Total Maximum Daily Loads of Fecal Bacteria for the Non-Tidal Jones Falls Basin in Baltimore City and Baltimore County, Maryland

FINAL

MARYLAND DEPARTMENT OF THE ENVIRONMENT

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List of Abbreviations

ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
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
CWP	Center for Watershed Protection
DNR	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
SHA	State Highway Administration
SSO	Sanitary Sewer Overflows
STATSGO	State Soil Geographic
TARSA	Technical and Regulatory Services Administration
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WRAS	Watershed Restoration Action Strategy
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 Jones Falls (basin number 02-13-09-04). 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 Jones Falls and all tributaries above Lake Roland, a designated Use III waterbody (Water Contact Recreation, Protection of Aquatic Life and Natural Trout Waters), and Jones Falls between North Avenue (Baltimore City) and Lake Roland, a designated Use IV waterbody (Water Contact Recreation, Protection of Aquatic Life and Recreational Trout Waters) [Code of Maryland Regulations (COMAR) 26.08.02.08.08] in the State's 303(d) List as impaired by metals (copper and lead) (1996), nutrients (1996), sediments (1996), bacteria (fecal coliform) (2002), polychlorinated biphenyls (PCBs) - Lake Roland (2002), and by impacts to biological communities (2004). This document proposes to establish a TMDL for fecal bacteria in Jones Falls and its tributaries that will allow for the attainment of the designated use, primary contact recreation. The impairment for metals (copper and lead) was removed from the 303(d) List through a water quality analyses approved by EPA in December 2, 2004. A TMDL for chlordane was approved by EPA on March 23, 2001. The listings for nutrients, sediments, PCBs 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 all readily available data from the past five years was considered.

To establish baseline and allowable pollutant 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 bacteria monitoring data. The sources of fecal bacteria were estimated at five representative stations in the Jones Falls watershed where samples were collected for one year. Multiple antibiotic resistance analysis (ARA) source tracking was used to determine the relative proportion of domestic (pets and human associated animals), human (human waste), livestock (agricultural related animals), and wildlife (mammals and waterfowl) source categories.

The allowable load is determined by estimating a baseline load from current monitoring data. The baseline load is estimated using a long-term geometric mean and weighting factors from the flow duration curve. The TMDL load for fecal bacteria entering Jones Falls 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 five subwatersheds of Jones Falls, it was estimated that water quality standards could not be attained with the MPRs. Thus, a second scenario was applied allowing greater reductions that may not be feasible.

The fecal bacteria TMDL developed for the Jones Falls watershed is 860 billion MPN *E. coli*/day. 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 LA is 212 billion MPN *E. coli*/day. The WWTP WLA is 0.05 billion MPN *E. coli*/day. The MS4s WLA is 647.95 billion MPN *E. coli*/day and the CSO load allocation is 0.0 MPN *E. coli*/day. 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.

Once the EPA has approved a TMDL, and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) is expected to take place. MDE intends for the required reduction to be implemented in an iterative process that first addresses those sources with the largest impacts to water quality and creating the greatest risks to human health, with consideration given to ease and cost of implementation. In addition, follow up monitoring plans will be established to track progress and to assess the implementation efforts. As previously stated, water quality standards cannot be attained in the Jones Falls subwatersheds using the MPR scenario. This may occur in subwatersheds where wildlife is a significant component or in subwatersheds that require very high reductions of fecal bacteria loads 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 in Jones Falls (basin number 02-13-09-04). 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 Jones Falls and all tributaries above Lake Roland, a designated Use III waterbody (Water Contact Recreation, Protection of Aquatic Life and Natural Trout Waters), and Jones Falls between North Avenue (Baltimore City) and Lake Roland, a designated Use IV waterbody (Water Contact Recreation, Protection of Aquatic Life and Recreational Trout Waters) [Code of Maryland Regulations (COMAR) 26.08.02.08.08] in the State’s 303(d) List as impaired by metals (copper and lead) (1996), nutrients (1996), sediments (1996), bacteria (fecal coliform) (2002), PCBs (Lake Roland) (2002) and by impacts to biological communities (2004). This document proposes to establish a TMDL of fecal bacteria in Jones Falls and its tributaries that will allow for the attainment of the designated use, primary contact recreation. The impairment for metals (copper and lead) was removed from the 303(d) List through a water quality analyses approved by EPA in December 2, 2004. A TMDL for chlordane was approved by EPA on March 23, 2001. The listings for nutrients, sediments, PCBs 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 all readily available data from the past five years was considered.

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 (EPA, 1986).

In 1986, EPA published “Ambient Water Quality Criteria for Bacteria”, in which three indicator organisms were assessed to determine their correlation with swimming-associated illnesses. Fecal coliform, *E. coli* and enterococci were the indicators used in the analysis. Fecal coliform 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 (EPA, 1986) demonstrated that fecal coliform showed less correlation to swimming-associated gastroenteritis than either *E. coli* or enterococci.

The Jones Falls watershed was listed on the Maryland 303(d) List in 2002 using fecal coliform as the indicator organism. Based on EPA's guidance (EPA, 1986), adopted by Maryland in 2004, the State has revised the bacteria water quality criteria and it is now based on water column limits for either *E. coli* or enterococci. Because multiple monitoring datasets are available within this watershed for various pathogen indicators, the general term fecal bacteria will be used to refer to the impairing substance throughout this document. The TMDL will be based on the pathogen indicator organisms specified in Maryland's current bacteria water quality criteria, either *E. coli* or enterococci. The indicator organism used in the Jones Falls TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Jones Falls watershed is located in the Patapsco River region of the Chesapeake Bay watershed within Maryland (see Figure 2.1.1). The watershed covers a portion of Baltimore County and Baltimore City, Maryland. Jones Falls proper flows east and south from its headwaters in Garrison, Maryland to its discharge into the Inner Harbor in downtown Baltimore City. An impoundment is located at Lake Roland, just north of the Baltimore County/City boundary. Several tributaries drain to the Jones Falls mainstem, including Moores Branch, Roland Run, Towson Run, Western Run, and Stoney Run. The entire Jones Falls watershed area comprises 37,290 acres (58.3 sq. mi.).

Jones Falls is a free flowing, non-tidal stream. Due to the density of the urban landscape in downtown Baltimore City, Jones Falls flows through roughly three miles of underground duct before discharging into the Baltimore Harbor. This flow regime changes the effective watershed area considered for this report. First, runoff from the area above the underground portion of the watershed does not flow into the Jones Falls mainstem, but rather is routed directly to the Baltimore Harbor. Second, it is not possible to monitor in the underground portion of the stream. Therefore, the watershed area considered for this TMDL is the effective watershed area (*i.e.*, the land area draining to the above-ground portion of the stream). The lower extent of the watershed area will be determined by the location of the most downstream monitoring station in the Jones Falls mainstem before going underground. Therefore, the area of the effective Jones Falls watershed considered in this TMDL analysis is 34,122 acres (53.3 sq. mi.).

Geology/Soils

The Jones Falls watershed lies within the Piedmont and Coastal Plain provinces of central Maryland. The Piedmont province is characterized by gentle to steep rolling topography, and low hills and ridges. The surficial geology is characterized by crystalline rocks of volcanic origin and often determines the limits of stream bank and streambed. These crystalline formations decrease in elevation from northwest to southeast and eventually extend beneath the younger sediments of the Coastal Plain. The fall line represents the transition between the Atlantic Coastal Plain province and the Piedmont province. The Atlantic Coastal Plain surficial geology is characterized by thick, unconsolidated marine sediments deposited over the crystalline rock of the piedmont province. The deposits include clays, silts, sands, and gravels (Coastal Environmental Services, 1995).

The Jones Falls watershed drains from northwest to southeast, following the gradient of the underlying crystalline bedrock in the Piedmont province. The surface elevations range from approximately 680 feet to sea level at the discharge. Stream channels of the sub-watersheds are well incised in the Eastern Piedmont, and exhibit relatively straight reaches and sharp bends, reflecting their tendency to following zones of fractured or weathered rock. The stream channels broaden abruptly as they flow down across the fall line into the soft, flat Coastal Plain sediments (Coastal Environmental Services, 1995).

Above the Baltimore City/County boundary, Jones Falls lies predominantly in the Baile soil series. Soils in this series are very deep, poorly drained, exhibit slow to moderately slow permeability, and occur on upland depressions and slopes. The secondary soil series in the Baltimore County area of the watershed is the Hatboro soil series, which has similar characteristics as the Baile soil series and is often found in flood plains.

In Baltimore City the primary soil series is the Lehigh series. This series is characterized by deep and somewhat poorly drained soil with slow permeability. The secondary soil series present in the lower Jones Falls watershed is the Beltsville soil series, which is distinguished by being moderately well drained and often found in upland regions of the coastal plain geologic region. The spatial distributions for each soil series are shown in Figure 2.1.2.

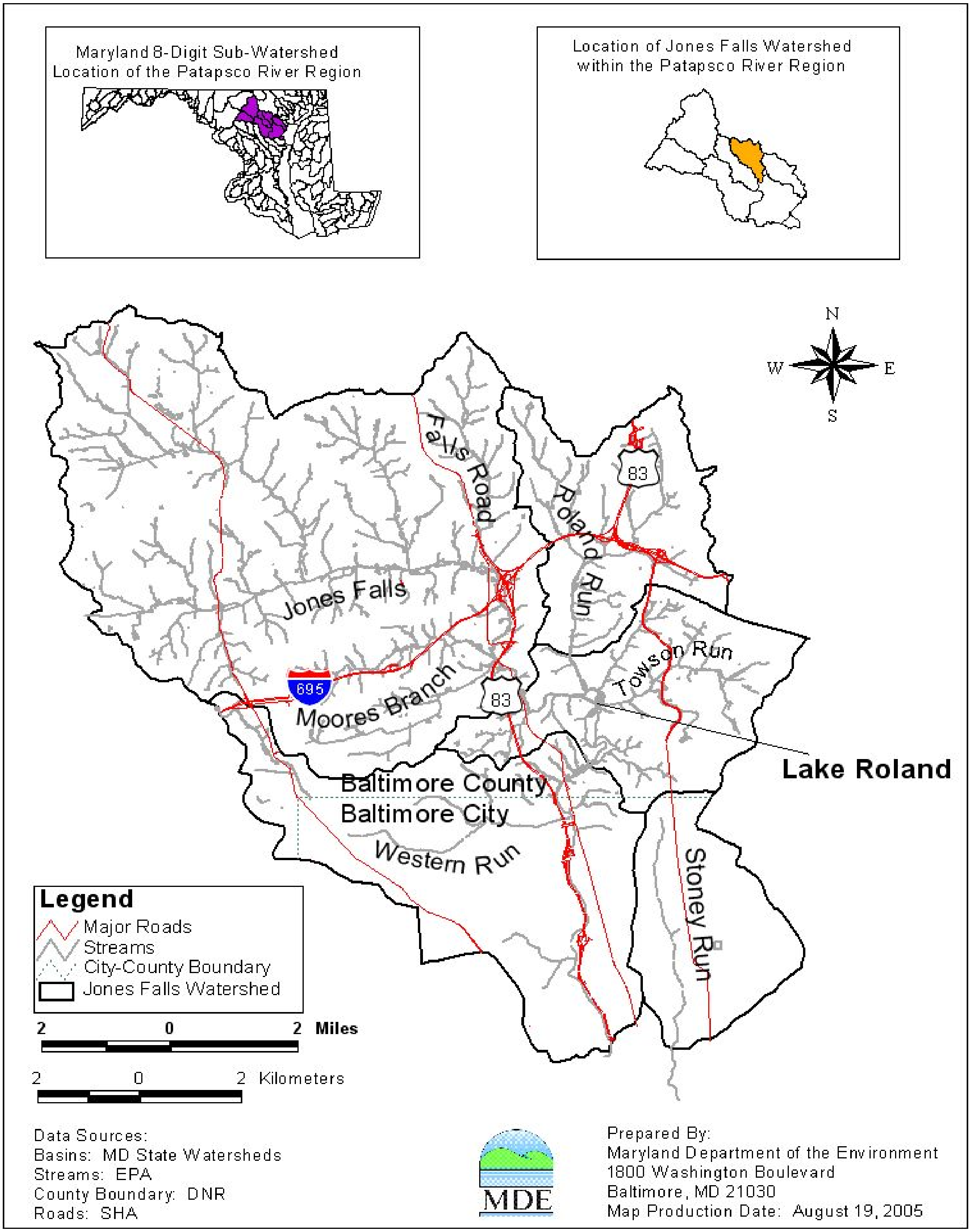

Figure 2.1.1: Location Map of the Jones Falls Watershed

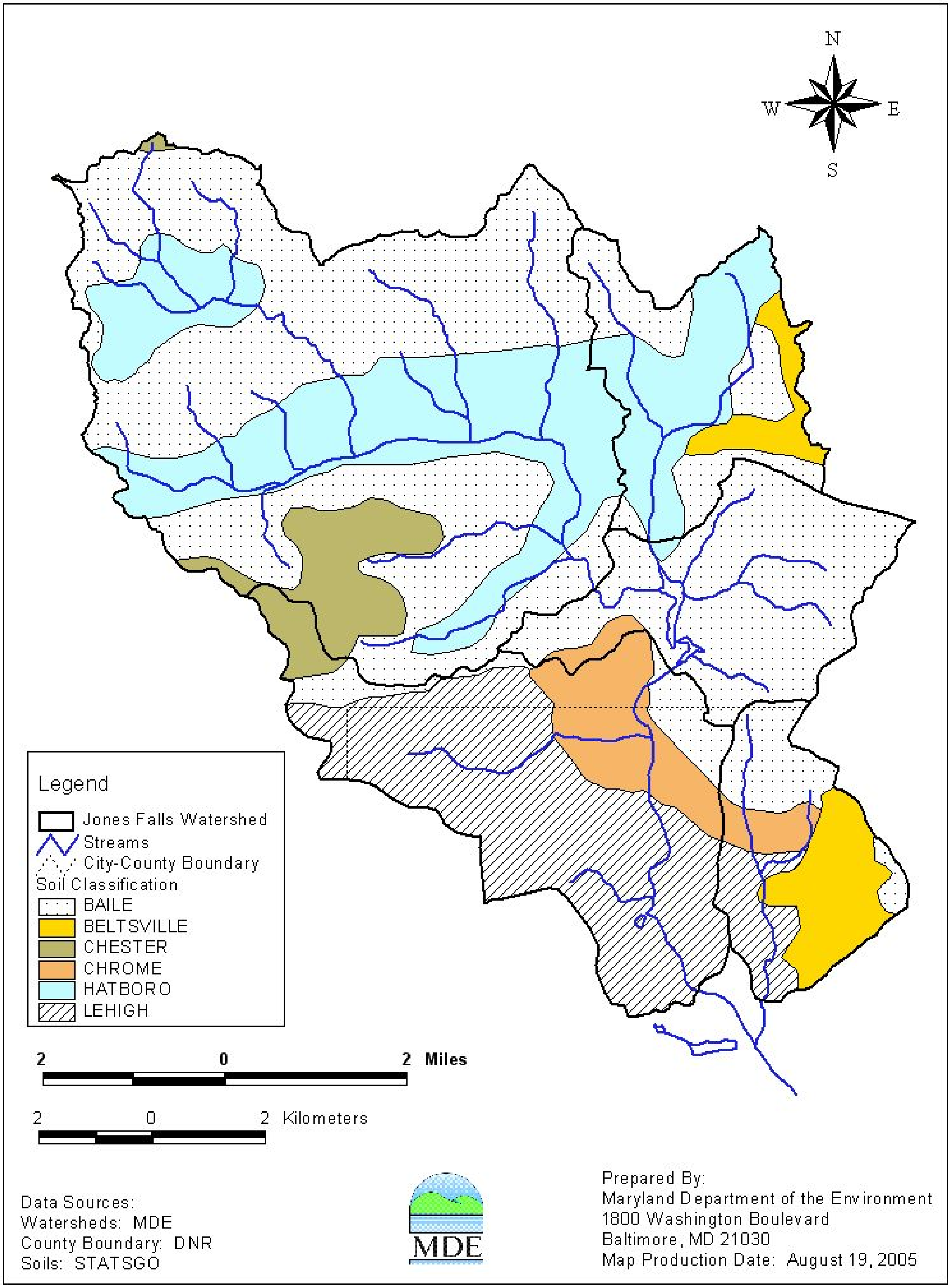

Figure 2.1.2: General Soil Series in the Jones Falls Watershed

Land Use

The Jones Falls watershed encompasses 34,122 acres (53.3 sq. mi.) within urban Baltimore City and suburban Baltimore County. The Jones Falls 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 residential and forested. Park and forest lands cover 16% of the watershed and are concentrated in the Baltimore County portion of the watershed. The residential and commercial land uses cover approximately 75% of the watershed and are more concentrated in the Baltimore City portion of the watershed. The land use percentage distribution for Jones Falls 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 Jones Falls Watershed

Land Type	Acreage	Percentage
Forest	5,901	17.3
Residential	20,080	60.9
Commercial	4,486	13.1
Crops	2,326	6.8
Pasture	547	1.6
Water	54	0.2
Totals	**34,122**	**100%**

Population

The total population in the Jones Falls watershed is estimated to be 152,195. 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 Jones Falls 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 was calculated using Table 2.1.2 in the Jones Falls watershed.

