12.9056	160
	03/18/2003	12.6549	10
	03/31/2003	8.1563	570
	04/22/2003	22.5516	90
	05/06/2003	27.1386	190
	05/20/2003	7.5516	280
	06/03/2003	5.5015	190
	06/17/2003	4.9558	180
	06/24/2003	3.7463	340
	07/08/2003	15.7817	380
	07/22/2003	35.4130	160
	08/05/2003	27.5664	960
	08/19/2003	21.8437	170
	08/26/2003	53.5546	180
	09/09/2003	29.6165	200
	09/23/2003	0.0590	20100
	10/07/2003	20.8555	60
	10/21/2003	18.7611	160

Station	**Date**	**Daily flow frequency**	***E. coli* Concentration (MPN/100ml)**
PAT0176	10/02/2002	97.9056	40
	10/22/2002	85.8407	40
	11/13/2002	22.0059	180
	12/03/2002	72.2419	4
	12/17/2002	25.3982	20
	01/07/2003	18.2448	50
	01/22/2003	41.6519	10
	02/04/2003	27.1386	30
	03/04/2003	12.9056	140
	03/18/2003	12.6549	10
	03/31/2003	8.1563	440
	04/22/2003	22.5516	50
	05/06/2003	27.1386	180
	05/20/2003	7.5516	190
	06/03/2003	5.5015	260
	06/17/2003	4.9558	160
	06/24/2003	3.7463	150
	07/08/2003	15.7817	90
	07/22/2003	35.4130	40
	08/05/2003	27.5664	230
	08/19/2003	21.8437	120
	08/26/2003	53.5546	110
	09/09/2003	29.6165	150
	09/23/2003	0.0590	29900
	10/07/2003	20.8555	100
	10/21/2003	18.7611	70

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
PAT0222	10/02/2002	97.9056	190
	10/22/2002	85.8407	190
	11/13/2002	22.0059	270
	12/03/2002	72.2419	3
	12/17/2002	25.3982	60
	01/07/2003	18.2448	40
	01/22/2003	41.6519	30
	02/04/2003	27.1386	40
	03/04/2003	12.9056	130
	03/18/2003	12.6549	40
	03/31/2003	8.1563	790
	04/22/2003	22.5516	140
	05/06/2003	27.1386	300
	05/20/2003	7.5516	190
	06/03/2003	5.5015	230
	06/17/2003	4.9558	100
	06/24/2003	3.7463	110
	07/08/2003	15.7817	110
	07/22/2003	35.4130	50
	08/05/2003	27.5664	440
	08/19/2003	21.8437	250
	08/26/2003	53.5546	150
	09/09/2003	29.6165	120
	09/23/2003	0.0590	46100
	10/07/2003	20.8555	40
	10/21/2003	18.7611	140

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
PAT0285	10/02/2002	97.9056	30
	10/22/2002	85.8407	30
	11/13/2002	22.0059	380
	12/03/2002	72.2419	2
	12/17/2002	25.3982	90
	01/07/2003	18.2448	90
	01/22/2003	41.6519	10
	02/04/2003	27.1386	40
	03/04/2003	12.9056	60
	03/18/2003	12.6549	70
	03/31/2003	8.1563	630
	04/22/2003	22.5516	10
	05/06/2003	27.1386	110
	05/20/2003	7.5516	40
	06/03/2003	5.5015	170
	06/17/2003	4.9558	150
	06/24/2003	3.7463	110
	07/08/2003	15.7817	70
	07/22/2003	35.4130	80
	08/05/2003	27.5664	200
	08/19/2003	21.8437	120
	08/26/2003	53.5546	180
	09/09/2003	29.6165	110
	09/23/2003	0.0590	32600
	10/07/2003	20.8555	70
	10/21/2003	18.7611	110

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
PAT0347	10/02/2002	97.9056	40
	10/22/2002	85.8407	90
	11/13/2002	22.0059	880
	12/03/2002	72.2419	5
	12/17/2002	25.3982	70
	01/07/2003	18.2448	100
	01/22/2003	41.6519	10
	02/04/2003	27.1386	30
	03/04/2003	12.9056	90
	03/18/2003	12.6549	30
	03/31/2003	8.1563	2600
	04/22/2003	22.5516	20
	05/06/2003	27.1386	240
	05/20/2003	7.5516	60
	06/03/2003	5.5015	130
	06/17/2003	4.9558	100
	06/24/2003	3.7463	130
	07/08/2003	15.7817	150
	07/22/2003	35.4130	190
	08/05/2003	27.5664	160
	08/19/2003	21.8437	190
	08/26/2003	53.5546	110
	09/09/2003	29.6165	190
	09/23/2003	0.0590	21900
	10/07/2003	20.8555	30
	10/21/2003	18.7611	100

