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

FINAL

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Submitted to:

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List of Abbreviations

ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
CFU	Colony Forming Units
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
EPA	United States 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
RCC	Rates of Correct Classification
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria in the Liberty Reservoir watershed (MD basin number 02-13-09-07). 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 identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, states are required to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards or demonstrate that water quality standards are being met.

The Maryland Department of the Environment (MDE) has identified the tributaries of Liberty Reservoir in the State of Maryland's 303(d) List as impaired by fecal bacteria and impacts to biological communities (listed in 2002). The reservoir itself is not listed as impaired by fecal bacteria, but is listed as impaired by nutrients and sediments (listed in 1996) and by methylmercury (listed in 2002). The mainstem North Branch Patapsco River, mainstem West Branch Patapsco River and Cranberry Branch and its tributaries have been designated as Use IV-P (Recreational Trout Waters and Public Water Supply) waters. Roaring Run has been designated as Use III (Nontidal Cold Water). Beaver Run, Cooks Branch, East Branch Patapsco River, Keysers Run, Locust Run, Morgan Run, Norris Run and all their tributaries have been designated as Use III-P (Nontidal Cold Water and Public Water Supply). Liberty Reservoir and all remaining tributaries have been designated as Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08K. Chromium and lead impairments (listed in 1996) have been removed from the 303(d) List through a water quality analysis (WQA) submitted to EPA in September 24, 2003. This document proposes to establish a TMDL for fecal bacteria in the Liberty Reservoir watershed that will allow for attainment of the beneficial use designation of primary water contact recreation. The listing for sediments, nutrients, methylmercury in fish tissue, and impacts to biological communities will be addressed separately at a future date. MDE monitored the Liberty Reservoir watershed from 2003 to 2004 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered.

For this TMDL analysis, the Liberty Reservoir basin has been divided into six subwatersheds, which include Beaver Run (BEA0016), Middle Run (MDE0026), Morgan Run (MOR0040), Little Morgan Run (LMR0015), and North Branch Patapsco River (NPA0165). The sixth subwatershed encompasses all unmonitored areas downstream of the five stations, except the impoundment, and will be referred to as the Downstream Subwatershed. The pollutant loads set forth in this document are for these six subwatersheds. The North Branch Patapsco River subwatershed (NPA0165) was delisted in 2004 from the State of Maryland's 303(d) List, based on the long-term geometric mean analysis of fecal coliform; however, additional analysis has been conducted and the results indicate that the subwatershed is impaired; therefore, it is included in this TMDL. To establish baseline and allowable pollutant loads for this TMDL, a flow duration curve approach was employed, using bacteria data from MDE and flow strata estimated from United States Geological Survey (USGS) daily flow monitoring. The sources of fecal bacteria are estimated at five representative stations in the Liberty Reservoir watershed where samples were collected for one year. Multiple antibiotic resistance analysis (ARA) source tracking was used to determine the relative proportion of domestic (pets and human associated animals), human (human waste), livestock (agriculture-related animals), and wildlife (mammals and waterfowl) source categories.

The baseline load is estimated based on current monitoring data, using a long-term geometric mean and weighting factors from the flow duration curve. The TMDL for fecal bacteria is established after considering three different hydrological conditions: high flow and low flow annual conditions, and an average seasonal condition (the period between May 1st and September 30th, when water contact recreation is more prevalent). This allowable load is reported in units of Most Probable Number (MPN)/year and represents a long-term load estimated over a variety of hydrological conditions.

Two scenarios were developed, with the first assessing if attainment of current water quality standards could be achieved by applying maximum practicable reductions (MPRs), and the second applying higher reductions than MPRs. Scenario solutions were based on an optimization method where the objective was to minimize the overall risk to human health, assuming that the risk varies over the four bacteria source categories. In three of the subwatersheds, it was estimated that water quality standards could be attained with MPRs; however, in three subwatersheds (NPA0165, MDE0026, and the downstream subwatershed) where it was estimated that water quality standards could not be attained, higher maximum reductions were applied.

The baseline loads are summarized in the following table:

MD 8-Digit Liberty Reservoir Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)						
Total Baseline Load	=	**Nonpoint Source BL**	+	**Stormwater BL**	+	**WWTP BL**
1,083,248	=	979,511	+	102,692	+	1,045

The MD 8-digit Liberty Reservoir TMDL, representing the sum of individual TMDLs for the six subwatersheds, is distributed between a load allocation (LA) for nonpoint sources and waste load allocations (WLA) for point sources. Point sources include any National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants (WWTPs) and NPDES regulated stormwater (SW) discharges, including county and municipal separate storm sewer systems (MS4s). The margin of safety (MOS) has been incorporated using a conservative assumption by estimating the loading capacity of the stream based on a water quality endpoint concentration more stringent than the applicable MD water quality standard criterion. The *E. coli* water quality criterion concentration was reduced by 5%, from 126 MPN/100ml to 119.7 MPN/100ml.

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

MD 8-Digit Liberty Reservoir Fecal Bacteria TMDL (Billion MPN *E. coli*/year)								
TMDL	**=**	**LA**	**+**	**WLA**			**+**	**MOS**
				SW WLA	**+**	**WWTP WLA**		
361,008	=	350,638	+	9,325	+	1,045	+	Incorpo-rated

The long-term annual average TMDL represents a reduction of approximately 67 % from the baseline load of 1,083,248 billion MPN *E. coli*/year.

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

MD 8-Digit Liberty Reservoir Fecal Bacteria MDL Summary (Billion MPN *E. coli*/day)								
MDL	**=**	**LA**	**+**	**WLA**			**+**	**MOS**
				SW WLA	**+**	**WWTP WLA**		
11,580	=	11,295	+	276	+	9	+	Incorpo-rated

Once EPA has approved a TMDL, and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. MDE intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impacts to water quality and creating the greatest risks to human health, with consideration given to ease and cost of implementation. In addition, follow-up monitoring plans will be established to track progress and to assess the implementation efforts. As previously stated, water quality standards could be attained in three of the subwatersheds using MPRs. However, in three other subwatersheds it was estimated that water quality standards could not be attained. MPRs may not be sufficient in subwatersheds where wildlife is a significant component or where very high reductions of fecal bacteria loads are required to meet water quality standards. In these cases, it is expected that the MPR scenario will be the first stage of TMDL implementation. Progress will be made through the iterative implementation process described above, and the situation will be reevaluated in the future.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria in the Liberty Reservoir watershed (MD basin number 02-13-09-07). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to develop a TMDL for each impaired water quality limited segment (WQLS) on the Section 303(d) List, taking into account seasonal variations and a protective margin of safety (MOS) to account for uncertainty. A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

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

The Maryland Department of the Environment (MDE) has identified the tributaries of Liberty Reservoir in the State of Maryland's 303(d) List as impaired by fecal bacteria and impacts to biological communities (listed in 2002). The reservoir itself is not listed as impaired by fecal bacteria, but is listed as impaired by nutrients and sediments (listed in 1996) and by methylmercury (listed in 2002). The mainstem North Branch Patapsco River, mainstem West Branch Patapsco River and Cranberry Branch and its tributaries have been designated as Use IV-P (Recreational Trout Waters and Public Water Supply) waters. Roaring Run has been designated as Use III (Nontidal Cold Water). Beaver Run, Cooks Branch, East Branch Patapsco River, Keysers Run, Locust Run, Morgan Run, Norris Run and all their tributaries have been designated as Use III-P (Nontidal Cold Water and Public Water Supply). Liberty Reservoir and all remaining tributaries have been designated as Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08K. Chromium and lead impairments (listed in 1996) have been removed from the 303(d) List through a water quality analysis (WQA) submitted to EPA in September 24, 2003. This document proposes to establish a TMDL for fecal bacteria in the Liberty Reservoir watershed that will allow for attainment of the beneficial use designation of primary water contact recreation. The listing for sediments, nutrients, methylmercury in fish tissue, and impacts to biological communities will be addressed separately at a future date. MDE monitored the Liberty Reservoir watershed from 2003 to 2004 for fecal bacteria. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered.

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

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

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

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Liberty Reservoir watershed is located in the Patapsco River basin of Maryland (See Figure 2.1.1) with a total drainage area of 104,800 acres (163.75 square miles). The majority of the watershed is located in Carroll County, MD with a portion in Baltimore County, MD (See Figure 2.1.1). The North Branch Patapsco River is the main tributary flowing into and out of Liberty Reservoir. The river's west branch begins north of Westminster and the east branch begins south of Manchester. Flowing south, the river becomes Liberty Reservoir, a drinking water supply for Carroll and Baltimore Counties, and Baltimore City. The major tributaries include Beaver Run, Morgan Run, Middle Run, and Little Morgan Run.

Land Use

The Liberty Reservoir watershed covers an area of 104,800 acres. Based on the 2002 Maryland Department of Planning (MDP) land use/land cover data, forest and agriculture land account for over 64% of the watershed and urban land accounts for 27% of the watershed. The land use 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 subwatershed considered in the analysis. Note that the subwatersheds are identified by their MDE monitoring station, and are listed by flow from upstream to downstream. The sixth subwatershed encompasses all unmonitored areas downstream of the five monitoring stations, excepting the impoundment, and is identified as the Downstream Subwatershed.

Table 2.1.1: Land Use Distribution for the Liberty Reservoir Basin

Land Type	Area (acres)	Percentage (%)
Forest	32,043	31%
Agricultural	34,630	33%
Urban	27,879	27%
Pasture	6,895	7%
Water	3,353	3%
Total	**104,800**	**100**

Table 2.1.2: Land Use Distribution per Subwatershed in the Liberty Reservoir Basin

Station / Subwatershed	Land Use Area (%)				
	Agricultural	Forest	Urban	Pasture	Water
NPA0165 / North Branch Patapsco River	43%	23%	26%	7%	0%
BEA0016 / Beaver Run	33%	22%	40%	6%	0%
MDE0026 / Middle Run	33%	17%	38%	12%	0%
MOR0040 / Morgan Run	40%	32%	19%	9%	0%
LMR0015 / Little Morgan Run	28%	32%	33%	7%	0%
Downstream Subwatershed	19%	42%	25%	4%	10%

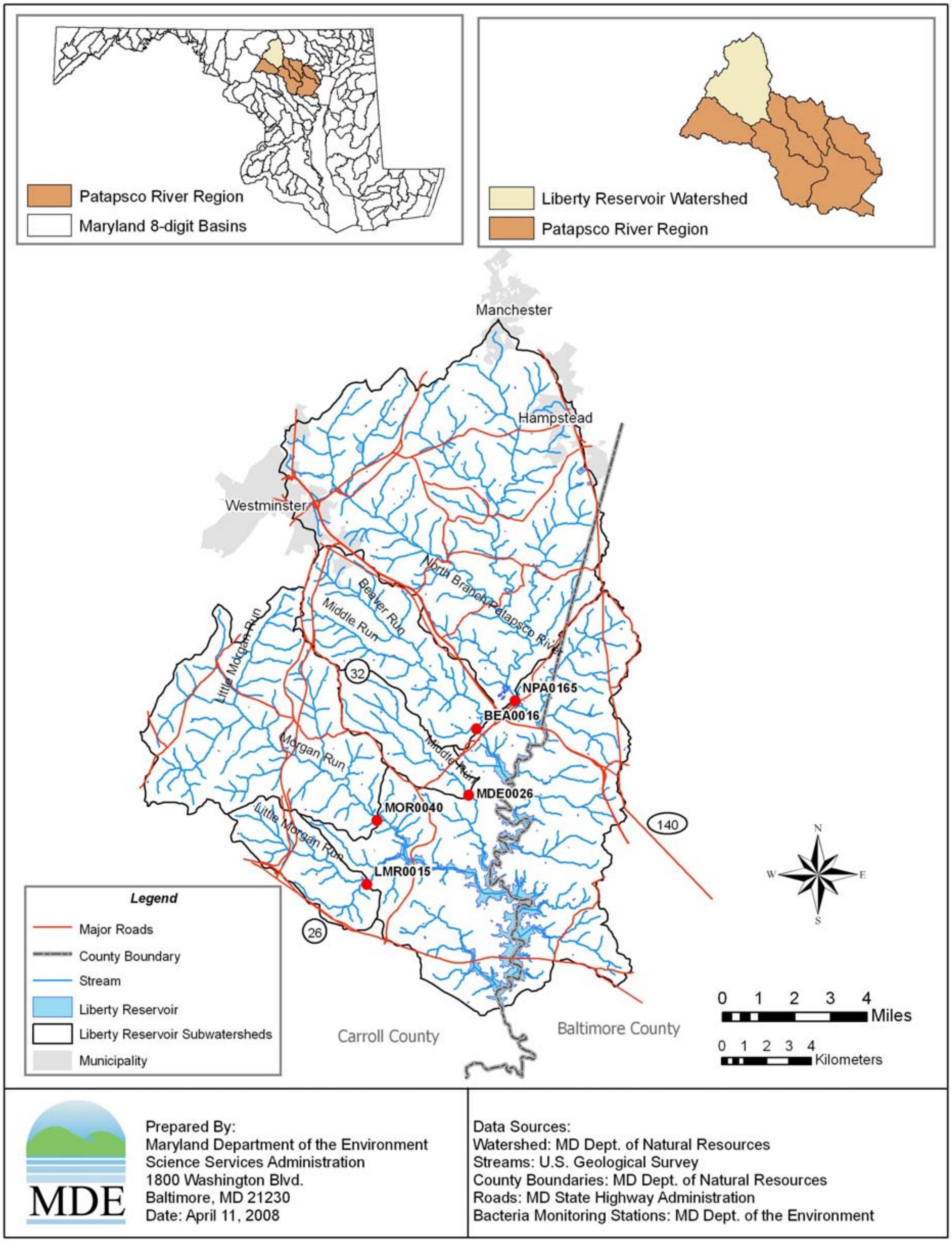

Figure 2.1.1: Location Map of the Area in the Liberty Reservoir Watershed

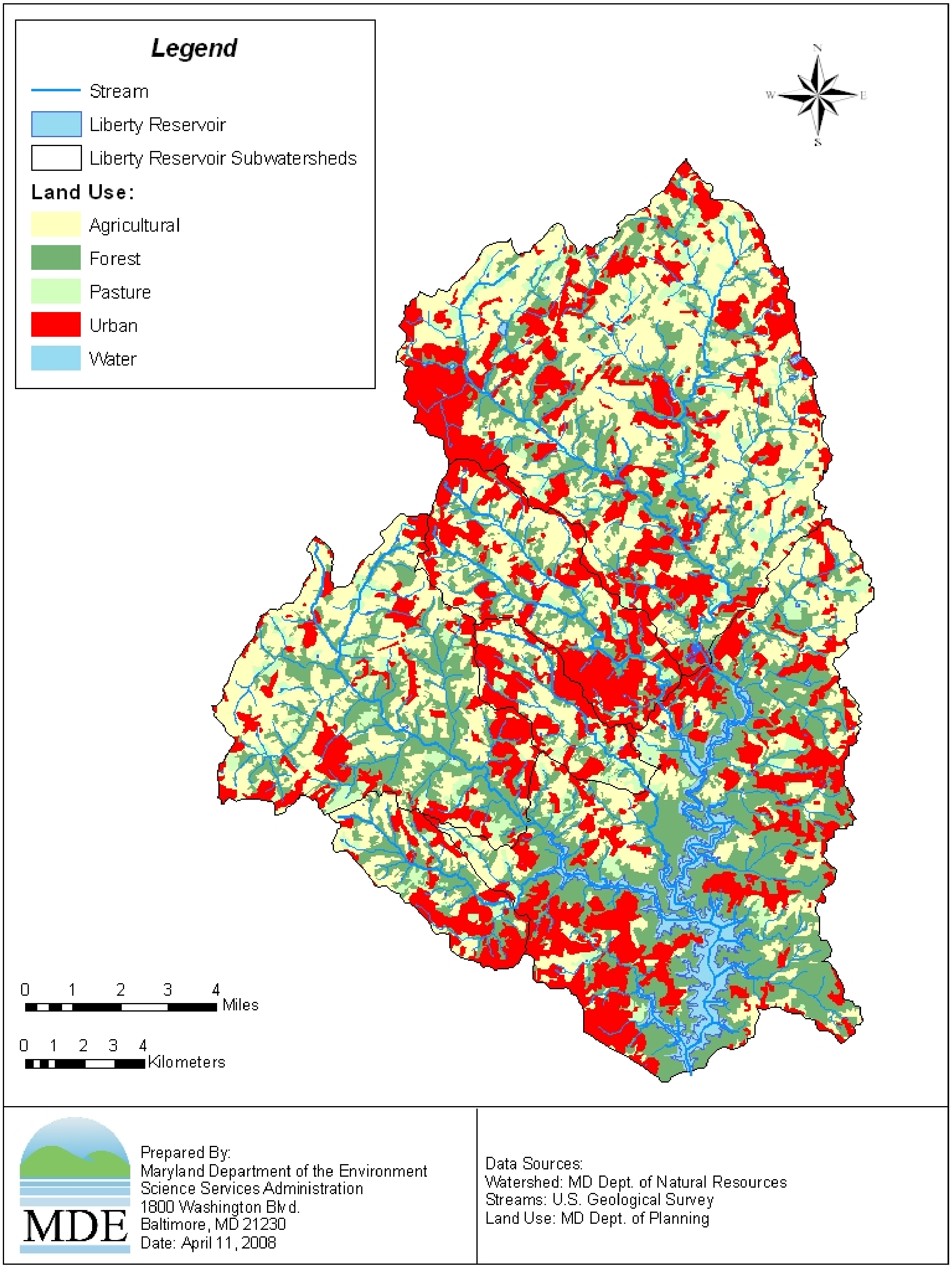

Figure 2.1.2: Land Use of the Liberty Reservoir Watershed

Population

The total population in the Liberty Reservoir watershed is estimated to be 62,584 people. Figure 2.1.3 depicts the population density in the region. The human population and the number of dwellings were estimated based on a weighted average from the 2000 Census GIS Block Groups and the 2002 MDP Land Use Land Cover. Since the boundaries of the watershed differ from the boundaries of the block groups, residential land use data were used to extract the necessary areas of the Census block groups. The MDP residential density designations shown in Table 2.1.3 were used for this estimation.

Table 2.1.3: Number of Dwellings Per Acre

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

Based on these densities and the population data from the census block groups the population for each subwatershed was estimated and is presented in Table 2.1.4.

Table 2.1.4: Total Population Per Subwatershed in the Liberty Reservoir Watershed

Tributary	Station	Population
North Branch Patapsco River	NPA0165	**22,929**
Beaver Run	BEA0016	8,104
Middle Run	MDE0026	2,869
Morgan Run	MOR0040	7,612
Little Morgan Run	LMR0015	3,758
Downstream Subwatershed		17,312
Total		**62,584**

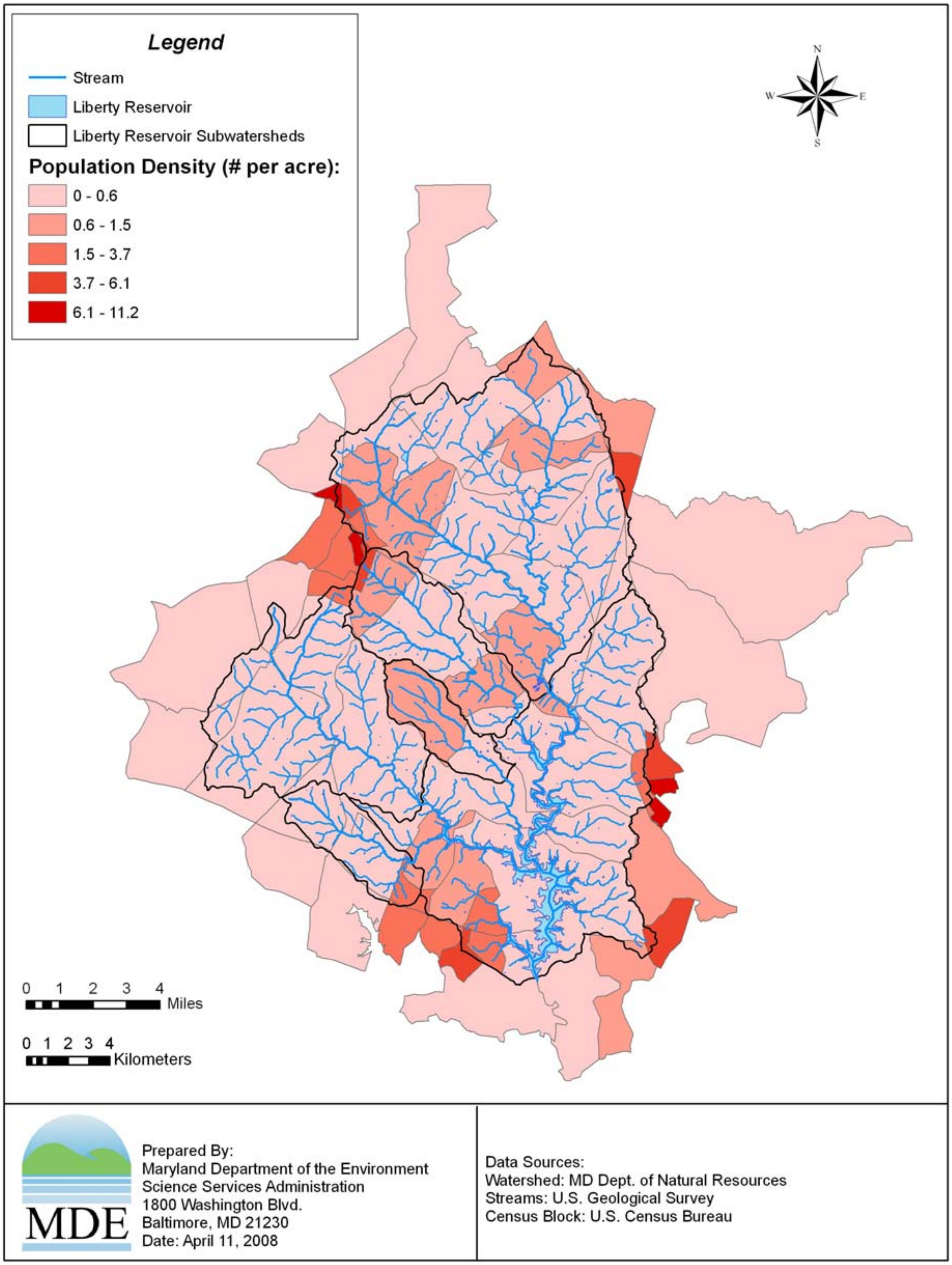

Figure 2.1.3: Population Density in the Liberty Reservoir Watershed

2.2 Water Quality Characterization

EPA's guidance document, "Ambient Water Quality Criteria for Bacteria" (1986), recommended that states use *E. coli* (for fresh water) or enterococci (for fresh or salt water) as pathogen indicators. Fecal bacteria, *E. coli*, and enterococci were assessed as indicator organisms for predicting human health impacts. A statistical analysis found that the highest correlation to gastrointestinal illness was linked to elevated levels of *E. coli* and enterococci in fresh water (enterococci in salt water).