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 Jones Falls Watershed

Subwatershed	Population	Dwellings
UQQ0005	32,791	9,956
JON0184	35,517	13,558
JON0082	28,570	8,276
JON0039	35,812	20,783
SRU0005	19,505	7,207
Total	152,195	59,780

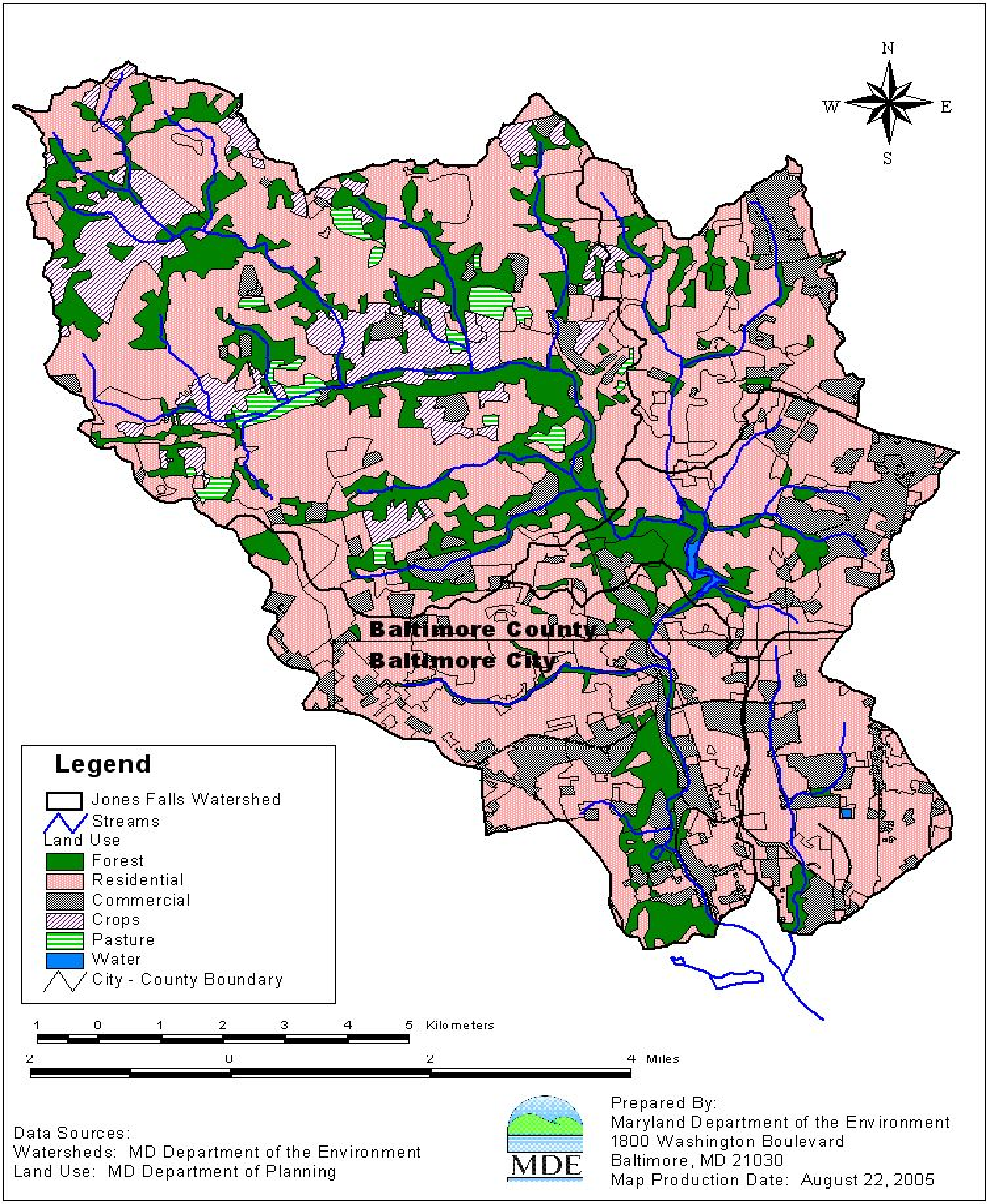

Figure 2.1.3: Land Use of the Jones Falls Watershed

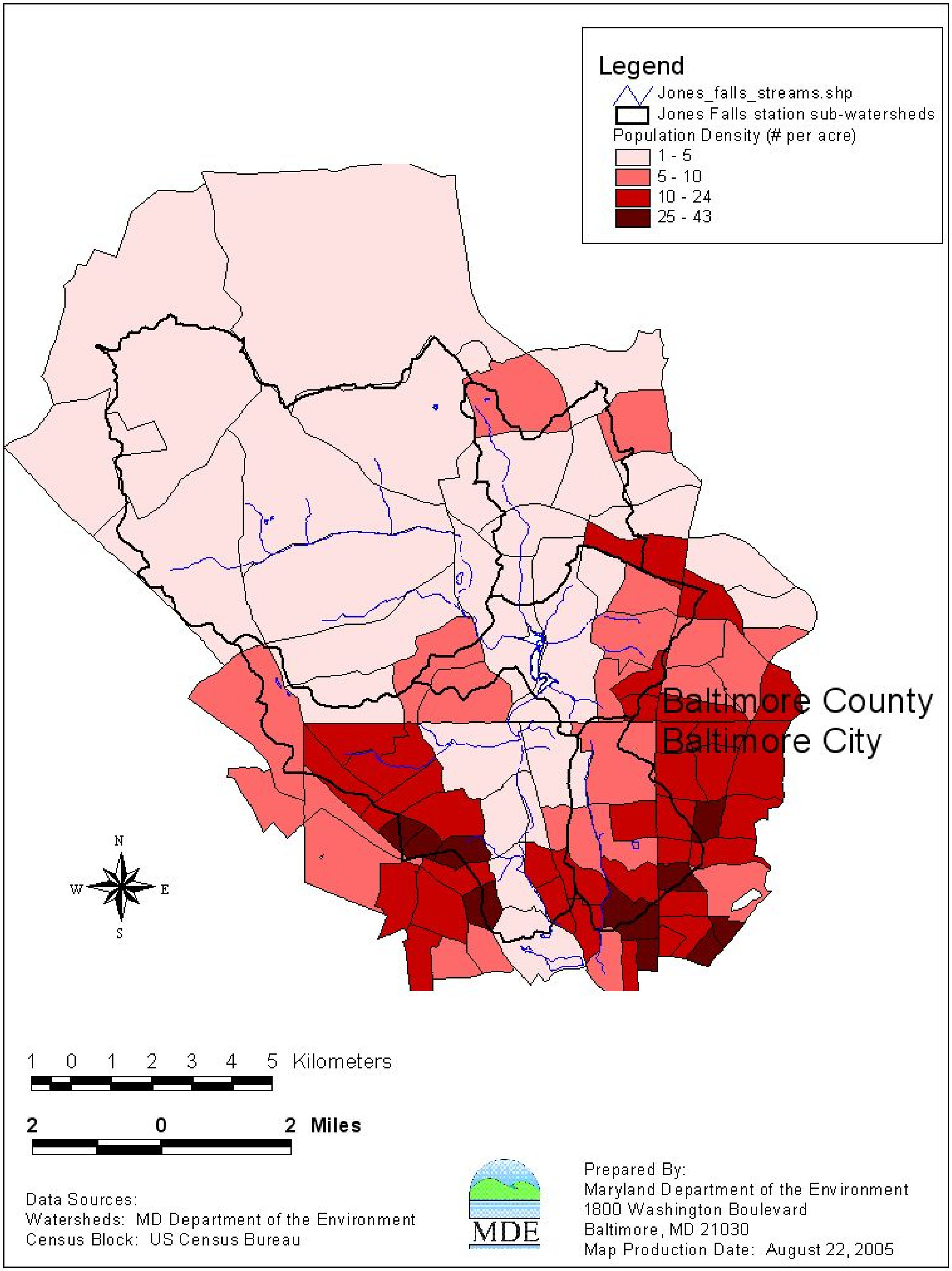

Figure 2.1.4: Population Density in Jones Falls Watershed

2.2 Water Quality Characterization

From EPA's guidance document "Ambient Water Quality Criteria for Bacteria" (1986), 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), leading EPA to propose that states use *E. coli* or enterococci as pathogen indicators.

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 (EPA, 1986), this fecal coliform geometric mean target equates to an approximate risk of 8 illnesses per 1,000 swimmers at fresh water beaches and 19 illnesses per 1,000 swimmers at marine beaches (enterococci only), which is consistent with MDE's revised Use I bacteria criteria. Therefore the original 303(d) List fecal coliform listings can be addressed using the refined bacteria indicator organisms to assure that risk levels are acceptable.

<u>Bacteria Monitoring</u>

Table 2.2.1 lists the historical monitoring data for the Jones Falls watershed. MDE conducted monitoring sampling from October 2002 through June 2003. Monitoring Station JON0184 (CORE) was used by the Maryland Department of Natural Resources (DNR) to identify the bacterial impairment. There are five MDE monitoring stations in the Jones Falls watershed. In addition to the bacteria monitoring stations, there are three United States Geological Survey (USGS) gaging stations used in deriving the surface flow in Jones Falls. The locations of these stations are shown in Tables 2.2.2 to 2.2.4 and Figure 2.2.1. Observations recorded during the period 2002-2003 from the five MDE monitoring stations are shown in Appendix A. In general, based on statewide monitoring data, fecal bacteria concentrations are higher in the headwaters. This is consistent with findings from Wickham, *et al*. (2005) regarding pathogens in Maryland, where the likelihood of an impairment decreases with watershed size. A table listing the monitoring results from the Jones Falls watershed appears in Appendix A.

Bacteria counts are highly variable and results are presented on a log scale for the five monitoring stations for data collected for October 2002 through June 2003. Ranges were typically between 10 and 10,000 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Jones Falls Watershed

Sponsor	Location	Date	Design	Summary
Maryland Department of Natural Resources (DNR) CORE Monitoring	Baltimore County	1995 - 1999	Fecal Coliform*	JON0184 - High Bacteria concentrations
Maryland Department of Natural Resources (DNR) CORE Monitoring	Baltimore County	10/02 to 10/03	Fecal Coliform*	2002 305(b) Update – JON0184 show bacteria geometric mean of 344 MPN/100mL
Baltimore City	Baltimore City	1997 - 2001	Fecal Coliform*	Geometric Mean = 2,724 MPN/100mL
MDE	Baltimore City and Baltimore County	10/02 – 06/03	*E Coli*	5 stations Enumeration 2x per Month

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

Table 2.2.2: Locations of DNR (CORE) Monitoring Station in the Jones Falls Watershed

Monitoring Station	Observation Period	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
JON0184	1995-1999	39 23.47	76 39.66

Table 2.2.3: Locations of MDE Monitoring Stations in the Jones Falls Watershed

Monitoring Station	Observation Period	Total Observation	LATITUDE Dec-Deg	LONGITUDE Dec-Deg
JON0184	2002-2003	24	39 23.47	76 39.66
UQQ0005	2002-2003	24	39 23.92	76 38.93
JON0082	2002-2003	24	39 22.69	76 38.66
JON0039	2002-2003	24	39 19.65	76 38.42
SRU0005	2002-2003	24	39 19.55	76 37.56

Table 2.2.4: Locations of USGS Gauging Stations in Jones Falls Watershed

Monitoring Station	Observation Period	LATITUDE Dec-deg	LONGITUDE Dec-deg
01589440	1992 - 2004	39 23.50	76 39.66
01589478	1992 - 2003	39 18.56	76 37.17

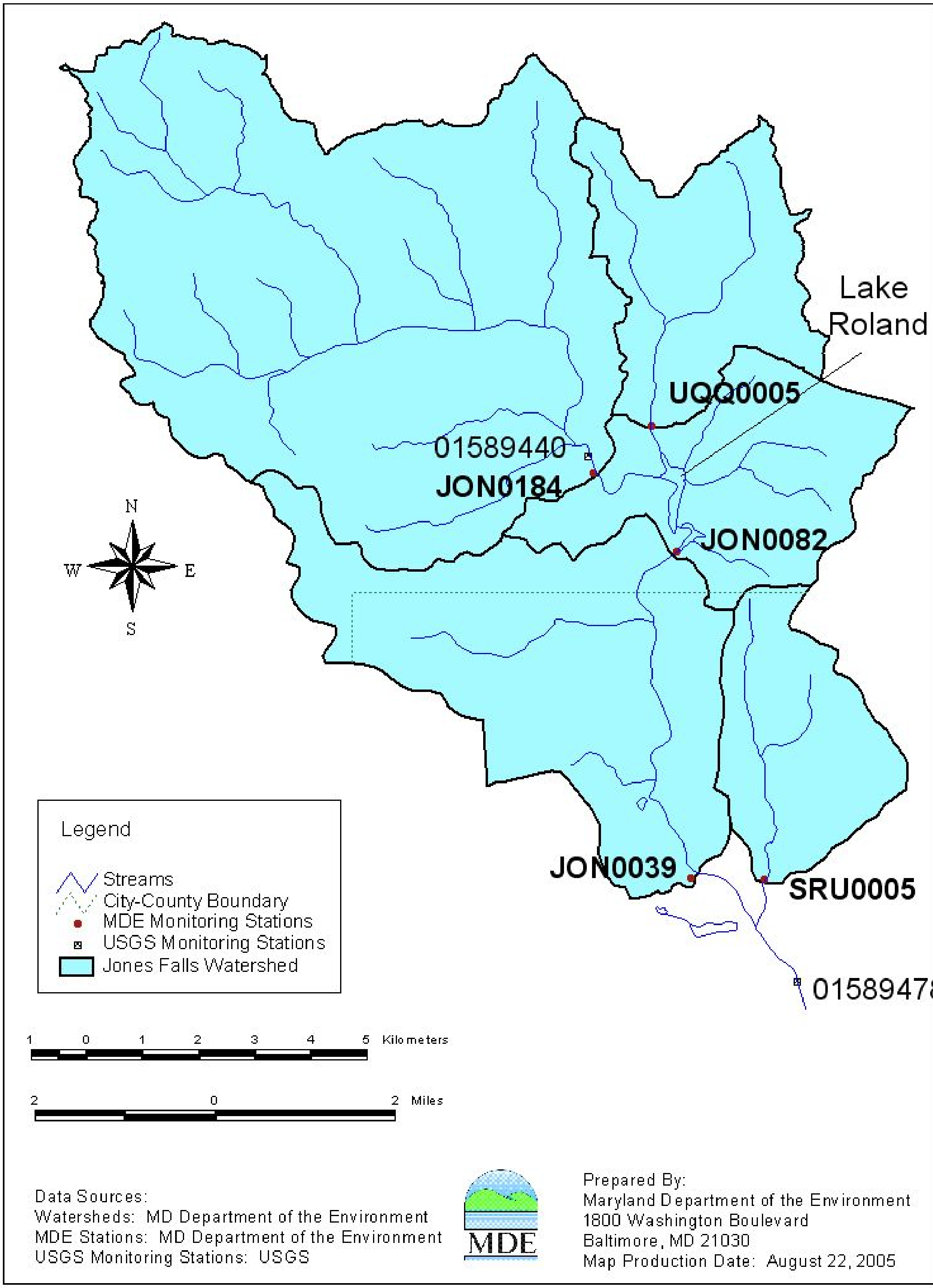

Figure 2.2.1: Monitoring Stations in the Jones Falls Watershed

2.3 Water Quality Impairment

Designated Uses and Water Quality Standard

The Maryland water quality standards Surface Water Use Designations for Jones Falls are Use III for the mainstem and all tributaries above Lake Roland (Nontidal Cold Water), and Use IV for Jones Falls from North Avenue to Lake Roland Dam (Recreational Trout Waters). See COMAR 26.08.02.08R(b). Jones Falls 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 cfu/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

The water quality impairments in the Jones Falls watershed were assessed by comparing both the annual and the seasonal (May 1st – September 30th) steady-state geometric means of *E. coli* concentrations with the water quality criterion. The steady-state condition is defined as unbiased sampling targeting average flow conditions and/or equally sampling or providing for unbiased sampling of high and low flows. The 1986 EPA criteria document assumed steady-state flow in determining the risk at various bacterial concentrations, and therefore the chosen criterion value also reflects steady-state conditions (EPA, 1986). The steady-state geometric mean condition can be estimated either by monitoring design or more practically by statistical analysis as follows:

1. A stratified monitoring design is used where the number of samples collected is proportional to the duration of high flows, mid flows and low flows within the watershed. This sample design allows a geometric mean to be calculated directly from the monitoring data.

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

A routine monitoring design was used to collect bacteria data in the Jones Falls 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.

