Total Maximum Daily Loads of Fecal Bacteria for the Herring Run Basin in Baltimore City and Baltimore County, Maryland

FINAL

MARYLAND
DEPARTMENT OF THE ENVIRONMENT

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Submitted to:

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June 2007

EPA Submittal Date: June 18, 2007
EPA Approval Date: December 4, 2007

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List of Abbreviations

ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BCDPW	Baltimore City Department of Public Works
BMP	Best Management Practice
BST	Bacteria Source Tracking
CAFO	Confined Animal Feeding Operations
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
CFU	Colony Forming Units
COMAR	Code of Maryland Regulations
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
DNR	Maryland Department of Natural Resources
EPA	Environmental Protection Agency
GIS	Geographic Information System
LA	Load Allocation
LTCP	Long Term Control Plan
MACS	Maryland Agricultural Cost Share Program
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
ml	Milliliter(s)
MOS	Margin of Safety
MPN	Most Probable Number
MPR	Maximum Practicable Reduction
MS4	Municipal Separate Storm Sewer System
MST	Microbial Source Tracking
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resources Conservation Service
RCC	Rates of Correct Classification
SSO	Sanitary Sewer Overflows
STATSGO	State Soil Geographic
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
VADEQ	Virginia Department of Environmental Quality
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plan

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 Herring Run (basin numbers 02-13-09-01-10-40, 41, 42). Section 303(d) of the federal Clean Water Act (CWA) and the 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 Herring Run in the State's 2002 303(d) List as impaired by fecal bacteria. Herring Run is designated as a Use IV waterbody (Water Contact Recreation, Protection of Aquatic Life and Natural Trout Waters) [Code of Maryland Regulations (COMAR) 26.08.02.08K(5)(c)]. As part of the Back River watershed, Herring Run has also been identified as impaired by nutrients (1996), sediments (1996), and impacts to biological communities (2002). This document proposes to establish a TMDL for fecal bacteria in Herring Run that will allow for the attainment of the primary contact recreation designated use. The listings for suspended sediments and impacts to biological communities will be addressed separately at a future date. A TMDL for nutrients for the entire Back River watershed (basin number 02-13-09-01) was completed in 2004 and approved by EPA on June 29, 2005. A data solicitation for fecal bacteria was conducted by MDE in 2003, and all readily available data from the past five years were considered. Data supplied by the Baltimore City Department of Public Works (BCDPW) were used in the development of the Herring Run TMDL.

The sources of fecal bacteria were estimated at three representative stations in the Herring Run watershed where the BCDPW collected fecal coliform samples for four years. These fecal coliform samples were translated to *E. coli*, the fecal bacteria indicator used by the State of Maryland. Translation of fecal coliform data to *E. coli* data was achieved by using a translator equation developed from a regression analysis developed by the State of Virginia Department of Environmental Quality (VA DEQ). 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 (agricultural related animals), and wildlife (mammals and waterfowl) source categories.

To establish baseline loads for this TMDL, a flow duration curve approach was used incorporating flow strata estimated from United States Geological Survey (USGS) daily flow monitoring data and current bacteria monitoring data. The baseline load is estimated using a long-term geometric mean and weighting factors from the flow duration curve. The TMDLs or allowable pollutant loads are established using fecal bacteria (*E. coli*) criteria concentrations. The TMDL load for fecal bacteria (*E. coli*) entering Herring Run is established after considering four different hydrological conditions: high flow and low flow annual conditions; and high flow and low flow seasonal conditions (the period between May 1st and September 30th where water contact recreation is more prevalent). This allowable load is reported in units of Most Probable

Number (MPN)/day and represents a long-term load estimated over a variety of hydrological conditions.

Two scenarios were developed, the first assessing whether attainment of current water quality standards could be achieved with maximum practicable reductions (MPRs) applied, and the second allowing 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 the three subwatersheds of Herring Run, it was estimated that water quality standards could not be attained with the MPRs. Thus, a second scenario was applied allowing greater reductions than MPRs.

The fecal bacteria long-term annual average TMDL for the Herring Run watershed is 652,460 billion MPN *E. coli*/year (1,788 MPN/day) with a maximum daily load of 42,266 MPN/day. This long-term annual average TMDL represents a reduction of approximately 93.4 % from the baseline load of 9,850,940 billion MPN/year. The TMDL is distributed between a load allocation (LA) for nonpoint sources and waste load allocations (WLA) for point sources, including National Pollutant Elimination System (NPDES) wastewater treatment plants (WWTPs), NPDES municipal separate storm sewer systems (MS4) and NPDES combined sewer overflows (CSOs).

The long-term annual average allocations are as follows: the LA is 73,872 billion MPN *E. coli*/year. There are no WWTPs with permits regulating the discharge of fecal coliform in the Herring Run, therefore the WWTP WLA is 0.0 billion MPN *E. coli*/year. The MS4 WLA is 578,588 billion MPN *E. coli*/year. Under consent decrees, sanitary sewer overflows (SSOs) and CSOs are to be eliminated in both Baltimore City and Baltimore County; therefore, the CSO WLA is 0.0 MPN *E. coli*/year. The margin of safety (MOS) has been incorporated using a conservative assumption by estimating the loading capacity of the stream based on a more stringent water quality endpoint concentration. The *E. coli* water quality criterion concentration was reduced by 5%, from 126 MPN/100ml to 119.7 MPN/100ml.

The maximum daily loads, estimated using the 99.5th percentile of predicted long-term annual average TMDL concentrations (after source controls), are allocated as follows: the LA is 4,768 billion MPN *E. coli*/day. The MS4 WLA is 37,498 billion MPN *E. coli*/day.

Once EPA has approved a TMDL, and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. As previously stated, water quality standards cannot be attained in the Herring Run subwatersheds using the MPR scenario. This may occur in subwatersheds where wildlife is a significant component or where very high reductions of fecal bacteria loads are required to meet water quality standards. Therefore, MDE proposes a staged approach to implementation of the required reductions, beginning with the MPR scenario, as an iterative process that first addresses those sources making the largest impacts on 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 effectiveness of implementation efforts.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria (*E. coli*) in Herring Run (basin numbers 02-13-09-01-10-40, 41, 42). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the 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 Herring Run in the State's 2002 303(d) List as impaired by fecal bacteria. Herring Run is designated as a Use IV waterbody (Water Contact Recreation, Protection of Aquatic Life and Natural Trout Waters) [Code of Maryland Regulations (COMAR) 26.08.02.08K(5)(c)]. As part of the Back River watershed, Herring Run has also been identified as impaired by nutrients (1996), sediments (1996), and impacts to biological communities (2002). This document proposes to establish a TMDL of fecal bacteria in Herring Run and its tributaries that will allow for the attainment of the primary contact recreation designated use. A TMDL for nutrients for the entire Back River watershed (basin number 02-13-09-01) was completed in 2004 and approved by EPA on June 29, 2005. The impairment for sediments and impacts to biological communities will be addressed separately at a future date. A data solicitation for fecal bacteria was conducted by MDE in 2003 and in 2006. Data received from the Baltimore City Department of Public Works (BCDPW) were selected for use in the analysis.

Fecal bacteria are microscopic single-celled organisms (primarily fecal coliforms 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, consumption of molluscan bivalves (shellfish), and 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 (USEPA 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 are a subgroup of total coliform bacteria and *E. coli* are a subgroup of fecal coliform. 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 (USEPA 1986) demonstrated that fecal coliform showed less correlation to swimming-associated gastroenteritis than either *E. coli* or enterococci.

The Herring Run watershed was listed on the Maryland 303(d) List in 2002 using fecal coliform as the indicator organism. Based on EPA's guidance (USEPA 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. Therefore, the original fecal coliform data received from BCDPW will be "translated" to *E. coli*, using a translator equation developed from a regression analysis developed by the State of Virginia Department of Environmental Quality (VA DEQ).

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

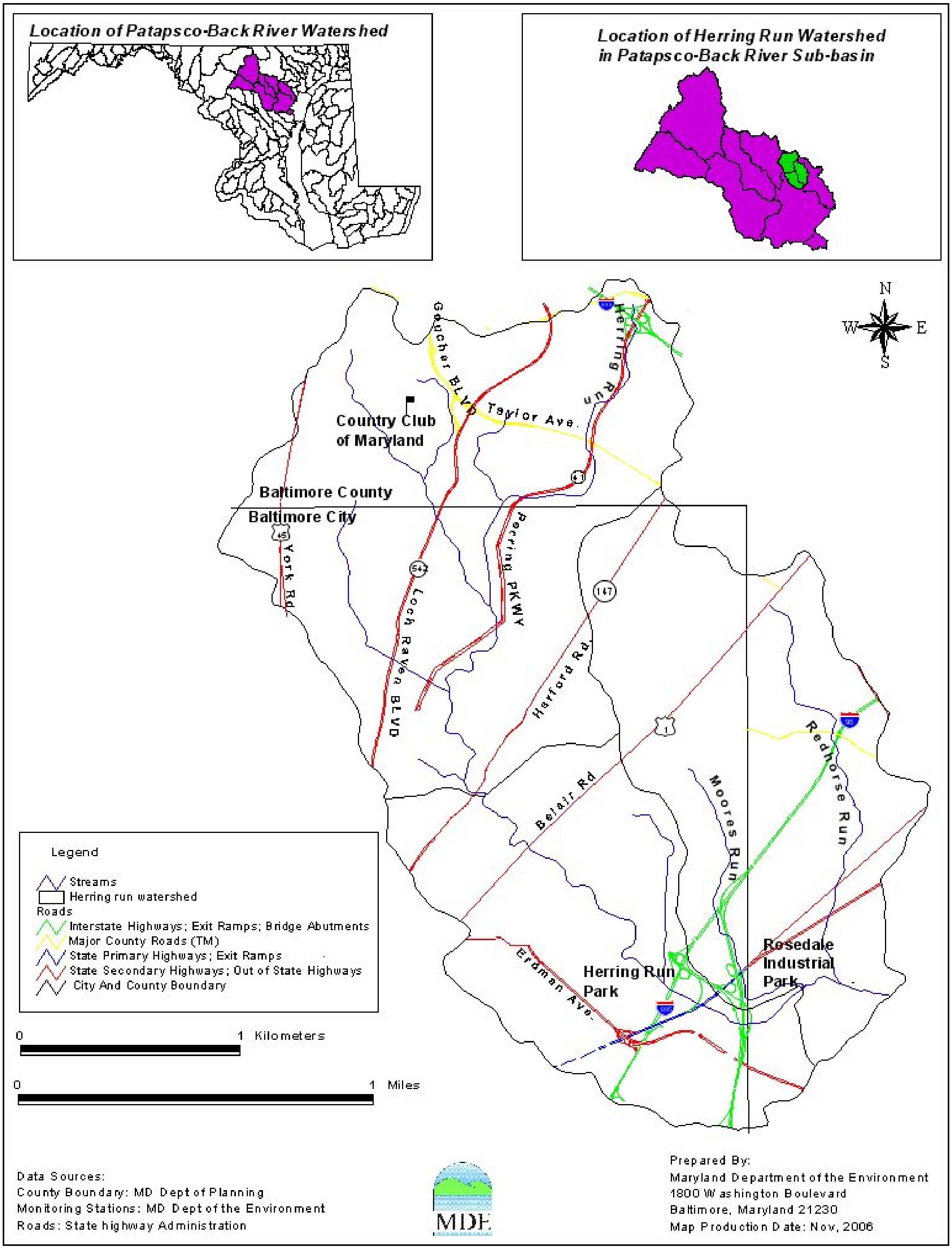
Location

The Herring Run watershed is a subwatershed of the Back River basin located in Southern Baltimore County and northern Baltimore City, Maryland (see Figure 2.1.1). The headwaters of Herring Run begin somewhere in the center of Towson in Baltimore County. An unnamed tributary to Herring Run flows through the Country Club of Maryland and continues through Regester Avenue near the Baltimore City line. Once the unnamed tributary flows under Northern Parkway, it connects with the mainstem of Herring Run. The mainstem of Herring Run originates in the region known as Loch Raven near Taylor Avenue and Perring Parkway. Herring Run watershed includes Herring Run, West Herring Run, Chinquapin Run, Moores Run, and Redhouse Run. Herring Run and all its tributaries are non-tidal.

Geology/Soils

The Herring Run watershed encompasses 19,198.8 acres (30 sq. mi). The watershed lies entirely in the Piedmont physiographic province. This province is characterized by gentle to steep rolling topography, low hills and ridges. The surficial geology is characterized by crystalline igneous and metamorphic rocks of volcanic origin consisting primarily of schist and gneiss. These formations are resistant to short-term erosion and often determine the limits of stream bank and streambeds.

The Herring Run watershed lies predominantly in the Beltsville soil series (see Figure 2.1.2). Soils in this series are fine-loamy, mixed, mesic Typic Fragiudults and are very deep and moderately well drained soils (USDA 1995). The Othello series are found in the northwest portion of the watershed and the silt Othello series occurs at the southern portion of the watershed. The eastern central section is of the Lehigh series. The soils within the subwatersheds consist primarily of type C soils. The remaining is classified as type B or type D soils. Types C and D soils have relatively low infiltration capacity relative to types A and B soils.



Data Sources:
County Boundary: MD Dept of Planning
Monitoring Stations: MD Dept of the Environment
Roads: State highway Administration

Prepared By:
Maryland Department of the Environment
1800 Washington Boulevard
Baltimore, Maryland 21230
Map Production Date: Nov, 2006

Figure 2.1.1: Location Map of the Herring Run Watershed

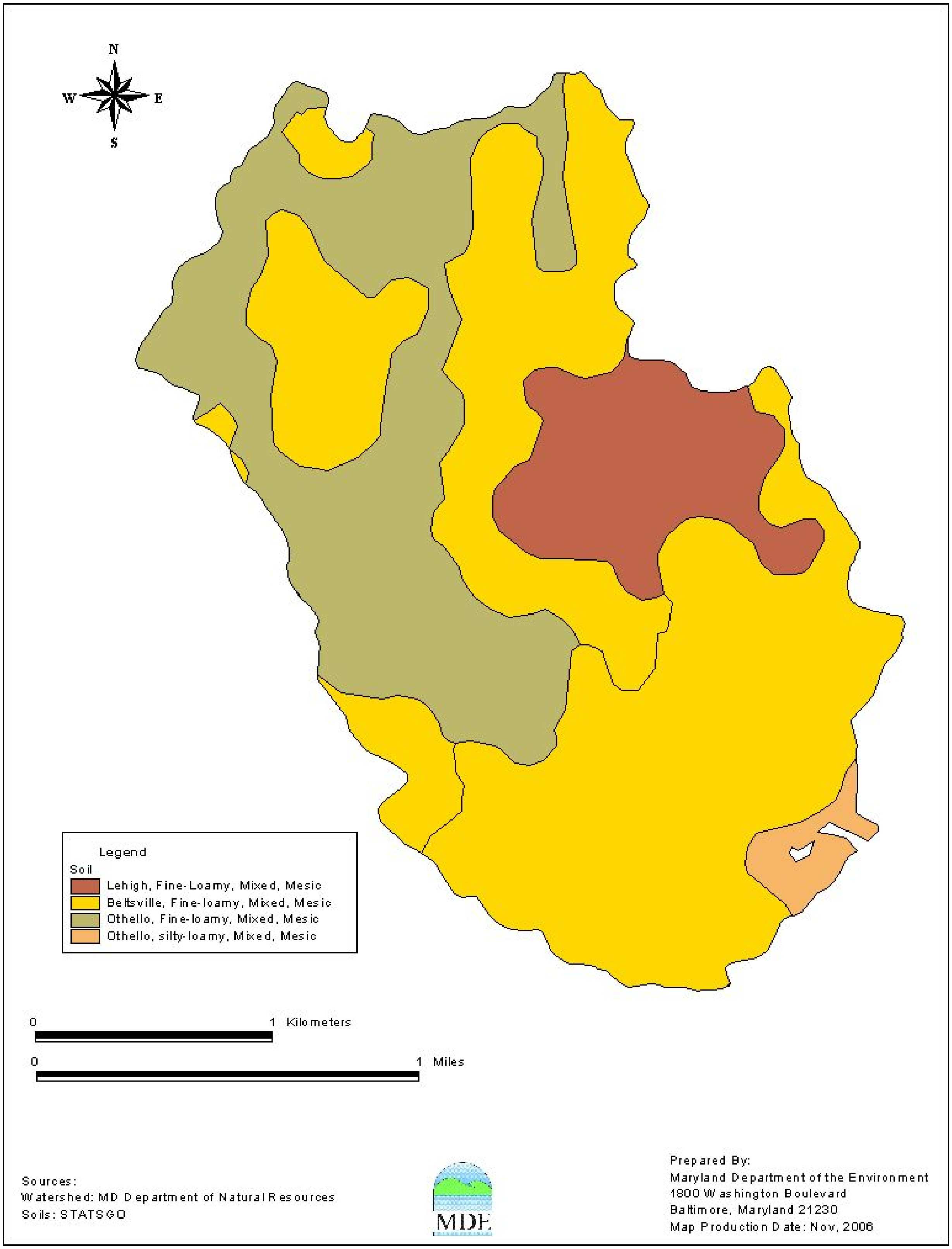


Figure 2.1.2: General Soil Series in the Herring Run Watershed

Land Use

The Herring Run watershed encompasses 19,199 acres (30 sq. mi) within urban Baltimore City and suburban Baltimore County. The Herring Run watershed is one of the most densely populated watersheds within the Chesapeake Bay drainage basin.

