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

FINAL

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

Submitted to:

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

September 2006

EPA Submittal Date: Sept. 9, 2006
EPA Approval Date: Dec. 4, 2007

Table of Contents

List of Figures

List of Tables

List of Abbreviations

APHA	American Public Health Association
ARCC	Average rates of correct classification
ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
CFU	Colony Forming Units
COMAR	Code of Maryland Regulations
CSO	Combined Sewer Overflow
CSS	Combined Sewer System
CWA	Clean Water Act
DNR	Department of Natural Resources
EPA	Environmental Protection Agency
GIS	Geographic Information System
LA	Load Allocation
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
RCC	Rates of Correct Classification
SSO	Sanitary Sewer Overflows
STATSGO	State Soil Geographic
TMDL	Total Maximum Daily Load
USDA	United States Department of Agriculture
USGS	United States Geological Survey
WQIA	Water Quality Improvement Act
WLA	Wasteload Allocation
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plan

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for fecal bacteria in the non-tidal portion of Gwynns Falls (basin number 02130905). 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 Gwynns Falls in the State of Maryland's 303(d) List as impaired by nutrients (1996), sediments (1996), bacteria (fecal coliform) (2002), and impacts to biological communities (2002). The designated uses for Gwynns Falls are as follows: Gwynns Falls and tributaries above Reisterstown Road – Use III (Nontidal Cold Water); Dead Run and tributaries – Use IV (Recreational Trout Waters); and all remaining waters – Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life). See Code of Maryland Regulations (COMAR) 26.08.02.08K(3)(e) & (5)(e). This document proposes to establish a TMDL for fecal bacteria in Gwynns Falls and its tributaries that will allow for the attainment of the designated use of primary contact recreation. The listings for sediments, nutrients, 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 were considered.

To establish baseline and allowable pollutant loads for this TMDL, a flow duration curve approach was employed, using flow strata estimated from United States Geological Survey (USGS) daily flow monitoring data and bacteria monitoring data. The sources of fecal bacteria are estimated at four representative stations in the Gwynns 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 Gwynns 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 the 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 requiring higher maximum reductions. 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 four subwatersheds of Gwynns Falls, it was estimated that water quality standards could not be attained with the MPRs. Thus, a second scenario allowing greater reductions, which may not be feasible, was applied.

The fecal bacteria TMDL developed for the Gwynns Falls watershed is 917.4 billion *E. coli* MPN/day. The TMDL is distributed between load allocation (LA) for nonpoint sources and waste load allocations (WLA) for point sources, including National Pollutant Discharge Elimination System (NPDES) wastewater treatment plants (WWTPs), municipal separate storm sewer systems (MS4), and NPDES combined sewer overflows (CSOs). There are no WWTPs located in the Gwynns Falls watershed. The LA is 176.0 billion *E. coli* MPN/day. The MS4 WLA is 741.4 billion *E. coli* MPN/day and the CSO WLA is 0.0 billion *E. coli* MPN/day. The margin of safety (MOS) is explicit and has been incorporated 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 Gwynns 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 the non-tidal portion of Gwynns Falls (basin number 02130905). 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 Gwynns Falls in the State's 303(d) List as impaired by nutrients (1996), sediments (1996), bacteria (fecal coliform) (2002), and impacts to biological communities (2002). The designated uses for Gwynns Falls are as follows: Gwynns Falls and tributaries above Reisterstown Road – Use III (Nontidal Cold Water); Dead Run and tributaries – Use IV (Recreational Trout Waters); and all remaining waters – Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life). See Code of Maryland Regulations (COMAR) 26.08.02.08K(3)(e) & (5)(e). This document proposes to establish a TMDL for fecal bacteria in Gwynns Falls and its tributaries that will allow for the attainment of the designated use primary contact recreation. The listings for sediments, nutrients, 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 were considered.

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

The Gwynns Falls watershed was listed on the Maryland 303(d) List 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 Gwynns Falls TMDL analysis was *E. coli*.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Gwynns Falls watershed is located in the Patapsco River Basin within Maryland (see Figure 2.1.1). The watershed encompasses 41,710 acres (61 square miles) in Baltimore City and Baltimore County, Maryland. The headwaters of the Gwynns Falls begin in Glyndon, Maryland and flows southeast until its confluence with the Middle Branch of the Patapsco River near downtown Baltimore. Five major tributaries of the Gwynns Falls, listed north to south, include: Red Run, Horsehead Branch, Scotts Level Branch, Dead Run, and Maidens Choice Creek.

Geology/Soils

The Gwynns Falls watershed lies within the Piedmont and Atlantic Coastal Plain Provinces of Central Maryland. The Piedmont Province is characterized by gentle to steep rolling topography, low hills and ridges. The surface geology is characterized by crystalline rocks of volcanic origin consisting primarily of schist and gneiss. These formations are resistant to short-term erosion and often determine the limits of stream bank and 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 surface 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. In the areas around the head of tide, the topography is flat, with elevations below 100 feet. The elevations steadily increase going north to approximately 600 feet in the headwaters. Streambeds throughout the basin are comprised of rock and rubble with gradually sloped stream banks.

The Gwynns Falls watershed lies predominantly in the Baile and Lehigh soil series. The Lehigh soil series consists of somewhat poorly drained to moderately well-drained, rather shallow soils. The Baile soil series consists of deep, poorly drained, nearly level to gently sloping, dominantly gray soils of the Piedmont Plateau. Baile soils have a high available moisture capacity and a water table that is seasonally at or near the surface (U.S. Department of Agriculture (USDA), 1977). The spatial distributions for each soil series are shown in Figure 2.1.2.

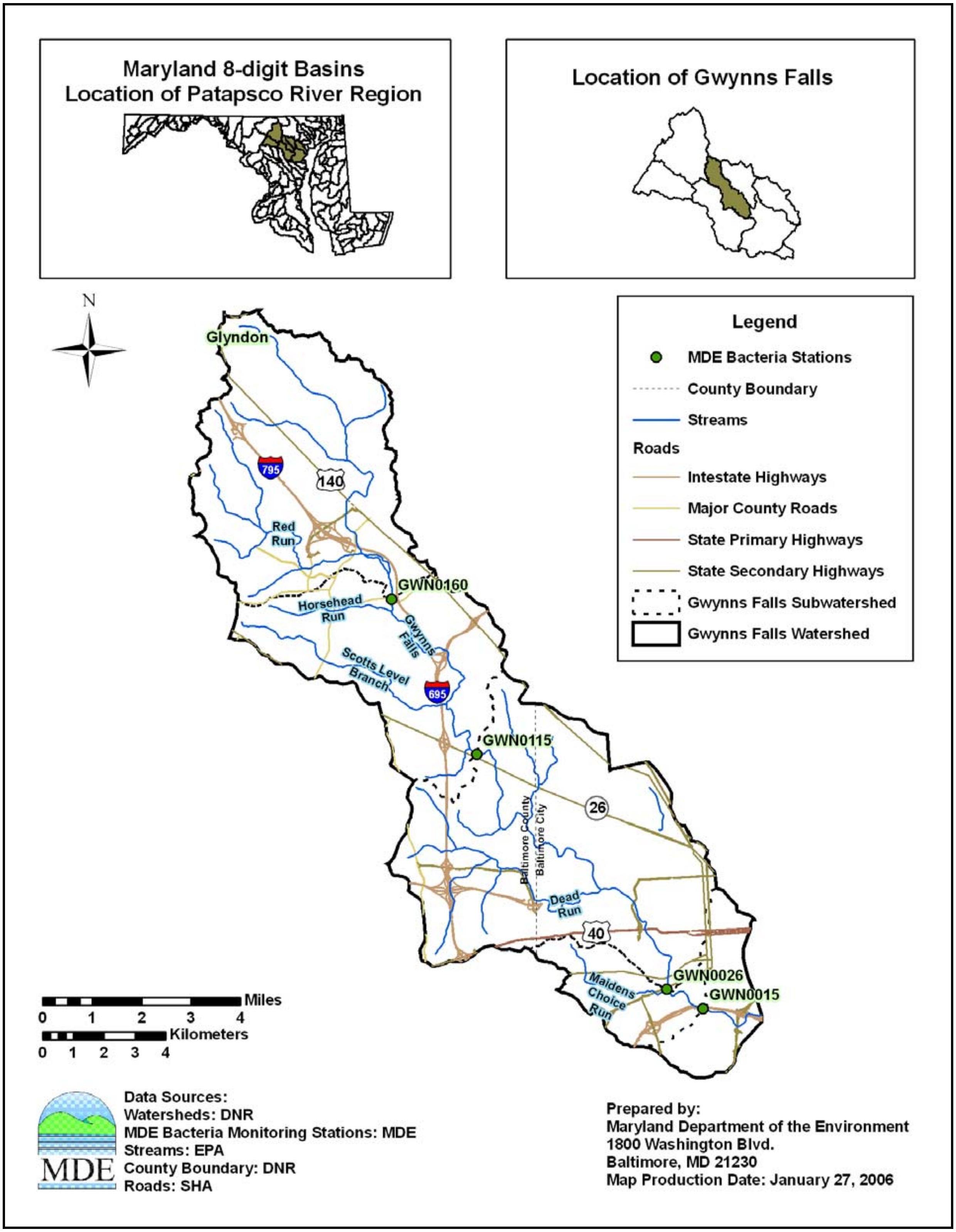

Figure 2.1.1: Location Map of the Gwynns Falls Watershed

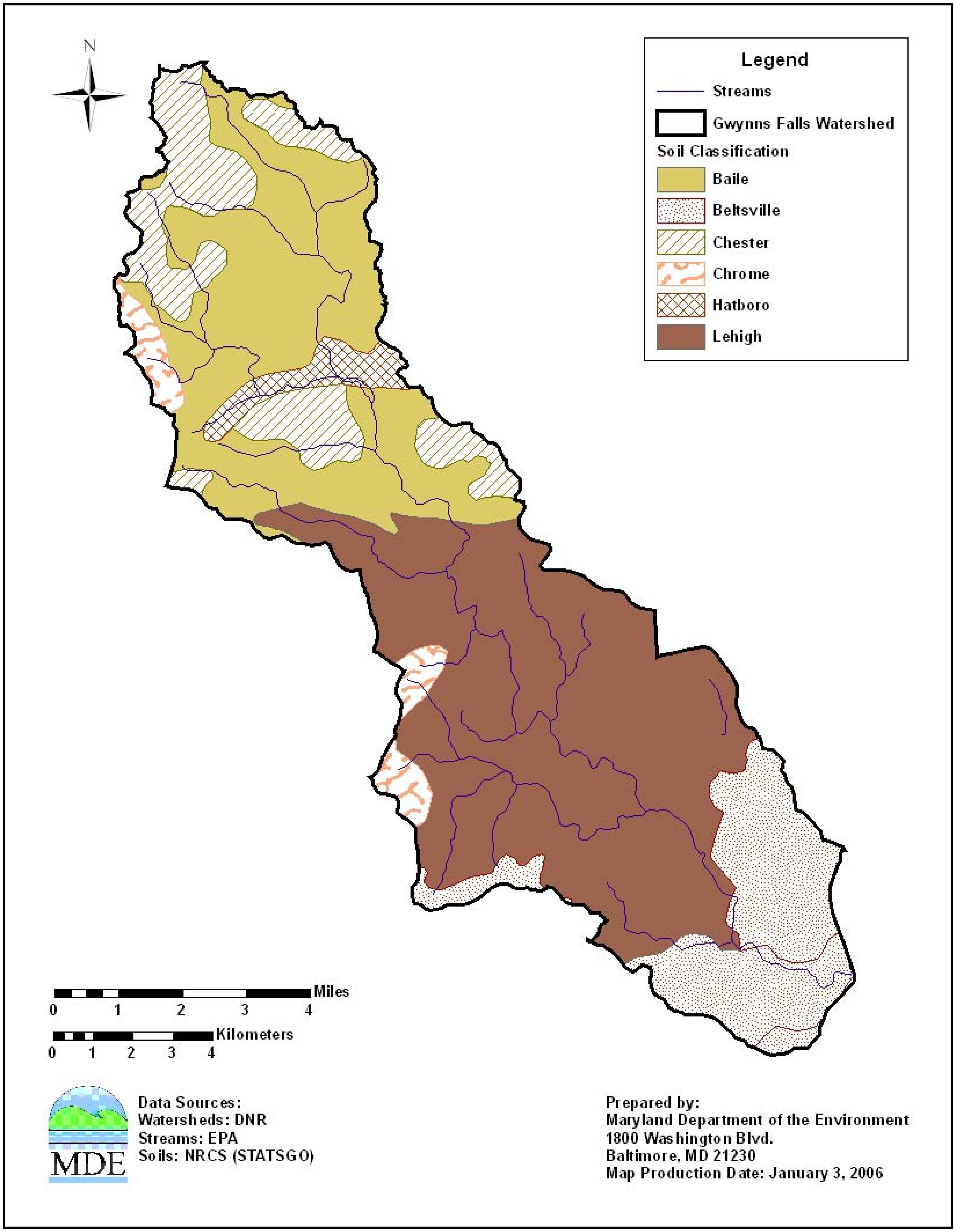

Figure 2.1.2: General Soil Series in the Gwynns Falls Watershed

Land Use

The 2002 Maryland Department of Planning (MDP) land use/land cover data show that the Gwynns Falls watershed is primarily a residential and commercial region. The watershed contains 23,860 acres (37.3 square miles) of residential land use and 9,367 acres (14.6 square miles) of commercial land use. Forest lands account for 7,068 acres (11 square miles) of the watershed, found primarily along the mainstem and tributaries of Gwynns Falls. A small portion of the watershed consists of crops and pasture lands at 921 (1.4 square miles) and 333 acres (0.5 square miles), respectively. The land use percentage distribution for the Gwynns Falls watershed is displayed in Table 2.1.1, and spatial distributions for each land use are presented in Figure 2.1.3.

Table 2.1.1: Land Use Percentage Distribution for Gwynns Falls Watershed

Land Type	Acreage	Percentage
Forest	7,068	16.9%
Residential	23,860	57.2%
Commercial	9,367	22.5%
Crops	921	2.2%
Pasture	333	0.8%
Water	161	0.4%
Totals	**41,710**	**100%**

Population

The total population in the Gwynns Falls watershed is estimated to be 315,828. Figure 2.1.4 displays the population density in the watershed. The human population and the number of households 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 Gwynns 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 Gwynns 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. These results are presented in Table 2.1.3.