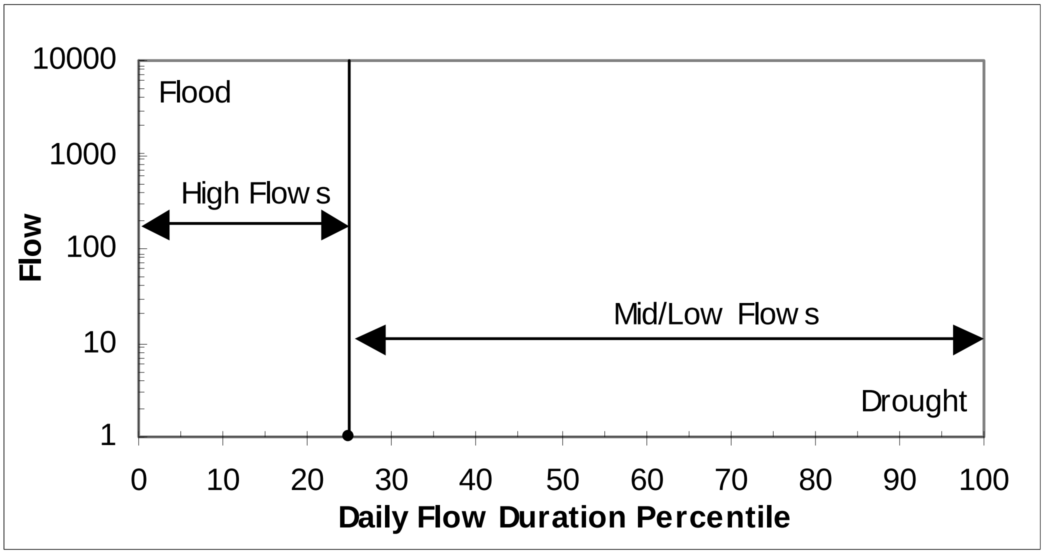

Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

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 25^{th} to 30^{th} daily flow duration percentiles were representative of average daily flows. It is assumed for this analysis that flows above the 25^{th} percentile represent high flows and flows below the 25^{th} 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. The weighting factors for an average hydrological year used in the Jones Falls 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 Jones Falls Watershed (Average Hydrology Year)

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

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

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

where

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

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

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

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

Cgm = 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 Jones Falls subwatersheds for the annual and the seasonal (May 1st –September 30th) periods.

Table 2.3.3: Jones Falls 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)
JON0184	**High**	6	40	36,500	532	306
	Low	18	40	1,260	254	
UQQ0005	**High**	6	40	14,400	593	406
	Low	18	30	2,600	358	
JON082	**High**	6	40	22,800	619	141
	Low	18	10	3,450	86	
JON0039	**High**	9	210	43,500	2,679	712
	Low	15	70	3,260	458	
SRU0005	**High**	9	450	54,800	4,545	2,392
	Low	15	240	24,190	1,931	

Table 2.3.4: Jones Falls 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)	Annual Steady-state Geometric Mean (MPN/100ml)	Annual Overall Geometric Mean (MPN/100ml)
JON0184	**High**	4	420	36,500	1,545	664
	Low	8	150	1,210	501	
UQQ0005	**High**	4	460	14,400	1,368	976
	Low	8	300	2,600	872	
JON082	**High**	4	230	22,800	1,152	236
	Low	8	10	3,260	139	
JON0039	**High**	5	210	43,500	1,164	495
	Low	7	140	2,050	372	
SRU0005	**High**	5	750	54,800	9,105	3343
	Low	7	530	24,190	2,394	

2.4 Source Assessment

<u>Nonpoint Source Assessment</u>

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 Jones Falls watershed consists primarily of forested and developed land uses; 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

Sewage collection systems within the Jones Falls 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 on-site disposal (septic) systems located in the northern and western part of the Jones Falls watershed. Table 2.4.1 displays the number of septic systems and households per subwatershed. Figure 2.4.1 presents the areas covered by sewers and the septics location in the Jones Falls watershed.

Table 2.4.1: Septic Systems and Households per Subwatershed in Jones Falls Watershed

Subwatershed Station	Households per Subwatershed	Septics Systems (units)
UQQ0005	9,956	633
SRU0005	7,207	0
JON0184	13,558	3,998
JON0082	8,276	464
JON0039	20,783	134

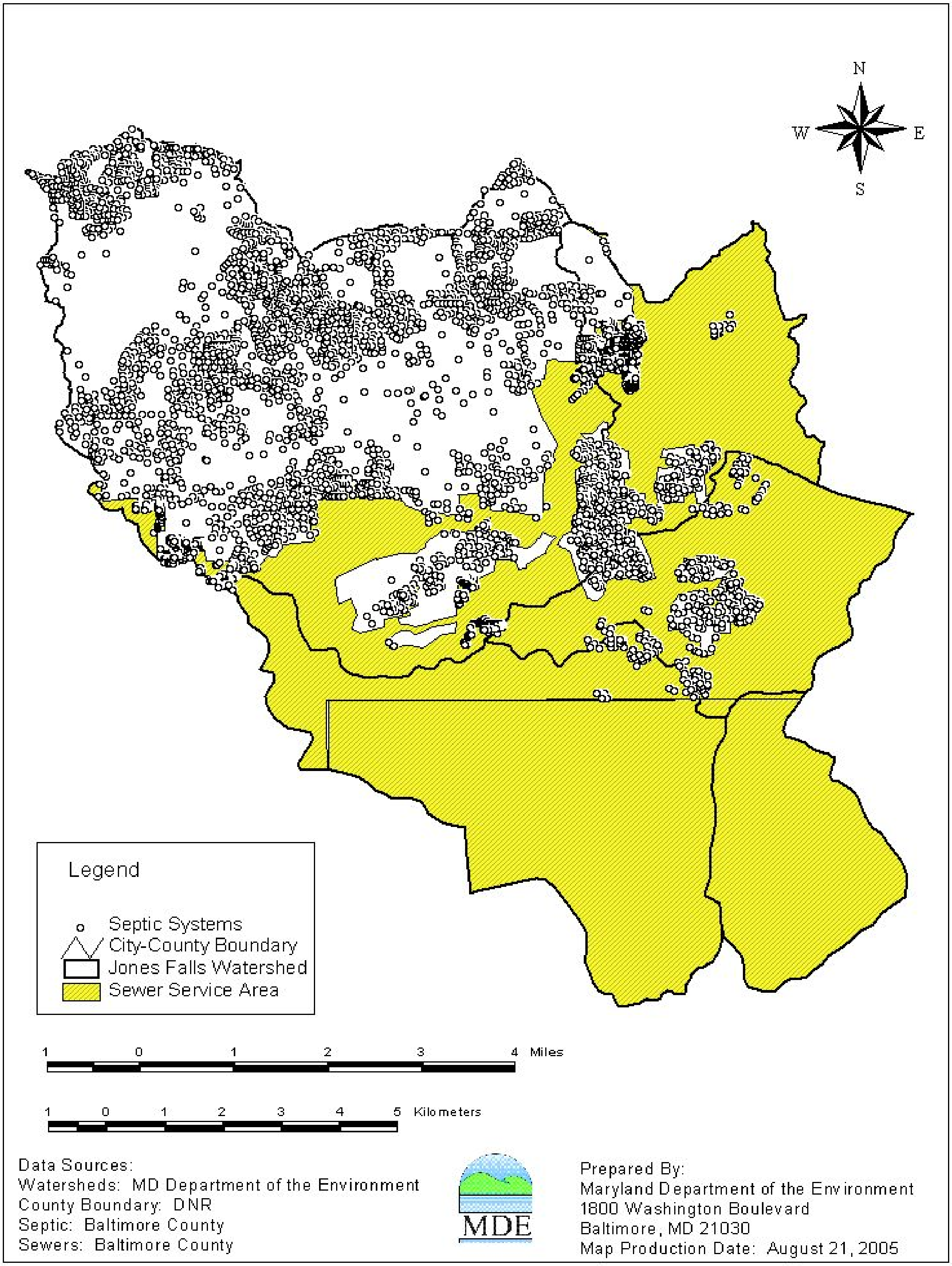

Figure 2.4.1: Sanitary Sewer Service Area and Septics in the Jones Falls Watershed

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 Stormwater Systems (MS4)

The Jones Falls 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 higher in Jones Falls during dry weather than during wet weather, because the wastewater is exfiltrating (seeping) into the stream.

Sanitary 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, 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 to 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.

[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 64 SSO events reported between October 2002 and October 2003. Approximately 454,066 gallons of SSO discharge were released through various waterways (surface water, groundwater, sanitary sewers, *etc*.) in the Jones Falls mainstem and tributaries (MDE, Water Management Administration). Figure 2.4.2 depicts the location where SSOs occurred between October 2002 and 2003 in the Jones Falls watershed.

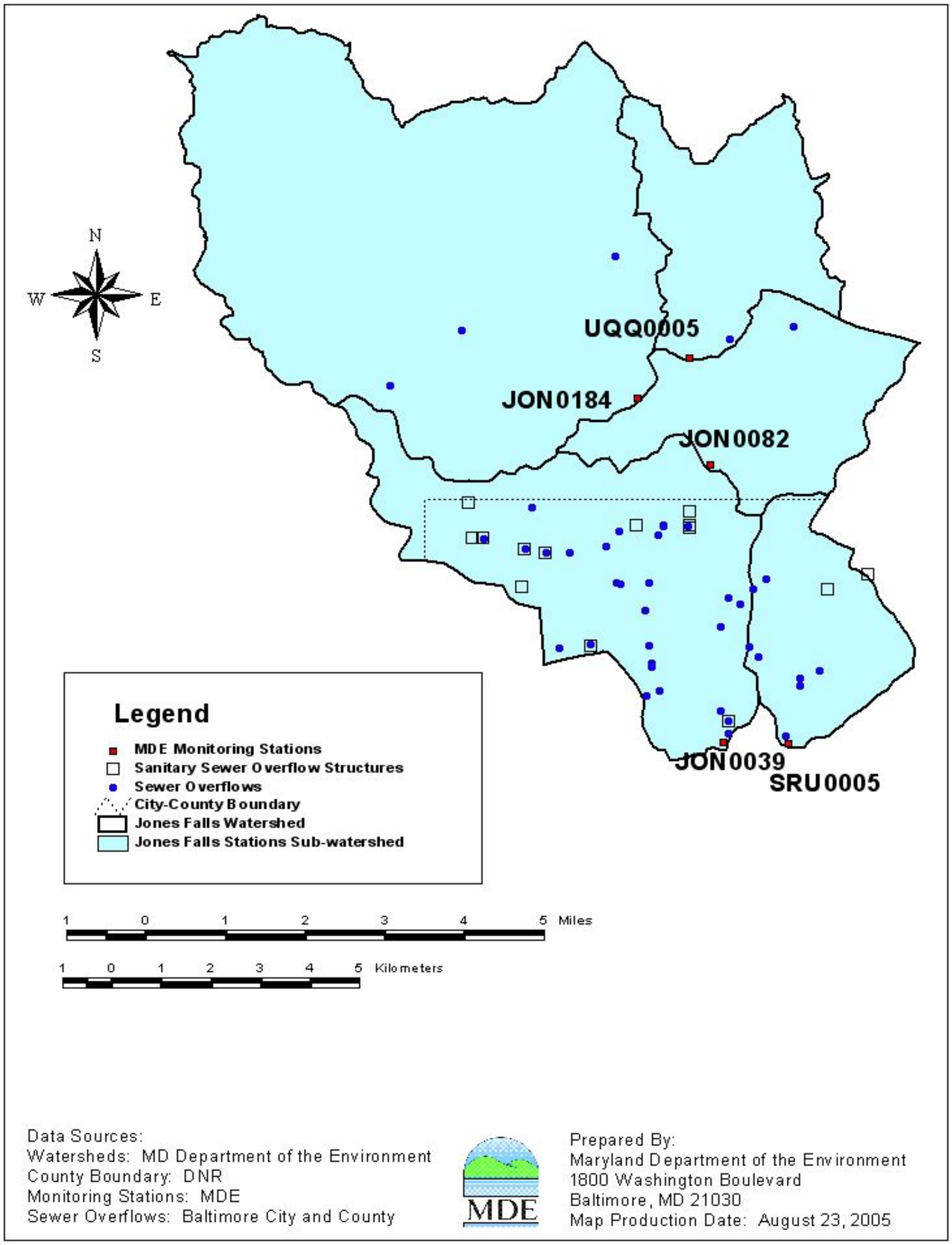

Figure 2.4.2: Location of Sanitary Sewer Overflows in the Jones Falls Watershed

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 Jones Falls 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 17 sewer overflow structures. Table 2.4.2 and Figure 2.4.3 display the location of CSO and SSO structures which discharge into the Jones Falls and its tributaries.

Table 2.4.2: Sanitary and Combined Sewer Overflow Structures in the Jones Falls Watershed

Treatment Plant	NPDES ID	CSO/SSO Structure ID	Type	Latitude	Longitude	Receiving Water
Back River WWTP	MD0021555	20	SSO	39.372	-76.701	Western Run
		21	SSO	39.365	-76.700	Western Run
		22	SSO	39.365	-76.697	Western Run
		23	SSO	39.363	-76.688	Western Run
		24	SSO	39.362	-76.683	Western Run
		29	SSO	39.367	-76.662	Western Run
		31	SSO	39.356	-76.688	Western Run
		32	SSO	39.353	-76.693	Western Run
		33	SSO	39.367	-76.649	Jones Falls
		34	SSO	39.367	-76.649	Jones Falls
		36	SSO	39.370	-76.649	Jones Falls
		67	SSO	39.313	-76.622	Jones Falls
		68	SSO	39.311	-76.621	Jones Falls
		69	SSO	39.307	-76.618	Jones Falls
		72	SSO	39.305	-76.611	Jones Falls
		125	SSO	39.308	-76.618	Jones Falls
		129	SSO	39.355	-76.617	Stoney Run

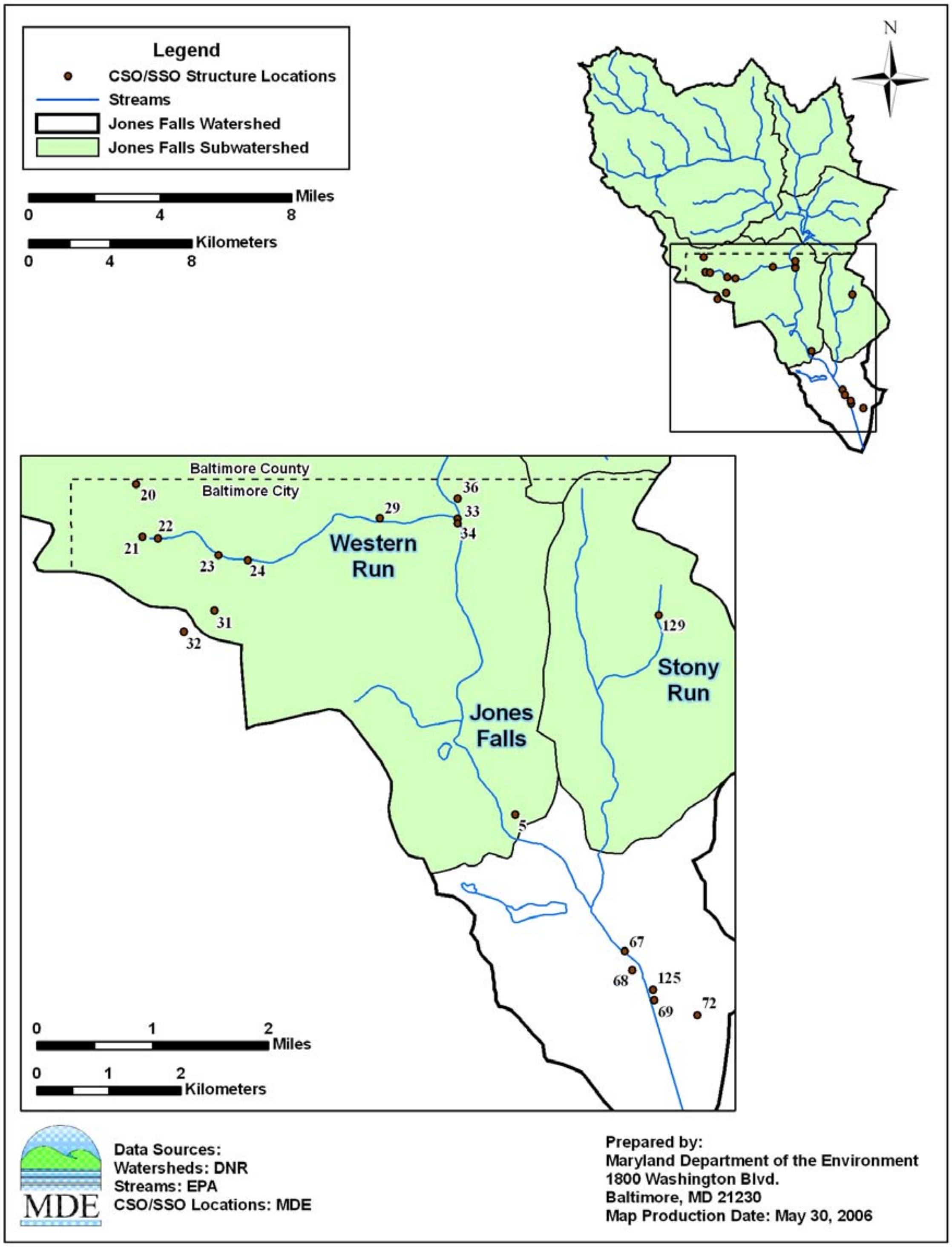

Figure 2.4.3: Sanitary and Combined Sewer Overflows Structures in the Jones Falls Watershed

Municipal and Industrial WWTPs

Based on the point source permitting information, there are seven NPDES industrial WWTPs in the watershed but none of them are permitted to discharge fecal bacteria into Jones Falls. There are two NPDES municipal point source facilities with permits regulating the discharge of fecal bacteria directly into the Jones Falls watershed: Villa Julie College and St. Timothy's School (Table 2.4.3 and Figure 2.4.4). The St. Timothy's School NPDES WWTP has a current permit, but the company managing the plant has informed MDE that the WWTP will be connected to the Baltimore County collection system by the end of July 2006 (Telephone conversation with Mr. Robert Corn, Miller Environmental Services, June 2006).