The 2000 Maryland Department of Planning (MDP) land use/land cover data shows that the watershed can be characterized as primarily urban development. Park and forest lands cover 8% of the watershed and are concentrated in the Baltimore County portion of the watershed. The residential land use covers approximately 60% and commercial land uses cover approximately 31% of the watershed, and are more concentrated in the Baltimore City portion of the watershed. The land use percentage distribution for the Herring Run Basin is shown in Table 2.1.1, and spatial distributions for each land use are shown in Figure 2.1.3.

Table 2.1.1: Land Use Percentage Distribution for the Herring Run Watershed

Land Type	Acreage	Percentage
Forest	1,523	8 %
Residential	11,678	60 %
Commercial	5,872	31 %
Water	126	1 %
Totals	**19,199**	**100%**

Population

The total population in the Herring Run watershed is estimated to be 75,372. Figure 2.1.4 displays the population density in the watershed. Urban areas are more densely populated within the Baltimore City limits. The population is less dense in the suburban areas of Baltimore County.

The population and the number of households in the watershed were estimated based on a weighted average from the Geographic Information System (GIS) 2000 Census Block and the 2002 MDP land use cover. Since the Herring Run watershed is a sub-area of the Census Block, the GIS tool was used to extract the areas from the 2000 Census Block within the watershed. Based on the land use for residential density (low, medium, high) from the MDP land use cover, the number of dwellings per acre in the watershed was calculated using Table 2.1.2.

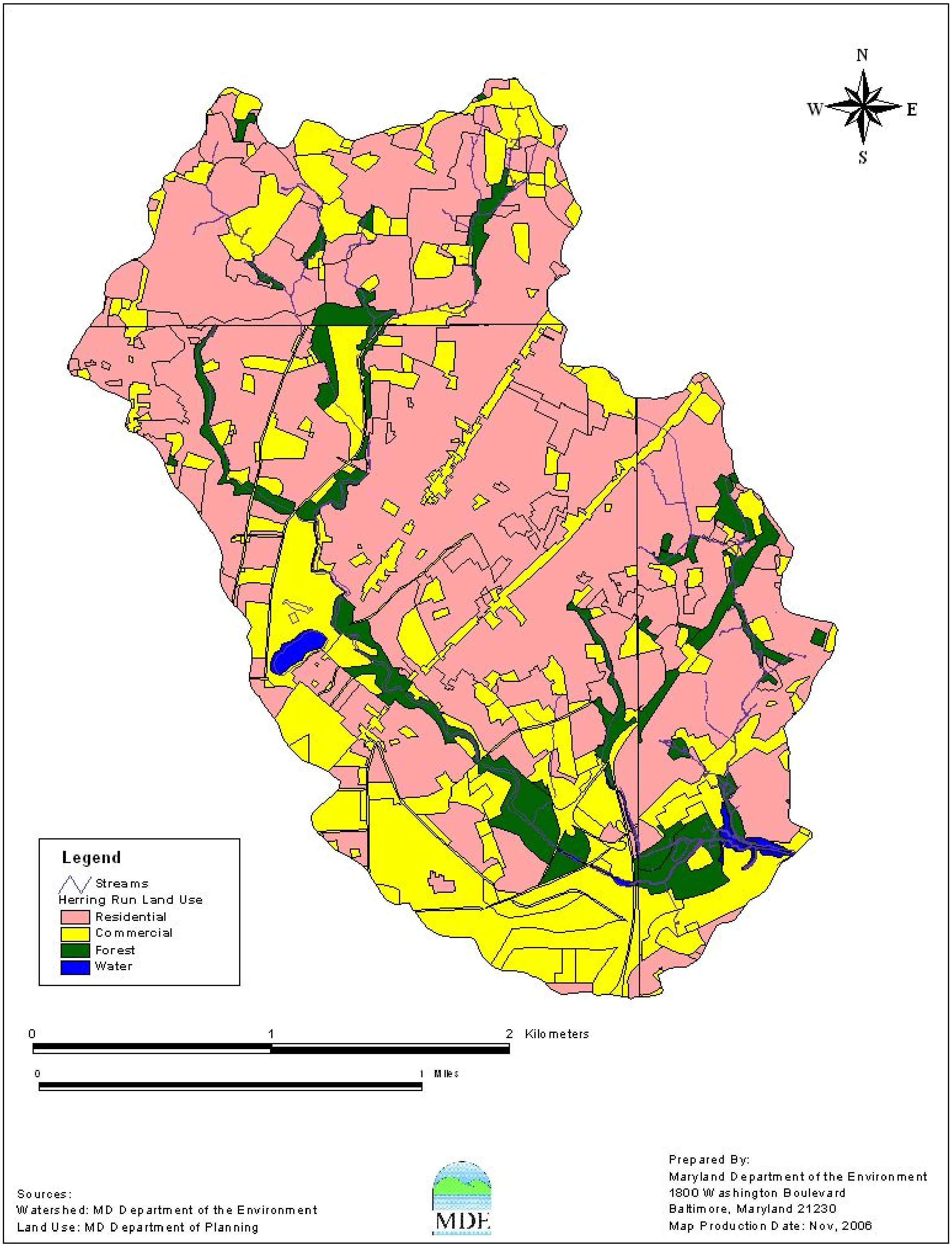
Table 2.1.2: Number of Dwellings Per Acre

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

Based on the number of households from the total population from the Census Block and the number of dwellings per acre from the MDP land use cover, population per subwatershed was calculated (Table 2.1.3).

Table 2.1.3: Total Population Per Subwatershed in the Herring Run Watershed

Subwatershed	Population	Dwellings
Harford Rd	43,118	35,757
Pulaski Hgwy	11,510	11,745
Biddle & 62nd St	20,744	16,783
Total	75,372	64,285



Sources:
Watershed: MD Department of the Environment
Land Use: MD Department of Planning

Prepared By:
Maryland Department of the Environment
1800 Washington Boulevard
Baltimore, Maryland 21230
Map Production Date: Nov, 2006

Figure 2.1.3: Land Use of the Herring Run Watershed

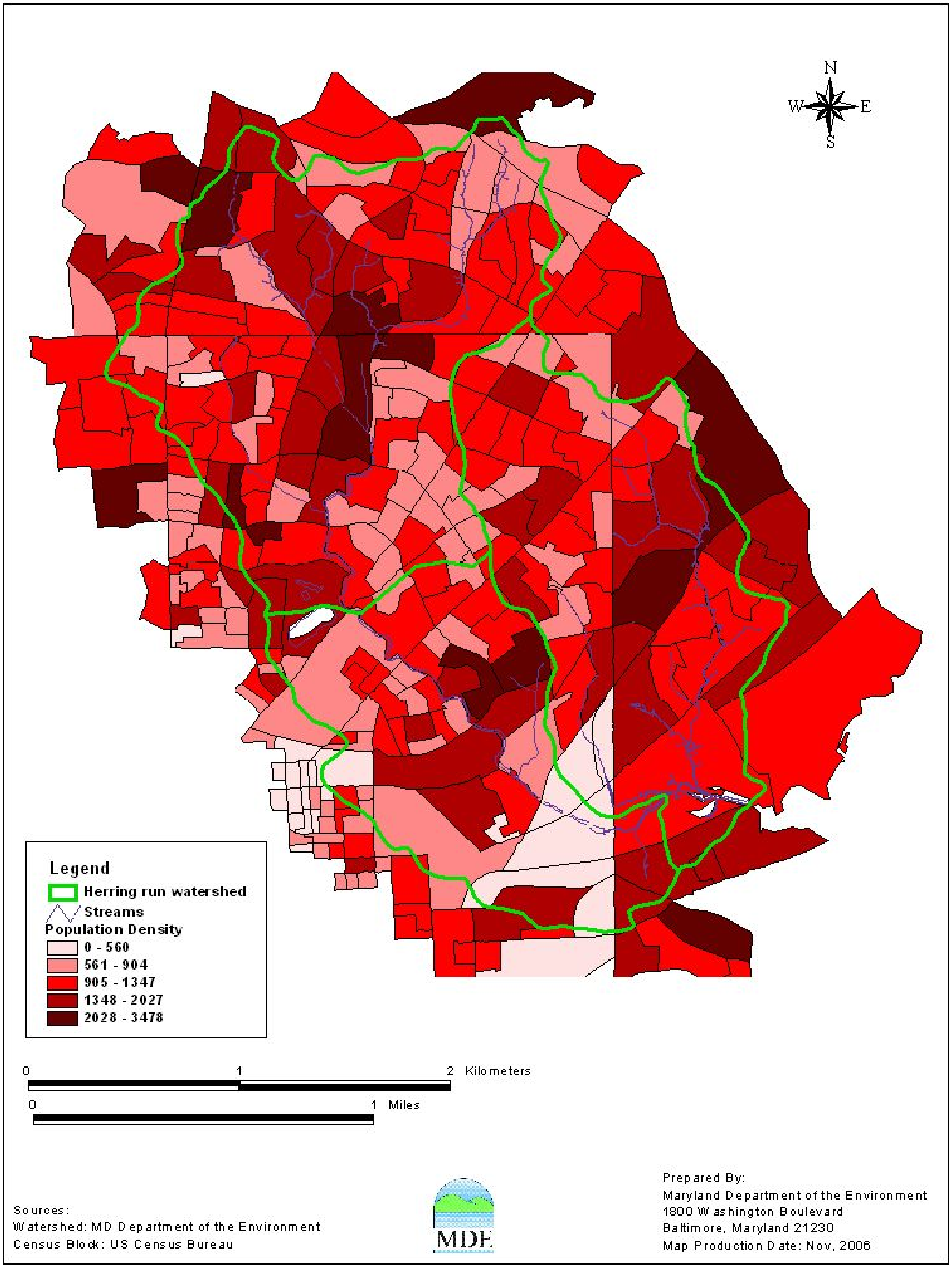


Figure 2.1.4: Population Density in the Herring Run Watershed

2.2 Water Quality Characterization

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

As per EPA's guidance, Maryland has adopted the new indicator organisms, *E. coli* and enterococci, for the protection of public health in Use I, II, III and IV waters. These bacteria listings were originally assessed using fecal coliform bacteria. The assessment was based on a geometric mean of the monitoring data, where the result could not exceed a geometric mean of 200 MPN/100ml. From EPA's analysis (USEPA 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 assure that risk levels are acceptable.

Bacteria Monitoring

Table 2.2.1 lists the monitoring data for the Herring Run watershed. HER0065 is the only MDE monitoring station in the Herring Run watershed, which was used to identify the bacterial impairment, where MDE conducted intensive monitoring from October 2002 through October 2003. Baltimore City Department of Public Works (BCDPW) has conducted extensive monitoring at many stations throughout the watershed. Three of these BCDPW stations, representative of the watershed, were selected for the TMDL development: Harford Road, Pulaski Highway and Biddle Street stations.

Bacteria counts are highly variable in the Herring Run. This is typical for all streams due to the nature of bacteria and its relationship to flow. BCDPW data were collected from January 2002 through August 2005. Ranges were typically between 20 and 170,000 MPN *E. coli*/100 ml. USGS gage station 01585200 located in the Herring Run watershed was used in the estimation of the surface flow. The locations of MDE and BCDPW stations are shown in Table 2.2.2 and Table 2.2.3, and illustrated in Figure 2.2.1. Location of the USGS flow station is shown in Table 2.2.4. Observations recorded during the period 2002-2003 from BCDPW monitoring stations are displayed in Table A-1 and illustrated in Figure A-1 in Appendix A.

Table 2.2.1: Monitoring Data in the Herring Run Watershed

Sponsor	Location	Date	Design	Summary
Baltimore City Department of Public Works*	Baltimore City	2002-2005	Fecal Coliform	3 stations used in the TMDL analysis 1 sample per month High bacteria concentrations
MDE	Baltimore City	11/02 – 09/03	*E. coli*	1 station 2 enumerations per month Data for upstream subwatershed only, used for impairment assessment.
MDE*	Baltimore City	11/02-09/03	Bacteria Source Tracking (BST) (*E. coli*)	1 station Antibiotic Resistance Analysis (ARA) 1 sample per month

* Data used in the TMDL analysis

Table 2.2.2: Locations of MDE Monitoring Station in the Herring Run Watershed

Monitoring Station	Observation Period	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
HER0065	11/02 – 09/03	39^{o} 20.72’	76^{o} 34.85’

Table 2.2.3: Locations of BCDPW Monitoring Stations in the Herring Run Watershed

Monitoring Station	Observation Period	Total Observations	LATITUDE Dec-Deg	LONGITUDE Dec-Deg
Harford Rd	01/02 - 08/05	42	41^{o} 34’ 10.2’’	79^{o} 34’ 23.66’’
Pulaski Hwy	01/02 - 08/05	41	41^{o} 35’ 55.0’’	79^{o} 36’ 42.8’’
Biddle St	01/02 - 08/05	42	41^{o} 36’ 18.2’’	79^{o} 36’ 26.8’’

Table 2.2.4: Locations of USGS Gauging Stations in Herring Run Watershed

Monitoring Station	Observation Period	LATITUDE Dec-deg	LONGITUDE Dec-deg
01585200	10/1996 – 10/2005	39^{o} 22.42’	76^{o} 35.06’

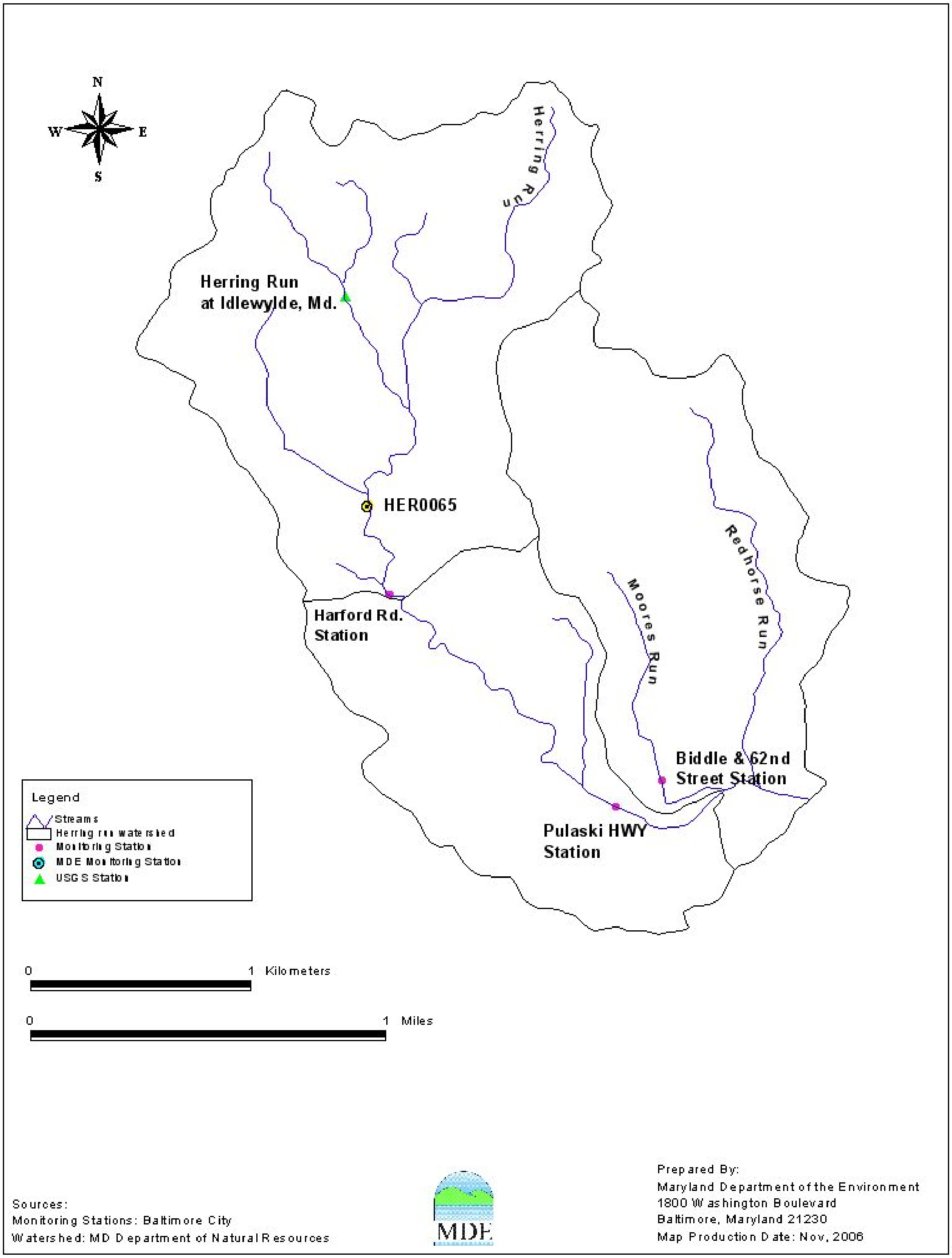


Figure 2.2.1: Monitoring Stations in the Herring Run Watershed

2.3 Water Quality Impairment

Designated Uses and Water Quality Standard

The Maryland water quality standards Surface Water Use Designation for Herring Run is Use IV (Water Contact Recreation, Protection of Aquatic Life and Natural Trout Waters) See COMAR

26.08.02.08K(5)(c). Herring Run was first listed in the State's 2002 303(d) List as impaired by fecal coliform bacteria, and has been included on the final 2004 Integrated 303(d) List.