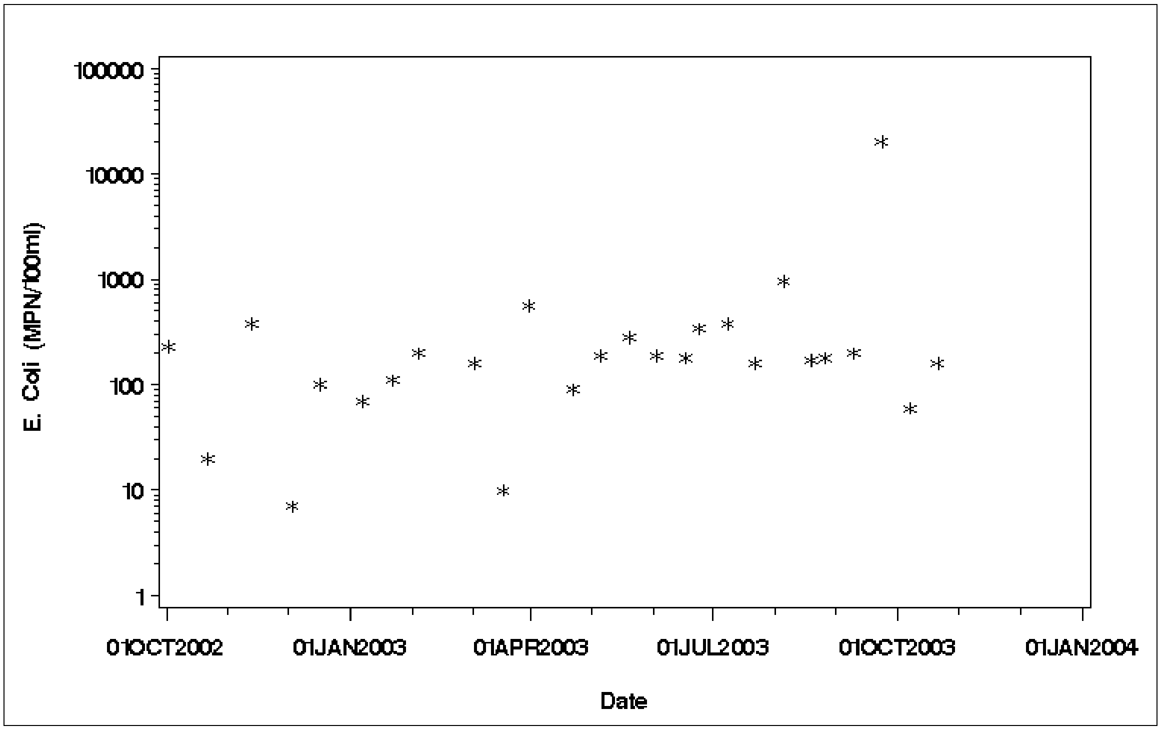

Figure A-1: *E. coli* Concentration vs. Time for MDE Monitoring Station PAT0148

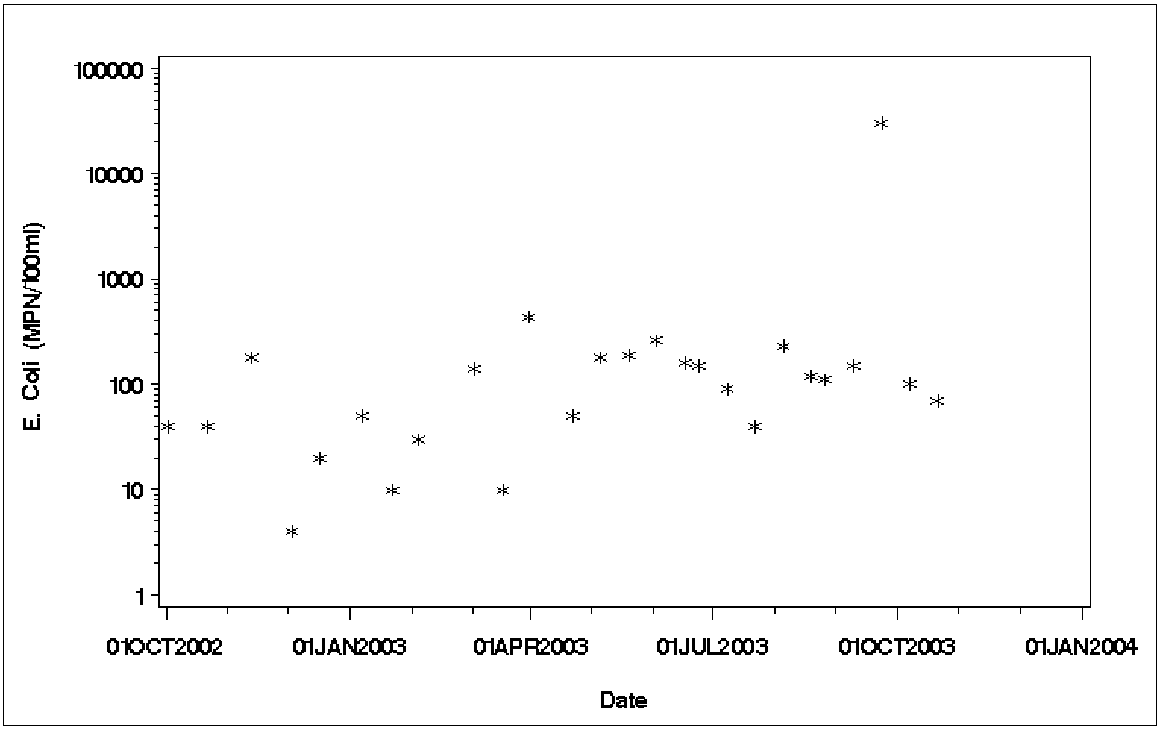

Figure A-2: *E. coli* Concentration vs. Time for MDE Monitoring Station PAT0176

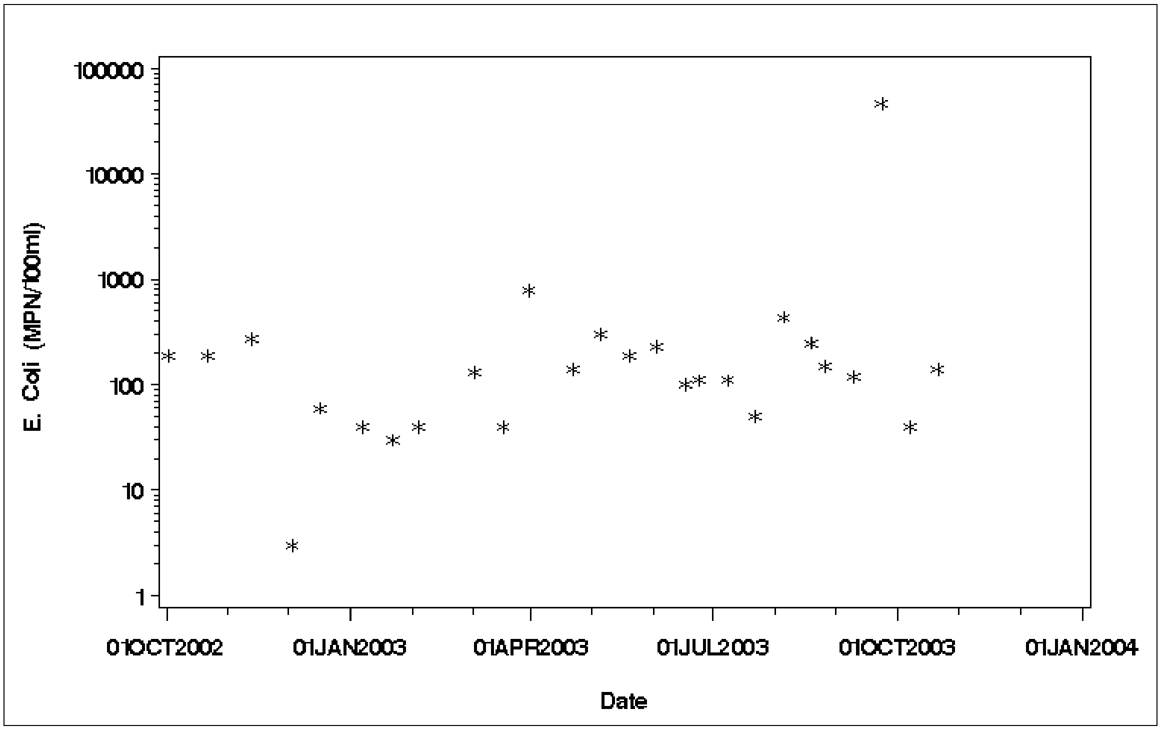

Figure A-3: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station PAT0222**

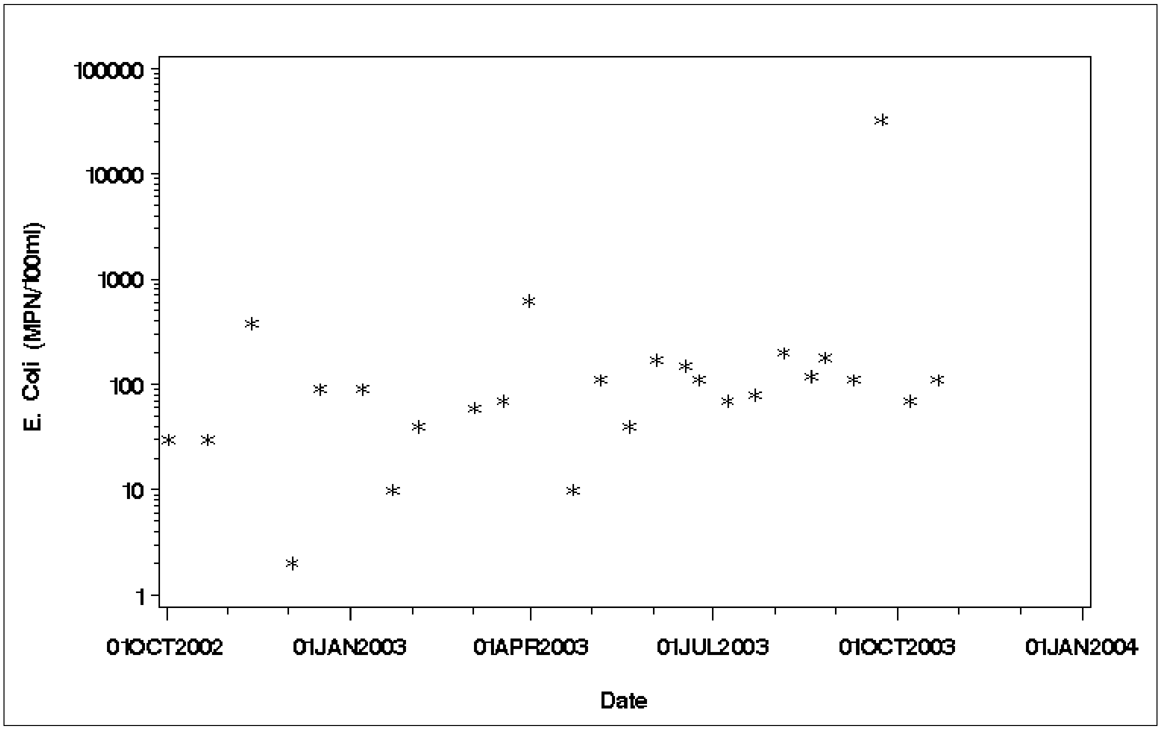

Figure A-4: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station PAT0285**

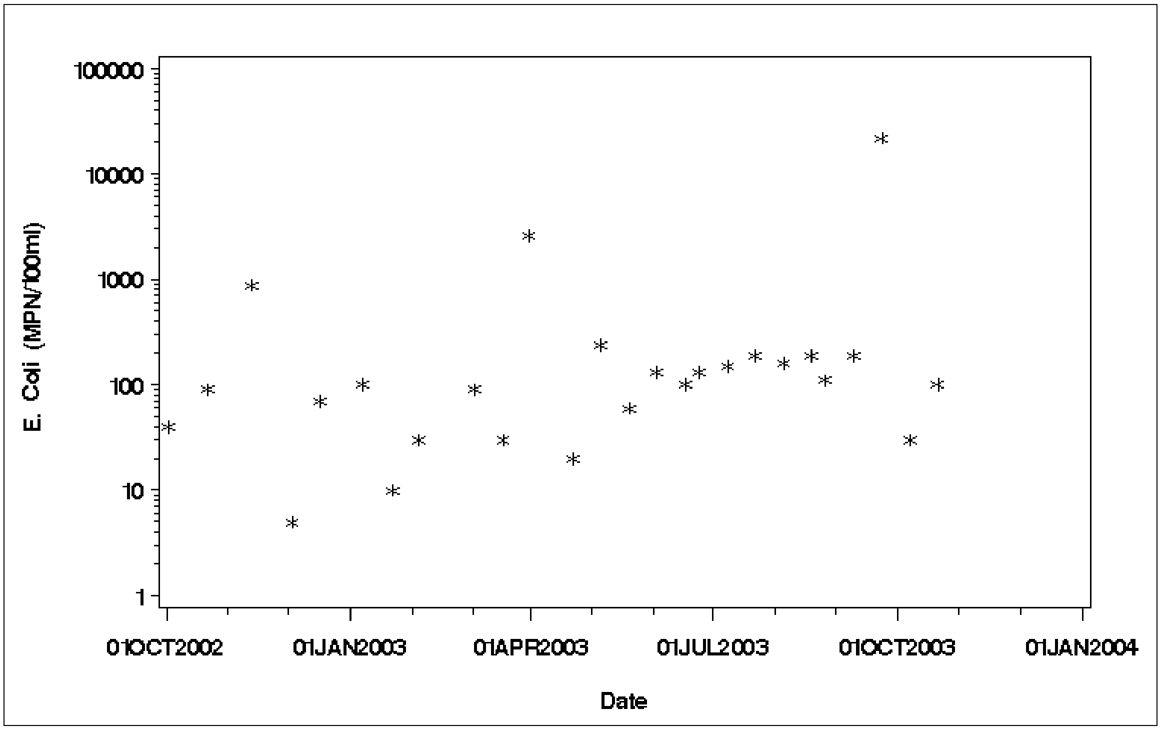

Figure A-5: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station PAT0347**

Appendix B - Flow Duration Curve Analysis to Define Strata

The Patapsco River Lower North Branch 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 is one USGS gage station in the Patapsco River Lower North Branch watershed used for the analysis. The site is listed in Table B-1 and the flow duration curve for the site is presented in Figure B-1.