Table 2.4.3: NPDES municipal WWTPs with permits regulating the discharge of fecal bacteria directly in the Jones Falls Watershed (02-13-09-04)

Permittee	NPDES Permit No.	County	Average Annual Flow (MGD)	Average Annual Fecal Coliform Concentrations (MPN/100ml)	Fecal Coliform Load Per Day (Billion MPN/day)
Villa Julie WWTP	MD0066001	Baltimore County	0.0078	14.50	0.0043
St. Timothy's School WWTP	MD0056103	Baltimore County	0.0053	48.14	0.0097

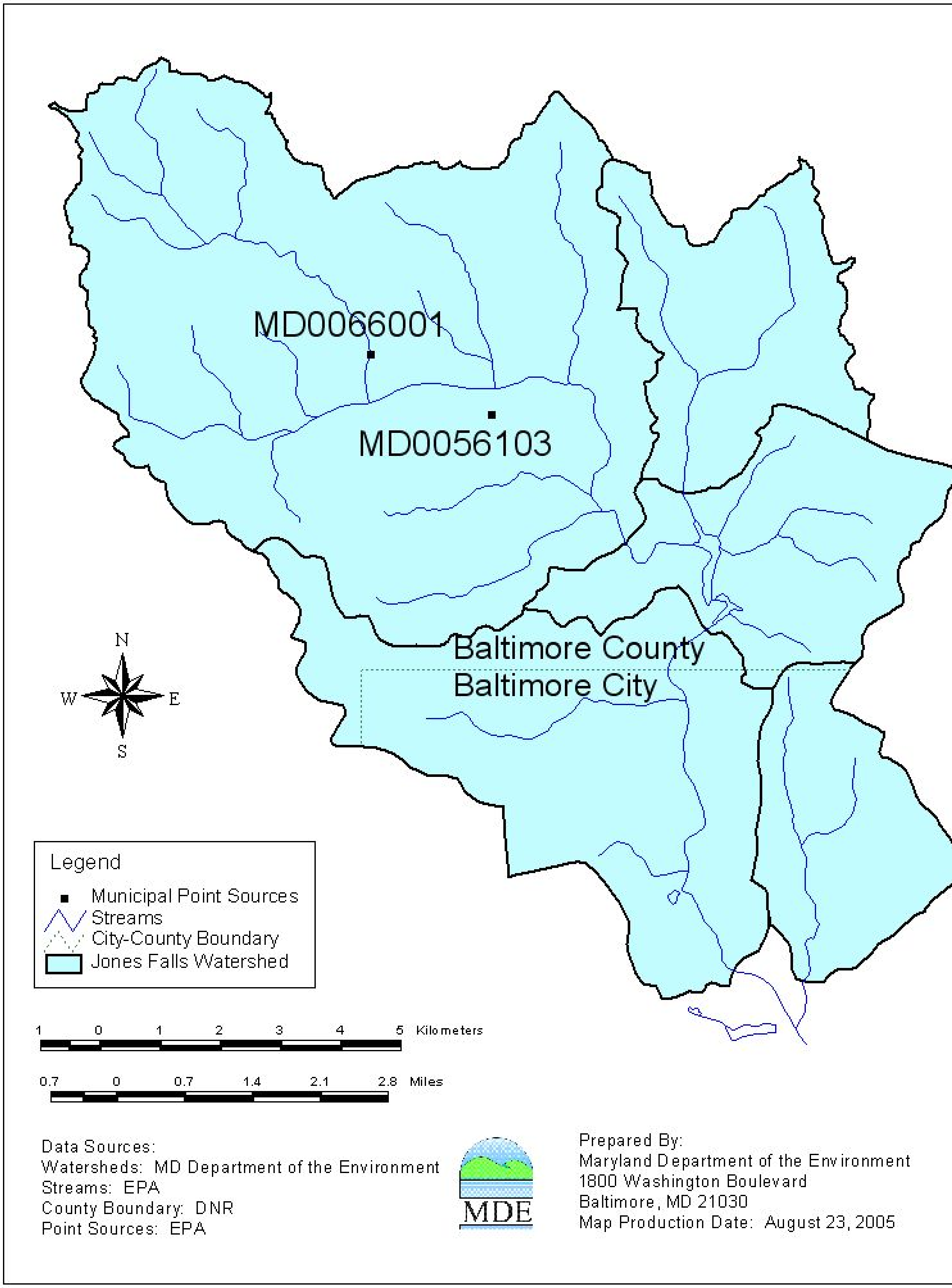

Figure 2.4.4: NPDES WWTPs with Permits Regulating the Discharge of Fecal Bacteria in the Jones Falls Watershed

Bacteria Source Tracking

Bacteria source tracking (BST) was used to identify the relative contribution of bacteria from different sources in in-stream water samples. BST Monitoring was conducted at four stations throughout the Jones falls 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 log10 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 Tables 2.4.4 and 2.4.5. Details of the BST data can be found in Appendix C.

Table 2.4.4: Distribution of Fecal Bacteria Source Loads in the Jones Falls Watershed for the Average Annual Period

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
UQQ0005	High Flow	16	40	14	7	23
	Low Flow	14	67	4	4	12
	Weighted	14	60	6	5	15
SRU0005	High Flow	9	74	3	1	13
	Low Flow	11	57	4	1	27
	Weighted	10	61	4	1	23
JON0184	High Flow	16	44	17	9	14
	Low Flow	26	46	13	2	12
	Weighted	24	45	14	4	13
JON0082	High Flow	9	56	13	3	20
	Low Flow	23	44	10	4	19
	Weighted	19	48	11	4	19
JON0039	High Flow	20	62	2	1	15
	Low Flow	17	58	10	4	11
	Weighted	17	59	8	3	12

Table 2.4.5: Distribution of Fecal Bacteria Source Loads in the Jones Falls Watershed for the Seasonal Period (May 1st – September 30th)

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
UQQ0005	High Flow	17	45	14	6	17
	Low Flow	14	66	4	4	13
	Weighted	15	61	7	4	14
SRU0005	High Flow	15	73	6	0	6
	Low Flow	10	67	8	1	14
	Weighted	11	68	7	1	12
JON0184	High Flow	19	53	15	8	4
	Low Flow	28	45	11	1	14
	Weighted	26	47	13	3	11
JON0082	High Flow	13	66	7	2	11
	Low Flow	20	52	11	2	13
	Weighted	18	56	10	2	13
JON0039	High Flow	23	55	3	0	18
	Low Flow	21	51	12	4	12
	Weighted	22	52	10	3	13

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 Jones Falls 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 on 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 (EPA, 1985), and the second (Method 9223B) is a statistical estimate of the number of colonies (APHA, 1998.) Enumeration results indicate the extreme variability in the 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 be problematic due to the many assumptions required and the limited available data. For example, when considering septic systems, information is required on spatial location of failing septic systems, consideration of transport to in-stream assessment location and estimation of the load from the septic system (degree of failure). Secondary sources, such as illicit discharges, also add to the uncertainty in a bacteria water quality model.

Estimating domestic animal sources requires information regarding the pet population in a watershed, how often the owners clean up after them, and the spatial location of the pet waste relative to the stream (near-field for upland transport). Livestock sources are limited by spatial resolution of Agricultural Census information (available at the county level), site-specific issues relating to animals' confinement, and confidentiality of data related to the development of Nutrient Management Plans. The most uncertain source category is wildlife. In an urban environment, this can result from the increased deer populations near streams to rat populations in storm sewers. In rural areas, estimation of wildlife populations and habitat locations in a watershed is required.

MDE appreciates the inherent uncertainty in developing traditional water quality models for the calculation of bacteria TMDLs. Traditional water quality modeling is very expensive and time consuming and, as identified, contains many potential uncertainties. MDE believes it should be reserved for specific constituents and complex situations. In this TMDL, MDE applies an analytical method which, when combined with BST analysis, appears to provide reasonable results (Cleland, 2003). Using this approach, Maryland can address more impaired streams in the same time period than by using the traditional water quality modeling methods.

4.2 Analysis Framework

This TMDL analysis uses flow duration curves to identify flow intervals that are indicators of hydrological conditions (*i.e.*, annual average, critical conditions). As explained previously, this analytical method, combined with water quality monitoring data and BST provides a better description of water quality and 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.

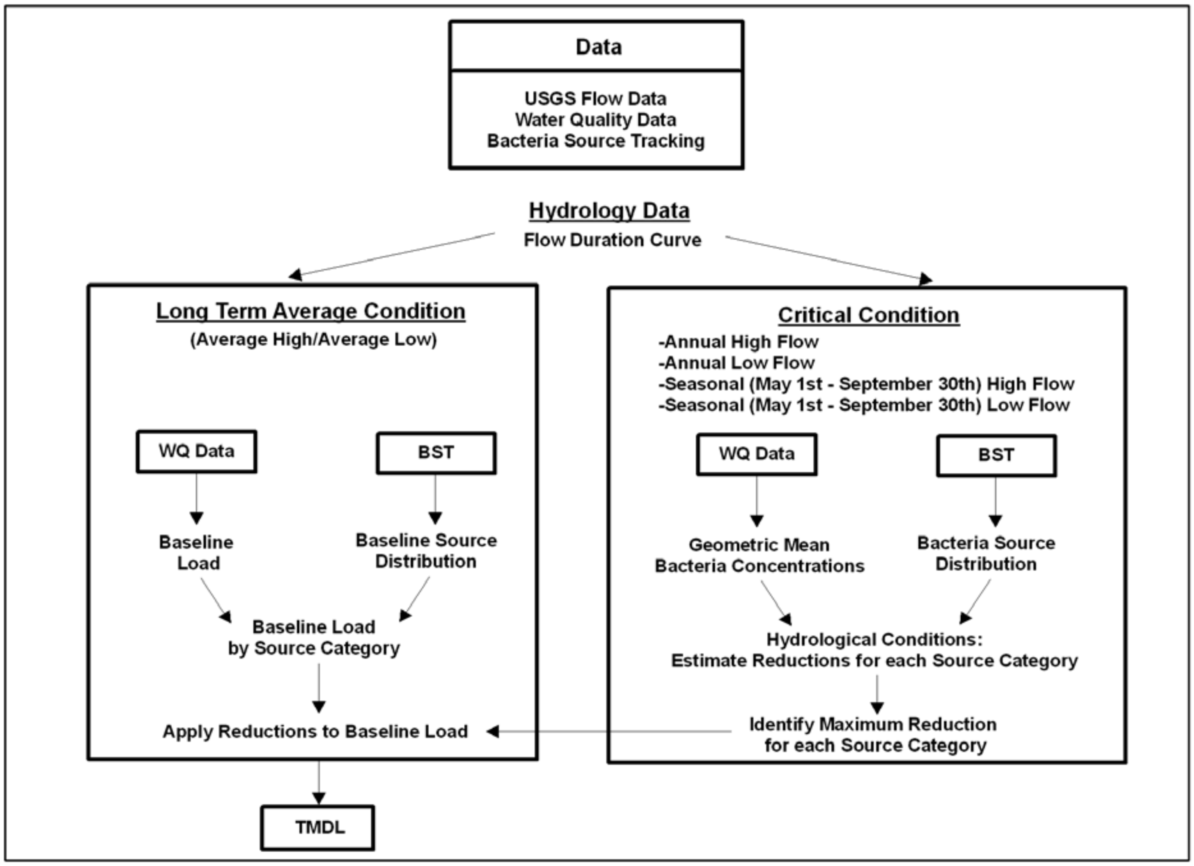

Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analysis Framework

4.3 Estimating Baseline Loads

Baseline loads estimated in this TMDL analysis are reported as long-term average 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 smearing 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:

$F_1 = A_i / C_i$ (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, since nearby long-term flow monitoring data are available.

The loads for each stratum are estimated as follows:

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

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 MPN/day (2.4466x107)

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

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

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

In the Jones Falls 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		JON0184	UQQ0005	JON0082sub	JON0039sub	SRU0005
Area (mi^2)		26.03	5.81	6.43	11.79	4.53
High Flow	**Daily Average Flow (cfs)**	80.9	18.1	20.0	77.8	17.8
	***E. coli* Concentration (MPN/100ml)**	532.6	592.9	2,952.6	5,211.2	4,544.6
	Bias Correction Factor	12.0	4.7	6.7	3.6	3.0
Low Flow	**Daily Average Flow (cfs)**	19.1	4.4	4.9	5.5	3.1
	***E. coli* Concentration (MPN/100ml)**	254.5	357.7	637.2	1,270.6	1,931.5
	Bias Correction Factor	1.6	2.0	5.7	1.8	2.3
Baseline Load (Billion *E. coli* MPN/day)		3,305	367	2,431	9,152	1,744

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. For stations JON0082 and JON0039, there is an upstream monitoring station (Figure 4.3.1). The subwatersheds were defined with the extension sub to the station name (e.g., JON0082sub, JON0039sub) and the total baseline loads from the upstream watersheds, estimated from the monitoring data, were multiplied by a transport factor derived from first order decay. The decay factor for *E. coli* used in the analysis was obtained from the study "Pathogen Decay in Urban Waters" by Easton *et al* (2001), and was estimated by linear regression of counts of microorganisms versus time (Die-off plots). The estimated transported loads were then subtracted from the downstream cumulative load to estimate the adjacent subwatershed load.

