Total Maximum Daily Loads of Fecal Bacteria for the Patuxent River Upper Basin in Anne Arundel and Prince George's Counties, Maryland

FINAL

DEPARTMENT OF THE ENVIRONMENT
1800 Washington Boulevard, Suite 540
Baltimore MD 21230-1718

Submitted to:

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

September 2010

EPA Submittal Date: September 28, 2010
EPA Approval Date: August 9, 2011

Table of Contents

List of Figures ii
List of Tables iii
List of Abbreviations v
EXECUTIVE SUMMARY vi
1.0 INTRODUCTION 1
2.0 SETTING AND WATER QUALITY DESCRIPTION 3
  2.1 General Setting 3
  2.2 Water Quality Characterization 9
  2.3 Water Quality Impairment 12
  2.4 Source Assessment 13
3.0 TARGETED WATER QUALITY GOAL 18
4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION 19
  4.1 Overview 19
  4.2 Analytical Framework 20
  4.3 Estimating Baseline Loads 21
  4.4 Bacteria Source Tracking 27
  4.5 Critical Condition and Seasonality 29
  4.6 Margin of Safety 30
  4.7 Scenario Descriptions 31
  4.8 TMDL Loading Caps 34
  4.9 TMDL Allocations 37
  4.10 Summary 41
5.0 ASSURANCE OF IMPLEMENTATION 44
REFERENCES 46
Appendix A – Bacteria Data A1
Appendix B - Flow Duration Curve Analysis to Define Strata B1
Appendix C – BST Report C1
Appendix D – Estimating Maximum Daily Loads D1

List of Figures

Figure 2.1.1: Location Map of the Patuxent River Upper Watershed 4
Figure 2.1.2: Land Use of the Patuxent River Upper Watershed 6
Figure 2.1.3: Population Density in the Patuxent River Upper Watershed 8
Figure 2.2.1: Monitoring Stations and Subwatersheds in the Patuxent River Upper Watershed 11
Figure 2.4.1: Sanitary Sewer Service Areas and Septic Locations in the Patuxent River Upper Watershed 15
Figure 2.4.2: Patuxent River Upper Watershed Relative Contributions by Probable Sources of Fecal Bacteria Contamination.. 18
Figure 4.2.1: Diagram of the Non-tidal Bacteria TMDL Analysis Framework 21
Figure 4.3.1: Conceptual Diagram of Flow Duration Zones 22
Figure A-1: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0561 .... A4
Figure A-2: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0613 .... A4
Figure A-3: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0630 .... A5
Figure B-1: Flow Duration Curve for Patuxent River Upper Watershed USGS Sites B2
Figure B-2: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0561 (Annual Condition) B4
Figure B-3: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0561 (Seasonal Condition) B4
Figure B-4: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0613 (Annual Condition) B5
Figure B-5: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0613 (Seasonal Condition) B5
Figure B-6: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0630 (Annual Condition) B6
Figure B-7: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0630 (Seasonal Condition) B6
Figure C-1: Relative contributions by probable sources of *Enterococcus* contamination..........C11

List of Tables

Table 2.1.1: Land Use Percentage Distribution for the Patuxent River Upper Watershed 5

Table 2.1.2: Land Use Percentage Distribution for the Patuxent River Upper Watershed by Subwatershed 5

Table 2.1.3: Total Population per Subwatershed in the Patuxent River Upper Watershed 7

Table 2.2.1: Historical Monitoring Data in the MD 8-digit Patuxent River Upper Watershed..... 9

Table 2.2.2: Location of DNR Core Stations in the MD 8-digit Patuxent River Upper Watershed 10

Table 2.2.3: Location of MDE Monitoring Stations in the MD 8-digit Patuxent River Upper Watershed 10

Table 2.2.4: Location of USGS Gauging Stations in the MD 8-digit Patuxent River Upper Watershed 10

Table 2.3.1: Bacteria Criteria Values 12

Table 2.3.2: Patuxent River Upper Watershed Dry Weather Steady-State Geometric Means.... 13

Table 2.4.1: Septic Systems Per Subwatershed in the Patuxent River Upper Watershed 14

Table 4.3.1: Weighting Factors for Average Hydrology Year Used for Estimation of Geometric Means in the Patuxent River Upper Watershed 23

Table 4.3.2: Patuxent River Upper Watershed Annual Weighted Geometric Means 24

Table 4.3.3: Patuxent River Upper Watershed Seasonal (May 1 - September 30) Dry Weather Period Steady-State Geometric Means 24

Table 4.3.4: Subdivided Watersheds in the Patuxent River Upper Watershed 26

Table 4.3.5: Baseline Loads Calculations 27

Table 4.3.6: Baseline Loads Summary 27

Table 4.4.1: Distribution of Fecal Bacteria Source Loads in the Patuxent River Upper Watershed for the Average Annual Period 29

Table 4.4.2: Distribution of Fecal Bacteria Source Loads in the Patuxent River Upper Watershed for the Seasonal (May 1 – September 30) Dry Weather Period 29

Table 4.5.1: Required Fecal Bacteria Reductions (by Condition) to Meet Water Quality Standards 30

Table 4.7.1: Bacteria Source Distributions and Corresponding Baseline Loads Used in the Annual Average TMDL Analysis 31

Table 4.7.2: Maximum Practicable Reduction Targets 32

Table 4.7.3: Practicable Reduction Scenario Results 34

Table 4.8.1: Annual Average TMDL Loading Caps 35

Table 4.8.2: Annual Average TMDL Loading Caps by Source Category 36

Table 4.8.3: Patuxent River Upper Watershed Maximum Daily Loads Summary 37

Table 4.9.1: Potential Source Contributions for TMDL Allocation Categories in the Listed MD 8-digit Patuxent River Upper Watershed ... 39

Table 4.9.2: Stormwater Baseline Loads in the Listed MD 8-digit Patuxent River Upper Watershed ... 40

Table 4.9.3: Annual Average Stormwater Allocations ... 41

Table 4.10.1: Patuxent River Upper Watershed Annual Average TMDL ... 41

Table 4.10.2: Patuxent River Upper Watershed Maximum Daily Loads ... 42

Table 4.10.3: Annual Average TMDL Summary for the Listed MD 8-Digit Patuxent River Upper Watershed ... 42

Table 4.10.4: MDL Summary for the Listed MD 8-Digit Patuxent River Upper Watershed ... 43

Table A-1: Measured Bacteria Concentration with Daily Flow Frequency ... A1

Table B-1: USGS Sites in the Patuxent River Upper Watershed ... B1

Table B-2: Definition of Flow Regimes ... B2

Table B-3: Weighting Factors for Estimation of Geometric Mean ... B3

Table C-1: Antibiotics and concentrations used for ARA. ... C5

Table C-2: Source category, total isolates, and number of unique patterns. ... C7

Table C-3: Actual versus predicted sources, with rates of correct classification (RCC) (% correct) for each source and ARCC for the library. ... C7

Table C-4: Predicted host source distribution of water isolates, based on posterior probability averaging. ... C8

Table C-5: Enterococcus isolates obtained from water collected during the spring, summer, fall, and winter seasons at the Upper Patuxent River Watershed monitoring stations. ... C8

Table C-6: Predicted source count distribution by station and date. ... C8

Table C-7: Predicted source percent distribution by station and date. ... C9

Table D-1: Percentiles of Maximum Observed Bacteria Concentrations ... D4

Table D-2: Long-term Annual Average (LTA) TMDL Bacteria Concentrations ... D5

Table D-3: Maximum Daily Load (MDL) Concentrations ... D6

Table D-4: Maximum Daily Loads Summary ... D7

Table D-5: Patuxent River Upper Watershed Maximum Daily Loads ... D7

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 for the portion of the Patuxent River Upper watershed (MD basin number 02-13-11-04) from Queen Anne Bridge Road to the confluence with the Little Patuxent River. 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 Patuxent River Upper 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), fecal bacteria (2008), and impacts to biological communities (listed in 2002, 2004 and 2006). Cash Lake, an impoundment in the Patuxent River Upper watershed, was listed in 2004 for methylmercury in fish tissue. The waters of the MD 8-digit Patuxent River Upper 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).

This document proposes to establish a TMDL for fecal bacteria in the Patuxent River Upper watershed, from Queen Anne Bridge Road to the confluence with Little Patuxent River, that will allow for attainment of the beneficial use designation of water contact recreation. The listings for sediment, impacts to biological communities, and methylmercury will be addressed in separate TMDL documents. The listing for phosphorus was addressed with a Water Quality Analysis in 2007. MDE monitored the Patuxent River Upper watershed from 2008-2009 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 Patuxent River Upper watershed has been divided into three subwatersheds. For convenience, each subwatershed will be referenced by the downstream bacteria monitoring station's name and location. The subwatersheds are PXT0561 (Patuxent River at Queen Anne Bridge Rd.), PXT0613 (Patuxent River at Governor Bridge Rd.), and PXT0630 (Patuxent River at Rt. 3). The pollutant loads set forth in this document are for these three 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 three representative stations in the Patuxent River Upper 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 listed portion of the Patuxent River Upper 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, if necessary, 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 all three of the subwatersheds, it was estimated that water quality standards could be attained within MPRs.

To account for contributions from areas upstream of the listed portion (including the unlisted upstream portion of the Patuxent River Upper watershed and the MD 8-digit watersheds of Little Patuxent River, Middle Patuxent River, Rocky Gorge Dam, and Brighton Dam), an upstream load allocation (LA_{US}), determined to be necessary in order to meet water quality standards in the listed portion (LP) of the MD 8-digit Patuxent River Upper watershed, is also included in this TMDL. The baseline loads are summarized in the following table:

MD 8-Digit Patuxent River Upper Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)

Total Baseline Load	=	**Upstream Baseline Load**[1]	+	**Baseline Load Contribution from Listed Portion of MD 8-digit Patuxent River Upper**				
		BL_{US}		**Nonpoint Source BL_{LP}**	+	**NPDES Stormwater BL_{LP}**	+	**WWTP BL_{LP}**
12,040,565	=	11,261,074	+	617,658	+	161,833	+	0

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

The TMDL contribution from the listed portion of the MD 8-digit Patuxent River Upper watershed, representing the sum of individual TMDLs for the three subwatersheds or portions thereof within the listed portion, is distributed between a load allocation (LA_{LP}) for nonpoint sources and waste load allocations (WLA_{LP}) 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 TMDL of fecal bacteria is presented in the following table:

Fecal Bacteria TMDL for the Listed MD 8-Digit Patuxent River Upper Watershed (Billion MPN *E. coli*/year)

TMDL	=	LA			+	WLA			+	MOS
		LA_{US}[1]	+	**LA_{LP}**		**SW WLA_{LP}**	+	**WWTP WLA_{LP}**		
6,033,746	=	5,621,888	+	320,742	+	91,116	+	0	+	Incorporated

Upstream Load Allocation

TMDL Contribution from Listed Portion of MD 8-Digit Patuxent River Upper Watershed (411,858)

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

The LA_{US} accounts for contributions from upstream of the listed portion of the MD 8-digit Patuxent River Upper watershed and is determined to be necessary in order to meet water quality standards in this listed portion. The LA_{US} represents a reduction of approximately 50.1% from the baseline load of 11,261,074 billion MPN *E. coli*/year. The TMDL contribution from the listed portion of the MD 8-digit Patuxent River Upper watershed (411,858 billion MPN *E. coli*/year) represents a reduction of approximately 47.2% from the baseline load contribution of 779,491 billion MPN *E. coli*/year. The overall average reduction is 49.9%.

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:

Fecal Bacteria MDL for the Listed MD 8-Digit Patuxent River Upper Watershed (Billion MPN *E. coli*/day)

MDL	=	LA			+	WLA			+	MOS
		LA_{US}	+	**LA_{LP}**		**SW WLA_{LP}**	+	**WWTP WLA_{LP}**		
66,353	=	61,567	+	3,744	+	1,042	+	0	+	Incorporated

Upstream MDL

MDL Contribution from Listed Portion of MD 8-Digit Patuxent River Upper Watershed (4,786)

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.

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 for the portion of the Patuxent River Upper watershed (MD basin number 02-13-11-04) from Queen Anne Bridge Road to the confluence with Little Patuxent River. 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 Patuxent River Upper 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), fecal bacteria (2008), and impacts to biological communities (listed in 2002, 2004 and 2006). Cash Lake, an impoundment in the Patuxent River Upper watershed, was listed in 2004 for methylmercury in fish tissue. The waters of the MD 8-digit Patuxent River Upper 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).

This document proposes to establish a TMDL for fecal bacteria in the Patuxent River Upper watershed, from Queen Anne Bridge Road to the confluence with the Little Patuxent River, that will allow for attainment of the beneficial use designation of water contact recreation. The listings for sediment, impacts to biological communities, and methylmercury will be addressed in separate TMDL documents. The listing for phosphorus was addressed with a Water Quality Analysis in 2007. MDE monitored the Patuxent River Upper watershed from 2008-2009 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 upstream of the listed portion (including the upstream portion of the Patuxent River Upper watershed and the MD 8-digit watersheds of Little Patuxent River, Middle Patuxent River, Rocky Gorge Dam, and Brighton Dam), an upstream load allocation (LA_U), determined to be necessary in order to meet water quality standards in the listed portion of the MD 8-digit Patuxent River Upper 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 Patuxent River Upper TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The listed portion of the MD 8-digit Patuxent River Upper watershed begins at the confluence with Little Patuxent River and ends at the crossing of Queen Anne Bridge Road. The watershed is located in the Patuxent River region of the Chesapeake Bay watershed within Maryland. The watershed covers portions of Anne Arundel and Prince George’s Counties (see Figure 2.1.1). It also includes portions of the towns of Bowie, Davidsonville, and Mitchellville. The listed watershed area covers 28.7 square miles (18,362 acres), with an additional 342.1 square miles (218,951 acres) draining from upstream areas.