Water Quality Criteria

The State water quality standard for bacteria (*E. coli*) used in this study is as follows (COMAR 26.08.02.03-3):

Table 2.3.1: Bacteria Criteria Values from Table 1 COMAR 26.08.02.03-3 Water Quality Criteria Specific to Designated Uses.

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

Interpretation of Bacteria Data for General Recreational Use

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

Recreational Waters

A steady-state geometric mean will be calculated with available data where there are at least five representative sampling events. The data shall be from samples collected during steady-state conditions and during the beach season (Memorial Day through Labor Day) to be representative of the critical condition. If the resulting steady-state geometric mean is greater than 126 MPN/100 ml *E. coli* 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

To assess water quality impairment in the Herring Run watershed, both the annual and the seasonal (May 1st – September 30th) steady-state geometric means of *E. coli* concentrations are compared with the water quality criterion.

As mentioned in the Bacteria Monitoring section, three BCDPW monitoring stations, Harford Road, Pulaski Highway and Biddle Street stations were selected for the TMDL development. BCDPW uses fecal coliform as the organism indicator, and in order to compare these existing fecal coliform data against the *E. coli* standard of 126 MPN/100ml, it was necessary to translate the fecal coliform data to *E. coli* data. This translation was achieved by using a translator equation developed from a regression analysis of 493 paired fecal coliform/*E. coli* samples from the Virginia Department of Environmental Quality (VADEQ) statewide monitoring network. The translator equation resulting from the regression analysis is as follows:

$$\text{Log}_2\,(\textit{E. coli}) = -0.0172 + 0.91905 * \text{Log}_2\,(\text{Fecal Coliform})$$

With the translated data, steady-state geometric means of *E. coli* can be estimated and used for comparison 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 (USEPA 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.

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 on an annual and seasonal basis.

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

A routine monitoring design was used to collect bacteria data in the Herring Run watershed. To estimate the steady-state geometric means, 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 means 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.

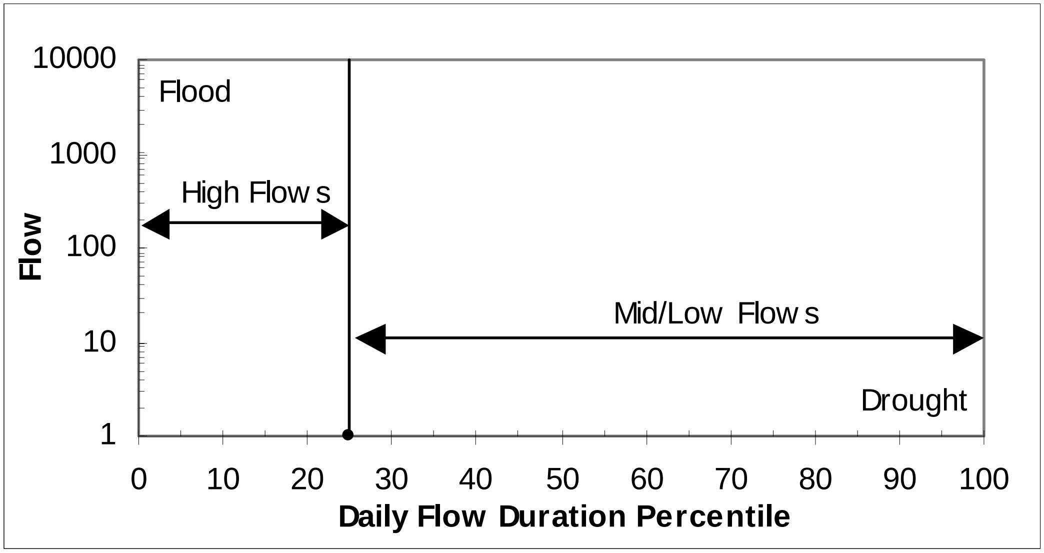


Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

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 period (mid flows) between the high and low flow durations that is representative of varying contributions of surface flow inputs that result from differing rainfall volumes and antecedent soil moisture conditions. The division of the entire flow regime into strata enables the estimation of a less biased geometric mean from routine monitoring data that more closely approaches steady state. Based on a flow analysis of several watersheds throughout Maryland, it was determined that flows within the 25th to 30th daily flow duration percentiles were representative of average daily flows. It is assumed for this analysis that flows above the 25th percentile represent high flows and flows below the 25th percentile represent mid/low flows. A detailed method of how the flow strata were defined is presented in Appendix B.

Factors for estimating a steady-state geometric mean are based on the frequency of each flow stratum. The weighting factor accounts for the proportion of time that each flow stratum represents. Bacteria enumeration results for samples within a specified flow stratum will receive their corresponding weighting factor. The weighting factors for an average hydrological year used in the Herring Run TMDL analysis are presented in the following table (Table 2.3.2).

Table 2.3.2: Weighting factors for Average Hydrology Year Used for Estimation of Geometric Means in the Herring Run Watershed (Average Hydrology Year)

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

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 *i*

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

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

C_{gm} = Steady-state geometric mean concentration

Tables 2.3.3 and 2.3.4 present the maximum and minimum concentrations by stratum, geometric means by stratum and the overall steady-state geometric mean for the Herring Run subwatersheds for the annual and the seasonal (May 1st –September 30th) periods.

Table 2.3.3: Herring Run Annual Steady-state Geometric Mean by Stratum per Subwatersheds

Station	Flow Stratum	# Samples	*E. coli* Minimum (MPN/100ml)	*E. coli* Maximum (MPN/100ml)	Annual Steady-state Geometric Mean (MPN/100ml)	Annual Overall Geometric Mean (MPN/100ml)
Harford Rd	**High**	9	299	170,789	6,471	1,063
	Low	33	36	5,967	582	
Pulaski Hwy	**High**	9	187	63,367	3,500	644
	Low	32	7	2,479	366	
Biddle St	**High**	9	111	106,800	2,016	1,462
	Low	33	23	86,997	1,313	

Table 2.3.4: Herring Run Seasonal (May 1st-September 30th) Period Steady-state Geometric Mean by Stratum per Subwatersheds

Station	Flow Stratum	# Samples	*E. coli* Minimum (MPN/100ml)	*E. coli* Maximum (MPN/100ml)	Seasonal Steady-state Geometric Mean (MPN/100ml)	Seasonal Overall Geometric Mean (MPN/100ml)
Harford Rd	**High**	5	1,215	86,997	9,129	1,176
	Low	12	49	5,967	594	
Pulaski Hwy	**High**	5	187	42,473	4,326	1,003
	Low	12	146	2,479	616	
Biddle St	**High**	5	528	106,800	3,840	2,283
	Low	12	299	12,868	1,920	

2.4 Source Assessment

Nonpoint Source Assessment

Nonpoint sources of fecal bacteria do not have one discharge point but occur over the entire length of a stream or waterbody. During rain events, surface runoff transports water and fecal bacteria over the land surface and discharges to the stream system. This transport is dictated by rainfall, soil type, land use, and topography of the watershed. Many types of nonpoint sources introduce fecal bacteria to the land surface, including the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. The deposition of non-human fecal bacteria directly to the stream occurs when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions from human activities generally arise from failing septic systems and their associated drain fields or leaking infrastructure (i.e., sewer systems). Land use in the Herring Run watershed consists primarily of developed land uses (residential and commercial); therefore, sources associated with agricultural land use (i.e., livestock) represent a minimal contribution to the load allocation (LA) in this watershed. The entire watershed is covered by two National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) individual permits; therefore, contributions from domestic animal and human sources will be categorized under point sources or Waste Load Allocations (WLAs). Wildlife contributions will be distributed between WLAs and LAs due to the presence of wildlife in both developed and undeveloped areas of the watershed.

Sewer Systems

The Herring Run watershed is serviced entirely by sewers. Sewage collection systems within the Herring Run watershed convey wastewater from municipalities in Baltimore County and Baltimore City. The wastewater is treated by one municipal wastewater treatment plant (WWTP), the Back River WWTP. Some sections of the Baltimore City sewage collection system are combined sewer systems (CSSs), receiving stormwater as well as wastewater. In addition, storm water in the watershed is conveyed through storm sewers covered by NPDES MS4 permits. Because the bacteria sources associated with these sewer systems are thus derived from point sources, they are addressed in the Point Source Assessment section below.

Septic Systems

There are no on-site disposal (septic) systems located in the Herring Run watershed.

Point Source Assessment

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

Municipal Separate Storm Sewer Systems (MS4)

The Herring Run watershed is located in Baltimore City and Baltimore County, which are both individual Phase I National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) permit jurisdictions. The MS4 permits cover stormwater discharges from the municipal separate stormwater sewer systems in the City and the County.

Baltimore City has conducted stormwater monitoring for 15 years in the area, both at the outfalls and in the stream. The City has monitored for fecal bacteria during base flow and storm events. Broken sanitary pipes laid in the streambed are a major source of fecal bacteria. As a result, fecal concentrations are high in Herring Run during dry weather because the wastewater is exfiltrating (seeping) into the stream.

Sanitary Sewer and Combine Sewer Overflows

Sanitary Sewer Overflows (SSOs) occur when the capacity of a sanitary sewer is exceeded. There are several factors that may contribute to SSOs from a sewer system, including pipe capacity, operations and maintenance effectiveness, sewer design, age of system, pipe materials, blockages, geology and building codes. SSOs are prohibited by the facilities' permit and therefore 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.

In 2002, Baltimore City, MDE, and EPA entered into a civil consent decree to address SSOs and combined sewer overflows (CSOs)[1] within its jurisdictional boundaries. See U.S., et al., v. Mayor and City Council of Baltimore, JFM-02-12524, Consent Decree (entered Sept. 30, 2002). Similarly, in 2005, Baltimore County, MDE and EPA entered into a civil consent decree to address SSOs in the County. See U.S., et al. v. Baltimore County, AMD-05-2028, Consent Decree (entered Sept. 20, 2006). The consent decrees require the City and the County evaluate their sanitary sewer systems and to repair, replace, or rehabilitate the systems as indicated by the results of those evaluations, with all work to be completed by January 2016 for Baltimore City and by March 2020 for Baltimore County.

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[1] A "combined sewer system" is a sewer system in which stormwater and sanitary sewerage are conveyed through a common set of pipes for treatment at a wastewater treatment plant. A CSO is an overflow from such a combined system. Baltimore City agreed in the Consent Decree to separate the sanitary and stormwater lines in the small areas served by a combined system and has completed that separation.

There were a total of 72 SSO events reported between January 2002 and December 2004. Approximately 124,198,400 gallons of SSO discharge were released through various waterways (surface water, groundwater, sanitary sewers, etc.) in the Herring Run mainstem and tributaries (MDE, Water Management Administration). Figure 2.4.1 depicts the location where SSOs occurred between January 2002 and December 2004 in the Herring Run watershed.

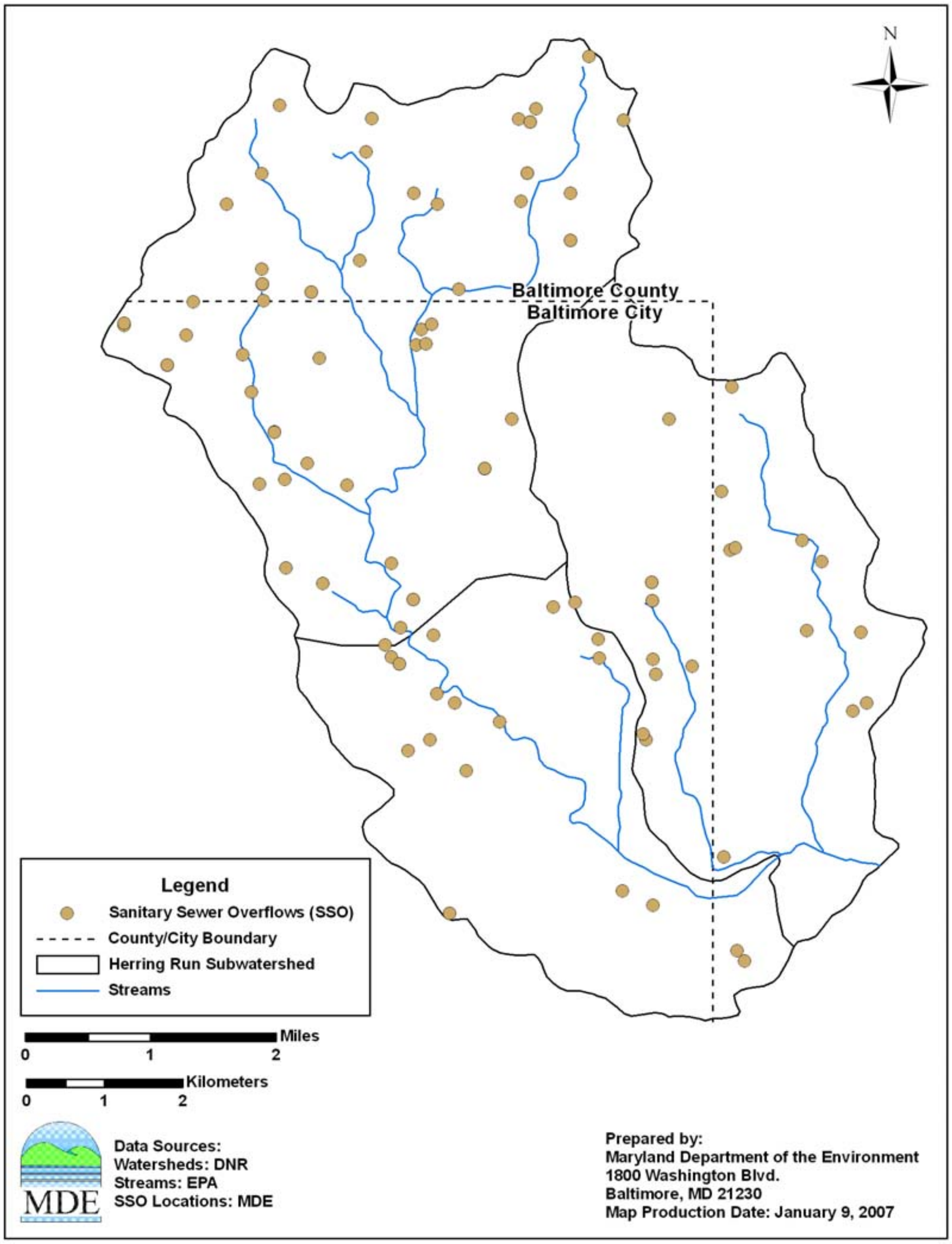

Figure 2.4.1: Location of Sanitary Sewer Overflows in the Herring Run Watershed

SSO and CSO Structures

CSO and SSO structures, which are a part of the sewage collection system infrastructure, are designed to release sewage when the capacity of a combined or separate sewer system is exceeded, in order to prevent backups within the collection system. Like non-structural SSOs, there are several factors that may contribute to structural CSOs and SSOs from a sewage collection system, including pipe capacity, operations and maintenance effectiveness, sewer design, age of system, pipe materials, geology and building codes. Structural CSOs and SSOs are designed to discharge; therefore, they are subject to NPDES permit requirements. As explained in the preceding section, all overflow structures will be eliminated from the sanitary sewer system by January 2016 for Baltimore City and by March 2020 for Baltimore County.