Table B-1: USGS Sites in the Patapsco River Lower North Branch Watershed

USGS Site #	Dates Used	Location
01589000	10/01/1979 – 9/30/2004	Patapsco River at Hollofield, MD

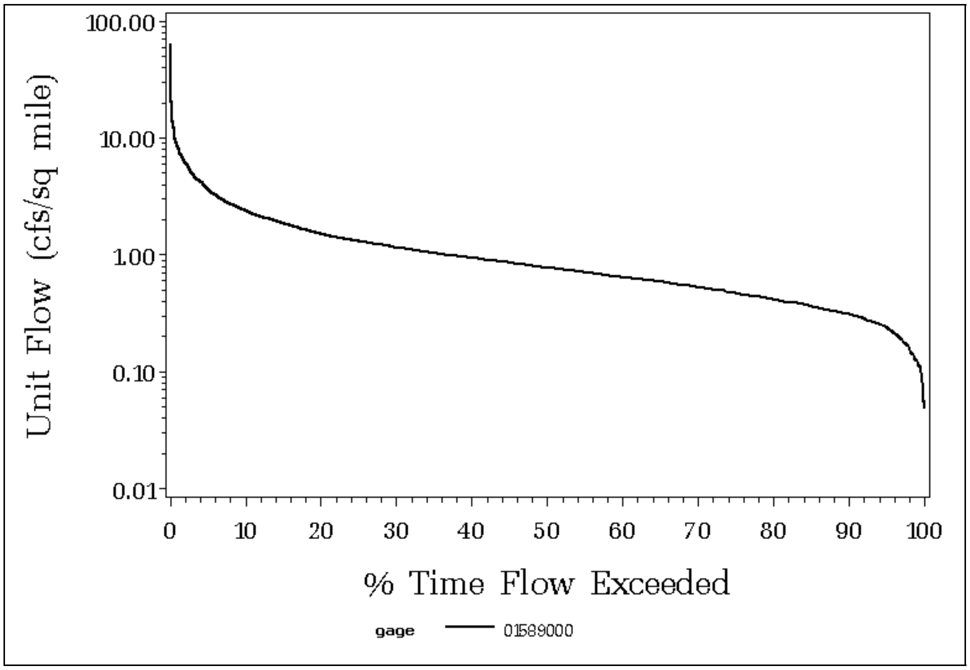

Figure B-1: Flow Duration Curve for USGS Gage 01589000

Based on the flow data from the Patapsco River gage station the long-term average daily unit flow is 1.24 cfs/sq. mile, which corresponds to a flow frequency of 27.2%. 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 27.2 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 27.2% and a low flow condition will be defined as occurring when the daily flow duration percentile is greater than 27.2%. 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. Figures B-2 to B-11 show the Patapsco River Lower North Branch watershed *E. coli* monitoring data with corresponding flow frequency for the average annual and the dry weather steady-state seasonal conditions.

Maryland's water quality standards for bacteria state that, when available, the geometric mean indicator should be based on at least five samples. 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 Patapsco River Lower North Branch watershed, for the annual average flow condition, there are sufficient samples in both the high flow and low flow strata to estimate the geometric means. However, in the dry weather steady-state seasonal (May 1st – September 30th) condition, there are only two samples within the low flow strata; therefore, for this condition an overall geometric mean will be calculated.

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

(1) Average Annual Hydrological Condition
(2) Dry Weather Seasonal (May 1st – September 30th) Condition

Weighted geometric means for the average annual and the overall seasonal conditions geometric means are plotted with the monitoring data on Figures B-2 to B-11.

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

Condition	Averaging Period	Water Quality Data Used	Fraction High Flow	Fraction Low Flow
Annual Average	365 days	All	0.272	0.728
Dry Weather Seasonal	May 1st – Sept. 30th	Dry Weather Samples During May 1st – Sept. 30th	1.000	

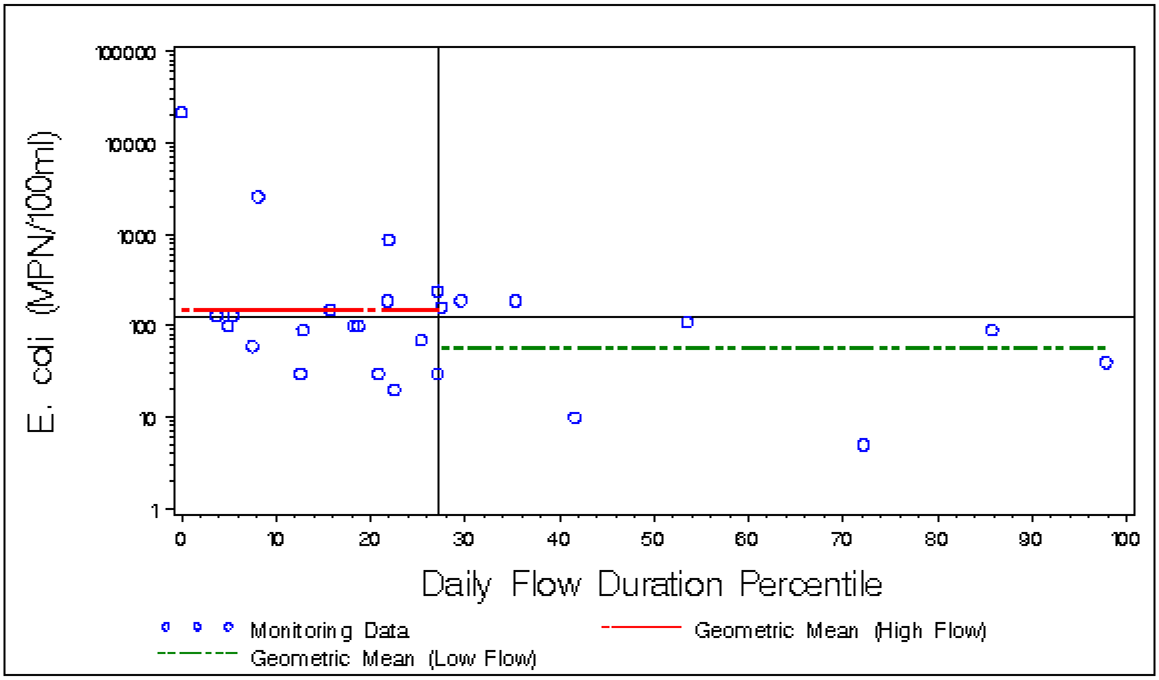

Figure B-2: ***E. coli*** **Concentration vs. Flow Duration for Monitoring Station PAT0347 (Annual Condition)**

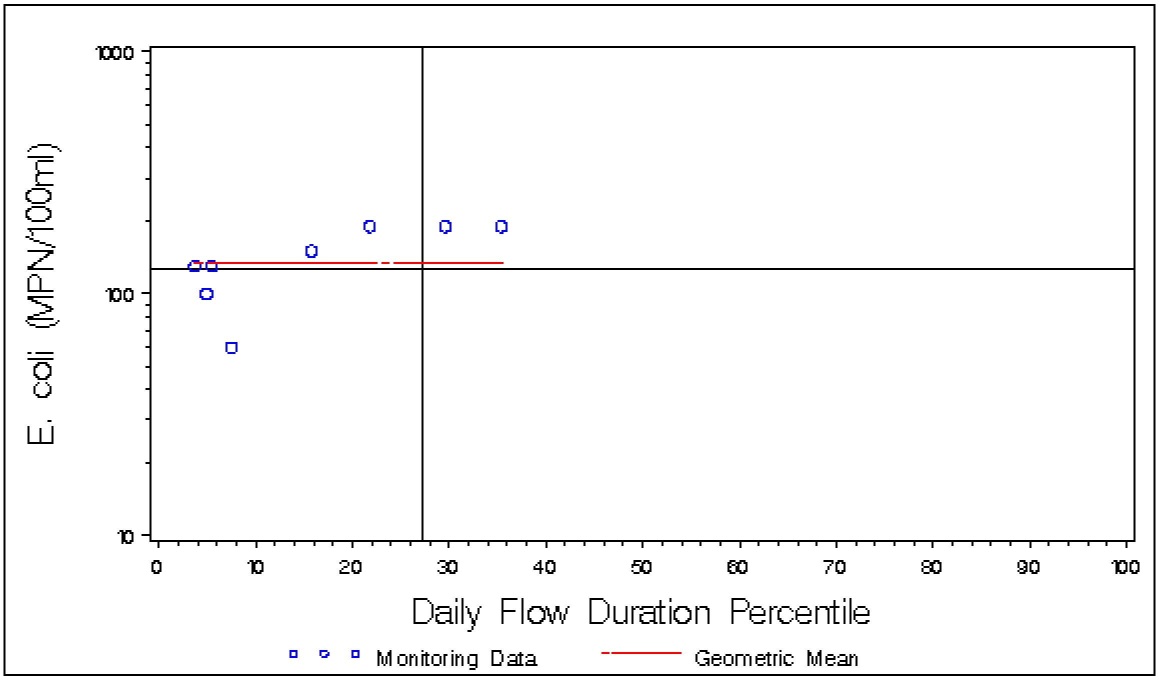

Figure B-3: ***E. coli*** **Concentration vs. Flow Duration for Monitoring Station PAT0347 (Seasonal Condition)**