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

Bacteria Monitoring

Table 2.2.1 lists the historical monitoring data available for the Liberty Reservoir basin. MDE conducted bacteria monitoring at five stations in the Liberty Reservoir watershed from November 2003 through October 2004. Three United States Geological Survey (USGS) gauge stations, 01586000, 01586210 and 01586610, were used to derive the surface flow. The locations of these stations are shown in Tables 2.2.2 and 2.2.3 and in Figure 2.2.1. Observations recorded from the five MDE monitoring stations are provided in Appendix A.

Bacteria counts are highly variable which is typical due to the nature of bacteria and their relationship to flow. The E. coli counts for the five stations ranged between 10 and 24,190 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Liberty Reservoir Watershed

Organization	Date	Design	Summary
MDE	11/2003 through 10/2004	*E. coli*	5 stations 2 samples per month
MDE	11/2003 through 10/2004	BST (*Enterococcus*)	5 stations 1 sample per month

Table 2.2.2: Locations of MDE Monitoring Stations in the Liberty Reservoir Watershed

Tributary	Station Code	Observation Period	Total Observations	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
North Branch Patapsco River	NPA0016	2003-2004	24	39.501	-76.883
Beaver Run	BEA0016	2003-2004	24	39.489	-76.904
Middle Run	MDE0026	2003-2004	24	39.463	-76.908
Morgan Run	MOR0040	2003-2004	24	39.452	-76.955
Little Morgan Run	LMR0015	2003-2004	24	39.425	-76.961

Table 2.2.3: Location of USGS Gauging Stations in the Liberty Reservoir Watershed

Site Number	Observation Period Used	Total Observations	Latitude (Decimal Degrees)	Longitude (Decimal Degrees)
01586000	1988-2007	6,939	39.501	-76.885
01586210	1988-2007	6,927	39.487	-76.902
01586610	1988-2006	6,574	39.451	-76.953

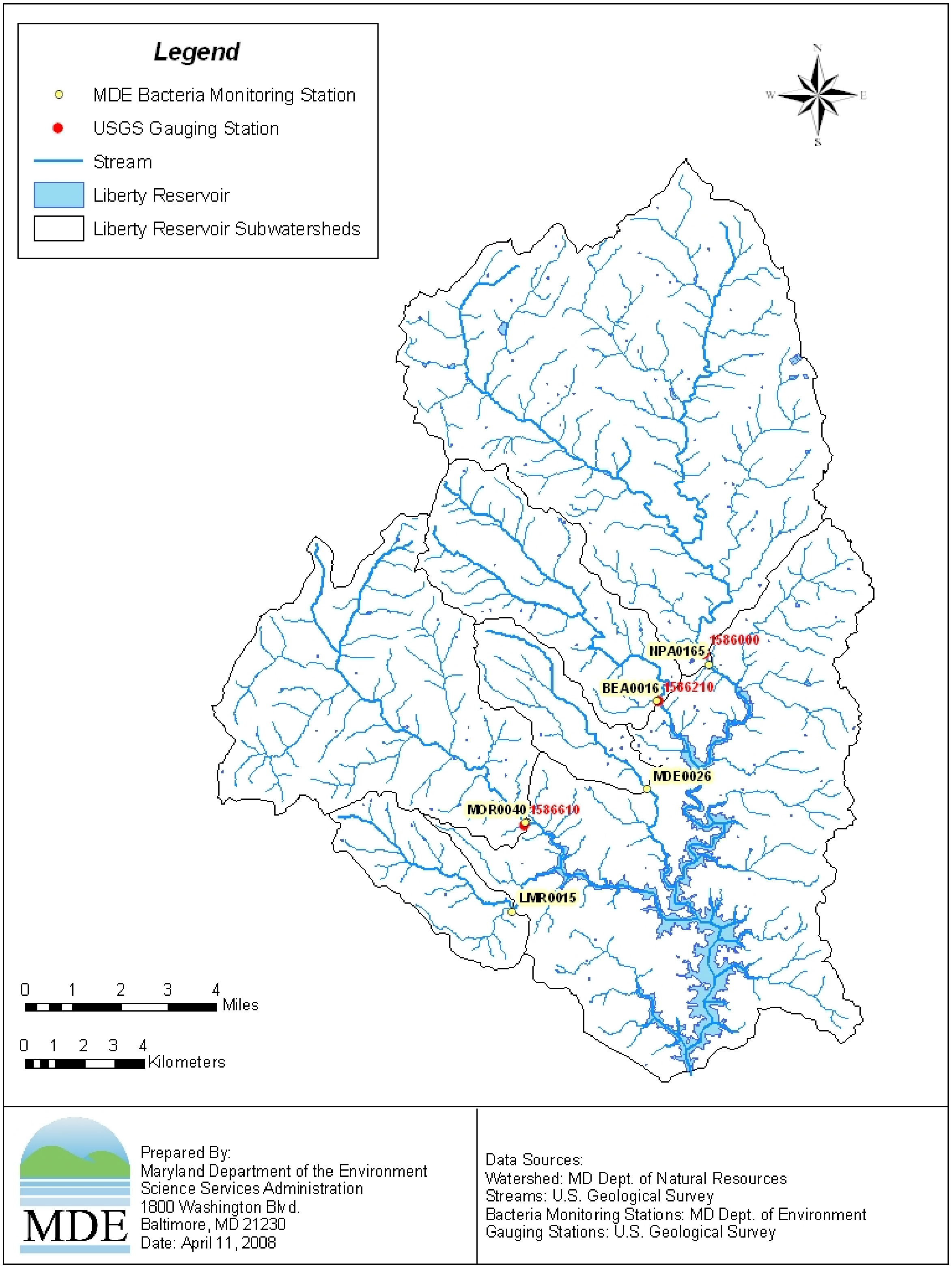

Figure 2.2.1: Monitoring Stations for the Liberty Reservoir Watershed

2.3 Water Quality Impairment

<u>Designated Uses and Water Quality Standard</u>

The Maryland water quality standards Surface Water Use Designation for the mainstem North Branch Patapsco River, mainstem West Branch Patapsco River and Cranberry Branch and it's tributaries is Use IV- P (Recreational Trout Waters and Public Water Supply). Roaring Run has been designated as Use III (Nontidal Cold Water). Beaver Run, Cooks Branch, East Branch Patapsco River, Keysers Run, Locust Run, Morgan Run, Norris Run and all their tributaries have been designated as Use III-P (Nontidal Cold Water and Public Water Supply). Liberty Reservoir and all remaining tributaries have been designated as Use I-P (Water Contact Recreation, Protection of Aquatic Life, and Public Water Supply). See Code of Maryland Regulations (COMAR) 26.08.02.08K. The Liberty Reservoir watershed was listed on Maryland's 303(d) List in 2002 as impaired by fecal bacteria. Data collected by MDE from 2003 to 2004 showed high levels of fecal bacteria in five monitoring stations throughout the watershed, confirming the fecal bacteria impairment and resulting in the development of this fecal bacteria TMDL.

Water Quality Criteria

The State water quality standard for bacteria (*E. coli*) 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/100 ml

Interpretation of Bacteria Data for General Recreational Use

The relevant portion (for freshwater) of the listing methodology pursuant to the 2006 Integrated 303(d) List for all Use Waters - Water Contact Recreation and Protection of Aquatic Life is as follows:

Recreational Waters

A steady-state geometric mean will be calculated with available data where there are at least five representative sampling events. The data shall be from samples collected during steady-state conditions and during the beach season (Memorial Day through Labor Day) to be representative of the critical condition. If the resulting steady-state geometric mean is greater than 126 *E. coli* MPN/100 ml in freshwater, the waterbody will be listed as impaired. If fewer than five representative sampling events for an area being assessed are available, data from the previous two years will be evaluated in the same way. The single sample maximum criterion applies only to beaches and is to be used for closure and advisory decisions based on short term exceedances of the geometric mean portion of the standard.

Water Quality Assessment

Bacteria water quality impairment in the Liberty Reservoir basin was assessed by comparing both the annual and the seasonal (May 1^{st} –September 30^{th}) steady-state geometric means of *E. coli* concentrations with the water quality criterion.

The steady-state condition is defined as unbiased sampling targeting average flow conditions and/or equally sampling or providing for unbiased sampling of high and low flows. The 1986 EPA criteria document assumed steady-state flow in determining the risk at various bacterial concentrations, and therefore the chosen criterion value also reflects steady-state conditions (US EPA 1986). The steady-state geometric mean condition can be estimated either by monitoring design or more practically by statistical analysis as follows:

1. A stratified monitoring design is used where the number of samples collected is proportional to the duration of high flows, mid flows and low flows within the watershed. This sample design allows a geometric mean to be calculated directly from the monitoring data without bias.

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

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

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

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

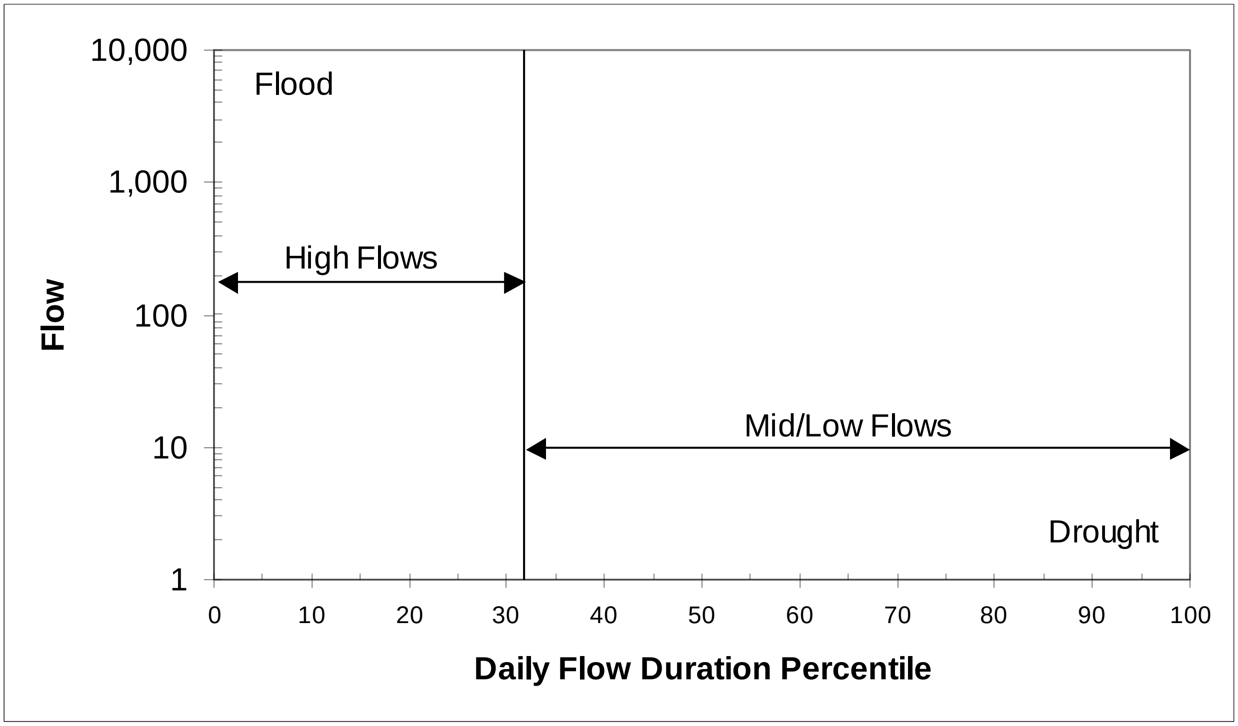

Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

During high flows, a significant portion of the total stream flow is from surface flow contributions. Low flow conditions represent periods with minimal rainfall and surface runoff. There is typically a transitional mid flow period between the high and low flow durations, representative of varying contributions of surface flow inputs that result from differing rainfall volumes and antecedent soil moisture conditions. The division of the entire flow regime into strata enables the estimation of a less biased geometric mean from routine monitoring data that more closely approaches steady-state. Based on flow data of USGS gages 01586000, 01586210 and 01586610 it was determined that the long-term average daily flow corresponds to a daily flow duration of 32%. Hence for this analysis it is defined that flows greater than the 32 percentile flow represent high flows, and flows less than the 32 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 steady-state geometric mean are based on the frequency of each flow stratum. The weighting factor accounts for the proportion of time each flow stratum represents. The weighting factors for an average hydrological year used in the Liberty Reservoir TMDL analysis are presented in Table 2.3.2.

Table 2.3.2: Weighting Factors for Average Hydrology Year Used for Estimation of Geometric Means in the Liberty Reservoir Watershed

Flow Duration Zone	Duration Interval	Weighting Factor
High Flows	0 – 32%	0.317
Mid/Low Flows	32 – 100%	0.683

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

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

where,

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

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

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

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

where,

C_{gm} = Steady-state geometric mean concentration

Tables 2.3.3 and 2.3.4 present the maximum and minimum concentrations and the geometric means by stratum, and the overall steady-state geometric mean for the Liberty Reservoir subwatersheds for the annual and seasonal (May 1^{st} – September 30^{th}) periods. For the seasonal period, no samples fell in the high flow zone. As such, for the seasonal analysis, only the overall geometric mean for the period was applied. For the downstream subwatershed the average high and low flow geometric mean concentrations of the five upstream watersheds were applied to account for the unmonitored streams.

Table 2.3.3: Liberty Reservoir Basin Annual Steady-State Geometric Mean by Flow Stratum per Monitoring Station

Station / Tributary	Flow Stratum	Number of Samples	*E. coli* Minimum Concentration (MPN/100ml)	*E. coli* Maximum Concentration (MPN/100ml)	Annual Steady State Geometric Mean (MPN/100ml)	Annual Weighted Geometric Mean (MPN/100ml)
NPA0165 North Branch Patapsco River	**High**	14	10	9,800	107	236
	Low	10	70	5,800	339	
BEA0016 Beaver Run	**High**	13	20	930	82	153
	Low	11	20	4,400	204	
MDE0026 Middle Run	**High**	13	30	24,190	217	402
	Low	11	220	1,670	534	
MOR0040 Morgan Run	**High**	11	10	1,990	66	106
	Low	13	10	960	132	
LMR0015 Little Morgan Run	**High**	11	10	1,330	40	102
	Low	13	10	620	158	
Downstream Subwatershed	**High**	N/A			102	200
	Low				274	

Table 2.3.4: Liberty Reservoir Basin Seasonal Period (May 1 – September 30) Steady-State Geometric Mean per Monitoring Station

Station / Tributary	Number of Samples	*E. coli* Minimum Concentration (MPN/100ml)	*E. coli* Maximum Concentration (MPN/100ml)	Seasonal Steady State Geometric Mean (MPN/100ml)
NPA0165 North Branch Patapsco River	10	110	5,800	427
BEA0016 Beaver Run	10	60	4,400	278
MDE0026 Middle Run	10	250	1,670	607
MOR0040 Morgan Run	10	50	960	172
LMR0015 Little Morgan Run	10	50	510	200
Downstream Subwatershed	N/A			337

2.4 Source Assessment

Nonpoint Source Assessment

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

The Liberty Reservoir watershed is serviced by both sewer systems and septic systems. Sewer systems are either present or planned in the towns of Westminster, Manchester, Hampstead, Eldersburg, and Reisterstown. The wastewater treatment plants (WWTP) for these towns do not fall within the Liberty Reservoir watershed. On-site disposal (septic) systems are located throughout the Liberty Reservoir basin. Table 2.4.1 presents the total number of septic systems per subwatershed. Figure 2.4.1 depicts the sewer service areas and the locations of the septic systems.

Table 2.4.1: Septic Systems per Subwatershed in the Liberty Reservoir Basin

Station / Subwatershed	Septic Systems (units)
NPA0165 / North Branch Patapsco River	4,739
BEA0016 / Beaver Run	1,980
MDE0026 / Middle Run	961
MOR0040 / Morgan Run	2,245
LMR0015 / Little Morgan Run	1,309
Downstream Subwatershed	4,085
Total	**15,319**

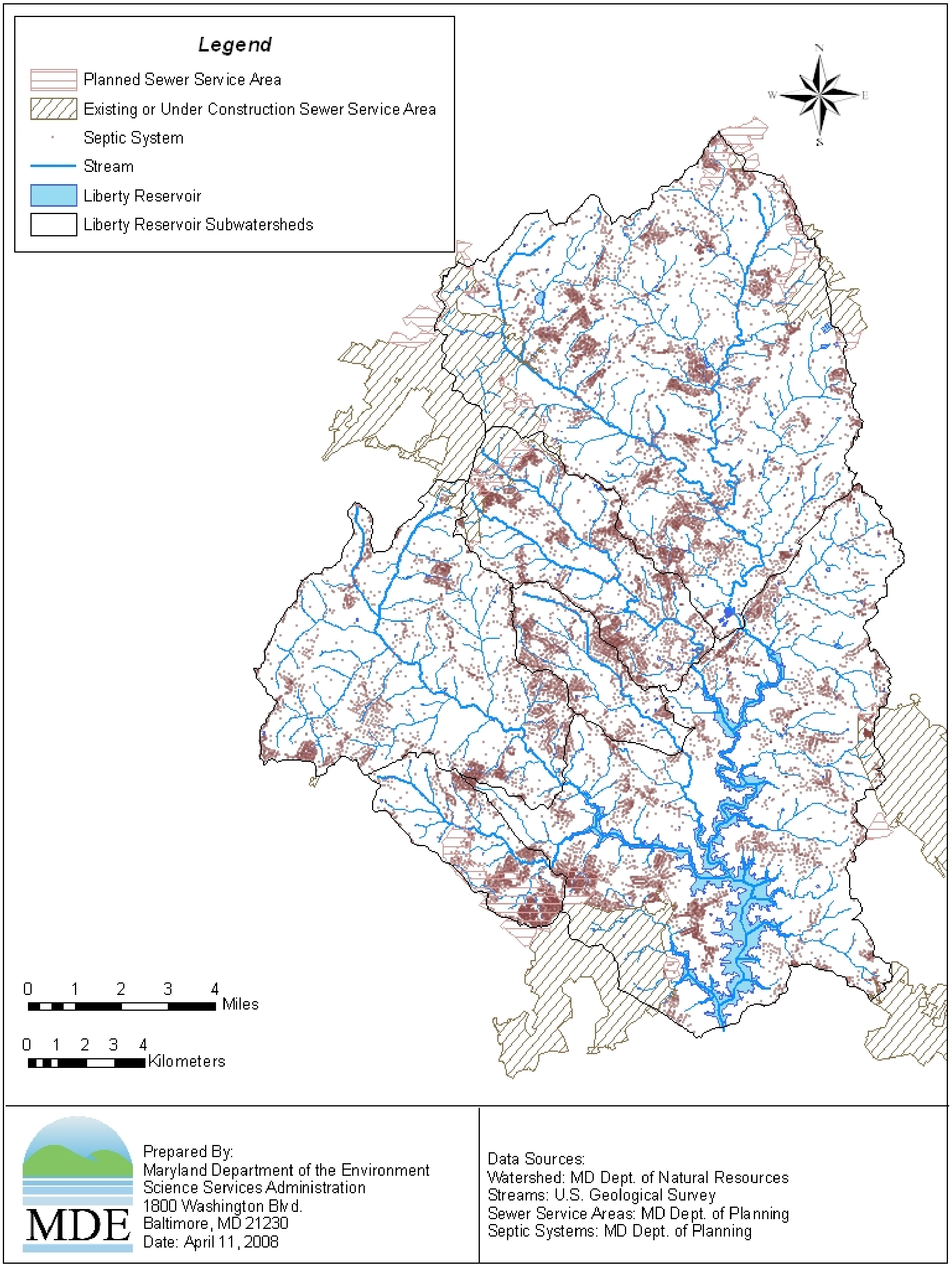

Figure 2.4.1: Septic Systems and Sewer Service Areas in the Liberty Reservoir Watershed

Point Source Assessment

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

NPDES Regulated Stormwater

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

The Liberty Reservoir basin is located in Baltimore and Carroll Counties, which both have individual NPDES Phase I MS4 permits. The municipalities of Westminster, Hampstead and Manchester are also covered by a general NPDES Phase II MS4 permit. Statements and information provided to MDE by the two Counties characterize much of the Liberty Reservoir watershed as essentially outside the reach of each County's stormwater system management plan (with the exception of the Westminster, Hampstead, and Manchester Phase II areas, and the Eldersburg Phase I urban area):

> "The Liberty Reservoir serves as a drinking water reservoir for the Baltimore metropolitan region. Predominate land use for the Baltimore County portion of the Liberty Reservoir watershed is forest cover. As such, an NPDES urban stormwater management plan is not required. Current zoning and reforestation activities will maintain the Liberty Reservoir watershed's undeveloped status." (Baltimore County 2006)
>
> "The Liberty Reservoir serves as a source of drinking water for the Baltimore metropolitan region. In addition, the Carroll County Commissioners also withdraw raw water from the Liberty Reservoir that is treated and distributed to a service area in the Eldersburg and Sykesville areas of Carroll County. As Liberty Lake lies upon the jurisdictional boundary between Carroll and Baltimore Counties, the western shoreline and the predominate watershed area is located within Carroll County.
>
> "The incorporated towns of Westminster, Hampstead and Manchester, as well as the Eldersburg area in southern Carroll County, along the MD Rt. 26 corridor, constitute the

> predominate urban areas in Carroll County within the Liberty watershed. Westminster, Hampstead and Manchester are covered under the MS4 Phase II General Permit. The Eldersburg urban area is located along MD Rt. 26 west of Liberty Reservoir to a point just west of the MD Rt. 32 and east of the Piney Run Reservoir. It also extends somewhat north of MD Rt. 26, along MD Rt. 32 and south to the State lands around Springfield Hospital and the Patapsco Valley Park system and the incorporated Town of Sykesville. The approximate 3500 acre Eldersburg urban area is served by public water and sewer and is characterized by a mix of residential, commercial and light industrial development. The development within the Eldersburg area is generally served by a concentrated systemic urban storm sewer collection and management system. In addition, the Snowdens Run subwatershed is the subject of Carroll County's current watershed assessment and restoration planning efforts, as defined by the County's Phase I MS4 NPDES permit. Conversely, the remaining unincorporated lands within the Liberty watershed within Carroll County are generally characterized by agriculture or large lot residential uses with some light commercial and some isolated industrial land uses. Much of the development in those unincorporated areas is not served by an organized storm sewer management system, but rather by small fragmented systems that are often discharged through infiltration." (Carroll County, 2008)

MDE's Water Management Administration (WMA) has confirmed these characterizations of the watershed. Carroll County's Department of Planning has provided MDE with data and GIS files delineating the reach of the Phase II stormwater areas in Westminster, Manchester and Hampstead and the Phase I stormwater system in the Eldersburg urban area. Additionally, there are thirteen industrial stormwater permits in the watershed outside of these areas.