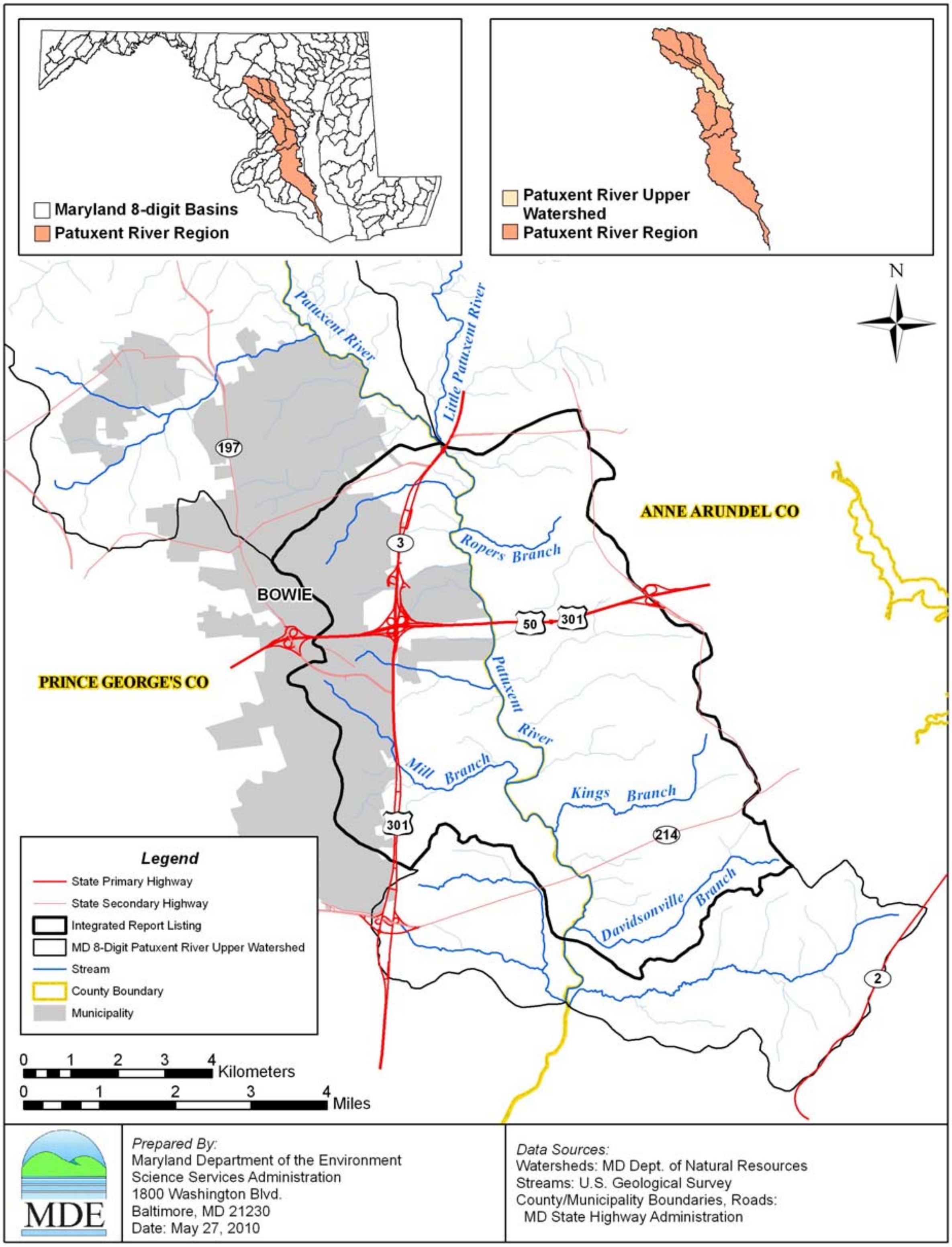


Figure 2.1.1: Location Map of the Patuxent River Upper Watershed

Land Use

Based on the 2002 Maryland Department of Planning (MDP) land use/land cover data, the Patuxent River Upper watershed can be characterized as primarily forest and urban land with significant agricultural use. Within the listed watershed, urban land is predominant in the eastern portion, with agricultural land in the west, and forest mainly along the Patuxent River.

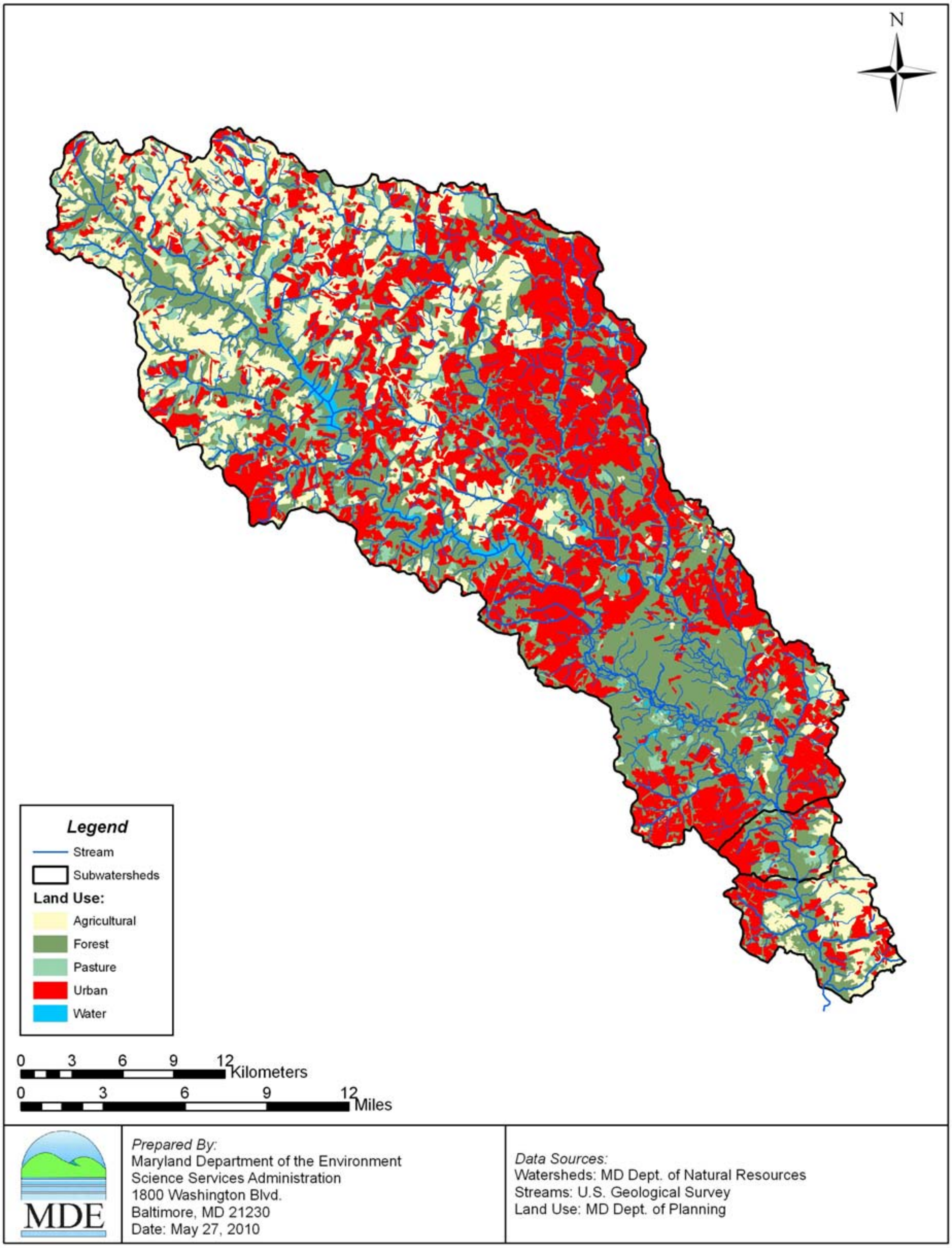
The land use acreage and percentage distribution is shown in Table 2.1.1, and spatial distributions for each land use are shown in Figure 2.1.2. Table 2.1.2 shows the land use percentage distribution for each of the two subwatersheds considered in the analysis as well as the upstream subwatershed. Note 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 Patuxent River Upper Watershed

Land Type	Listed Area		Upstream Area		*Total*	
	Acres	%	Acres	%	Acres	%
Urban	5,473	29.8	82,383	37.6	87,856	37.0
Forest	7,100	38.7	79,014	36.1	86,114	36.3
Agricultural	4,694	25.6	43,393	19.8	48,086	20.3
Pasture	1,053	5.7	11,605	5.3	12,658	5.3
Water	42	0.2	2,537	1.2	2,580	1.1
Total	**18,362**	**100**	**218,933**	**100**	**237,294**	**100**

Table 2.1.2: Land Use Percentage Distribution for the Patuxent River Upper Watershed by Subwatershed

Station / Subwatershed	Land Use Area (%)				
	Urban	Forest	Agricultural	Pasture	Water
PXT0630 Patuxent River at Rt. 3	37.6	36.1	19.8	5.3	1.2
PXT0613 / Pax. R. at Governor Bridge Rd.	33.3	47.9	8.5	9.9	0.3
PXT0561 / Pax. R. at Queen Anne Bridge Rd.	28.1	34.2	33.8	3.7	0.2



Prepared By:
Maryland Department of the Environment
Science Services Administration
1800 Washington Blvd.
Baltimore, MD 21230
Date: May 27, 2010

Data Sources:
Watersheds: MD Dept. of Natural Resources
Streams: U.S. Geological Survey
Land Use: MD Dept. of Planning

Figure 2.1.2: Land Use of the Patuxent River Upper Watershed

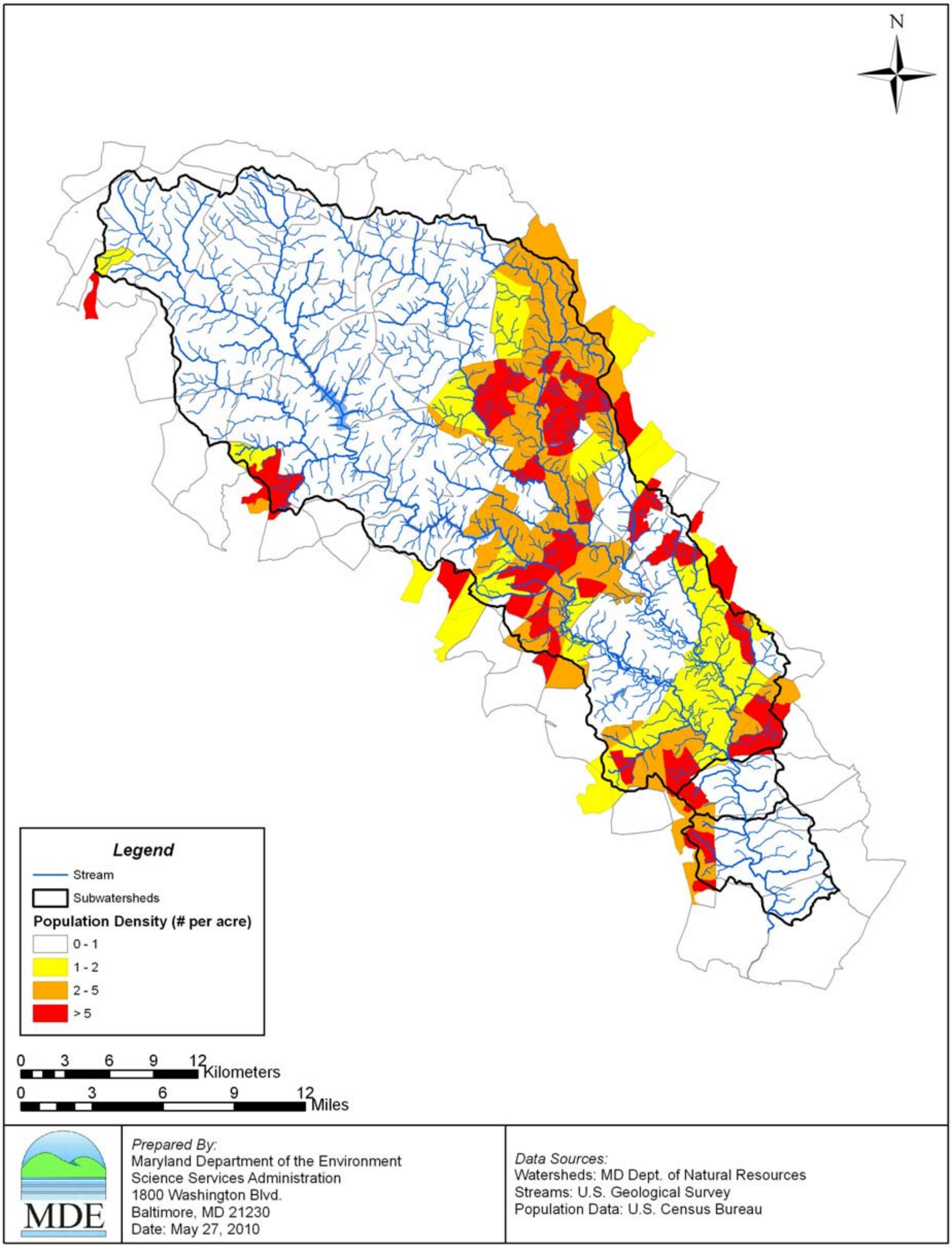
Population

The total population in the listed portion of the Patuxent River Upper watershed is estimated to be 20,587. 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 Patuxent River Upper Watershed

Station / Subwatershed	Population
PXT0630 / Patuxent River at Rt. 3	343,443
PXT0613 / Pax. R. at Governor Bridge Rd.*	7,516
PXT0561 / Pax. R. at Queen Anne Bridge Rd.*	13,071
Total	**364,030**

*These two subwatersheds comprise the listed portion of the Patuxent River Upper watershed.