In the Herring Run watershed, the Back River WWTP is responsible for all CSO and SSO structural releases under their associated NPDES permits. The watershed contains a total of 7 sewer overflow structures. Table 2.4.1 and Figure 2.4.2 display the location of CSO and SSO structures which discharge into Herring Run and its tributaries.

Table 2.4.1: Sanitary and Combined Sewer Overflow Structures in the Herring Run Watershed

Treatment Plant	NPDES ID	CSO/SSO Structure ID	Type	Latitude	Longitude	Receiving Water
Back River WWTP	MD0021555	88	SSO	39.358	-76.607	Herring Run
		92	Siphon Blowoff	39.294	-76.524	Herring Run
		93	SSO	39.329	-76.538	Moores Run
		94	Siphon Blowoff	39.311	-76.541	Moores Run
		109	SSO	39.338	-76.548	Moores Run
		118	SSO	39.353	-76.547	Moores Run
		119	SSO	39.356	-76.550	Moores Run

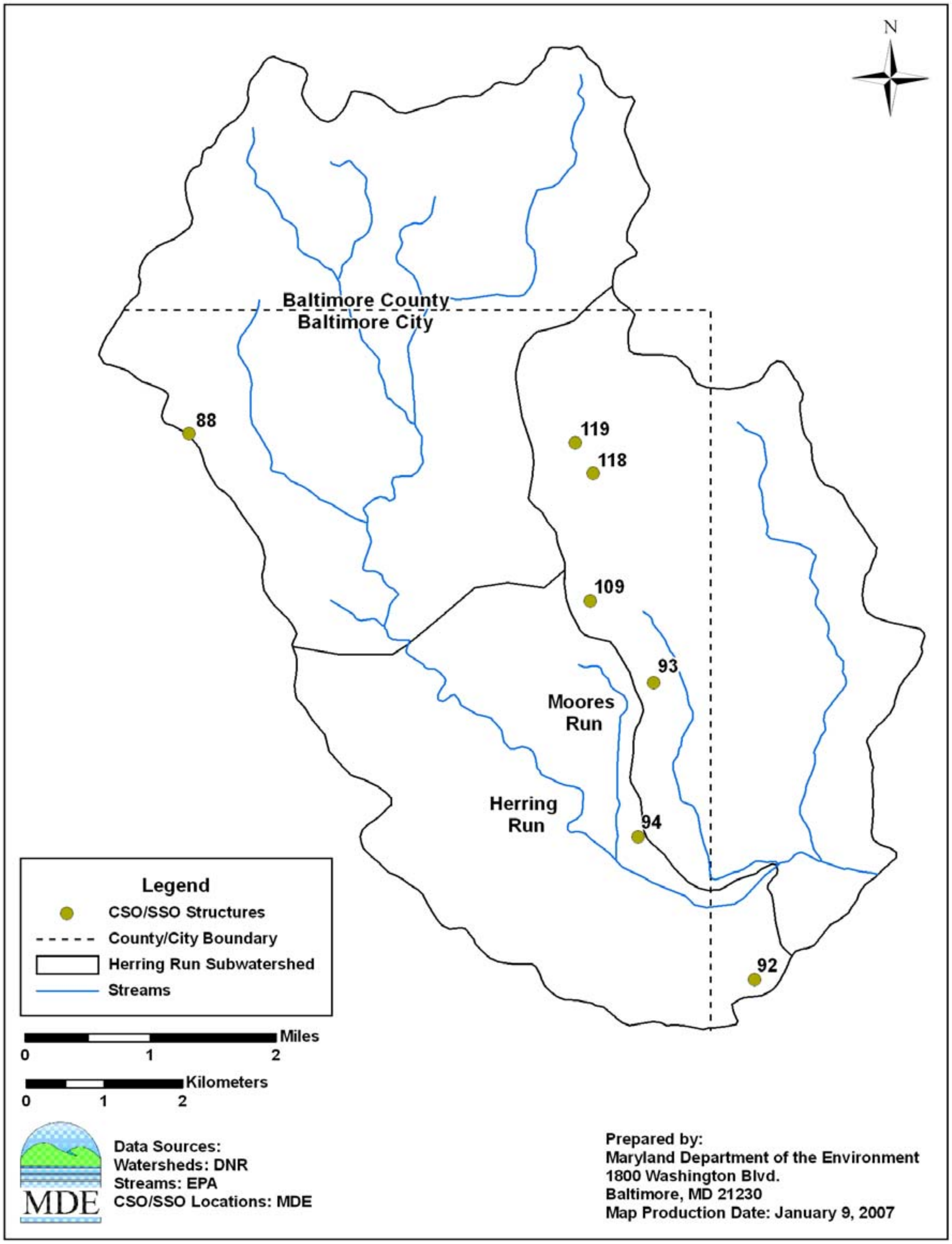

Figure 2.4.2: Sanitary and Combined Sewer Overflows Structures in the Herring Run Watershed

Municipal and Industrial WWTPs

There are no municipal WWTPs and only one industrial NPDES point source (Taylor Avenue Associates). This industrial facility does not discharge effluent containing fecal bacteria and therefore has no permit limits regulating the discharge fecal bacteria into Herring Run or its tributaries.

Bacteria Source Tracking

Bacteria source tracking (BST) was used to identify the relative contribution of bacteria from different sources in in-stream water samples. MDE conducted BST Monitoring at one station in the Herring Run watershed with 12 samples (one per month) collected for a one-year duration. Sources are defined as domestic (pets and human associated animals), human (human waste), livestock (agricultural animals), and wildlife (mammals and waterfowl). To identify sources, samples are collected within the watershed from known fecal sources and the patterns of antibiotic resistance of these known sources are compared to isolates of unknown bacteria from ambient samples. Details of the BST methodology and data can be found in Appendix C.

An accurate representation of the expected average source at each station is estimated by using a stratified weighted mean of the identified sample results over the specified period. 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 as follows:

1. Calculate the percentage of isolates per source per each sample date (S).
2. Calculate the weighted percentage (MS) of each source per flow strata (high/low) (see Section 4). The weighting is based on the $\log_{10}$ bacteria concentration for the water sample.
3. The final weighted mean source percentage, for each source category, is based on the proportion of time in each flow duration zone (see Appendix C).

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

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

where

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

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

The complete distributions of the annual and seasonal periods source loads are listed in Table 2.4.2. Details of the BST data can be found in Appendix C.

Table 2.4.2: Distribution of Fecal Bacteria Source Loads in the Herring Run Watershed (Annual and Seasonal Period)

Station	Period	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
HER0065	**Seasonal**	**High**	13	37	0	0	50
		Low	8	57	0	14	21
		Weighted	9	52	0	10	29
	Annual	**High**	20	40	0	0	40
		Low	11	57	0	11	21
		Weighted	13	53	0	8	26

Source Distribution

The final bacteria source distribution is derived from the source proportions listed in Table 2.4.2. For the purposes of the TMDL analysis and allocations, the percentage of sources identified as "unknown" were removed and the known sources were then redistributed proportionally so that they totaled 100%. The annual average bacteria source distribution and corresponding baseline loads are presented in Table 2.4.3. The seasonal period source distribution and corresponding baseline loads are presented in Table 2.4.4.

Table 2.4.3: Annual Average Bacteria Source Distributions and Corresponding Baseline Loads Used in the TMDL Analysis

Station	Domestic		Human		Livestock		Wildlife	
	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)	%	Load (Billion *E. coli* MPN/year)
Harford Rd	18.9	1,190,425	70.7	4,446,259	0.0	0.0	10.4	652,126
Pulaski Hwy	18.9	377,170	70.7	1,408,735	0.0	0.0	10.4	206,617
Biddle & 62nd St.	18.9	297,115	70.7	1,109,729	0.0	0.0	10.4	162,762

Table 2.4.4: Seasonal Bacteria Source Distributions and Corresponding Baseline Loads

Station	Domestic		Human		Livestock		Wildlife	
	%	Load Billion *E. coli* MPN/season	%	Load Billion *E. coli* MPN/season	%	Load Billion *E. coli* MPN/season	%	Load Billion *E. coli* MPN/season
Harford Rd	14.2	526,236	72.6	2,690,476	0.0	0.0	13.2	489,178
Pulaski Hwy	14.2	146,798	72.6	750,529	0.0	0.0	13.2	136,460
Biddle & 62nd St.	14.2	174,090	72.6	890,067	0.0	0.0	13.2	161,830

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 Herring Run 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 with the estimation of 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. The analysis methodology is based on available monitoring data and is specific to a free flowing stream system. The fourth section addresses critical conditions and seasonality. The fifth section presents the margin of safety. The sixth section discusses TMDL loading caps. The seventh section presents TMDL scenario descriptions. The eighth section presents the load allocations. Finally, in the ninth section, 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 (WLA) for point sources, load allocations (LA) 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 accurate estimations of source inputs are 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., *E. coli*), 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 (USEPA 1985), and the second (Method 9223B) is a statistical estimate of the number of colonies (APHA 1998). Enumeration results indicate the extreme variability in total bacteria counts. The distribution of the enumeration results from water samples tends to be lognormal, with a strong positive skew of the data. Estimating loads of constituents that vary by orders of magnitude can introduce much uncertainty and result in large confidence intervals around the final results.

Estimating bacteria sources can also be problematic, due to the many assumptions required and to limited available data. Lack of specific numeric and spatial location data for several source categories, from failing septic systems to domestic animal, livestock, and wildlife populations, can create many potential uncertainties in traditional water quality modeling. For this reason, MDE applies an analytical method combined with the bacteria source tracking described above, for the calculation of this TMDL.

4.2 Analysis Framework

This TMDL analysis uses a flow duration curve framework to identify flow intervals that are indicators of hydrological conditions (i.e., annual average, 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.

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

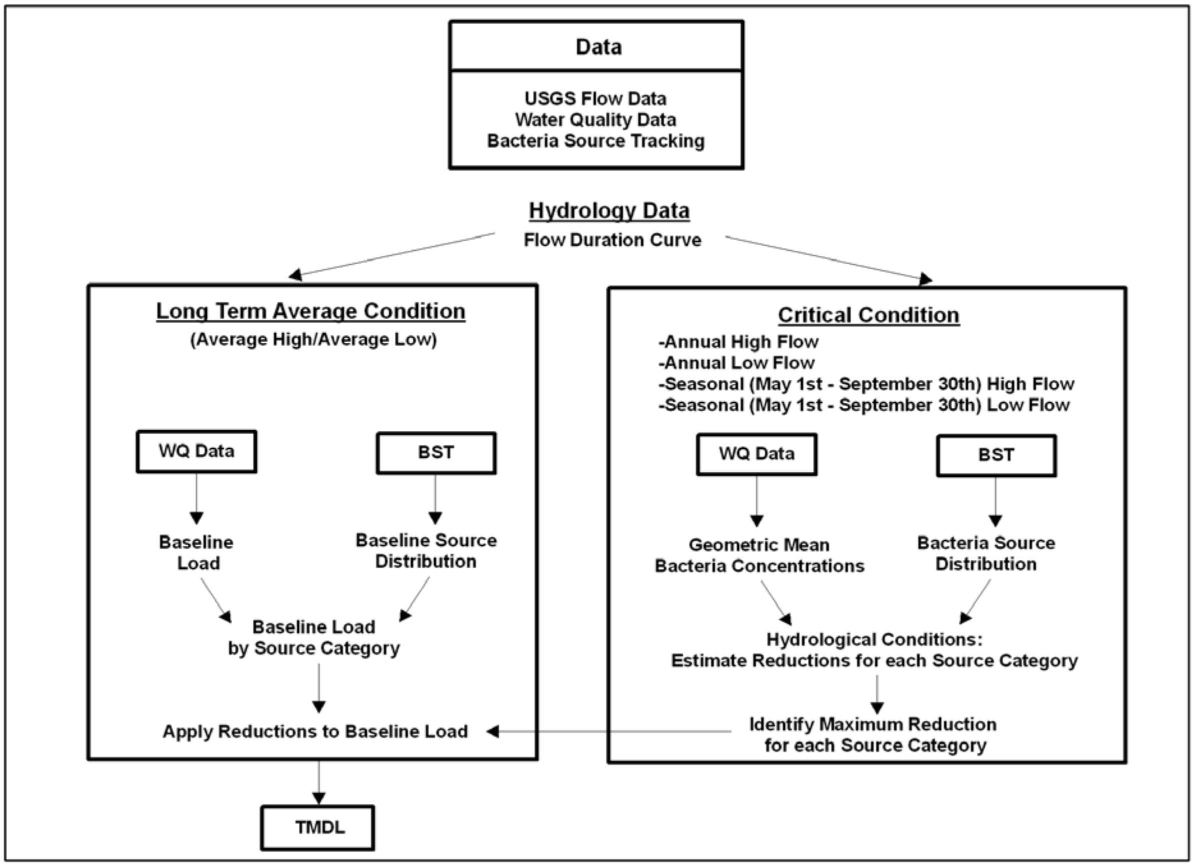

Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads estimated in this TMDL analysis are reported as long-term average annual loads. 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 correction factor (Ferguson 1986; Cohn et al. 1989; Duan 1983). There is much literature on the applicability of 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.

The bias correction factor is estimated as follows:

$$F_1 = A_i / C_i \qquad (6)$$

F_1 = Bias correction factor
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, with available nearby long-term flow monitoring data.

The loads for each stratum are estimated as follows:

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

where

L_i = Daily average load (MPN/day) at each station for stratum i
Q_i = Daily average flow (cfs) for stratum i
C_i = long term annual geometric mean for stratum i
F_1= Bias correction factor
F_2= Unit conversion factor from cfs*MPN/100ml to Billion MPN/day (2.4466×10^{-2})

For each subwatershed, the total baseline load is estimated as follows:

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

L_t = Daily average load at station (MPN/day)
W_i= Proportion or weighting factor of stratum i

In the Herring Run watershed, weighting factors of 0.25 for high flow and 0.75 for low flow were used to estimate the average annual baseline load expressed as billion MPN *E. coli*/day. Results are found in Table 4.3.1.

Table 4.3.1: Baseline Load Calculations

Station		Harford Rd	Pulaski Hwy	Biddle & 62nd St
Area (mi²)		13.0	7.4	9.5
High Flow	**Daily Average Flow (cfs)**	54.2	31.0	39.6
	***E. coli* Concentration (MPN/100ml)**	6,471	3,500	2,016
	Bias Correction Factor	7.97	8.17	7.99
Low Flow	**Daily Average Flow (cfs)**	5.95	3.40	4.35
	***E. coli* Concentration (MPN/100ml)**	582	366	1,313
	Bias Correction Factor	1.90	1.97	3.77
Baseline Load (Billion *E. coli* MPN/day)		17,230	5,459	4,300

Estimating Subwatershed Loads

To treat each subwatershed as a separate entity, thus allowing separate loads and reduction targets for watersheds that have one or more upstream monitored sub-watersheds, they were subdivided into unique watershed segments. Herring Run has three subwatersheds, one of them with upstream and downstream monitoring stations. This subwatershed is monitored at the Pulaski Hwy station (See Figure 2.2.1 above). This subwatershed was identified with extension sub to the station name (Pulaski Hwy sub).