Table 2.1.3: Total Population Per Subwatershed in Gwynns Falls Watershed

Subwatershed	Population	Dwellings
GWN0015	23,498	6,785
GWN0026	177,152	54,725
GWN0115	56,752	26,625
GWN0160	58,426	26,309
Total	315,828	114,444

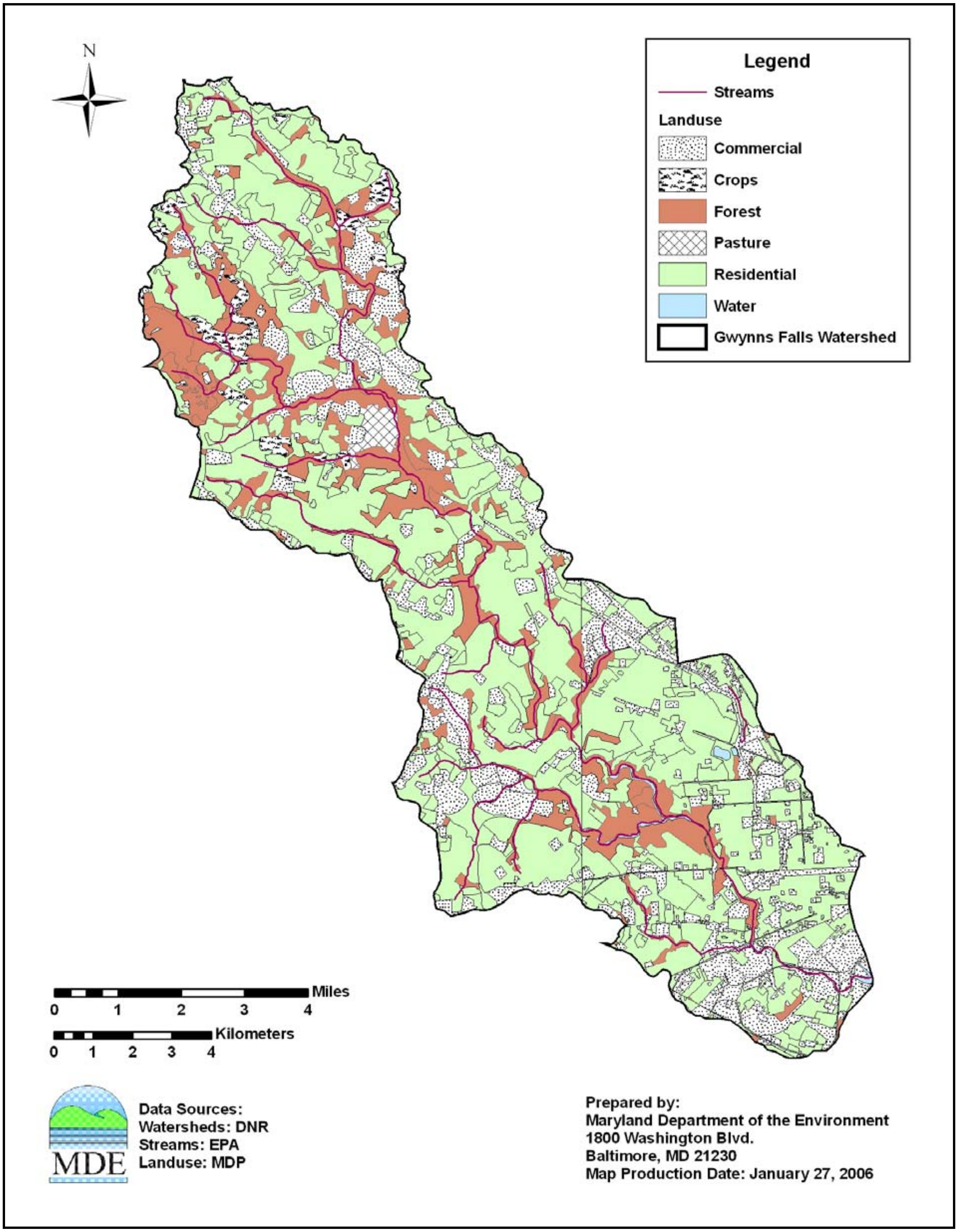

Figure 2.1.3: Land Use of the Gwynns Falls Watershed

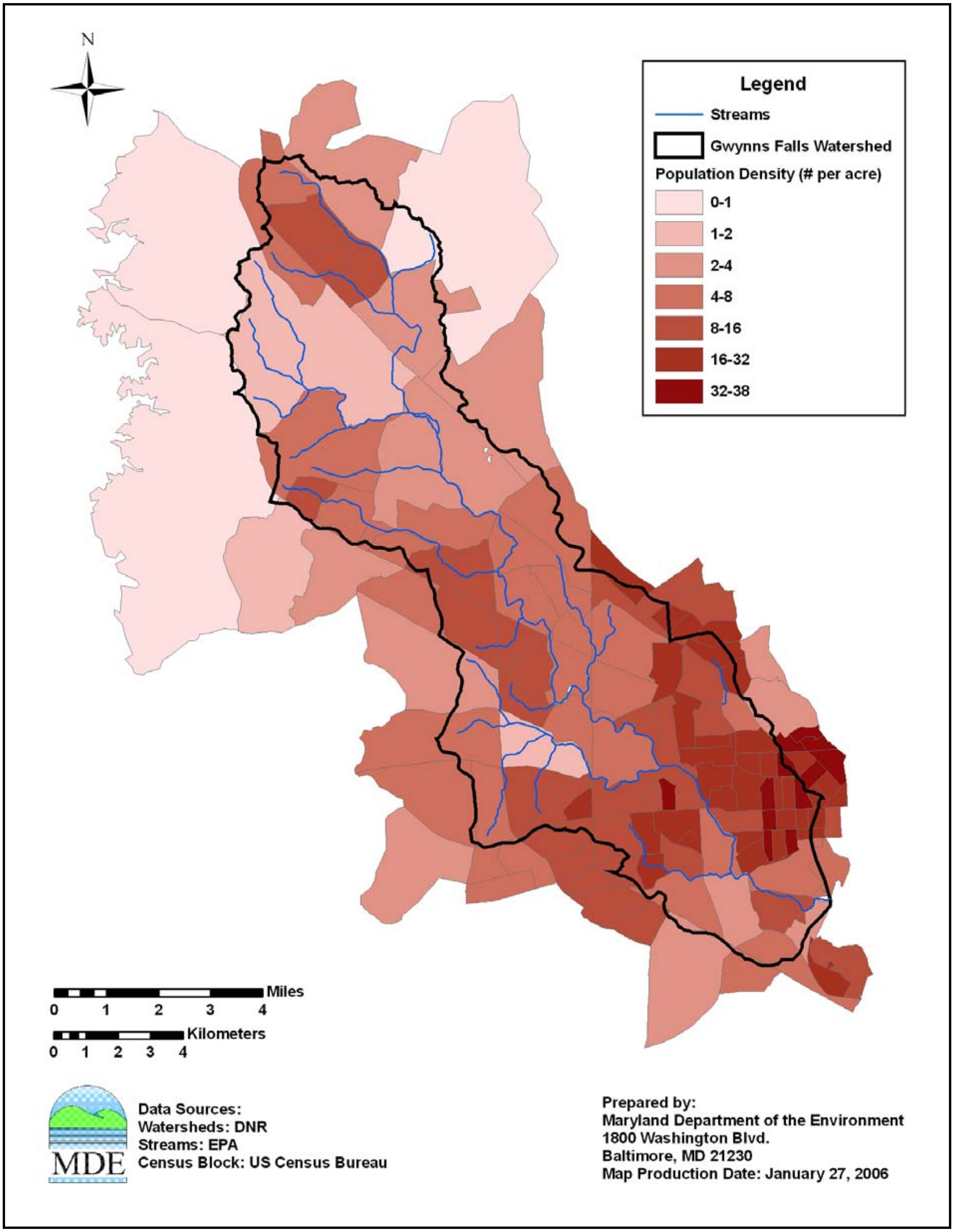

Figure 2.1.4: Population Density in Gwynns Falls Watershed

2.2 Water Quality Characterization

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

As per EPA's guidance, Maryland has adopted the new indicator organisms, *E. coli* and enterococci, for the protection of public health in Use I, II, and IV waters. These 303(d) bacteria listings were originally assessed using fecal coliform bacteria in 2002. 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 ensure that risk levels are acceptable.

Bacteria Monitoring

Table 2.2.1 lists the historical monitoring data for the Gwynns Falls watershed. Bacterial data collected at Maryland Department of Natural Resources (DNR) CORE monitoring station GWN0115 were used by MDE to identify the bacterial impairment. MDE conducted additional bacteria monitoring at four stations throughout Gwynns Falls from October 2002 through October 2003. USGS gage station 01589300, located in the Gwynns Falls watershed at Villa Nova, MD, was used in the estimation of the surface flow. The gage flow data was incomplete for this station; therefore, the flow for unobserved periods (01/01/1992 to 10/01/1996) was estimated using MDE's Patapsco/Back River Watershed Stormwater Management Model (SWMM) calibrated to USGS gage station 01589300. The locations of these stations are shown in Tables 2.2.2 – 2.2.4 and in Figure 2.2.1. Observations recorded from MDE's monitoring station are displayed in Appendix A.

Bacteria counts are highly variable in Gwynns Falls. This is typical for all streams due to the nature of bacteria and their relationship to flow. Bacteria counts ranged between 20 and 86,600 MPN/100 ml.

Table 2.2.1: Historical Monitoring Data in the Gwynns Falls Watershed

Organization	Date	Parameter	Summary
DNR CORE Monitoring	01/95 to 12/03	Fecal Coliform*	GWN0115: Gwynns Falls near intersection of Liberty Road and Essex Road (Milford, MD)
MDE	10/02 to 10/03	*E. coli*	2 station Enumeration 2x per month
MDE	10/02 to 10/03	BST (*E. coli*)	2 station ARA Bacterial Source Tracking (BST) 1x per month

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

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

Monitoring Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
GWN0115	1/4/95 - 12/8/03	104	39.346	-76.734

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

Monitoring Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
GWN0015	2002-2003	26	39.271	-76.648
GWN0026	2002-2003	23	39.277	-76.662
GWN0115	2002-2003	26	39.346	-76.734
GWN0160	2002-2003	23	39.392	-76.765

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

Gage Station	Observation Period	Total Observations	LATITUDE Decimal Degrees	LONGITUDE Decimal Degrees
1589300	1992-2006	5126	39.346	-76.734

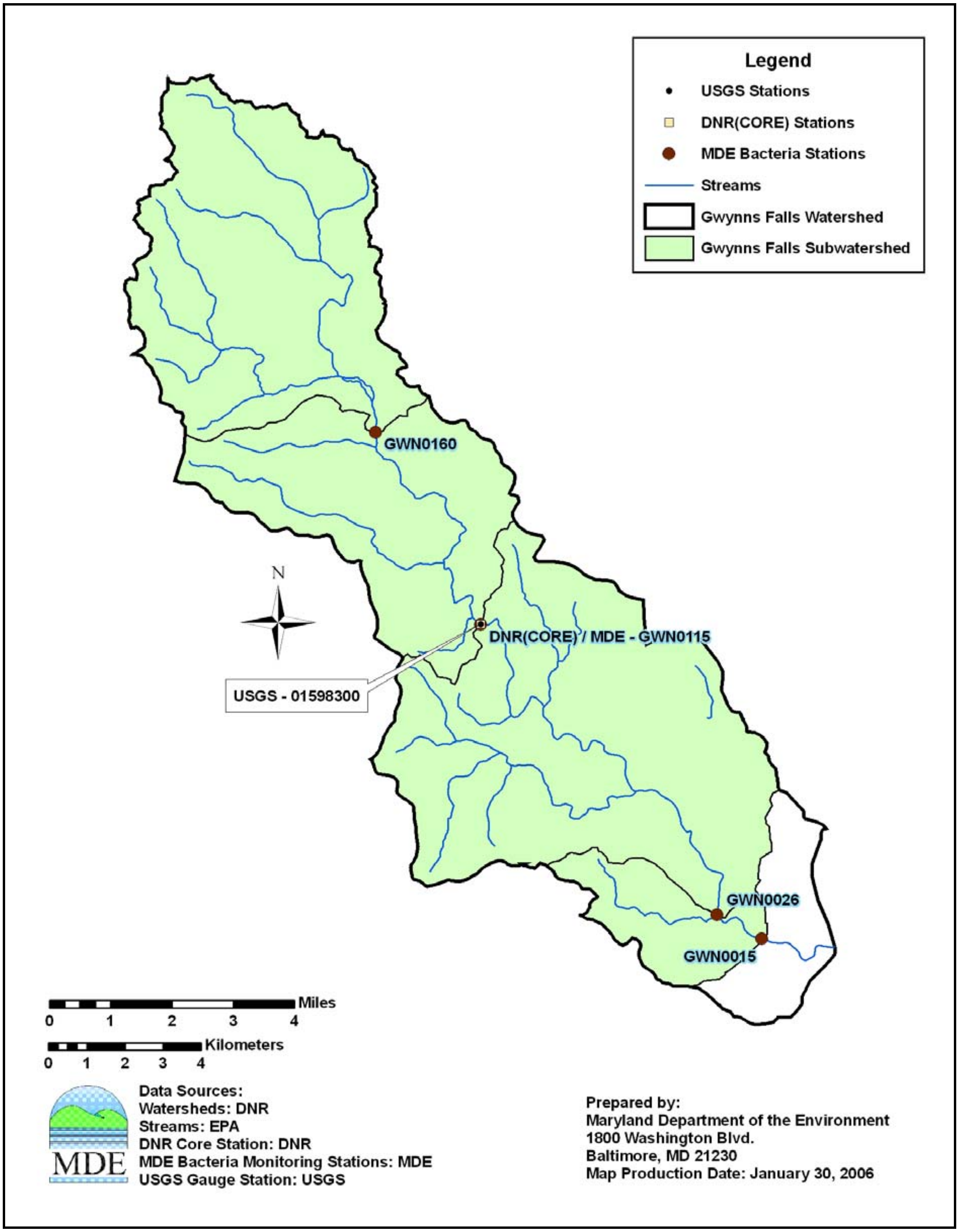

Figure 2.2.1: Monitoring Stations in the Gwynns Falls Watershed

2.3 Water Quality Impairment

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

The Maryland water quality standards Surface Water Use Designations for Gwynns Falls are as follows: Gwynns Falls and tributaries above Reisterstown Road – Use III (Non-tidal Cold Water); Dead Run and tributaries – Use IV (Recreational Trout Waters); and all remaining waters – Use I (Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life) (COMAR 26.08.02.08R(3)(e) & (4)(e)). Gwynns Falls has been included on the final 2004 Integrated 303(d) List as impaired by fecal coliform bacteria.

Water Quality Criteria

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

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

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

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 (MDE, January 2006):

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

Bacteria water quality impairment in Gwynns Falls was 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 by 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 Gwynns 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.