Prepared By:
Maryland Department of the Environment
Science Services Administration
1800 Washington Blvd.
Baltimore, MD 21230
Date: May 27, 2010

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 Patuxent River Upper 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 Patuxent River Upper watershed. MDE conducted monitoring sampling at three stations in the Patuxent River Upper watershed from October 2008 through October 2009. Two United States Geological Survey (USGS) gage stations were used in deriving the surface water flow. The locations of these stations are shown in Tables 2.2.2 to 2.2.4 and in Figure 2.2.1. Observations recorded from the three 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 three stations ranged between 10 and 19,860 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the MD 8-digit Patuxent River Upper Watershed

Organization	Date	Design	Summary
DNR	01/1986 through 04/1998	Fecal Coliform*	1 station 1 sample per month
MDE	10/2008 through 10/2009	*E. coli*	3 stations 2 samples per month
MDE	10/2008 through 10/2009	BST (*Enterococcus)*	3 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 Patuxent River Upper Watershed

Station	Tributary	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
TF1.0	Patuxent River	38.956	-76.694

Table 2.2.3: Location of MDE Monitoring Stations in the MD 8-digit Patuxent River Upper Watershed

Tributary	Station	Observation Period	Total Observations	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
Patuxent River	PAT0630	2008 – 2009	25	38.989	-76.705
Patuxent River	PAT0613	2008 – 2009	25	38.952	-76.694
Patuxent River	PAT0561	2008 – 2009	25	38.895	-76.676

Table 2.2.4: Location of USGS Gauging Stations in the MD 8-digit Patuxent River Upper Watershed

Site Number	Observation Period Used	Total Observations	Latitude	Longitude
01592500	1984-2009	9,131	39.116	-76.874
01594440	1984-2009	9,131	38.956	-76.694

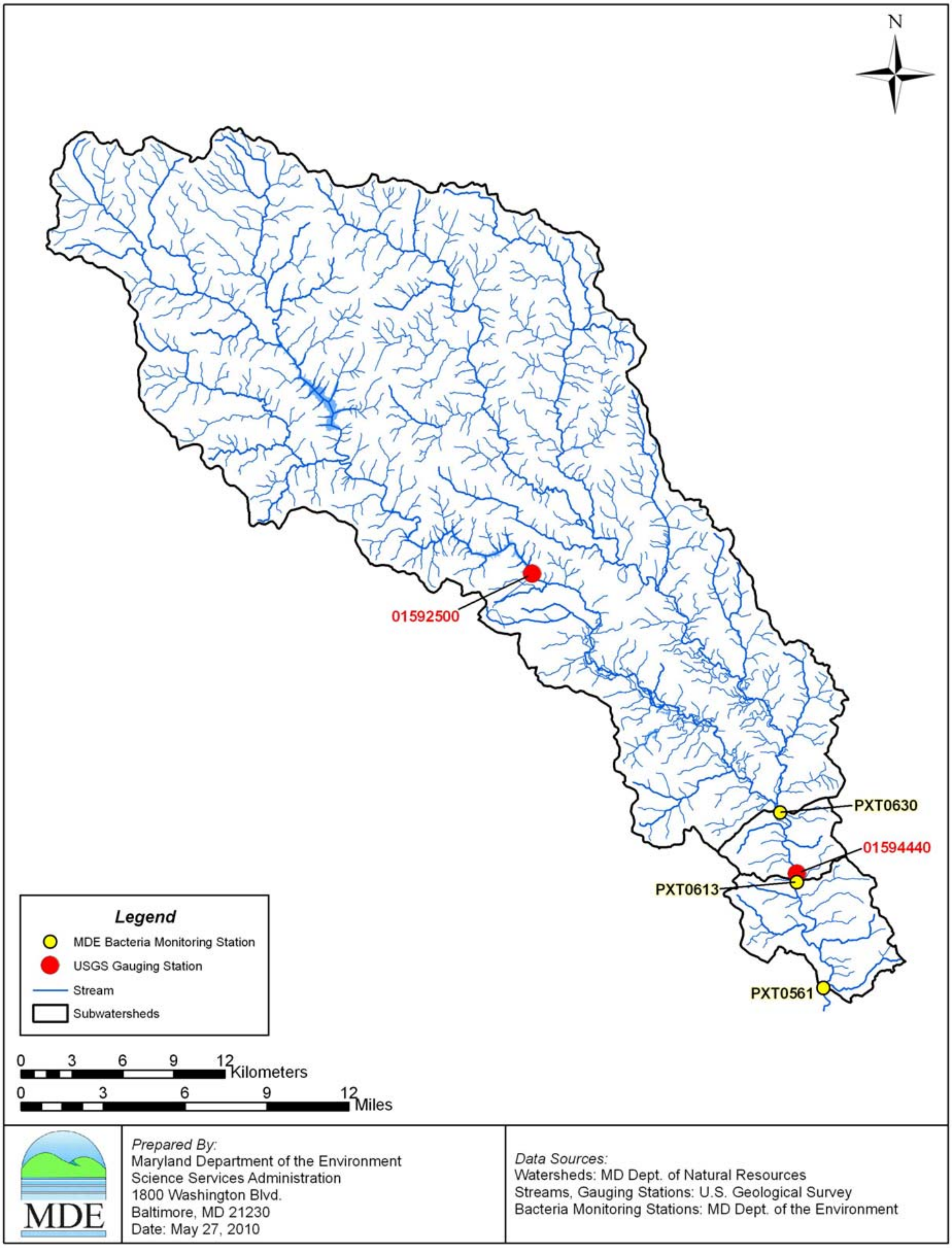


Figure 2.2.1: Monitoring Stations and Subwatersheds in the Patuxent River Upper Watershed

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 Patuxent River Upper watershed is Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life). See COMAR 26.08.02.07F(5). The MD 8-digit Patuxent River Upper 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. This impairment listing is limited to the portion of the Patuxent River Upper watershed from Queen Anne Bridge Road to the confluence with Little Patuxent River

Water Quality Criteria

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

Table 2.3.1: Bacteria Criteria Values
(Source: COMAR 26.08.02.03-3 Water Quality Criteria Specific to Designated Uses; Table 1)

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

Water Quality Assessment

Interpretation of Bacteria Data for General Recreational Use

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

A steady-state geometric mean will be calculated with available data from the previous two (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 listed MD 8-digit Patuxent River Upper watershed was assessed as explained above, by comparing the dry weather steady-state geometric means of *E. coli* concentrations for each subwatershed of the Patuxent River Upper with the water quality criterion. The 1986 EPA criteria guidance document assumed steady-state conditions in determining the risk at various bacterial concentrations, and therefore the chosen criterion value of 126 cfu/100 ml *E. coli* also reflects steady-state conditions (EPA 1986).

The dry weather steady-state geometric means are calculated using samples taken during non-rainy days and from May 1st to September 30th, capturing the beach season. Results of these calculations are presented in Table 2.3.2. As shown in the table below, all three of subwatersheds of the Patuxent River Upper watershed 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: Patuxent River Upper 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)
PXT0630 Patuxent River at Rt. 3	5	159	126
PXT0613 Pax. R. at Governor Bridge Rd.	5	193	126
PXT0561 Pax. R. at Queen Anne Bridge Rd.	5	160	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

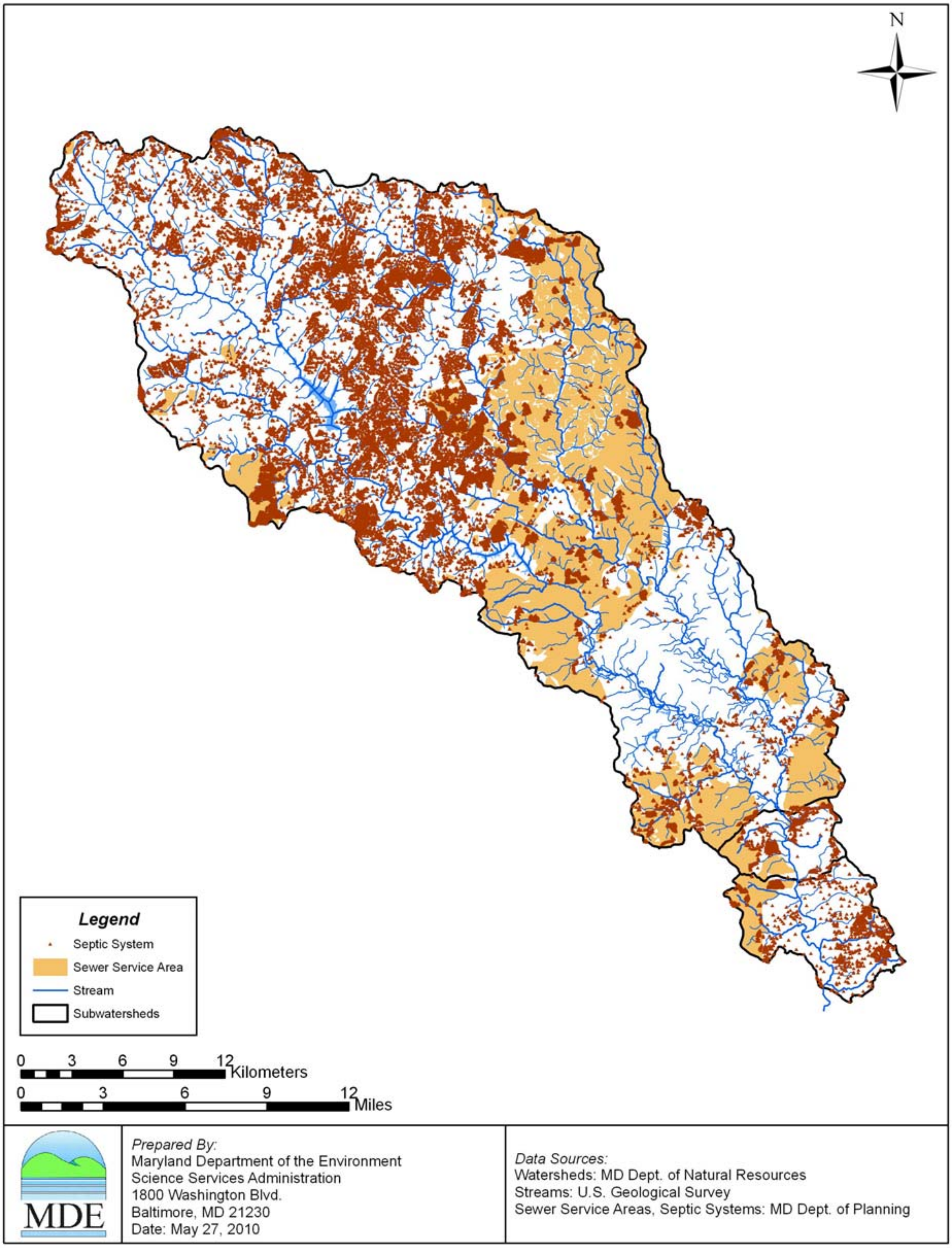
The MD 8-digit Patuxent River Upper watershed is serviced by both sewer systems and septic systems. Within the listed portion of the watershed, sewer systems are present in the area of Bowie. Wastewater from most of these areas is collected either by the Bowie WWTP, and treated and discharged into the Patuxent River upstream of the listed watershed, or by the Western Branch WWTP, where it is treated and discharged into Western Branch in the Western Branch watershed.

Septic Systems

On-site disposal (septic) systems are located throughout the Patuxent River Upper watershed. Table 2.4.1 presents the number of septic systems per subwatershed. 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 Patuxent River Upper Watershed

Station / Subwatershed	**Septic Systems**
PXT0630 Patuxent River at Rt. 3	27,126
PXT0613 Pax. R. at Governor Bridge Rd.	556
PXT0561 Pax. R. at Queen Anne Bridge Rd.	1,825
Total	**29,507**



Prepared By:
Maryland Department of the Environment
Science Services Administration
1800 Washington Blvd.
Baltimore, MD 21230
Date: May 27, 2010

Data Sources:
Watersheds: MD Dept. of Natural Resources
Streams: U.S. Geological Survey
Sewer Service Areas, Septic Systems: MD Dept. of Planning

Figure 2.4.1: Sanitary Sewer Service Areas and Septic Locations in the Patuxent River Upper Watershed

Point Source Assessment

There are two broad types of National Pollutant Discharge Elimination System (NPDES) permits considered in this analysis; process water and stormwater. The process water category includes those loads generated by discharge sources whose permits have bacteria limits. The stormwater category includes all NPDES regulated stormwater discharges. Both categories include individual and general permits. In terms of process water, individual permits are issued for both industrial and municipal WWTPs, and for stormwater, individual permits are issued for Phase I municipal separate storm sewer systems (MS4s). General process water permits have been established for surface water discharges from: surface coal mines; mineral mines; quarries; borrow pits; ready-mix concrete; asphalt plants; seafood processors; hydrostatic testing of tanks and pipelines; marinas; and concentrated animal feeding operations. General stormwater permits include Phase II (small municipal, state, and federal) MS4s and stormwater discharges associated with industrial activity. Also, stormwater management is included in the permit requirements for some of the individual and general process water permits.

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 listed portion of the Patuxent River Upper watershed is located in Anne Arundel and Prince George's Counties, both of which are Phase I NPDES MS4 permitted jurisdictions (NPDES permit # MD0068306 and MD0068284, respectively). 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 no SSOs reported to MDE between October 2008 and October 2009 in the listed portion of the Patuxent River Upper 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 no municipal or industrial facilities with NPDES permits regulating the discharge of fecal bacteria in the listed portion of the Patuxent River Upper 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 three stations in the Patuxent River Upper 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 Patuxent River Upper watershed. Details of the BST methodology and data can be found in Appendix C.

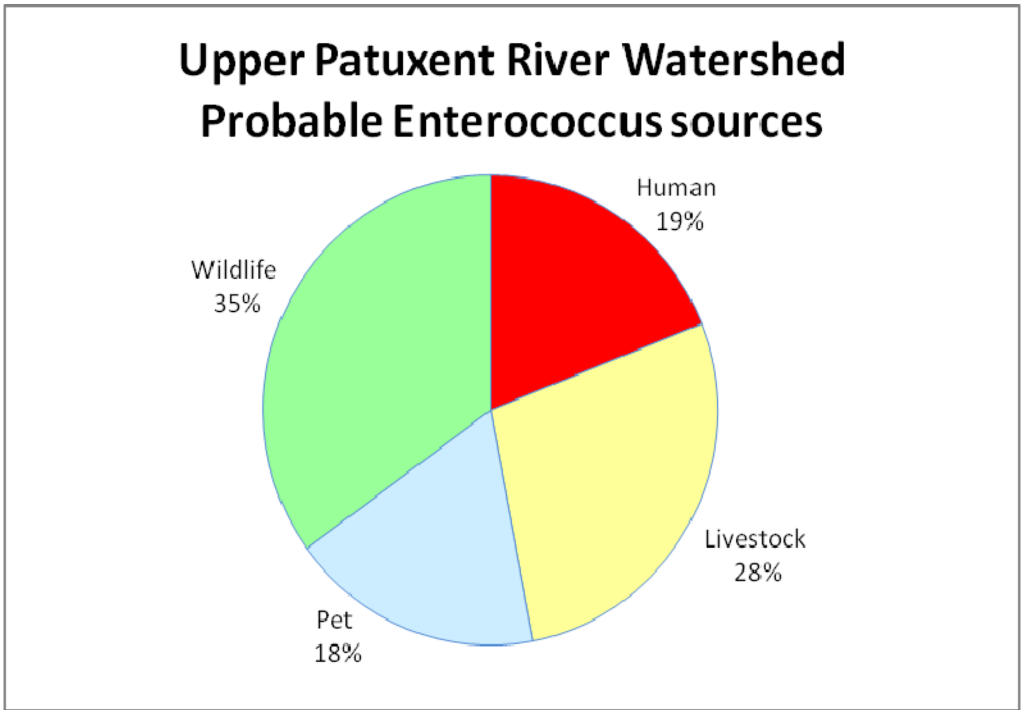


Figure 2.4.2: Patuxent River Upper Watershed Relative Contributions by Probable Sources of Fecal Bacteria Contamination

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 listed portion of the MD 8-digit Patuxent River Upper 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 Patuxent River Upper. 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.