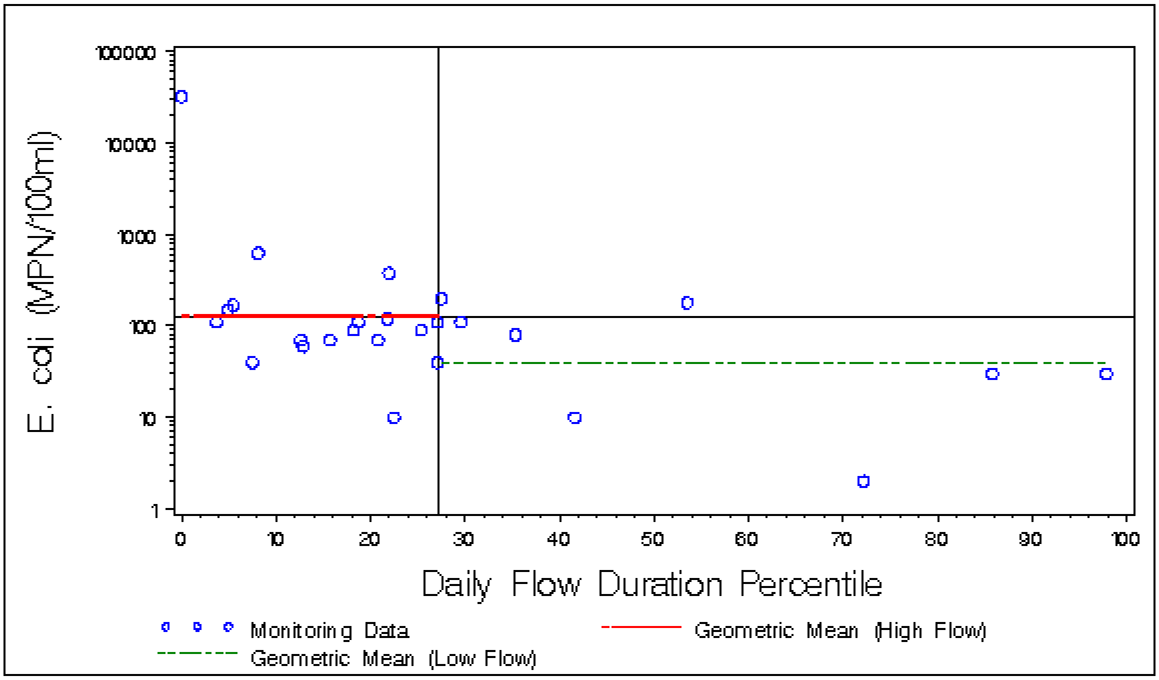

Figure B-4: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0285 (Annual Condition)

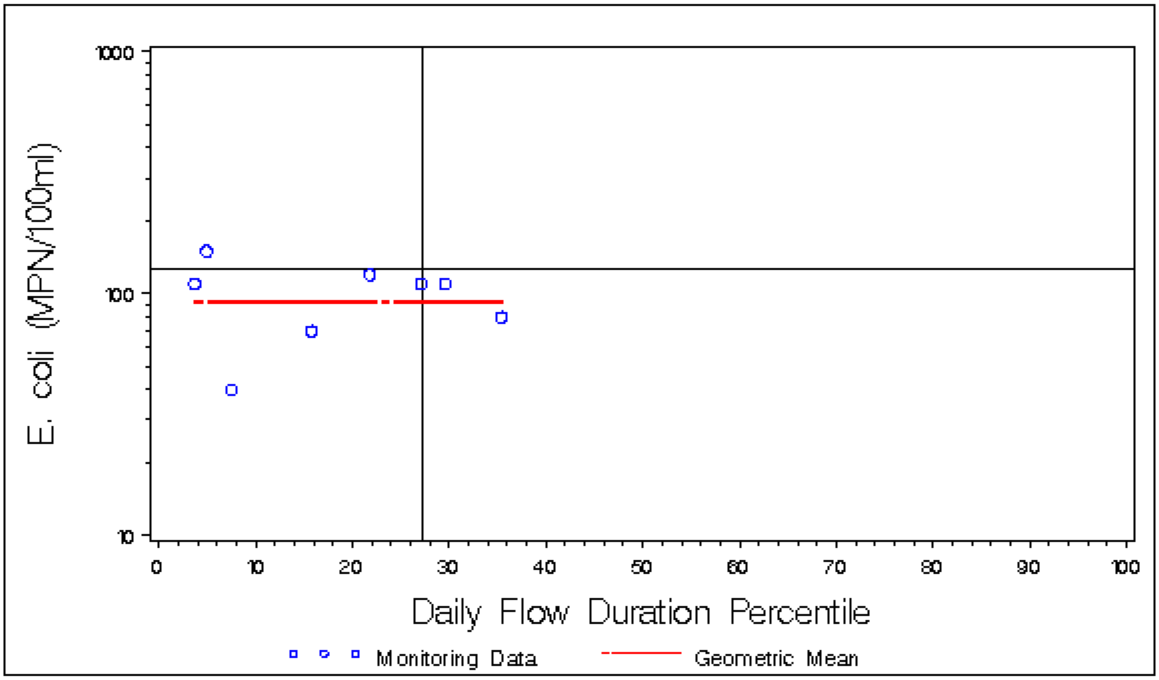

Figure B-5: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0285 (Seasonal Condition)

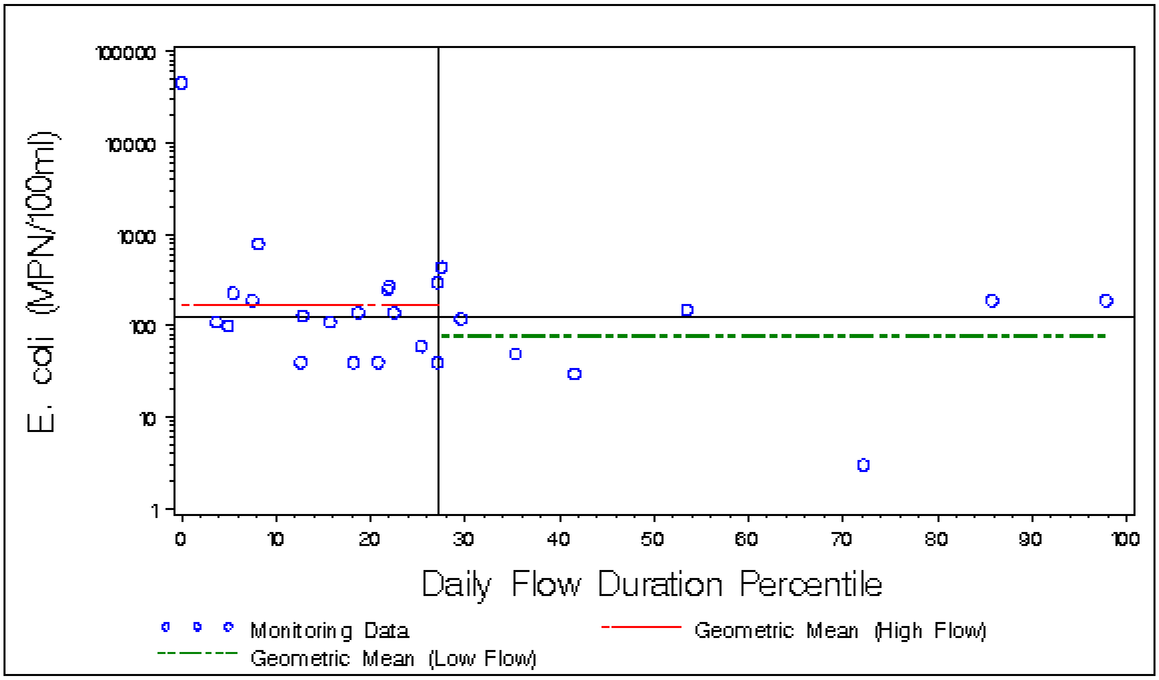

Figure B-6: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0222 (Annual Condition)

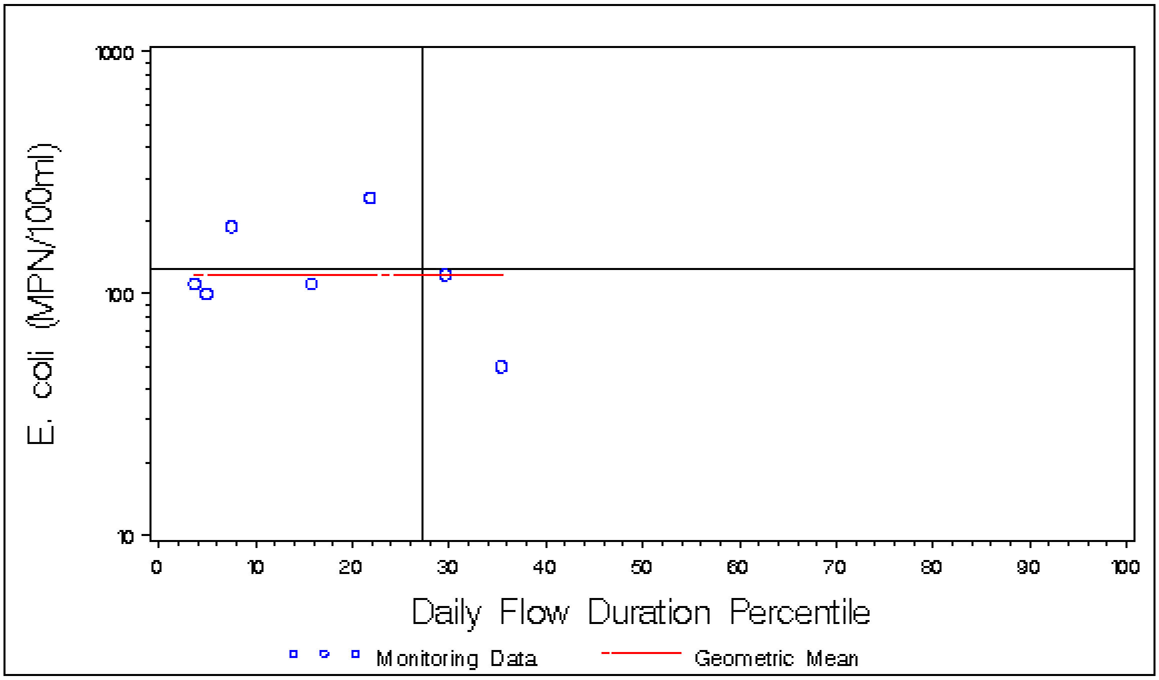

Figure B-7: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0222 (Seasonal Condition)