Several anthropogenic and non-anthropogenic factors such as soil, geology, the presence of septics or CSOs, can affect bacteria loadings into the streams. A special scenario has been seen in subwatersheds Harford Rd and Pulaski Hwy. In the subwatershed monitored at station

Harford Rd, the bacteria loadings are significantly greater than the cumulative loads at the downstream station monitored at Pulaski Hwy. Bacteria loads are greater in the upper reaches of Herring Run due to the existence of SSOs and CSOs, which greatly elevate bacteria levels during storm events. As these bacteria loads are transported downstream, they come into contact with urban runoff that likely contains toxics materials and other pollutants in which bacteria cannot survive and quickly die off. For this reason, transported loads from the station located at Harford Rd to the station located at Pulaski Hwy will not be considered in the estimation of loads from subwatershed Pulaski Hwy sub, and the load as measured at this station, not accounting for transported loads from the station at Harford Rd, will be assigned to the subwatershed monitored at Pulaski Hwy.

The subwatershed load is estimated by first estimating the subwatershed flow using the general equation for flow mass balance as follows:

$$\sum Q_{us} + Q_{sub} = Q_{ds} \qquad (9)$$

where

Q_{us} = Upstream flow
Q_{sub} = Subwatershed flow
Q_{ds} = Downstream flow

The loads by stratum are then estimated as shown above using equations (6), (7) and (8).

Source estimates from the bacteria source tracking analysis are completed for one station (HER0065), located upstream of the station at Harford Rd. Sources estimated at station HER0065 are assigned to the three stations used in the TMDL analysis (Harford Rd, Pulaski Hwy, and Biddle St stations).

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 captured by assessing the time period when water contact recreation is expected (May 1st - September 30th). The average hydrological condition over a 9-year period is approximately 25% high flow and 75% low flow as defined in Appendix B. Using the definition of a high flow condition occurring when the daily flow duration interval is less than 25% and a low flow condition occurring when the daily flow duration interval is greater than 25%, the critical hydrological condition can be estimated by the percent of high or low flows during a specific period and hydrological condition.

Maryland's proposed fecal bacteria TMDL for Herring Run has been determined by assessing various hydrological conditions to account for seasonal and annual averaging periods (Table 4.4.1). The following four conditions were used to account for the critical condition: annual high flow, annual low flow, seasonal high flow and seasonal low flow.

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

Hydrological Condition		Averaging Period	Water Quality Data Used	Subwatershed	Fraction High Flow	Fraction Low Flow	Period
Annual	High	365 days	All	Harford Rd Pulaski Hwy Biddle and 62nd St	0.54	0.46	Feb 19, 2003 - Feb 18, 2004,
	Low	365 days	All	Harford Rd Pulaski Hwy Biddle and 62nd St	0.10	0.90	April 16, 2001 - April 15, 2002, Aug 3, 2001 – Aug 2, 2002
Seasonal	High	May 1st – Sept 30th	May 1st – Sept 30th	Harford Rd Pulaski Hwy Biddle and 62nd St	0.42	0.58	May 1 - Sept 30, 2003
	Low	May 1st – Sept 30th	May 1st – Sept 30th	Harford Rd Pulaski Hwy Biddle and 62nd St	0.10	0.90	May 1 - Sept 30, 1997

The critical condition is determined by the maximum reduction per source that satisfies all four conditions in each subwatershed, and is required to meet the water quality standard while minimizing the risk to water contact recreation. It is assumed that the reduction that can be implemented to a bacteria source category will be constant through all conditions.

The monitoring data for all stations located in the Herring Run watershed cover a sufficient temporal span (at least one year) to estimate annual and seasonal conditions. The required reductions to meet water quality standards in each subwatershed and for each hydrological condition are presented in Table 4.4.2.

Table 4.4.2: Required Reductions to Meet Water Quality Standards

Station	Hydrological Condition		Domestic %	Human %	Livestock %	Wildlife %
Harford Rd	Annual	High flow	98.0%	98.0%	0.0%	41.4%
		Low flow	85.7%	98.0%	0.0%	0.0%
	Seasonal	High flow	98.0%	98.0%	0.0%	54.7%
		Low flow	98.0%	98.0%	0.0%	13.4%
	Maximum Source Reduction		98.0%	98.0%	0.0%	54.7%
Pulaski Hwy	Annual	High flow	92.2%	98.0%	0.0%	0.0%
		Low flow	23.5%	98.0%	0.0%	0.0%
	Seasonal	High flow	98.0%	98.0%	0.0%	33.3%
		Low flow	98.0%	98.0%	0.0%	9.3%
	Maximum Source Reduction		98.0%	98.0%	0.0%	33.3%
Biddle & 62nd St	Annual	High flow	98.0%	98.0%	0.0%	15.7%
		Low flow	98.0%	98.0%	0.0%	43.9%
	Seasonal	High flow	98.0%	98.0%	0.0%	71.8%
		Low flow	98.0%	98.0%	0.0%	73.8%
	Maximum Source Reduction		98.0%	98.0%	0.0%	73.8%

4.5 Margin of Safety

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

Based on EPA guidance, the MOS can be achieved through two approaches (EPA 1991). One approach is to reserve a portion of the loading capacity as a separate term in the TMDL (i.e., TMDL = LA + WLA + MOS). The second approach is to incorporate the MOS as conservative assumptions used in the TMDL analysis. For this TMDL, the second approach was used by estimating the loading capacity of the stream based on a 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

Practicable Reduction Targets

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.6.1. These values are based on best professional judgment and a review of the available literature. It is assumed that human sources would potentially confer the highest risk of gastrointestinal illness and therefore should have the highest reduction. If a municipal 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 4.6.1: Maximum Practicable Reduction Targets

	Human	Domestic	Livestock	Wildlife
Max Practical Reduction per Source	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 waste offer a public health risk that is orders of magnitude less than that associated with human waste.[4]

[1] USEPA. 1984. Health Effects Criteria for Fresh Recreational Waters. EPA-600/1-84-004. U.S. Environmental Protection Agency, Washington, DC.

[2] USEPA. 1999. Preliminary Data Summary of Urban Storm Water Best Management Practices. EPA-821-R-99-012. U.S. Environmental Protection Agency, Washington, DC.

[3] USEPA. 2004. Agricultural BMP Descriptions as Defined for The Chesapeake Bay Program Watershed Model. Nutrient Subcommittee Agricultural Nutrient Reduction Workshop.

[4] Environmental Indicators and Shellfish Safety. 1994. Edited by Cameron, R., Mackeney and Merle D. Pierson, Chapman & Hall.

As previously stated, these practicable reduction targets are based on the available literature and best professional judgment. There is much uncertainty with estimated reductions from best management practices (BMPs). The BMP efficiency for bacteria reduction ranged from –6% to +99% based on a total of 10 observations (USEPA 1999). The MPR to agricultural lands was based on sediment reductions identified by the EPA (USEPA 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 for each bacteria source category was defined on a scale of one to five, where it was assumed that human sources had the highest risk (5), domestic animal and livestock next (3) and wildlife the lowest (1) (see Table 4.6.2). The objective is to minimize the sum of the risk for all conditions while meeting the maximum practicable reduction constraints. The model was defined as follows:

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

Where

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

and

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

Therefore the risk score can be represented as:

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

where

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

The model is subject to the following constraints:

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

In none of the subwatersheds could the constraints of this MPR scenario be satisfied, indicating there was not a practicable solution. A summary of the analysis is presented in Table 4.6.2.

Table 4.6.2: Practicable Reduction Results

Station	**Applied Reductions**				**WQS Achievable**
	Domestic %	**Human %**	**Livestock %**	**Wildlife %**	
Harford Rd	75.0%	95.0%	75.0%	0.0%	No
Pulaski Hwy	75.0%	95.0%	75.0%	0.0%	No
Biddle & 62nd St.	75.0%	95.0%	75.0%	0.0%	No

The TMDL must specify load allocations that will meet the water quality standards. In the practicable reduction targets scenario none of the subwatersheds could meet water quality standards based on MPRs.

To further develop the TMDL, the constraints on the MPRs were relaxed in all three subwatersheds where the water quality attainment was not achievable with the MPRs. In these subwatersheds, the maximum allowable reduction was increased to 98% for all sources, including wildlife. A similar optimization procedure was used to minimize risk. Again, the objective is to minimize the sum of the risk for all conditions while meeting the maximum practicable reduction constraints. The model was defined in the manner as shown in the practicable reduction scenario but subject to the following constraints:

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

The summary of the analysis is presented in Table 4.6.3.

Table 4.6.3: TMDL Reduction Results: Optimization Model Allowing Up to 98% Reductions

Station	Domestic %	Human %	Livestock %	Wildlife %	Target Reduction %
Harford Rd	98.0	98.0	0.0	54.7	93.5
Pulaski Hwy	98.0	98.0	0.0	33.3	91.3
Biddle & 62nd St.	98.0	98.0	0.0	73.8	95.5

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 loading caps presented in this section are for the watersheds located upstream of monitoring stations at Harford Rd, Pulaski Hwy and Biddle St. Both annual average and daily loading caps are estimated for these subwatersheds. Descriptions of how these loads were calculated are presented below.

Annual Average TMDL

The annual average TMDL loading caps are estimated by first determining the baseline or current condition loads for each subwatershed and the associated geometric mean from the available monitoring data. This annual average baseline load is estimated using the geometric mean concentration and average daily flow for each flow stratum. The loads from these two strata are then weighted to represent average conditions (see Table 4.3.1), based on the proportion of each stratum, to estimate the total long-term loading rate.

Next, the percent reduction required to meet the water quality criterion is estimated from the observed bacteria concentrations accounting for the critical conditions (See Section 4.4). A reduction in concentration is proportional to a reduction in load; thus the TMDL is equal to the current baseline load multiplied by one minus the required reduction. This reduction, estimated as explained in Section 4.4, represents the maximum reduction per source that satisfies all hydrological conditions in each subwatershed, and is required to meet water quality standards.

$$TMDL = L_b * (1 - R) \qquad (14)$$

where

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

The annual average bacteria TMDLs for the subwatersheds are shown in Table 4.7.1.

Table 4.7.1: Herring Run Subwatersheds Annual Average TMDL Summary

Station	Baseline Load *E. coli* (Billion MPN/year)	Long Term Average TMDL Load *E. coli* (Billion MPN/year)	% Target Reduction
Harford Rd	6,288,811	408,147	93.5%
Pulaski Hwy	1,992,522	173,532	91.3%
Biddle & 62nd St	1,569,606	70,781	95.5%
Total	9,850,939	652,459	93.4%

Maximum Daily Loads

Selection of an appropriate method for translating a TMDL based on a longer time period into one using a daily time period requires decisions regarding 1) the level of resolution, and 2) the level of protection. The level of resolution pertains to the amount of detail used in specifying the maximum daily load. The level of protection represents how often the maximum daily load is expected to be exceeded. Draft EPA/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 Herring Run maximum daily loads, a "representative daily load" option was selected as the level of resolution, and a value "that will be exceeded with a pre-defined probability" was selected as the level of protection. In these options, the maximum daily loads are two single daily loads that correspond to the two flow strata, with an upper bound percentile that accounts for the variability of daily loads. The upper bound percentile and the maximum daily loads were estimated following EPA's "*Technical Support Document for Water Quality-Based Toxics Control*" (1991 TSD) (USEPA 1991); and "*Approaches For Developing a Daily Load Expression for TMDLs Computed for Longer Term Averages*" (USEPA 2006).

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

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

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

Results of the daily bacteria TMDLs analysis for the Herring Run subwatersheds are shown in Table 4.7.2

Table 4.7.2: Herring Run Watershed Maximum Daily Loads Summary

Station		**Maximum Daily Load by Stratum (Billion *E. coli* MPN/day)**	**Maximum Daily Load (Weighted) (Billion *E. coli* MPN/day)**
Harford Rd	High Flow	105,634	26,485
	Low Flow	102	
Pulaski Hwy	High Flow	45,169	11,292
	Low Flow	53	
Biddle & 62nd St	High Flow	16,708	4,489
	Low Flow	417	

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

4.8 TMDL Allocation

The TMDL allocations include the load allocation (LA) for nonpoint sources, and waste load allocations (WLA) for point sources, including WWTPs (if WWTPs are present in the watershed), stormwater (where MS4 permits are required), and CSOs (in watersheds with permitted CSOs and long-term control plans (LTCPs) not expecting complete elimination of CSOs). The margin of safety is explicit and is expressed as a 5% reduction of the *E. coli* water quality criterion concentration, from 126 MPN/100ml to 119.7 MPN/100ml. The final loads are based on average hydrological conditions with reductions estimated based on critical hydrological conditions. The load reduction scenario results in a load allocation that will achieve water quality standards. The State reserves the right to revise these allocations provided such allocations are consistent with the achievement of water quality standards.

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 or nonpoint sources and the WLA or point sources (WWTPs, MS4 permits and CSOs, if applicable). Only the final LA or WLA is reported in this TMDL. Note that the assignment of a small allowable human load to MS4s is in consideration of any persistence of such loads in the watershed despite elimination of CSOs/SSOs, due to sources beyond the reach of the sanitary sewer systems. The term “allowable load” means the load that the waterbody can assimilate and still meet water quality standards.

Table 4.8.1: Potential Source Contributions for the Herring Run TMDL Allocations

Allocation Category	**LA**	**WLA**		
		WWTPs	**MS4s**	**CSOs**
Human		N/A	X	N/A
Domestic			X	
Livestock	X			
Wildlife	X		X	

Load Allocation (LA)

All four bacteria source categories could potentially contribute to nonpoint source loads. For human sources, if the watershed has no MS4 or regulated stormwater permits, the nonpoint source contribution is estimated by subtracting any WWTP and CSO loads from the TMDL human load, and assigned to the LA. However, in watersheds covered by MS4 permits, any such nonpoint sources of human bacteria (i.e., beyond the reach of the sanitary sewers systems) are assigned to the MS4-WLA. There are no NPDES WWTPs with permits regulating the discharge of bacteria in the Herring Run watershed. There are no subwatersheds with assigned NPDES CSO WLA (i.e., the CSO WLA = 0.0), on the assumption that, under LTCPs for both Baltimore City and Baltimore County, bacteria loads will essentially be eliminated from their sanitary sewer systems.

Livestock loads are all assigned to the LA. Domestic animals (pets) allocation is assigned to the LA if no MS4 permits exist for the watershed. Since the entire Herring Run watershed is covered by NPDES MS4 permits, bacteria loads from domestic animal sources are assigned to WLA-MS4 in all three subwatersheds of Herring Run. However, wildlife sources will be distributed between the LA and the WLA-MS4, based on a ratio of the amount of urban land compared to pasture and forest land in the watershed.

Waste Load Allocation (WLA)

Municipal Separate Storm Sewer Systems (MS4)

Both individual and general NPDES Phase I and Phase II stormwater permits are point sources subject to WLA assignment in the TMDL. Quantification of rainfall-driven nonpoint source loads, such as those transported by stormwater through MS4s, is uncertain. EPA recognized this in its guidance document entitled "Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs" (November 2002), which states that available data and information usually are not detailed enough to determine WLAs for NPDES-regulated stormwater discharges on an outfall-specific basis. Therefore, in watersheds with an existing MS4 permit, domestic animal bacteria loads will be grouped together into a single WLA-MS4 load, along with other nonpoint source loads subject to stormwater transport and discharge. In watersheds with no existing individual MS4 permits, these loads will be included in the LA.

The jurisdictions within the Herring Run watershed, Baltimore County and Baltimore City, are covered by individual Phase I MS4 program regulations. Based on EPA's guidance, the MS4 WLA is presented as one combined load for the entire land area of each county. In the future, when more detailed data and information become available, it is anticipated that MDE will revise the WLA into appropriate WLAs and LAs, and may also revise the LA accordingly. Note that the overall reductions in the TMDL will not change.

The WLA-MS4 category includes any other NPDES-regulated Phase I and Phase II stormwater entities within the two jurisdictions' portions of the watershed, in addition to the City's and County's MS4s. The WLA-MS4 distribution between Baltimore City and Baltimore County is presented in Table 4.8.2.