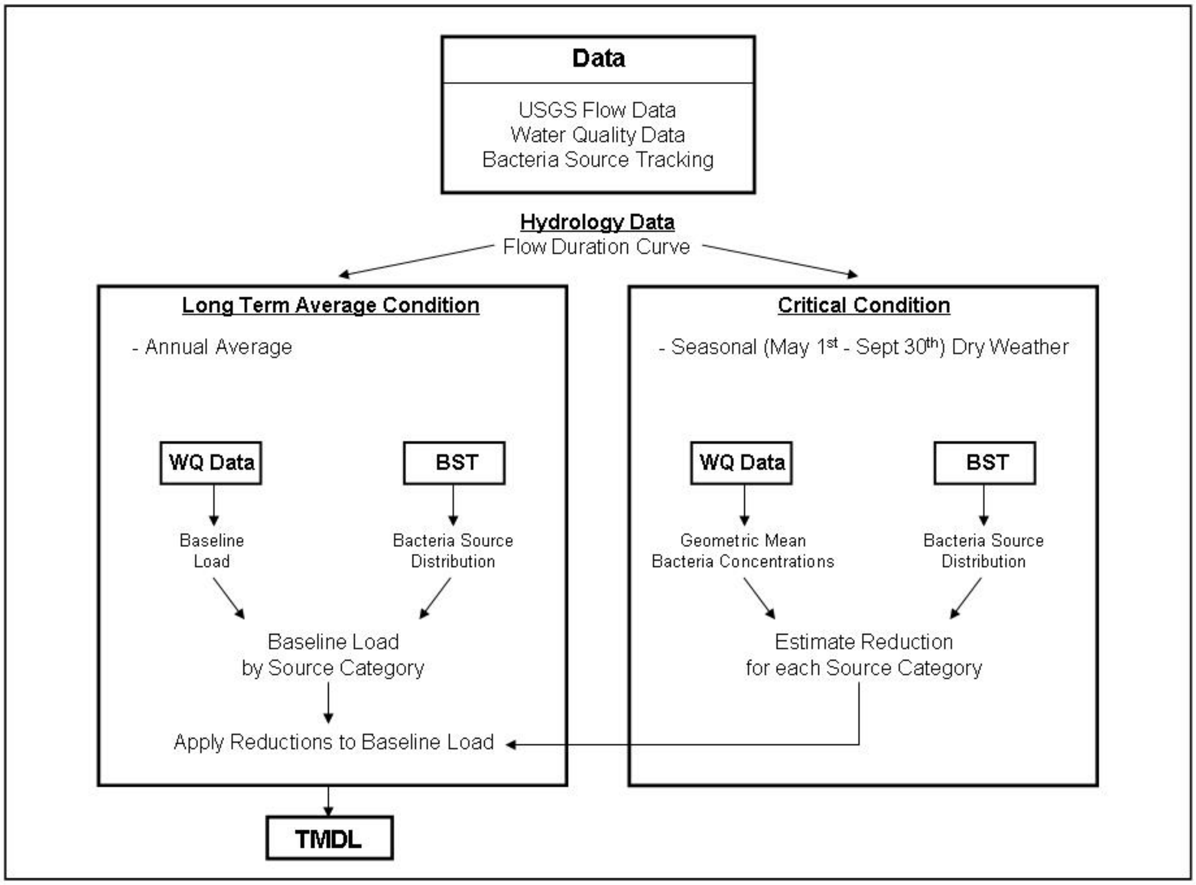


Figure 4.2.1: Diagram of the Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads are estimated for all subwatersheds of the Patuxent River Upper watershed, including, for computational purposes, the areas upstream of the listed portion of the 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 Patuxent River Upper watershed. To estimate the weighted geometric mean, the monitoring data were first reviewed by plotting the sample results versus their corresponding daily flow duration percentile.

To calculate the weighted geometric mean with routine monitoring data, a conceptual model was developed by dividing the daily flow frequency for the stream segment into strata that are representative of hydrologic conditions. A conceptual continuum of flows is illustrated in Figure 4.3.1.

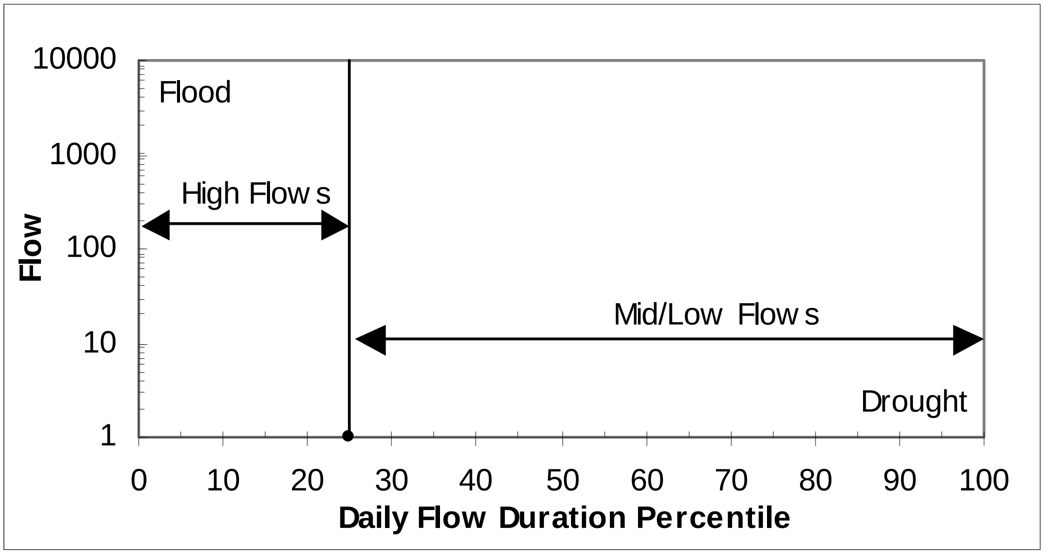


Figure 4.3.1: Conceptual Diagram of Flow Duration Zones

During high flows, a significant portion of the total stream flow is from surface flow contributions. Low flow conditions represent periods with minimal rainfall and surface runoff. There is typically a transitional mid flow period between the high and low flow durations, representative of varying contributions of surface flow inputs that result from differing rainfall volumes and antecedent soil moisture conditions. Because the bacteria samples were taken during a routine monitoring design and not a stratified monitoring design, the division of the entire flow regime into strata enables the estimation of a less flow-biased geometric mean.

Based on flow data of USGS gages 01592500 and 01594440 it was determined that the long-term average daily flow corresponds to a daily flow duration of 27.6%. Hence, for this analysis flows greater than the 27.6 percentile flow represent high flows, and flows less than the 27.6 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 Patuxent River Upper watershed TMDL analysis are presented in Table 4.3.1.

Table 4.3.1: Weighting Factors for Average Hydrology Year Used for Estimation of Geometric Means in the Patuxent River Upper Watershed

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 27.6%	0.276
Mid/Low Flows	27.6 – 100%	0.724

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 high 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 Patuxent River Upper. 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: Patuxent River Upper 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)
PXT0630 Patuxent River at Rt. 3	**High**	5	840	19,860	2,521	240
	Low	20	10	880	98	
PXT0613 Pax. R. at Governor Bridge Rd.	**High**	5	660	17,330	2,395	229
	Low	20	10	720	94	
PXT0561 Pax. R. at Queen Anne Bridge Rd.	**High**	5	570	5,790	1,747	216
	Low	20	20	240	97	

* Used for estimating average annual baseline loads

Table 4.3.3: Patuxent River Upper 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)
PXT0630 Patuxent River at Rt. 3	5	110	190	159
PXT0613 Pax. R. at Governor Bridge Rd.	5	80	360	193
PXT0561 Pax. R. at Queen Anne Bridge Rd.	5	100	240	160

* Used for assessing seasonality and critical condition

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 Patuxent River Upper watershed, weighting factors of 0.276 for high flow and 0.724 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 Patuxent River Upper watershed two stations have upstream monitoring stations, as listed in Table 4.3.4. In these two cases the subwatershed is differentiated by adding the extension "sub" to the name of the downstream monitoring station. For example, PXT0561sub signifies only the area and load between stations PXT0561 and PXT0613 while PXT0561 refers to the cumulative area draining to that station. There are a total of three subwatersheds (two making up the listed portion of the MD 8-digit Patuxent River Upper watershed, and one covering the upstream areas) considered in this analysis, corresponding to the three monitoring stations.

Table 4.3.4: Subdivided Watersheds in the Patuxent River Upper Watershed

Subwatershed	Upstream Station(s)
PXT0613sub	PXT0630
PXT0561sub	PXT0613

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 PXT0613 is not considered in the estimation of the load from subwatershed PXT0561sub. Instead the bacteria concentration measured at station PXT0561 is assigned to that subwatershed.

This assumption is used due to a special scenario seen in the subwatershed of PXT0561sub. 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 located upstream of the listed area, 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)	
PXT0630[1]	342.1	818.6	2,521	187.1	98	11,261,074
PXT0613sub	9.3	28.4	2,395	6.8	94	378,765
PXT0561sub	19.4	58.8	1,747	14.1	97	400,726

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper watershed

The total baseline load for all subwatersheds or portions thereof located in the listed portion of the MD 8-digit Patuxent River Upper watershed is estimated as 779,491 billion MPN *E. coli*/year. The total baseline load for the areas upstream of this listed portion of the watershed is 11,261,074 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 Patuxent River Upper Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)								
Total Baseline Load	=	Upstream Baseline Load[1]	+	Baseline Load Contribution from Listed Portion of MD 8-digit Patuxent River Upper				
		BL_{US}		Nonpoint Source BL_{LP}	+	NPDES Stormwater BL_{LP}	+	WWTP BL_{LP}
12,040,565	=	11,261,074	+	617,658	+	161,833	+	0

[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 Patuxent River Upper 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 a weighted percentage (MS) of each source per flow strata (high/low). The weighting is based on the $\log_{10}$ bacteria concentration for the water sample.
3. The final weighted mean source percentage for each source category is based on the proportion of time in each flow duration zone.

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:

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

where,

$$MS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})} \qquad (8)$$

and where,

MS_k = weighted mean proportion of isolates of source k
$MS_{i,k}$ = weighted mean proportion of isolates for source k in stratum i
W_i = proportion covered by stratum i
i = stratum
j = sample
k = 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 Patuxent River Upper Watershed for the Average Annual Period

Station	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife
PXT0630	**High**	15.8	25.5	35.5	23.2
	Low	17.8	18.3	28.6	35.5
	Weighted	17.1	20.3	30.6	32.1
PXT0613	**High**	15.7	28.5	28.0	27.8
	Low	18.3	16.2	25.4	40.1
	Weighted	17.6	19.6	26.1	36.7
PXT0561	**High**	15.0	22.7	35.7	26.5
	Low	18.9	15.1	25.3	40.7
	Weighted	17.8	17.2	28.1	36.8

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

Station	% Domestic Animals	% Human	% Livestock	% Wildlife
PXT0630	16.5	13.8	24.0	45.7
PXT0613	17.4	15.3	17.8	49.5
PXT0561	14.5	14.5	30.5	40.5

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 Patuxent River Upper 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 no samples were taken during high 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 Patuxent River Upper watershed are shown in Table 4.5.1. For computational purposes, the calculations include the subwatershed located upstream of the listed portion of the MD 8-digit Patuxent River Upper watershed.

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

Station	Condition	Domestic Animals %	Human %	Livestock %	Wildlife %
PXT0630[1]	Annual	46.3	95.0	75.0	0.0
	Seasonal	22.6	95.0	32.9	0.0
	Maximum Source Reduction	**46.3**	**95.0**	**75.0**	**0.0**
PXT0613sub	Annual	54.2	95.0	75.0	0.0
	Seasonal	66.2	95.0	67.6	0.0
	Maximum Source Reduction	**66.2**	**95.0**	**75.0**	**0.0**
PXT0561sub	Annual	45.4	95.0	71.6	0.0
	Seasonal	14.3	95.0	30.2	0.0
	Maximum Source Reduction	**45.4**	**95.0**	**71.6**	**0.0**

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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 PXT0613sub, and PXT0561sub were based on the sources identified at stations PXT0613, and PXT0561 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)	
PXT0630[1]	17.1	1,922,243	20.3	2,283,588	30.6	3,440,506	32.1	3,614,737	11,261,074
PXT0613sub	17.6	66,696	19.6	74,295	26.1	98,796	36.7	138,978	378,765
PXT0561sub	17.8	71,497	17.2	69,063	28.1	112,764	36.8	147,402	400,726

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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:

$$\text{Risk Score} = \text{Min} \sum_{i=1}^{4} P_j * W_j \qquad (9)$$

where,

$$P_j = \frac{(1 - R_i) * Pb_j}{1 - TR} \qquad (10)$$

and,

$$TR = \frac{C - C_{cr}}{C} \qquad (11)$$

Therefore the risk score can be represented as:

$$Risk\ Score = Min \sum_{i=1}^{4} \left[\frac{(1 - R_j) * Pb_j}{(1 - \frac{C - Ccr}{C})} * W_j \right] \qquad (12)$$

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:

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

The constraints of this scenario were satisfied in all three of the subwatersheds. 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 %		
PXT0630[1]	46.3	95.0	75.0	0.0	50.1	50.1
PXT0613sub	66.2	95.0	75.0	0.0	49.9	49.9
PXT0561sub	45.4	95.0	71.6	0.0	44.6	44.6

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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, all of the three subwatersheds could meet water quality standards based on MPRs. Therefore a second scenario applying higher reductions is not needed.