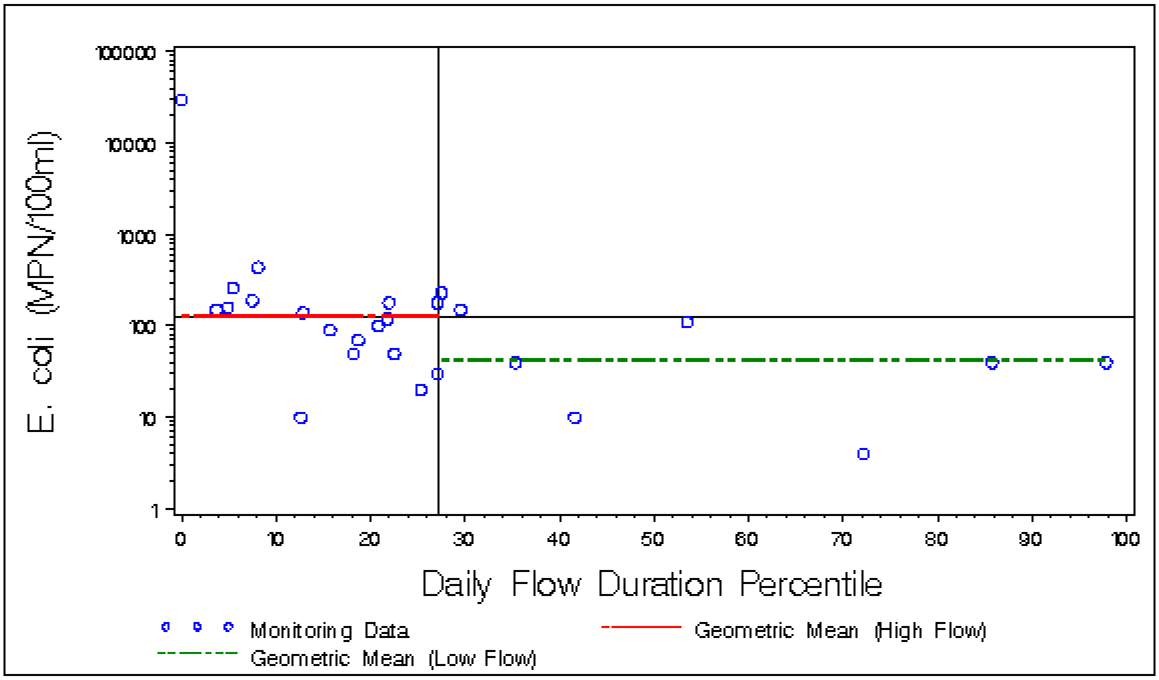

Figure B-8: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0176 (Annual Condition)

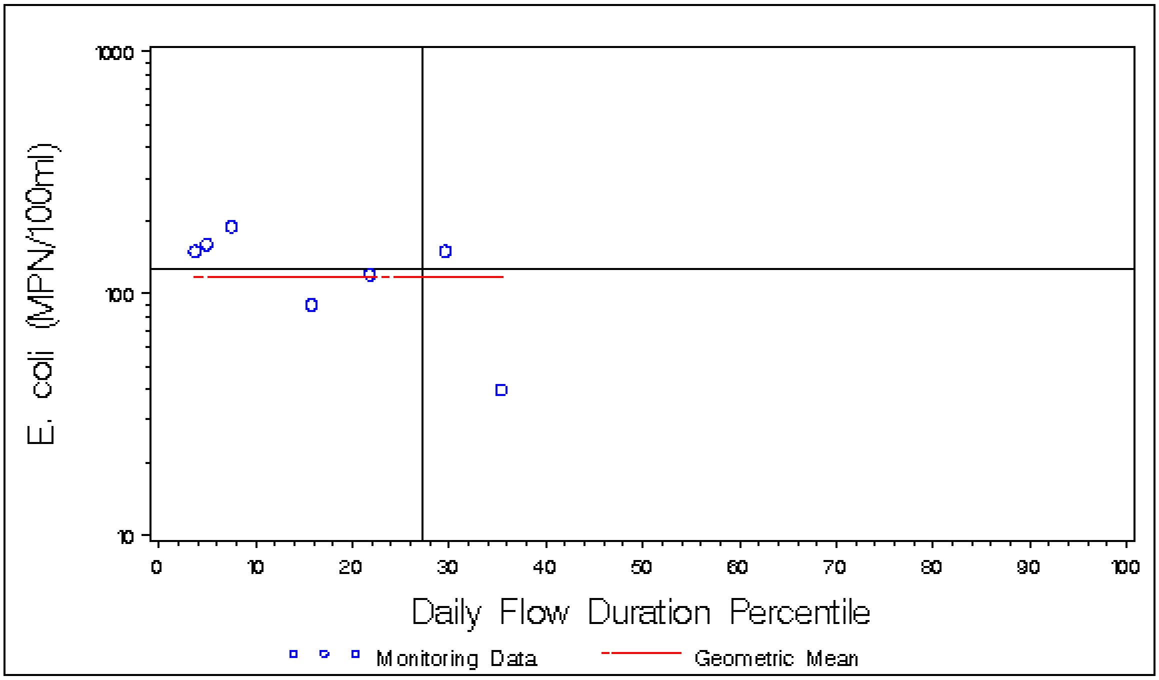

Figure B-9: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0176 (Seasonal Condition)

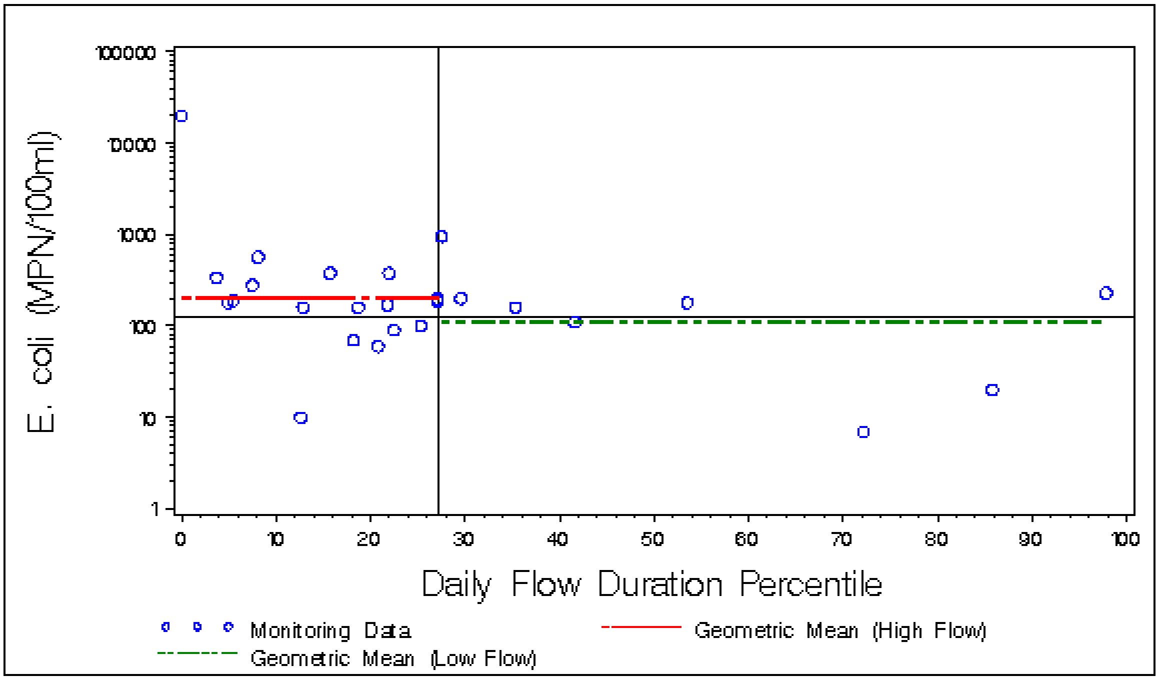

Figure B-10: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0148 (Annual Condition)

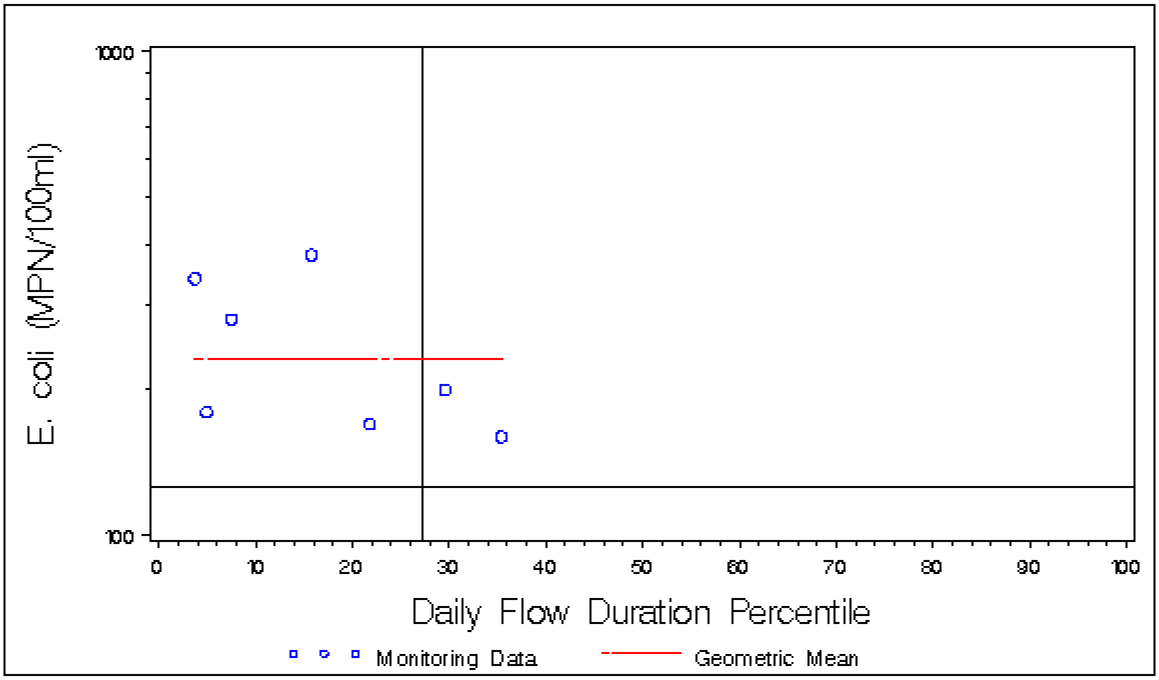

Figure B-11: *E. coli* Concentration vs. Flow Duration for Monitoring Station PAT0148 (Seasonal Condition)