The general equation for the flow mass balance is:

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

where

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

and the general equations for bacteria loading mass balance:

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

where

C_{us} = Upstream bacteria concentration
k = Bacteria (*E. coli*) decay coefficient (1/day) = 0.762 day^{-1}
t = travel time from upstream watershed to outlet
C_{sub} = Subwatershed bacteria concentration
C_{ds} = Downstream bacteria concentration

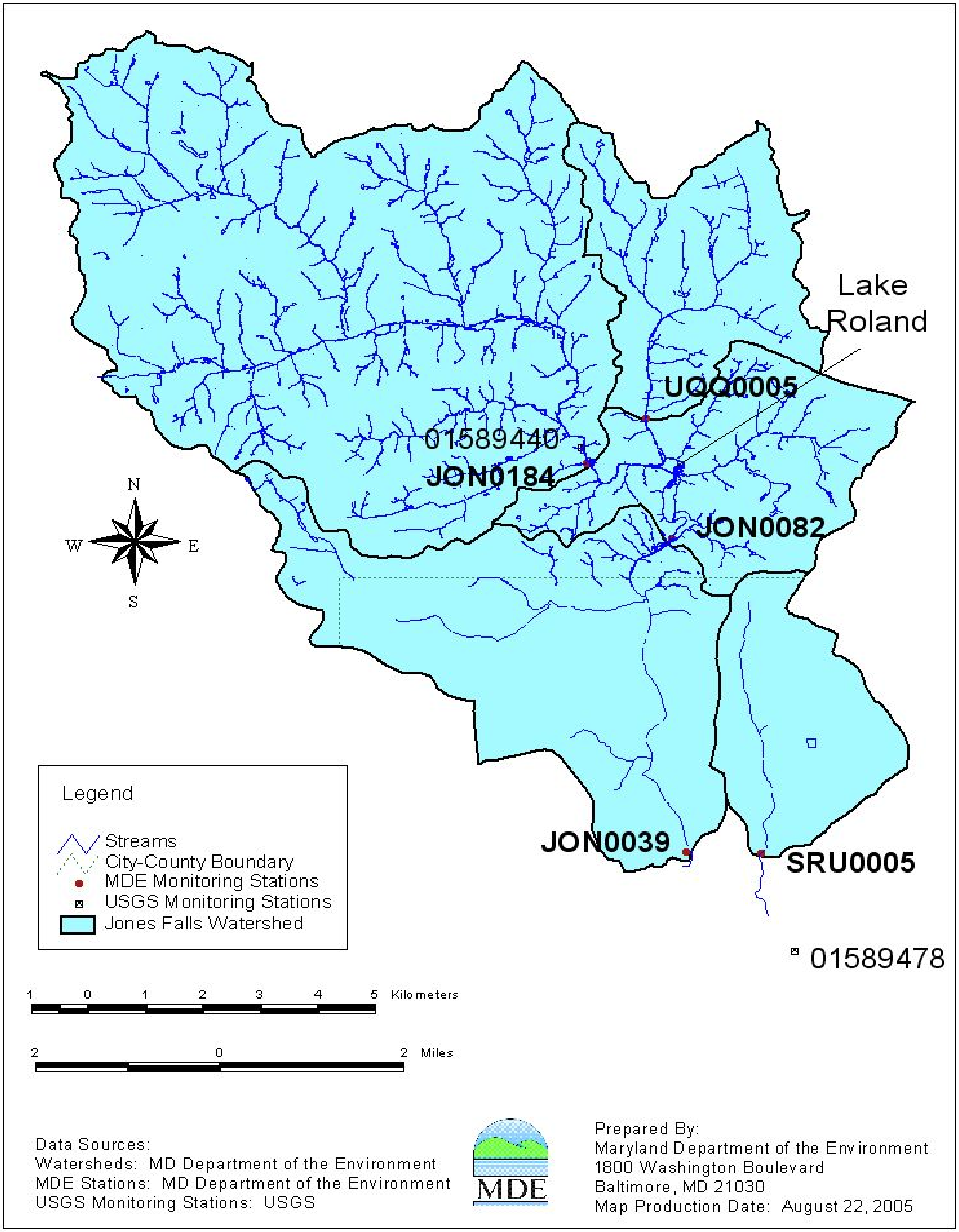

Figure 4.3.1: Monitoring Stations and Subwatersheds in the Jones Falls Watershed

The concentrations in the subwatersheds were estimated by considering the ratio of high flow concentration to low flow concentrations in the upstream watersheds. If the total load and average flow were used to estimate the geometric mean concentration, this estimated concentration would be biased if there was a correlation with flow and concentration. For example, in two strata, the steady-state geometric mean is estimated as follows:

$$L = (Q_{high} * W_{high} * C_{high}) + (Q_{low} * W_{low} * C_{low}) \quad (10)$$

L = Average Load
Q_i = Average flow for stratum i
W_i= Proportion of stratum i
C_i = Concentration for stratum i
n_i = number of samples in stratum i

The load in equation (10) is based on two concentrations and therefore when using the mass balance approach and the total load, this results in two unknowns, C_{high} and C_{low}, within one equation. Thus a relationship between C_{high} and C_{low}, must be estimated to solve for the concentration in both strata. This relationship is estimated using the average of the ratios estimated from the monitoring data in the upstream watersheds. Using this relationship, the following two equations result:

$$C_{low} = \frac{L}{Q_{high} * R * W_{high} + Q_{low} * W_{low}} \quad (11)$$

where

$$R = \frac{C_{high}}{C_{low}} \quad (12)$$

and the final geometric mean concentration is estimated as follows:

$$GM = 10^{W_{high} \log_{10}(C_{high}) + W_{low} \log_{10}(C_{low})} \quad (13)$$

Source estimates from the bacteria source tracking analysis are completed for each station and are based on the contribution from the upstream watershed, if applicable. Given the uncertainty of in-stream bacteria processes and the complexity involved in back-calculating an accurate source transport factor, the sources for JON0082sub, and JON0039sub were assigned from the analysis for JON0082, and JON0039, respectively.

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 15-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 Jones Falls 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	JON0184, UQQ0005, JON0082sub	0.80	0.20	April 1996 to March 1997
				JON0039sub, SRU0005	0.59	0.41	April 1996 to March 1997
	Low	365 days	All	JON0184, UQQ0005, JON0082sub	0.02	0.98	September 2001 to August 2002
				JON0039sub, SRU0005	0.08	0.92	August 2001 to July 2002
Seasonal	High	May 1st – Sept 30th	May 1st – Sept 30th	JON0184, UQQ0005, JON0082sub	0.78	0.22	May 1st, 1996 to September 30th, 1996
				JON0039sub, SRU0005	0.53	0.47	May 1st 2003 to September 30th, 2003
	Low	May 1st – Sept 30th	May 1st – Sept 30th	JON0184, UQQ0005, JON0082sub	0.01	0.99	May 1st, 2002 to September 30th, 2002
				JON0039sub, SRU0005	0.10	0.90	May 1st 1997 to September 30th, 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 Jones Falls 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 %
JON0184	Annual	High flow	58.0%	98.0%	60.1%	0.0%
		Low flow	0.0%	98.0%	16.9%	0.0%
	Seasonal	High flow	97.7%	98.0%	90.1%	0.0%
		Low flow	49.1%	98.0%	64.6%	0.0%
	Maximum Source Reduction		97.7%	98.0%	90.1%	0.0%
UQQ0005	Annual	High flow	89.9%	98.0%	78.3%	0.0%
		Low flow	0.0%	86.2%	0.0%	0.0%
	Seasonal	High flow	96.6%	98.0%	90.8%	0.0%
		Low flow	60.1%	98.0%	70.7%	0.0%
	Maximum Source Reduction		96.6%	98.0%	90.8%	0.0%
JON0082sub	Annual	High flow	98.0%	98.0%	98.0%	11.1%
		Low flow	69.6%	98.0%	72.6%	0.0%
	Seasonal	High flow	98.0%	98.0%	98.0%	42.5%
		Low flow	73.4%	98.0%	74.1%	0.0%
	Maximum Source Reduction		98.0%	98.0%	98.0%	42.5%
JON0039sub	Annual	High flow	98.0%	98.0%	98.0%	23.0%
		Low flow	84.5%	98.0%	98.0%	0.0%
	Seasonal	High flow	73.7%	98.0%	88.1%	0.0%
		Low flow	56.5%	98.0%	72.4%	0.0%
	Maximum Source Reduction		98.0%	98.0%	98.0%	23.0%
SRU0005	Annual	High flow	89.5%	98.0%	98.0%	0.0%
		Low flow	77.4%	98.0%	98.0%	0.0%
	Seasonal	High flow	98.0%	98.0%	98.0%	75.7%
		Low flow	98.0%	98.0%	98.0%	38.3%
	Maximum Source Reduction		98.0%	98.0%	98.0%	75.7%

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, April 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 TMDL Loading Caps

The TMDL loading cap is an estimate of the assimilative capacity of the monitored watershed and is provided in MPN/day. The loading caps presented in this section are for the watersheds located upstream of monitoring stations JON0184, UQQ0005, JON0082, JON0039 and SRU0005.

The TMDL is based on a long-term average hydrological condition. Estimation of the TMDL requires knowledge of how the bacteria concentrations vary with flow rate or the flow duration interval. This concentration versus flow relationship is accounted for by using the strata defined on the flow duration curve.

The 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. The 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.

$$TMDL = L_b * (1 - R) \qquad (12)$$

where

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

The bacteria TMDLs for the subwatersheds are shown in Table 4.6.1

Table 4.6.1: Jones Falls Watershed TMDL Summary

Station	**Baseline Load *E. coli* (Billion MPN/day)**	**TMDL Load *E. coli* (Billion MPN/day)**	**% Target Reduction**
JON0184	3,305	250	92.4%
UQQ0005	367	29	92.1%
JON0082sub	2,431	115	95.3%
JON0039sub	9,152	428	95.3%
SRU0005	1,744	38	97.8%
Total	16,998	860	-

4.7 Scenario Descriptions

Source Distribution

The final source distribution is derived from the source proportions listed in Table 2.4.4. For the purposes of the TMDL analysis and allocations, the percentage of sources identified as "unknown" were removed and the known sources were then scaled up proportionally so that they totaled 100%. The source distribution used in this scenario is presented in Table 4.7.1.

Table 4.7.1: Baseline Loads Source Distributions

Station	Domestic		Human		Livestock		Wildlife	
	%	Load (Billion *E. coli* MPN/day)	%	Load (Billion *E. coli* MPN/day)	%	Load (Billion *E. coli* MPN/day)	%	Load (Billion *E. coli* MPN/day)
JON0184	27.4%	906.5	52.0%	1,719.2	16.3%	538.1	4.3%	141.5
UQQ0005	16.8%	61.6	70.5%	258.6	7.4%	27.1	5.3%	19.3
JON0082sub	24.1%	585.5	57.8%	1,404.7	13.2%	321.8	4.9%	118.7
JON0039sub	19.9%	1,816.7	67.5%	6,175.6	9.1%	832.3	3.6%	327.3
SRU0005	13.8%	240.4	80.1%	1,396.2	5.4%	94.1	0.7%	13.0

Practicable Reduction Targets

The maximum practicable reduction (MPR) for each of the four source categories is listed in Table 4.7.2. These values are based on 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 domestic WWTP is located in the upstream watershed, this is considered in the MPR so as to not violate the permitted loads. The domestic animal category includes sources from pets (*e.g.*, dogs) and the MPR is based on an estimated success of education and outreach programs.

Table 4.7.2: Maximum Practicable Reduction Targets

	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]

*Since much of the human sources in this watershed are due to infrastructure failure, correction of exfiltration required by a consent decree may result in greater reductions than in other watersheds.

[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 (EPA, 1999). The MPR to agricultural lands was based on sediment reductions identified by the EPA (EPA, 2004).

The practicable reduction scenario was developed based on an optimization analysis whereby a subjective estimate of risk was minimized, and constraints were set on maximum reduction and allowable background conditions. Risk was defined on a scale of one to five, where it was assumed that human sources had the highest risk (5), domestic animal and livestock next (3) and wildlife the lowest (1) (see Table 4.7.2). 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:

$$\text{Min} \sum_{i=1}^{4} (Ph*5 + Pd*3 + Pl*3 + Pw*1) \qquad i = \text{hydrological condition}$$

Subject to

C = Ccr
0 <= Rh <= 95%
0 <= Rl <= 75%
0 <= Rd <= 75%
Rw = 0
Ph, Pl, Pd, Pw >= 1%

Where

Ph = % human source in final allocation
Pd = % domestic animal source in final allocation
Pl = % livestock source in final allocation
Pw = % wildlife source in final allocation
C = In-stream concentration
Ccr = Water quality criterion
Rh = Reduction applied to human sources
Rl = Reduction applied to livestock sources
Rd = Reduction applied to domestic animal sources
Rw = Reduction applied to wildlife sources

In none of the subwatersheds could the constraints of this scenario be satisfied, indicating there was not a practicable solution. A summary of the analysis is presented in Table 4.7.3.

Table 4.7.3: Practicable Reduction Results

Station	Applied Reductions				WQS Achievable
	Domestic %	Human %	Livestock %	Wildlife %	
JON0184	75.0%	95.0%	75.0%	0.0%	No
UQQ0005	75.0%	95.0%	75.0%	0.0%	No
JON0082sub	75.0%	95.0%	75.0%	0.0%	No
JON0039sub	75.0%	95.0%	75.0%	0.0%	No
SRU0005	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 five subwatersheds where the water quality attainment was not achievable with the MPRs. In this subwatershed, 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 as follows:

$$\text{Min} \sum_{i=1}^{7} (Ph*5 + Pd*3 + Pl*3 + Pw*1) \qquad i = \text{hydrological condition}$$

Subject to

C = Ccr
0 <= Rh <= 98%
0 <= Rl <= 98%
0 <= Rd <= 98%
0 <= Rw <= 98%
Ph, Pl, Pd, Pw >= 1%

Where

Ph = % human source in final allocation
Pd = % domestic animal source in final allocation
Pl = % livestock source in final allocation
Pw = % wildlife source in final allocation
C = In-stream concentration
Ccr = Water quality criterion
Rh = Reduction applied to human sources
Rl = Reduction applied to livestock sources
Rd = Reduction applied to domestic animal sources
Rw = Reduction applied to wildlife sources

The summary of the analysis is presented in Table 4.7.4.

Table 4.7.4: TMDL Reduction Results: Optimization Model Up to 98% Reduction

Station	Domestic %	Human %	Livestock %	Wildlife %	Target Reduction
JON0184	97.7%	98.0%	90.1%	0.0%	92.4%
UQQ0005	96.6%	98.0%	90.8%	0.0%	92.1%
JON0082sub	98.0%	98.0%	98.0%	42.5%	95.3%
JON0039sub	98.0%	98.0%	98.0%	23.0%	95.3%
SRU0005	98.0%	98.0%	98.0%	75.7%	97.8%

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 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.

Table 4.8.1: Potential Source Contributions for the Jones Falls TMDL Allocations

Allocation Category	LA	WLA		
		WWTPs	MS4s	CSOs
Human		X	X	
Domestic			X	
Livestock	X			
Wildlife	X		X	

Load Allocation (LA)

All four bacteria source categories could contribute to nonpoint source loads (LA). For the human sources, the nonpoint source contribution (LA) in subwatersheds with WWTPs and CSOs is estimated by subtracting the WWTP (if applicable) and CSO loads (if applicable) from the final human load. There are two NPDES WWTPs in subwatershed JON0184, but only one will receive a WLA. There are no subwatersheds in the Jones Falls watershed with assigned NPDES CSS WLA.

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 Jones Falls watershed is covered by NPDES MS4 permits, bacteria loads from domestic animal sources are assigned to WLA-MS4 in all five subwatersheds of Jones Falls. 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 MS4 Phase I and Phase II permits are point sources subject to WLA assignment in the TMDL. Quantification of rainfall-driven nonpoint source loads 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 lumped into a single WLA-MS4 load. In watersheds with no existing individual MS4 permits, these loads will be included in the LA.

The jurisdictions within the Jones Falls 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 LAs accordingly. Note that the overall reductions in the TMDL will not change. 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/day)**		
	Baltimore City	Baltimore County	Total
JON0184	N/A	127.95	127.95
UQQ0005	N/A	23.44	23.44
JON0082sub	N/A	89.84	89.84
JON0039sub	278.24	92.75	370.99
SRU0005	35.70	N/A	35.70
Total	313.94	333.98	647.92

N/A – not applicable – subwatersheds within the County or the City only

Municipal and Industrial WWTPs

As explained in the source assessment section above, there are no industrial WWTPs with permits regulating the discharge of bacteria into Jones Falls. There are two municipal WWTPs with permits regulating the discharge of bacteria directly into the Jones Falls watershed. Only

Villa Julie College WWTP will receive a WLA. St. Timothy's WWTP will be connected to the Baltimore County collection system by the end of July 2006 and therefore it will not receive an allocation. This allocation is derived from the human source load and it is based on the permitted flow of the plant and the *E. coli* criterion concentration.

Combined Sewer Systems

There are two jurisdictions with NPDES CSSs within the Jones Falls watershed (See section 2.4, Source Assessment, for more detailed information). These jurisdictions with CSOs permitted to discharge in the Jones Falls have developed their Long Term Control Plans (LTCP), which state that CSOs are to be eliminated by the dates noted in the LTCPs. Therefore, no load will be assigned to WLA-CSOs in these jurisdictions and the final human load in the corresponding subwatersheds is allocated to the WLA-MS4.

4.9 Summary

The TMDLs for the Jones Falls subwatersheds are presented in Table 4.9.1.

Table 4.9.1: Jones Falls Watershed TMDL

Subwatershed	**TMDL**	**LA**	**WLA WWTP**	**WLA MS4**	**WLA CSOs**
	Billion MPN *E. coli*/day				
JON0184	250.16	122.17	0.05	127.95	0.0
UQQ0005	29.07	5.62	0.00	23.44	0.0
JON0082sub	114.54	24.70	0.00	89.84	0.0
JON0039sub	428.36	57.37	0.00	370.99	0.0
SRU0005	37.77	2.07	0.00	35.70	0.0
TOTAL	859.90	211.93	0.05	647.92	0.0

In all five 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 Jones Falls watershed, the TMDL analysis indicates that reduction of fecal bacteria loads from all sources including wildlife are beyond the maximum practicable reduction (MPR) targets. Jones Falls 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 Jones Falls 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 Jones Falls 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 Long Term Control Plan (“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 Jones Falls 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.

REFERENCES

American Public Health Association, American Water Works Association, and Water Environment Federation, 1998, Standard methods for the examination of water and wastewater (20th ed.): Washington, D.C., American Public Health Association

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

Coastal Environmental Services. Patapsco/Baltimore Harbor Watershed Study: Ambient Conditions, Pollutant Loads and Recommendation for Further Action. Prepared for Maryland Department of the Environment, Coastal Environmental Services, Inc., Linthicum, MD. 1995.

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

Code of Maryland Regulations (COMAR), 26.08.02.03-3A(1). Bacteriological Criteria for Use I, III, IV-P Waters, Website http://www.dsd.state.md.us/comar/26/26.08.02.03-3.htm., last visited 4/15/06.

Code of Maryland Regulations (COMAR), 26.08.02.08 K(3)(e) & (5)(e). Stream Segment Designations, Website http://www.dsd.state.md.us/comar/26/26.08.02.08.htm, last visited 4/15/06.