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 three subwatersheds located upstream of their respective monitoring stations. One of these subwatersheds represents the entire area upstream of the listed portion of the MD 8-digit Patuxent River Upper watershed. A TMDL summary for the listed Patuxent River Upper watershed will include an upstream load allocation to indicate estimated loads necessary to meet water quality standards in the listed portion of the MD 8-digit Patuxent River Upper 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.

$$\text{TMDL Loading Cap} = L_b * (1 - R) \qquad (13)$$

where,

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

The annual average bacteria TMDL loading caps for the subwatersheds are shown in Tables 4.8.1 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**
PXT0630[1]	11,261,074	5,621,888	50.1
PXT0613sub	378,765	189,949	49.9
PXT0561sub	400,726	221,909	44.6
Total	**12,040,565**	**6,033,746**	**49.9**

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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)	
PXT0630[1]	18.4	1,032,846	2.0	114,179	15.3	860,126	64.3	3,614,737	5,621,888
PXT0613sub	11.9	22,557	2.0	3,715	13.0	24,699	73.2	138,978	189,949
PXT0561sub	17.6	39,036	1.6	3,453	14.4	32,018	66.4	147,402	221,909

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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 Patuxent River Upper 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 Patuxent River Upper subwatersheds are shown in Table 4.8.3.

Table 4.8.3: Patuxent River Upper Watershed Maximum Daily Loads Summary

Subwatershed	Flow Stratum	Maximum Daily Load (Billion *E. coli* MPN/day)	
		by Stratum	Weighted by Stratum
PXT0630[1]	High Low	220,005 1,168	61,567
PXT0613sub	High Low	8,665 60	2,435
PXT0561sub	High Low	8,335 70	2,351

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper watershed

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

4.9 TMDL Allocations

The Patuxent River Upper watershed fecal bacteria TMDL is composed of the following components:

$$TMDL = LA_{US} + WLA_{LP} + LA_{LP} + MOS \qquad (14)$$

where,

LA_{LP} = Load Allocation for listed portion of MD 8-digit Patuxent River Upper Watershed
WLA_{LP} = Waste Load Allocation for listed portion of MD 8-digit Patuxent River Upper Watershed
LA_{US} = Load Allocation for area upstream of listed portion
MOS = Margin of Safety

The TMDL allocation for the listed portion of the MD 8-digit Patuxent River Upper basin includes load allocations (LA_{LP}) for nonpoint sources and waste load allocations (WLA_{LP}) for point sources including WWTPs and NPDES-regulated stormwater discharges. The Stormwater (SW) WLA_{LP} 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_{LP} and to the SW-WLA_{LP} and WWTP-WLA_{LP} is provided in the subsections that follow.

In addition to these allocation categories for the listed portion of the MD 8-digit Patuxent River Upper watershed, the TMDL includes an upstream load allocation for the watershed area upstream of this listed portion (LA_{US}). The LA_{US} is presented as a "lump-sum" upstream load comprising all bacteria source categories. The LA_{US}, determined to be necessary in order to meet water quality standards in the listed MD 8-digit Patuxent River Upper 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_{LP} (those nonpoint sources or portions thereof not transported and discharged by stormwater systems) and the WLA_{LP} (point sources including WWTPs, and NPDES regulated stormwater discharges). Only the final LA_{LP} or WLA_{LP} is reported in this TMDL. Note that the assignment of an allowable human load to the LA_{LP} 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 Listed MD 8-digit Patuxent River Upper Watershed

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

* These allocations apply only to the listed portion of the MD 8-digit Patuxent River Upper watershed. The TMDL allocation scenario load attributed to the area upstream of this portion includes all four bacteria source categories in one single load.

LA_{LP}

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

WLA_{LP}

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_{LP} and the LA_{LP} 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_{LP} and LA_{LP} 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.

The listed portion of the Patuxent River Upper watershed is located in Anne Arundel and Prince George's Counties, both of which are Phase I NPDES MS4 permitted jurisdictions (NPDES permit #MD0068306 and MD0068284, respectively).. 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 listed portion of the MD 8-digit Patuxent River Upper watershed are presented by jurisdiction and subwatershed in Table 4.9.2. The corresponding SW-WLA$_{LP}$ 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 22% from Anne Arundel County and 53% from Prince George's County. Upon approval of the TMDL, "NPDES-regulated municipal stormwater and small construction storm water discharges effluent limits should be expressed as BMPs or other similar requirements, rather than as numeric effluent limits" (US EPA 2002a).

Table 4.9.2: Stormwater Baseline Loads in the Listed MD 8-digit Patuxent River Upper Watershed

Subwatershed[1]	**Anne Arundel County SW-BL$_{LP}$**	**Prince George's County SW-BL$_{LP}$**
	(Billion MPN E. coli/year)	
PXT0613sub	20,761	55,633
PXT0561sub	29,855	55,584

[1] Drainage to PXT0630 is entirely upstream of the listed portion of the MD 8-digit Patuxent River Upper watershed.

Table 4.9.3: Annual Average Stormwater Allocations

Subwatershed[1]	Anne Arundel County SW-WLA$_{LP}$	Prince George's County SW-WLA$_{LP}$
	(Billion MPN E. coli/year)	
PXT0613sub	13,393	20,838
PXT0561sub	25,890	30,995

[1] Drainage to PXT0630 is entirely upstream of the listed portion of the MD 8-digit Patuxent River Upper watershed.

Municipal and Industrial WWTPs

As explained in the source assessment section above, there are no NPDES permitted point source facilities with permits regulating the discharge of fecal bacteria in the listed portion of the MD 8-digit Patuxent River Upper watershed.

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.

Table 4.10.1: Patuxent River Upper Watershed Annual Average TMDL

Subwatershed	Total Allocation	LA$_{LP}$	SW-WLA$_{LP}$	WWTP-WLA$_{LP}$
	(Billion MPN *E. coli* /year)			
PXT0613sub	189,949	155,718	34,231	0
PXT0561sub	221,909	165,024	56,885	0
Listed MD 8-digit Patuxent River Upper Total	411,858	320,742	91,116	0
Upstream Load	5,621,888			
TMDL[1]	**6,033,746**			

[1] The MOS is incorporated.

Table 4.10.2: Patuxent River Upper Watershed Maximum Daily Loads

Subwatershed	**Total Allocation**	**LA_{LP}**	**$SW\text{-}WLA_{LP}$**	**$WWTP\text{-}WLA_{LP}$**
	(Billion MPN *E. coli* /day)			
PXT0613sub	2,435	1,996	439	0
PXT0561sub	2,351	1,748	603	0
Listed MD 8-digit Patuxent River Upper Total	4,786	3,744	1,042	0
Upstream Load	61,567			
***MDL*[1]**	**66,353**			

[1] The MOS is incorporated.

The long-term annual average fecal bacteria TMDL summary for the listed portion of the MD 8-digit Patuxent River Upper watershed is presented in Table 4.10.3. Note that the upstream load allocation (LA_{US}) is determined to be necessary in order to meet water quality standards in the listed portion.

Table 4.10.3: Annual Average TMDL Summary for the Listed MD 8-Digit Patuxent River Upper Watershed

(Billion MPN *E. coli*/year)										
TMDL	=	**LA**			+	**WLA**			+	**MOS**
		LA_{US}[1]	+	**LA_{LP}**		**SW WLA_{LP}**	+	**WWTP WLA_{LP}**		
6,033,746	=	5,621,888	+	320,742	+	91,116	+	0	+	Incorpo-rated

Upstream Load Allocation

TMDL Contribution from Listed Portion of MD 8-Digit Patuxent River Upper Watershed (411,858)

[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 listed portion of the MD 8-digit Patuxent River Upper watershed are summarized in Table 4.10.4.

Table 4.10.4: MDL Summary for the Listed MD 8-Digit Patuxent River Upper Watershed

(Billion MPN *E. coli*/day)										
MDL	=	**LA**			+	**WLA**			+	**MOS**
		LA_{US}	+	**LA_{LP}**		**SW WLA_{LP}**	+	**WWTP WLA_{LP}**		
66,353	=	61,567	+	3,744	+	1,042	+	0	+	Incorpo-rated

Upstream MDL

MDL Contribution from Listed Portion of MD 8-Digit Patuxent River Upper Watershed (4,786)

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 all of the three Patuxent River Upper subwatersheds, water quality standards can be achieved within the maximum practicable reduction rates specified in Table 4.7.3.

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 Patuxent River Upper watershed, the TMDL analysis indicates that, for all three subwatersheds, the reductions of fecal bacteria loads are within the MPR targets. These MPR targets were defined based on a literature review of best management practice (BMP) effectiveness and assuming a zero reduction for wildlife sources. The fecal bacteria load reductions required to meet water quality criteria may be achieved by implementing effluent limitations and cost-effective, reasonable BMPs to nonpoint sources. 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. 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 Patuxent River Upper watershed is managed under NPDES MS4 permits for Anne Arundel and Prince George’s Counties 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 Patuxent River Upper 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. In such cases, managing the overpopulation of wildlife may be an option for state and local stakeholders.

For the Patuxent River Upper watershed, reduction of wildlife sources was not necessary in the TMDL analysis. However, 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)
PXT0561	10/23/2008	89.5970	50
	11/06/2008	73.4779	170
	11/20/2008	69.7219	100
	12/04/2008	64.2247	90
	12/18/2008	15.1445	660
	01/08/2009	1.5878	570
	01/22/2009	67.8712	20
	02/05/2009	61.2681	90
	02/19/2009	59.4174	60
	03/05/2009	63.9400	20
	03/19/2009	65.5607	20
	04/02/2009	53.3509	100
	04/16/2009	2.7595	1530
	05/07/2009	1.5112	4880
	05/21/2009	57.7749	170
	06/04/2009	1.7959	5790
	06/25/2009	47.8428	240
	07/09/2009	76.2374	100
	07/23/2009	84.1218	120
	08/06/2009	80.8366	150
	08/20/2009	82.8077	170
	09/17/2009	79.6102	230
	09/24/2009	86.6732	150
	10/08/2009	90.3964	200
	10/22/2009	60.0635	210

Station	**Date**	**Daily flow frequency**	***E. coli* Concentration (MPN/100ml)**
PXT0613	10/23/2008	89.5970	20
	11/06/2008	73.4779	120
	11/20/2008	69.7219	120
	12/04/2008	64.2247	100
	12/18/2008	15.1445	660
	01/08/2009	1.5878	850
	01/22/2009	67.8712	30
	02/05/2009	61.2681	10
	02/19/2009	59.4174	110
	03/05/2009	63.9400	10
	03/19/2009	65.5607	20
	04/02/2009	53.3509	30
	04/16/2009	2.7595	1250
	05/07/2009	1.5112	6490
	05/21/2009	57.7749	80
	06/04/2009	1.7959	17330
	06/25/2009	47.8428	190
	07/09/2009	76.2374	150
	07/23/2009	84.1218	150
	08/06/2009	80.8366	230
	08/20/2009	82.8077	330
	09/17/2009	79.6102	720
	09/24/2009	86.6732	360
	10/08/2009	90.3964	210
	10/22/2009	60.0635	330

Station	**Date**	**Daily flow frequency**	***E. coli*** **Concentration (MPN/100ml)**
PXT0630	10/23/2008	89.5970	30
	11/06/2008	73.4779	150
	11/20/2008	69.7219	90
	12/04/2008	64.2247	40
	12/18/2008	15.1445	840
	01/08/2009	1.5878	1180
	01/22/2009	67.8712	30
	02/05/2009	61.2681	60
	02/19/2009	59.4174	110
	03/05/2009	63.9400	40
	03/19/2009	65.5607	10
	04/02/2009	53.3509	30
	04/16/2009	2.7595	1190
	05/07/2009	1.5112	4350
	05/21/2009	57.7749	110
	06/04/2009	1.7959	19860
	06/25/2009	47.8428	160
	07/09/2009	76.2374	160
	07/23/2009	84.1218	880
	08/06/2009	80.8366	120
	08/20/2009	82.8077	190
	09/17/2009	79.6102	490
	09/24/2009	86.6732	190
	10/08/2009	90.3964	150
	10/22/2009	60.0635	210