Appendix C – BST Report

Maryland Department of the Environment

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

November 2005 – June 2007

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Final Report
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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: Deep Creek, Dividing Creek, Little Youghiogheny River, Patapsco River, Prettyboy Reservoir, and the Youghiogheny River. Also included in the study were the following tidal shellfish harvesting areas: the Chester River, Corsica River, Herring and Turnville Creeks, Laws and Upper Thorofare, Manokin River, and the Pocomoke River 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 (Hagedorn, 1999; Wiggins, 1999). A pilot study using PFGE, a genotypic BST method, was used on a subset of known-source isolates collected from the Pocomoke River Watershed.

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

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

LABORATORY METHODS

Isolation of *Enterococcus* from Known-Source Samples. Fecal samples, identified to source, were delivered to the Salisbury University (SU) BST lab by Maryland Department of the Environment (MDE) personnel. Fecal material suspended in phosphate buffered saline was plated onto selective m-Enterococcus agar. After incubation at 37^{o} C, up to eight (8) *Enterococcus* isolates were randomly selected from each fecal sample for ARA testing.

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

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

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

The following table includes the antibiotics and concentrations used for isolates in analyses for all the study watersheds.

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

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

KNOWN-SOURCE LIBRARY

Construction and Use. Fecal samples (scat) from known sources in each watershed were collected during the study period by MDE personnel and delivered to the BST Laboratory at SU. *Enterococcus* isolates were obtained from known sources (e.g., human, 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. A combined library of known sources was used for the nontidal Little Youghiogheny River and the Youghiogheny River Watersheds using patterns from scat obtained from both watersheds, and the water isolate patterns of each were compared to the combined library. A combined known-source library was also used for the nontidal Patapsco River and Pretty Boy Reservoir Watersheds, with water isolate patterns of each compared to this combined library. For the 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.

Patapsco River Watershed ARA Results

Known-Source Library. A 501 known-source isolate library was constructed from sources in the Patapsco River (Table C-2a) and combined with the 615 known-source isolate library for the Pretty Boy Reservoir (Table C-2b), for a total of 1,116 known-source isolates in the PAT-PRE library (Table C-2c). 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, goat, horse), pet (dog), and wildlife (deer, fox, goose, heron, rabbit, squirrel) (Table C-2a, Table C-2b, Table C-2c). The library was analyzed for its ability to take a subset of the library isolates and correctly predict the identity of their host sources when they were treated as unknowns. Average rates of correct classification (ARCC) for the library were found by repeating this analysis using several probability cutoff points, as described above. The number-not-classified for each probability was determined. From these results, the percent unknown and percent correct classification (RCCs) was calculated (Table C-3).

Table C-2a: Category, total number, and number of unique patterns in the Patapsco River known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
human	human	93	53
livestock	horse	58	16
pet	dog	86	47
wildlife	deer, fox, goose, heron, rabbit, squirrel	264	48
Total		501	164

Table C-2b: Category, total number, and number of unique patterns in the Pretty Boy River known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
human	human	163	105
livestock	cow, goat, horse	221	66
pet	dog	64	31
wildlife	deer, fox, goose	167	56
Total		615	258

Table C-2c: Category and total number in the combined Patapsco River and Pretty Boy Reservoir known-source library.

Category	Potential Sources	Total Isolates
human	human	256
livestock	horse	279
pet	dog	150
wildlife	deer, fox, goose, heron, rabbit, squirrel	431
Total		1,116

For the Patapsco River Watershed, a cutoff probability of 0.50 (50%) using the combined PAT-PRE library was shown to yield an overall rate of correct classification of 63% (Table C-3). The resulting rates of correction classification (RCCs) for the four categories of sources in the Patapsco River portion of the library are shown in Table C-4.

Table C-3: Number of isolates not classified, percent unknown, and percent correct for eight (8) cutoff probabilities for Patapsco River known-source isolates using the combined Patapsco River – Pretty Boy Reservoir know-source library.

Threshold	0	0.25	0.375	**0.5**	0.6	0.7	0.8	0.9
% correct	66.9%	66.9%	67.2%	**62.9%**	76.4%	85.6%	88.7%	95.5%
% unknown	0.0%	0.0%	2.0%	**45.7%**	63.7%	73.7%	77.0%	86.6%
# not classified	0	0	10	**229**	319	369	386	434

Figure C-1: Patapsco River Classification Model: Percent Correct versus Percent Unknown using the combined Patapsco River-Pretty Boy Reservoir library.

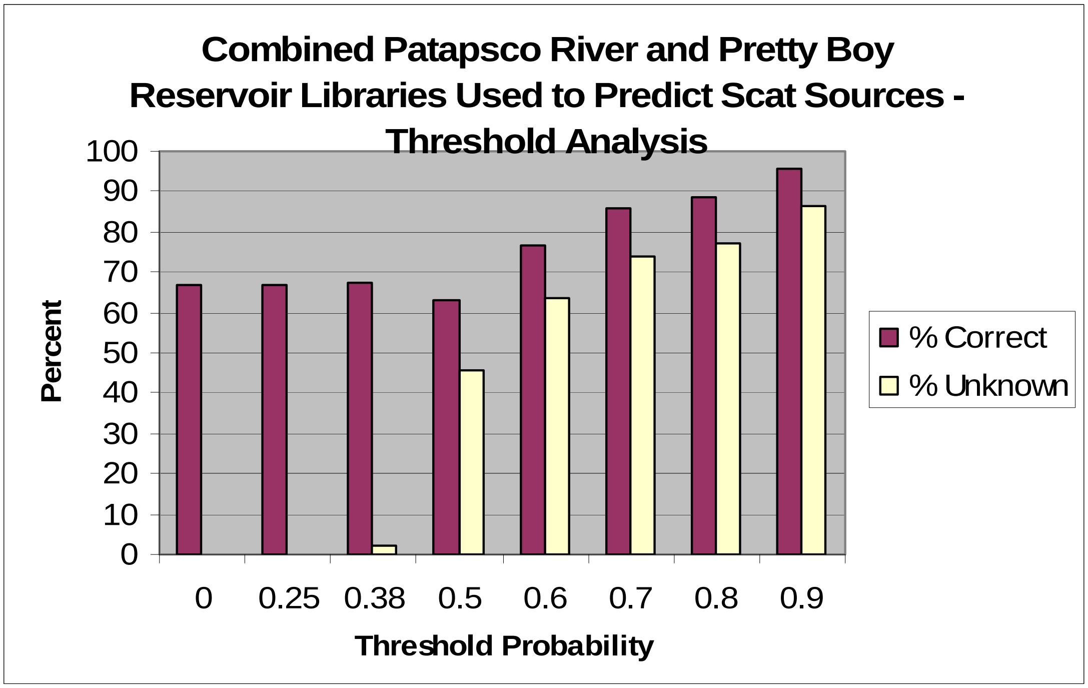


Table C-4: Actual species categories versus predicted categories, at 50% probability cutoff, with rates of correct classification (RCC) for each category.

	Predicted						
Actual	Human	Livestock	Pet	Wildlife	Unknown	Total	RCC*
human	58	11	7	4	13	93	72.5%
livestock	2	24	2	2	28	58	80.0%
pet	4	6	51	3	22	86	79.7%
wildlife	7	21	32	38	166	264	38.8%
Total	71	62	92	47	229	501	

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

Patapsco River Water Samples. Monthly monitoring from five (5) monitoring stations on Patapsco River was the source of water samples The maximum number of *Enterococcus* isolates per water sample was 24, although the number of isolates that actually grew was sometimes less than 24. A total of 1,383 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicate that 76% 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	314	22.7%	30.0%
livestock	400	28.9%	38.2%
pet	271	19.6%	25.9%
wildlife	62	4.5%	5.9%
unknown	336	24.3%	
Total	1383	100.0%	100.0%
% classified	75.7%		

*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 the Patapsco River's five (5) monitoring stations.