Code of Maryland Regulations (COMAR), 26.08.10. Overflows or Bypasses, Website http://www.dsd.state.md.us/comar/26/26.08.02.08.htm, last visited 4/15/06.

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

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

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

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

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

Maryland Department of the Environment. Patapsco/Back River Watershed SWMM Model Report. June 2002.

Maryland Department of the Environment. Managing Maryland for Results. July 2005.

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

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

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

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

U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS). Soil Survey of Baltimore County, MD, 1977.

U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS). State Soil Geographic (STATSGO) DataBase. 1995.

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

U.S. Environmental Protection Agency and Maryland Department of the Environment v. Mayor and City Council of Baltimore, Consolidated Case Number: JFM-02-12524, Consent Decree (entered Sept. 30, 2002).

U.S. Environmental Protection Agency and Maryland Department of the Environment v. Baltimore County, Consolidated Case Number: AMD-05-2028, Consent Decree (entered Sept. 20, 2006).

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

U.S. Environmental Protection Agency. Ambient Water Quality Criteria for Bacteria-1986, EPA-440/5-84-002. 1986.

U.S. Environmental Protection Agency. Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLAs) for Storm Water Sources and NPDES Permit Requirements Based on Those WLAs. Washington, DC. November 2002.

U.S. Environmental Protection Agency. Guidance for water quality-based decisions: The TMDL Process, EPA 440/4-91-001. Washington, DC. 1991.

U.S. Environmental Protection Agency, Office of Water. Bacteria Indicator Tool User's Guide. EPA-823-B-01-003. 2000.

U.S. Environmental Protection Agency. Protocol for developing Pathogen TMDLs, EPA 841-R-00-002, Office of Water (4503F). Washington, DC. 134pp. 2001.

U.S. Environmental Protection Agency. National Recommended Water Quality Criteria: 2002. EPA-822-R-02-047. November 2002.

U.S. Environmental Protection Agency, Office of Water. Implementation Guidance for Ambient Water Quality Criteria for Bacteria. EPA-823-B-02-003. Washington, D.C. 2003.

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

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	E. Coli MPN/100ml
JON0039	10/08/2002	98.7882	160
JON0039	10/22/2002	90.3286	200
JON0039	11/13/2002	23.1182	3870
JON0039	11/25/2002	72.6870	70
JON0039	12/03/2002	78.2568	3260
JON0039	12/17/2002	43.8592	1670
JON0039	01/07/2003	26.1244	930
JON0039	01/22/2003	61.2212	2100
JON0039	02/04/2003	17.9212	24190
JON0039	03/04/2003	17.1988	4350
JON0039	03/18/2003	20.9275	8160
JON0039	04/22/2003	33.9082	350
JON0039	05/06/2003	33.9082	400
JON0039	05/20/2003	28.3151	490
JON0039	06/03/2003	17.9212	1670
JON0039	06/17/2003	17.5950	260
JON0039	06/24/2003	18.4106	540
JON0039	07/08/2003	30.9252	400
JON0039	07/22/2003	14.6586	210
JON0039	08/05/2003	39.3381	2050
JON0039	08/19/2003	54.3696	190
JON0039	08/26/2003	38.4759	140
JON0039	09/09/2003	59.6364	230
JON0039	09/23/2003	0.0932	43500
JON0082	10/08/2002	98.5318	30
JON0082	10/22/2002	93.9408	80
JON0082	11/13/2002	37.5670	3450
JON0082	11/25/2002	70.5197	10
JON0082	12/03/2002	77.6742	20
JON0082	12/17/2002	42.6474	200
JON0082	01/07/2003	30.6688	170

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	E. Coli MPN/100ml
JON0082	01/22/2003	63.1554	10
JON0082	02/04/2003	38.9187	30
JON0082	03/04/2003	17.2221	800
JON0082	03/18/2003	19.7856	40
JON0082	04/22/2003	33.1857	30
JON0082	05/06/2003	37.5670	30
JON0082	05/20/2003	26.8702	240
JON0082	06/03/2003	18.6903	570
JON0082	06/17/2003	23.1881	230
JON0082	06/24/2003	14.3323	590
JON0082	07/08/2003	29.2007	3260
JON0082	07/22/2003	50.1282	10
JON0082	08/05/2003	45.2575	930
JON0082	08/19/2003	54.3696	160
JON0082	08/26/2003	54.3696	40
JON0082	09/09/2003	57.0030	100
JON0082	09/23/2003	0.1398	22800
JON0184	10/08/2002	98.5318	380
JON0184	10/22/2002	93.9408	210
JON0184	11/13/2002	37.5670	1260
JON0184	11/25/2002	70.5197	40
JON0184	12/03/2002	77.6742	130
JON0184	12/17/2002	42.6474	150
JON0184	01/07/2003	30.6688	110
JON0184	01/22/2003	63.1554	50
JON0184	02/04/2003	38.9187	130
JON0184	03/04/2003	17.2221	100
JON0184	03/18/2003	19.7856	40
JON0184	04/22/2003	33.1857	90
JON0184	05/06/2003	37.5670	150
JON0184	05/20/2003	26.8702	310
JON0184	06/03/2003	18.6903	420
JON0184	06/17/2003	23.1881	610

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	E. Coli MPN/100ml
JON0184	06/24/2003	14.3323	610
JON0184	07/08/2003	29.2007	1210
JON0184	07/22/2003	50.1282	1190
JON0184	08/05/2003	45.2575	490
JON0184	08/19/2003	54.3696	610
JON0184	08/26/2003	54.3696	510
JON0184	09/09/2003	57.0030	390
JON0184	09/23/2003	0.1398	36500
SRU0005	10/08/2002	98.7882	2850
SRU0005	10/22/2002	90.3286	1790
SRU0005	11/13/2002	23.1182	1480
SRU0005	11/25/2002	72.6870	1200
SRU0005	12/03/2002	78.2568	5790
SRU0005	12/17/2002	43.8592	750
SRU0005	01/07/2003	26.1244	340
SRU0005	01/22/2003	61.2212	240
SRU0005	02/04/2003	17.9212	24190
SRU0005	03/04/2003	17.1988	450
SRU0005	03/18/2003	20.9275	820
SRU0005	04/22/2003	33.9082	19860
SRU0005	05/06/2003	33.9082	1370
SRU0005	05/20/2003	28.3151	1390
SRU0005	06/03/2003	17.9212	750
SRU0005	06/17/2003	17.5950	7270
SRU0005	06/24/2003	18.4106	8660
SRU0005	07/08/2003	30.9252	1940
SRU0005	07/22/2003	14.6586	24190
SRU0005	08/05/2003	39.3381	2760
SRU0005	08/19/2003	54.3696	24190
SRU0005	08/26/2003	38.4759	530
SRU0005	09/09/2003	59.6364	3450
SRU0005	09/23/2003	0.0932	54800
UQQ0005	10/08/2002	98.5318	210

SAMPLING STATION IDENTIFIER	Date	Daily flow frequency	E. Coli MPN/100ml
UQQ0005	10/22/2002	93.9408	290
UQQ0005	11/13/2002	37.5670	500
UQQ0005	11/25/2002	70.5197	60
UQQ0005	12/03/2002	77.6742	130
UQQ0005	12/17/2002	42.6474	150
UQQ0005	01/07/2003	30.6688	90
UQQ0005	01/22/2003	63.1554	30
UQQ0005	02/04/2003	38.9187	2050
UQQ0005	03/04/2003	17.2221	40
UQQ0005	03/18/2003	19.7856	310
UQQ0005	04/22/2003	33.1857	140
UQQ0005	05/06/2003	37.5670	300
UQQ0005	05/20/2003	26.8702	730
UQQ0005	06/03/2003	18.6903	460
UQQ0005	06/17/2003	23.1881	460
UQQ0005	06/24/2003	14.3323	1150
UQQ0005	07/08/2003	29.2007	2600
UQQ0005	07/22/2003	50.1282	1720
UQQ0005	08/05/2003	45.2575	1780
UQQ0005	08/19/2003	54.3696	1080
UQQ0005	08/26/2003	54.3696	590
UQQ0005	09/09/2003	57.0030	300
UQQ0005	09/23/2003	0.1398	14400

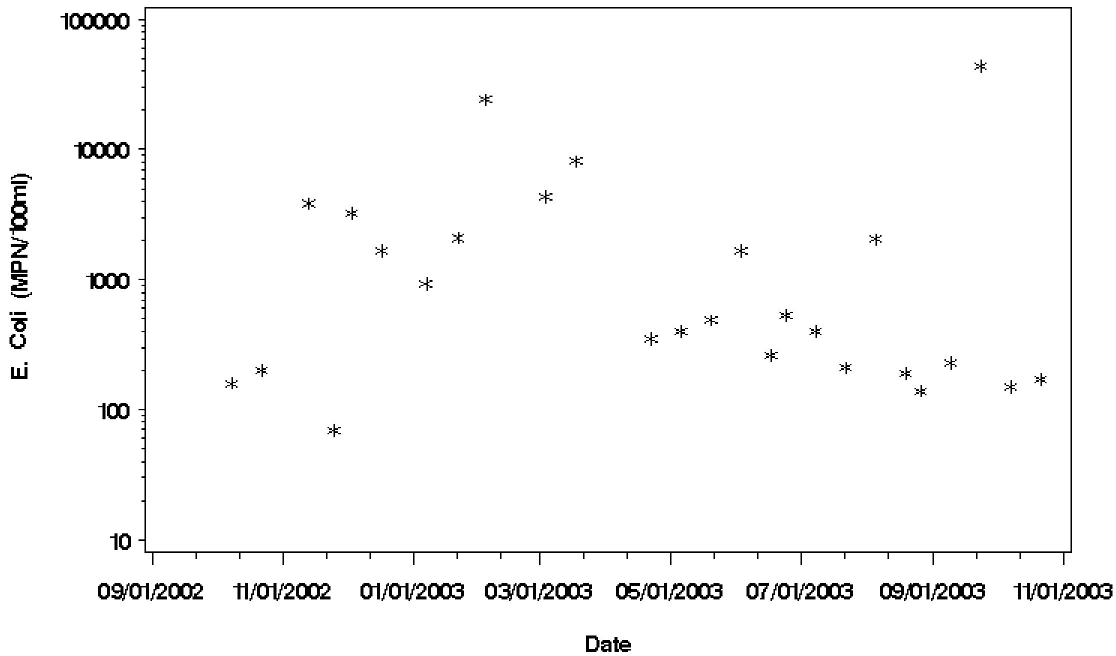

Figure A-1: *E. coli* Concentration vs. Time for Jones Falls Monitoring Station JON0039

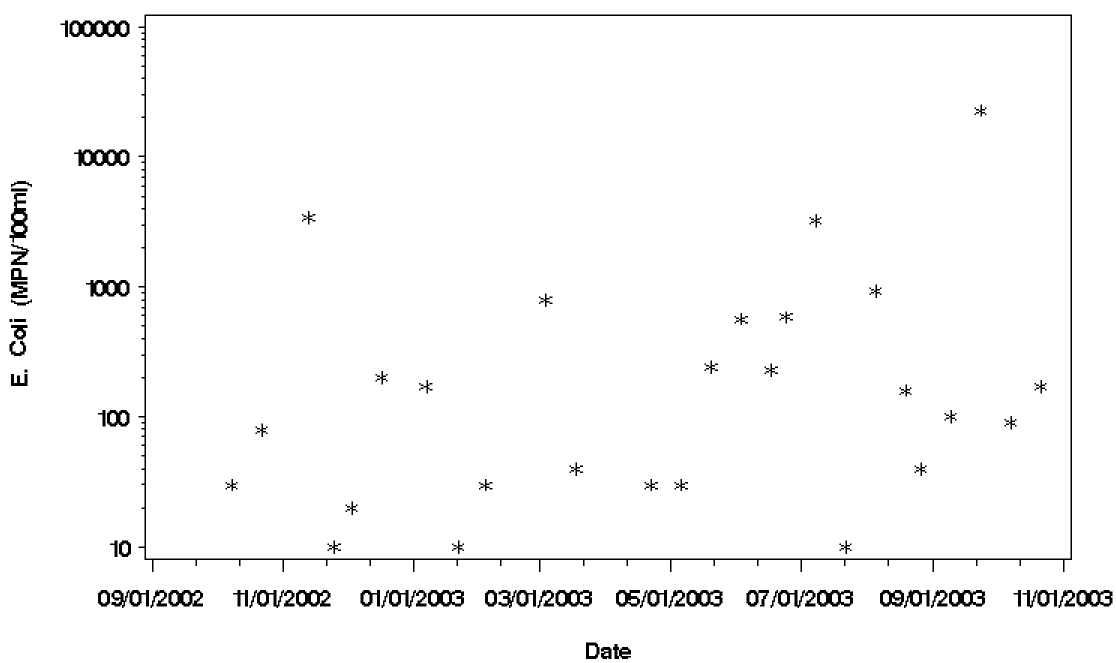

Figure A-2: *E. coli* Concentration vs. Time for Jones Falls Monitoring Station JON0082

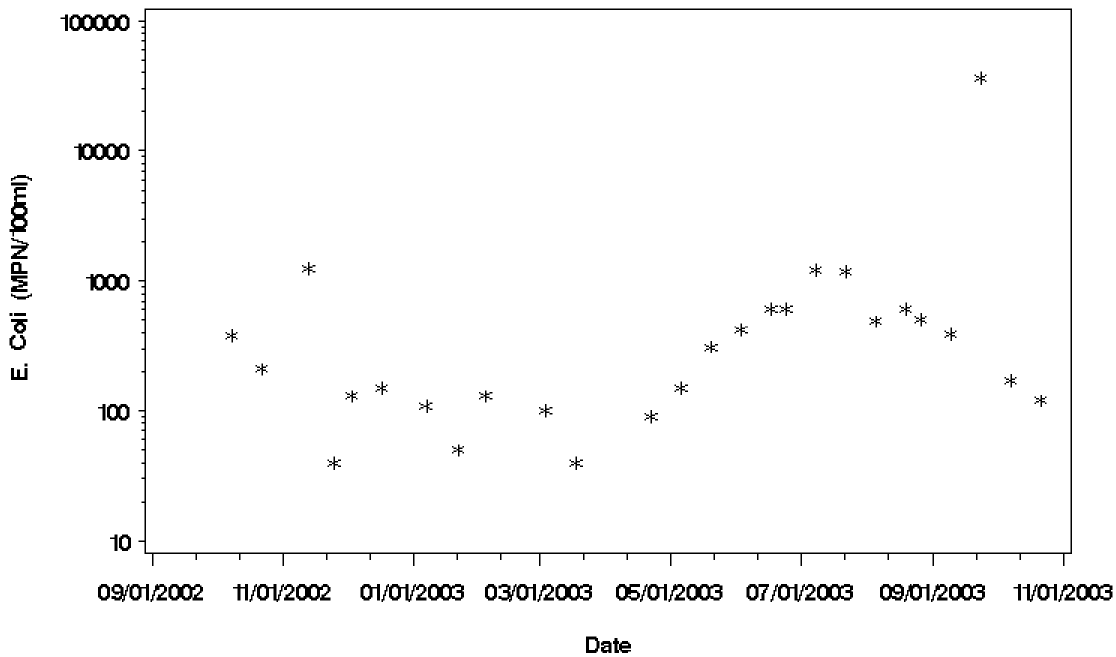

Figure A-3: *E. coli* Concentration vs. Time for Jones Falls Monitoring Station JON0184

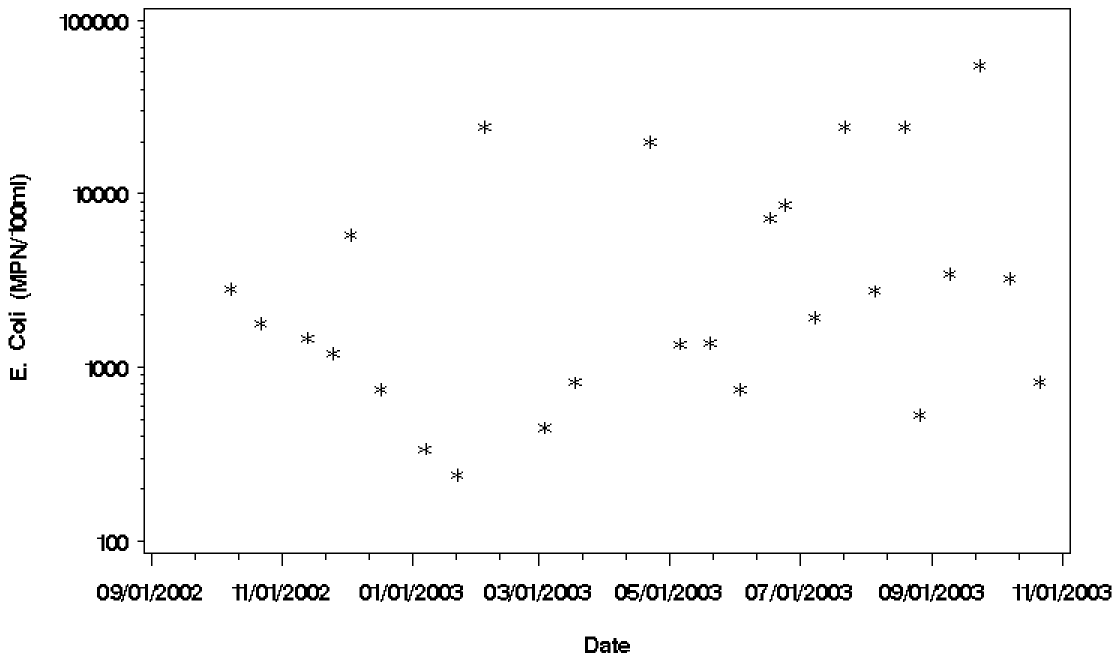

Figure A-4: *E. coli* Concentration vs. Time for Jones Falls Monitoring Station SRU0005

