FINAL

Total Maximum Daily Loads of Bacteria for Impaired Recreational Areas in Marley Creek and Furnace Creek of Baltimore Harbor Basin in Anne Arundel County, Maryland

MARYLAND

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Submitted to:

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July 2010

EPA Submittal Date: Sept. 9, 2010
EPA Approval Date: March 10, 2011

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List of Abbreviations

ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
CFR	Code of Federal Regulations
cms	Cubic Meters per Second
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
EFDC	Environmental Fluid Dynamics Code
EPA	Environmental Protection Agency
FA	Future Allocation
FDA	U.S. Food and Drug Administration
GIS	Geographic Information System
K_1	Diurnal tidal constituent with a tidal period of 23.93 hours
K_2	Semi-diurnal tidal constituent with a tidal period of 11.97 hours
km	Kilometer
LA	Load Allocation
L_D	Load From Diffuse Sources
m	Meter
M_2	Semi-diurnal tidal constituent with a tidal period of 12.42 hours
MACS	Maryland Agricultural Cost Share Program
MDE	Maryland Department of the Environment
MDP	Maryland Department of Planning
mgd	Million Gallons per Day
ml	Milliliter(s)
MOS	Margin of Safety
MPN	Most Probable Number
MS4	Municipal Separate Storm Sewer Systems
MSSCC	Maryland State's Soil Conservation Committee
N_2	Semi-diurnal tidal constituent with a tidal period of 12.66 hours
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSSP	National Shellfish Sanitation Program
O_1	Diurnal tidal constituent with a tidal period of 25.82 hours
PCBs	polychlorinated biphenyls
S_2	Semi-diurnal tidal constituent with a tidal period of 12.00 hours
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
VIMS	Virginia Institute of Marine Science
WLA	Wasteload Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for bacteria in Marley Creek and Furnace Creek within the Baltimore Harbor watershed (MD basin number 02130903, AU-IDs: MD-PATMH-FURNACE_CREEK and MD-PATMH-MARLEY_CREEK). Section 303(d) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, states are required to either establish a TMDL of the specified substance that the waterbody can receive without violating water quality standards or demonstrate that water quality standards are being met.

Marley Creek and Furnace Creek are located in Anne Arundel County. They are designated as Use I: Water Contact Recreation and Protection of Nontidal Warmwater Aquatic Life (COMAR 26.08.02.02). Marley Creek and Furnace Creek were first identified on the 1998 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE). The designated use in the creeks were listed as impaired by elevated levels of bacteria. In the *2008 Integrated Report of Surface Water Quality* (MDE 2008), the bacteria impairment (enterococci) was clarified for these creeks. The designated uses in Baltimore Harbor were listed as impaired by sediments (1996), nutrients (1996), bacteria (1998), polychlorinated biphenyls (PCBs, 1998), various metals (1998), impacts to biological communities (2002) and debris/floatables/trash (2008). This document, upon EPA approval, establishes a TMDL for enterococci bacteria in Marley Creek and Furnace Creek, which will allow for the attainment of their designated use. A TMDL was completed for the nutrient listing in 2007. The listings for sediments, impacts to biological communities, PCBs, metals and debris/floatables/trash in the Baltimore Harbor Basin will be addressed at a future date.

An inverse modeling approach using a three-dimensional model, the Environmental Fluid Dynamics Code (EFDC) model, was used to estimate current bacteria loads and to establish allowable loads for the waters of the impaired recreational areas in Marley Creek and Furnace Creek. The inverse three-dimensional model incorporates influences of freshwater discharge, tidal and density-induced transport, and bacteria decay, thereby representing the fate and transport of bacteria in the area. The loadings from potential sources (human, livestock, pets and wildlife) were assessed based on the bacteria source tracking (BST) data.