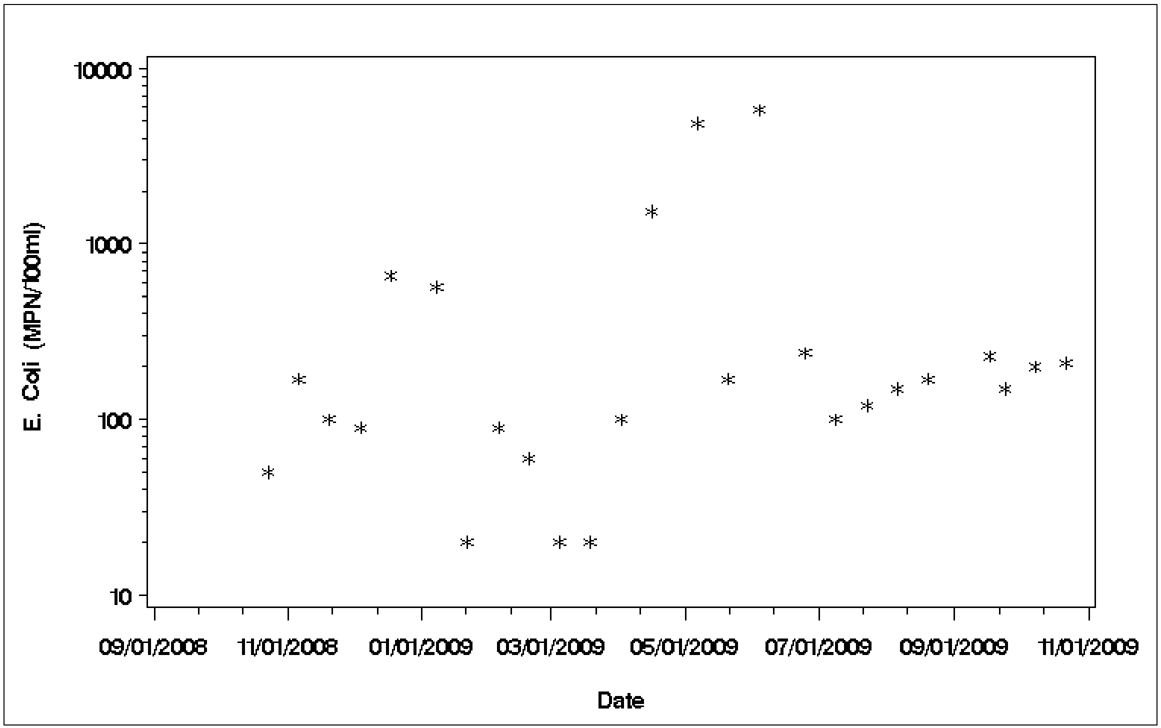

Figure A-1: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0561

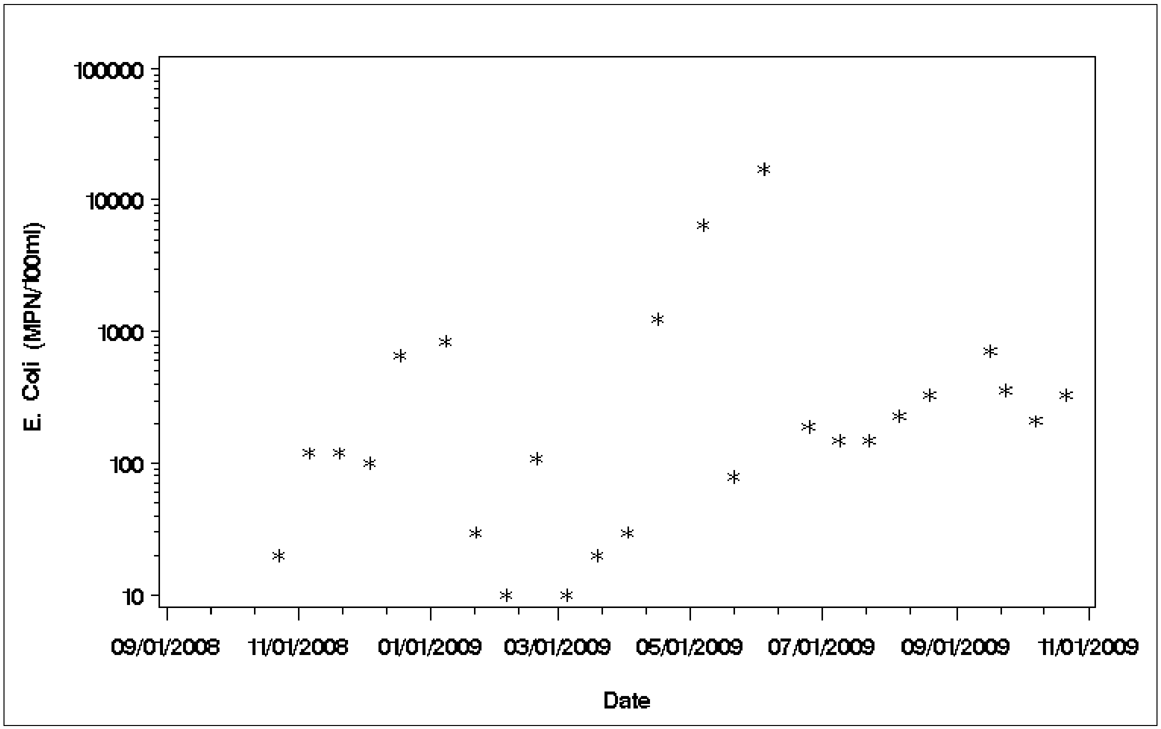

Figure A-2: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0613

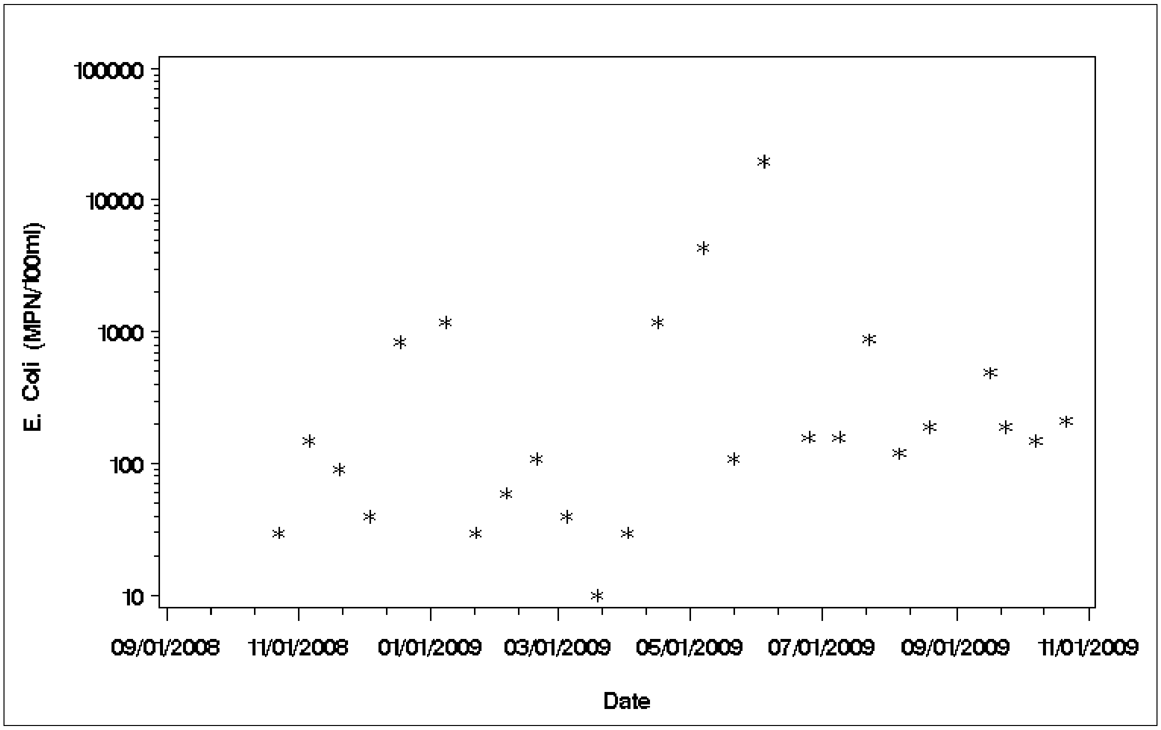

Figure A-3: *E. coli* Concentration vs. Time for MDE Monitoring Station PXT0630

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Appendix B - Flow Duration Curve Analysis to Define Strata

The Patuxent River Upper watershed was assessed to determine hydrologically significant strata. The purpose of these strata is to apply weights to monitoring data and thus reduce bias associated with the monitoring design. The strata group hydrologically similar water quality samples and provide a better estimate of the mean concentration at the monitoring station.

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

Flow Analysis

There are two USGS gage stations in the Patuxent River Upper watershed used for the analysis. These sites are listed in Table B-1. Flow duration curves for these sites are presented in Figure B-1.

Table B-1: USGS Sites in the Patuxent River Upper Watershed

USGS Site #	Dates Used	Location
01592500	11/01/1984 – 10/31/2009	Patuxent River near Laurel, MD
01594440	11/01/1984 – 10/31/2009	Patuxent River near Bowie, MD

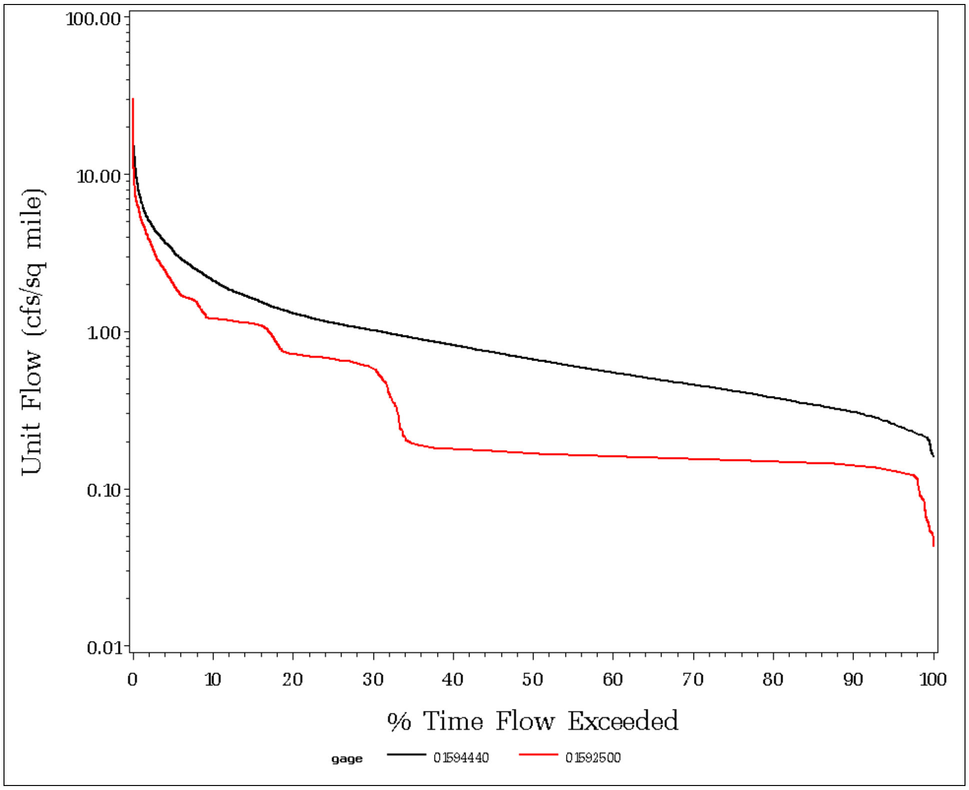

Figure B-1: Flow Duration Curve for Patuxent River Upper Watershed USGS Sites

The long-term average daily unit flow at the gage station near Bowie, MD corresponds to a corresponds to a flow frequency of 27.6%. 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 27.6 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 27.6% and a low flow condition will be defined as occurring when the daily flow duration percentile is greater than 27.6%. 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-7 show the Patuxent River Upper 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 Patuxent River Upper 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 no samples within the high 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-7.

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	0.276	0.728
Dry Weather Seasonal	May 1st – Sept. 30th	Dry Weather Samples During May 1st – Sept. 30th	1.000	

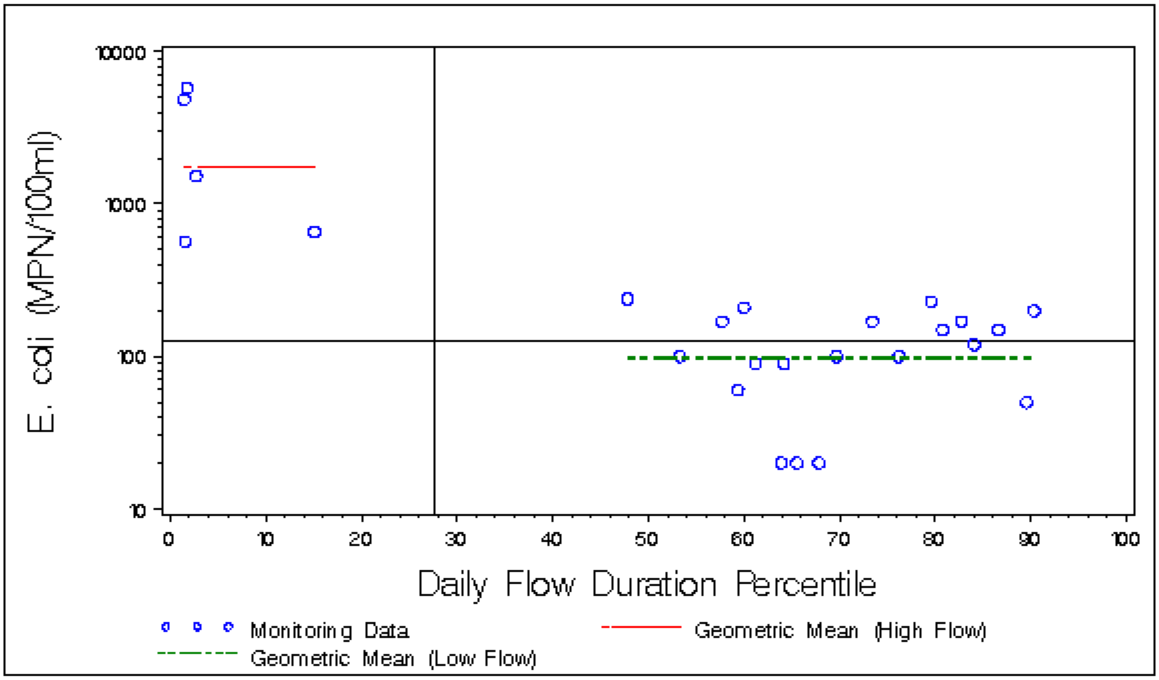

Figure B-2: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0561 (Annual Condition)

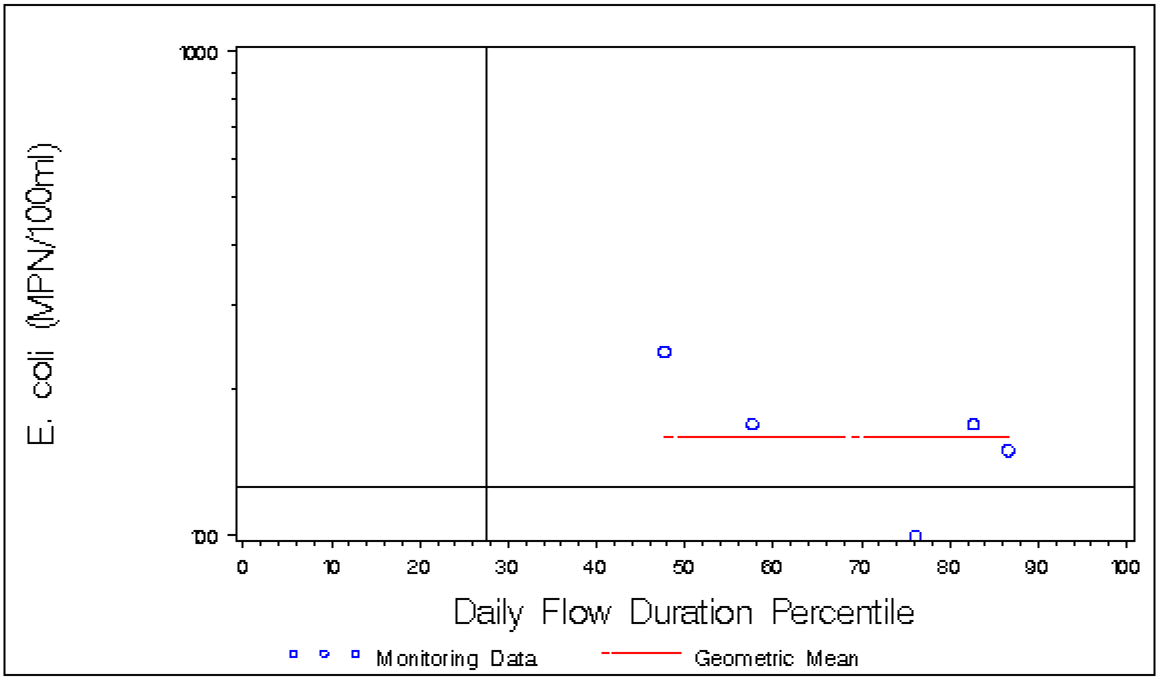

Figure B-3: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0561 (Seasonal Condition)