Table 4.8.2: MS4 Stormwater Allocations

Station	**WLA – MS4 Loads (Billion MPN/year)**				
	Baltimore City	%	Baltimore County	%	Total
Harford Rd	186,712	52%	174,169	48%	360,881
Pulaski Hwy	153,151	93%	12,112	7%	165,263
Biddle & 62nd St.	24,433	47%	28,011	53%	52,444
Total	214,292		364,296		578,588

Municipal and Industrial WWTPs

As explained in the source assessment section above, there are no municipal or industrial WWTPs with permits regulating the discharge of bacteria into Herring Run.

Sanitary Sewer and Combined Sewer Systems

There are two jurisdictions with NPDES CSSs and/or sanitary sewer systems within the Herring Run watershed (See section 2.4, Source Assessment, for more detailed information). A federal consent decree between EPA, MDE and Baltimore City requires the elimination of all CSO structures by a certain date. In addition, that consent decree and a similar one between EPA, MDE and Baltimore County, require the City and the County to evaluate their sanitary sewer systems and to repair, replace, or rehabilitate the systems. For example, broken pipes and any general infrastructure failure should be fixed. Sanitary sewer systems must not be a source of bacteria loads in the watershed; therefore, no allocation to sanitary sewers systems or to SSOs is allowed. A 0.0 MPN E. coli/year allocation is assigned to WLA-CSOs in these jurisdictions, on the assumption that implementation of the requirements of the consent decrees will result in the virtual elimination of current loads. Thus, the elimination of SSOs and CSOs is expected to significantly reduce current bacteria loads from human sources. In consideration of any human sources of fecal bacteria outside the reach of the sanitary sewer systems that may persist in the Herring Run watershed, an allowable human load in the corresponding subwatersheds is allocated to the WLA-MS4. An allowable load is that which the waterbody can assimilate and still meet water quality standards.

4.9 Summary

The long-term annual average TMDLs and the daily TMDLs for the Herring Run subwatersheds are presented in Tables 4.9.1 and 4.9.2.

Table 4.9.1: Herring Run Watershed Long-term Annual Average TMDL

Subwatershed	**TMDL**	**LA**	**WLA MS4**
	Billion MPN/year		
Harford Rd	408,147	47,266	360,881
Pulaski Hwy	173,532	8,269	165,263
Biddle & 62nd St.	70,781	18,337	52,444
TOTAL	652,459	73,872	578,588

Table 4.9.2: Herring Run Watershed Maximum Daily Loads

Subwatershed	TMDL	LA	WLA MS4
	Billion MPN/day		
Harford Rd	26,485	3,067	23,418
Pulaski Hwy	11,292	538	10,754
Biddle & 62nd St.	4,489	1,163	3,326
TOTAL	42,266	4,768	37,498

In all three subwatersheds, based on the maximum practicable reduction rates specified, water quality standards cannot be achieved. This occurs in watersheds that require very high reductions to meet water quality standards. However, if there is no feasible TMDL scenario, then MPRs are increased to provide estimates of the reductions required to meet water quality standards. For these watersheds, it is noted that the reductions may be beyond practical limits. In these cases, it is expected that the first stage of implementation will be to implement the MPR scenario.

5.0 ASSURANCE OF IMPLEMENTATION

Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and wasteload allocations can and will be implemented. In the Herring Run watershed, the TMDL analysis indicates that reduction of fecal bacteria loads from all sources including wildlife are beyond the maximum practicable reduction (MPR) targets. Herring Run and its tributaries may not be able to attain water quality standards. The extent of the fecal bacteria load reductions required to meet water quality criteria in the watershed of Herring Run are not feasible by effluent limitations or by implementing cost-effective and reasonable best management practices. 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.

The most significant planned implementation measures in the Herring Run watershed involve the separation of combined sewer systems in Baltimore City and the elimination of sanitary sewer overflows in Baltimore City and Baltimore County. Each of these jurisdictions is obligated under a judicial consent decree and judgment to adopt and implement a LTCP to eliminate sewer overflows. See Consent Decree and Judgments, Consolidated Case Number: JFM-02-12524, Baltimore City Consent Decree (entered Sept. 30, 2002); and Consolidated Case Number: AMD-05-2028, Baltimore County Consent Decree (entered Sept. 20, 2006). The judicial decrees and judgments require the jurisdictions to implement these LTCPs by January 2016 for Baltimore City and by March 2020 for Baltimore County. Deadlines for LTCP implementation will be incorporated into NPDES permits and, if shorter than the court ordered deadline, permits will reflect what can be feasibly accomplished with consideration to the complexity of the engineering, the availability of resources, and the need for inter-jurisdictional coordination.

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.

In 1983, the EPA Nationwide Urban Runoff Program found that stormwater runoff from urban areas contains the same general types of pollutants found in wastewater, and that 30% of identified cases of water quality impairment were attributable to stormwater discharges. In November 1990, EPA required jurisdictions with a population greater than 100,000 to apply for NPDES Permits for stormwater discharges. The jurisdictions where the Herring Run watershed is located, Baltimore County and Baltimore City, are required to participate in the stormwater NPDES program, and have to comply with the NPDES Permit regulations for stormwater discharges. The permit-required management programs are being implemented in the County and City to meet locally established watershed protection and restoration goals and to control stormwater discharges to the maximum extent practicable. These jurisdiction-wide programs are designed to control stormwater discharges to the maximum extent practical. Funding sources for implementation include the State Water Quality Revolving Loan Fund and the Stormwater Pollution Cost Share Program. Details of this program and additional funding sources can be found at http://www.dnr.state.md.us/bay/services/summaries.html.

Additionally, MDE's "Managing Maryland for Results" (MDE 2005) states the following related to separate sewer system overflows and combined sewer system overflows:

> Objective 4.5: Reduce the quantity in gallons of sewage overflows [total for Combined Sewer System Overflows (CSO) and Separate Sewer System Overflows (SSO)] equivalent to a 50% reduction of 2001 amounts (50, 821,102 gallons) by the year 2010 through implementation of EPA's minimum control strategies, long-term control plans (LTCPs), and collection system improvements in capacity, inflow and infiltration reduction, operation and maintenance.
>
> Strategy 4.5.1: MDE adopted new regulations effective March 28, 2005 to detail procedures that must be followed regarding reporting overflows or treatment plant bypasses and also to require public notification of certain sewage overflows.
>
> Strategy 4.5.2: MDE will inspect and take enforcement actions against those CSO jurisdictions that have not developed long-term control plans by dates set within current consent or judicial orders.

> Strategy 4.5.3: MDE will take enforcement actions to require that jurisdictions experiencing significant or repeated SSOs take appropriate steps to eliminate overflows, and will fulfill the commitment in the EPA 106 grant for NPDES enforcement regarding the initiation of formal enforcement actions against 20% of jurisdictions in Maryland with CSOs and significant SSO problems annually.

Implementation and Wildlife Sources

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

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

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Appendix A – Table of Bacteria Concentration Raw Data per Sampling Date with Corresponding Daily Flow Frequency

Table A-1: Bacteria Concentration Raw Data

Station	Date	Daily Flow Frequency	E. Coli MPN/100ml
BIDDLE	01/15/2002	85.5187	2,479
BIDDLE	02/19/2002	93.0940	1,550
BIDDLE	03/19/2002	77.3045	5,967
BIDDLE	04/16/2002	75.4487	2,479
BIDDLE	05/21/2002	90.8123	719
BIDDLE	06/04/2002	96.4709	1,215
BIDDLE	07/09/2002	12.5342	617
BIDDLE	08/06/2002	61.6672	1,166
BIDDLE	09/17/2002	92.0901	407
BIDDLE	10/01/2002	68.7253	299
BIDDLE	11/13/2002	49.3155	1,215
BIDDLE	12/03/2002	72.2543	111
BIDDLE	01/14/2003	53.2400	460
BIDDLE	02/25/2003	19.0751	3,819
BIDDLE	03/25/2003	29.2364	299
BIDDLE	04/22/2003	36.2945	3,819
BIDDLE	05/20/2003	38.7283	1,455
BIDDLE	06/17/2003	10.6480	528
BIDDLE	07/22/2003	7.6970	9,677
BIDDLE	08/12/2003	65.0137	10,080
BIDDLE	09/24/2003	19.7140	2,479
BIDDLE	10/21/2003	53.2400	5,967
BIDDLE	11/11/2003	23.7298	111
BIDDLE	12/09/2003	19.7140	407
BIDDLE	01/13/2004	27.5023	86,997
BIDDLE	02/24/2004	30.8792	87
BIDDLE	03/23/2004	45.9994	23

Station	Date	Daily Flow Frequency	E. Coli MPN/100ml
BIDDLE	04/27/2004	27.5023	920
BIDDLE	05/18/2004	43.8394	12,868
BIDDLE	06/29/2004	70.6723	5,118
BIDDLE	08/24/2004	76.6961	920
BIDDLE	10/26/2004	74.9011	187
BIDDLE	11/30/2004	49.3155	1,550
BIDDLE	12/14/2004	53.2400	3,819
BIDDLE	01/25/2005	56.0694	719
BIDDLE	02/22/2005	49.3155	920
BIDDLE	03/29/2005	14.2988	3,819
BIDDLE	04/26/2005	53.2400	3,819
BIDDLE	05/17/2005	69.5163	299
BIDDLE	06/28/2005	7.3928	106,800
BIDDLE	07/26/2005	75.4487	5,967
BIDDLE	08/23/2005	90.8123	3,819
HARFORD	01/15/2002	85.5187	407
HARFORD	02/19/2002	93.0940	460
HARFORD	03/19/2002	77.3045	460
HARFORD	04/16/2002	75.4487	719
HARFORD	05/21/2002	90.8123	1,166
HARFORD	06/04/2002	96.4709	55
HARFORD	07/09/2002	12.5342	1,215
HARFORD	08/06/2002	61.6672	49
HARFORD	09/17/2002	92.0901	920
HARFORD	10/01/2002	68.7253	460
HARFORD	11/13/2002	49.3155	2,479
HARFORD	12/03/2002	72.2543	719
HARFORD	01/14/2003	53.2400	299
HARFORD	02/25/2003	19.0751	170,789
HARFORD	03/25/2003	29.2364	719

Station	Date	Daily Flow Frequency	E. Coli MPN/100ml
HARFORD	04/22/2003	36.2945	146
HARFORD	05/20/2003	38.7283	920
HARFORD	06/17/2003	10.6480	86,997
HARFORD	07/22/2003	7.6970	7,635
HARFORD	08/12/2003	65.0137	1,550
HARFORD	09/24/2003	19.7140	3,819
HARFORD	10/21/2003	53.2400	617
HARFORD	11/11/2003	23.7298	299
HARFORD	12/09/2003	19.7140	2,479
HARFORD	01/13/2004	27.5023	2,479
HARFORD	02/24/2004	30.8792	2,479
HARFORD	03/23/2004	45.9994	36
HARFORD	04/27/2004	27.5023	460
HARFORD	05/18/2004	43.8394	5,967
HARFORD	06/29/2004	70.6723	719
HARFORD	08/24/2004	76.6961	407
HARFORD	10/26/2004	74.9011	187
HARFORD	11/30/2004	49.3155	719
HARFORD	12/14/2004	53.2400	1,550
HARFORD	01/25/2005	56.0694	1,215
HARFORD	02/22/2005	49.3155	299
HARFORD	03/29/2005	14.2988	2,479
HARFORD	04/26/2005	53.2400	1,215
HARFORD	05/17/2005	69.5163	299
HARFORD	06/28/2005	7.3928	20,578
HARFORD	07/26/2005	75.4487	1,455
HARFORD	08/23/2005	90.8123	617
PULASKI	01/15/2002	85.5187	74
PULASKI	02/19/2002	93.0940	140
PULASKI	03/19/2002	77.3045	299

Station	Date	Daily Flow Frequency	E. Coli MPN/100ml
PULASKI	04/16/2002	75.4487	187
PULASKI	05/21/2002	90.8123	1,550
PULASKI	06/04/2002	96.4709	719
PULASKI	07/09/2002	12.5342	2,479
PULASKI	08/06/2002	61.6672	146
PULASKI	09/17/2002	92.0901	460
PULASKI	10/01/2002	68.7253	617
PULASKI	11/13/2002	49.3155	1,166
PULASKI	12/03/2002	72.2543	2479
PULASKI	01/14/2003	53.2400	719
PULASKI	02/25/2003	19.0751	63,367
PULASKI	03/25/2003	29.2364	187
PULASKI	04/22/2003	36.2945	111
PULASKI	05/20/2003	38.7283	513
PULASKI	06/17/2003	10.6480	42,473
PULASKI	07/22/2003	7.6970	187
PULASKI	08/12/2003	65.0137	719
PULASKI	09/24/2003	19.7140	7,635
PULASKI	10/21/2003	53.2400	299
PULASKI	11/11/2003	23.7298	299
PULASKI	12/09/2003	19.7140	719
PULASKI	01/13/2004	27.5023	146
PULASKI	02/24/2004	30.8792	111
PULASKI	03/23/2004	45.9994	7
PULASKI	04/27/2004	27.5023	1,215
PULASKI	05/18/2004	43.8394	2,479
PULASKI	06/29/2004	70.6723	920
PULASKI	08/24/2004	76.6961	299
PULASKI	10/26/2004	74.9011	299
PULASKI	11/30/2004	49.3155	299

Station	Date	Daily Flow Frequency	E. Coli MPN/100ml
PULASKI	01/25/2005	56.0694	460
PULASKI	02/22/2005	49.3155	460
PULASKI	03/29/2005	14.2988	3,819
PULASKI	04/26/2005	53.2400	299
PULASKI	05/17/2005	69.5163	187
PULASKI	06/28/2005	7.3928	10,080
PULASKI	07/26/2005	75.4487	920
PULASKI	08/23/2005	90.8123	920

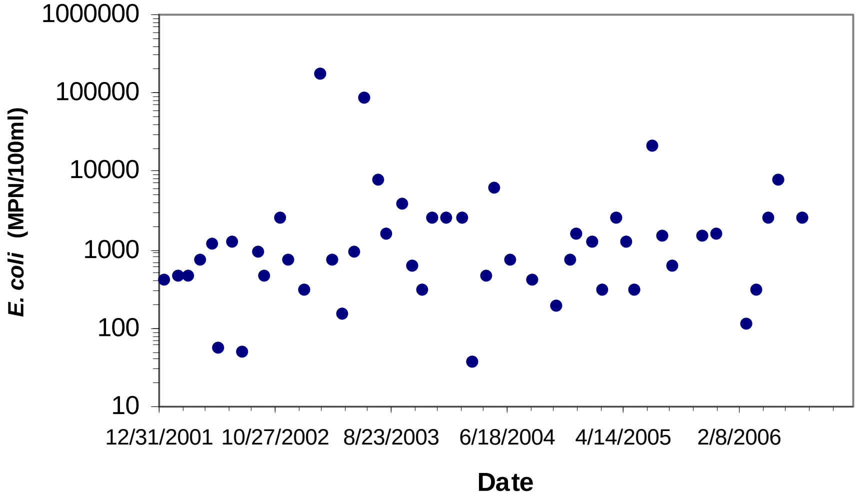

Figure A-1: *E. coli* Concentration vs. Time for Herring Run Monitoring Station at Harford Rd.

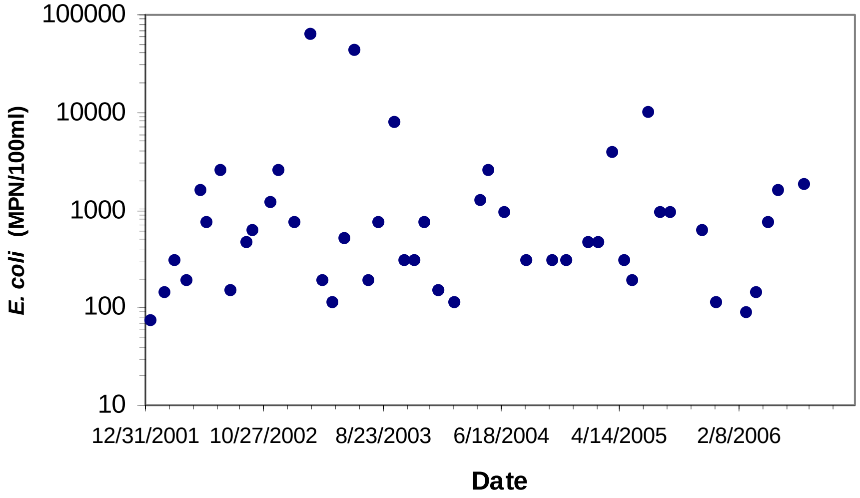

Figure A-2: *E. coli* Concentration vs. Time for Herring Run Monitoring Station at Pulaski Hwy.