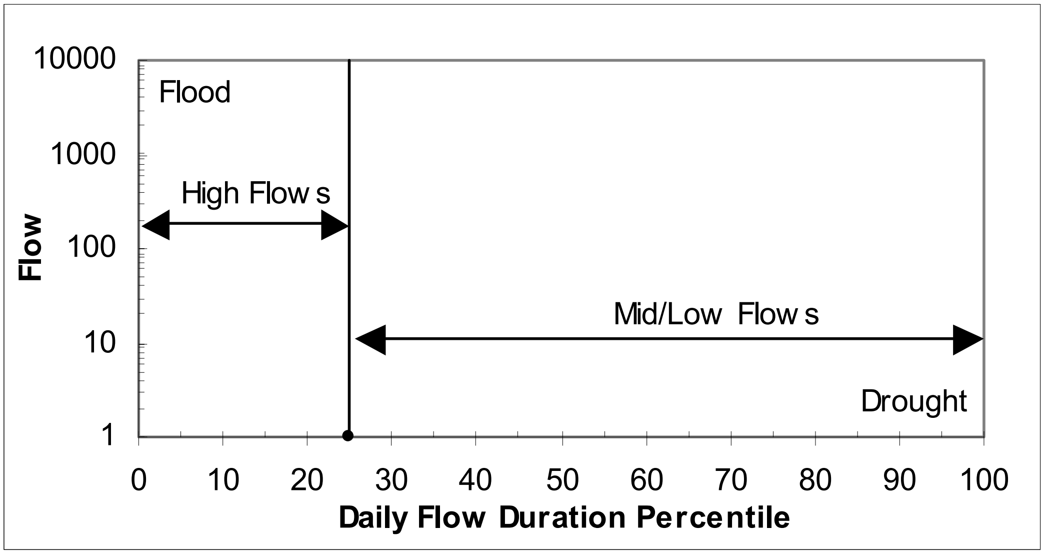

Figure 2.3.1: Conceptual Diagram of Flow Duration Zones

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 20^{th} to 28^{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 Gwynns 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 Gwynns 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:

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

C_{gm} = Steady state geometric mean concentration

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

Table 2.3.3: Gwynns Falls Annual Steady State Geometric Mean by Stratum per Subwatersheds

Station	Flow Stratum	Samples (#)	*E. coli* Minimum Concentration (MPN/100ml)	*E. coli* Maximum Concentration (MPN/100ml)	Annual Steady State Geometric Mean (MPN/100ml)	Annual Weighted Geometric Mean (MPN/100ml)
GWN0015	High	7	15,530	86,600	40,086	32,470
	Low	19	5,800	77,000	30,267	
GWN0026	High	6	280	38,700	3,633	753
	Low	17	60	4,350	446	
GWN0115	High	7	320	16,700	1,009	321
	Low	19	20	5,790	219	
GWN0160	High	6	110	23,800	1,611	508
	Low	17	60	2,050	345	

Table 2.3.4: Gwynns Falls Seasonal (May 1st-September 30th) Period Steady State Geometric Mean by Stratum per Subwatersheds

Station	Flow Stratum	Samples (#)	*E. coli* Minimum Concentration (MPN/100ml)	*E. coli* Maximum Concentration (MPN/100ml)	Seasonal Steady State Geometric Mean (MPN/100ml)	Seasonal Weighted Geometric Mean (MPN/100ml)
GWN0015	High	3	43,500	86,600	62,529	40,716
	Low	9	5,800	77,000	35,290	
GWN0026	High	3	280	38,700	1,498	528
	Low	9	60	2,600	373	
GWN0115	High	3	620	16,700	1,954	842
	Low	9	310	5,790	636	
GWN0160	High	3	820	23,800	3,102	1,062
	Low	9	360	2,050	743	

2.4 Source Assessment

Nonpoint Source Assessment

Nonpoint sources of fecal bacteria do not have one discharge point but occur over the entire length of a stream or waterbody. During rain events, surface runoff transports water and fecal bacteria over the land surface and discharges to the stream system. This transport is dictated by rainfall, soil type, land use, and topography of the watershed. sMany 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 from leaking infrastructure (*i.e.*, sewer systems). Land use in the Gwynns Falls watershed consists primarily of forested and developed land uses; therefore, sources associated with agricultural land use (*i.e.,* livestock) are not a consideration in this analysis. The entire watershed is covered by two National Pollutant Discharge Elimination System (NPDES) Municipal Separate Storm Sewer System (MS4) individual permits; thus, contributions from domestic animal and human sources will be categorized under point sources or Waste Load Allocations (WLA). Wildlife contributions will be distributed between WLAs and Load Allocations (LA) due to the presence of wildlife in both developed and undeveloped areas of the watershed.

Sewer Systems

The Gwynns Falls sewage collection system conveys wastewater from municipalities in Baltimore County and Baltimore City. The wastewater is then treated by two municipal wastewater treatment plants (WWTPs), the Patapsco and Back River WWTPs. Two sections of the sewage collection system, located in the Forest Park and Walbrook regions of Baltimore City, are combined sewer systems (CSSs) receiving stormwater as well as wastewater. In addition, stormwater 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

Several septic systems are located in the northwestern region of the watershed in areas where no sewer service exists (See Figure 2.4.1). Table 2.4.1 displays the number of septic systems and households per subwatershed.

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

Subwatershed Station	Septics Systems (units)	Households per Subwatershed
GWN0015	0	4,521
GWN0026	193	47,729
GWN0115	3021	26,495
GWN0160	8073	26,260
Total	**11,287**	**105,005**

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 Gwynns Falls watershed is located in Baltimore City and Baltimore County; both are Phase I NPDES MS4 permit jurisdictions. The MS4 permit covers stormwater discharges from the municipal separate stormwater sewer system in the City and County.

Baltimore City has conducted stormwater monitoring for 15 years in the area, both at the outfalls and in-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 much higher in Gwynns Falls during dry weather than during wet weather, because the sanitary system 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 Clean Water Act and, where applicable, by the jurisdiction's wastewater treatment plant discharge permits. SSOs must be reported to MDE's Water Management Administration in accordance with COMAR 26.08.10, to be addressed under the State's compliance and enforcement program.

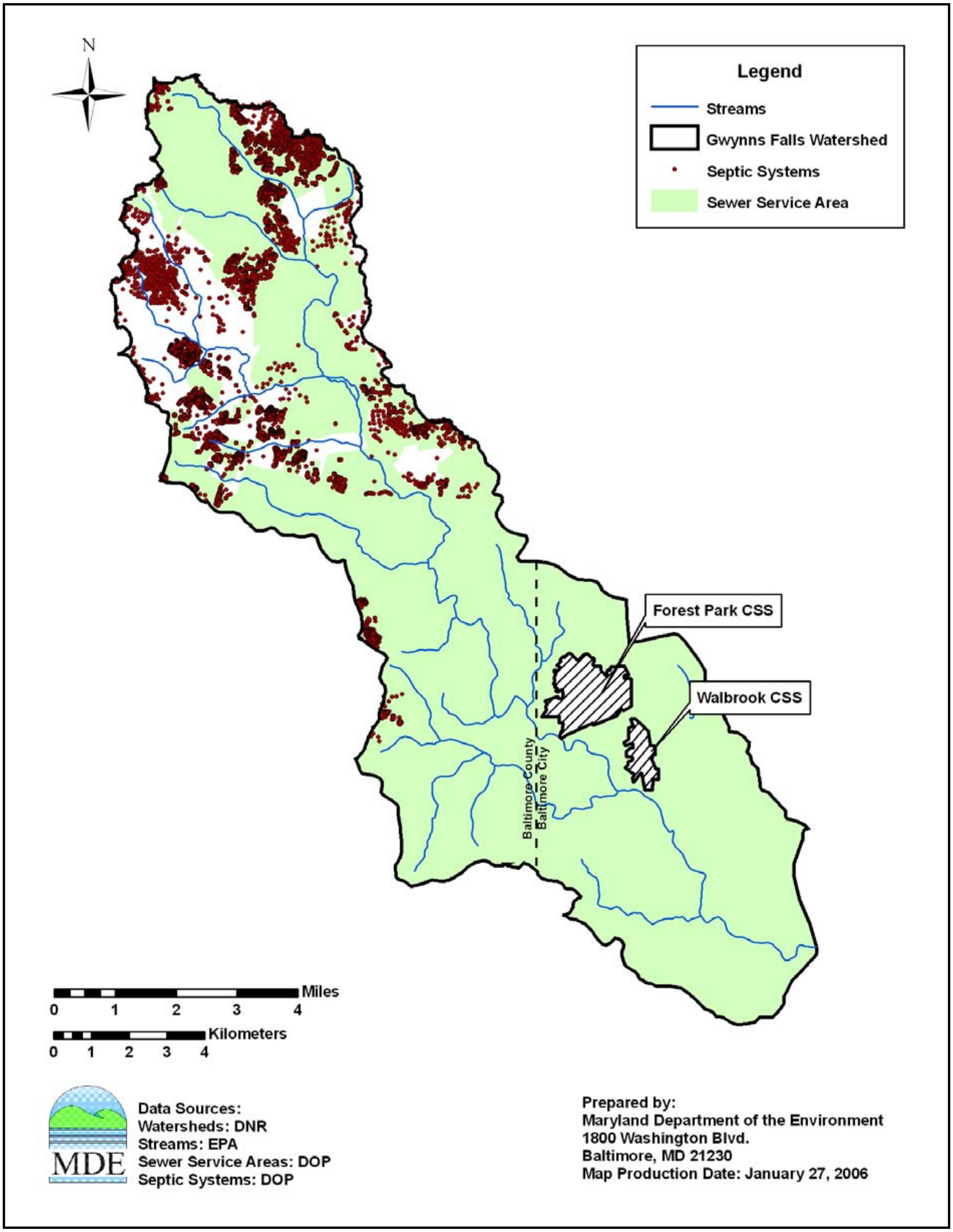

Figure 2.4.1: Sanitary Sewer Service Area and Septics in the Gwynns Falls Watershed

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 (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 (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 system 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.

There were a total of 188 SSO events reported between October 2002 and October 2003. Approximately 1.4 million gallons of SSO discharge were released through various waterways (surface water, groundwater, sanitary sewers, etc.) in the Gwynns Falls mainstem and tributaries (MDE, Water Management Administration). Figure 2.4.2 depicts the location of the SSO events.

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 Gwynns Falls watershed, the Patapsco and Back River WWTP are responsible for all CSO and SSO structural releases under their associated NPDES permits. The watershed contains a total of 38 sewer overflow structures. Table 2.4.2 and Figure 2.4.3 display the location of CSO and SSO structures which discharge into the Gwynns Falls and its tributaries.

[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.

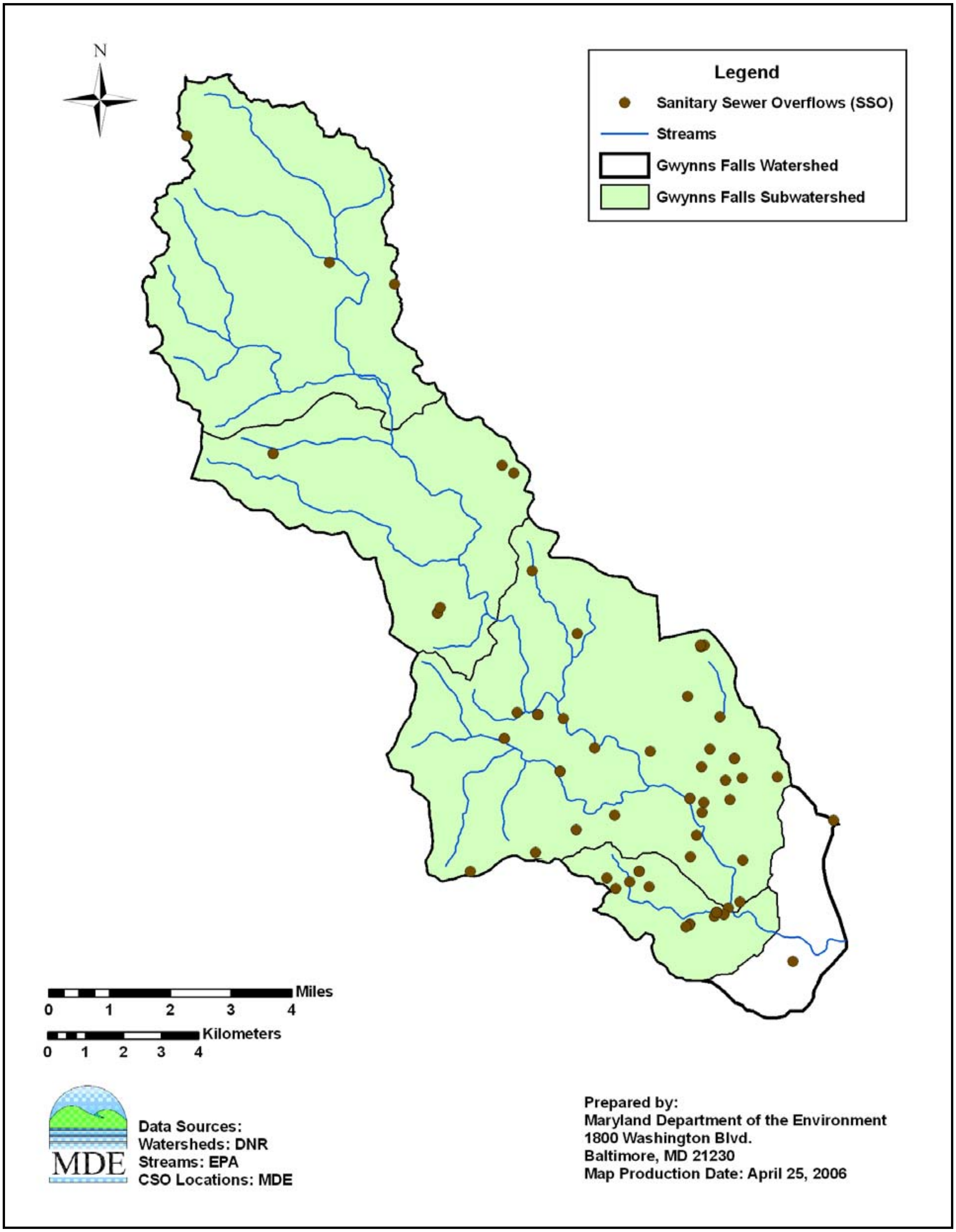

Figure 2.4.2: Sanitary Sewer Overflow Locations in the Gwynns Falls Watershed

Table 2.4.2: Sanitary Sewer Overflow Structures in the Gwynns Falls Watershed

Treatment Plant	NPDES ID	CSO/SSO Structure ID	Type	Latitude	Longitude	Receiving Water
Back River WWTP	MD0021555	79	SSO	39.277	-76.663	Gwynns Falls
		81	SSO	39.277	-76.662	Gwynns Falls
		55	SSO	39.345	-76.672	Gwynns Run
		56	SSO	39.339	-76.671	Gwynns Run
		57	SSO	39.340	-76.671	Gwynns Run
		60	SSO	39.325	-76.674	Gwynns Run
		63	SSO	39.323	-76.666	Gwynns Run
		103	SSO	39.327	-76.675	Gwynns Run
		106	SSO	39.306	-76.664	Gwynns Run
		107	SSO	39.307	-76.663	Gwynns Run
		126	SSO	39.332	-76.675	Gwynns Run
		127	SSO	39.331	-76.675	Gwynns Run
		128	SSO	39.333	-76.676	Gwynns Run
		130	SSO	39.328	-76.664	Gwynns Run
		131	SSO	39.340	-76.670	Gwynns Run
Patapsco WWTP	MD0021601	10P	CSO	39.326	-76.695	Gwynns Falls
		11P	CSO	39.323	-76.700	Gwynns Falls
		13P	CSO	39.319	-76.704	Gwynns Falls
		18P	CSO	39.329	-76.686	Gwynns Falls
		19P	CSO	39.327	-76.688	Gwynns Falls
		21P	CSO	39.308	-76.680	Gwynns Falls
		31P	CSO	39.326	-76.692	Gwynns Falls
		16P	SSO	39.295	-76.709	Dead Run
		17P	SSO	39.297	-76.702	Dead Run
		84	SSO	39.267	-76.632	Gwynns Falls
		12P	SSO	39.320	-76.700	Gwynns Falls
		22P	SSO	39.306	-76.679	Gwynns Falls
		25P	SSO	39.325	-76.700	Gwynns Falls
		26P	SSO	39.324	-76.701	Gwynns Falls
		27P	SSO	39.325	-76.687	Gwynns Falls
		6	SSO	39.274	-76.666	Maidens Choice Run
		23P	SSO	39.286	-76.713	Maidens Choice Run
		24P	SSO	39.279	-76.709	Maidens Choice Run
		32P	SSO	39.274	-76.675	Maidens Choice Run
		28P	SSO	39.342	-76.694	Powder Mill
		29P	SSO	39.342	-76.692	Powder Mill
		30P	SSO	39.342	-76.692	Powder Mill
		33P	SSO	39.343	-76.702	Powder Mill