The allowable bacteria load for the area was computed using a geometric mean concentration water quality criterion for enterococci of 35 cfu/100ml for steady-state, dry weather conditions during the beach season (from Memorial Day to Labor Day). An implicit Margin of Safety (MOS) was incorporated into the analysis to account for uncertainty. The TMDLs developed for Marley Creek and Furnace Creek watersheds for enterococci are as follows:

Waterbody	Enterococci Baseline Load [counts per day]	Enterococci TMDL [counts per day]
Marley Creek	6.19×10^{12}	1.50×10^{12}
Furnace Creek	3.66×10^{12}	8.14×10^{11}

The goal of TMDL allocation is to determine the maximum allowable loads from each known source in the watershed that will ensure the attainment of the water quality standard. The TMDL allocations proposed in this document were developed based on the scenario requiring the biggest percent reduction. For Marley Creek and Furnace Creek, the available steady-state data were collected during beach seasons from 2005 to 2008. For a conservative purpose, the maximum two-year-rolling geometric mean concentration of Enterococci from 2005 to 2008 was chosen to estimate the baseline load. The TMDLs require a reduction of bacteria of 75.75% for Marley Creek, and 77.79% for Furnace Creek, respectively.

Once EPA has approved this TMDL, MDE will begin an iterative process of implementation, focusing first on those sources that have the greatest impact on water quality (i.e., contact recreation) while giving consideration to the relative ease of implementation and cost. The source contributions identified during the BST survey may be used as a tool to target and prioritize initial implementation efforts.

1.0 INTRODUCTION

Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each State to develop a Total Maximum Daily Load (TMDL) for each impaired water quality limited segment (WQLS) on the Section 303(d) list, taking into account seasonal variations and including a protective margin of safety (MOS) to account for scientific uncertainty (CFR 2006a). 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/or numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

Marley Creek and Furnace Creek are located in Anne Arundel County. They are designated as Use I: Water Contact Recreation, and Protection of Nontidal Warmwater Aquatic Life (COMAR 26.08.02.02). Marley Creek and Furnace Creek (MD basin number 02130903, AU-IDs: MD-PATMH-FURNACE_CREEK and MD-PATMH-MARLEY_CREEK) were first identified on the 1998 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE). The designated use in the creeks were listed as impaired by elevated levels of bacteria. In the *2008 Integrated Report of Surface Water Quality* (MDE 2008), the bacteria impairment (enterococci) was clarified for these creeks. The designated uses in Baltimore Harbor were listed as impaired by sediments (1996), nutrients (1996), bacteria (1998), polychlorinated biphenyls (PCBs, 1998), various metals (1998), impacts to biological communities (2002) and debris/floatables/trash (2008). This document, upon EPA approval, establishes a TMDL for enterococci bacteria in Marley Creek and Furnace Creek, which will allow for the attainment of their designated use. A TMDL was completed for the nutrient listing in 2007. The listings for sediments, impacts to biological communities, PCBs, metals and debris/floatables/trash in the Baltimore Harbor Basin will be addressed at a future date.

Fecal bacteria are microscopic single-celled organisms (primarily fecal coliform and fecal Streptococci) found in the intestinal tracts of humans and other 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 human. Infections due to pathogen-contaminated recreation waters include gastrointestinal, respiratory, eye, ear, nose, throat, and skin diseases (USEPA 1986).

In 1986, EPA published “Ambient Water Quality Criteria for Bacteria”, in which three indicator organisms were assessed to determine their correlation with swimming-associated illnesses: fecal coliform, *E. coli* and enterococci. Fecal coliform bacteria are a subgroup of total coliform bacteria and *E. coli* bacteria are a subgroup of fecal coliform. Most fecal coliform bacteria are harmless and are found in great quantities in the intestines of warm-blooded organisms, including the human population. 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 epidemiological studies conducted by EPA demonstrated that *E. coli* and enterococci had the best quantifiable relationship between the density of an indicator in the water and the potential human health risks associated with swimming in sewage contaminated waters.