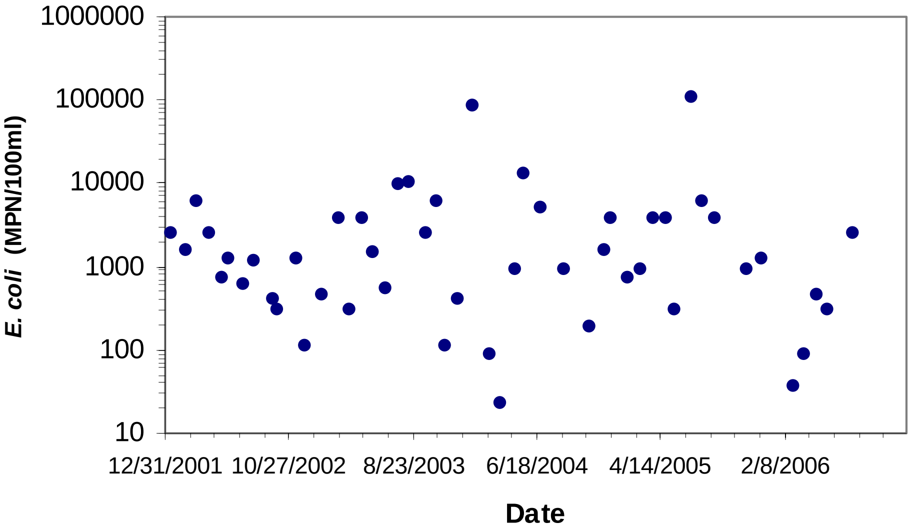

Figure A-3: *E. coli* Concentration vs. Time for Herring Run Monitoring Station at Biddle & 62nd St.

Appendix B - Flow Duration Curve Analysis to Define Strata

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

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

Flow Analysis

There is a United States Geological Survey (USGS) gage station in the Herring Run watershed. The gage and dates of information used are as follows:

Table B-1: USGS Gages in the Herring Run Watershed

USGS Gage #	Dates used
01585200	Oct 1, 1996 to Sep 30, 2005

The flow duration curve for this gage is presented in Figure B-1.

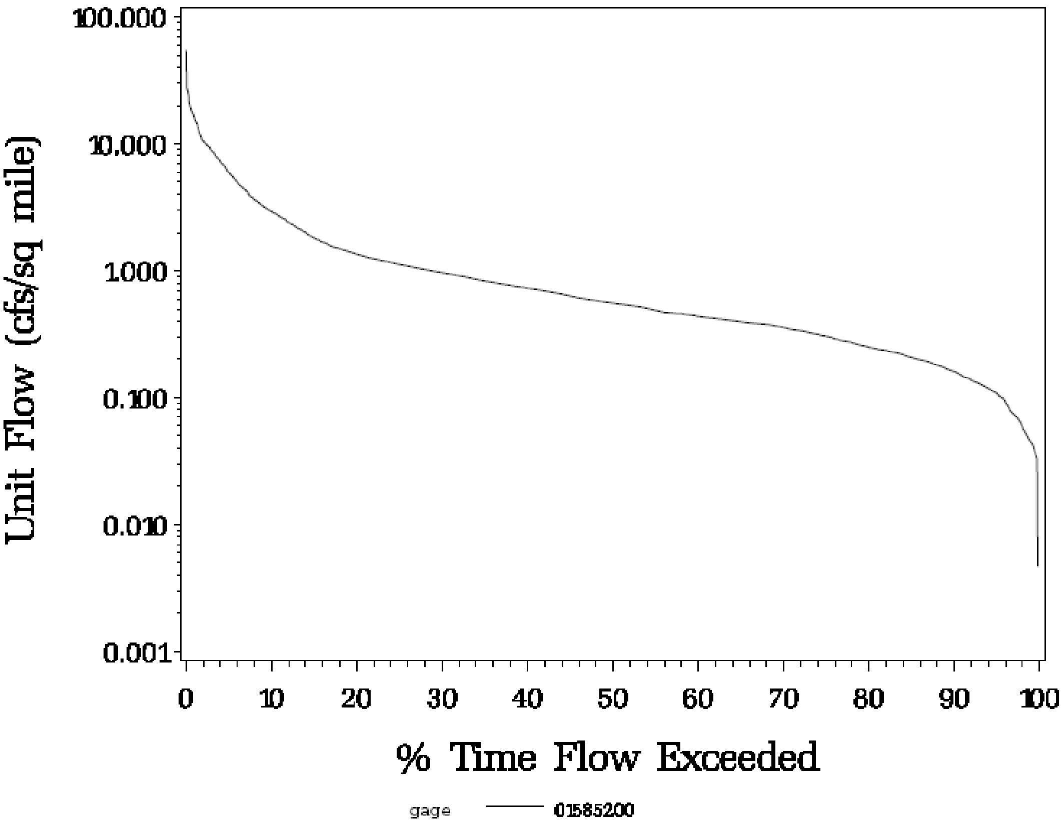

Figure B-1: Herring Run Flow Duration Curve

Based on the long-term flow data for the Herring Run watershed and other watersheds in the region (i.e., Gwynns Falls and Jones Falls), the long term average daily unit flows range between 1.2 to 1.6 cfs/sq. mile, which corresponds to a range of 20th to 28th flow frequency based on the flow duration curves of these watersheds. Using the definition of a high flow condition occurring when flows are higher than the long-term average flow and a low flow condition occurring when flows are lower than the long-term average flow, the 25th percentile threshold was selected to define the limits between high flow and low flows. Therefore, a high flow condition will be defined as occurring when the daily flow duration percentile is less than 25% and a low flow condition will be define as occurring when the daily flow duration percentile is greater than 25%. Definitions of high and low range flows are presented in Table B-2.

Table B-2: Definition of Flow Regimes

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

Flow-Data Analysis

The final analysis to define the daily flow duration intervals (flow regions, strata) includes the bacteria monitoring data. Bacteria (enterococci or *E. coli*) monitoring data are "placed" within the regions (stratum) based on the daily flow duration percentile of the date of sampling. Figures B-2 to B-6 show the Herring Run *E. coli* monitoring data with corresponding flow frequency for the annual average and the seasonal conditions.

Maryland's water quality standards for bacteria state that 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 fewer than five representative sampling events are available, the previous two years will be evaluated. In Herring Run, there are sufficient samples in the high flow strata to estimate the geometric mean. For the low flow strata less than five samples exist; therefore, the mid and low flow strata will be combined to calculate the geometric mean.

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

(1) Annual Average Hydrological Condition
(2) Annual High Flow Condition
(3) Annual Low Flow Condition
(4) Seasonal (May 1st – September 30th) High Flow Condition
(5) Seasonal (May 1st – September 30th) Low 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-6.

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

Hydrological Condition		Averaging Period	Water Quality Data Used	Subwatershed	Fraction High Flow	Fraction Low Flow	Period
Annual	High	365 days	All	Harford Rd Pulaski Hwy Biddle and 62nd St	0.54	0.46	Feb 19, 2003 - Feb 18, 2004,
	Low	365 days	All	Harford Rd Pulaski Hwy Biddle and 62nd St	0.10	0.90	April 16, 2001 - April 15, 2002, Aug 3, 2001 - Aug 2, 2002
Seasonal	High	May 1st – Sept 30th	May 1st – Sept 30th	Harford Rd Pulaski Hwy Biddle and 62nd St	0.42	0.58	May 1 - Sept 30, 2003
	Low	May 1st – Sept 30th	May 1st – Sept 30th	Harford Rd Pulaski Hwy Biddle and 62nd St	0.10	0.90	May 1 - Sept 30, 1997

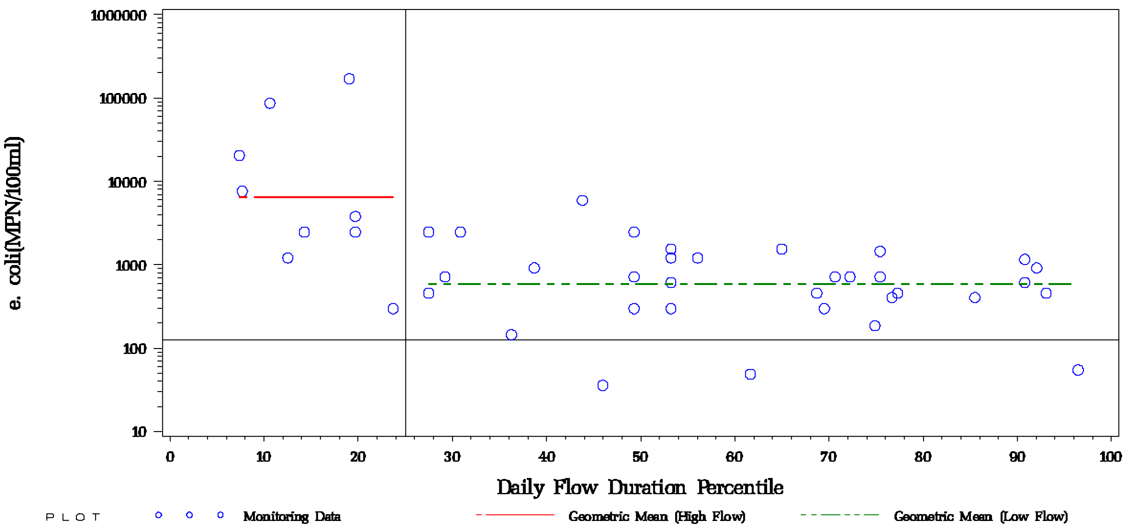

Figure B-2: *E. coli* Concentration vs. Flow Duration for Herring Run Monitoring Station at Harford Rd. (Average Annual Condition)

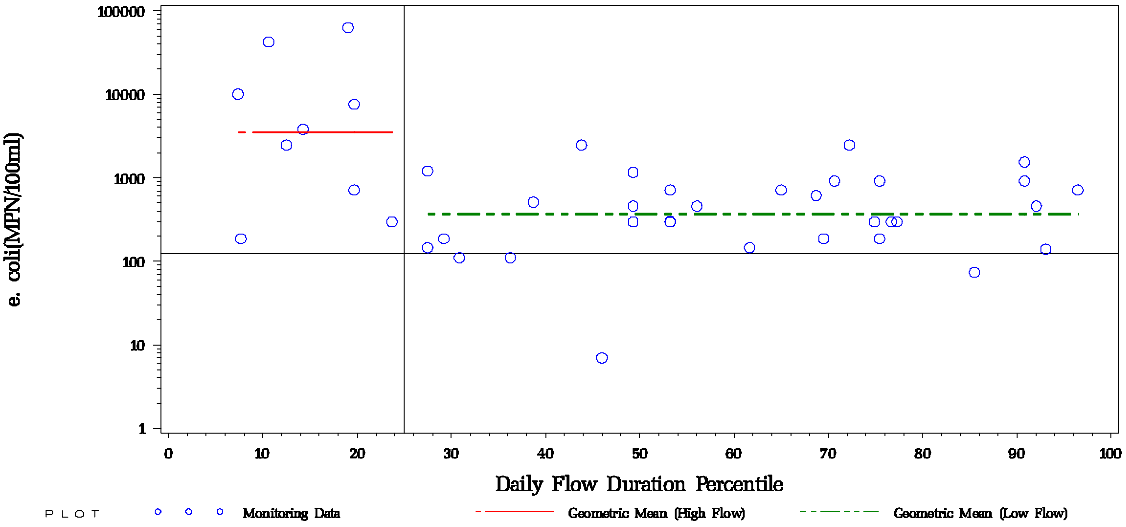

Figure B-3: ***E. coli*** **Concentration vs. Flow Duration for Herring Run Monitoring Station at Pulaski Hwy (Average Annual Condition)**

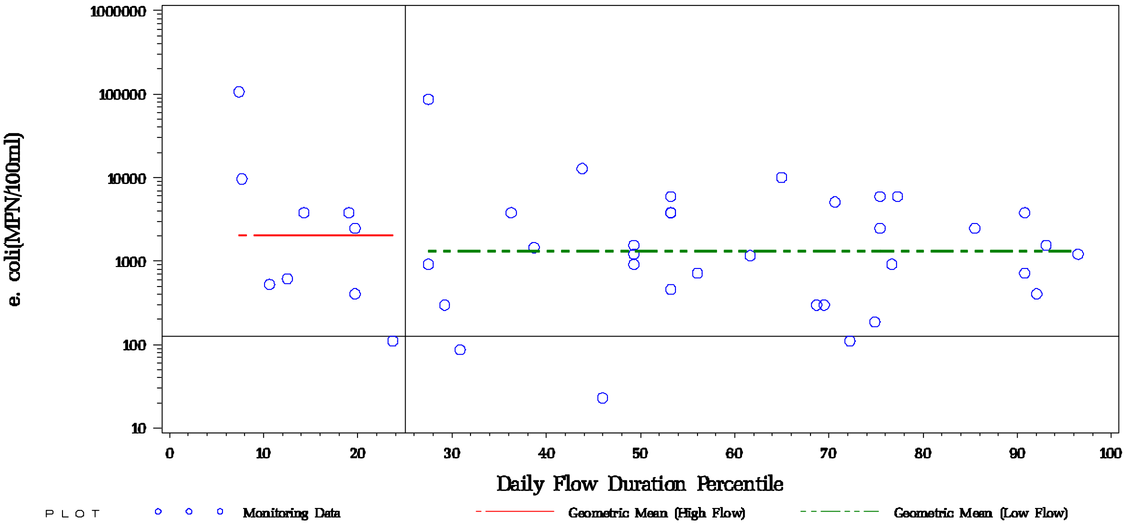

Figure B-4: ***E. coli*** **Concentration vs. Flow Duration for Herring Run Monitoring Station at Biddle & 62nd St. (Average Annual Condition)**

Appendix C - BST Report

Maryland Department of the Environment
Contract Number U00P4200187

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

November 1, 2003 – October 31, 2005

Final Report
January 31, 2006

Revised 02.03.2006

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INTRODUCTION

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

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

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

In this BST project, we studied the following Maryland nontidal watersheds: Gwynns Falls, Jones Falls, Herring Run, Georges Creek, and Wills Creek. The methodology used was the ARA with *Enterococcus* spp. as the indicator organism. Previous BST publications have demonstrated the predictive value of using this particular technique and indicator organism (Hagedorn, 1999; Wiggins, 1999).

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 10 *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. *Enterococcus* 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

Pulsed-Field Gel Electrophoresis: DNA characterization was performed using contour-clamped homogenous electric field (CHEF) PFGE. *Enterococcus* isolates were identified to species (*E. faecalis, E. faecium, E. casseliflavus*) using the Biolog, Inc. Microstation™ System and MicroLog™ software. Isolates were then prepared for analysis using CHEF Bacterial Genomic DNA Plug Kit (Bio-Rad Laboratories, Inc., Hercules, CA). The DNA in each plug was cut with *Sma*I restriction enzyme. DNA fragments were separated according to base pair size using the CHEF Mapper® XA Chiller System (Bio-Rad Laboratories, Inc., Hercules, CA.). Gel bands were stained with either ethidium bromide or SYBR® green and were photographed on a long-wave UV transilluminator and analyzed with Kodak Digital Science Electrophoresis Documentation and Analysis System (Eastman Kodak Co., Rochester, NY.). Banding patterns were analyzed using BioNumerics®, a product of Applied Maths, Inc., Austin, TX.

KNOWN-SOURCE LIBRARY

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

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

We imposed an additional requirement in our classification method for determining the sources of water sample isolates. We interpreted the proportion of the majority source among the library isolates in a *terminal* node as a probability. This proportion is an estimate of the probability that an isolate with unknown source, but with the same antibiotic resistance pattern as the library isolates in the *terminal* node, came from the source of the majority of the library isolates in the *terminal* node. If that probability was less than a specified *acceptable source identification probability*, we did not assign a source to the water sample isolates identified with that *terminal* node. Instead we assigned "Unknown" as the source for that node and "Unknown" for the source of all water sample isolates identified with that node. The *acceptable source identification probability* for the tree-classification model for an individual watershed is shown in the Results section for that watershed.