Sanitary Sewer Overflows

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

There were a total of six SSOs reported to MDE between November 2003 and October 2004 in the Liberty Reservoir watershed. Approximately 7,825 gallons of SSOs were discharged through various waterways (surface water, groundwater, sanitary sewers, etc.). Figure 2.4.2 shows the locations where SSOs occurred in the watershed between November 2003 and October 2004. Two of the events reported occurred at the same location.

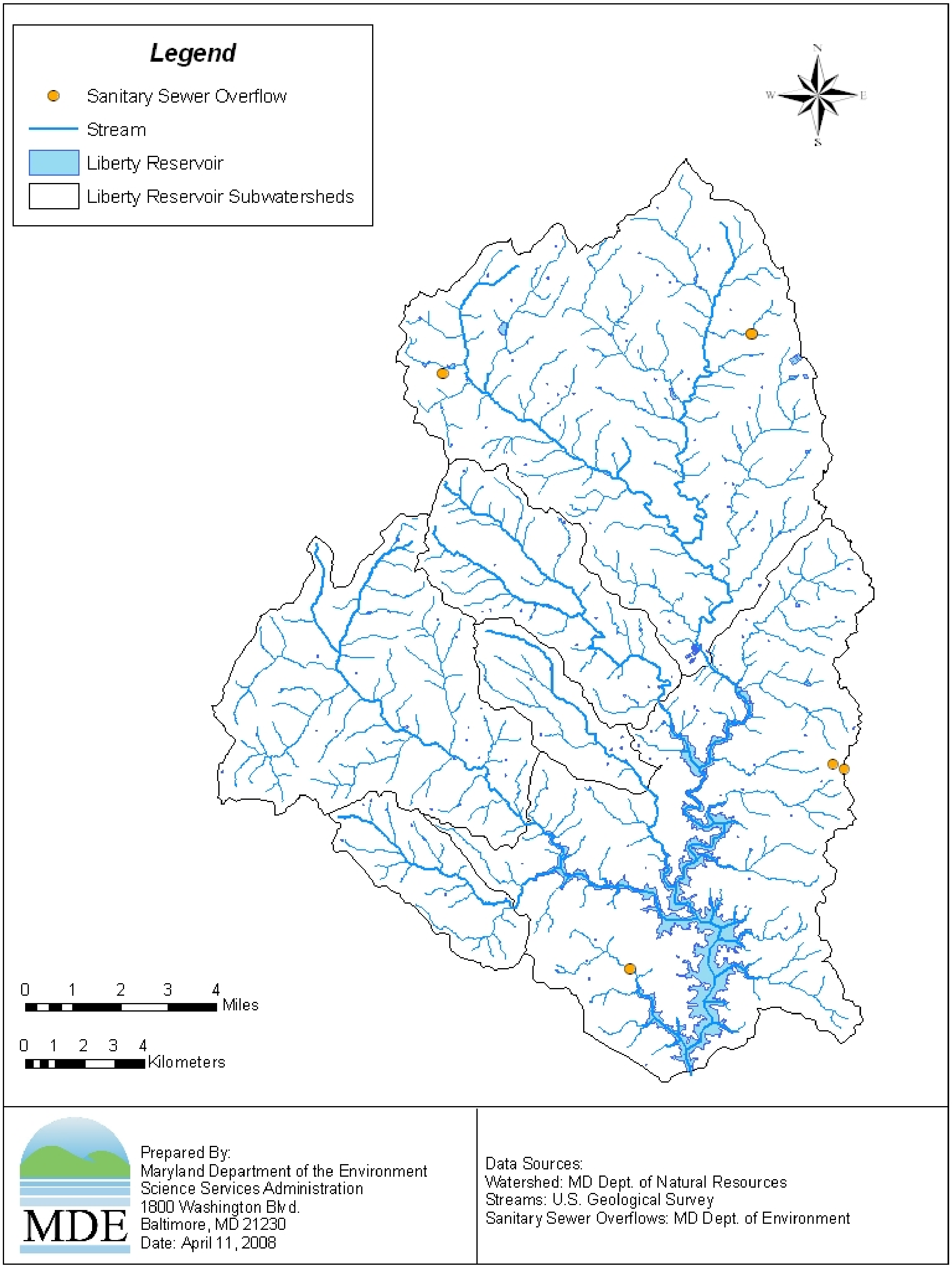

Figure 2.4.2: Sanitary Sewer Overflow Areas in the Liberty Reservoir Watershed

Municipal and Industrial Wastewater Treatment Plants (WWTPs)

Wastewater treatment plants 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 two active industrial NPDES permitted point source facilities with permits regulating the discharge of fecal bacteria in the Liberty Reservoir watershed. These two facilities combined treat approximately 0.45 MGD (million gallons per day). There are no municipal facilities in the Liberty Reservoir watershed with NPDES permits regulating the discharge of fecal bacteria. Table 2.4.2 lists these facilities and Figure 2.4.3 shows their location in the watershed.

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

Facility	NPDES Permit No.	County	Average Flow (MGD)	Fecal Coliform Concentration Annual AVG (MPN/100ml)	Fecal Coliform Load (Billion MPN/day)
Congoleum Corporation	MD0001384	Carroll	0.194	11.01	0.081
AG/GFI Hampstead, Inc	MD0001881	Carroll	0.255	2.00	0.019

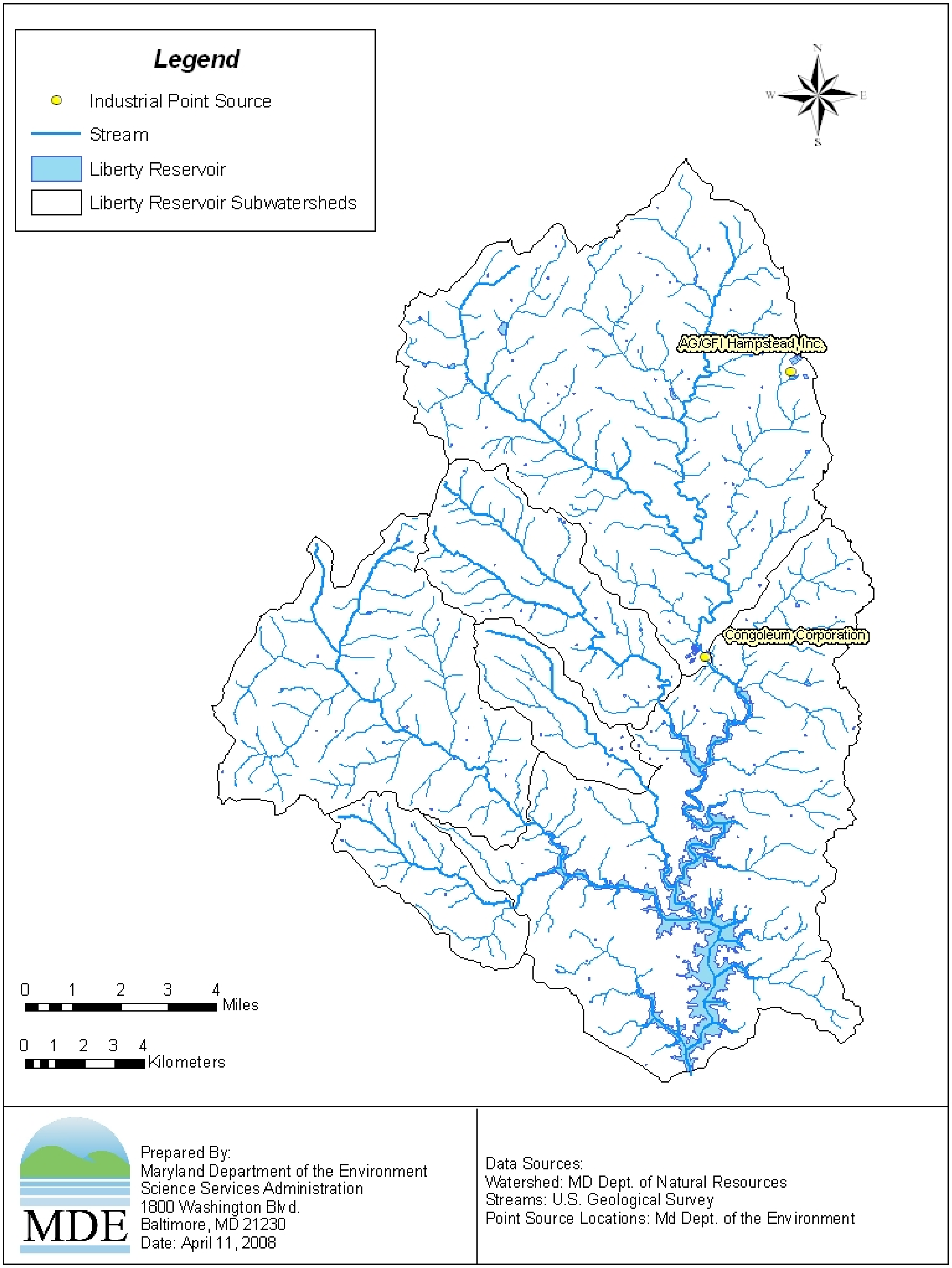

Figure 2.4.3: Permitted Point Sources Discharging Fecal Bacteria in the Liberty Reservoir Watershed

Bacteria Source Tracking

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

An accurate representation of the expected contribution of each source at each station is estimated by using a stratified weighted mean of the identified sample results. The weighting factors are based on the $\log_{10}$ of the bacteria concentration and the percent of time that represents the high stream flow or low stream flow (see Appendix B). The procedure for calculating the stratified weighted mean of the sources per monitoring station is as follows:

1. Calculate the percentage of isolates per source per each sample date (S).
2. Calculate an initial 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. Adjust the weighted percentage based on the classification of known sources.
4. The final weighted mean source percentage, for each source category, is based on the proportion of time in each flow duration zone.

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

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

where,

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

where,

$$IMS_{i,k} = \frac{\sum_{j=1}^{n_i} \log_{10}(C_{i,j}) * S_{i,j,k}}{\sum_{j=1}^{n_i} \log_{10}(C_{i,j})} \qquad (6)$$

and where,

MS_l = weighted mean proportion of isolates of source *l*
$MS_{i,l}$ = adjusted weighted mean proportion of isolates for source *l* in stratum *i*
$IMS_{i,k}$ = initial weighted mean proportion of isolates for source *k* in stratum *i*

W_i = proportion covered by stratum i
$A_{l,k}$ = number of known source l isolates initially predicted as source k
P_k = number of total known isolates initially predicted as source k
i = stratum
j = sample
k = source category (1=human, 2=domestic, 3=livestock, 4=wildlife, 5=unknown)
l = final source category (1=human, 2=domestic, 3=livestock, 4=wildlife)
$C_{i,j}$ = concentration for sample j in stratum i
$S_{i,j,k}$ = proportion of isolates for sample j, of source k in stratum i
n_i = number of samples in stratum i

The complete distributions of the annual and seasonal periods source loads are listed in Tables 2.4.3 and 2.4.4. Details of the BST data and tables with the BST analysis results can be found in Appendix C. For the downstream subwatershed averages of the three upstream source percentages were used.

In the seasonal period, either no or fewer than five samples fell in the high flow category in these subwatersheds; therefore, a distribution by flow stratum was not calculated due to an insufficient number of samples. For the seasonal analysis, all samples between May 1st and September 30th were used to calculate an average seasonal distribution.

Table 2.4.3: Distribution of Fecal Bacteria Source Loads in the Liberty Reservoir Basin for the Average Annual Period

Station	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife
NPA00165	High	8.1	16.8	50.9	24.2
	Low	15.3	37.3	17.9	29.5
	Weighted	13.0	30.8	28.4	27.8
BEA0016	High	17.7	24.2	34.7	23.4
	Low	12.3	31.5	25.0	31.2
	Weighted	14.0	29.2	28.1	28.8
MDE0026	High	17.9	24.5	33.8	23.8
	Low	18.1	27.1	25.9	28.9
	Weighted	18.1	26.3	28.4	27.3
MOR0040	High	14.7	12.1	38.7	34.5
	Low	16.2	25.6	26.9	31.3
	Weighted	15.7	21.3	30.7	32.3
LMR0015	High	12.2	4.4	49.9	33.5
	Low	16.5	11.6	35.0	36.8
	Weighted	15.1	9.3	39.8	35.8
Downstream Subwatershed	High	14.1	16.4	41.6	27.9
	Low	15.7	26.6	26.1	31.5
	Weighted	15.2	23.4	31.0	30.4

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

Station	% Domestic Animals	% Human	% Livestock	% Wildlife
NPA0165	10.1	12.3	36.5	37.4
BEA0016	11.3	30.9	26.7	31.1
MDE0026	20.2	28.2	24.2	27.4
MOR0040	17.0	23.5	28.6	30.9
LMR0015	13.8	12.3	36.5	37.4
Downstream Subwatershed	14.5	24.9	29.6	31.0

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 ensure attainment of water quality standards in the Liberty Reservoir watershed. These standards are described fully in Section 2.3, "Water Quality Impairment."

4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION

4.1 Overview

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

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

For many reasons, bacteria are difficult to simulate in water quality models. They reproduce and die off in a non-linear fashion as a function of many environmental factors, including temperature, pH, turbidity (UV light penetration) and settling. They occur in concentrations that vary widely (i.e., over orders of magnitude) and 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 (Method 1600) is a direct estimate of the bacteria colonies (US EPA 1985). 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 the limited data available. 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

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

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

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

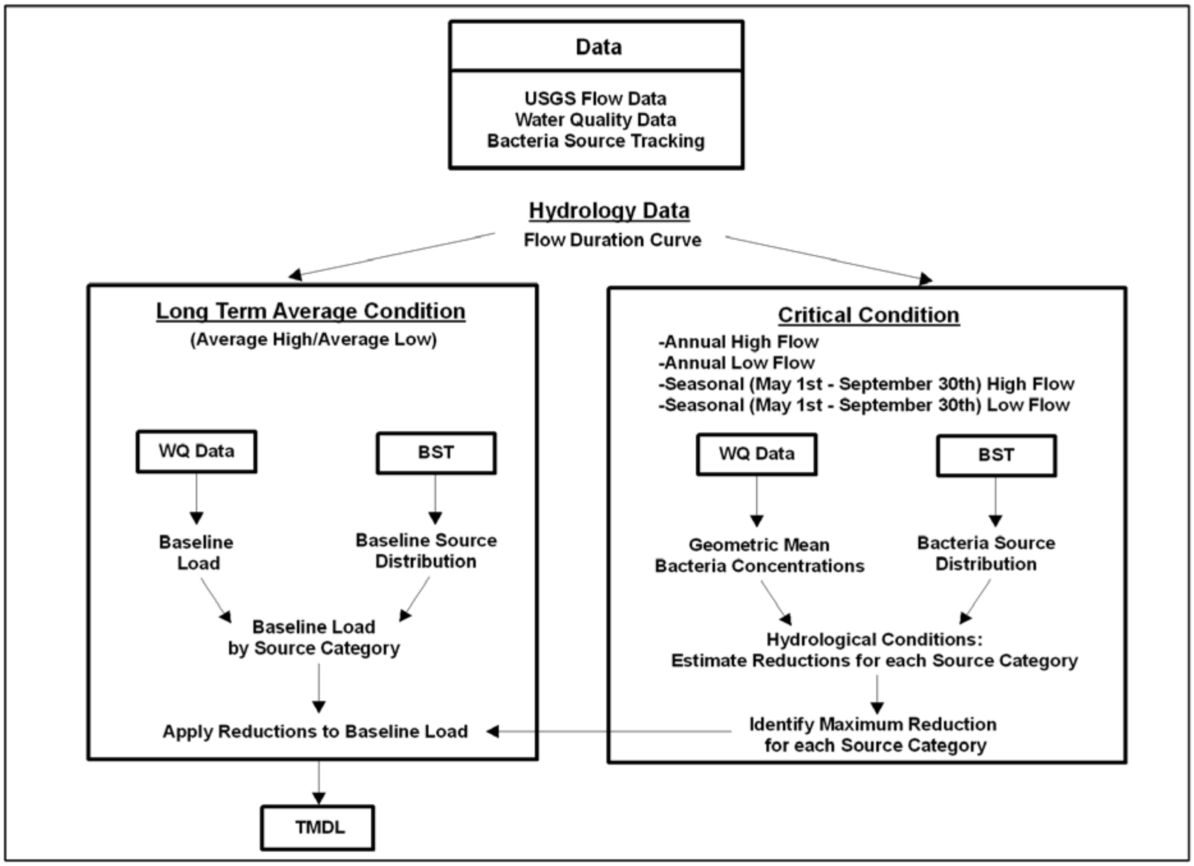

Figure 4.2.1: Diagram of the Non-Tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

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).

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

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

$$F_{1i} = A_i/C_i \qquad (7)$$

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:

$$L_i = Q_i * C_i * F_{1i} * F_2 \qquad (8)$$

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:

$$L = \sum_{i=1}^{2} L_i * W_i \qquad (9)$$

where,

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

In the Liberty Reservoir watershed, weighting factors of 0.317 for high flow and 0.683 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 are subdivided into unique watershed segments, thus allowing individual load and reduction targets to be determined for each. In the Liberty Reservoir watershed the portion of the watershed downstream of the five monitoring stations, as listed in Table 4.3.1, is referred to as the Downstream Subwatershed. This identification represents only the area and load downstream of the five stations.

Table 4.3.1: Subdivided Watersheds in the Liberty Reservoir Watershed

Subwatershed	Upstream Station(s)
Downstream Subwatershed	NPA0165, BEA0016, MDE0026, MOR0040, LMR0015

Bacteria loads from this subwatershed are joined by loads from the upstream subwatersheds to result in the concentration that would be measured downstream. However, for the purposes of this TMDL, the downstream bacteria concentration is assigned as the average of the five upstream concentrations and is assumed to be representative of the downstream subwatershed. The bacteria source distribution for the downstream subwatershed is also assigned as the average of the BST analysis results of the five upstream stations.

Results of the baseline load calculations are presented in Table 4.3.2. A summary of the baseline loads is given in Table 4.3.3.

Table 4.3.2: Baseline Load 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)	
NPA0165	56.0	136.7	107	35.9	339	525,154
BEA0016	14.1	33.9	82	9.3	204	49,032
MDE0026	6.1	14.8	217	4.0	534	103,531
MOR0040	28.1	73.8	66	18.0	132	76,369
LMR0015	7.1	18.6	40	4.6	158	15,078
Downstream Subwatershed	52.4	127.8	102	33.6	274	314,084

Table 4.3.3: Liberty Reservoir Baseline Loads Summary

MD 8-Digit Liberty Reservoir Fecal Bacteria Baseline Loads (Billion MPN *E. coli*/year)						
Total Baseline Load	=	**Nonpoint Source BL**	+	**Stormwater BL**	+	**WWTP BL**
1,083,248	=	979,511	+	102,692	+	1,045

4.4 Critical Condition and Seasonality

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

For this TMDL the critical condition is determined by assessing annual and seasonal hydrological conditions for high flow and low flow periods. Seasonality is assessed as the time period when water contact recreation is expected, specifically May 1st through September 30th. For this TMDL analysis, the average hydrological condition over a 20-year period has been estimated as 32% high flow and 68% low flow as defined in Appendix B. Using the definition of a high flow condition as occurring when the daily flow duration interval is less than 32% and a low flow condition as occurring when the daily flow duration interval is greater than 32%, critical hydrological condition can be estimated by the percent of high or low flows during a specific period.

Using long-term flow data from USGS stations 01586000, 01586210, and 01586610, critical condition and seasonality has been determined by assessing various hydrological conditions to account for seasonal and annual averaging periods. The four conditions listed in Table 4.4.1 were used to account for the annual, critical, and seasonal conditions.

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

USGS Gage	Hydrological Condition		Averaging Period	Water Quality Data Used	Fraction High Flow	Fraction Low Flow	Condition Period
01586000	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.778	0.223	May 2003 – May 2004
		Dry	365 days	All	0.019	0.981	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period
01586210	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.805	0.196	Jan. 1997 – Jan. 1998
		Dry	365 days	All	0.017	0.984	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period
01586610	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.934	0.066	Jan. 1996 – Jan. 1997
		Dry	365 days	All	0.011	0.989	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period

The critical condition requirement is met by determining the maximum reduction per bacteria source that satisfies all hydrological 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 all conditions.

The bacteria monitoring data for the five stations in the Liberty Reservoir basin 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 all samples of the seasonal period were taken during low flow, a geometric mean cannot be established for the high flow condition. Therefore an 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 Liberty Reservoir basin are shown in Table 4.4.2.