Maryland promulgated EPA's 1986 bacteria criteria in 2004 for all Use I waters - enterococci (marine or freshwater) and *E. coli* (freshwater only). Maryland's bacteria indicator criteria are conservative and protect public from the potential risks associated with swimming and other primary contact recreation activities. A few high values of the indicator may or may not be indicative of impairment. Therefore, it is necessary to evaluate the results from indicator organisms from multiple sampling events over time to adequately quantify water quality conditions (MDE 2008).

The bacteria impairment for Marley Creek and Furnace Creek was based on data collected by Anne Arundel County Health department. MDE works closely with county health departments who also submit monitoring data to MDE. In this study, the criterion for Use I waters, adopted by MDE is that the steady-state geometric mean density of enterococci shall not exceed 35 cfu/100 ml (MDE 2008).

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Marley Creek and Furnace Creek are located in Anne Arundel County, as shown in Figure 2.1.1. Furnace Creek drains to Marley Creek, and the latter drains to Curtis Creek, which eventually discharges to the Patapsco River. The drainage area, affecting the water quality of the impaired area of Marley Creek and Furnace Creek, is 16,728 acres (67.7 km^2).

The 2000 Maryland Department of Planning (MDP) land use/land cover data show that the Marley Creek and Furnace Creek watershed can be primarily characterized as urban, with 68% of the area being urban. About 25% of the area is forested. The land use information for the impaired recreational area in Marley Creek and Furnace Creek Basin is shown in Table 2.1.1 and Figure 2.1.2. Residential urban land use identified in Table 2.1.1 includes low-density residential, medium-density residential, and high-density residential. Non-residential urban land use in this table includes commercial, industrial, institutional, extractive, and open urban land.

The dominant tide in this region is the lunar semi-diurnal (M_2) tide, with a tidal range of 0.335 m at the nearby tidal station - Fort Carroll with a tidal period of 12.42 hours (NOAA 2009). Because of tidal fluctuation, loading discharged from the subwatersheds located upstream and downstream have an effect on the impaired area. The drainage basin of the impaired area is determined based on the characteristics of tidal induced bacteria transport in the area.