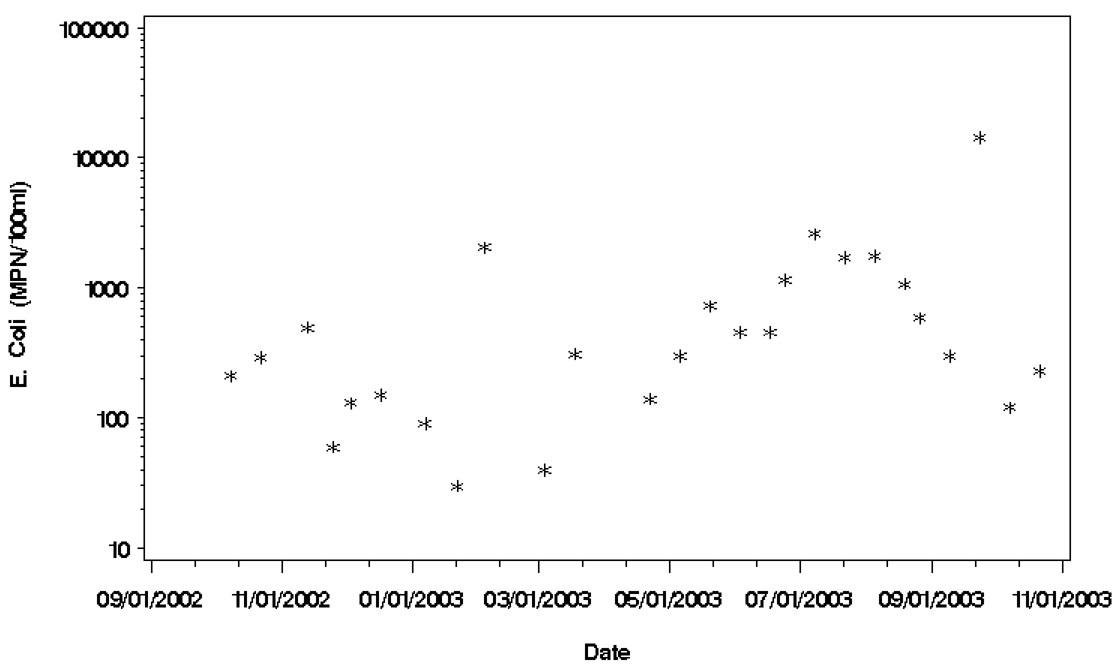

Figure A-5: *E. coli* Concentration vs. Time for Jones Falls Monitoring Station UQQ0005

Appendix B - Flow Duration Curve Analysis to Define Strata

The Jones Falls 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

The Jones Falls Watershed has two active USGS flow gages, 1589440 and 1589478. The gage and dates of information used are as follows:

Table B-1: USGS Gages in the Jones Falls Watershed

USGS Gage #	Dates used	Description
1589440	October 1, 1992 – September 30, 2003	Jones Falls at Sorrento, MD
1589478	December 26, 1999 – September 30, 2003 (SWWM model substituted for 1991 thru 12/25/1999).	Jones Falls at Maryland Avenue, Baltimore, MD

Flow duration curves for these gages are presented in Figure B-1.

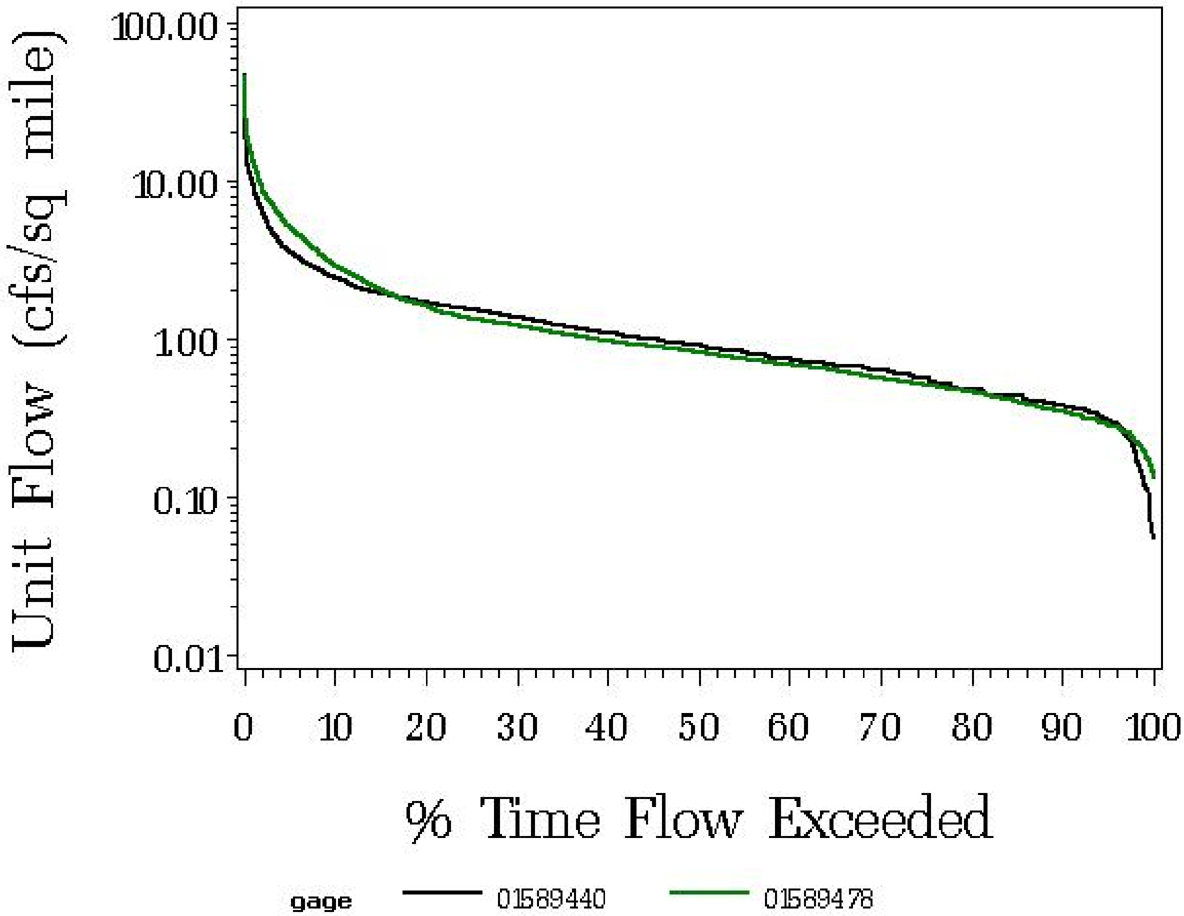

Figure B-1: Jones Falls Flow Duration Curves

Based on the long-term flow data for the Jones Falls watershed and other watersheds in the region (*i.e.* Gwynns Falls and Herring Run), 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 Jones Falls *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 Jones Falls, 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
Annual	High	365 days	All	JON0184, UQQ0005, JON0082sub	0.80	0.20
				JON0039sub, SRU0005	0.59	0.41
	Low	365 days	All	JON0184, UQQ0005, JON0082sub	0.02	0.98
				JON0039sub, SRU0005	0.08	0.92
Seasonal	High	May 1st – Sept 30th	May 1st – Sept 30th	JON0184, UQQ0005, JON0082sub	0.78	0.22
				JON0039sub, SRU0005	0.53	0.47
	Low	May 1st – Sept 30th	May 1st – Sept 30th	JON0184, UQQ0005, JON0082sub	0.01	0.99
				JON0039sub, SRU0005	0.10	0.90

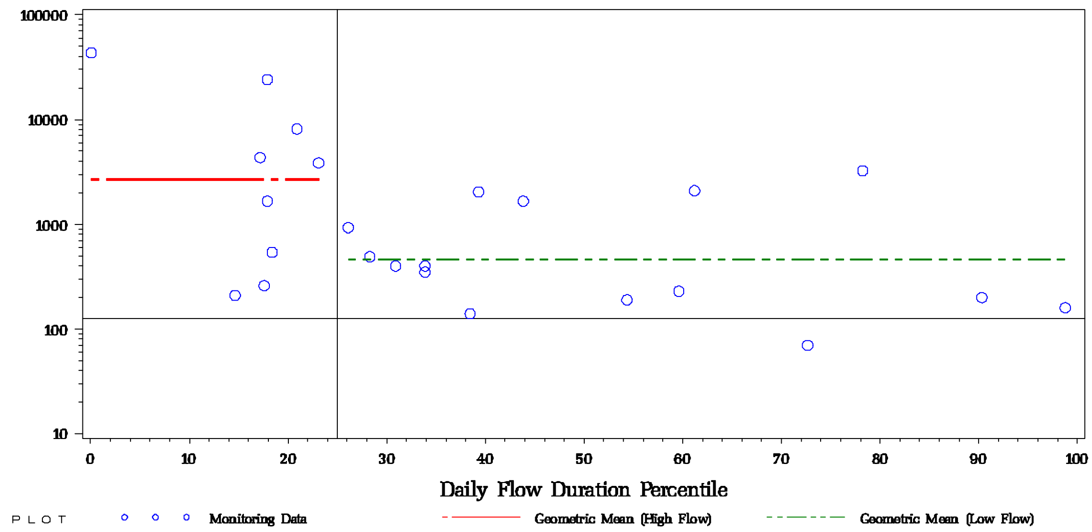

Figure B-2: *E. coli* Concentration vs. Flow Duration for Jones Falls Monitoring Station JON0039 (Average Annual Condition)

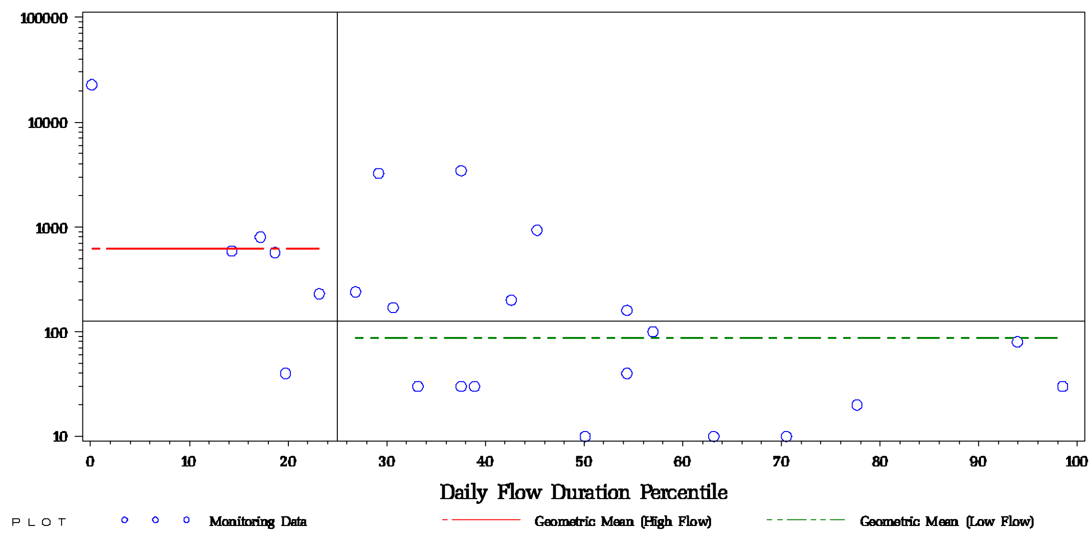

Figure B-3: *E. coli* Concentration vs. Flow Duration for Jones Falls Monitoring Station JON0082 (Average Annual Condition)

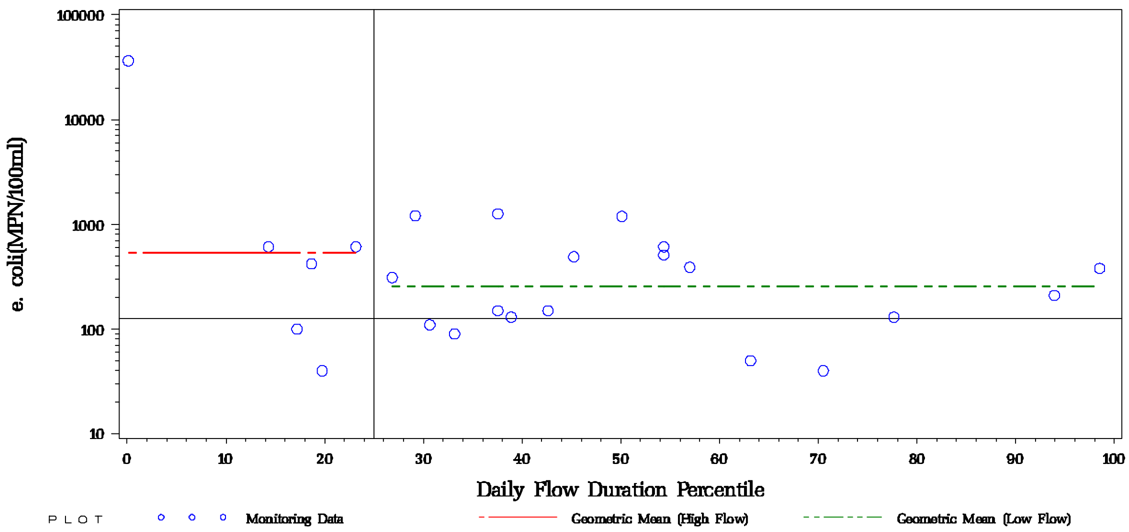

Figure B-4: *E. coli* Concentration vs. Flow Duration for Jones Falls Monitoring Station JON0184 (Average Annual Condition)

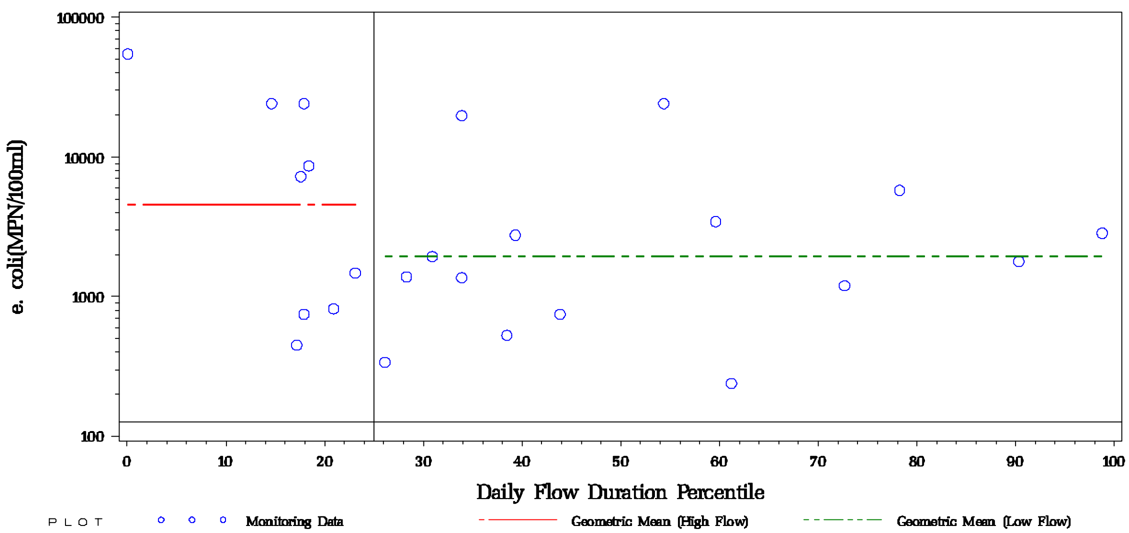

Figure B-5: *E. coli* Concentration vs. Flow Duration for Jones Falls Monitoring Station SRU0005 (Average Annual Condition)

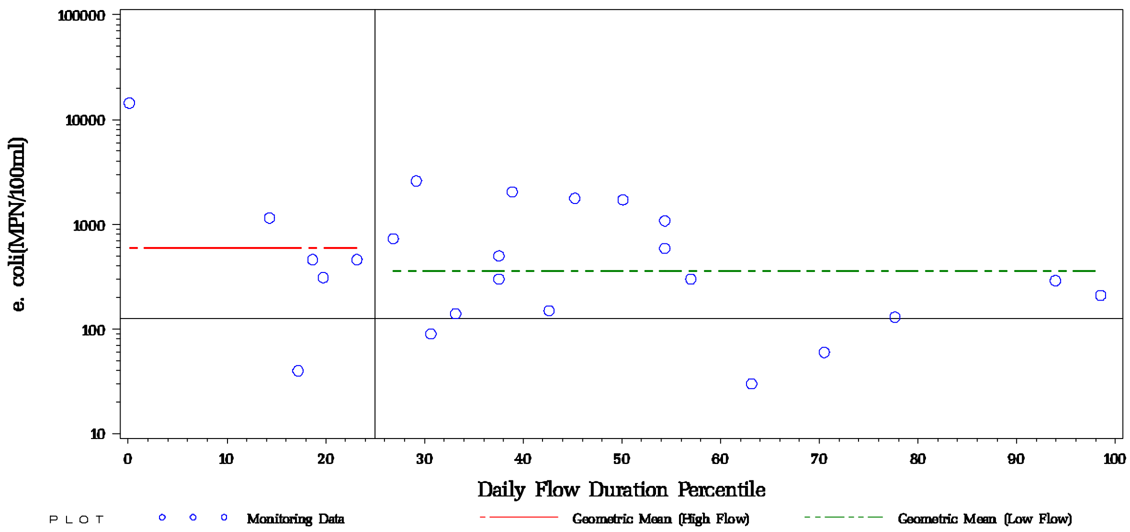

Figure B-6: *E. coli* Concentration vs. Flow Duration for Jones Falls Monitoring Station UQQ0005 (Average Annual Condition)

Appendix C - Identifying Sources of Fecal Pollution in 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. Also included in the study was the Patuxent River Watershed shellfish harvesting area. The methodology used was the ARA with *Enterococcus* spp. as the indicator organism. Previous BST publications have demonstrated the predictive value of using this particular technique and indicator organism (Hagedorn, 1999; Wiggins, 1999). A pilot study using PFGE, a genotypic BST method, was used on a subset of known-source isolates collected from the Patuxent River Watershed.