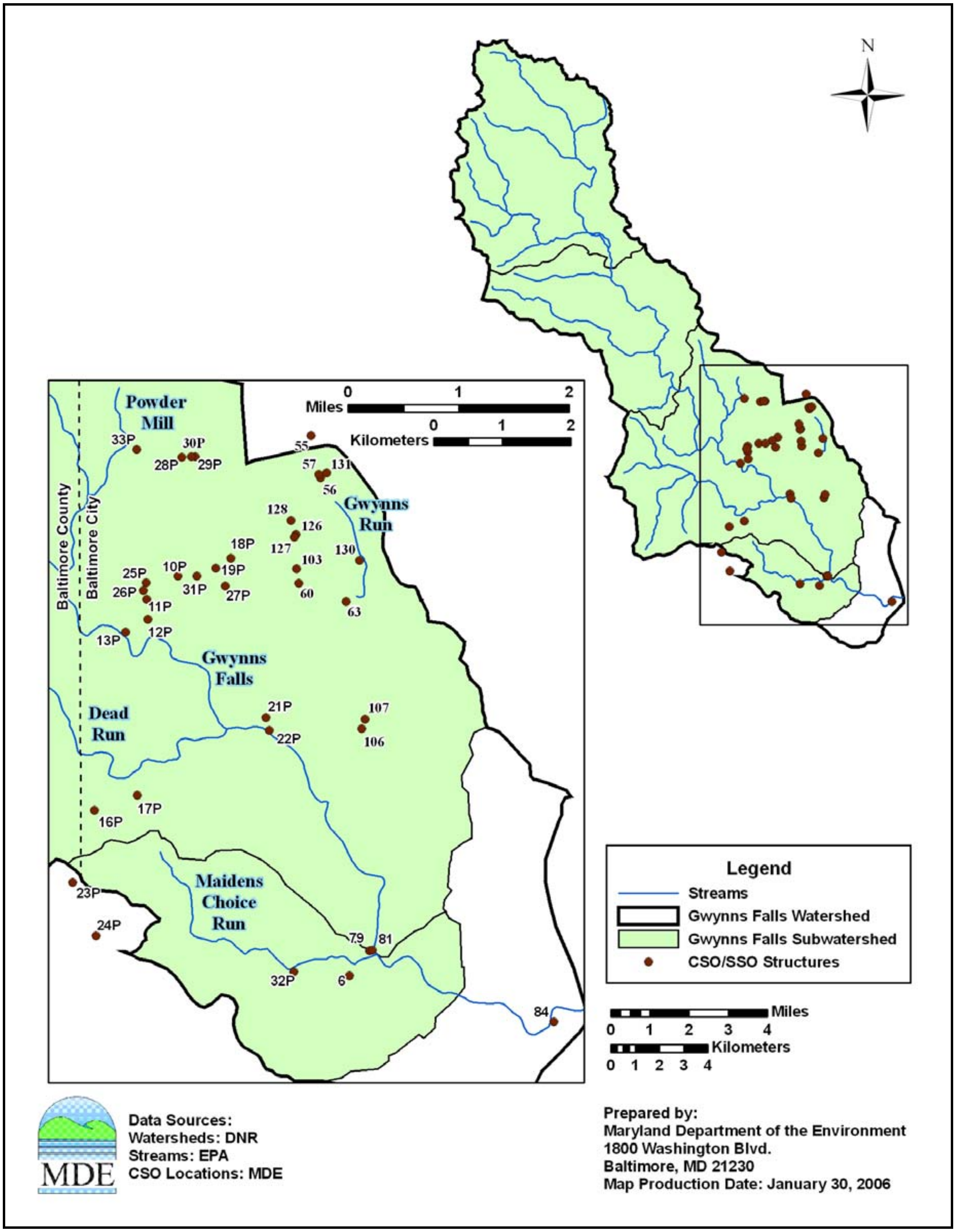

Figure 2.4.3: Sanitary Sewer Overflow Structure Locations in the Gwynns Falls Watershed

There were a total of 31 CSO events reported between October 2002 and October 2003. Approximately 3.8 million gallons of CSO discharge were released in the Gwynns Falls mainstem and tributaries (MDE, Water Management Administration).

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 Gwynns 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 contribution from each source 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 is 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 log10 bacteria concentration for the water sample.
3. The final weighted mean source percentage, for each source category, is based on the proportion of time in each flow duration zone (see Appendix C).

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

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

where

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

M_k = weighted mean proportion of isolates of source k
$MS_{i,k}$ = Weighted mean proportion of isolates for source k in stratum i
W_i = Proportion covered by stratum i
i = stratum

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

The complete distributions of the annual and seasonal periods source loads are listed in Table 2.4.3 and 2.4.4. Details of the BST data can be found in Appendix C.

Table 2.4.3: Distribution of Fecal Bacteria Source Loads in the Gwynns Falls Watershed for the Average Annual Period

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
GWN0015	High Flow	10	73	0	4	13
	Low Flow	21	66	0	2	11
	Weighted	18	68	0	2	12
GWN0026	High Flow	14	66	0	12	8
	Low Flow	27	47	0	10	16
	Weighted	24	52	0	10	14
GWN0115	High Flow	11	48	0	16	25
	Low Flow	14	44	0	31	11
	Weighted	14	45	0	27	14
GWN0160	High Flow	10	65	0	15	10
	Low Flow	8	59	0	21	12
	Weighted	8	60	0	20	12

Table 2.4.4: Distribution of Fecal Bacteria Source Loads in the Gwynns Falls Watershed for the Seasonal Period (May 1st – September 30th)

STATION	Flow Stratum	% Domestic Animals	% Human	% Livestock	% Wildlife	% Unknown
GWN0015	High Flow	10	61	0	4	25
	Low Flow	17	65	0	2	16
	Weighted	16	63	0	3	18
GWN0026	High Flow	3	55	0	26	16
	Low Flow	23	43	0	16	18
	Weighted	18	45	0	19	18
GWN0115	High Flow	2	45	0	14	39
	Low Flow	9	53	0	27	11
	Weighted	7	51	0	24	18
GWN0160	High Flow	12	54	0	22	12
	Low Flow	7	60	0	22	11
	Weighted	8	58	0	22	12

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

To be most effective, the TMDL provides a basis for allocating loads among the known pollutant sources in the watershed so that appropriate control measures can be implemented and water quality standards achieved. By definition, the TMDL is the sum of the individual waste load allocations (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, federal regulations (40 CFR 130.2(i)) provide that the TMDL can be expressed in terms of "mass per time, toxicity or other appropriate measure."

For many reasons, bacteria are difficult to simulate in water quality models. They reproduce and die off in a non-linear fashion as a function of many environmental factors, including temperature, pH, turbidity (UV light penetration), and settling. They occur in concentrations that vary widely (*i.e.*, over orders of magnitude) and an accurate estimation of source inputs is difficult to develop. Finally, limited data are available to characterize the effectiveness of any program or practice at reducing bacteria loads (Schueler, 1999).

Bacteria concentrations, determined through laboratory analysis of in-stream water samples for bacteria indicators (*e.g.*, *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 (American Public Health Association (APHA), 1998). Enumeration results demonstrate 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 the 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, provides reasonable results (Cleland, 2003). Using this approach, MDE can address more impaired streams in the same time period than using the traditional water quality modeling methods.

4.2 Analytical 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.

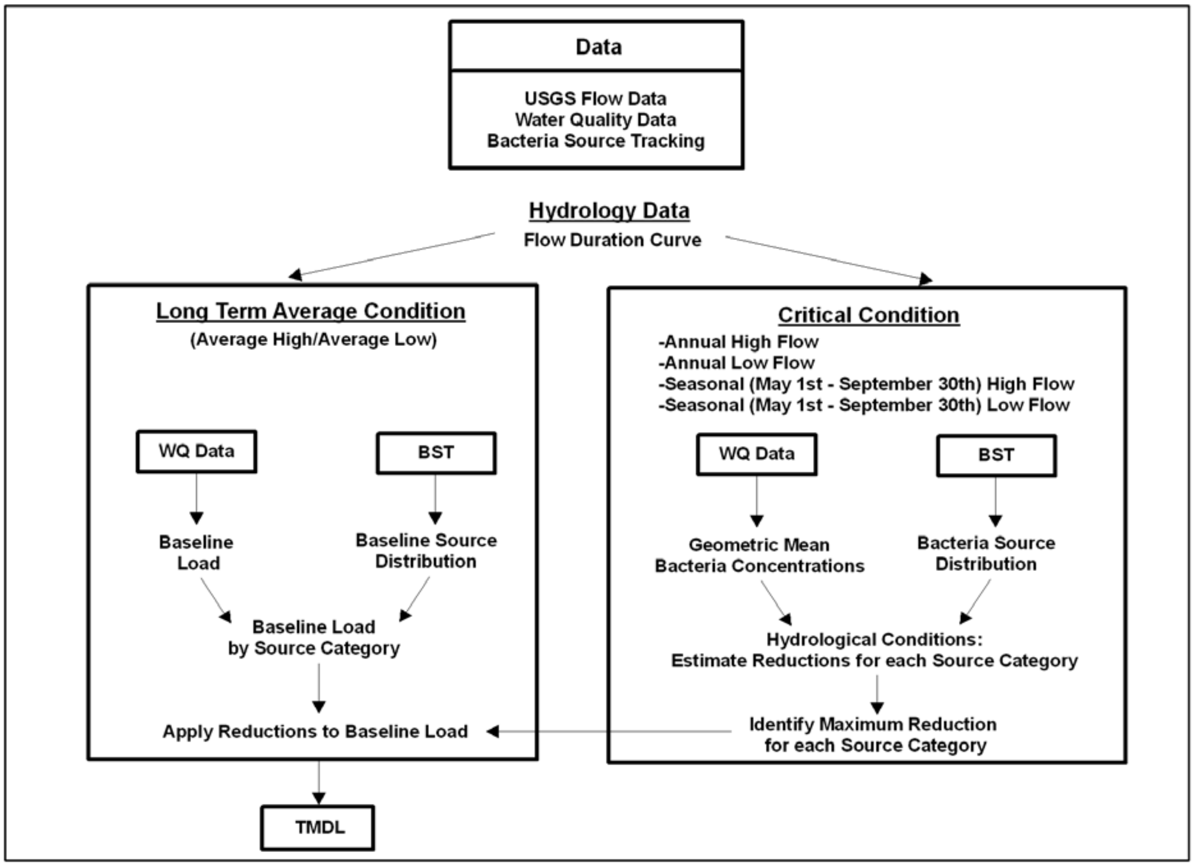

Figure 4.2.1: Diagram of Non-tidal Bacteria TMDL Analytical Framework

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

Table 4.3.1: Baseline Load Calculations

Station		GWN0160	GWN0115sub	GWN0026sub	GWN0015sub
Area (mi^2)		19.2	13.4	24.8	4.0
High Flow	**Daily Average Flow (cfs)**	74.9	52.3	96.7	15.5
	E. coli **Concentration (MPN/100ml)**	1611.3	302.3	8109.8	740277.0
	Bias Correction Factor	3.2	2.9	3.6	1.2
Low Flow	**Daily Average Flow (cfs)**	14.0	9.8	18.1	2.9
	E. coli **Concentration (MPN/100ml)**	345.4	65.2	1271.1	156243.6
	Bias Correction Factor	1.6	2.6	1.7	1.2
Baseline Load (Billion *E. coli* MPN/day)		2539.6	314.8	17990.7	90620.3

The Gwynns Falls watershed was delineated into four subwatershed segments based on the location of each monitoring station. Baseline loads were estimated for each station. For subwatersheds with upstream monitoring stations, the total baseline load from upstream stations was multiplied by a transport factor derived from first order decay and subtracted from the downstream cumulative load to estimate the adjacent subwatershed baseline load. 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). For stations GWN0115, GWN0026 and GWN0015 there is an upstream monitoring station. These subwatersheds were defined with the extension sub to the station name (*e.g.*, GWN0115sub). Refer back to Figure 2.2.1 for subwatershed locations. Refer back to Figure 2.2.1 for subwatershed locations.

The general equation for the flow mass balance is:

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

where

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

and the general equations for bacteria loading mass balance:

$$\sum (e^{kt} * Q_{us} * C_{us}) + Q_{sub} * C_{sub} = Q_{ds} * C_{ds} \qquad (10)$$

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

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:

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

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}, in the same 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:

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

where

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

and the final geometric mean concentration is estimated as follows:

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

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 GWN0115sub, GWN0026sub, and GWN0015sub were assigned from the analysis for GWN0115, GWN0026, and GWN0015, 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 as occurring when the daily flow duration interval is less than 25% and a low flow condition as 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.

As stated above, Maryland's proposed fecal bacteria TMDL for Gwynns Falls has been determined by assessing various hydrological conditions to account for seasonal and annual averaging periods. The following four conditions shown in Table 4.4.1 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	Fraction High Flow	Fraction Low Flow	Condition Period
Annual	Average	365 days	All	0.25	0.75	Long Term Average
	Wet	365 days	All	0.56	0.44	Jan 1997 - Jan 1998
	Dry	365 days	All	0.06	0.94	May 1994 - May 1995
Seasonal	Wet	May 1st – Sept 30th	May 1st – Sept 30th	0.46	0.54	May 1996 - Sep 1996
	Dry	May 1st – Sept 30th	May 1st – Sept 30th	0.00	1.00	May 1993 - Sep 1993

The critical condition is determined by the maximum reduction per source that satisfies all four conditions, 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 (*e.g.*, pet waste can be reduced by 75%).

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

Table 4.4.2: Required Reductions of Fecal Bacteria to Meet Water Quality Standards

Station	Time Period	Hydrological Condition	Domestic %	Human %	Livestock %	Wildlife %
GWN0160	Annual	Wet	98%	98%	0%	33%
		Dry	28%	98%	0%	0%
	Seasonal	Wet	98%	98%	0%	76%
		Dry	98%	98%	0%	47%
	Maximum Source Reduction		**98%**	**98%**	**0%**	**76%**
GWN0115sub	Annual	Wet	0%	32%	0%	0%
		Dry	0%	0%	0%	0%
	Seasonal	Wet	96%	98%	0%	2%
		Dry	0%	82%	0%	0%
	Maximum Source Reduction		**96%**	**98%**	**0%**	**2%**
GWN0026sub	Annual	Wet	98%	98%	0%	85%
		Dry	98%	98%	0%	45%
	Seasonal	Wet	98%	98%	0%	78%
		Dry	98%	98%	0%	45%
	Maximum Source Reduction		**98%**	**98%**	**0%**	**85%**
GWN0015sub	Annual	Wet	99.998%	99.9996%	0%	99.096%
		Dry	99.997%	99.9991%	0%	97.037%
	Seasonal	Wet	99.999%	99.9998%	0%	99.562%
		Dry	99.998%	99.9996%	0%	98.890%
	Maximum Source Reduction		**99.999%**	**99.9998%**	**0%**	**99.562%**

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 GWN0160, GWN0115, GWN0026, and GWN0015.

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: Gwynns Falls Watershed TMDL Summary

Station	Baseline Load (Billion *E. coli* MPN/day)	TMDL Load (Billion *E. coli* MPN/day)	% Target Reduction
GWN0160	2539.6	172.5	93.2%
GWN0115sub	314.8	103.4	67.2%
GWN0026sub	17990.7	629.9	96.5%
GWN0015sub	90620.3	11.5	99.99%
Total	111465.5	917.4	

4.7 Scenario Descriptions

Source Distribution

The final source distribution is derived from the source proportions listed in Table 2.4.3. 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 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)
GWN0160	9.2%	233.7	68.5%	1740.4	0.0%	0.0	22.3%	565.5
GWN0115sub	15.6%	49.1	52.5%	165.3	0.0%	0.0	31.9%	100.4
GWN0026sub	27.8%	5009.4	60.1%	10821.2	0.0%	0.0	12.0%	2160.1
GWN0015sub	20.6%	18667.8	76.6%	69410.0	0.0%	0.0	2.8%	2542.6

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 in order 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 all four subwatersheds, the constraints of this scenario could not 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 %	
GWN0160	75.0%	95.0%	75.0%	0.0%	No
GWN0115sub	75.0%	95.0%	75.0%	0.0%	No
GWN0026sub	75.0%	95.0%	75.0%	0.0%	No
GWN0015sub	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 four subwatersheds could meet water quality standards based on MPRs.