Table 4.4.2: Required Fecal Bacteria Reductions (by Hydrological Condition per Subwatershed) to Meet Water Quality Standards

Station / Tributary	Hydrological Condition		Domestic Animals %	Human %	Livestock %	Wildlife %
NPA0165 North Branch Patapsco River	Annual	Average	10.1	95.0	63.7	0.0
		Wet	0.0	82.0	0.0	0.0
		Dry	14.4	98.0	91.0	0.0
	Seasonal	Average	98.0	98.0	98.0	4.9
	Maximum Source Reduction		**98.0**	**98.0**	**98.0**	**4.9**
BEA0016 Beaver Run	Annual	Average	0.0	74.6	0.0	0.0
		Wet	0.0	0.0	0.0	0.0
		Dry	47.4	95.0	19.2	0.0
	Seasonal	Average	73.9	95.0	72.3	0.0
	Maximum Source Reduction		**73.9**	**95.0**	**72.3**	**0.0**
MDE0026 Middle Run	Annual	Average	91.9	98.0	98.0	0.0
		Wet	68.0	98.0	52.6	0.0
		Dry	98.0	98.0	98.0	26.0
	Seasonal	Average	98.0	98.0	98.0	33.3
	Maximum Source Reduction		**98.0**	**98.0**	**98.0**	**33.3**
MOR0040 Morgan Run	Annual	Average	0.0	0.0	0.0	0.0
		Wet	0.0	0.0	0.0	0.0
		Dry	0.0	34.9	0.0	0.0
	Seasonal	Average	12.5	95.0	21.0	0.0
	Maximum Source Reduction		**12.5**	**95.0**	**21.0**	**0.0**
LMR0015 Little Morgan Run	Annual	Average	0.0	0.0	0.0	0.0
		Wet	0.0	0.0	0.0	0.0
		Dry	13.3	95.0	28.4	0.0
	Seasonal	Average	25.8	95.0	68.5	0.0
	Maximum Source Reduction		**25.8**	**95.0**	**68.5**	**0.0**
Downstream Subwatershed	Annual	Average	18.1	95.0	53.2	0.0
		Wet	0.0	36.9	0.0	0.0
		Dry	61.2	95.0	75.0	0.0
	Seasonal	Average	75.9	98.0	98.0	0.0
	Maximum Source Reduction		**75.9**	**98.0**	**98.0**	**0.0**

4.5 Margin of Safety

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

Based on EPA guidance, the MOS can be achieved through two approaches (US EPA 1991a). 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.

4.6 Scenario Descriptions

Source Distribution

The final bacteria source distribution and corresponding baseline loads are derived from the source proportions listed in Table 2.4.3. The source distribution and baseline loads used in the TMDL scenarios are presented in Table 4.6.1.

Table 4.6.1: 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)	
NPA0165	13.0	68,231	30.8	161,843	28.4	149,083	27.8	145,997	525,154
BEA0016	14.0	6,873	29.2	14,302	28.0	13,754	28.8	14,103	49,032
MDE0026	18.1	18,705	26.3	27,221	28.4	29,386	27.3	28,219	103,531
MOR0040	15.7	12,025	21.3	16,276	30.7	23,422	32.3	24,646	76,369
LMR0015	15.1	2,283	9.3	1,407	39.8	5,994	35.8	5,394	15,078
Downstream Subwatershed	15.2	47,718	23.4	73,448	31.0	97,521	30.4	95,397	314,084

<u>First Scenario: Fecal Bacteria Practicable Reduction Targets</u>

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.6.2. These values are based on review of the available literature and best professional judgment. It is assumed that human sources would potentially have the highest risk of causing gastrointestinal illness and therefore should have the highest reduction. If a domestic WWTP is located in the upstream watershed, this is considered in the MPR so as to not violate the permitted loads. The domestic animal category includes sources from pets (e.g., dogs) and the MPR is based on an estimated success of education and outreach programs.

Table 4.6.2: Maximum Practicable Reduction Targets

Max Practicable Reduction per Source	Human	Domestic	Livestock	Wildlife
	95%	75%	75%	0%
Rationale	(a) Direct source inputs. (b) Human pathogens more prevalent in humans than animals. (c) Enteric viral diseases spread from human to human.[1]	Target goal reflects uncertainty in effectiveness of urban BMPs[2] and is also based on best professional judgment	Target goal based on sediment reductions from BMPs[3] and best professional judgment	No programmatic approaches for wildlife reduction to meet water quality standards. Waters contaminated by wild animal wastes offer a public health risk that is orders of magnitude less than that associated with human waste.[4]

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

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

The practicable reduction scenario was developed based on an optimization analysis whereby a subjective estimate of risk was minimized and constraints were set on maximum reduction and allowable background conditions. Risk was defined on a scale of one to five, where it was assumed that human sources had the highest risk (5), domestic animals and livestock next (3), and wildlife the lowest (1) (See Table 4.6.2). The model was defined as follows:

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

where,

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

and,

$$TR = \frac{C - C_{cr}}{C} \tag{11}$$

Therefore the risk score can be represented as:

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

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:

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

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

Table 4.6.3: Maximum Practicable Reduction Scenario Results

Subwatershed	Applied Reductions				Total Reduction %	Target Reduction %	Achievable?
	Domestic Animals %	Human %	Livestock %	Wildlife %			
NPA0165	75.0	95.0	75.0	0.0	60.3	72.1	No
BEA0016	73.9	95.0	72.3	0.0	58.3	58.3	Yes
MDE0026	75.0	95.0	75.0	0.0	59.8	80.4	No
MOR0040	12.5	95.0	21.0	0.0	28.6	28.6	Yes
LMR0015	25.8	95.0	68.5	0.0	40.0	40.0	Yes
Downstream Subwatershed	75.0	95.0	75.0	0.0	56.9	64.9	No

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, three of the six subwatersheds could meet water quality standards based on MPRs. Therefore, this second scenario was applied only to subwatersheds NPA0165, MDE0026, and the downstream subwatershed where water quality standards could not be met by applying the MPRs.

To further develop the TMDL, a second scenario was analyzed in which the constraints on the MPRs were relaxed. In these subwatersheds, the maximum allowable reduction was increased to 98% for all sources, including wildlife. A similar optimization procedure as before was used to minimize risk. Again, the objective is to minimize the sum of the risk for all conditions while meeting the scenario reduction constraints. The model was defined in the same manner as considered in the practicable reduction scenario but subject to the following constraints:

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

A summary of the results of this second scenario analysis is presented in Table 4.6.4.

Table 4.6.4: Reduction Results Based on Optimization Model Allowing up to 98% Reduction of All Sources

Subwatershed	Applied Reductions				Total Reduction %	Target Reduction %
	Domestic %	Human %	Livestock %	Wildlife %		
NPA0165	98.0	98.0	98.0	4.9	72.1	72.1
BEA0016	73.9	95.0	72.3	0.0	58.3	58.3
MDE0026	98.0	98.0	98.0	33.3	80.4	80.4
MOR0040	12.5	95.0	21.0	0.0	28.6	28.6
LMR0015	25.8	95.0	68.5	0.0	40.0	40.0
Downstream Subwatershed	75.9	98.0	98.0	0.0	64.9	64.9

4.7 TMDL Loading Caps

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

The TMDL loading caps are provided in billion MPN *E. coli*/day. These loading caps are for the five subwatersheds located upstream of their respective monitoring stations (NPA0165, BEA0016, MDE0026, MOR0040, and LMR0015) as well as the one downstream watershed.

Annual Average TMDL Loading Caps

As explained in the sections above, the annual average TMDL loading caps are estimated by first determining the baseline or current condition loads for each subwatershed and the associated geometric mean from the available monitoring data. This annual average baseline load is estimated using the geometric mean concentration and 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 4.4). A reduction in concentration is proportional to a reduction in load; thus the TMDL is equal to the current baseline load multiplied by one minus the required reduction. This reduction, estimated as explained in Section 4.4, represents the maximum reduction per source that satisfies all hydrological conditions in each subwatershed, and 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 4.7.1 and 4.7.2.

Table 4.7.1: 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
NPA0165 North Branch Patapsco River	525,154	146,397	72.1
BEA0016 Beaver Run	49,032	20,425	58.3
MDE0026 Middle Run	103,531	20,333	80.4
MOR0040 Morgan Run	76,369	54,496	28.6
LMR0015 Little Morgan Run	15,078	9,044	40.0
Downstream Subwatershed	314,084	110,313	64.9
Total	**1,083,248**	**361,008**	**66.7**

Table 4.7.2: 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)	
NPA0165 North Branch Patapsco River	0.9	1,364	2.2	3,237	2.0	2,982	94.8	138,814	146,397
BEA0016 Beaver Run	8.8	1,797	3.5	715	18.7	3,810	69.0	14,103	20,425
MDE0026 Middle Run	1.8	374	2.7	545	2.9	588	92.6	18,826	20,333
MOR0040 Morgan Run	19.3	10,526	1.5	814	34.0	18,510	45.2	24,646	54,496
LMR0015 Little Morgan Run	18.7	1,693	0.8	70	20.9	1,889	59.6	5,392	9,044
Downstream Subwatershed	10.4	11,496	1.3	1,469	1.8	1,950	86.5	95,398	110,313

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

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

Third, based on the estimated long-term average (LTA) TMDL concentrations, the 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 Liberty Reservoir subwatersheds are shown in Table 4.7.3.

Table 4.7.3: Maximum Daily Loads Summary

Subwatershed	Flow Stratum	Maximum Daily Load (Billion *E. coli* MPN/day)	
		by Stratum	Weighted by Stratum
NPA0165	High	10,981	5,586
	Low	3,082	
BEA0016	High	756	779
	Low	789	
MDE0026	High	1,721	594
	Low	71	
MOR0040	High	4,727	2,330
	Low	1,217	
LMR0015	High	590	362
	Low	256	
Downstream Subwatershed	High	3,755	1,930
	Low	1,083	

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

4.8 TMDL Allocation

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

$$TMDL = LA + WLA + MOS \qquad (14)$$

where,

LA = Load Allocation
WLA = Waste Load Allocation
MOS = Margin of Safety

The TMDL allocation includes load allocations (LA) for nonpoint sources and waste load allocations (WLA) for point sources including WWTPs and NPDES-regulated stormwater discharges. The Stormwater (SW) WLA 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 and to the SW-WLA and WWTP-WLA is provided in the subsections that follow.

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.

<u>Bacteria Source Categories and Allocation Distributions</u>

The bacteria sources are grouped into four categories that are also consistent with divisions for various management strategies. The categories are human, domestic animal, livestock and wildlife. TMDL allocation rules are presented in Table 4.8.1. This table identifies how the TMDL will be allocated among the LA (those nonpoint sources or portions thereof not transported and discharged by stormwater systems) and the WLA (point sources including WWTPs and NPDES regulated stormwater discharges). Only the final LA or WLA is reported in this TMDL.

Table 4.8.1: Potential Source Contributions for TMDL Allocation Categories

Source Category	TMDL Allocation Categories		
	LA	WLA	
		WWTP*	Stormwater
Human	X	X	X
Domestic	X		X
Livestock	X		
Wildlife	X		X

* Industrial facilities

<u>LA</u>

All four bacteria source categories could potentially contribute to nonpoint source loads. For human sources, if the watershed has no MS4s or other NPDES-regulated Phase I or Phase II stormwater discharges, the nonpoint source contribution is estimated by subtracting any WWTP and/or CSO loads from the TMDL human load, and is then assigned to the LA. However, in watersheds covered by NPDES-regulated stormwater permits, any such nonpoint sources of human bacteria (i.e., beyond the reach of the sanitary sewer systems) are assigned to the SW-WLA (see below). For this TMDL, information provided by the two Counties identifies limited areas of the watershed that are subject to stormwater management controls. Therefore, in the Liberty Reservoir TMDL, the human nonpoint source load is distributed between the SW-WLA and the LA on the basis of the delineation of these areas.

Livestock loads are all assigned to the LA. Domestic animals (pets) loads are assigned to the LA in watersheds with no MS4s or other NPDES-regulated stormwater systems. Although the entire Liberty Reservoir watershed lies within counties with Phase I NPDES MS4 permits, bacteria loads from domestic animal, human and wildlife sources are distributed between the SW-WLA, for areas delineated as subject to stormwater management, and the LA for the remaining areas not served by stormwater systems.

<u>WLA</u>

NPDES Regulated Stormwater

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

Information regarding the stormwater management status of the Liberty Reservoir watershed, provided to MDE by Baltimore and Carroll Counties, allowed for the determination of the SW-WLA based on the spatial delineation of the extent of organized stormwater systems within each County's jurisdiction. In this case, bacteria loads from domestic animal sources and human nonpoint sources are distributed between the SW-WLA and the LA based on a ratio of the population in the areas under stormwater management to the population in remaining areas not served by organized stormwater systems. The bacteria load from wildlife sources is distributed between the SW-WLA and the LA based on a ratio of the per capita acreage in the areas under stormwater management to the per capita acreage in remaining areas not served by organized stormwater systems. This weighting allows for a greater domestic animal and human source allocation in areas more populated by humans, and a greater wildlife source allocation to areas less populated by humans. Permitted discharges outside of Phase I and Phase II MS4 areas are factored into an "Other SW-WLA" based on the percentage of the area of non-residential urban impervious land. In watersheds with no existing NPDES-regulated stormwater permits, these loads will be included entirely in the LA. [Note: The human nonpoint source load in the SW-WLA is estimated by subtracting any loads allocated to WWTPs and CSOs, if present, from the total allowable (TMDL) human load. There are no municipal and two industrial wastewater treatment facilities with NPDES permits regulating the discharge of fecal bacteria in the Liberty Reservoir watershed. There are no NPDES CSO permits in the watershed.]

The MD portion of the Liberty Reservoir watershed lies within the jurisdictions of Baltimore County and Carroll County, which both have individual Phase I MS4 permits. The municipalities of Westminster, Hampstead and Manchester in Carroll County are also covered by a general Phase II MS4 permit. Based on EPA's guidance and information made available to MDE by the two Counties, SW-WLAs are presented as combined loads for each of the areas within the three Phase II jurisdictions in Carroll County that are subject to stormwater management, including any other separately permitted stormwater dischargers within those areas. Additionally an "Other SW-WLA" is provided for Carroll County's Phase I regulated stormwater systems in the Eldersburg urban area and any other NPDES-regulated stormwater dischargers in Carroll County's portion of the watershed (outside of the three Phase II municipalities). The remaining areas of the watershed (including the entire Baltimore County portion) are outside the reach of the Counties' organized stormwater systems and therefore not subject to WLA assignment. (See Section 2.4 Source Assessment, pp. 21-22, for the Counties' stormwater management assessments of the Liberty watershed.). The SW-WLA includes loads from sources such as leaks from broken sanitary infrastructure and failing septic systems, which may be transported through the storm drain system. These loads may be more effectively controlled through other management programs, but at this time such components cannot be determined separately. As stormwater assessment and/or other program monitoring efforts result in a more refined source assessment, MDE reserves the right to revise the current SW-WLA, provided the revisions are consistent with achieving water quality standards. 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). The SW-WLA distribution for the Liberty Reservoir watershed is presented in Table 4.8.2.

Table 4.8.2: Annual Average Stormwater Allocations in the Liberty Reservoir Watershed

Subwatershed	Hampstead SW-WLA	Manchester SW-WLA	Westminster SW-WLA	Carroll County Other SW-WLA
	(Billion MPN *E. coli*/year)			
NPA0165	458	243	1,330	1,506
BEA0016	0	0	32	340
MDE0026	0	0	0	67
MOR0040	0	0	0	58
LMR0015	0	0	0	967
Downstream Subwatershed	0	0	0	4,325

Municipal and Industrial WWTPs

Based on MDE's point source permitting information, there are two industrial NPDES permitted point source facilities regulating the discharge of fecal bacteria in the Liberty Reservoir basin, which include: 1) Congoleum Corporation (MD0001384), and 2) AG/GFI Hampstead, Inc. (MD0001881). The fecal bacteria WLAs for the WWTPs are typically estimated using the design flows of the plants stated in the facilities' NPDES permits and the *E. coli* criterion of 126 MPN/100ml. Since the permits for these two minor industrial facilities provide no design flows, the maximum flows reported in 2004 were used to calculate the WLA. Bacteria loads assigned to the WWTPs are allocated as the WWTP-WLA.

4.9 Summary

The long-term annual average TMDL and TMDL allocations are presented in Table 4.9.1. Table 4.9.2 presents the maximum daily loads for the subwatersheds.

Table 4.9.1: Annual Average TMDL

Subwatershed	Total Allocation	LA	SW-WLA	WWTP-WLA
	(Billion MPN *E. coli* /year)			
NPA0165	146,397	141,816	3,536	1,045
BEA0016	20,425	20,054	372	0
MDE0026	20,333	20,265	67	0
MOR0040	54,496	54,438	58	0
LMR0015	9,044	8,077	967	0
Downstream Subwatershed	110,313	105,988	4,325	0
TMDL[1]	**361,008**	**350,638**	**9,325**	**1,045**

[1]The MOS is incorporated.

Table 4.9.2: Maximum Daily Loads

Subwatershed	Total Allocation	LA	SW-WLA	WWTP-WLA
	(Billion MPN *E. coli* /year)			
NPA0165	5,586	5,434	143	9
BEA0016	779	764	14	0
MDE0026	594	592	2	0
MOR0040	2,330	2,328	2	0
LMR0015	362	323	39	0
Downstream Subwatershed	1,930	1,854	76	0
MDL[1]	**11,580**	**11,295**	**276**	**9**

[1]The MOS is incorporated.

The long-term annual average fecal bacteria TMDL summary for the entire Liberty Reservoir basin is presented in Table 4.9.3.

Table 4.9.3: Annual Average TMDL Summary

MD 8-Digit Liberty Reservoir Fecal Bacteria TMDL (Billion MPN *E. coli*/year)								
TMDL	**=**	**LA**	**+**	**WLA**			**+**	**MOS**
				SW WLA	**+**	**WWTP WLA**		
361,008	=	350,638	+	9,325	+	1,045	+	Incorpo-rated

The fecal bacteria MDL summary for the entire Liberty Reservoir basin is presented in Table 4.9.4.

Table 4.9.4: MDL Summary

MD 8-Digit Liberty Reservoir Fecal Bacteria MDL Summary (Billion MPN *E. coli*/day)								
MDL	**=**	**LA**	**+**	**WLA**			**+**	**MOS**
				SW WLA	**+**	**WWTP WLA**		
11,580	=	11,295	+	276	+	9	+	Incorpo-rated

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 the subwatersheds of the Liberty Reservoir basin, water quality standards can be achieved in three out of the six subwatersheds with the maximum practicable reduction rates specified in Table 4.6.3. However, in three subwatersheds water quality standards can not be achieved with the maximum practicable reduction rates specified in Table 4.6.3. The TMDLs shown in Tables 4.9.1 and 4.9.2 represent reductions from current bacteria loadings that are beyond practical reductions for subwatershed NPA0165, MDE0026, and the downstream subwatershed. In cases where such high reductions are required to meet standards, it is expected that the first stage of implementation will be to carry out the MPR scenario.

5.0 ASSURANCE OF IMPLEMENTATION

Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and waste load allocations can and will be implemented. In the Liberty Reservoir watershed, the TMDL analysis indicates that, for three of the subwatersheds (NPA0165, MDE0026, and the downstream subwatershed) the reduction of fecal bacteria is beyond the MPR targets. These MPR targets were defined based on a literature review of BMPs effectiveness and assuming a zero reduction for wildlife sources. The Liberty Reservoir, North Branch Patapsco River, Middle Run, and the downstream subwatershed and their tributaries may not be able to attain water quality standards. The fecal bacteria load reductions required to meet water quality criteria in the Liberty Reservoir basin are not feasible by implementing effluent limitations and cost-effective, reasonable BMPs to nonpoint sources. Therefore, MDE proposes a staged approach to implementation beginning with the MPR scenario, with regularly scheduled follow-up monitoring to assess the effectiveness of the implementation plan.

Additional reductions will be achieved through the implementation of BMPs; however, the literature reports considerable uncertainty concerning the effectiveness of BMPs in treating bacteria. As an example, pet waste education programs have varying results based on stakeholder involvement. Additionally, the extent of wildlife reduction associated with various BMPs methods (e.g., structural, non-structural, etc.) is uncertain. Therefore, MDE intends for the required reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality and human health risk, with consideration given to ease of implementation and cost. The iterative implementation of BMPs in the watershed has several benefits: tracking of water quality improvements following BMP implementation through follow-up stream monitoring; providing a mechanism for developing public support through periodic updates on BMP implementation; and helping to ensure that the most cost-effective practices are implemented first.

Potential funding sources for implementation include the Maryland's Agricultural Cost Share Program (MACS), which provides grants to farmers to help protect natural resources, and the Environmental Quality and Incentives Program, which focuses on implementing conservation practices and BMPs on land involved with livestock and production. Though not directly linked, it is assumed that the nutrient management plans from the Water Quality Improvement Act of 1998 (WQIA) will have some reduction of bacteria from manure application practices.

Implementation and Wildlife Sources

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

After developing and implementing, to the maximum extent possible, a reduction goal based on the anthropogenic sources identified in the TMDL, Maryland anticipates that implementation to reduce the controllable nonpoint sources may also reduce some wildlife inputs to the waters.

6.0 PUBLIC PARTICIPATION

Stakeholders were informed by a March 28, 2008 MDE mailing of a notice of intent to develop a fecal bacteria TMDL for the Liberty Reservoir basin. The notice letters provided MDE contact information and offered upon request an informational briefing on the proposed TMDL. MDE received requests for a briefing from Carroll County's Health Department and Department of Planning, as well as from Mr. Gould Charshee of the Baltimore Metropolitan Council's Reservoir Technical Group (RTG). An informational briefing was provided to the RTG on July 10, 2008 and notification letters announcing availability of the draft TMDL for public review provided information on the briefing, noting that it was open to all interested parties. Another briefing was provided to officials of the Carroll County government on July 17, 2008.

A public notice of intent to establish the Liberty Reservoir fecal bacteria TMDL, announcing the opening and closing dates of the formal 30-day Public Comment Period, was published in The Carroll County Times and the Baltimore County newspaper, The Jeffersonian. The notice was also sent to MDE's stakeholder distribution list for the Liberty Reservoir watershed and all other interested parties. All were invited to send written comments on the draft TMDL to MDE. The public notice announced the availability of the draft TMDL documents, which were placed in identified public libraries located in each of the two counties that share the watershed. The 30-day public notice also provided information on how to access the draft TMDL documents on MDE's website.

All written comments received by the close of the comment period are recorded and formally responded to in a Comment Response Document (CRD), to be included in the draft final TMDL documentation package submitted to EPA for the Agency's approval. Receipt of each set of comments is acknowledged by MDE, either by letter or email to comment authors. Following EPA approval of the TMDL, the responses are made available when the CRD is posted on MDE's website, together with the final approved TMDL documentation. The CRD is also mailed to stakeholders, including all those who sent comments to MDE, along with an approval notification letter.

REFERENCES

Baltimore County, MD. 2006. NPDES - Municipal Stormwater Discharge Permit, 2006 Annual Report. Department of Environmental Protection and Resource Management. June 15, 2006. Towson, MD.