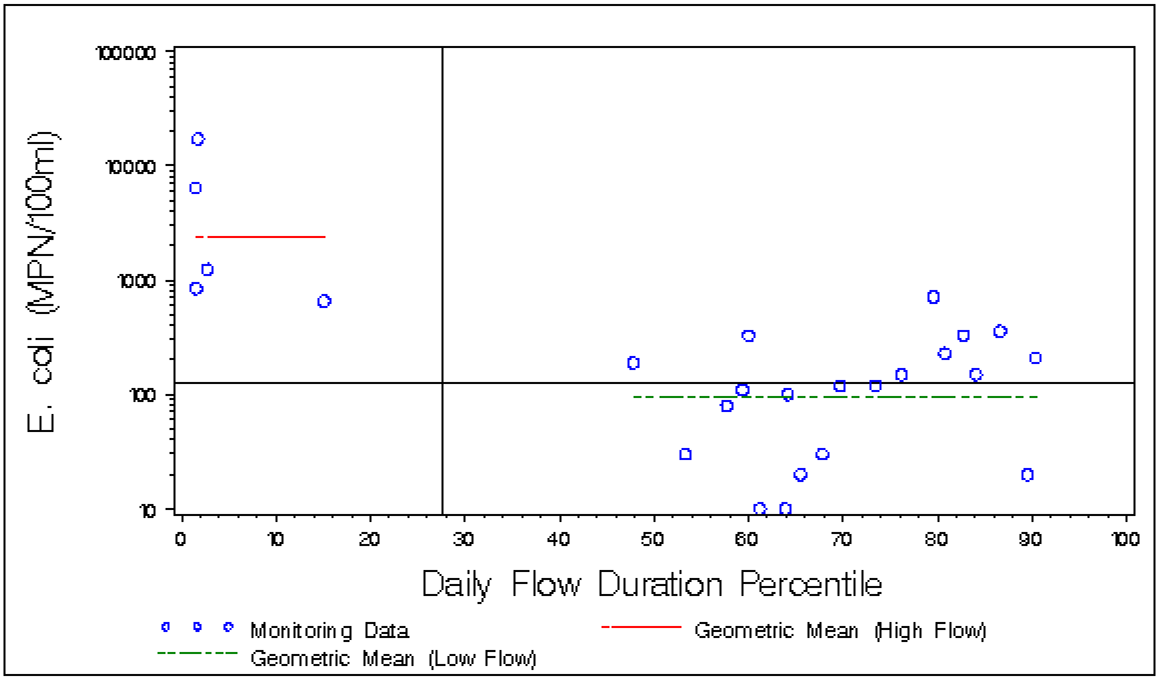

Figure B-4: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0613 (Annual Condition)

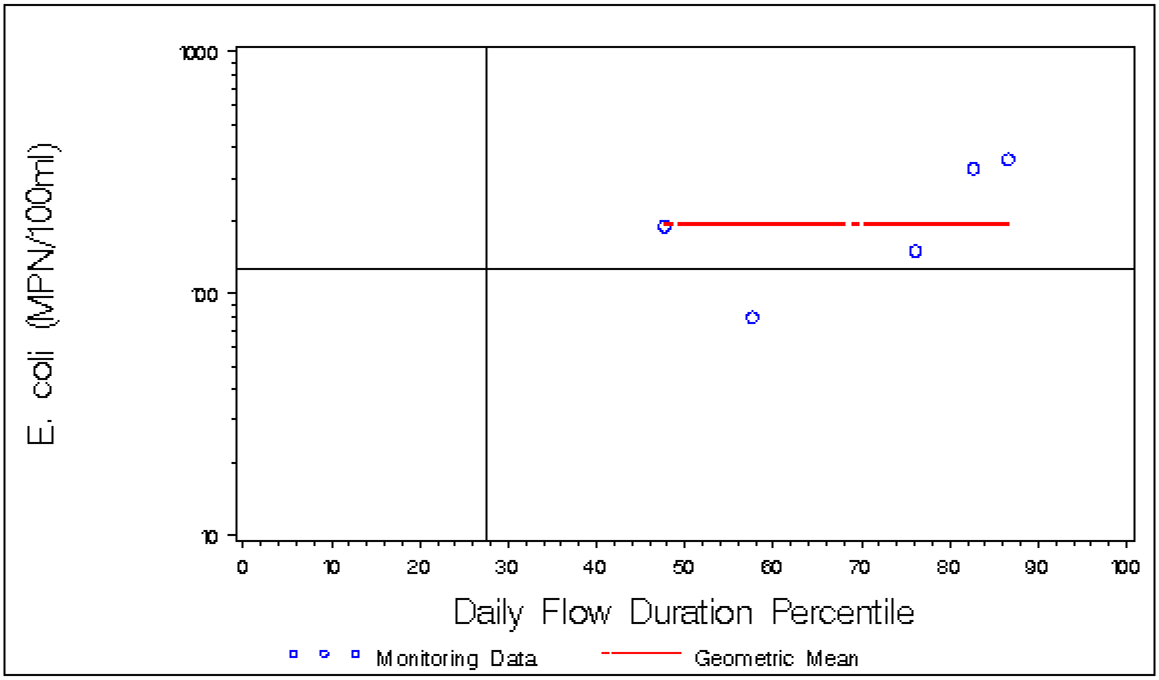

Figure B-5: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0613 (Seasonal Condition)

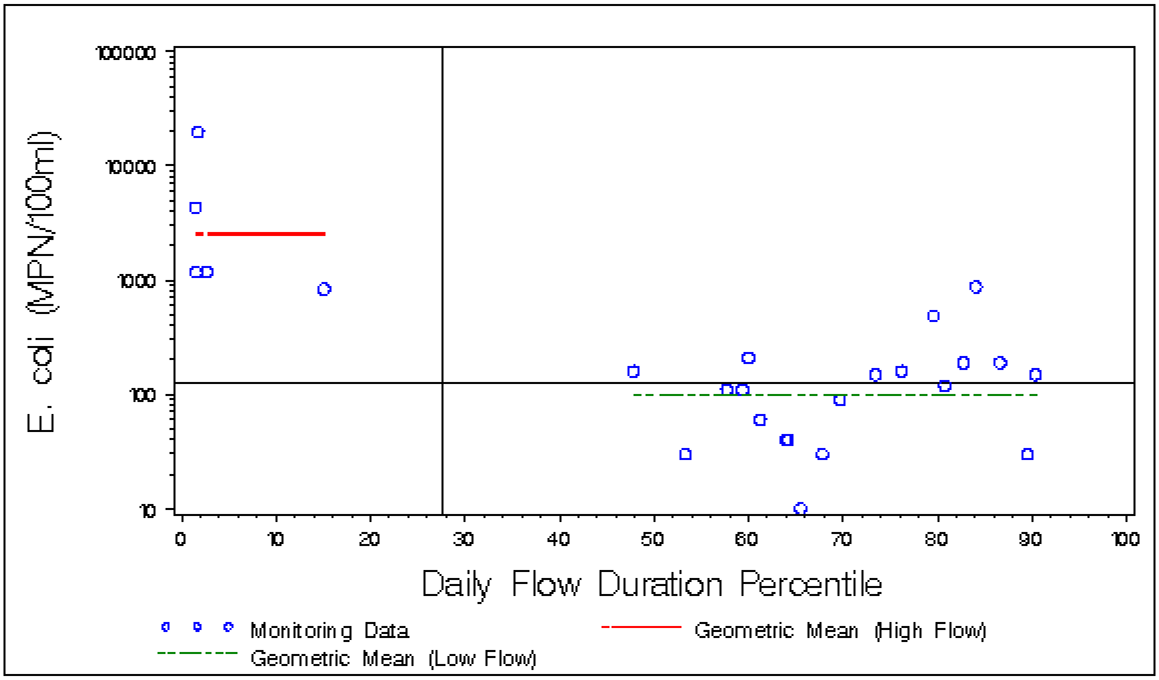

Figure B-6: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0630 (Annual Condition)

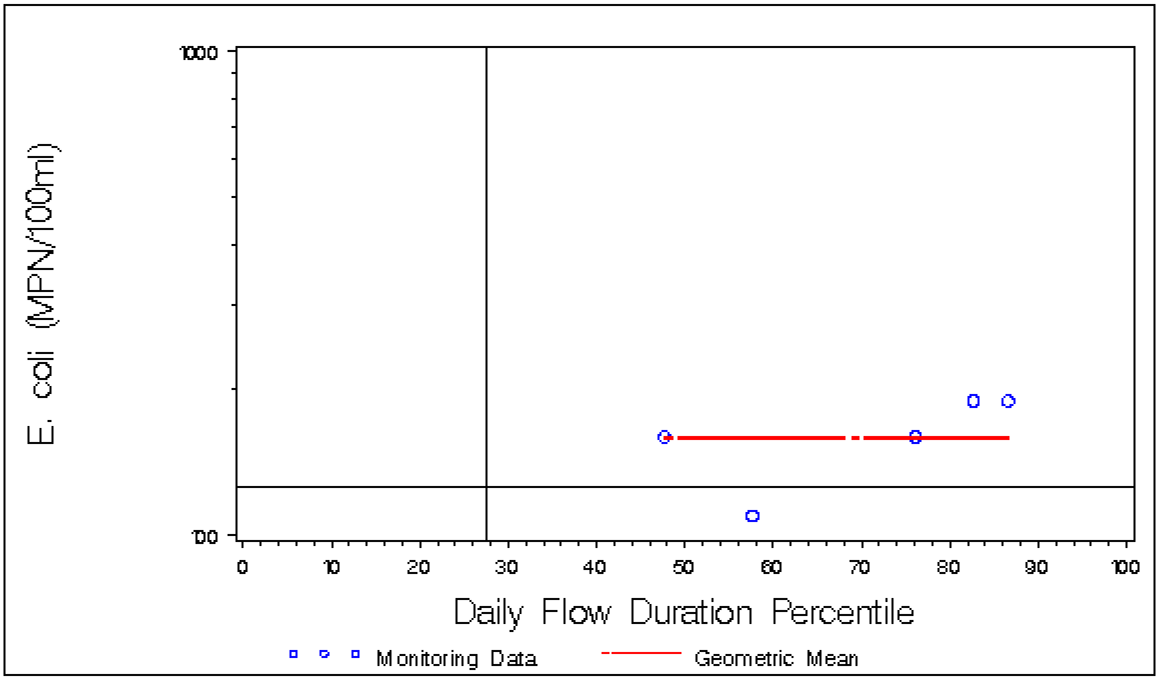

Figure B-7: *E. coli* Concentration vs. Flow Duration for Monitoring Station PXT0630 (Seasonal Condition)

Appendix C – BST Report

Final Report

Maryland Department of the Environment

MOU U00P9200391

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

November 2008 – June 2010

Mark F. Frana, Ph.D. and Elichia A. Venso, Ph.D.
Bacterial Source Tracking Laboratory
Department of Biological Sciences
Salisbury University, Salisbury, MD

June 14, 2010

Table of Contents

Introduction C3

Laboratory Methods C4

Known-Source Library C5

Statistical Analysis C6

ARA Results C7

References C11

Acknowledgements C12

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 reviews (Santo Domingo and Sadowsky, Eds. 2007), 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 caffeine or optical brighteners from laundry detergents or (Simpson *et al.* 2002).

Many of the molecular and biochemical methods of MST are “library-based,” requiring the collection of a database of fingerprints or patterns obtained from indicator organisms isolated from known sources. Statistical analysis determines fingerprints/patterns of known-source species or categories of species (*i.e.*, human, livestock, pet, 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 tidal watersheds/shellfish harvesting areas: the Corsica River Watershed, the Lower Choptank River Watershed (divided into subwatersheds A through G), Monie Bay Watershed, and the Upper Patuxent River Watershed. The methodology used was ARA, with *Enterococcus* spp. as the indicator organism. Previous BST publications have demonstrated the predictive value of using this particular technique and indicator organism (Greenburg *et al*. 2010; Price *et al.* 2006; Hagedorn 1999; Wiggins 1999). A subset of human scat isolates collected from watersheds across Maryland were analyzed using PFGE (a genotypic method) that is analogous to a pilot study of scat isolates from deer that was conducted during the 2007 and 2008 BST projects. The results of the pilot study will be released in an addendum in the future.

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 (Greenburg *et al.* 2010; Price *et al*. 2006; Wiggins 1999).

LABORATORY METHODS

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

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

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

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

Table C-1 below lists 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
Bacitracin	25, 50
Cephalothin	10, 15, 30, 50
Chloramphenicol	10
Chlortetracycline	60, 80, 100
Erythromycin	10
Gentamycin	5, 10, 15
Kanamycin	25, 50
Neomycin	40, 60, 80
Oxytetracycline	20, 40, 60, 80, 100
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 (i.e., human, livestock (chicken, cow, domestic duck, donkey, goat, horse, mule, sheep), pet (cat, dog), wildlife (beaver, blue heron, deer, duck, fox, goose, opossum, rabbit, raccoon, robin, seagull, squirrel, wild turkey). 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. 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

Our objective is to estimate the probability distribution for bacterial sources likely to contaminate surface waters. We use a statistical method, tree classification, to analyze watershed library data consisting of ARA isolate profiles.[1] The statistical analysis results are predictive relationships between isolate characteristics and bacterial sources. These predictive relationships, collectively referred to as a model, are used to estimate probabilities of bacterial source origin for each isolate. When applied to a water sample isolate of unknown origin, these relationships lead to an estimate of the probability of source origin for each source. For example, if there were four sources of bacteria potentially contaminating surface waters, the model applied to a specific water sample isolate would produce four probabilities, the probabilities of source origin for that water sample isolate. Averaging each of the four probabilities across all water sample isolates produces an estimate of the probability distribution for bacteria sources. The source probability distribution estimate may be used to determine the source or sources responsible the largest contributions of bacterial contamination to surface waters.

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1 The tree classification method we employed is known as CART®, Classification and Regression Trees, Salford Systems, San Diego, CA. For details, refer to: Breiman L, et al. *Classification and Regression Trees*. Pacific Grove: Wadsworth, 1984; Steinberg D and Colla P. *CART—Classification and Regression Trees.* San Diego, CA: Salford Systems, 1997; and The Elements of Statistical Learning: Data Mining, Inference, and Prediction; Hastie T, Tibshirani R, and Friedman J. Springer 2001.