To further develop the TMDL, the constraints on the MPRs were relaxed in all four subwatersheds where the water quality attainment was not achievable with the MPRs. In these subwatersheds, the maximum allowable reductions were 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 required reductions and TMDL allocations by source category for each subwatershed are presented in Table 4.7.4 and Table 4.7.5, respectively. For subwatershed GWN0015sub a maximum reduction constraint of 98% for all bacterial sources was insufficient in order to meet the target reduction, therefore the constraint was further relaxed to a maximum reduction of 100%.

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

Station	Domestic %	Human %	Livestock %	Wildlife %	Target Reduction
GWN0160	98.0%	98.0%	0.0%	76.5%	93.2%
GWN0115sub	96.0%	98.0%	0.0%	2.3%	67.2%
GWN0026sub	98.0%	98.0%	0.0%	85.5%	96.5%
GWN0015sub	99.9989%	99.9998%	0.0%	99.6%	99.987%

Table 4.7.5: TMDL Reduction Results: Reduced Loads by Source

Station	Domestic (Billion *E. coli* MPN/day)	Human (Billion *E. coli* MPN/day)	Livestock (Billion *E.coli* MPN/day)	Wildlife (Billion *E. coli* MPN/day)	Total (Billion *E. coli* MPN/day)
GWN0160	4.7	34.8	0.0	133.1	172.5
GWN0115sub	1.9	3.3	0.0	98.2	103.4
GWN0026sub	100.2	216.4	0.0	313.3	629.9
GWN0015sub	0.2	0.2	0.0	11.1	11.5

4.8 TMDL Allocation

The TMDL allocation includes load allocations (LA) for nonpoint sources and waste load allocations (WLA) for point sources and for stormwater (where MS4 permits are required). The margin of safety is explicit and has been incorporated in the analysis by estimating the loading capacity of the stream based on a more stringent water quality endpoint concentration. It 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 but take into account critical conditions. The load reduction scenario results in allocations that will achieve water quality standards. The State reserves the right to revise these allocations provided such revisions are consistent with the achievement of water quality standards.

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 MS4 permits and the LA.

Table 4.8.1: Potential Source Contributions for TMDL Allocations

Allocation Category	LA	WLA		
		WWTP	MS4	CSOs
Human			X	
Domestic			X	
Livestock				
Wildlife	X		X	

The entire Gwynns Falls watershed is covered by MS4 permits; therefore, with no wastewater treatment plants (WWTPs) permitted to discharge fecal bacteria in the watershed, the final human load is allocated entirely to WLA-MS4. Domestic pets are also allocated entirely to WLA-MS4. There are no livestock contributions in the Gwynns Falls watershed. Note that only the final WLA is reported in this TMDL. Wildlife is distributed between the LA and WLA-MS4, based on a ratio of the amount of urban land compared to pasture and forest land in the watershed.

Baltimore County and Baltimore City have developed Long Term Control Plans (LTCPs) based on consent decrees between the jurisdictions and MDE, which require the elimination of all CSOs by March 2020 and January 2016, respectively; therefore, a zero allocation will be assigned to WLA-CSOs.

<u>MS4 Stormwater Allocations</u>

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 Gwynns 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 *E. coli* MPN/day)		
	Baltimore City	Baltimore County	Total
GWN0160	N/A	110.0	110.0
GWN0115sub	N/A	69.6	69.6
GWN0026sub	311.7	239.7	551.3
GWN0015sub	10.2	0.3	10.5

N/A – not applicable – subwatershed within Baltimore County only

4.9 Summary

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

Table 4.9.1: Gwynns Falls Watershed TMDL

Station	TMDL Load (Billion *E. coli* MPN/day)	LA Load (Billion *E. coli* MPN/day)	WLA – MS-4 Load (Billion *E. coli* MPN/day)	WLA-CSO Load (Billion *E. coli* MPN/day)
GWN0160	172.5	62.6	110.0	0
GWN0115sub	103.4	33.8	69.6	0
GWN0026sub	629.9	78.6	551.3	0
GWN0015sub	11.5	1.0	10.5	0
Total	**917.4**	**176.0**	**741.4**	**0.0**

In all four subwatersheds, based on the practicable reduction rates specified, water quality standards could not be achieved. This may occur in watersheds where wildlife is a significant component or 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 this case, 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 Gwynns 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. Gwynns 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 Gwynns 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 Gwynns 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 BMP 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 Gwynns Falls watershed is located, Baltimore County and Baltimore City, are required to participate in the stormwater

NPDES program, and must 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, 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 LTCPs 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. Under Section 106 of the Clean Water Act, EPA is authorized to issue grants to states for the purpose of assisting in establishing and carrying out pollution control programs.

Implementation and Wildlife Sources

It is expected that in some waters for which TMDLs will be developed, the bacteria source analysis may indicate that after controls are in place for all anthropogenic sources, the waterbody will not meet water quality standards. Neither MD 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, MD 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.

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

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 – MDE Monitoring Station Bacteria Data

Table A-1: Bacteria Concentration Raw Data per Sampling Date with Corresponding Daily Flow Frequency

Station	Date	Daily Flow Frequency	*E. coli* Concentration (MPN/100ml)
GWN0015	10/08/02	98.87	24190
GWN0015	10/22/02	89.45	19860
GWN0015	11/13/02	17.81	15530
GWN0015	11/25/02	68.93	24190
GWN0015	12/03/02	77.57	24190
GWN0015	12/17/02	46.28	18400
GWN0015	01/07/03	28.96	24190
GWN0015	01/22/03	61.54	72700
GWN0015	02/04/03	17.81	26000
GWN0015	03/04/03	17.81	29100
GWN0015	03/18/03	20.56	57900
GWN0015	04/22/03	38.29	38700
GWN0015	05/06/03	40.08	36500
GWN0015	05/20/03	30.25	36500
GWN0015	06/03/03	16.62	86600
GWN0015	06/17/03	21.73	64900
GWN0015	06/24/03	27.85	24190
GWN0015	07/08/03	48.80	57900
GWN0015	07/22/03	42.27	24190
GWN0015	08/05/03	32.77	77000
GWN0015	08/19/03	51.26	5800
GWN0015	08/26/03	32.77	61300
GWN0015	09/09/03	58.40	68700
GWN0015	09/23/03	0.14	43500
GWN0015	10/07/03	61.54	41100

Station	Date	Daily Flow Frequency	*E. coli* Concentration (MPN/100ml)
GWN0015	10/21/03	58.40	11200
GWN0026	11/25/02	68.93	210
GWN0026	12/03/02	77.57	630
GWN0026	12/17/02	46.28	270
GWN0026	01/07/03	28.96	4350
GWN0026	01/22/03	61.54	820
GWN0026	02/04/03	17.81	17330
GWN0026	03/04/03	17.81	19860
GWN0026	03/18/03	20.56	1990
GWN0026	04/22/03	38.29	370
GWN0026	05/06/03	40.08	670
GWN0026	05/20/03	30.25	600
GWN0026	06/03/03	16.62	280
GWN0026	06/17/03	21.73	310
GWN0026	06/24/03	27.85	210
GWN0026	07/08/03	48.80	820
GWN0026	07/22/03	42.27	60
GWN0026	08/05/03	32.77	2600
GWN0026	08/19/03	51.26	370
GWN0026	08/26/03	32.77	160
GWN0026	09/09/03	58.40	220
GWN0026	09/23/03	0.14	38700
GWN0026	10/07/03	61.54	480
GWN0026	10/21/03	58.40	340
GWN0115	10/08/02	98.87	190
GWN0115	10/22/02	89.45	120
GWN0115	11/13/02	17.81	660
GWN0115	11/25/02	68.93	30

Station	Date	Daily Flow Frequency	*E. coli* Concentration (MPN/100ml)
GWN0115	12/03/02	77.57	70
GWN0115	12/17/02	46.28	120
GWN0115	01/07/03	28.96	160
GWN0115	01/22/03	61.54	20
GWN0115	02/04/03	17.81	1210
GWN0115	03/04/03	17.81	560
GWN0115	03/18/03	20.56	320
GWN0115	04/22/03	38.29	60
GWN0115	05/06/03	40.08	750
GWN0115	05/20/03	30.25	460
GWN0115	06/03/03	16.62	720
GWN0115	06/17/03	21.73	620
GWN0115	06/24/03	27.85	730
GWN0115	07/08/03	48.80	540
GWN0115	07/22/03	42.27	380
GWN0115	08/05/03	32.77	5790
GWN0115	08/19/03	51.26	460
GWN0115	08/26/03	32.77	310
GWN0115	09/09/03	58.40	400
GWN0115	09/23/03	0.14	16700
GWN0115	10/07/03	61.54	120
GWN0115	10/21/03	58.40	130
GWN0160	11/25/02	68.93	60
GWN0160	12/03/02	77.57	200
GWN0160	12/17/02	46.28	120
GWN0160	01/07/03	28.96	110
GWN0160	01/22/03	61.54	150
GWN0160	02/04/03	17.81	110

Station	**Date**	**Daily Flow Frequency**	***E. coli*** **Concentration (MPN/100ml)**
GWN0160	03/04/03	17.81	3650
GWN0160	03/18/03	20.56	1460
GWN0160	04/22/03	38.29	350
GWN0160	05/06/03	40.08	1020
GWN0160	05/20/03	30.25	360
GWN0160	06/03/03	16.62	820
GWN0160	06/17/03	21.73	1530
GWN0160	06/24/03	27.85	2010
GWN0160	07/08/03	48.80	880
GWN0160	07/22/03	42.27	550
GWN0160	08/05/03	32.77	2050
GWN0160	08/19/03	51.26	470
GWN0160	08/26/03	32.77	490
GWN0160	09/09/03	58.40	410
GWN0160	09/23/03	0.14	23800
GWN0160	10/07/03	61.54	130
GWN0160	10/21/03	58.40	190

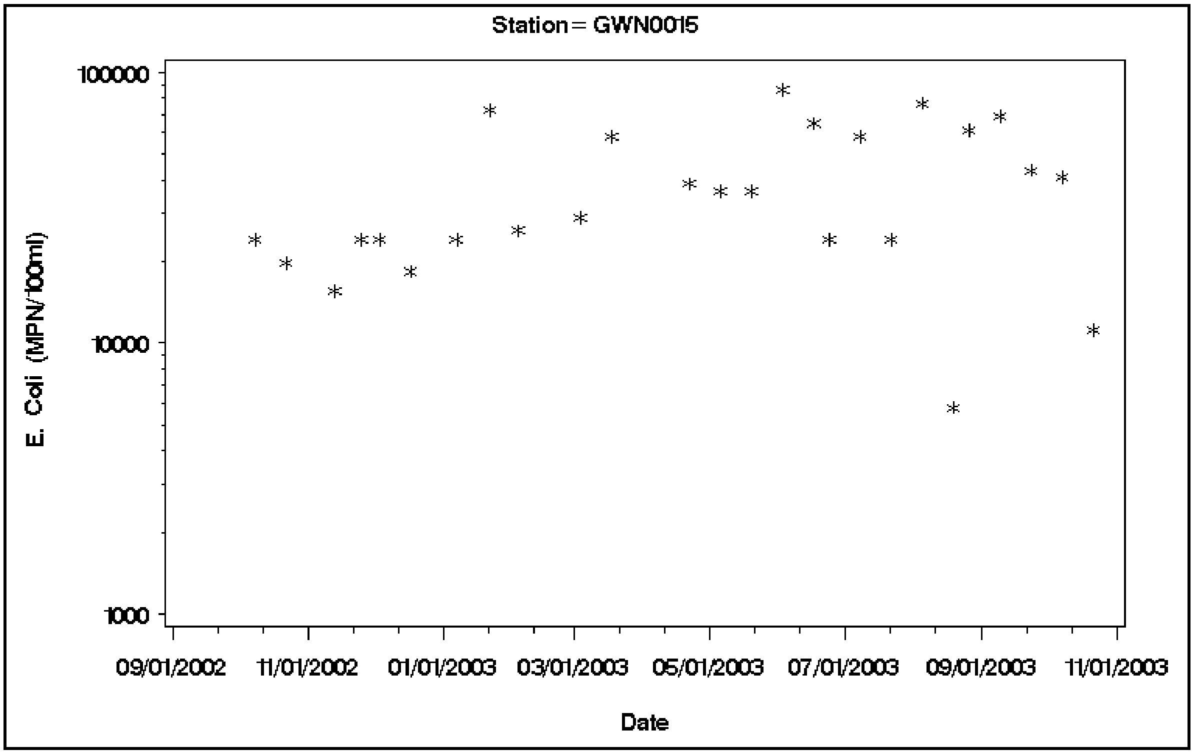

Figure A-1: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station GWN0015**

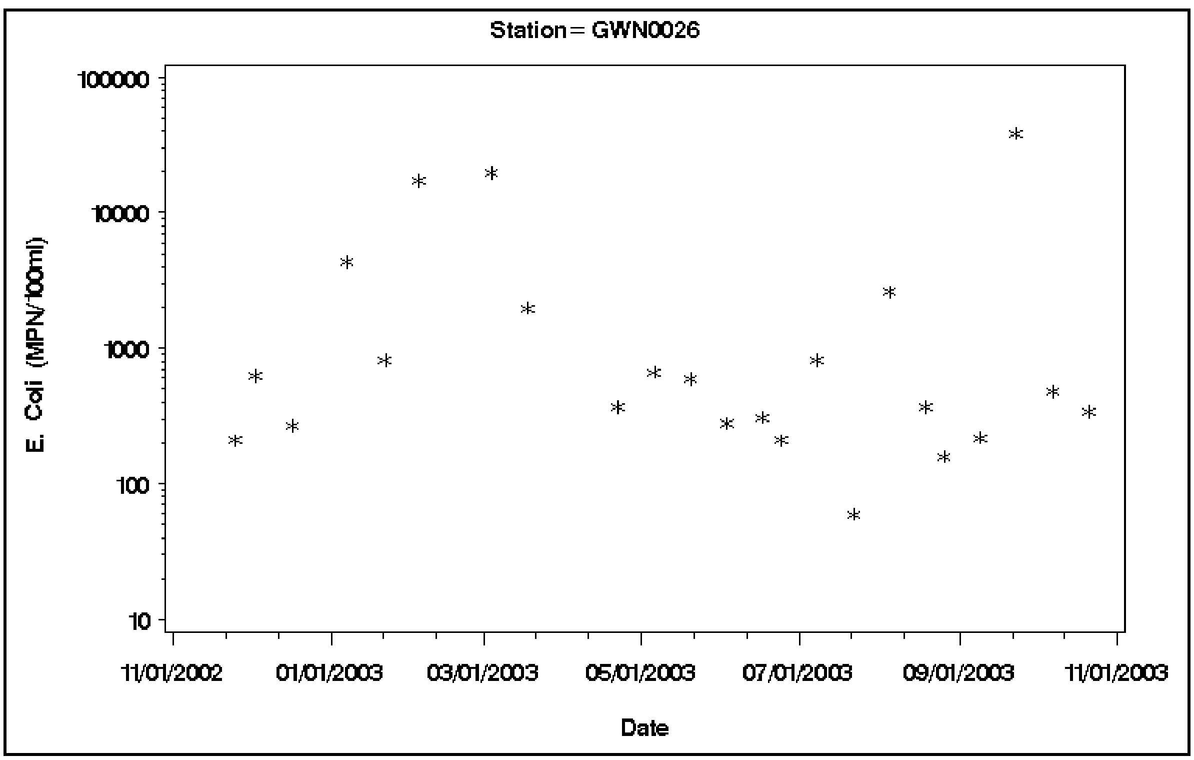

Figure A-2: ***E. coli*** **Concentration vs. Time for MDE Monitoring Station GWN0026**