Cameron, R., Mackeney and Merle D. Pierson, eds. 1994. Environmental Indicators and Shellfish Safety. Chapman & Hall.

Carroll County, MD. 2008. NPDES - Municipal Stormwater Discharge Permit. 2008 Annual Report (Draft). Office of Environmental Compliance, Department of Planning. June 16, 2008. Westminster, MD.

Cleland, Bruce. 2003. TMDL Development from the "Bottom Up" – Part III: Duration Curves and Wet-weather Assessments. America's Clean Water Foundation. Washington D.C.

CFR (Code of Federal Regulations), 40 CFR 130.2(i), 40 CFR 130.7(c)(1). Website http://www.access.gpo.gov/nara/cfr/waisidx_04/40cfr130_04.html, last visited 06/24/05.

COMAR (Code of Maryland Regulations), 26.08.02.02, 26.08.02.03-3, 26.08.02.07, and 26.08.02.08. Website http://www.dsd.state.md.us/comar, last visited 09/21/07.

Cohn, T.A., L.L. DeLong, E.J. Gilroy, R.M. Hirsch, and D.K. Wells. 1989. Estimating Constituent Loads. Water Resources Research 25: 937-942.

Duan, N. 1983. Smearing Estimate: A Nonparametric Retransformation Method. Journal of the American Statistical Association 78:605-610.

Ferguson, R.I. 1986. River Loads Underestimated by Rating Curves. Water Resources Research 22: 74-76.

DNR (Maryland Department of Natural Resources). Maryland DNR Forest Service – Pocomoke State Forest. Website http://www.dnr.state.md.us/publiclands/eastern/pocomokeforest.asp, last visited 08/10/07.

MDP (Maryland Department of Planning). 2002. 2002 Land Use, Land Cover Map Series.

————. 2003. Estimates of Septic Systems. Baltimore: Maryland Department of Planning, Comprehensive Planning Unit.

MDE (Maryland Department of the Environment). 2002. 2002 List of Impaired Surface Waters [303(d) List] and Integrated Assessment of Water Quality in Maryland.

————. 2004. 2004 FINAL List of Impaired Surface Waters [303(d) List] and Integrated Assessment of Water Quality in Maryland.

————. 2006. 2006 FINAL List of Impaired Surface Waters [303(d) List] and Integrated Assessment of Water Quality in Maryland.

Richards, R.P. 1998. Estimation of pollutant loads in rivers and streams: A guidance document for NPS programs. Project report prepared under Grant X998397-01-0, U.S. Environmental Protection Agency, Region VIII, Denver. 108 p.

Schueler, T. 1999. Microbes and Urban Watersheds. Watershed Protection Techniques. 3(1): 551-596.

U.S. Department of Commerce. 2000. United States Census Bureau's GIS Coverage. Washington DC: US Bureau of the Census.

US EPA (U.S. Environmental Protection Agency). 1984. Health Effects Criteria for Fresh Recreational Waters. EPA-600/1-84-004.

————. 1985. Test Methods for Eschericichia coli and Enterococci in Water by the Membrane Filter Procedure. EPA600/4-85-076. Washington, DC. NTIS PB86-158052.

————. 1986. Ambient Water Quality Criteria for Bacteria-1986. EPA-440/5-84-002.

————. 1991a. Guidance for Water Quality-Based Decisions: The TMDL Process. EPA 440/4-91-001.

————. 1991b. Technical Support Document (TSD) for Water Quality-Based Toxics Control. EPA/505/2-90-001. Office of Water, Washington, D.C.

————. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012.

————. 2000. Bacteria Indicator Tool User's Guide. Office of Water. EPA-823-B-01-003.

————. 2001. Protocol for Developing Pathogen TMDLs. Office of Water. EPA 841-R-00-002. 134pp.

————. 2002a. Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs. November 22, 2002 U.S. EPA Memorandum.

————. 2002b. National Recommended Water Quality Criteria: 2002. EPA-822-R-02-047. November 2002.

————. 2003. Implementation Guidance for Ambient Water Quality Criteria for Bacteria: Draft. Office of Water, Washington, D.C. EPA-823-B-02-003.

————. 2004. Agricultural BMP Descriptions as Defined for The Chesapeake Bay Program Watershed Model. Nutrient Subcommittee Agricultural Nutrient Reduction Workshop.

————. 2006a. Establishing TMDL "Daily" Loads in Light of the Decision by the U.S. Court of Appeals for the D.C. Circuit in *Friends of the Earth, Inc. v. EPA, et al.*, No. 05-5015, (April 25, 2006) and Implications for NPDES Permits. Memorandum from Benjamin Grumbles, Assistant Administrator. Office of Water, Washington, D.C. November 15, 2006.

————. 2006b. Approaches For Developing a Daily Load Expression for TMDLs Computed for Longer Term Averages. Draft guidance document. Washington, D.C. October 2006.

————. 2007. An Approach for Using Load Duration Curves in the Development of TMDLs. EPA 841-B-07-006.

USGS (United States Geological Survey). 1996. HYSEP: A Computer Program for Streamflow Hydrograph Separation and Analysis. USGS Water-Resource Investigations Report 96-4040. Website http://pa.water.usgs.gov/reports/wrir96-4040.pdf, last visited 08/16/07.

APPENDIX A – BACTERIA DATA

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

Station	Date	Daily flow frequency	*E. Coli* MPN/100ml
BEA0016	11/05/2003	18.7500	200
BEA0016	11/19/2003	2.6848	280
BEA0016	12/03/2003	20.6120	150
BEA0016	12/17/2003	1.4290	930
BEA0016	01/05/2004	9.4255	40
BEA0016	01/20/2004	20.6120	50
BEA0016	02/02/2004	10.7679	30
BEA0016	02/17/2004	20.6120	70
BEA0016	03/01/2004	24.7113	20
BEA0016	03/15/2004	22.6905	20
BEA0016	04/05/2004	12.4134	70
BEA0016	04/19/2004	15.5889	30
BEA0016	05/10/2004	32.3037	170
BEA0016	05/24/2004	34.7575	160
BEA0016	06/07/2004	29.8788	280
BEA0016	06/21/2004	44.3418	260
BEA0016	07/06/2004	48.2679	4400
BEA0016	07/19/2004	52.3961	570
BEA0016	08/09/2004	60.1617	200
BEA0016	08/23/2004	71.0162	60
BEA0016	09/07/2004	77.0208	150
BEA0016	09/20/2004	74.2783	310
BEA0016	10/04/2004	57.4913	130
BEA0016	10/18/2004	60.6813	20

Station	Date	Daily flow frequency	*E. Coli* MPN/100ml
LMR0015	11/05/2003	14.0837	120
LMR0015	11/19/2003	1.3232	20
LMR0015	12/03/2003	13.1103	70
LMR0015	12/17/2003	0.7605	1330
LMR0015	01/05/2004	11.7262	30
LMR0015	01/20/2004	31.5589	10
LMR0015	02/02/2004	36.7452	10
LMR0015	02/17/2004	23.4677	60
LMR0015	03/01/2004	27.9544	20
LMR0015	03/15/2004	29.1863	10
LMR0015	04/05/2004	12.0760	10
LMR0015	04/19/2004	16.1977	50
LMR0015	05/10/2004	35.6350	110
LMR0015	05/24/2004	51.7567	50
LMR0015	06/07/2004	42.7072	170
LMR0015	06/21/2004	56.5323	360
LMR0015	07/06/2004	58.8897	260
LMR0015	07/19/2004	64.2129	250
LMR0015	08/09/2004	61.4144	190
LMR0015	08/23/2004	73.7643	510
LMR0015	09/07/2004	85.7186	100
LMR0015	09/20/2004	70.1445	490
LMR0015	10/04/2004	58.8897	620
LMR0015	10/18/2004	70.1445	60

Station	Date	Daily flow frequency	*E. Coli* MPN/100ml
MDE0026	11/05/2003	18.7500	550
MDE0026	11/19/2003	2.6848	370
MDE0026	12/03/2003	20.6120	70
MDE0026	12/17/2003	1.4290	24190
MDE0026	01/05/2004	9.4255	110
MDE0026	01/20/2004	20.6120	70
MDE0026	02/02/2004	10.7679	30
MDE0026	02/17/2004	20.6120	100
MDE0026	03/01/2004	24.7113	120
MDE0026	03/15/2004	22.6905	60
MDE0026	04/05/2004	12.4134	250
MDE0026	04/19/2004	15.5889	190
MDE0026	05/10/2004	32.3037	310
MDE0026	05/24/2004	34.7575	590
MDE0026	06/07/2004	29.8788	860
MDE0026	06/21/2004	44.3418	420
MDE0026	07/06/2004	48.2679	840
MDE0026	07/19/2004	52.3961	1670
MDE0026	08/09/2004	60.1617	670
MDE0026	08/23/2004	71.0162	250
MDE0026	09/07/2004	77.0208	280
MDE0026	09/20/2004	74.2783	1550
MDE0026	10/04/2004	57.4913	590
MDE0026	10/18/2004	60.6813	220

Station	Date	Daily flow frequency	*E. Coli* MPN/100ml
MOR0040	11/05/2003	14.0837	130
MOR0040	11/19/2003	1.3232	90
MOR0040	12/03/2003	13.1103	60
MOR0040	12/17/2003	0.7605	1990
MOR0040	01/05/2004	11.7262	70
MOR0040	01/20/2004	31.5589	10
MOR0040	02/02/2004	36.7452	10
MOR0040	02/17/2004	23.4677	110
MOR0040	03/01/2004	27.9544	20
MOR0040	03/15/2004	29.1863	10
MOR0040	04/05/2004	12.0760	90
MOR0040	04/19/2004	16.1977	50
MOR0040	05/10/2004	35.6350	50
MOR0040	05/24/2004	51.7567	60
MOR0040	06/07/2004	42.7072	320
MOR0040	06/21/2004	56.5323	130
MOR0040	07/06/2004	58.8897	960
MOR0040	07/19/2004	64.2129	380
MOR0040	08/09/2004	61.4144	90
MOR0040	08/23/2004	73.7643	80
MOR0040	09/07/2004	85.7186	120
MOR0040	09/20/2004	70.1445	580
MOR0040	10/04/2004	58.8897	280
MOR0040	10/18/2004	70.1445	60

Station	Date	Daily flow frequency	*E. Coli* MPN/100ml
NPA0165	11/05/2003	18.8905	160
NPA0165	11/19/2003	2.3199	90
NPA0165	12/03/2003	20.2161	120
NPA0165	12/17/2003	1.3112	9800
NPA0165	01/05/2004	9.0778	60
NPA0165	01/20/2004	21.2248	50
NPA0165	02/02/2004	28.6311	10
NPA0165	02/17/2004	20.6628	40
NPA0165	03/01/2004	24.8991	30
NPA0165	03/15/2004	22.9827	20
NPA0165	04/05/2004	6.6427	190
NPA0165	04/19/2004	15.7637	90
NPA0165	05/10/2004	29.3228	150
NPA0165	05/24/2004	34.7262	320
NPA0165	06/07/2004	19.7406	880
NPA0165	06/21/2004	48.5879	320
NPA0165	07/06/2004	49.5677	5800
NPA0165	07/19/2004	51.7147	390
NPA0165	08/09/2004	48.5879	230
NPA0165	08/23/2004	61.5850	110
NPA0165	09/07/2004	73.5879	160
NPA0165	09/20/2004	56.4841	1620
NPA0165	10/04/2004	58.9914	190
NPA0165	10/18/2004	67.6081	70