Upper Patuxent River Watershed ARA Results

Known-Source Library. A 1,041 known-source isolate library was constructed from sources in the Upper Patuxent River Watershed. The number of unique antibiotic resistance patterns was calculated, and the known sources in the library were grouped into four categories: human, livestock (horse), pet (dog), and wildlife (deer, fox) (Table C-2). The library was analyzed for its ability to take a subset of the library isolates and correctly predict the identity of their host sources when they were treated as unknowns.

Table C-2: Source category, total isolates, and number of unique patterns.

Source category	Potential Sources	Total Isolates	Unique Patterns
Human	human	256	165
Livestock	horse	266	96
Pet	dog	242	128
Wildlife	deer, fox	277	103
Total		1041	492

For Upper Patuxent River Watershed, the rates of correct classification (RCC) were calculated and the average rate of correct classification (ARCC) for the library was determined as described above in the "Statistical Analysis" section of this document. (Table C-3).

Table C-3: Actual versus predicted sources, with rates of correct classification (RCC) (% correct) for each source and ARCC for the library.

	Predicted					
Actual	Human	Livestock	Pet	Wildlife	Total	RCC
Human	172	19	32	33	256	67.2%
Livestock	19	203	9	35	266	76.3%
Pet	34	20	143	45	242	59.1%
Wildlife	17	76	27	157	277	56.7%
Total	242	318	211	270	1041	
			ARCC:			64.8%

Upper Patuxent River Watershed Water Samples. Monthly monitoring from three (3) monitoring stations on the Upper Patuxent River Watershed 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 737 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by source category are shown in Table C-4.

Table C-4: Predicted host source distribution of water isolates, based on posterior probability averaging.

Source	Count	Percent
Human	182.98	18.77%
Livestock	274.29	28.13%
Pet	175.20	17.97%
Wildlife	342.53	35.13%
Total	975	100.0%

The seasonal distribution of water isolates from samples collected at the sampling stations is shown below in Table C-5.

Table C-5: Enterococcus isolates obtained from water collected during the spring, summer, fall, and winter seasons at the Upper Patuxent River Watershed monitoring stations.

	Season				
Station	Spring	Summer	Fall	Winter	Total
PXT0561	60	72	66	40	238
PXT0613	70	68	64	46	248
PXT0630	69	70	68	44	251
Total	199	210	198	130	737

Tables C-6 and C-7 on the following pages show the numbers and percentages, respectively, of probable sources for the monitoring stations by date.

Table C-6: Predicted source count distribution by station and date.

		Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Total
PXT0561	11/20/08	1.86	5.02	3.87	9.25	20
PXT0613	11/20/08	0.60	12.34	1.85	8.21	23
PXT0630	11/20/08	2.09	8.97	2.89	10.06	24
PXT0561	12/04/08	2.69	7.80	5.52	6.99	23
PXT0613	12/04/08	2.12	6.35	3.28	5.25	17
PXT0630	12/04/08	3.11	8.53	4.06	5.29	21
PXT0561	01/08/09	8.06	6.47	5.22	4.25	24
PXT0613	01/08/09	6.79	7.13	4.61	5.48	24
PXT0630	01/08/09	8.41	4.85	4.78	5.95	24
PXT0561	02/05/09	1.71	2.73	3.15	5.41	13
PXT0613	02/05/09	3.43	4.92	2.19	4.47	15
PXT0630	02/05/09	3.56	2.62	2.57	4.25	13
PXT0561	03/05/09	0.82	1.16	0.39	0.62	3

Table C-6: Predicted source count distribution by station and date (continued).

		Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Total
PXT0613	03/05/09	2.18	2.05	1.17	1.61	7
PXT0630	03/05/09	3.04	1.70	1.46	0.80	7
PXT0561	04/02/09	3.70	2.13	2.58	3.59	12
PXT0613	04/02/09	7.01	4.04	6.08	4.88	22
PXT0630	04/02/09	5.00	4.89	6.02	5.09	21
PXT0561	05/07/09	5.41	10.42	2.84	5.33	24
PXT0613	05/07/09	6.31	6.60	4.00	7.09	24
PXT0630	05/07/09	6.75	6.12	4.81	6.32	24
PXT0561	06/04/09	3.60	8.30	3.19	8.92	24
PXT0613	06/04/09	7.35	6.54	2.96	7.15	24
PXT0630	06/04/09	3.94	13.20	2.20	4.66	24
PXT0561	07/09/09	3.48	7.33	3.47	9.72	24
PXT0613	07/09/09	3.68	4.27	4.18	11.87	24
PXT0630	07/09/09	3.17	5.53	3.80	10.51	23
PXT0561	08/06/09	4.25	2.92	4.82	12.00	24
PXT0613	08/06/09	4.17	4.47	3.89	11.47	24
PXT0630	08/06/09	4.32	4.12	4.04	11.52	24
PXT0561	09/07/09	1.93	5.23	4.63	12.21	24
PXT0613	09/07/09	2.96	2.10	4.91	10.04	20
PXT0630	09/07/09	3.97	6.85	3.73	8.45	23
PXT0561	10/08/09	2.21	7.32	3.01	10.45	23
PXT0613	10/08/09	3.34	5.16	4.47	11.03	24
PXT0630	10/08/09	1.36	9.21	2.97	9.46	23
	Total	138.38	209.39	129.61	259.65	737

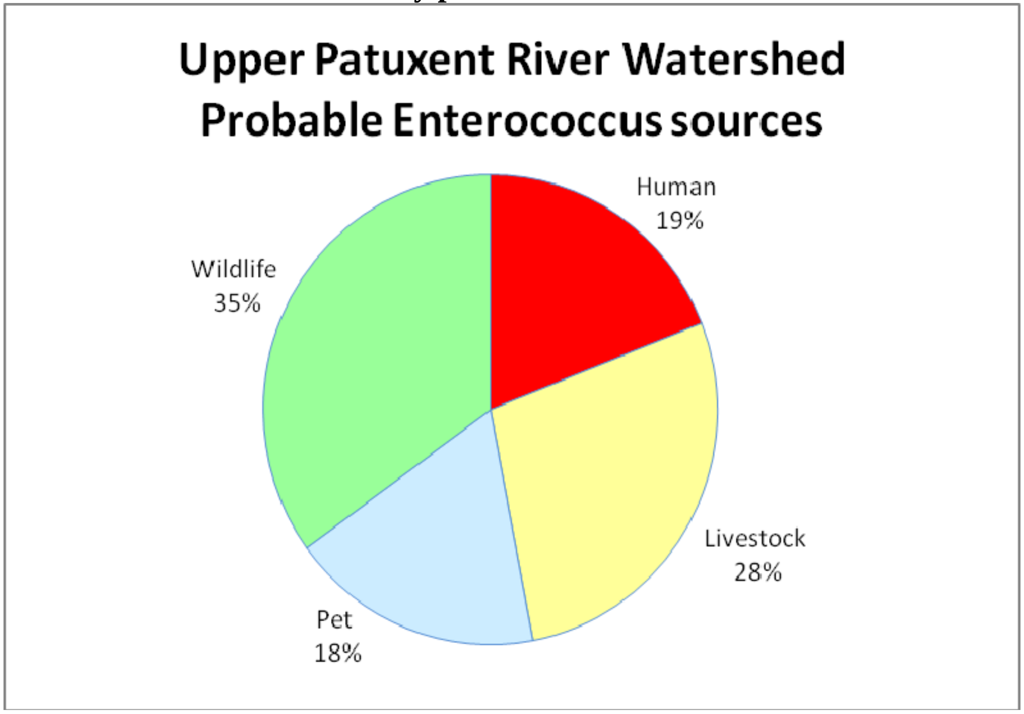
Table C-7: Predicted source percent distribution by station and date.

		Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Total
PXT0561	11/20/08	9.30%	25.09%	19.37%	46.25%	100%
PXT0613	11/20/08	2.59%	53.66%	8.05%	35.70%	100%
PXT0630	11/20/08	8.70%	37.36%	12.04%	41.90%	100%
PXT0561	12/04/08	11.71%	33.91%	24.00%	30.38%	100%
PXT0613	12/04/08	12.47%	37.36%	19.26%	30.90%	100%
PXT0630	12/04/08	14.81%	40.62%	19.35%	25.21%	100%
PXT0561	01/08/09	33.58%	26.95%	21.75%	17.72%	100%
PXT0613	01/08/09	28.28%	29.70%	19.20%	22.82%	100%
PXT0630	01/08/09	35.06%	20.22%	19.91%	24.81%	100%
PXT0561	02/05/09	13.13%	21.00%	24.24%	41.62%	100%
PXT0613	02/05/09	22.86%	32.78%	14.57%	29.78%	100%

Table C-7: Predicted source percentage distribution by station and date (continued).

		Predicted Source				
Station	Date	Human	Livestock	Pet	Wildlife	Total
PXT0630	02/05/09	27.39%	20.14%	19.78%	32.69%	100%
PXT0561	03/05/09	27.34%	38.71%	13.16%	20.78%	100%
PXT0613	03/05/09	31.12%	29.26%	16.65%	22.97%	100%
PXT0630	03/05/09	43.36%	24.32%	20.82%	11.49%	100%
PXT0561	04/02/09	30.81%	17.75%	21.50%	29.94%	100%
PXT0613	04/02/09	31.85%	18.36%	27.62%	22.17%	100%
PXT0630	04/02/09	23.83%	23.28%	28.67%	24.22%	100%
PXT0561	05/07/09	22.53%	43.42%	11.83%	22.22%	100%
PXT0613	05/07/09	26.29%	27.51%	16.67%	29.52%	100%
PXT0630	05/07/09	28.13%	25.50%	20.03%	26.34%	100%
PXT0561	06/04/09	14.99%	34.58%	13.28%	37.16%	100%
PXT0613	06/04/09	30.62%	27.26%	12.31%	29.81%	100%
PXT0630	06/04/09	16.42%	54.99%	9.17%	19.42%	100%
PXT0561	07/09/09	14.49%	30.54%	14.46%	40.51%	100%
PXT0613	07/09/09	15.33%	17.79%	17.41%	49.46%	100%
PXT0630	07/09/09	13.79%	24.03%	16.50%	45.68%	100%
PXT0561	08/06/09	17.72%	12.17%	20.10%	50.01%	100%
PXT0613	08/06/09	17.39%	18.61%	16.22%	47.78%	100%
PXT0630	08/06/09	17.98%	17.16%	16.85%	48.01%	100%
PXT0561	09/07/09	8.03%	21.77%	19.30%	50.89%	100%
PXT0613	09/07/09	14.79%	10.50%	24.53%	50.19%	100%
PXT0630	09/07/09	17.27%	29.78%	16.23%	36.73%	100%
PXT0561	10/08/09	9.62%	31.82%	13.10%	45.46%	100%
PXT0613	10/08/09	13.92%	21.50%	18.62%	45.95%	100%
PXT0630	10/08/09	5.89%	40.06%	12.92%	41.13%	100%
	Total	18.78%	28.41%	17.59%	35.23%	100%

Figure C-1: Relative contributions by probable sources of *Enterococcus* contamination.



Upper Patuxent River Watershed Summary

The use of ARA was successful for identification of probable bacterial sources in the Upper Patuxent River Watershed. The highest RCC for the library was for livestock (76.3%), followed by human (67.2%), pet (59.1%), and wildlife (57.7%). The largest category of potential sources in the watershed was wildlife (35%), followed by livestock (28%), human (19%), and pet (18%) (Fig. C-1).

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ACKNOWLEDGEMENTS

We gratefully acknowledge the funding support of Maryland Department of the Environment (MDE) and the support and participation of the Science Services Administration of MDE. We further wish to thank the Richard A. Henson School of Science and Technology of Salisbury University, Salisbury, MD, for its support. We also want to acknowledge Dr. Bertram Price, Joshua Greenberg, and Adam Ware of Price Associates, Inc., for their contributions to the statistical analysis in this project. Finally, we wish to thank Lesley Frana and Anne Adkins for their indispensable work in the BST Laboratory.

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 listed portion of the MD 8-digit Patuxent River Upper 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 Patuxent River Upper 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 three monitoring stations of the Patuxent River Upper 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 Patuxent River Upper watershed, a value measured during low-flow conditions at the PXT0613 station resulted in the highest percentile of both strata of the three stations. This value translates to the 95.0th 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 (%)
PXT0630[1]	High	19,860	94.2
	Low	490	94.6
PXT0613	High	17,330	91.8
	Low	720	95.0
PXT0561	High	5,790	86.5
	Low	240	86.9

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper watershed

The 95.0th percentile value results in a maximum daily load that would not be exceeded 95.0% 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 (5) and (6):

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

And from equation (13):

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

Therefore,

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

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:

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

$C_{LTA\text{-}L} = C_{b\text{-}L}*(1\text{-}R_L)$ (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)
PXT0630[1]	High	1,259	2,984
	Low	49	81
PXT0613	High	1,201	3,293
	Low	47	101
PXT0561	High	967	1,743
	Low	54	74

*Only arithmetic parameters are used in the daily loads analysis.
[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper watershed

The next step is to calculate the 95.0th 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 95.0th 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)
PXT0630[1]	High	2.15	10,985
	Low	1.32	255
PXT0613	High	2.55	12,491
	Low	1.90	361
PXT0561	High	1.50	5,789
	Low	0.95	202

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper watershed

With the 95.0th 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:

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

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 is 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).

There are no NPDES-regulated point sources to consider in the listed portion of the MD 8-digit Patuxent River Upper watershed.

The Maximum Daily Loads for the Patuxent River Upper subwatersheds, including those located upstream of the listed portion, 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
PXT0630[1]	High Low	220,005 1,168	61,567
PXT0613sub	High Low	8,665 80	2,435
PXT0561sub	High Low	8,335 70	2,351

[1] Subwatershed located upstream of listed portion of the MD 8-digit Patuxent River Upper 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 listed MD 8-digit Patuxent River Upper watershed are presented in Table D-5.

Table D-5: Patuxent River Upper Watershed Maximum Daily Loads

Subwatershed	Total Allocation	LA_{LP}	$SW\text{-}WLA_{LP}$	$WWTP\text{-}WLA_{LP}$
	(Billion MPN *E. coli* /day)			
PXT0613sub	2,435	1,996	439	0
PXT0561sub	2,351	1,748	603	0
Listed MD 8-digit Patuxent River Upper Total	4,786	3,744	1,042	0
Upstream Load	61,567			
MDL	**66,353**			

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