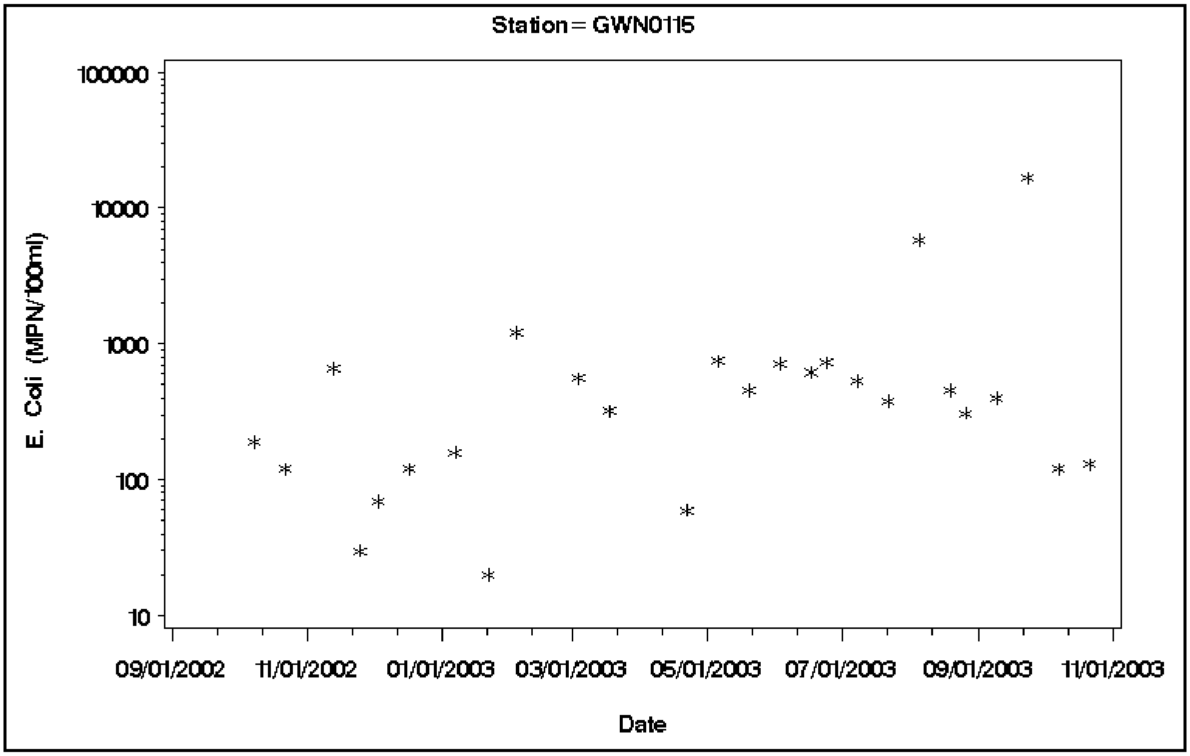

Figure A-3: *E. coli* Concentration vs. Time for MDE Monitoring Station GWN0115

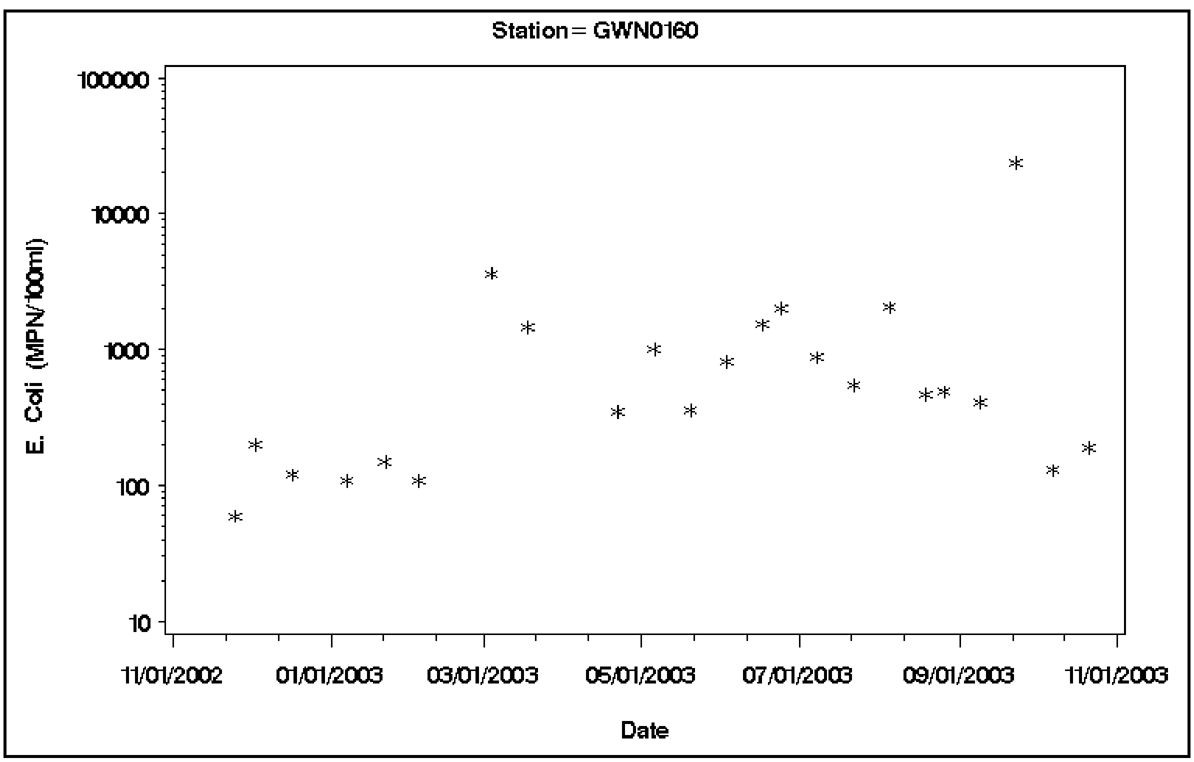

Figure A-4: *E. coli* Concentration vs. Time for MDE Monitoring Station GWN0160

Appendix B - Flow Duration Curve Analysis to Define Strata

The Gwynns 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

There is a United States Geological Survey (USGS) gage station in the Gwynns Falls watershed. The gage flow data are incomplete for this station, therefore the flow for unobserved periods (1/01/1992 to 10/01/1996) was estimated using MDE's Patapsco/Back River watershed SWMM model calibrated to USGS gage station (01589300). The gage and dates of information used are as follows:

Table B-1: USGS Gages used in the Gwynns Falls Watershed

USGS Gage #	Dates used	Description
01589300	October 1, 1996 to January 17, 2006	USGS Active Gage 01589300 on Gwynns Falls at Villa Nova
01589300 (estimate)	Jan 1, 1992 to Dec 31, 1996	Estimated flow based on SWMM calibrated to USGS Gage 01589300 (MDE, 2002)

The flow duration curve for the estimated gage is presented in figure B-1.

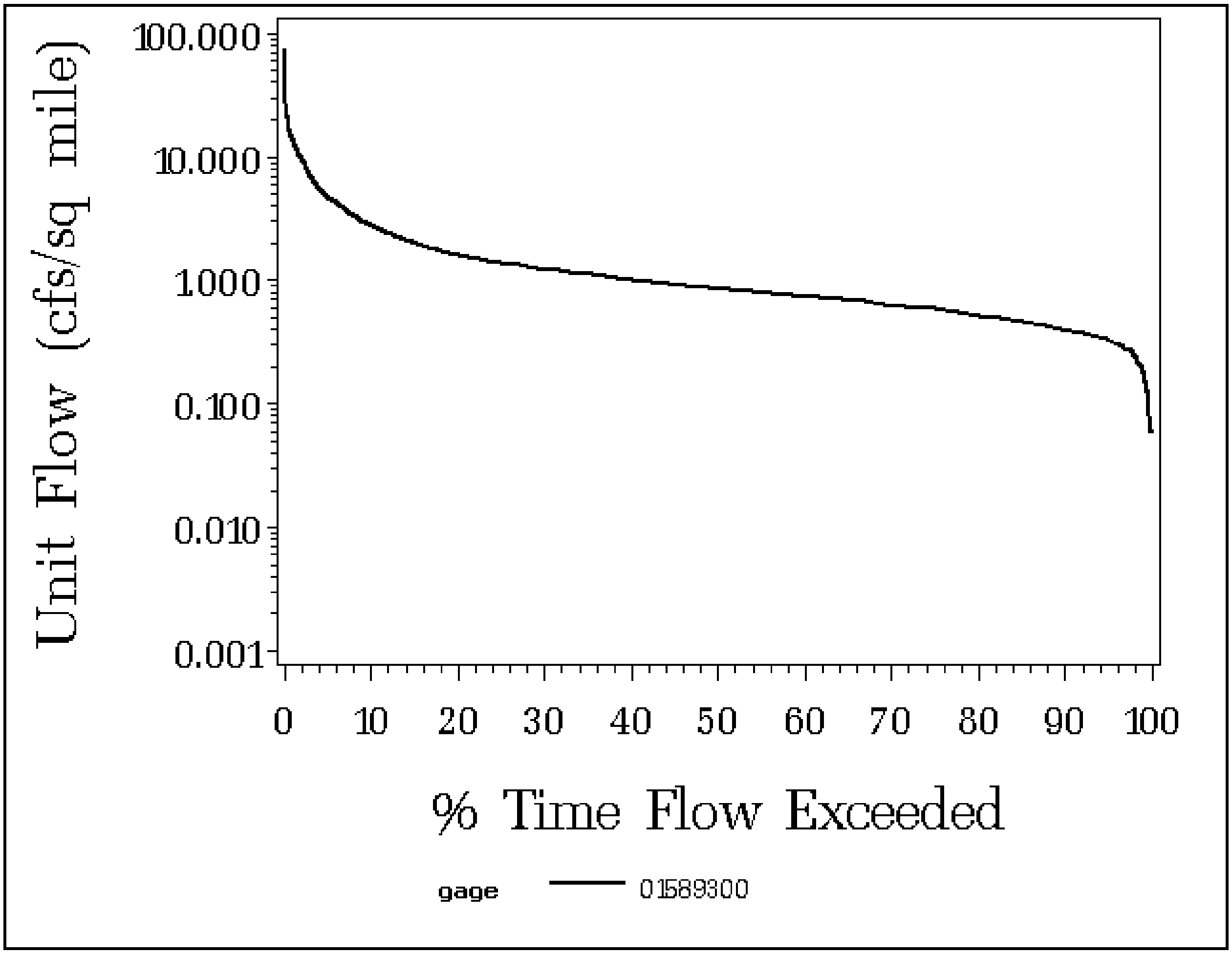

Figure B-1: Gwynns Falls Flow Duration Curves

Based on the long-term flow data for the Gwynns Falls watershed and other watersheds in the area (*i. e.*, Jones Falls, 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 as occurring when flows are higher than the long-term average flow and a low flow condition as occurring when flows are lower than the long-term average flow, the 25th percentile threshold was selected to define the limits between high flow and mid/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 defined as occurring when the daily flow duration percentile is greater than 25%. Definitions of high, mid, 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-5 show the Gwynns 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 Gwynns 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-5.

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

Hydrological Condition		Averaging Period	Water Quality Data Used	Fraction High Flow	Fraction Low Flow
Annual	Average	365 days	All	0.25	0.75
	Wet	365 days	All	0.56	0.44
	Dry	365 days	All	0.06	0.94
Seasonal	Wet	May 1st – Sept 30th	May 1st – Sept 30th	0.46	0.54

	Dry	May 1st – Sept 30th	May 1st – Sept 30th	0.00	1.00

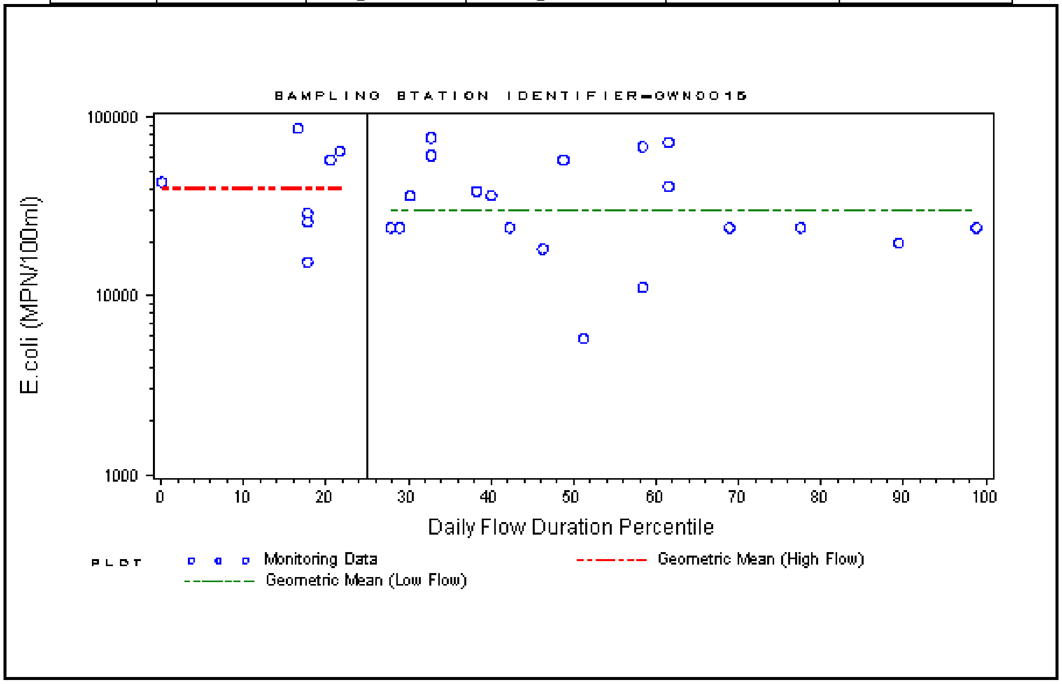

Figure B-2: *E. coli* Concentration vs. Flow Duration for Gwynns Falls Monitoring Station GWN0015 (Average Annual Condition)