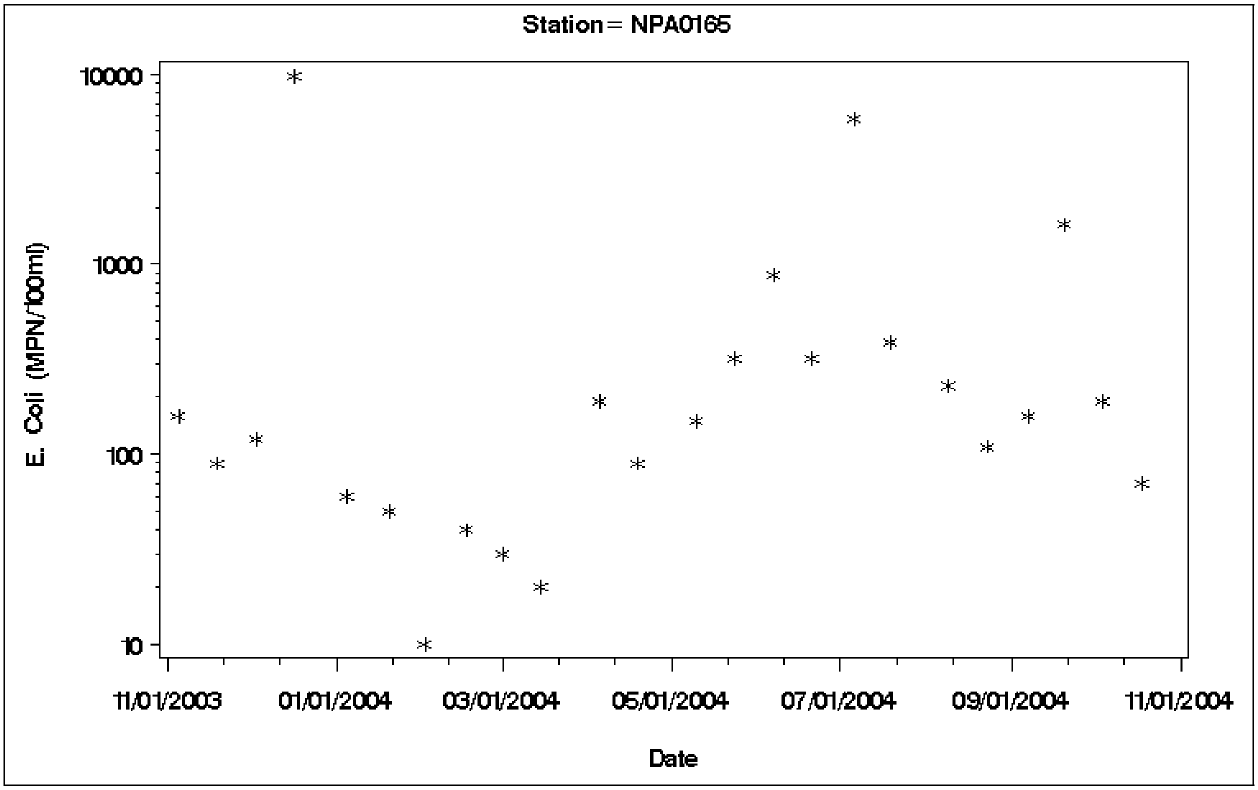

Figure A-1: *E. coli* Concentration vs. Time for MDE Monitoring Station NPA0165

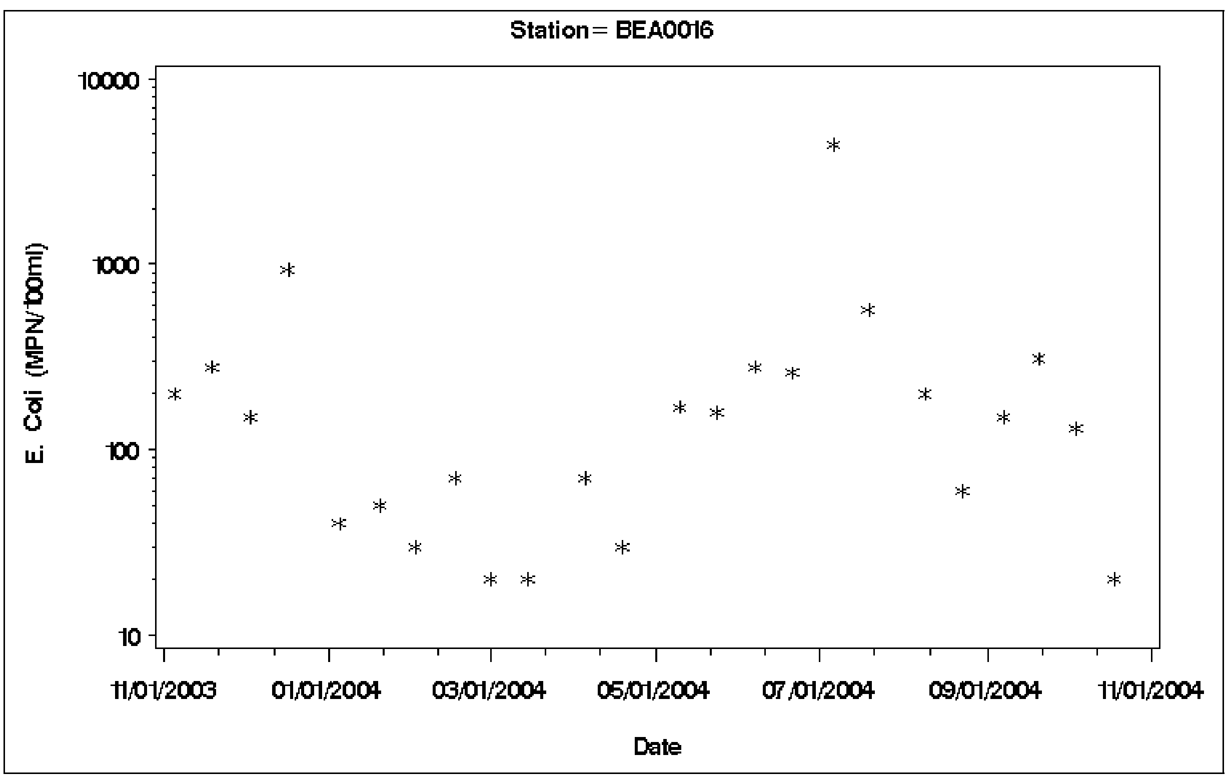

Figure A-2: *E. coli* Concentration vs. Time for MDE Monitoring Station BEA0016

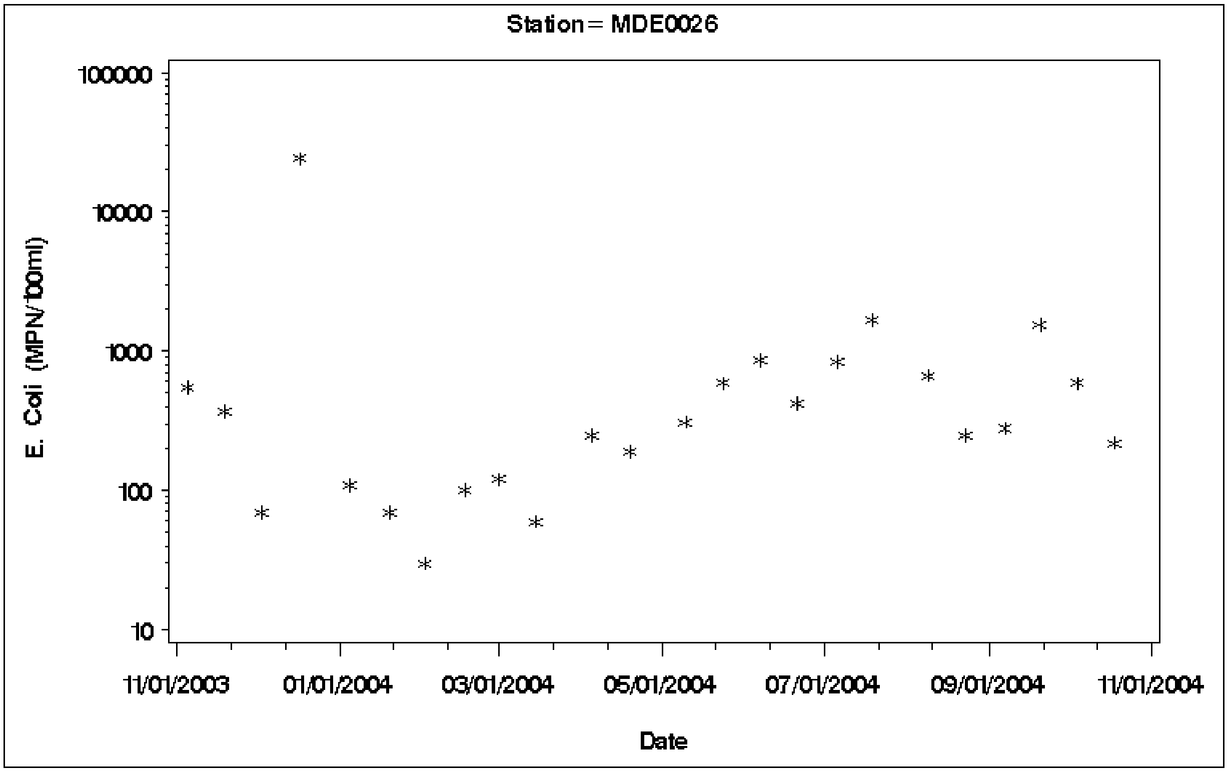

Figure A-3: *E. coli* Concentration vs. Time for MDE Monitoring Station MDE0026

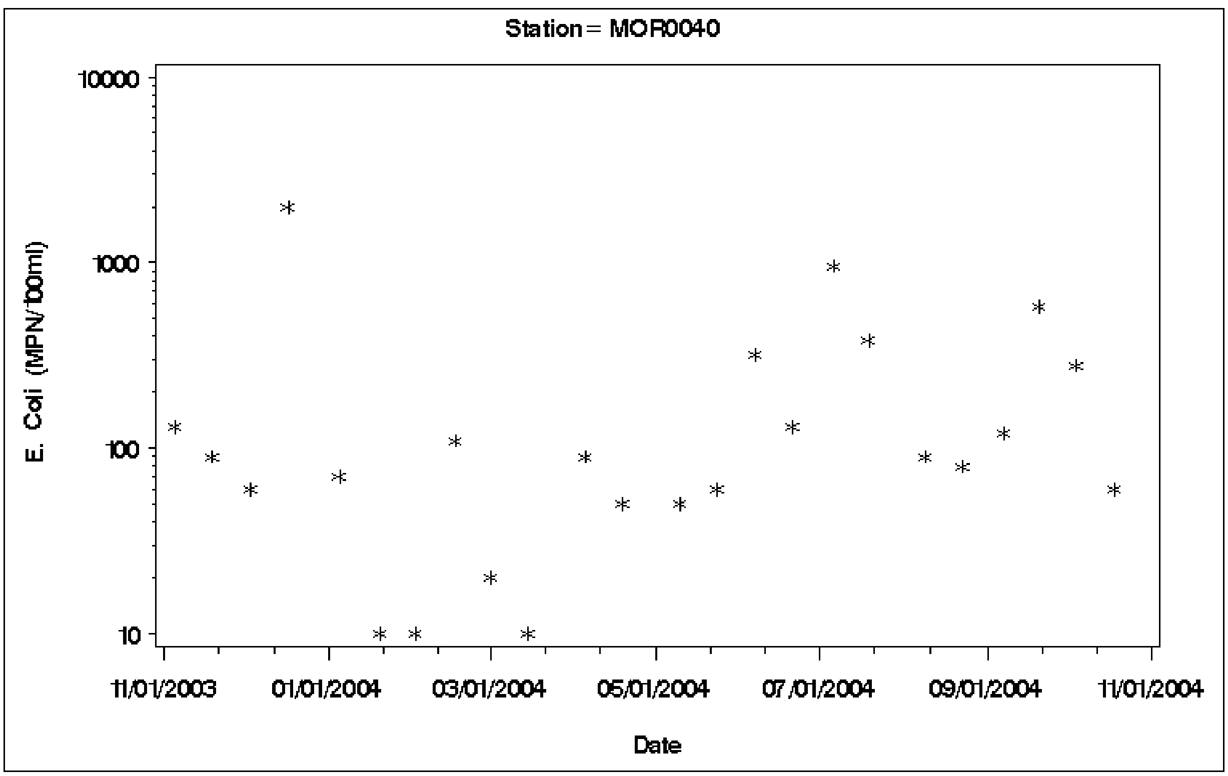

Figure A-4: *E. coli* Concentration vs. Time for MDE Monitoring Station MOR0040

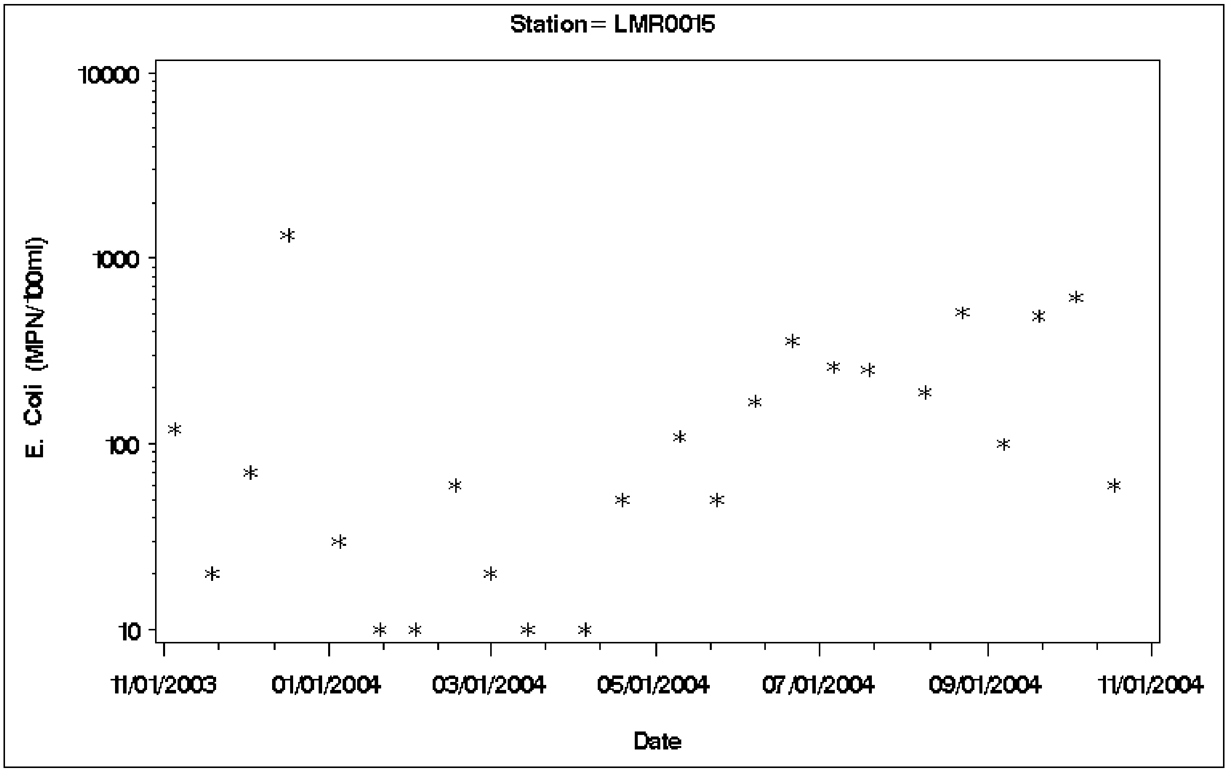

Figure A-5: *E. coli* Concentration vs. Time for MDE Monitoring Station LMR0015

APPENDIX B – FLOW DURATION CURVE ANALYSIS TO DEFINE STRATA

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

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

Flow Analysis

Three USGS gage stations are present in the Liberty Reservoir basin. The gage stations, #01586000 near Emory and Glen Falls Road, #01586210 near Gamber and Hughs road, and #01586610 near Poole road and Morgan Run were used for this analysis. The dates of information used were from October 1, 1988 to September 30, 2007 for gage stations 01586000 and 01586210 and from October 1, 1988 to September 30, 2006 for gage station 01586610. A flow duration curve for this gage station is presented in Figure B-1.

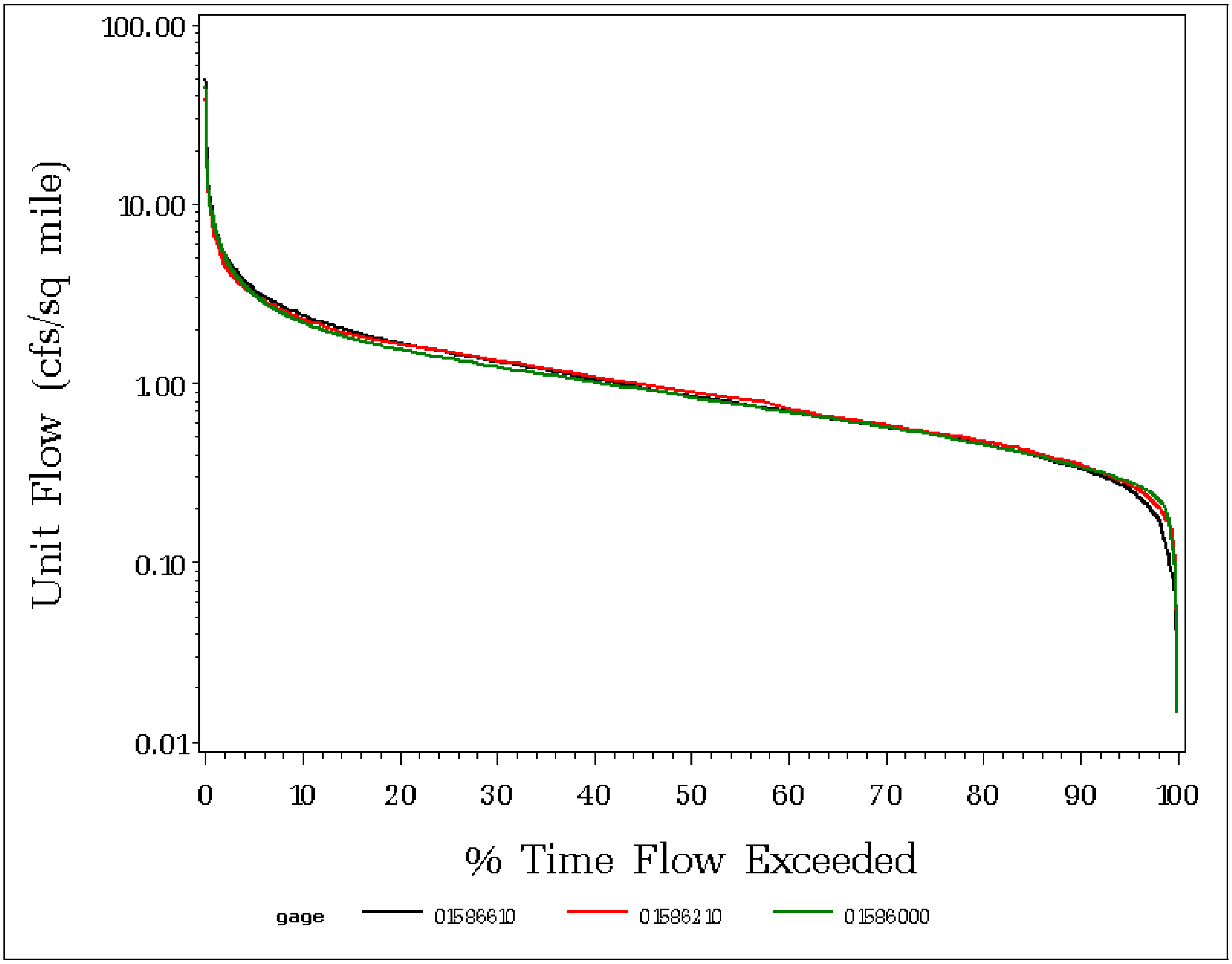

Figure B-1: Flow Duration Curve for USGS Gages 01586610, 01586210, and 01586000

Based on the flow data from the North Branch Patapsco River gage station, the long-term average daily unit flow is 1.21 cfs/sq. mile, for the Beaver Run gage station the long-term average daily unit flow is 1.23 cfs/sq. mile and for the Morgan Run gage station, the long-term average daily unit flow is 1.27 cfs/sq. mile, which corresponds to a flow frequency of 32%. 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 32 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 32% and a low flow condition will be defined as occurring when the daily flow duration percentile is greater than 32%. Definitions of high and low range flows are presented in Table B-1.

Table B-1: Definition of Flow Regimes

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

Flow Data Analysis

The final analysis to define the daily flow duration intervals (flow regions, strata) includes the bacteria monitoring data. Bacteria (*E. coli*) monitoring data are "placed" within the regions (strata) based on the daily flow duration percentile of the date of sampling. Figures B-2 to B-11 show the Liberty Reservoir basin *E. coli* monitoring data with corresponding flow frequency for the average annual and the 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 taken representatively over 30 days. Therefore, in situations in which fewer than five samples "fall" within a particular flow regime interval, the interval and the adjacent interval will be joined. In the Liberty Reservoir basin, 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 seasonal (May 1st – September 30th) flow condition, there are no samples within the high flow strata; therefore, for this condition an average seasonal geometric mean will be calculated.

Weighting factors for estimating a weighted geometric mean are based on the frequency of each flow stratum during the averaging period. The weighting factors for the averaging periods and hydrological conditions are presented in Table B-2. Averaging periods are defined in this report as:

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

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

Table B-2: Weighting Factors for Estimation of Geometric Mean

USGS Gage	Hydrological Condition		Averaging Period	Water Quality Data Used	Fraction High Flow	Fraction Low Flow	Condition Period
01586000	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.778	0.223	May 2003 – May 2004
		Dry	365 days	All	0.019	0.981	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period
01586210	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.805	0.196	Jan. 1997 – Jan. 1998
		Dry	365 days	All	0.017	0.984	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period
01586610	Annual	Average	365 days	All	0.32	0.68	Long Term Average
		Wet	365 days	All	0.934	0.066	Jan. 1996 – Jan. 1997
		Dry	365 days	All	0.011	0.989	Sept. 2001 – Sept. 2002
	Seasonal	Average	May 1st – Sept. 30th	May 1st – Sept. 30th	N/A	N/A	Long-Term Average For May – Sept. Period

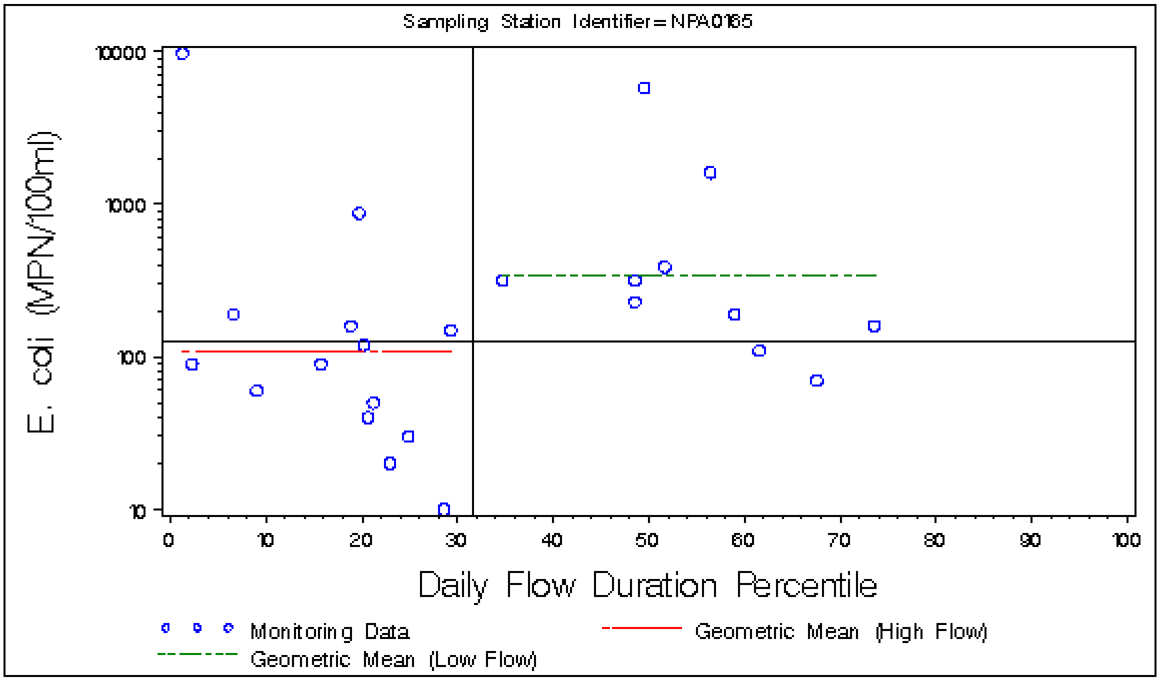

Figure B-2: *E. coli* Concentration vs. Flow Duration for Monitoring Station NPA0165 (Annual Condition)

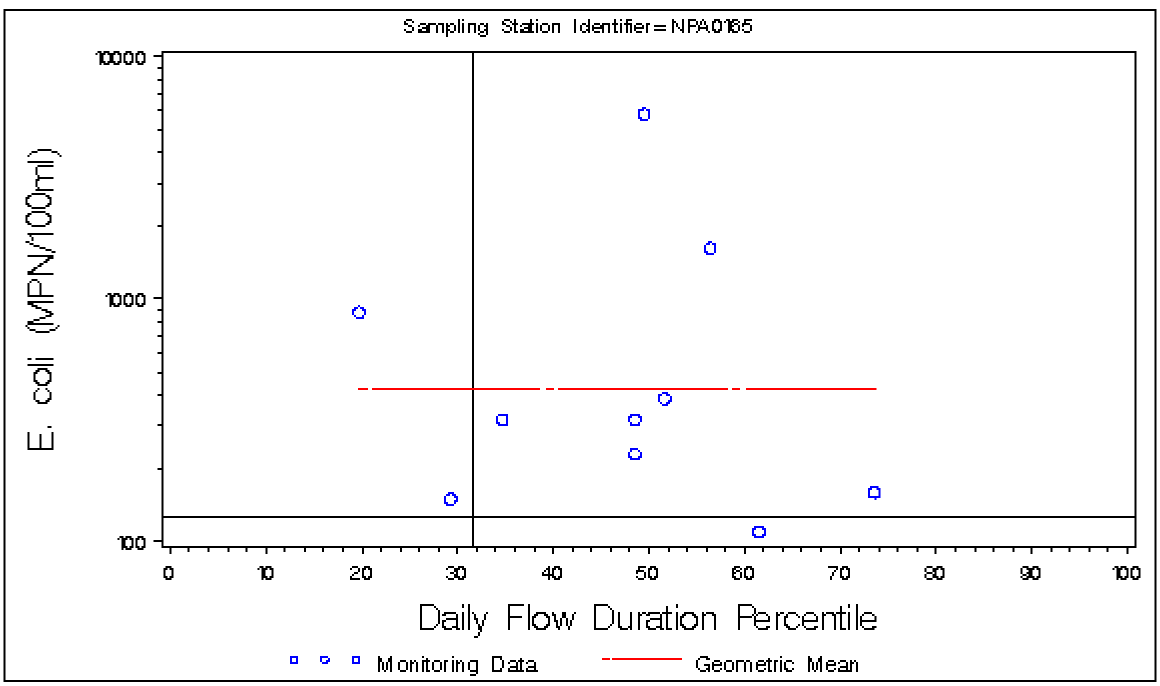

Figure B-3: *E. coli* Concentration vs. Flow Duration for Monitoring Station NPA0165 (Seasonal Condition)

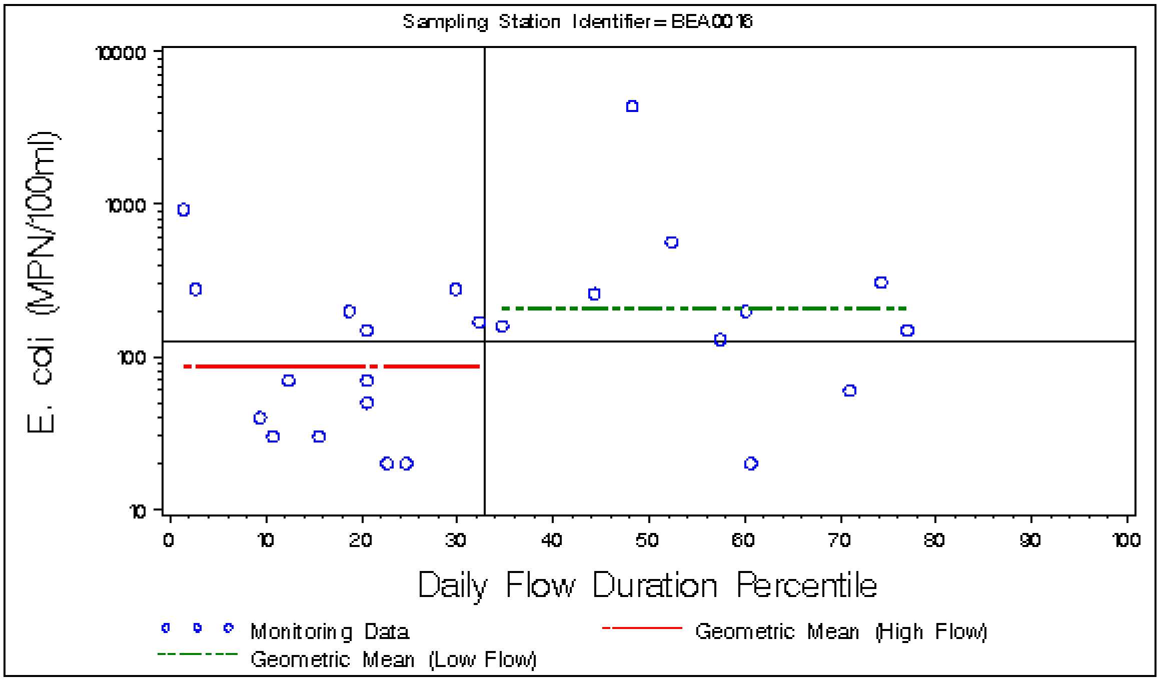

Figure B-4: *E. coli* Concentration vs. Flow Duration for Monitoring Station BEA0016 (Annual Condition)

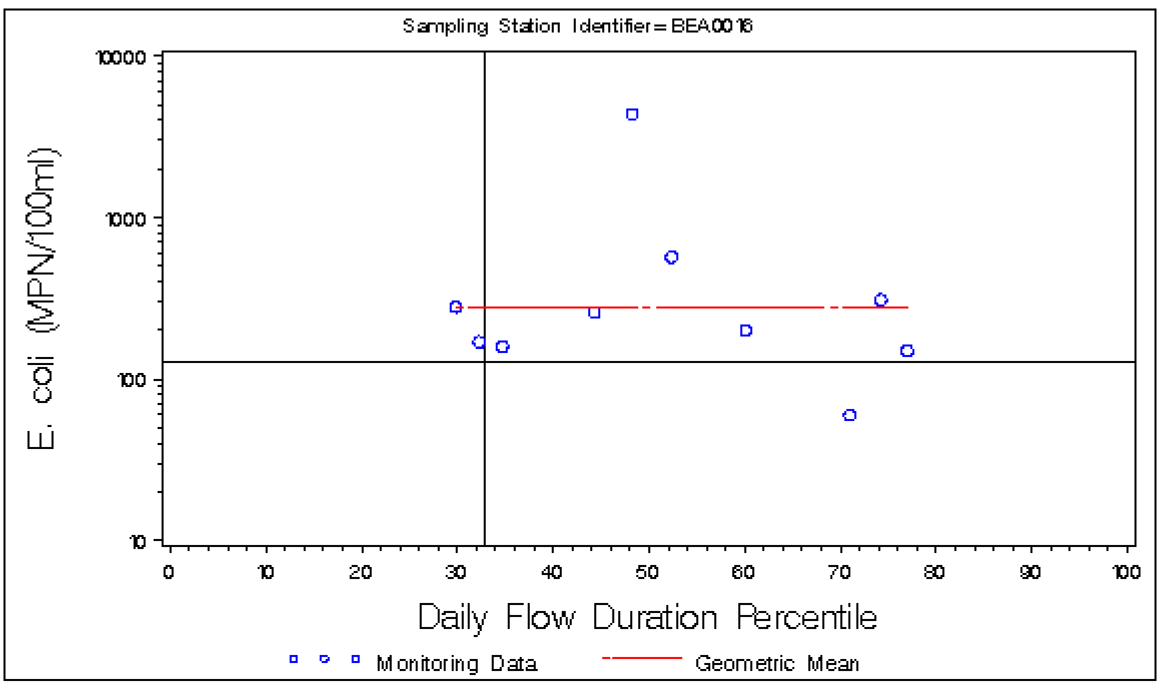

Figure B-5: *E. coli* Concentration vs. Flow Duration for Monitoring Station BEA0016 (Seasonal Condition)