Known-Source Library. The 630 known-source isolates in the library were grouped into three categories: pet (specifically dog), human, livestock (none), and wildlife (goose) (Table C-2). The library was analyzed for its ability to take a subset of the library isolates and correctly predict the identity of their host sources when they were treated as unknowns. Average rates of correct classification (ARCC) for the library were found by repeating this analysis using several probability cutoff points, as described above. The number-not-classified for each probability

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

[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.

was determined. From these results, the percent unknown and percent correct classification (RCCs) was calculated (Table C-3).

Table C-2: Category, potential sources, total number, and number of unique patterns in the known-source library.

Category	Potential Sources	Total Isolates	Unique Patterns
Pet	dog	103	63
Human	human	425	274
Wildlife	goose	102	32
Total		**630**	**369**

Table C-3: Number of isolates not classified, percent unknown, and percent correct for six (6) cutoff probabilities.

Cutoff Probability	Number Not Classified	Percent Unknown	Percent Correct
.25	0	0%	78%
.375	0	0%	78%
.50	0	0%	78%
.60	19	3%	78%
.70	82	13%	80%
.80	193	31%	89%
.90	391	62%	94%

A cutoff probability of 0.80 (80%) was shown to yield an ARCC of 89%. An increase to a 0.90 (90%) cutoff did not increase the rate of correct classification as much as it increased the percent unknown (Figure C-1). Therefore, using a cutoff probability of 0.80 (80%), the 193 isolates that were not useful in the prediction of probable sources were removed, leaving 437 isolates remaining in the library. This library was then used in the statistical prediction of probable sources of bacteria in water samples collected from the Herring Run Watershed. The rates of correct classification for the three categories of sources in the library, at 0.80 (80%) probability cutoff, are shown in Table C-4 below.

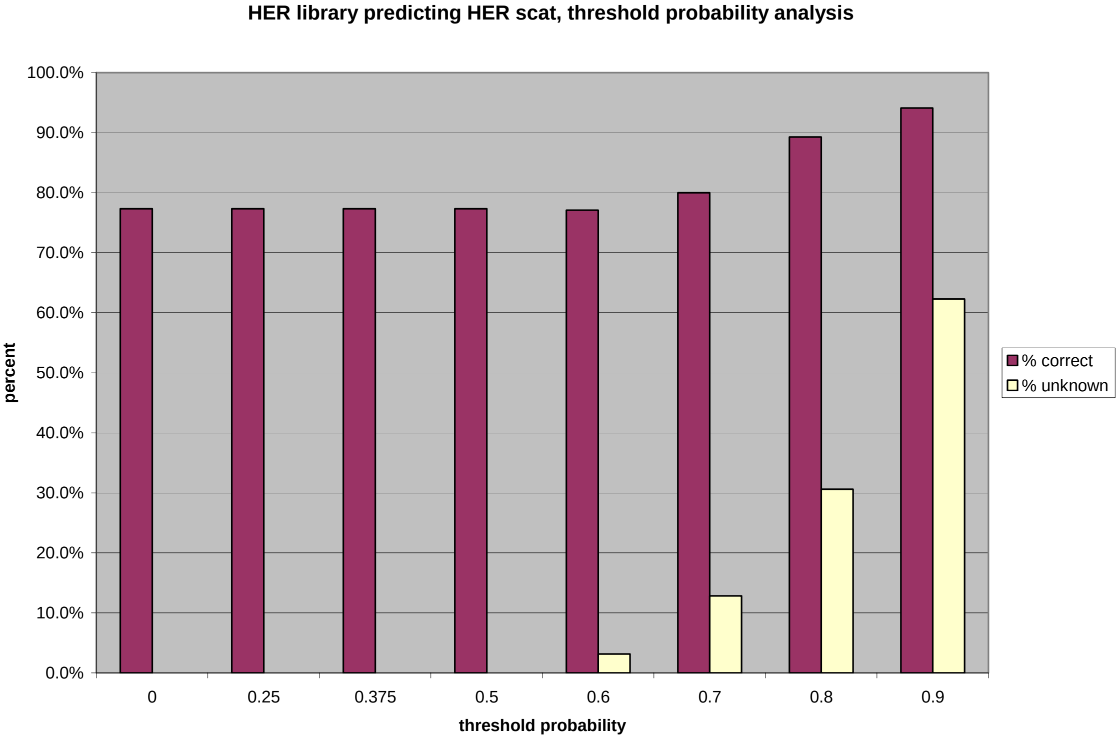

Figure C-1: Classification Model: Percent Correct versus Percent Unknown.

Table C-4: Actual species categories versus predicted categories, at an 80% probability cutoff, with rates of correct classification (RCC) for each category.

	Predicted →				
Actual ↓	HUMAN	PET	WILDLIFE	TOTAL	RCC[1]
HUMAN	**276**	13	25	314	88%
PET	3	**45**	4	52	87%
WILDLIFE	1	0	**71**	72	99%
Total	**280**	**58**	**100**	**438**	**89%**

[1] RCC = Actual number of predicted species category / Total number predicted.
Example: One hundred sixty-three (163) domestic correctly predicted / 175 total number predicted for domestic = 163/175 = 93%.

Herring Run Water Samples. Monthly monitoring from one (1) station on Herring Run was the source of water samples. The maximum number of *Enterococcus* isolates per water sample was 24, although the number of isolates that actually grew was sometimes fewer than 24. A total of 262 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicates that 73% of the water isolates were classified after excluding unknowns when using a 0.80 (80%) probability cutoff.

Table C-5: Potential host sources of water isolates by species category, number of isolates, percent isolates classified at cutoff probability of 80%.

Category	Number	% Isolates Classified 80% Prob.	% Isolates Classified (excluding unknowns)
HUMAN	134	51%	70%
LIVESTOCK	-	-	-
PET	36	14%	19%
WILDLIFE	21	8%	11%
UNKNOWN	71	27%	
Missing Data	0		
Total	262		
% Classified	**73%**		

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

Table C-6: *Enterococcus* isolates obtained from water collected during the fall, winter, spring, and summer seasons for the one (1) monitoring station.

Station	Spring	Summer	Fall	Winter	Total
HER0065	72	61	81	48	262
Total	**72**	**61**	**81**	**48**	**262**

Tables C-7 and C-8 below show the number and percent of probable sources of *Enterococcus* contamination in the watershed.

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

Station	date	% domestic	% human	% livestock	% wildlife	% unknown
HER0065	**11/13/2002**	1	9	0	4	10
HER0065	**12/03/2002**	3	15	0	1	5
HER0065	**01/07/2003**	9	15	0	0	0
HER0065	**02/04/2003**	8	11	0	0	5
HER0065	**04/22/2003**	1	20	0	1	2
HER0065	**05/06/2003**	3	2	0	6	13
HER0065	**06/03/2003**	5	5	0	0	14
HER0065	**07/08/2003**	1	18	0	0	1
HER0065	**08/05/2003**	3	12	0	2	5
HER0065	**09/09/2003**	0	13	0	5	1
HER0065	**09/23/2003**	2	11	0	0	11
HER0065	**10/07/2003**	0	3	0	2	4

Table C-8: Percentage of Sources per Station per Date

Station	date	% domestic	% human	% livestock	% wildlife	% unknown
HER0065	**11/13/2002**	4.1667	37.5000	0	16.6667	41.6667
HER0065	**12/03/2002**	12.5000	62.5000	0	4.1667	20.8333
HER0065	**01/07/2003**	37.5000	62.5000	0	0.0000	0.0000
HER0065	**02/04/2003**	33.3333	45.8333	0	0.0000	20.8333
HER0065	**04/22/2003**	4.1667	83.3333	0	4.1667	8.3333
HER0065	**05/06/2003**	12.5000	8.3333	0	25.0000	54.1667
HER0065	**06/03/2003**	20.8333	20.8333	0	0.0000	58.3333
HER0065	**07/08/2003**	5.0000	90.0000	0	0.0000	5.0000
HER0065	**08/05/2003**	13.6364	54.5455	0	9.0909	22.7273
HER0065	**09/09/2003**	0.0000	68.4211	0	26.3158	5.2632
HER0065	**09/23/2003**	8.3333	45.8333	0	0.0000	45.8333
HER0065	**10/07/2003**	0.0000	33.3333	0	22.2222	44.4444

Table C-9: *E. coli* Concentration and Percentage of Sources by Stratum (Annual Period)

SAMPLING STATION IDENTIFIER	DATE START SAMPLING	flow regime (1=high/ 2=low)	ecoli conc MPN/100ml	log mean conc	% domestic	% human	% livestock	% wildlife	% unknown
HER0065	**11/13/2002**	2	1080	3.03342	4.1667	37.5000	0	16.666	41.6667
HER0065	**11/25/2002**	2	60	1.77815	.	.	.	.	.
HER0065	**12/03/2002**	2	2600	3.41497	12.5000	62.5000	0	4.1667	20.8333
HER0065	**12/17/2002**	2	570	2.75587	.	.	.	.	.
HER0065	**01/07/2003**	2	4350	3.63849	37.5000	62.5000	0	0.0000	0.0000
HER0065	**01/22/2003**	2	90	1.95424	.	.	.	.	.
HER0065	**02/04/2003**	1	13000	4.11394	33.3333	45.8333	0	0.0000	20.8333
HER0065	**03/04/2003**	1	5170	3.71349	.	.	.	.	.
HER0065	**03/18/2003**	2	1520	3.18184	.	.	.	.	.
HER0065	**04/22/2003**	2	460	2.66276	4.1667	83.3333	0	4.1667	8.3333
HER0065	**05/06/2003**	2	1160	3.06446	12.5000	8.3333	0	25.000	54.1667
HER0065	**05/20/2003**	2	24190	4.38364	.	.	.	.	.
HER0065	**06/03/2003**	1	440	2.64345	20.8333	20.8333	0	0.0000	58.3333
HER0065	**06/17/2003**	1	1160	3.06446	.	.	.	.	.
HER0065	**06/24/2003**	2	590	2.77085	.	.	.	.	.
HER0065	**07/08/2003**	2	5480	3.73878	5.0000	90.0000	0	0.0000	5.0000
HER0065	**07/22/2003**	1	1960	3.29226	.	.	.	.	.
HER0065	**08/05/2003**	2	3130	3.49554	13.6364	54.5455	0	9.0909	22.7273
HER0065	**08/19/2003**	2	290	2.46240	.	.	.	.	.
HER0065	**08/26/2003**	1	190	2.27875	.	.	.	.	.
HER0065	**09/09/2003**	2	450	2.65321	0.0000	68.4211	0	26.315	5.2632
HER0065	**09/23/2003**	1	36500	4.56229	8.3333	45.8333	0	0.0000	45.8333
HER0065	**10/07/2003**	2	170	2.23045	0.0000	33.3333	0	22.222	44.4444
HER0065	**10/21/2003**	2	170	2.23045	.	.	.	.	.

Table C-10: Percentage of Sources per Station by Stratum (Annual Period)

SAMPLING STATION IDENTIFIER	flow regime (1=high/2=low)	% domestic	% human	% livestock	% wildlife	% unknow n
HER0065	1	20.3382	39.9952	0	0.0000	39.6666
HER0065	2	11.0099	56.7472	0	10.8713	21.3716

Table C-11: Overall Percentage of Sources per Station (Annual Period)

SAMPLING STATION IDENTIFIER	% Domestic	% Human	% Livestock	% Wildlife	% Unknown	% Total
HER0065	13.34	52.56	0.00	8.15	25.95	100.00%

Herring Run Summary

The use of ARA was successful for identification of bacterial sources in the Herring Run Watershed as evidenced by the acceptable ARCC (89%) for the library. The RCCs ranged from 87% to 99%. When water isolates were compared to the library and potential sources predicted, 73% of the isolates were classified by statistical analysis. The largest category of potential sources in the watershed as a whole was human (70%), followed by pet and wildlife (19% and 11% of the classified water isolates, respectively).

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ACKNOWLEDGEMENTS

We wish to thank the Richard A. Henson School of Science and Technology of Salisbury University, Salisbury, MD for its support. We also want to acknowledge Dr. Bertram Price and Joshua Greenberg of Price Associates, Inc., for their contributions to the statistical analysis in this project.

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

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

Level of Resolution

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

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

Probability Level

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

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

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

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

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

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

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

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

where

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

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

MDL = Maximum Daily Load (MPN/day)

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

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

CV = Coefficient of variation

Q = Flow (cfs)

F = conversion factor

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

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

Where

Z = z-score associated with upper bound percentile

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

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

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

CV = Coefficient of variation (arithmetic)

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

The highest percentile of all the stations analyzed by stratum will define the upper bound percentile to be used in estimating the maximum daily loads. As explained in Section 4.6, the value with the highest percentile by stratum was observed at the Biddle & 62nd St. station. In the case of Herring Run, a value measured during low-flow conditions at the Biddle Street station resulted in the highest percentile of all three stations and strata. This value translates to the 99.5th percentile, which is the upper boundary percentile to be used in the computation of the MDLs throughout this analysis. Results of the analysis to estimate the recurrence or upper boundary percentile are shown in Table D-1.

Table D-1: Percentiles of Maximum Observed Bacteria Concentrations in the Herring Run Subwatersheds

Station	Strata	Maximum Observed *E. coli* Concentration (MPN/100ml)	Percentile
Harford Rd	High Flow	170,789	94.6 %
	Low Flow	5,976	98.0 %
Pulaski Hwy	High Flow	63,367	92.1 %
	Low Flow	2,479	95.0 %
Biddle & 62nd St.	High Flow	106,800	97.4 %
	Low Flow	86,997	99.5 %

As seen in Table D-1, the highest percentile value obtained from all three stations and strata is 99.5%, therefore, the upper boundary percentile to be used to estimate MDLs in this analysis will equal 99.5%. This 99.5th percentile value results in a maximum daily load that would not be exceeded 99.5% of the time, as, in a similar manner, a TMDL that represents the long term average condition would be expected to be exceeded half the time even after all required controls were implemented.

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

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

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

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

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

And from equation (10)

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

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

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

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

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

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

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

Station	Strata	LTA Geometric Mean Concentrations (MPN/100ml)	LTA Arithmetic Mean* Concentrations (MPN/100ml)
Harford Rd	High Flow	421	3,351
	Low Flow	38	72
Pulaski Hwy	High Flow	305	2,488
	Low Flow	32	63
Biddle & 62nd St.	High Flow	91	724
	Low Flow	59	223

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

The next step is to calculate the 99.5th percentile (the MDL concentrations) of these expected concentrations (LTA concentrations) using the coefficient of variation of the baseline concentrations. Based on a general rule for coefficient of variations, the coefficient of variation of the distribution of the concentrations of a pollutant does not change after these concentrations have been reduced or controlled by a fixed proportion (Ott and Wayne 1995).

Therefore, the coefficient of variation estimated using the monitoring data concentrations does not change, and it can be used to estimate the 99.5th percentile of the long-term average TMDL concentrations (LTAC) using equation (D1). These values are shown in Table D-3.

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

Station	Strata	CV	MDL Concentrations (MPN/100ml)
Harford Rd	High Flow	7.90	79,660
	Low Flow	1.62	701
Pulaski Hwy	High Flow	8.11	59,555
	Low Flow	1.69	635
Biddle & 62nd St.	High Flow	7.92	17,245
	Low Flow	3.63	3,915

With the 99.5th percentiles of LTA TMDL bacteria concentrations estimated for both high flow and low flow strata as explained above, the maximum daily load for each subwatershed can be now estimated as:

$$Daily\ TMDL\ (MPN/day) = Q_H*(99.5^{th}C_{LTA\text{-}H})*F_{1H}*W_H + Q_L*(99.5^{th}C_{LTA\text{-}L})*F_{1L}*W_L$$

The Maximum Daily Loads for the Herring Run subwatersheds are presented in Table D-4 below.

Table D-4: Maximum Daily Loads (MDLs)

Station	Strata	Maximum Daily Load by Stratum (Billion *E. coli* MPN/day)
Harford Rd	High Flow	105,634
	Low Flow	102
Pulaski Hwy	High Flow	45,169
	Low Flow	53
Biddle & 62nd St.	High Flow	16,708
	Low Flow	417

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