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

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

LABORATORY METHODS

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

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. A combined library of known sources was used for Georges Creek and Wills Creek Watersheds using patterns from scat obtained from both watersheds, and the water isolate patterns of each were compared to the combined library.

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).

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

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.

ARA Results: Jones Falls Watershed

Known-Source Library. The 982 known-source isolates in the library were grouped into four categories: pet (specifically dog), human, livestock (horse), and wildlife (deer, fox, goose) (Tables 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 was determined. From these results, the percent unknown and percent correct classification (RCCs) was calculated (Table C-3).

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

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

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

Category	Potential Sources	Total Isolates	Unique Patterns
Pet	dog	144	68
Human	human	438	266
Livestock	horse	107	42
Wildlife	deer, fox, goose,	293	85
Total		**982**	**461**

TableC-3: Jones Falls. 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%	68%
.375	0	0%	68%
.50	128	13%	71%
.60	194	20%	72%
.70	521	53%	81%
.80	668	68%	90%
.90	855	87%	98%

A cutoff probability of 0.60 (60%) was shown to yield an ARCC of 72%. An increase to a 0.70 (70%) 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 0.60 (60%), the 194 isolates that were not useful in the prediction of probable sources were removed, leaving 788 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 Jones Falls Watershed. The rates of correct classification for the four categories of sources in the library, at a 0.60 (60%) cutoff, are shown in Table C-4 below.

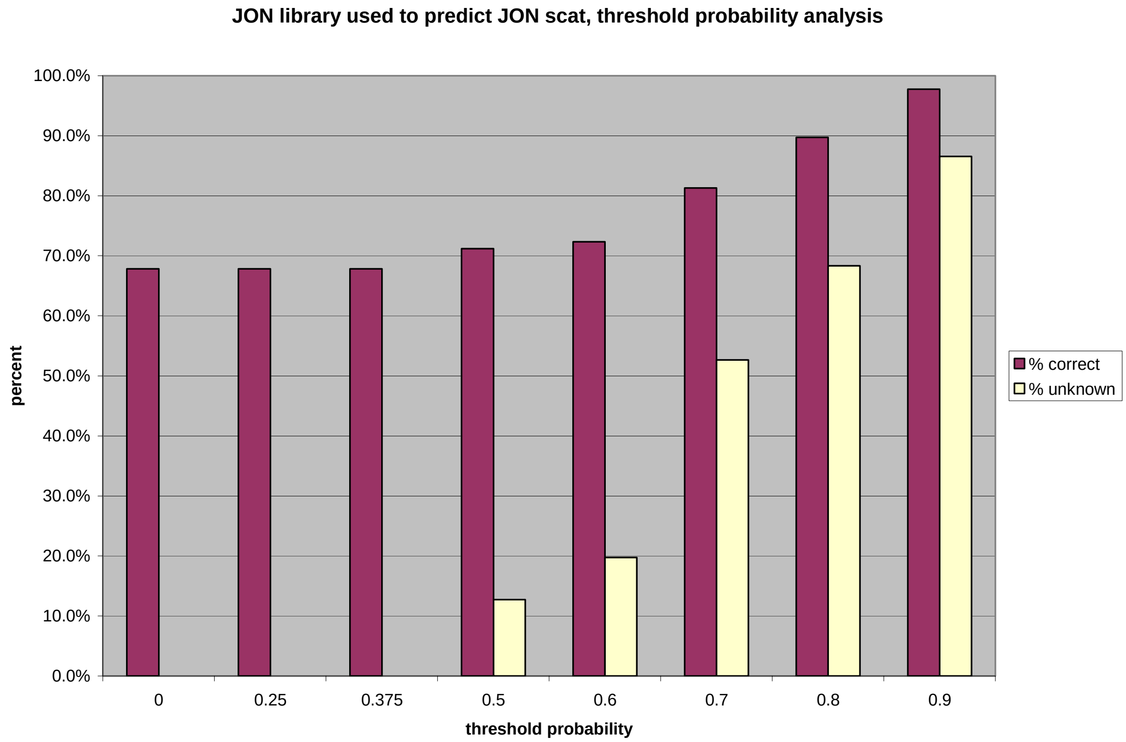

Figure C-1: Jones Falls. Classification Model: Percent Correct versus Percent Unknown.

Table C-4: Jones Falls. Actual species categories versus predicted categories, at a 60% probability cutoff, with rates of correct classification (RCC) for each category

			Predicted →			
Actual ↓	HUMAN	LIVESTOCK	PET	WILDLIFE	TOTAL	RCC[1]
HUMAN	**291**	16	37	20	364	80%
LIVESTOCK	5	**77**	2	7	91	85%
PET	8	5	**107**	3	123	87%
WILDLIFE	19	79	17	**95**	210	45%
Total	**323**	**177**	**163**	**125**	**788**	**72%**

[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%.

Jones Falls Water Samples. Monthly monitoring from five (5) stations on Jones Falls 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 1402 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicates that 85% of the water isolates were classified after excluding unknowns when using a 0.60 (60%) probability cutoff.

Table C-5: Jones Falls. Potential host sources of water isolates by species category, number of isolates, percent isolates classified at cutoff probability of 60%.

Category	Number	% Isolates Classified 60% Prob.	% Isolates Classified (excluding unknowns)
DOMESTIC	231	16%	19%
HUMAN	771	55%	65%
LIVESTOCK	137	10%	12%
WILDLIFE	48	3%	4%
UNKNOWN	215		
Missing Data	0		
Total	1402		
% Classified	**85%**		

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

Table C-6: Jones Falls. *Enterococcus* isolates obtained from water collected during the fall, winter, spring, and summer seasons for each of the five (5) monitoring stations.

Station	Spring	Summer	Fall	Winter	Total
JON0039	72	68	76	70	**286**
JON0082	60	51	88	72	**271**
JON0184	72	69	70	71	**282**
SRU0005	69	66	94	55	**284**
UQQ0005	70	66	89	54	**279**
Total	**343**	**320**	**417**	**322**	**1402**

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

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

Date	Site	Human	Livestock	Pet	Wildlife	Unknown	Total
11/13/02	JON0039	10	1	7	1	5	24
11/13/02	JON0082	4	3	14	0	2	23
11/13/02	JON0184	8	3	10	0	2	23
11/13/02	SRU0005	17	0	2	0	3	22
11/13/02	UQQ0005	16	0	4	0	1	21
12/03/02	JON0039	13	3	2	1	5	24
12/03/02	JON0082	4	4	2	6	3	19
12/03/02	JON0184	4	10	4	1	4	23
12/03/02	SRU0005	13	0	2	0	9	24
12/03/02	UQQ0005	18	1	3	0	1	23
01/07/03	JON0039	15	2	4	1	1	23
01/07/03	JON0082	13	0	1	0	10	24
01/07/03	JON0184	12	3	3	1	5	24
01/07/03	SRU0005	0	0	1	0	4	5
01/07/03	UQQ0005	8	2	2	1	7	20
02/04/03	JON0039	21	0	1	0	2	24
02/04/03	JON0082	18	1	1	3	1	24
02/04/03	JON0184	21	0	3	0	0	24
02/04/03	SRU0005	16	0	1	0	7	24
02/04/03	UQQ0005	19	0	3	0	2	24
03/04/03	JON0039	15	0	5	1	2	23
03/04/03	JON0082	7	6	0	1	10	24
03/04/03	JON0184	3	5	1	3	11	23
03/04/03	SRU0005	23	1	0	1	1	26
03/04/03	UQQ0005	2	1	1	1	5	10
04/22/03	JON0039	21	0	2	0	1	24
04/22/03	JON0082	3	1	1	0	8	13
04/22/03	JON0184	11	2	7	2	2	24
04/22/03	SRU0005	15	0	3	0	6	24
04/22/03	UQQ0005	13	2	3	4	2	24
05/06/03	JON0039	15	2	1	2	4	24
05/06/03	JON0082	3	9	1	4	6	23
05/06/03	JON0184	13	8	2	1	0	24
05/06/03	SRU0005	17	0	1	1	4	23
05/06/03	UQQ0005	20	0	1	0	3	24
05/07/03	SRU0005	1	0	0	0	0	1
06/03/03	JON0039	15	2	1	0	6	24
06/03/03	JON0082	19	3	0	0	2	24
06/03/03	JON0184	14	3	4	0	3	24
06/03/03	SRU0005	13	2	4	0	2	21
06/03/03	UQQ0005	9	0	5	0	8	22
07/08/03	JON0039	19	0	4	0	1	24
07/08/03	JON0082	16	0	7	0	1	24

07/08/03	JON0184	11	0	10	0	3	24
07/08/03	SRU0005	11	1	6	0	5	23
07/08/03	UQQ0005	11	0	5	0	7	23
08/05/03	JON0039	11	0	11	0	2	24
08/05/03	JON0082	8	1	7	0	6	22
08/05/03	JON0184	7	2	8	0	5	22
08/05/03	SRU0005	17	0	0	0	3	20
08/05/03	UQQ0005	19	0	2	0	0	21
09/09/03	JON0039	3	9	2	2	4	20
09/09/03	JON0082	4	1	0	0	0	5
09/09/03	JON0184	12	2	5	0	4	23
09/09/03	SRU0005	14	6	2	0	1	23
09/09/03	UQQ0005	9	4	4	4	1	22
09/23/03	JON0039	11	0	8	0	3	22
09/23/03	JON0082	14	1	5	1	3	24
09/23/03	JON0184	12	4	5	3	0	24
09/23/03	SRU0005	19	1	3	0	1	24
09/23/03	UQQ0005	10	5	3	2	1	21
10/07/03	JON0039	0	3	0	0	3	6
10/07/03	JON0082	3	17	1	0	1	22
10/07/03	SRU0005	9	0	15	0	0	24
10/07/03	UQQ0005	19	0	5	0	0	24
Total		771	137	231	48	215	1402

Table C-8: Jones Falls. BST Analysis: Percentage of Sources per Station per Date.

Date	Site	human	livestock	pet	wildlife	unknown
11/13/02	JON0039	42%	4%	29%	4%	21%
11/13/02	JON0082	17%	13%	61%	0%	9%
11/13/02	JON0184	35%	13%	43%	0%	9%
11/13/02	SRU0005	77%	0%	9%	0%	14%
11/13/02	UQQ0005	76%	0%	19%	0%	5%
12/03/02	JON0039	54%	13%	8%	4%	21%
12/03/02	JON0082	21%	21%	11%	32%	16%
12/03/02	JON0184	17%	43%	17%	4%	17%
12/03/02	SRU0005	54%	0%	8%	0%	38%
12/03/02	UQQ0005	78%	4%	13%	0%	4%
01/07/03	JON0039	65%	9%	17%	4%	4%
01/07/03	JON0082	54%	0%	4%	0%	42%
01/07/03	JON0184	50%	13%	13%	4%	21%
01/07/03	SRU0005	0%	0%	20%	0%	80%
01/07/03	UQQ0005	40%	10%	10%	5%	35%
02/04/03	JON0039	88%	0%	4%	0%	8%
02/04/03	JON0082	75%	4%	4%	13%	4%
02/04/03	JON0184	88%	0%	13%	0%	0%

02/04/03	SRU0005	67%	0%	4%	0%	29%
02/04/03	UQQ0005	79%	0%	13%	0%	8%
03/04/03	JON0039	65%	0%	22%	4%	9%
03/04/03	JON0082	29%	25%	0%	4%	42%
03/04/03	JON0184	13%	22%	4%	13%	48%
03/04/03	SRU0005	88%	4%	0%	4%	4%
03/04/03	UQQ0005	20%	10%	10%	10%	50%
04/22/03	JON0039	88%	0%	8%	0%	4%
04/22/03	JON0082	23%	8%	8%	0%	62%
04/22/03	JON0184	46%	8%	29%	8%	8%
04/22/03	SRU0005	63%	0%	13%	0%	25%
04/22/03	UQQ0005	54%	8%	13%	17%	8%
05/06/03	JON0039	63%	8%	4%	8%	17%
05/06/03	JON0082	13%	39%	4%	17%	26%
05/06/03	JON0184	54%	33%	8%	4%	0%
05/06/03	SRU0005	74%	0%	4%	4%	17%
05/06/03	UQQ0005	83%	0%	4%	0%	13%
05/07/03	SRU0005	100%	0%	0%	0%	0%
06/03/03	JON0039	63%	8%	4%	0%	25%
06/03/03	JON0082	79%	13%	0%	0%	8%
06/03/03	JON0184	58%	13%	17%	0%	13%
06/03/03	SRU0005	62%	10%	19%	0%	10%
06/03/03	UQQ0005	41%	0%	23%	0%	36%
07/08/03	JON0039	79%	0%	17%	0%	4%
07/08/03	JON0082	67%	0%	29%	0%	4%
07/08/03	JON0184	46%	0%	42%	0%	13%
07/08/03	SRU0005	48%	4%	26%	0%	22%
07/08/03	UQQ0005	48%	0%	22%	0%	30%
08/05/03	JON0039	46%	0%	46%	0%	8%
08/05/03	JON0082	36%	5%	32%	0%	27%
08/05/03	JON0184	32%	9%	36%	0%	23%
08/05/03	SRU0005	85%	0%	0%	0%	15%
08/05/03	UQQ0005	90%	0%	10%	0%	0%
09/09/03	JON0039	15%	45%	10%	10%	20%
09/09/03	JON0082	80%	20%	0%	0%	0%
09/09/03	JON0184	52%	9%	22%	0%	17%
09/09/03	SRU0005	61%	26%	9%	0%	4%
09/09/03	UQQ0005	41%	18%	18%	18%	5%
09/23/03	JON0039	50%	0%	36%	0%	14%
09/23/03	JON0082	58%	4%	21%	4%	13%
09/23/03	JON0184	50%	17%	21%	13%	0%
09/23/03	SRU0005	79%	4%	13%	0%	4%
09/23/03	UQQ0005	48%	24%	14%	10%	5%
10/07/03	JON0039	0%	50%	0%	0%	50%
10/07/03	JON0082	14%	77%	5%	0%	5%
10/07/03	SRU0005	38%	0%	63%	0%	0%
10/07/03	UQQ0005	79%	0%	21%	0%	0%
Total		55%	10%	16%	3%	15%

Jones Falls Summary

The use of ARA was successful for identification of bacterial sources in the Jones Falls Watershed as evidenced by the acceptable ARCC (72%) for the library. With the exception of the RCC for wildlife (45%), the RCCs ranged from 80% to 87%. Although wildlife has a low RCC, there will be no remedial action taken for wildlife sources. When water isolates were compared to the library and potential sources predicted, 85% of the isolates were classified by statistical analysis. The largest category of potential sources in the watershed as a whole was human (65%), followed by pet and livestock, (19% and 12% of the classified isolates, respectively). Three percent (4%) of the water isolates were classified as from wildlife.

REFERENCES

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

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

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

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

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

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

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

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

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