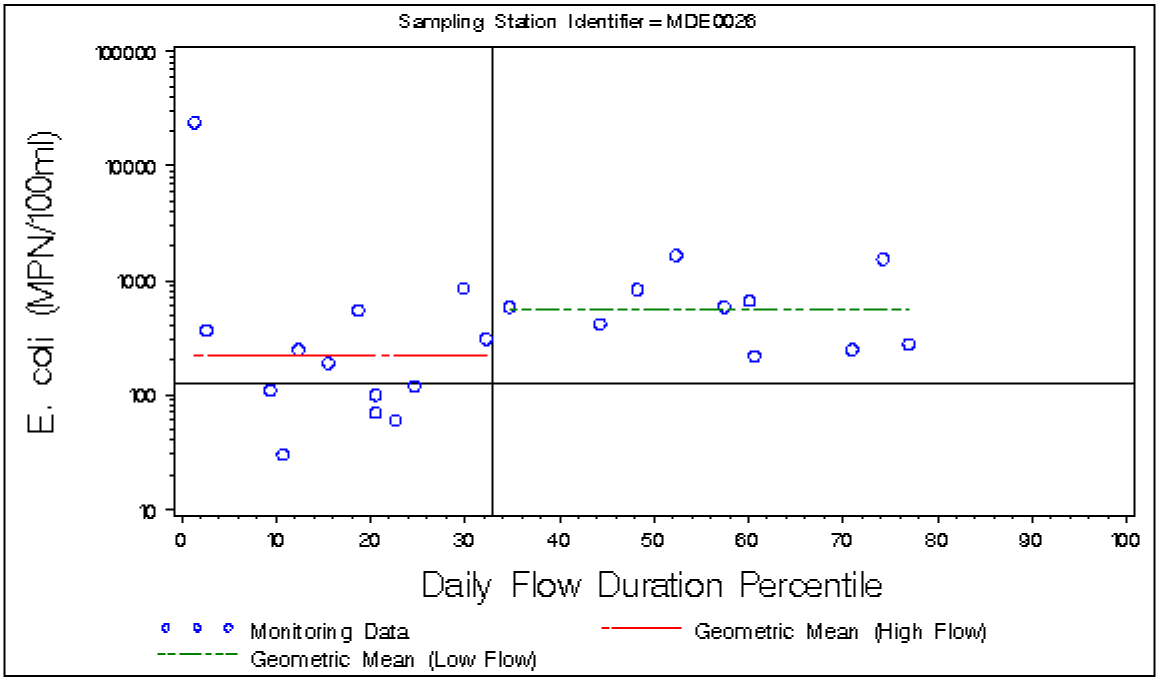

Figure B-6: *E. coli* Concentration vs. Flow Duration for Monitoring Station MDE0026 (Annual Condition)

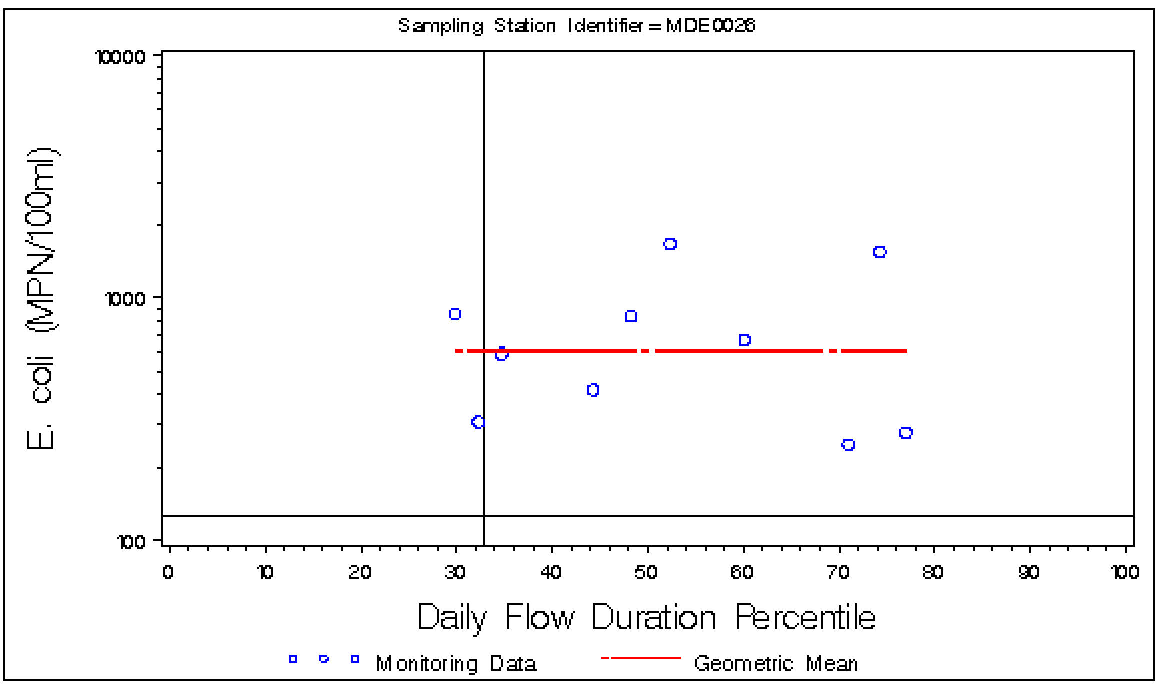

Figure B-7: *E. coli* Concentration vs. Flow Duration for Monitoring Station MDE0026 (Seasonal Condition)

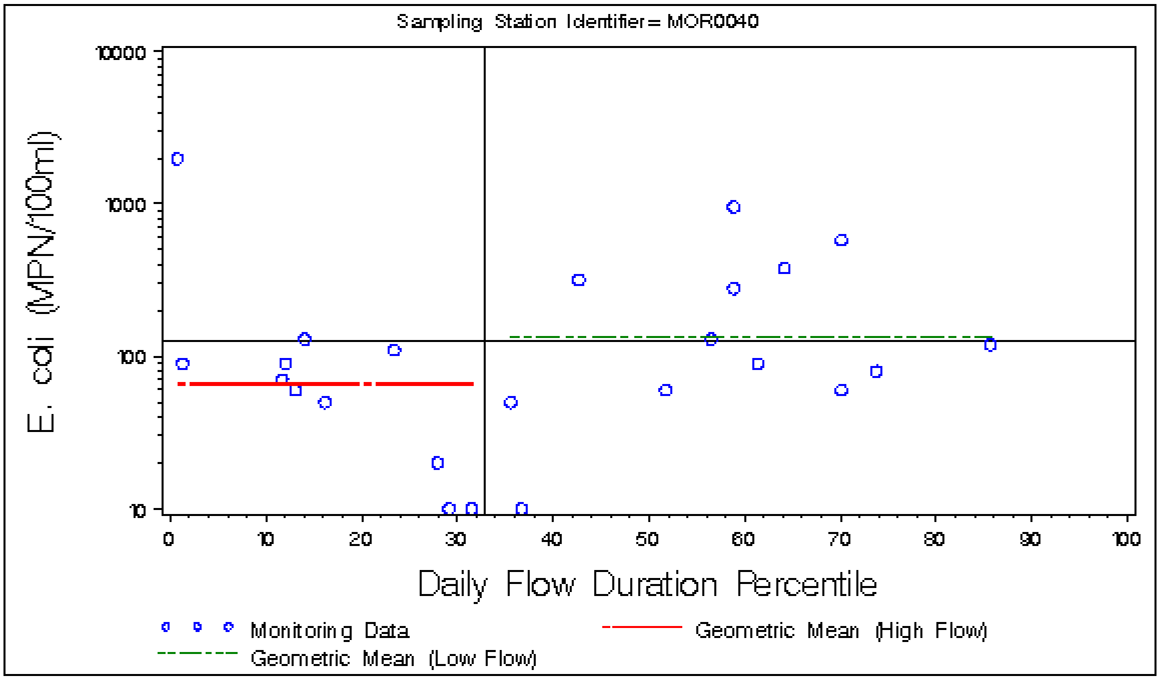

Figure B-8: *E. coli* Concentration vs. Flow Duration for Monitoring Station MOR0040 (Annual Condition)

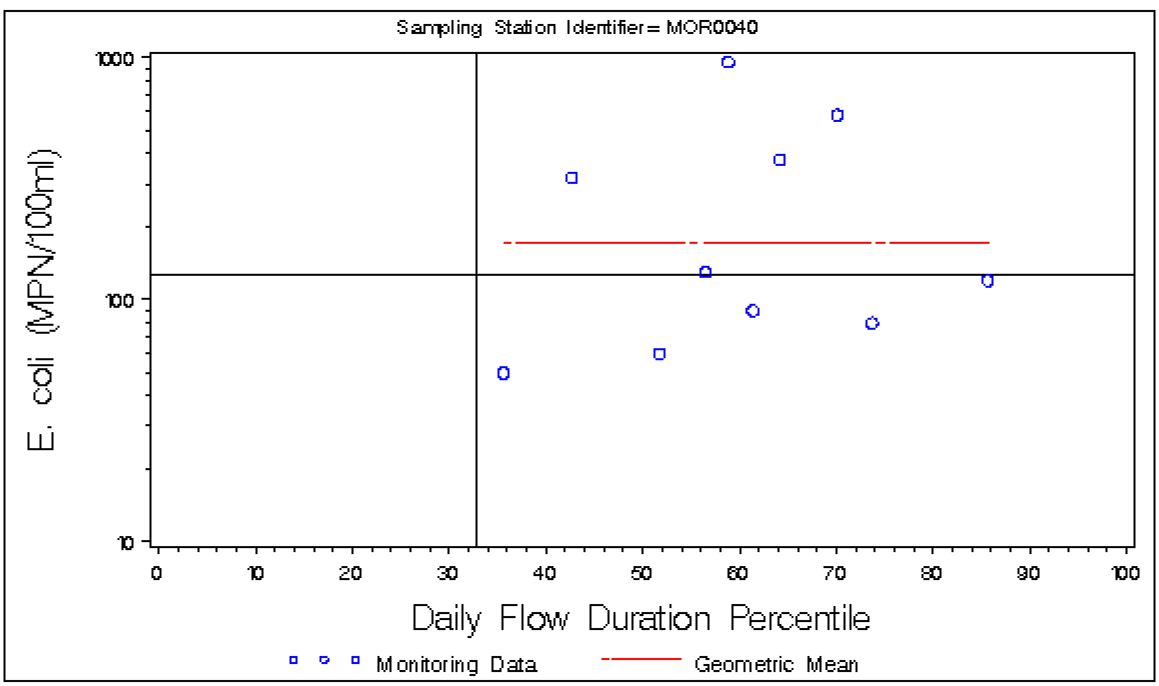

Figure B-9: *E. coli* Concentration vs. Flow Duration for Monitoring Station MOR0040 (Seasonal Condition)

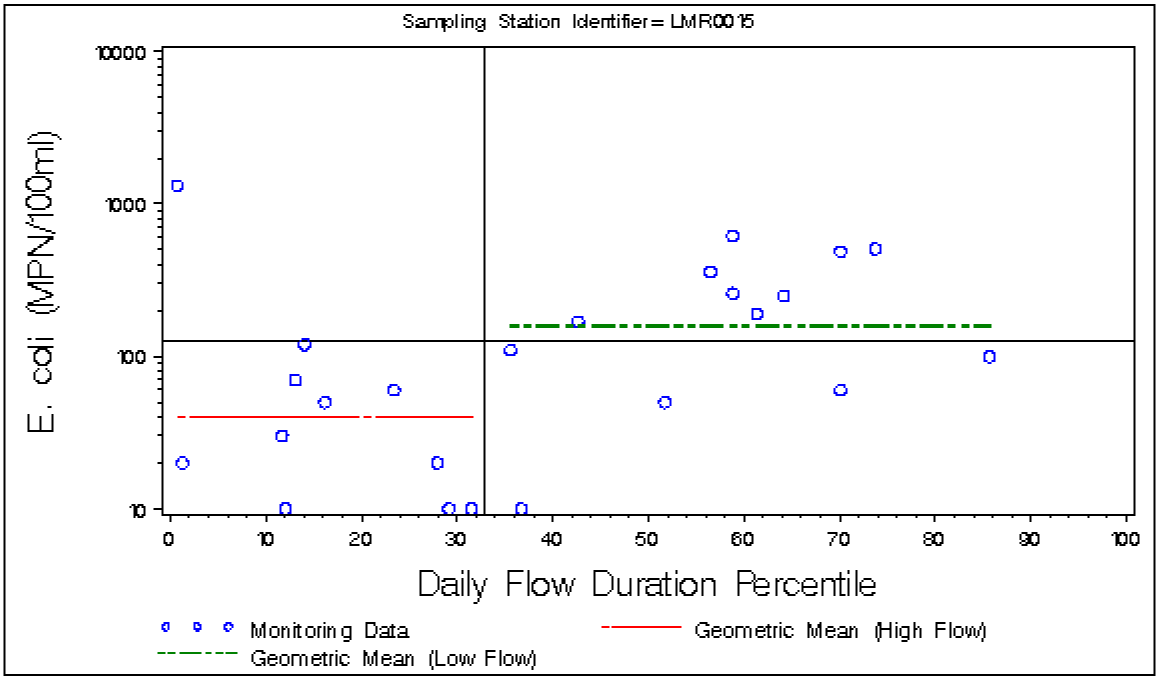

Figure B-10: *E. coli* Concentration vs. Flow Duration for Monitoring Station LMR0015 (Annual Condition)

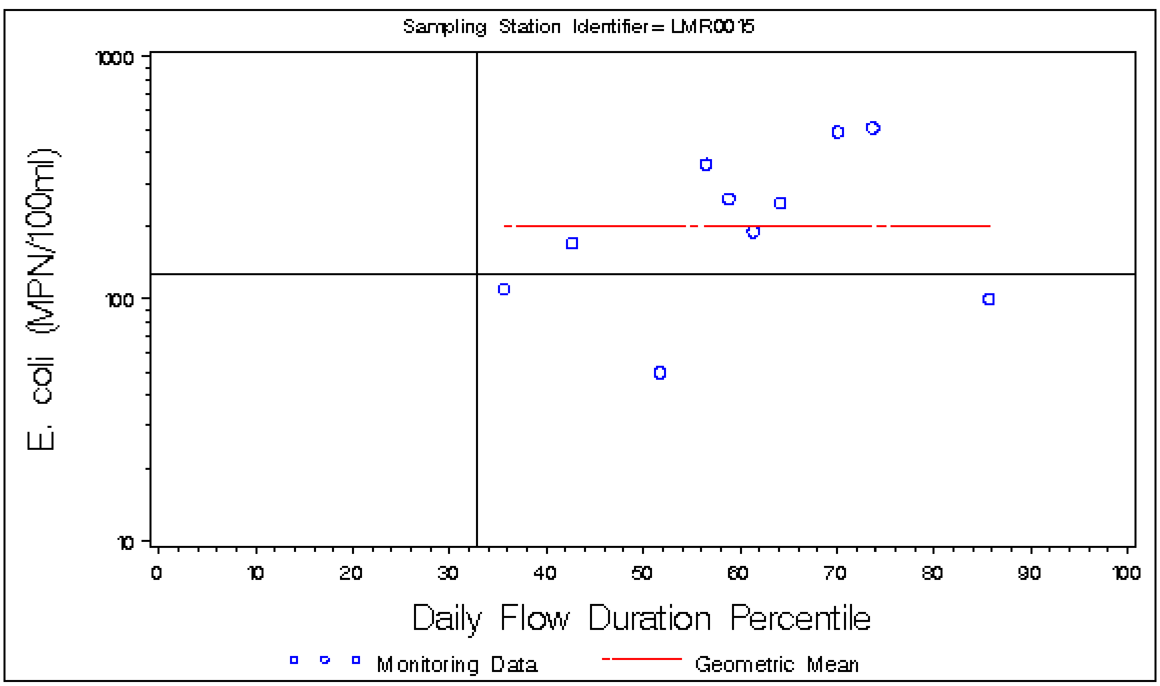

Figure B-11: *E. coli* Concentration vs. Flow Duration for Monitoring Station LMR0015 (Seasonal Condition)

APPENDIX C – BST REPORT

Maryland Department of the Environment

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

November 2006 – June 2008

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Final Report
June 30, 2008

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INTRODUCTION

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

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

Many of the molecular and biochemical methods of MST are "library-based," requiring the collection of a database of fingerprints or patterns obtained from indicator organisms isolated from known sources. Statistical analysis determines fingerprints/patterns of known sources species or categories of species (*i.e.*, human, livestock, pets, wildlife). Indicator isolates collected from water samples are analyzed using the same MST method to obtain their fingerprints or patterns, which are then statistically compared to those in the library. Based upon this comparison, the final results are expressed in terms of the "statistical probability" that the water isolates came from a given source (Simpson *et al*. 2002).

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

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

LABORATORY METHODS

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

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

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

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

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

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

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

KNOWN-SOURCE LIBRARY

Construction and Use. Fecal samples (scat) from known sources in each watershed were collected during the study period by MDE personnel and delivered to the BST Laboratory at SU. *Enterococcus* isolates were obtained from known sources (e.g., human, cow, goat, horse, dog, bear, beaver, deer, duck, fox, goose, heron, opossum, rabbit, raccoon, and squirrel). For each watershed, a library of patterns of *Enterococcus* isolate responses to the panel of antibiotics was analyzed using the statistical software CART® (Salford Systems, San Diego, CA). *Enterococcus* isolate response patterns were also obtained from bacteria in water samples collected at the monitoring stations in each basin. Using statistical techniques, these patterns were then compared to those in the appropriate library to identify the probable source of each water isolate.

STATISTICAL ANALYSIS

We applied a tree classification method, [1]CART®, to build a model that classifies isolates into source categories based on ARA data. CART® builds a classification tree by recursively splitting the library of isolates into two nodes. Each split is determined by the antibiotic variables (antibiotic resistance measured for a collection of antibiotics at varying concentrations). The first step in the tree-building process splits the library into two nodes by considering every binary split associated with every variable. The split is chosen that maximizes a specified index of homogeneity for isolate sources within each of the nodes. In subsequent steps, the same process is applied to each resulting node until a *stopping* criterion is satisfied. Nodes where an additional split would lead to only an insignificant increase in the *homogeneity index* relative to the *stopping* criterion are referred to as *terminal* nodes.[2] The collection of *terminal* nodes defines the classification model. Each *terminal* node is associated with one source, the source isolate with an unknown source), based that is most populous among the library isolates in the node. Each water sample isolate (*i.e*., an on its antibiotic resistance pattern, is identified with one specific *terminal* node and is assigned the source of the majority of library isolates in that *terminal* node.[3]

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

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

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

ARA RESULTS

Liberty Reservoir Watershed ARA Results

Known-Source Library. A 621 known-source isolate library was constructed from sources in the Liberty Reservoir Watershed. The number of unique antibiotic resistance patterns was calculated, and the known sources in the combined library were grouped into four categories: human, livestock (cow, horse), pet (dog), and wildlife (deer, duck, fox, goose, rabbit, raccoon) (Table 2-LIB). The library was analyzed for its ability to take a subset of the library isolates and correctly predict the identity of their host sources when they were treated as unknowns. Average rates of correct classification (ARCC) for the library were found by repeating this analysis using several probability cutoff points, as described above. The number-not-classified for each probability was determined. From these results, the percent unknown and percent correct classification (RCCs) was calculated (Table 3-LIB).

Table 2-LIB: Liberty Reservoir. Category, total number, and number of unique patterns in the Liberty Reservoir known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
Human	human	86	59
Livestock	cow, horse	210	55
Pet	dog	109	56
Wildlife	deer, duck, fox, goose, rabbit, raccoon	216	54
Total		621	224

For Liberty Reservoir Watershed, a cutoff probability of 0.70 (70%) was shown to yield an overall rate of correct classification of 85% (Figure 1-LIB; Table 3-LIB). The resulting rates of correction classification (RCCs) for the four categories of sources in the Liberty Reservoir portion of the library are shown in Table 4-LIB.

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

Threshold	0	0.375	0.5	0.6	**0.7**	0.8	0.9
% correct	75.2%	75.2%	75.2%	81.7%	**85.4%**	94.0%	95.5%
% unknown	0.0%	0.0%	0.8%	19.2%	**32.9%**	59.6%	68.1%
# not classified	0	0	5	119	**204**	370	423

Figure 1-LIB. Liberty Reservoir Classification Model: Percent Correct versus Percent Unknown using the Liberty Reservoir library.

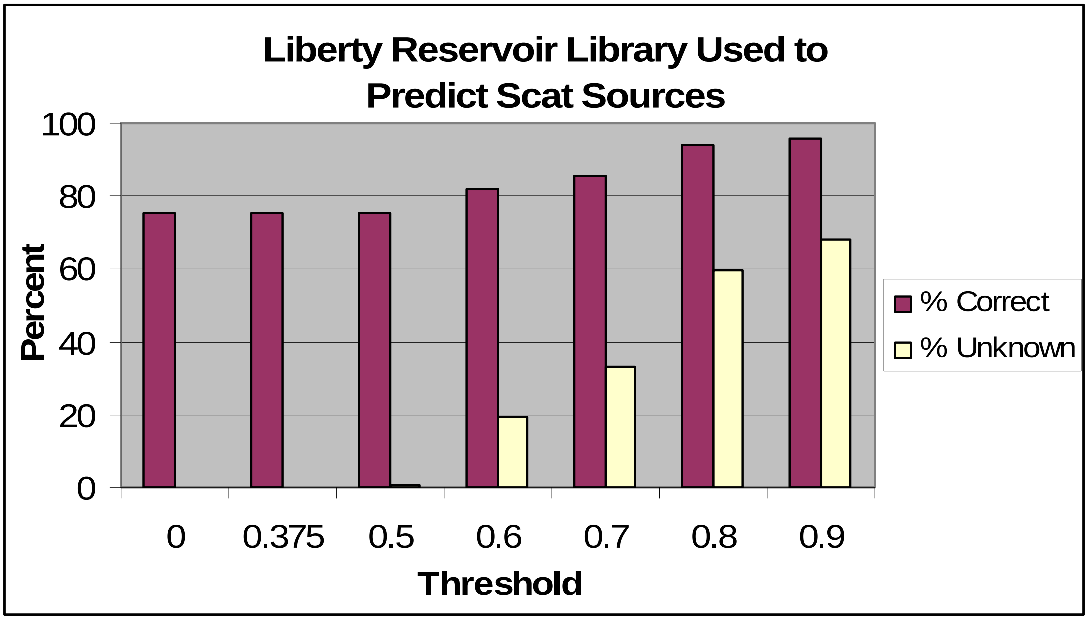


Table 4-LIB: Liberty Reservoir. Actual species categories versus predicted categories, at 70% probability cutoff, with rates of correct classification (RCC) for each category.