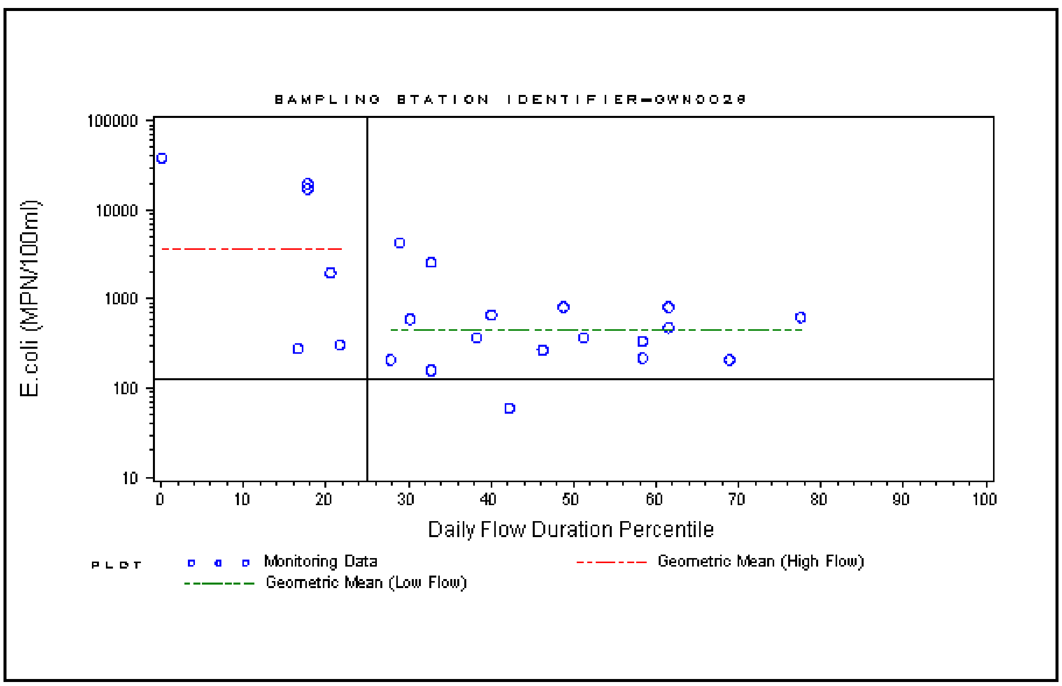

Figure B-3: *E. coli* Concentration vs. Flow Duration for Gwynns Falls Monitoring Station GWN0026 (Average Annual Condition)

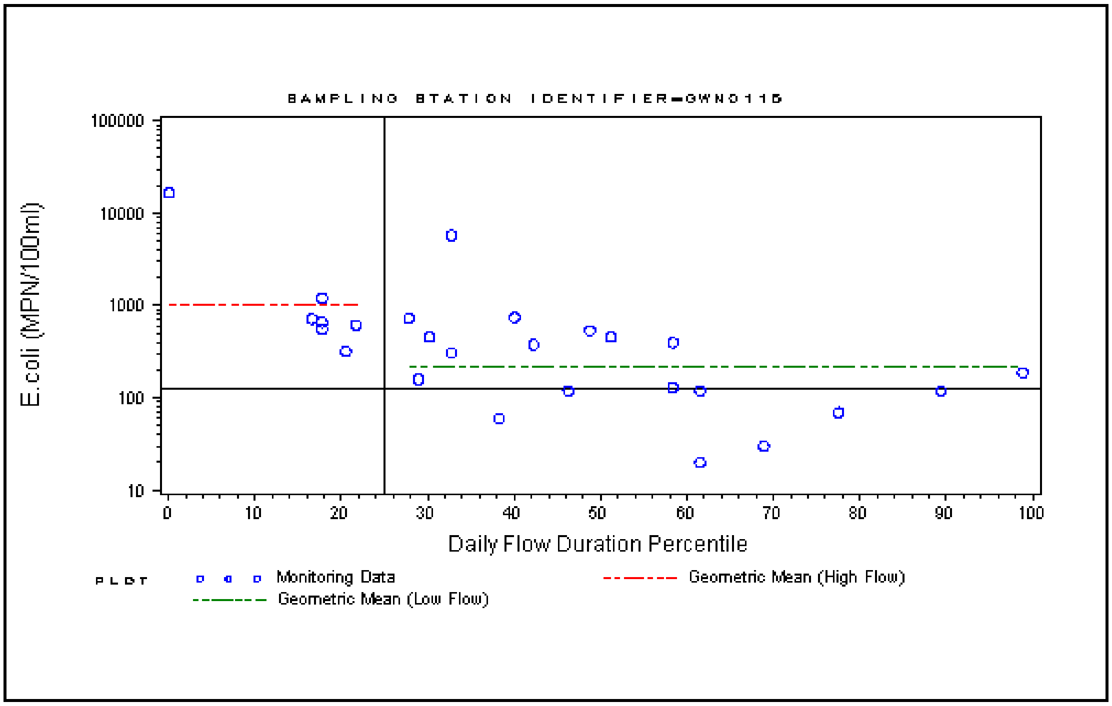

Figure B-4: *E. coli* Concentration vs. Flow Duration for Gwynns Falls Monitoring Station GWN0115 (Average Annual Condition)

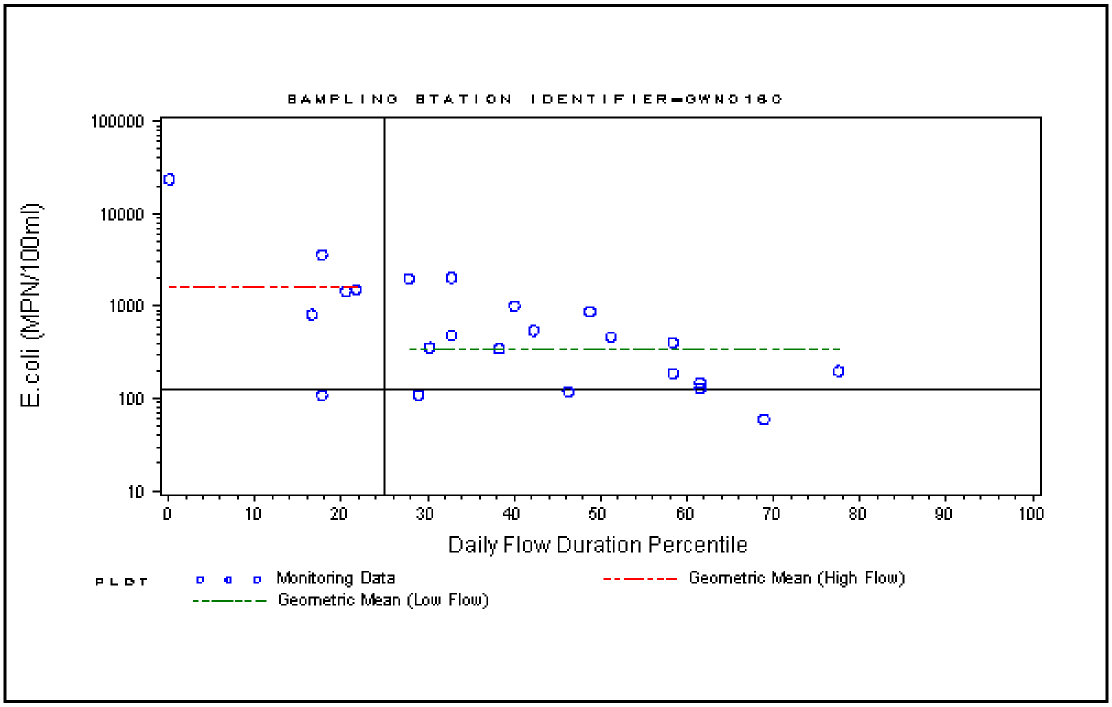

Figure B-5: *E. coli* Concentration vs. Flow Duration for Gwynns Falls Monitoring Station GWN0160 (Average Annual Condition)

Appendix C – Gwynns Falls BST Report

Maryland Department of the Environment

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

November 1, 2003 – October 31, 2005

Final Report
January 31, 2006

Revised 02.03.2006

Mark F. Frana, Ph.D. and Elichia A. Venso, Ph.D.
Co-Principal Investigators
Department of Biological Sciences and
Environmental Health Science
Salisbury University, Salisbury, MD

Table of Contents

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 watershed: Gwynns Falls, Jones Falls, and Herring Run. The methodology used was the ARA with *Enterococcus* spp. as the indicator organism. Previous BST publications have demonstrated the predictive value of using this particular technique and indicator organism (Hagedorn, 1999; Wiggins, 1999).

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

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

LABORATORY METHODS

Isolation of *Enterococcus* from Known-Source Samples. Fecal samples, identified to source, were delivered to the Salisbury University (SU) BST lab by Maryland Department of the Environment (MDE) personnel. Fecal material suspended in phosphate buffered saline was plated onto selective m-Enterococcus agar. After incubation at 37^{o} C, up to 10 *Enterococcus* isolates were randomly selected from each fecal sample for ARA testing.

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

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

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

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

Table C-1: Antibiotics and concentrations used for ARA

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

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). 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.

---

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

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

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

ARA RESULTS

Gwynns Falls Watershed

Known-Source Library. The 710 known-source isolates in the library were grouped into three categories: domestic (pets, specifically dogs), human, and wildlife (deer, 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).

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

Category	Potential Source	Total Isolates	Unique Patterns
Pet	dog	97	48
Human	human	347	240
Wildlife	deer, goose	266	65
Total		**710**	**353**

Table C-3: Gwynns 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%	82%
.375	0	0%	82%
.50	36	5%	83%
.60	85	12%	86%
.70	146	20.5%	88%
.80	199	28%	91%
.90	348	49%	97%

A cutoff probability of 0.80 (80%) was shown to yield a high ARCC of 91%. An increase to a 0.90 (90%) cutoff did not increase the rate of correct classification as much as it increased the percent unknown (Figure C-1). Therefore, using a cutoff probability of 0.80 (80%), the 199 isolates that were not useful in the prediction of probable sources were removed, leaving 511 isolates remaining in the library. This library was then used in the statistical prediction of probable sources of bacteria in water samples collected from Gwynns Falls. The rates of correct classification for the three categories of sources in the library, with a 0.80 (80%) probability cutoff, are shown in Table C-4 below.

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

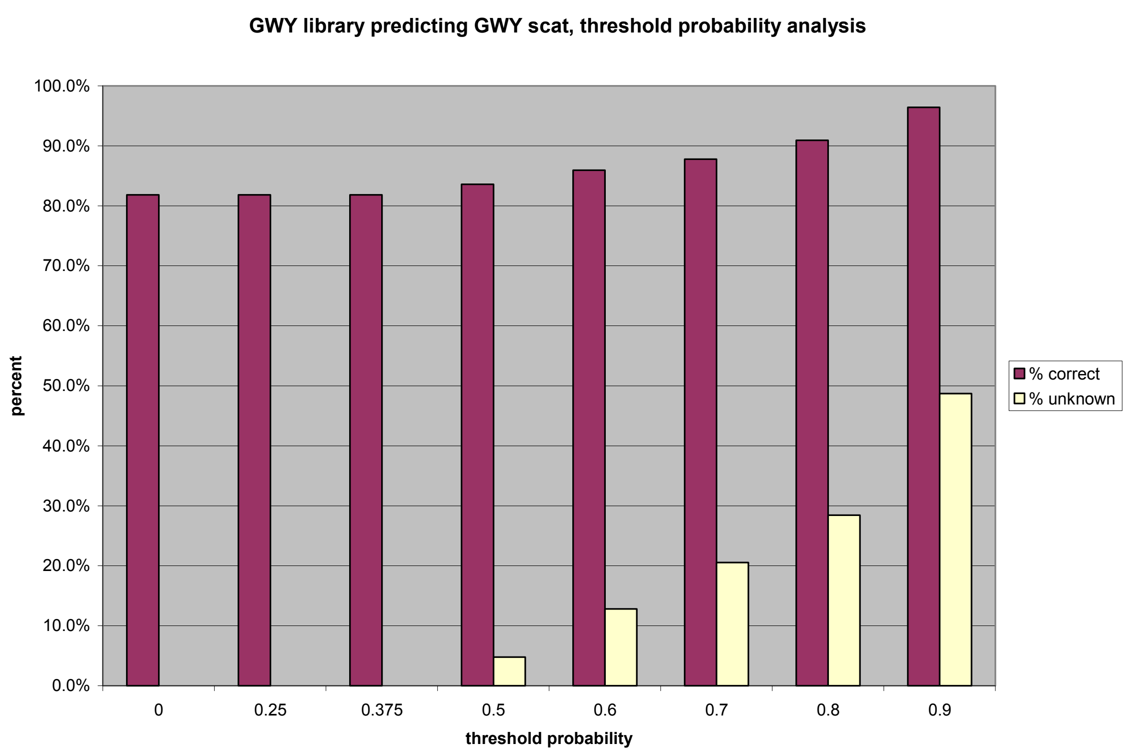

Table C-4: Gwynns Falls. Actual species categories versus predicted categories, at 80% cutoff, with rates of correct classification (RCC) for each category

	Predicted →				
Actual ↓	HUMAN	PET	WILDLIFE	TOTAL	RCC[1]
HUMAN	**250**	11	21	282	89%
PET	1	**48**	3	52	92%
WILDLIFE	7	3	**164**	174	94%
Total	**258**	**62**	**188**	**508**	**91%**

[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%.

Gwynns Falls Water Samples. Monthly monitoring from six (6) stations on Gwynns 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 1231 *Enterococcus* isolates were analyzed by statistical analysis. The BST results by species category, shown in Table C-5, indicates that 87% of the water isolates were classified after excluding unknowns when using an 0.80 (80%) probability cutoff.

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

Category	Number	% Isolates Classified 80% Prob.	% Isolates Classified (excluding unknowns)
DOMESTIC	190	15%	18%
HUMAN	691	56%	64%
WILDLIFE	196	16%	18%
UNKNOWN	154	13%	
Missing Data	0		
Total	1231		
% Classified	**87%**		

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

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

Station	Spring	Summer	Fall	Winter	Total
GWN0015	71	72	92	72	**307**
GWN0026	71	91	47	72	**281**
GWN0115	71	70	91	72	**304**
GWN0160	72	88	63	68	**291**
GWN0186	0	0	24	0	**24**
RDR0001	0	0	24	0	**24**
Total	**285**	**321**	**341**	**284**	**1231**

Tables C-7 through C-11 on the following pages show the results of BST analysis from the estimation of number of isolates per station per date to the final estimation of the overall percentage of bacteria sources by subwatershed.