Station	Spring	Summer	Fall	Winter	Total
PAT0148	66	69	78	71	284
PAT0176	69	62	84	68	283
PAT0222	72	67	75	62	276
PAT0285	51	67	74	66	258
PAT0347	65	65	82	70	282
Total	323	330	393	337	1383

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	Station	Station	Station	Station	Station	Station	Station
PAT0148	11/13/02	7	4	8	0	3	22
PAT0176	11/13/02	6	9	0	5	4	24
PAT0222	11/13/02	8	4	1	2	5	20
PAT0285	11/13/02	4	7	0	2	8	21
PAT0347	11/13/02	9	7	0	1	5	22
PAT0148	12/03/02	6	8	4	2	4	24
PAT0176	12/03/02	1	9	5	1	6	22
PAT0222	12/03/02	0	5	7	0	10	22
PAT0285	12/03/02	18	2	0	0	3	23
PAT0347	12/03/02	0	13	0	3	7	23
PAT0148	01/07/03	9	9	0	1	5	24
PAT0176	01/07/03	4	15	4	0	1	24
PAT0222	01/07/03	8	7	5	1	2	23
PAT0285	01/07/03	2	16	4	0	0	22
PAT0347	01/07/03	4	12	4	1	1	22
PAT0148	02/04/03	14	6	3	0	1	24
PAT0176	02/04/03	3	16	0	1	0	20
PAT0222	02/04/03	6	9	0	0	0	15
PAT0285	02/04/03	13	5	2	0	0	20
PAT0347	02/04/03	6	8	1	3	6	24
PAT0148	03/04/03	18	1	1	2	1	23
PAT0176	03/04/03	11	2	3	2	6	24
PAT0222	03/04/03	7	11	3	1	2	24
PAT0285	03/04/03	11	9	3	1	0	24
PAT0347	03/04/03	7	11	0	0	6	24
PAT0148	04/22/03	3	14	1	2	3	23
PAT0176	04/22/03	14	7	1	2	0	24
PAT0222	04/22/03	0	13	1	0	10	24
PAT0285	04/22/03	2	7	1	1	2	13
PAT0347	04/22/03	5	1	9	1	6	22
PAT0148	05/06/03	11	0	3	0	10	24
PAT0176	05/06/03	5	11	4	1	3	24
PAT0222	05/06/03	5	15	2	0	2	24
PAT0285	05/06/03	4	13	4	0	3	24
PAT0347	05/06/03	0	6	12	1	5	24
PAT0148	06/03/03	3	8	4	0	4	19
PAT0176	06/03/03	0	7	2	1	11	21
PAT0222	06/03/03	4	9	4	1	6	24

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

			Predicted	Source			
Station	Station	Station	Station	Station	Station	Station	Station
PAT0285	06/03/03	4	3	5	1	1	14
PAT0347	06/03/03	3	4	3	2	7	19
PAT0148	07/08/03	3	7	6	0	8	24
PAT0176	07/08/03	1	3	5	1	7	17
PAT0222	07/08/03	0	3	8	2	10	23
PAT0285	07/08/03	0	5	4	1	14	24
PAT0347	07/08/03	0	6	15	1	2	24
PAT0148	08/05/03	9	2	11	0	2	24
PAT0176	08/05/03	5	1	11	1	6	24
PAT0222	08/05/03	7	2	13	0	2	24
PAT0285	08/05/03	2	0	14	1	7	24
PAT0347	08/05/03	3	0	4	0	16	23
PAT0148	09/09/03	7	1	3	3	7	21
PAT0176	09/09/03	0	9	2	0	10	21
PAT0222	09/09/03	1	1	9	0	9	20
PAT0285	09/09/03	3	1	4	0	11	19
PAT0347	09/09/03	0	0	7	0	11	18
PAT0148	09/23/03	2	2	11	2	6	23
PAT0176	09/23/03	7	5	3	0	5	20
PAT0222	09/23/03	6	7	5	1	5	24
PAT0285	09/23/03	3	4	11	0	6	24
PAT0347	09/23/03	3	5	5	3	7	23
PAT0148	10/07/03	0	3	0	0	6	9
PAT0176	10/07/03	3	8	2	1	4	18
PAT0222	10/07/03	0	1	3	1	4	9
PAT0285	10/07/03	0	0	0	0	6	6
PAT0347	10/07/03	4	1	1	2	6	14
Total		314	400	271	62	336	1383

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

			Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
PAT0148	11/13/02	31.8%	18.2%	36.4%	0.0%	13.6%	100.0%
PAT0176	11/13/02	25.0%	37.5%	0.0%	20.8%	16.7%	100.0%
PAT0222	11/13/02	40.0%	20.0%	5.0%	10.0%	25.0%	100.0%
PAT0285	11/13/02	19.0%	33.3%	0.0%	9.5%	38.1%	100.0%
PAT0347	11/13/02	40.9%	31.8%	0.0%	4.5%	22.7%	100.0%
PAT0148	12/03/02	25.0%	33.3%	16.7%	8.3%	16.7%	100.0%
PAT0176	12/03/02	4.5%	40.9%	22.7%	4.5%	27.3%	100.0%
PAT0222	12/03/02	0.0%	22.7%	31.8%	0.0%	45.5%	100.0%
PAT0285	12/03/02	78.3%	8.7%	0.0%	0.0%	13.0%	100.0%

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

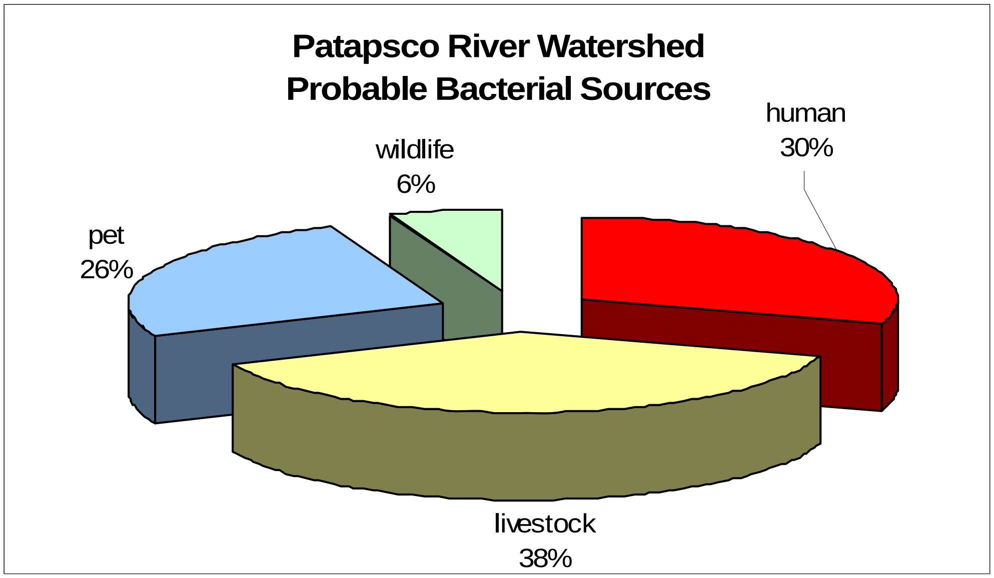
		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
PAT0347	12/03/02	0.0%	56.5%	0.0%	13.0%	30.4%	100.0%
PAT0148	01/07/03	37.5%	37.5%	0.0%	4.2%	20.8%	100.0%
PAT0176	01/07/03	16.7%	62.5%	16.7%	0.0%	4.2%	100.0%
PAT0222	01/07/03	34.8%	30.4%	21.7%	4.3%	8.7%	100.0%
PAT0285	01/07/03	9.1%	72.7%	18.2%	0.0%	0.0%	100.0%
PAT0347	01/07/03	18.2%	54.5%	18.2%	4.5%	4.5%	100.0%
PAT0148	02/04/03	58.3%	25.0%	12.5%	0.0%	4.2%	100.0%
PAT0176	02/04/03	15.0%	80.0%	0.0%	5.0%	0.0%	100.0%
PAT0222	02/04/03	40.0%	60.0%	0.0%	0.0%	0.0%	100.0%
PAT0285	02/04/03	65.0%	25.0%	10.0%	0.0%	0.0%	100.0%
PAT0347	02/04/03	25.0%	33.3%	4.2%	12.5%	25.0%	100.0%
PAT0148	03/04/03	78.3%	4.3%	4.3%	8.7%	4.3%	100.0%
PAT0176	03/04/03	45.8%	8.3%	12.5%	8.3%	25.0%	100.0%
PAT0222	03/04/03	29.2%	45.8%	12.5%	4.2%	8.3%	100.0%
PAT0285	03/04/03	45.8%	37.5%	12.5%	4.2%	0.0%	100.0%
PAT0347	03/04/03	29.2%	45.8%	0.0%	0.0%	25.0%	100.0%
PAT0148	04/22/03	13.0%	60.9%	4.3%	8.7%	13.0%	100.0%
PAT0176	04/22/03	58.3%	29.2%	4.2%	8.3%	0.0%	100.0%
PAT0222	04/22/03	0.0%	54.2%	4.2%	0.0%	41.7%	100.0%
PAT0285	04/22/03	15.4%	53.8%	7.7%	7.7%	15.4%	100.0%
PAT0347	04/22/03	22.7%	4.5%	40.9%	4.5%	27.3%	100.0%
PAT0148	05/06/03	45.8%	0.0%	12.5%	0.0%	41.7%	100.0%
PAT0176	05/06/03	20.8%	45.8%	16.7%	4.2%	12.5%	100.0%
PAT0222	05/06/03	20.8%	62.5%	8.3%	0.0%	8.3%	100.0%
PAT0285	05/06/03	16.7%	54.2%	16.7%	0.0%	12.5%	100.0%
PAT0347	05/06/03	0.0%	25.0%	50.0%	4.2%	20.8%	100.0%
PAT0148	06/03/03	15.8%	42.1%	21.1%	0.0%	21.1%	100.0%
PAT0176	06/03/03	0.0%	33.3%	9.5%	4.8%	52.4%	100.0%
PAT0222	06/03/03	16.7%	37.5%	16.7%	4.2%	25.0%	100.0%
PAT0285	06/03/03	28.6%	21.4%	35.7%	7.1%	7.1%	100.0%
PAT0347	06/03/03	15.8%	21.1%	15.8%	10.5%	36.8%	100.0%
PAT0148	07/08/03	12.5%	29.2%	25.0%	0.0%	33.3%	100.0%
PAT0176	07/08/03	5.9%	17.6%	29.4%	5.9%	41.2%	100.0%
PAT0222	07/08/03	0.0%	13.0%	34.8%	8.7%	43.5%	100.0%
PAT0285	07/08/03	0.0%	20.8%	16.7%	4.2%	58.3%	100.0%
PAT0347	07/08/03	0.0%	25.0%	62.5%	4.2%	8.3%	100.0%
PAT0148	08/05/03	37.5%	8.3%	45.8%	0.0%	8.3%	100.0%
PAT0176	08/05/03	20.8%	4.2%	45.8%	4.2%	25.0%	100.0%
PAT0222	08/05/03	29.2%	8.3%	54.2%	0.0%	8.3%	100.0%
PAT0285	08/05/03	8.3%	0.0%	58.3%	4.2%	29.2%	100.0%
PAT0347	08/05/03	13.0%	0.0%	17.4%	0.0%	69.6%	100.0%
PAT0148	09/09/03	33.3%	4.8%	14.3%	14.3%	33.3%	100.0%