	Predicted						
Actual	Human	Livestock	Pet	Wildlife	Unknown	Total	RCC*
Human	58	1	7	1	19	86	86.6%
Livestock	3	96	4	33	74	210	70.6%
Pet	2	0	68	2	37	109	94.4%
Wildlife	2	6	0	134	74	216	94.4%
Total	65	103	79	170	204	621	85.4%

*RCC = Actual number of predicted species category / Total number predicted. Example: 163 pet correctly predicted / 175 total number predicted for pet = 163/175 = 95%.

Liberty Reservoir Water Samples. Monthly monitoring from five (5) monitoring stations on Liberty Reservoir was the source of water samples. The maximum number of *Enterococcus* isolates per water sample was 24, although the number of isolates that actually grew was sometimes less than 24. A total of 1,159 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table 5-LIB, indicate that 74% of the water isolates were able to be classified to a probable host source when using a 0.70 (70%) probability threshold.

Table 5-LIB: Liberty Reservoir. Probable host sources of water isolates by species category, number of isolates, and percent isolates classified at a cutoff probability of 70%.

Source	Count	Percent	Percent Without Unknowns
Human	233	20.1%	27.3%
Livestock	230	19.8%	27.0%
Pet	122	10.5%	14.3%
Wildlife	267	23.0%	31.3%
Unknown	307	26.5%	
Total	1159	100.0%	100.0%
% classified	**73.5%**		

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

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

Table 6-LIB: Liberty Reservoir. *Enterococcus* isolates obtained from water collected during the spring, summer, fall, and winter seasons for Liberty Reservoir's five (5) monitoring stations.

	Season				
Station	Spring	Summer	Fall	Winter	Total
BEA0006	51	71	67	38	227
LMR0015	67	71	72	18	228
MDE0026	72	72	67	44	255
MOR0040	70	71	61	17	219
NPA0165	62	72	68	28	230
Total	322	357	335	145	1159

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

Table 7-LIB: Liberty Reservoir. BST Analysis: Number of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEA0006	11/19/03	2	5	4	5	4	20
BEA0006	12/03/03	5	6	3	1	9	24
BEA0006	01/05/04	0	3	3	2	11	19
BEA0006	02/17/04	7	4	1	1	4	17
BEA0006	03/01/04	1	0	0	0	1	2
BEA0006	04/05/04	3	5	1	2	7	18
BEA0006	05/10/04	2	3	0	4	0	9
BEA0006	06/07/04	6	4	5	5	4	24
BEA0006	07/06/04	12	1	2	4	4	23
BEA0006	08/09/04	8	0	1	12	3	24
BEA0006	09/07/04	3	5	1	5	10	24
BEA0006	10/04/04	6	0	6	3	8	23
LMR0015	11/19/03	0	10	0	6	8	24
LMR0015	12/03/03	0	7	6	6	5	24
LMR0015	01/05/04	0	4	1	1	3	9
LMR0015	02/17/04	0	4	0	2	1	7
LMR0015	03/01/04	0	0	0	1	1	2
LMR0015	04/05/04	1	8	1	4	5	19
LMR0015	05/10/04	3	10	0	4	7	24
LMR0015	06/07/04	0	4	0	9	11	24
LMR0015	07/06/04	4	0	1	15	3	23
LMR0015	08/09/04	3	2	0	8	11	24
LMR0015	09/07/04	1	10	11	1	1	24
LMR0015	10/04/04	1	3	6	7	7	24
MDE0026	11/19/03	3	6	3	2	8	22
MDE0026	12/03/03	8	2	2	6	6	24
MDE0026	01/05/04	0	8	2	6	6	22
MDE0026	02/17/04	4	5	1	1	4	15
MDE0026	03/01/04	2	1	2	1	1	7
MDE0026	04/05/04	11	5	2	0	6	24
MDE0026	05/10/04	9	6	1	4	4	24
MDE0026	06/07/04	4	3	6	8	3	24
MDE0026	07/06/04	13	0	10	1	0	24
MDE0026	08/09/04	6	0	1	9	8	24
MDE0026	09/07/04	0	4	2	5	13	24
MDE0026	10/04/04	2	3	2	7	7	21

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

			Predicted	Source			
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
MOR0040	11/19/03	1	5	0	3	6	15
MOR0040	12/03/03	6	4	1	2	11	24
MOR0040	01/05/04	0	1	0	6	1	8
MOR0040	02/17/04	1	0	3	1	2	7
MOR0040	03/01/04	0	1	0	0	1	2
MOR0040	04/05/04	1	7	1	8	6	23
MOR0040	05/10/04	12	2	1	8	0	23
MOR0040	06/07/04	1	3	1	7	12	24
MOR0040	07/06/04	7	1	8	3	4	23
MOR0040	08/09/04	3	2	0	4	15	24
MOR0040	09/07/04	3	6	1	5	9	24
MOR0040	10/04/04	8	1	2	7	4	22
NPA0165	11/19/03	2	1	1	14	3	21
NPA0165	12/03/03	11	5	0	5	3	24
NPA0165	01/05/04	2	4	0	1	5	12
NPA0165	02/17/04	0	7	1	2	3	13
NPA0165	03/01/04	0	2	0	0	1	3
NPA0165	04/05/04	1	16	2	0	5	24
NPA0165	05/10/04	4	5	0	1	5	15
NPA0165	06/07/04	3	11	1	2	6	23
NPA0165	07/06/04	9	2	4	5	4	24
NPA0165	08/09/04	12	1	1	9	1	24
NPA0165	09/07/04	6	2	0	13	3	24
NPA0165	10/04/04	10	0	7	3	3	23
Total		233	230	122	267	307	1159

Table 8-LIB: Liberty Reservoir. BST Analysis: Percent of Isolates per Station per Date.

				Predicted Source			
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
BEA0006	11/19/03	10%	25%	20%	25%	20%	100%
BEA0006	12/03/03	21%	25%	13%	4%	38%	100%
BEA0006	01/05/04	0%	16%	16%	11%	58%	100%
BEA0006	02/17/04	41%	24%	6%	6%	24%	100%
BEA0006	03/01/04	50%	0%	0%	0%	50%	100%
BEA0006	04/05/04	17%	28%	6%	11%	39%	100%
BEA0006	05/10/04	22%	33%	0%	44%	0%	100%
BEA0006	06/07/04	25%	17%	21%	21%	17%	100%
BEA0006	07/06/04	52%	4%	9%	17%	17%	100%
BEA0006	08/09/04	33%	0%	4%	50%	13%	100%
BEA0006	09/07/04	13%	21%	4%	21%	42%	100%

BEA0006	10/04/04	26%	0%	26%	13%	35%	100%

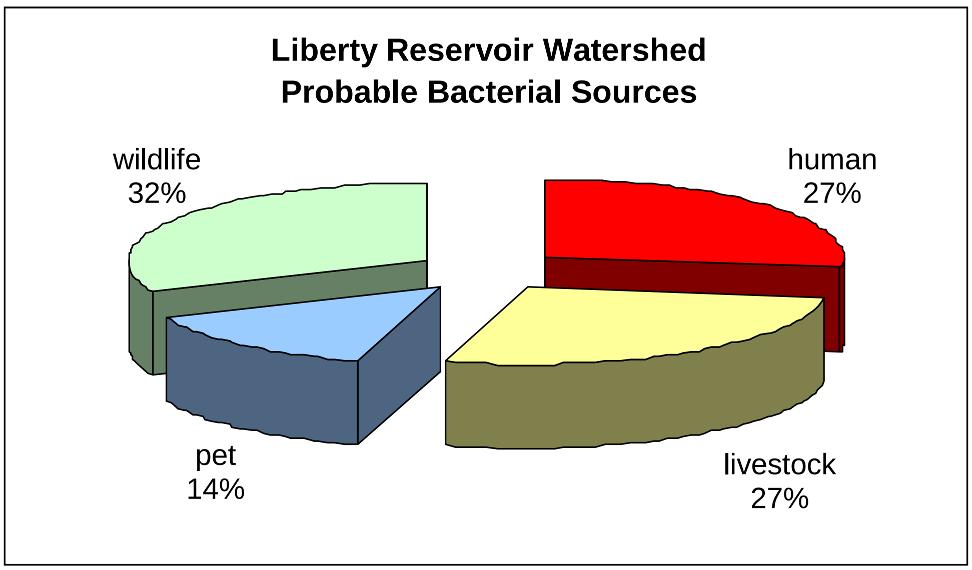
Table 8-LIB: Liberty Reservoir (continued). BST Analysis: Percent of Isolates per Station per Date.

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
LMR0015	11/19/03	0%	42%	0%	25%	33%	100%
LMR0015	12/03/03	0%	29%	25%	25%	21%	100%
LMR0015	01/05/04	0%	44%	11%	11%	33%	100%
LMR0015	02/17/04	0%	57%	0%	29%	14%	100%
LMR0015	03/01/04	0%	0%	0%	50%	50%	100%
LMR0015	04/05/04	5%	42%	5%	21%	26%	100%
LMR0015	05/10/04	13%	42%	0%	17%	29%	100%
LMR0015	06/07/04	0%	17%	0%	38%	46%	100%
LMR0015	07/06/04	17%	0%	4%	65%	13%	100%
LMR0015	08/09/04	13%	8%	0%	33%	46%	100%
LMR0015	09/07/04	4%	42%	46%	4%	4%	100%
LMR0015	10/04/04	4%	13%	25%	29%	29%	100%
MDE0026	11/19/03	14%	27%	14%	9%	36%	100%
MDE0026	12/03/03	33%	8%	8%	25%	25%	100%
MDE0026	01/05/04	0%	36%	9%	27%	27%	100%
MDE0026	02/17/04	27%	33%	7%	7%	27%	100%
MDE0026	03/01/04	29%	14%	29%	14%	14%	100%
MDE0026	04/05/04	46%	21%	8%	0%	25%	100%
MDE0026	05/10/04	38%	25%	4%	17%	17%	100%
MDE0026	06/07/04	17%	13%	25%	33%	13%	100%
MDE0026	07/06/04	54%	0%	42%	4%	0%	100%
MDE0026	08/09/04	25%	0%	4%	38%	33%	100%
MDE0026	09/07/04	0%	17%	8%	21%	54%	100%
MDE0026	10/04/04	10%	14%	10%	33%	33%	100%
MOR0040	11/19/03	7%	33%	0%	20%	40%	100%
MOR0040	12/03/03	25%	17%	4%	8%	46%	100%
MOR0040	01/05/04	0%	13%	0%	75%	13%	100%
MOR0040	02/17/04	14%	0%	43%	14%	29%	100%
MOR0040	03/01/04	0%	50%	0%	0%	50%	100%
MOR0040	04/05/04	4%	30%	4%	35%	26%	100%
MOR0040	05/10/04	52%	9%	4%	35%	0%	100%
MOR0040	06/07/04	4%	13%	4%	29%	50%	100%
MOR0040	07/06/04	30%	4%	35%	13%	17%	100%
MOR0040	08/09/04	13%	8%	0%	17%	63%	100%
MOR0040	09/07/04	13%	25%	4%	21%	38%	100%
MOR0040	10/04/04	36%	5%	9%	32%	18%	100%
NPA0165	11/19/03	10%	5%	5%	67%	14%	100%
NPA0165	12/03/03	46%	21%	0%	21%	13%	100%
NPA0165	01/05/04	17%	33%	0%	8%	42%	100%
NPA0165	02/17/04	0%	54%	8%	15%	23%	100%
NPA0165	03/01/04	0%	67%	0%	0%	33%	100%

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

		Predicted Source					
Station	Date	Human	Livestock	Pet	Wildlife	Unknown	Total
NPA0165	04/05/04	4%	67%	8%	0%	21%	100%
NPA0165	05/10/04	27%	33%	0%	7%	33%	100%
NPA0165	06/07/04	13%	48%	4%	9%	26%	100%
NPA0165	07/06/04	38%	8%	17%	21%	17%	100%
NPA0165	08/09/04	50%	4%	4%	38%	4%	100%
NPA0165	09/07/04	25%	8%	0%	54%	13%	100%
NPA0165	10/04/04	43%	0%	30%	13%	13%	100%
Total		20%	20%	11%	23%	26%	100%

Figure 2-LIB: Liberty Reservoir Watershed relative contributions by probable sources of *Enterococcus* contamination.



SUMMARY

Liberty Reservoir Summary

The use of ARA was successful for identification of probable bacterial sources in the Liberty Reservoir Watershed. When water isolates were compared to the library and potential sources predicted, 74% of the isolates were classified as to category by statistical analysis. The highest RCC for the library was 94% (for pet and wildlife), with 87% for human. Livestock had an RCC of 71%.

The largest category of potential sources in the watershed as a whole was wildlife (32% of classified water isolates), followed by human and livestock (27% each). The last potential source contribution was for pet (14%) (Fig. 2-LIB).

REFERENCES

Bell, J.B., Elliott, G.E. & Smith, D.W. (1983). Influence of Sewage Treatment an Urbanization on Selection of Multiple Resistance in Fecal Coliform Populations. *Appl. Environ. Microbiol.* 46, 227-32.

Department of Health and Human Services. Centers for Disease Control and Prevention. Pulsenet. "National Molecular Subtyping Network for Foodborne Disease Surveillance" http://www.cdc.gov/pulsenet [Available 01.26.06].

Hagedorn, C., Robinson, S.L., Filtz, J.R., Grubbs, S.M., Angier, T.A. & Beneau, R.B. (1999) Determining Sources of Fecal Pollution in a Rural Virginia Watershed with Antibiotic Resistance Patterns in Fecal Streptococci. *Appl. Environ. Microbiol.* 65, 5522-5531.

Krumperman, P.H. (1983) Multiple Antibiotic Resistance Indexing of *Escherichia coli* to Identify High-Risk Sources of Fecal Contamination of Foods. *Appl. Environ. Microbiol.* 46, 165-70.

Scott, T.M., Rose, J.B., Jenkins, T.M., Farrah, S.R. & Lukasik, J. 2002 Microbial Source Tracking: Current Methodology and Future Directions. *Appl. Environ. Microbiol.* 68(12), 3373-3385.

Simpson, J.M., Santo Domingo, J.W. & Reasoner, D.J. 2002 Microbial Source Tracking: State of the Science. *Environ. Sci. Technol.* 36(24), 5279-5288.

Wiggins, B.A. (1996) Discriminant Analysis of Antibiotic Resistance Patterns in Fecal Streptococci, a Method to Differentiate Human and Animal Sources of Fecal Pollution in Natural Waters. *Appl. Environ. Microbiol.* 62, 3997-4002.

Wiggins, B.A., Andrews, R.W., Conway, R.A., Corr, C.L., Dobratz, E. J., Dougherty, D.P., Eppard, J.R., Knupp, S.R., Limjoco, M.C., Mettenburg, J.M., Rinehardt, J.M., Sonsino, J., Torrijos, R.L. & Zimmerman, M.E. (1999) Use of Antibiotic Resistance Analysis to Identify Nonpoint Sources of Fecal Pollution. *Appl. Environ. Microbiol.* 65, 3483-3486.

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Adjustment of BST Results

As explained in the BST Summary for the Liberty Reservoir watershed, the percent of correct classification (RCC) for bacteria sources, especially for the livestock category can introduce a potential misclassification of the more probable sources in the watershed. This is seen in Table C-4, which shows results of the analysis of samples from known sources. For example, out of 621, 86 isolates were known to be of human source but only 58 were classified by the analysis as being of human source. Of those 86, one isolate was classified as wildlife, 7 as pet, 1 as livestock, and 19 as unknown. Similarly, of the other three categories, three isolates were known to be livestock, two isolates known to be from pets, and 2 isolates from wildlife were classified as human, resulting in a total of 65 of all 621 isolates classified as human of which only 58 were known to be of human source.

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

Example:

The current BST methodology provides the following source percentages for station BEA0016 during high flow conditions:

Source Category	Original Percentage
Pets	10.92%
Human	22.17 %
Livestock	22.06 %
Wildlife	16.90 %
Unknown	27.95 %

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

From Table C-4:

Source Category	Isolates known to be from Human Source	Total Isolates Predicted for Each category	Percentage
Pets	7	79	8.9%
Human	58	65	89.2%
Livestock	1	103	1.0%
Wildlife	1	170	0.6%
Unknown	19	204	9.3%
Total	86	621	13.8%

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

= (8.9 x 10.92) + (89.2 x 22.17) + (1.0 x 22.06) + (0.6 x 16.90) + (9.3 x 16.90) = 23.7 %

Thus the correct human source percentage, the value used in the TMDL analysis, is 23.7% and not 22.17%. Corrected percentages are also calculated as above for domestic animal, livestock and wildlife sources. The classification of unknown is eliminated in the process as all known isolates are of known source. For station BEA0016 during high flow condition the corrected source percentages are as follows:

Source Category	**Adjusted Percentage**
Pets	15.3 %
Human	23.7 %
Livestock	35.6 %
Wildlife	25.4 %

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 Liberty Reservoir watershed. The approach builds upon the TMDL analysis that was conducted to ensure that compliance with the annual average target will result in compliance with the applicable water quality standards. The annual average loading target was converted into allowable *daily* values by using the loadings developed from the TMDL analysis. The approach is consistent with available EPA guidance on generating daily loads for TMDLs.

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

<u>Level of Resolution</u>

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.

<u>Probability Level</u>

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 Liberty Reservoir basin MDL for nonpoint 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 four monitoring stations of the Liberty Reservoir basin. 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 Liberty Reservoir basin, a value measured during high flow conditions at the MDE0026 station resulted in the highest percentile of both strata of the five stations. This value translates to the 99.7^{th} 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 (%)
NPA0165 North Branch Patapsco River	**High**	9,800	99.6
	Low	5,800	98.5
BEA0016 Beaver Run	**High**	930	98.0
	Low	4,400	98.9
MDE0026 Middle Run	**High**	24,190	99.7
	Low	1,670	94.9
MOR0040 Morgan Run	**High**	1,990	99.1
	Low	960	94.8
LMR0015 Little Morgan Run	**High**	1,330	99.2
	Low	620	88.2

The 99.7th percentile value results in a maximum daily load that would not be exceeded 99.7% of the time, as, in a similar manner, a TMDL that represents the long-term average condition would be expected to be exceeded half the time even after all required controls were implemented.

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

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

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

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

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

And from equation (10):

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

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:

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

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

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

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

Subwatershed	Flow Stratum	LTA Geometric Mean *E. coli* Concentration (MPN/100ml)	LTA Arithmetic Mean* *E. coli* Concentration (MPN/100ml)
NPA0165 North Branch Patapsco River	**High**	30	127
	Low	95	122
BEA0016 Beaver Run	**High**	34	69
	Low	85	209
MDE0026 Middle Run	**High**	43	182
	Low	105	134
MOR0040 Morgan Run	**High**	47	135
	Low	94	199
LMR0015 Little Morgan Run	**High**	24	68
	Low	95	184

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

The next step is to calculate the 99.7th percentile (the MDL concentrations) of these expected concentrations (LTA concentrations) using the coefficient of variation of the baseline concentrations. Based on a general rule for coefficient of variations, the coefficient of variation of the distribution of pollutant concentrations does not change after these concentrations have been reduced or controlled by a fixed proportion (Ott 1995). Therefore, the coefficient of variation estimated using the monitoring data concentrations does not change, and it can be used to estimate the 99.7th 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)
NPA0165 North Branch Patapsco River	**High**	4.10	3,282
	Low	2.12	3,504
BEA0016 Beaver Run	**High**	1.76	911
	Low	2.25	3,483
MDE0026 Middle Run	**High**	4.15	4,751
	Low	0.79	720
MOR0040 Morgan Run	**High**	2.70	2,618
	Low	1.85	2,758
LMR0015 Little Morgan Run	**High**	2.65	1,295
	Low	1.66	2,296

With the 99.7^{th} percentiles of LTA TMDL bacteria concentrations estimated for both high flow and low flow strata as explained above, the maximum daily load for MS4 and nonpoint sources for each subwatershed can be now estimated as:

$$Daily\ TMDL\ (MPN/day) = Q_H*(99.7^{th}C_{LTA\text{-}H})*F_{1H}*W_H + Q_L*(99.7^{th}C_{LTA\text{-}L})*F_{1L}*W_L \qquad (D7)$$

Selected Approach for Defining Maximum Daily Loads for Other Point Sources

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

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

The Maximum Daily Loads for the Liberty Reservoir subwatersheds are presented in Table D-4 below. For the unmonitored downstream subwatershed an average of the five upstream station loads is used.

Table D-4: Maximum Daily Loads Summary

Subwatershed	Flow Stratum	Maximum Daily Load (Billion *E. coli* MPN/day)	
		by Stratum	Weighted by Stratum
NPA0165 North Branch Patapsco River	**High**	10,981	5,586
	Low	3,082	
BEA0016 Beaver Run	**High**	756	779
	Low	789	
MDE0026 Middle Run	**High**	1,721	594
	Low	71	
MOR0040 Morgan Run	**High**	4,727	2,330
	Low	1,217	
LMR0015 Little Morgan Run	**High**	590	362
	Low	256	
Downstream Subwatershed	**High**	3,755	1,930
	Low	1,083	

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 Liberty Reservoir basin are presented in Table D-5.

Table D-5: Maximum Daily Loads

Subwatershed	Total Allocation	LA	SW-WLA	WWTP-WLA
	(Billion MPN *E. coli* /year)			
NPA0165	5,586	5,434	143	9
BEA0016	779	764	14	0
MDE0026	594	592	2	0
MOR0040	2,330	2,328	2	0
LMR0015	362	323	39	0
Downstream Subwatershed	1,930	1,854	76	0
MDL[1]	**11,580**	**11,295**	**276**	**9**

REFERENCES

Limno-Tech, Inc. 2007. Draft Memorandum: Technical Approach for Four Alternative Options to Define Maximum Daily Loads for the Anacostia TMDL. Washington, DC. January 23, 2007.

EPA (U.S. Environmental Protection Agency). 2006. Approaches For Developing a Daily Load Expression for TMDLs Computed for Longer Term Averages. Draft guidance document. Washington, DC. October 2006.

EPA (U.S. Environmental Protection Agency). 1991. Technical Support Document for Water Quality-Based Toxics Control (1991 TSD). Washington, DC.

Ott, Wayne R. Environmental Statistics and Data Analysis. 1995. CRC Press. Pages 276 – 283.