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

Station	Date	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0015	11/13/2002	3	14	0	3	1
GWN0015	12/3/2002	7	15	0	1	0
GWN0015	1/7/2003	12	12	0	0	0
GWN0015	2/4/2003	2	21	0	0	1
GWN0015	3/4/2003	1	22	0	0	1
GWN0015	4/22/2003	0	20	0	0	3
GWN0015	5/6/2003	8	15	0	0	1
GWN0015	6/3/2003	2	18	0	1	3
GWN0015	7/8/2003	5	17	0	0	2

Station	**Date**	**Domestic %**	**Human %**	**Livestock %**	**Wildlife %**	**Unknown %**
GWN0015	8/5/2003	0	17	0	1	6
GWN0015	9/9/2003	4	13	0	1	6
GWN0015	9/23/2003	3	11	0	1	9
GWN0015	10/8/2003	6	13	0	1	4
GWN0026	12/3/2002	19	5	0	0	0
GWN0026	1/7/2003	10	12	0	0	2
GWN0026	2/4/2003	0	23	0	0	1
GWN0026	3/4/2003	11	13	0	0	0
GWN0026	4/22/2003	0	18	0	3	3
GWN0026	5/6/2003	1	19	0	2	2
GWN0026	6/3/2003	0	19	0	2	2
GWN0026	7/8/2003	6	9	0	4	4
GWN0026	7/22/2003	8	4	0	5	7
GWN0026	8/5/2003	8	9	0	4	3
GWN0026	9/9/2003	4	6	0	4	6
GWN0026	9/23/2003	1	8	0	7	4
GWN0026	10/7/2003	0	2	0	0	1
GWN0115	11/13/2002	0	13	0	9	1
GWN0115	12/3/2002	2	5	0	14	2
GWN0115	1/7/2003	9	15	0	0	0
GWN0115	2/4/2003	11	8	0	0	5
GWN0115	3/4/2003	1	16	0	3	4
GWN0115	4/22/2003	10	8	0	4	2

Station	Date	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0115	5/6/2003	2	12	0	9	1
GWN0115	6/3/2003	0	10	0	8	5
GWN0115	7/8/2003	4	9	0	6	4
GWN0115	8/5/2003	1	15	0	4	4
GWN0115	9/9/2003	2	13	0	7	1
GWN0115	9/23/2003	1	11	0	0	12
GWN0115	10/7/2003	0	0	0	16	5
GWN0160	12/3/2002	0	23	0	0	0
GWN0160	1/7/2003	5	10	0	7	0
GWN0160	2/4/2003	1	17	0	4	2
GWN0160	3/4/2003	2	18	0	0	2
GWN0160	4/22/2003	2	16	0	3	3
GWN0160	5/6/2003	3	16	0	4	1
GWN0160	6/3/2003	7	13	0	3	1
GWN0160	7/8/2003	0	14	0	9	0
GWN0160	7/22/2003	4	8	0	6	6
GWN0160	8/5/2003	1	19	0	0	3
GWN0160	9/9/2003	0	9	0	6	3
GWN0160	9/23/2003	0	13	0	7	4
GWN0160	10/7/2003	1	2	0	6	7

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

Station	Date	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0015	11/13/2002	14.29	66.67	0.00	14.29	4.76
GWN0015	12/3/2002	30.43	65.22	0.00	4.35	0.00
GWN0015	1/7/2003	50.00	50.00	0.00	0.00	0.00
GWN0015	2/4/2003	8.33	87.50	0.00	0.00	4.17
GWN0015	3/4/2003	4.17	91.67	0.00	0.00	4.17
GWN0015	4/22/2003	0.00	86.96	0.00	0.00	13.04
GWN0015	5/6/2003	33.33	62.50	0.00	0.00	4.17
GWN0015	6/3/2003	8.33	75.00	0.00	4.17	12.50
GWN0015	7/8/2003	20.83	70.83	0.00	0.00	8.33
GWN0015	8/5/2003	0.00	70.83	0.00	4.17	25.00
GWN0015	9/9/2003	16.67	54.17	0.00	4.17	25.00
GWN0015	9/23/2003	12.50	45.83	0.00	4.17	37.50
GWN0015	10/8/2003	25.00	54.17	0.00	4.17	16.67
GWN0026	12/3/2002	79.17	20.83	0.00	0.00	0.00
GWN0026	1/7/2003	41.67	50.00	0.00	0.00	8.33
GWN0026	2/4/2003	0.00	95.83	0.00	0.00	4.17
GWN0026	3/4/2003	45.83	54.17	0.00	0.00	0.00
GWN0026	4/22/2003	0.00	75.00	0.00	12.50	12.50
GWN0026	5/6/2003	4.17	79.17	0.00	8.33	8.33
GWN0026	6/3/2003	0.00	82.61	0.00	8.70	8.70
GWN0026	7/8/2003	26.09	39.13	0.00	17.39	17.39
GWN0026	7/22/2003	33.33	16.67	0.00	20.83	29.17

Station	Date	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0026	8/5/2003	33.33	37.50	0.00	16.67	12.50
GWN0026	9/9/2003	20.00	30.00	0.00	20.00	30.00
GWN0026	9/23/2003	5.00	40.00	0.00	35.00	20.00
GWN0026	10/7/2003	0.00	66.67	0.00	0.00	33.33
GWN0115	11/13/2002	0.00	56.52	0.00	39.13	4.35
GWN0115	12/3/2002	8.70	21.74	0.00	60.87	8.70
GWN0115	1/7/2003	37.50	62.50	0.00	0.00	0.00
GWN0115	2/4/2003	45.83	33.33	0.00	0.00	20.83
GWN0115	3/4/2003	4.17	66.67	0.00	12.50	16.67
GWN0115	4/22/2003	41.67	33.33	0.00	16.67	8.33
GWN0115	5/6/2003	8.33	50.00	0.00	37.50	4.17
GWN0115	6/3/2003	0.00	43.48	0.00	34.78	21.74
GWN0115	7/8/2003	17.39	39.13	0.00	26.09	17.39
GWN0115	8/5/2003	4.17	62.50	0.00	16.67	16.67
GWN0115	9/9/2003	8.70	56.52	0.00	30.43	4.35
GWN0115	9/23/2003	4.17	45.83	0.00	0.00	50.00
GWN0115	10/7/2003	0.00	0.00	0.00	76.19	23.81
GWN0160	12/3/2002	0.00	100.00	0.00	0.00	0.00
GWN0160	1/7/2003	22.73	45.46	0.00	31.82	0.00
GWN0160	2/4/2003	4.17	70.83	0.00	16.67	8.33
GWN0160	3/4/2003	9.09	81.82	0.00	0.00	9.09
GWN0160	4/22/2003	8.33	66.67	0.00	12.50	12.50
GWN0160	5/6/2003	12.50	66.67	0.00	16.67	4.17

Station	Date	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0160	6/3/2003	29.17	54.17	0.00	12.50	4.17
GWN0160	7/8/2003	0.00	60.87	0.00	39.13	0.00
GWN0160	7/22/2003	16.67	33.33	0.00	25.00	25.00
GWN0160	8/5/2003	4.35	82.61	0.00	0.00	13.04
GWN0160	9/9/2003	0.00	50.00	0.00	33.33	16.67
GWN0160	9/23/2003	0.00	54.17	0.00	29.17	16.67
GWN0160	10/7/2003	6.25	12.50	0.00	37.50	43.75

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

Station	Date	Flow Regime	*E. coli* Concentration (MPN/100ml)	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0015	11/13/02	High	15530	14.29	66.67	0.00	14.29	4.76
GWN0015	02/04/03	High	26000	8.33	87.50	0.00	0.00	4.17
GWN0015	03/04/03	High	29100	4.17	91.67	0.00	0.00	4.17
GWN0015	03/18/03	High	57900	.	.	.	.	.
GWN0015	06/03/03	High	86600	8.33	75.00	0.00	4.17	12.50
GWN0015	06/17/03	High	64900	.	.	.	.	.
GWN0015	09/23/03	High	43500	12.50	45.83	0.00	4.17	37.50
GWN0026	02/04/03	High	17330	0.00	95.83	0.00	0.00	4.17
GWN0026	03/04/03	High	19860	45.83	54.17	0.00	0.00	0.00
GWN0026	03/18/03	High	1990	.	.	.	.	.
GWN0026	06/03/03	High	280	0.00	82.61	0.00	8.70	8.70
GWN0026	06/17/03	High	310	.	.	.	.	.
GWN0026	09/23/03	High	38700	5.00	40.00	0.00	35.00	20.00
GWN0115	11/13/02	High	660	0.00	56.52	0.00	39.13	4.35
GWN0115	02/04/03	High	1210	45.83	33.33	0.00	0.00	20.83
GWN0115	03/04/03	High	560	4.17	66.67	0.00	12.50	16.67
GWN0115	03/18/03	High	320	.	.	.	.	.
GWN0115	06/03/03	High	720	0.00	43.48	0.00	34.78	21.74
GWN0115	06/17/03	High	620	.	.	.	.	.
GWN0115	09/23/03	High	16700	4.17	45.83	0.00	0.00	50.00
GWN0160	02/04/03	High	110	4.17	70.83	0.00	16.67	8.33
GWN0160	03/04/03	High	3650	9.09	81.82	0.00	0.00	9.09

Station	Date	Flow Regime	*E. coli* Concentration (MPN/100ml)	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0160	03/18/03	High	1460	.	.	.	.	.
GWN0160	06/03/03	High	820	29.17	54.17	0.00	12.50	4.17
GWN0160	06/17/03	High	1530	.	.	.	.	.
GWN0160	09/23/03	High	23800	0.00	54.17	0.00	29.17	16.67
GWN0015	10/08/02	Low	24190	.	.	.	.	.
GWN0015	10/22/02	Low	19860	.	.	.	.	.
GWN0015	11/25/02	Low	24190	.	.	.	.	.
GWN0015	12/03/02	Low	24190	30.43	65.22	0.00	4.35	0.00
GWN0015	12/17/02	Low	18400	.	.	.	.	.
GWN0015	01/07/03	Low	24190	50.00	50.00	0.00	0.00	0.00
GWN0015	01/22/03	Low	72700	.	.	.	.	.
GWN0015	04/22/03	Low	38700	0.00	86.96	0.00	0.00	13.04
GWN0015	05/06/03	Low	36500	33.33	62.50	0.00	0.00	4.17
GWN0015	05/20/03	Low	36500	.	.	.	.	.
GWN0015	06/24/03	Low	24190	.	.	.	.	.
GWN0015	07/08/03	Low	57900	20.83	70.83	0.00	0.00	8.33
GWN0015	07/22/03	Low	24190	.	.	.	.	.
GWN0015	08/05/03	Low	77000	0.00	70.83	0.00	4.17	25.00
GWN0015	08/19/03	Low	5800	.	.	.	.	.
GWN0015	08/26/03	Low	61300	.	.	.	.	.
GWN0015	09/09/03	Low	68700	16.67	54.17	0.00	4.17	25.00
GWN0015	10/07/03	Low	41100	.	.	.	.	.
GWN0015	10/21/03	Low	11200	.	.	.	.	.

Station	Date	Flow Regime	*E. coli* Concentration (MPN/100ml)	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0026	11/25/02	Low	210	.	.	.	.	.
GWN0026	12/03/02	Low	630	79.17	20.83	0.00	0.00	0.00
GWN0026	12/17/02	Low	270	.	.	.	.	.
GWN0026	01/07/03	Low	4350	41.67	50.00	0.00	0.00	8.33
GWN0026	01/22/03	Low	820	.	.	.	.	.
GWN0026	04/22/03	Low	370	0.00	75.00	0.00	12.50	12.50
GWN0026	05/06/03	Low	670	4.17	79.17	0.00	8.33	8.33
GWN0026	05/20/03	Low	600	.	.	.	.	.
GWN0026	06/24/03	Low	210	.	.	.	.	.
GWN0026	07/08/03	Low	820	26.09	39.13	0.00	17.39	17.39
GWN0026	07/22/03	Low	60	33.33	16.67	0.00	20.83	29.17
GWN0026	08/05/03	Low	2600	33.33	37.50	0.00	16.67	12.50
GWN0026	08/19/03	Low	370	.	.	.	.	.
GWN0026	08/26/03	Low	160	.	.	.	.	.
GWN0026	09/09/03	Low	220	20.00	30.00	0.00	20.00	30.00
GWN0026	10/07/03	Low	480	0.00	66.67	0.00	0.00	33.33
GWN0026	10/21/03	Low	340	.	.	.	.	.
GWN0115	10/08/02	Low	190	.	.	.	.	.
GWN0115	10/22/02	Low	120	.	.	.	.	.
GWN0115	11/25/02	Low	30	.	.	.	.	.
GWN0115	12/03/02	Low	70	8.70	21.74	0.00	60.87	8.70
GWN0115	12/17/02	Low	120	.	.	.	.	.
GWN0115	01/07/03	Low	160	37.50	62.50	0.00	0.00	0.00

Station	**Date**	**Flow Regime**	***E. coli* Concentration (MPN/100ml)**	**Domestic %**	**Human %**	**Livestock %**	**Wildlife %**	**Unknown %**
GWN0115	01/22/03	Low	20	.	.	.	.	.
GWN0115	04/22/03	Low	60	41.67	33.33	0.00	16.67	8.33
GWN0115	05/06/03	Low	750	8.33	50.00	0.00	37.50	4.17
GWN0115	05/20/03	Low	460	.	.	.	.	.
GWN0115	06/24/03	Low	730	.	.	.	.	.
GWN0115	07/08/03	Low	540	17.39	39.13	0.00	26.09	17.39
GWN0115	07/22/03	Low	380	.	.	.	.	.
GWN0115	08/05/03	Low	5790	4.17	62.50	0.00	16.67	16.67
GWN0115	08/19/03	Low	460	.	.	.	.	.
GWN0115	08/26/03	Low	310	.	.	.	.	.
GWN0115	09/09/03	Low	400	8.70	56.52	0.00	30.43	4.35
GWN0115	10/07/03	Low	120	0.00	0.00	0.00	76.19	23.81
GWN0115	10/21/03	Low	130	.	.	.	.	.
GWN0160	11/25/02	Low	60	.	.	.	.	.
GWN0160	12/03/02	Low	200	0.00	100.00	0.00	0.00	0.00
GWN0160	12/17/02	Low	120	.	.	.	.	.
GWN0160	01/07/03	Low	110	22.73	45.46	0.00	31.82	0.00
GWN0160	01/22/03	Low	150	.	.	.	.	.
GWN0160	04/22/03	Low	350	8.33	66.67	0.00	12.50	12.50
GWN0160	05/06/03	Low	1020	12.50	66.67	0.00	16.67	4.17
GWN0160	05/20/03	Low	360	.	.	.	.	.
GWN0160	06/24/03	Low	2010	.	.	.	.	.
GWN0160	07/08/03	Low	880	0.00	60.87	0.00	39.13	0.00

Station	Date	Flow Regime	*E. coli* Concentration (MPN/100ml)	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0160	07/22/03	Low	550	16.67	33.33	0.00	25.00	25.00
GWN0160	08/05/03	Low	2050	4.35	82.61	0.00	0.00	13.04
GWN0160	08/19/03	Low	470	.	.	.	.	.
GWN0160	08/26/03	Low	490	.	.	.	.	.
GWN0160	09/09/03	Low	410	0.00	50.00	0.00	33.33	16.67
GWN0160	10/07/03	Low	130	6.25	12.50	0.00	37.50	43.75
GWN0160	10/21/03	Low	190	.	.	.	.	.
GWN0015	10/08/03	.	.	25.00	54.17	0.00	4.17	16.67

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

Station	Flow Regime	Domestic %	Human %	Livestock %	Wildlife %	Unknown %
GWN0015	High	9.47	73.21	0.00	4.41	12.92
GWN0015	Low	21.12	65.88	0.00	1.84	11.16
GWN0026	High	14.12	65.80	0.00	11.68	8.39
GWN0026	Low	27.28	47.16	0.00	9.90	15.66
GWN0115	High	10.83	48.51	0.00	15.52	25.14
GWN0115	Low	14.21	43.77	0.00	31.26	10.76
GWN0160	High	9.76	64.44	0.00	15.36	10.43
GWN0160	Low	7.56	59.03	0.00	21.04	12.37

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

Station	Domestic %	Human %	Livestock %	Wildlife %	Unknown %	Total
GWN0015	18.21	67.71	0.00	2.48	11.60	100
GWN0026	23.99	51.82	0.00	10.34	13.84	100
GWN0115	13.37	44.95	0.00	27.32	14.36	100
GWN0160	8.11	60.39	0.00	19.62	11.88	100

Gwynns Falls Summary

The use of ARA was successful for identification of bacterial sources in the Gwynns Falls Watershed as evidenced by the high ARCC (91%) for the library. The lowest RCC (for human) is very acceptable 89%. When water isolates were compared to the library and potential sources predicted, 87% of the isolates were classified by statistical analysis. The largest category of potential sources in the watershed as a whole was human (64%), followed by domestic and wildlife, (both 18% of the classified isolates, respectively).

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.

ACKNOWLEDGEMENTS

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