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

Predicted Source

Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
PAT0176	09/09/03	0.0%	42.9%	9.5%	0.0%	47.6%	100.0%
PAT0222	09/09/03	5.0%	5.0%	45.0%	0.0%	45.0%	100.0%
PAT0285	09/09/03	15.8%	5.3%	21.1%	0.0%	57.9%	100.0%
PAT0347	09/09/03	0.0%	0.0%	38.9%	0.0%	61.1%	100.0%
PAT0148	09/23/03	8.7%	8.7%	47.8%	8.7%	26.1%	100.0%
PAT0176	09/23/03	35.0%	25.0%	15.0%	0.0%	25.0%	100.0%
PAT0222	09/23/03	25.0%	29.2%	20.8%	4.2%	20.8%	100.0%
PAT0285	09/23/03	12.5%	16.7%	45.8%	0.0%	25.0%	100.0%
PAT0347	09/23/03	13.0%	21.7%	21.7%	13.0%	30.4%	100.0%
PAT0148	10/07/03	0.0%	33.3%	0.0%	0.0%	66.7%	100.0%
PAT0176	10/07/03	16.7%	44.4%	11.1%	5.6%	22.2%	100.0%
PAT0222	10/07/03	0.0%	11.1%	33.3%	11.1%	44.4%	100.0%
PAT0285	10/07/03	0.0%	0.0%	0.0%	0.0%	100.0%	100.0%
PAT0347	10/07/03	28.6%	7.1%	7.1%	14.3%	42.9%	100.0%
Total		22.7%	28.9%	19.6%	4.5%	24.3%	100.0%

Figure C-2: Patapsco River Watershed relative contributions by probable sources of *Enterococcus* contamination.



Patapsco River Summary

The use of ARA was successful for identification of probable bacterial sources in the Patapsco River Watershed. When water isolates were compared to the library and potential sources predicted, 76% of the isolates were classified as to category by statistical analysis. The highest RCC for the library was 80% (for both livestock and pet). The RCCs for human and wildlife sources were 73% and 39%, respectively.

The largest category of potential sources in the watershed as a whole was livestock (38% of classified water isolates), followed by human (30%), pet (26%), and wildlife (6%) (Fig. C-2).

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Adjustment of BST Results

As explained in the BST Summary for the Patapsco River watershed, 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 501, 58 isolates were known to be of livestock source but only 24 were classified by the analysis as being of livestock source. Of those 58, 2 were classified as human, 2 as pet, 2 as wildlife and 28 as unknown. Similarly, of the other three categories, 11 isolates known to be human, 6 isolates known to be pet, and 21 known wildlife isolates were classified as livestock, resulting in a total of 62 of all 501 isolates classified as livestock of which only 24 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 PAT0347 during annual high flow conditions:

Source Category	Original Percentage
Pets	22.06 %
Human	18.61 %
Livestock	27.56 %
Wildlife	7.48 %
Unknown	24.29 %

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	7	92	7.6 %
Human	58	71	81.7 %
Livestock	11	62	17.7 %
Wildlife	4	47	8.5 %
Unknown	13	229	5.7 %

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

= (7.6 x 22.06) + (81.7 x 18.61) + (17.7 x 27.56) + (8.5 x 7.48) + (5.7 x 24.29) = 23.79 %

Thus the correct human source percentage, the value used in the TMDL analysis, is 23.79% and not 18.61%. 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 PAT0347 the annual high flow condition corrected source percentages are as follows:

Source Category	**Adjusted Percentage**
Pets	18.8 %
Human	23.8 %
Livestock	15.0 %
Wildlife	42.5 %

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 MD 8-digit Patapsco River Lower North Branch 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 Patapsco River Lower North Branch 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 five monitoring stations of the Patapsco River Lower North Branch 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 analyzed by stratum will define the upper bound percentile to be used in estimating the maximum daily limits. In the case of the Patapsco River Lower North Branch watershed, a value measured during high-flow conditions at the PAT0222 station resulted in the highest percentile of both strata of the five stations. This value translates to the 99.97th 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	Flow Stratum	Maximum Observed *E. coli* Concentration (MPN/100ml)	Percentile (%)
PAT0347[1]	High	21,900	99.8
	Low	190	80.5
PAT0285	High	32,600	99.96
	Low	200	84.9
PAT0222	High	46,100	99.97
	Low	440	86.8
PAT0176	High	29,900	99.95
	Low	230	89.4
PAT0148	High	20,100	99.92
	Low	960	92.2

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

The 99.97th percentile value results in a maximum daily load that would not be exceeded 99.97% of the time, as, in a similar manner, a TMDL that represents the long term average condition would be expected to be exceeded half the time even after all required controls were implemented.

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

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

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

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

And from equation (14):

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

Therefore,

$$L_b*(1-R) = Q_H*C_H*F_{1H}*W_H*(1-R) + Q_L*C_L*F_{1L}*W_L*(1-R) \qquad \text{(D4)}$$

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:

$$C_{LTA\text{-}H} = C_{b\text{-}H}*(1-R_H) \qquad \text{(D5)}$$

$$C_{LTA\text{-}L} = C_{b\text{-}L}*(1-R_L) \qquad \text{(D6)}$$

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	Flow Stratum	LTA Geometric Mean *E. coli* Concentration (MPN/100ml)	LTA Arithmetic Mean* *E. coli* Concentration (MPN/100ml)
PAT0347[1]	High	129	569
	Low	50	132
PAT0285	High	128	491
	Low	39	136
PAT0222	High	171	638
	Low	77	259
PAT0176	High	128	503
	Low	42	107
PAT0148	High	89	259
	Low	48	155

*Only arithmetic parameters are used in the daily loads analysis.
[1]Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

The next step is to calculate the 99.97th 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 99.97th 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	Flow Stratum	Coefficient of Variation	MDL *E. coli* Concentration (MPN/100ml)
PAT0347[1]	High	4.29	48,983
	Low	2.46	6,182
PAT0285	High	3.70	36,554
	Low	3.32	9,050
PAT0222	High	3.60	46,100
	Low	3.20	16,473
PAT0176	High	3.81	38,507
	Low	2.33	4,645
PAT0148	High	2.74	13,771
	Low	3.08	9,455

[1] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

With the 99.97th percentiles of LTA TMDL bacteria concentrations estimated for both high flow and low flow as explained above, the maximum daily load for MS4 and non-point sources for each subwatershed can be now estimated as:

$$\begin{aligned} \textit{Daily TMDL (MPN/day)} &= Q_H*(99.97^{th}C_{LTA\text{-}H})*F_{1H}*W_H \\ &\quad + Q_L*(99.97^{th}C_{LTA\text{-}L})*F_{1L}*W_L \end{aligned} \qquad \text{(D7)}$$

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 Patapsco River Lower North Branch watershed, to estimate the maximum daily loads for WWTPs, the annual average loads are multiplied by the multiplication factor as follows:

$$WWTP\text{-}WLA\ MDL\ \text{(billion MPN/day)} = [WWTP\text{-}WLA\ \text{(billion MPN/year)}]*(3.11/365) \quad \text{(D8)}$$

The Maximum Daily Loads for the Patapsco River Lower North Branch subwatersheds, including those partially located in the MD 8-digit South Branch Patapsco River watershed, are presented in Table D-4 below.

Table D-4: Maximum Daily Loads Summary

Subwatershed	**Flow Stratum**	**Maximum Daily Load (Billion *E. coli* MPN/day)**	
		by Stratum	**Weighted by Stratum**
PAT0347[1]	High Low	331,703 9,092	96,842
PAT0285sub	High Low	66,503 3,576	20,692
PAT0222sub	High Low	56,950 4,419	18,708
PAT0176sub	High Low	39,313 1,030	11,443
PAT0148sub	High Low	41,658 6,211	15,852

[11] Subwatersheds partially located in MD 8-digit South Branch Patapsco River watershed

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 MD 8-digit Patapsco River Lower North Branch watershed are presented in Table D-5.

Table D-5: MD 8-Digit Patapsco River Lower North Branch Watershed Maximum Daily Loads

Subwatershed	Total Allocation	LA_{LNB}	$SW\text{-}WLA_{LNB}$	$WWTP\text{-}WLA_{LNB}$
	(Billion MPN *E. coli* /day)			
PAT0347[1]	10,025	7,953	2,071	1
PAT0285sub	20,692	15,133	5,559	0
PAT0222sub	18,708	11,783	6,925	0
PAT0176sub	11,443	7,805	3,638	0
PAT0148sub	15,852	8,711	7,121	20
Total	**76,720**	**51,384**	**25,315**	**21**

[1] MD 8-digit Patapsco River Lower North Branch portion of the subwatershed only.

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