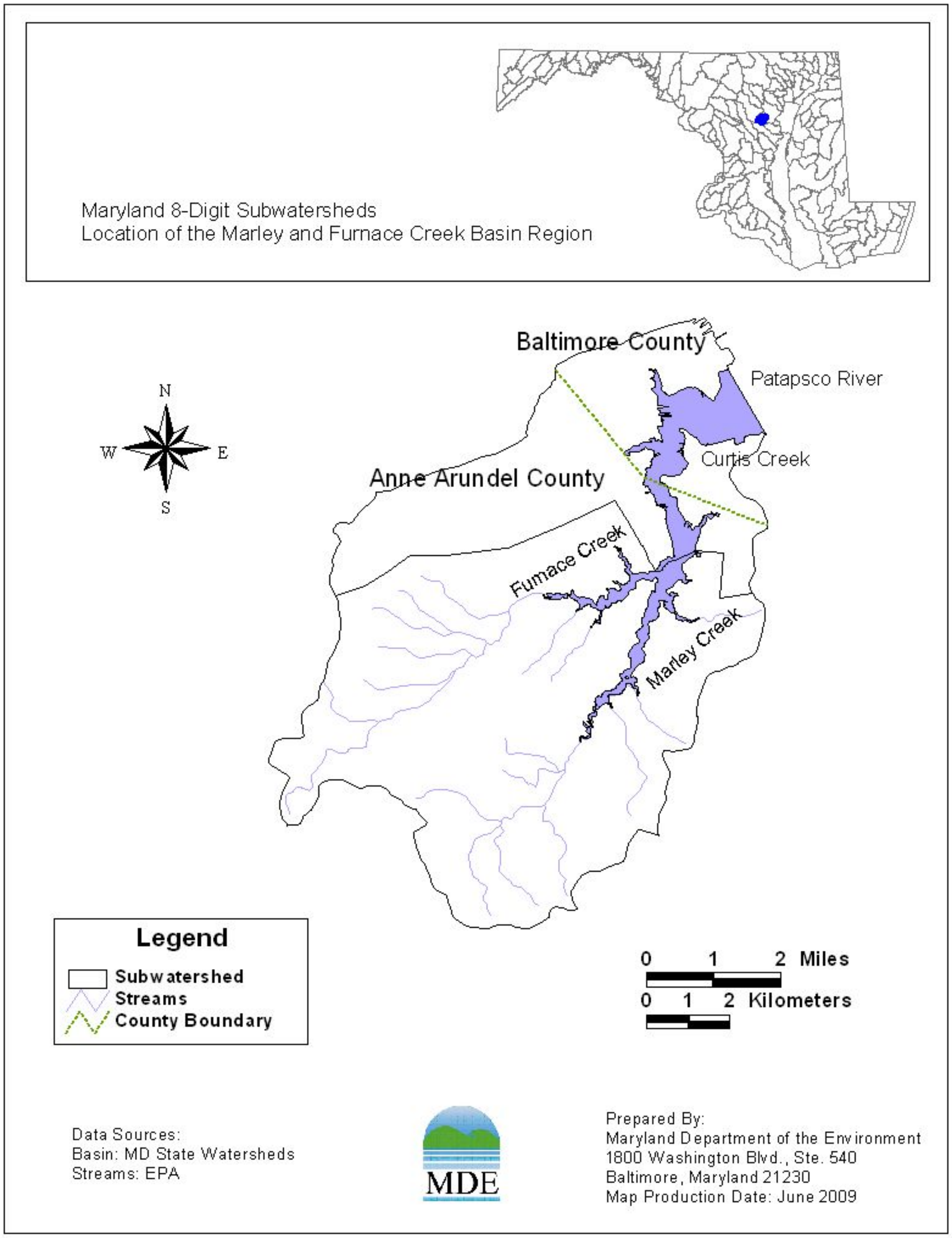

Figure 2.1.1: Location Map of Marley Creek and Furnace Creek

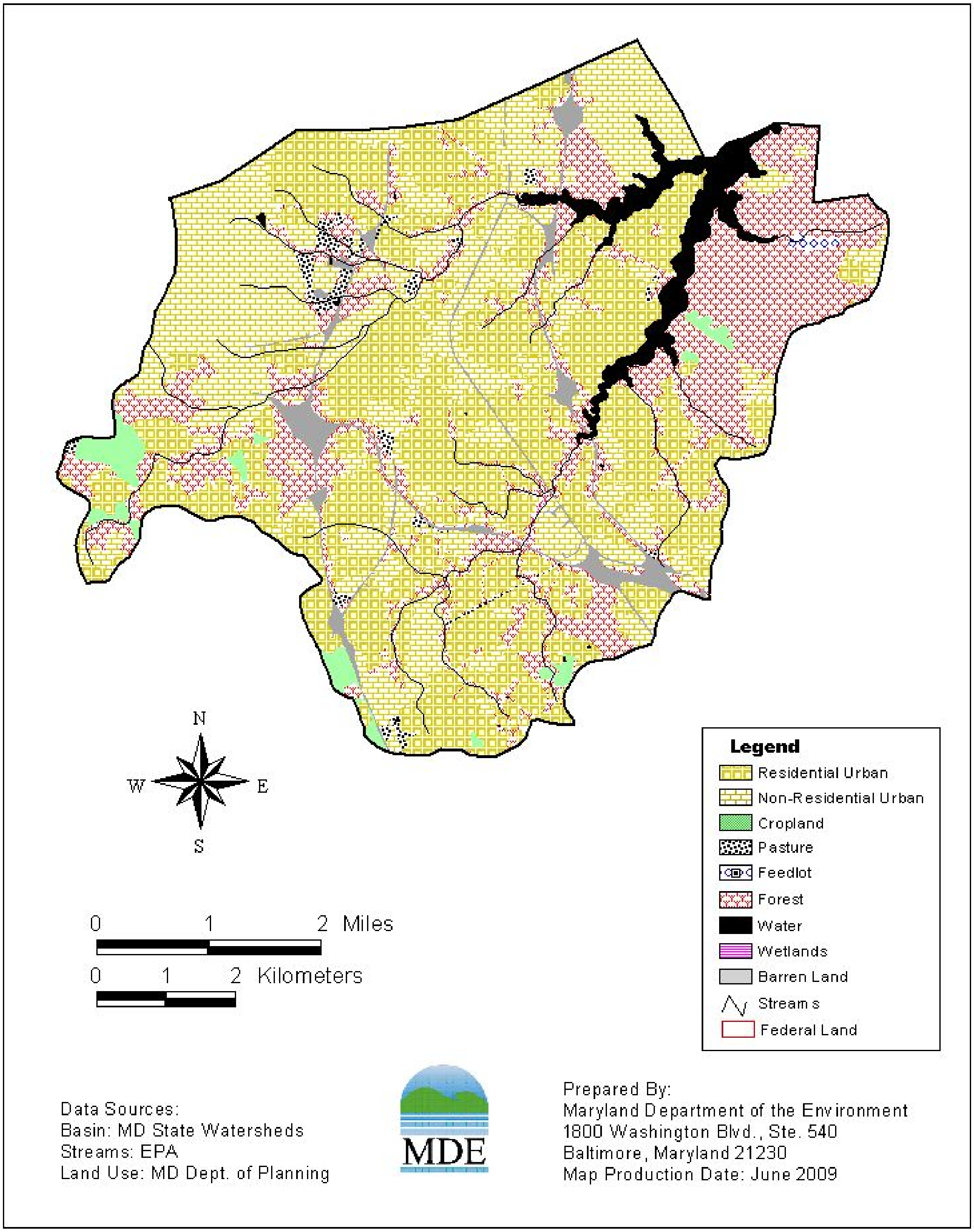

Figure 2.1.2: Land Use of Marley Creek and Furnace Creek Watersheds

Table 2.1.1: Land Use Percentage Distribution for Marley and Furnace Creek Watershed

Land Type	Marley Creek		Furnace Creek	
	Acre	%	Acre	%
Residential urban[1]	3,770.6	45.0	3,004.7	36.0
Non-Residential urban[2]	1,301.4	15.5	3,295.0	39.5
Cropland	154.6	1.8	183.4	2.2
Pasture	74.9	0.9	136.7	1.6
Feedlot	32.2	0.4	0.0	0.0
Forest	2,771.1	33.1	1,410.4	16.9
Water	3.2	0.0	9.8	0.1
Wetlands	6.1	0.0	0.0	0.0
Barren	268.5	3.2	305.8	3.7
Totals	**8,382.5**	**100**	**8,345.8**	**100**

Notes: [1] Includes low-density residential, medium-density residential, and high-density residential.
[2] Includes commercial, industrial, institutional, extractive, and open urban land.

2.2 Water Quality Characterization

EPA's guidance document, "Ambient Water Quality Criteria for Bacteria" (USEPA 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).

In Maryland, areas for recreational use (beaches) are monitored from at least two weeks before Memorial Day through Labor Day. Enterococci are used for this water quality assessment. There are six bacteria monitoring stations in the impaired recreational area of Marley Creek and Furnace Creek addressed in this report (Figure 2.2.1). The station identification and observations recorded during beach seasons from 2005 to 2008 are provided in Table 2.2.1. From 2005 to 2007, there was single observation of enterococci value in each sampling event, while in 2008 there were three observations in each sampling event (Figures 2.2.2-2.2.7). The presented observations are conducted each beach season during dry weather conditions, which represent a steady-state condition during the beach season. A tabulation of observed enterococci values are provided in Appendix E.

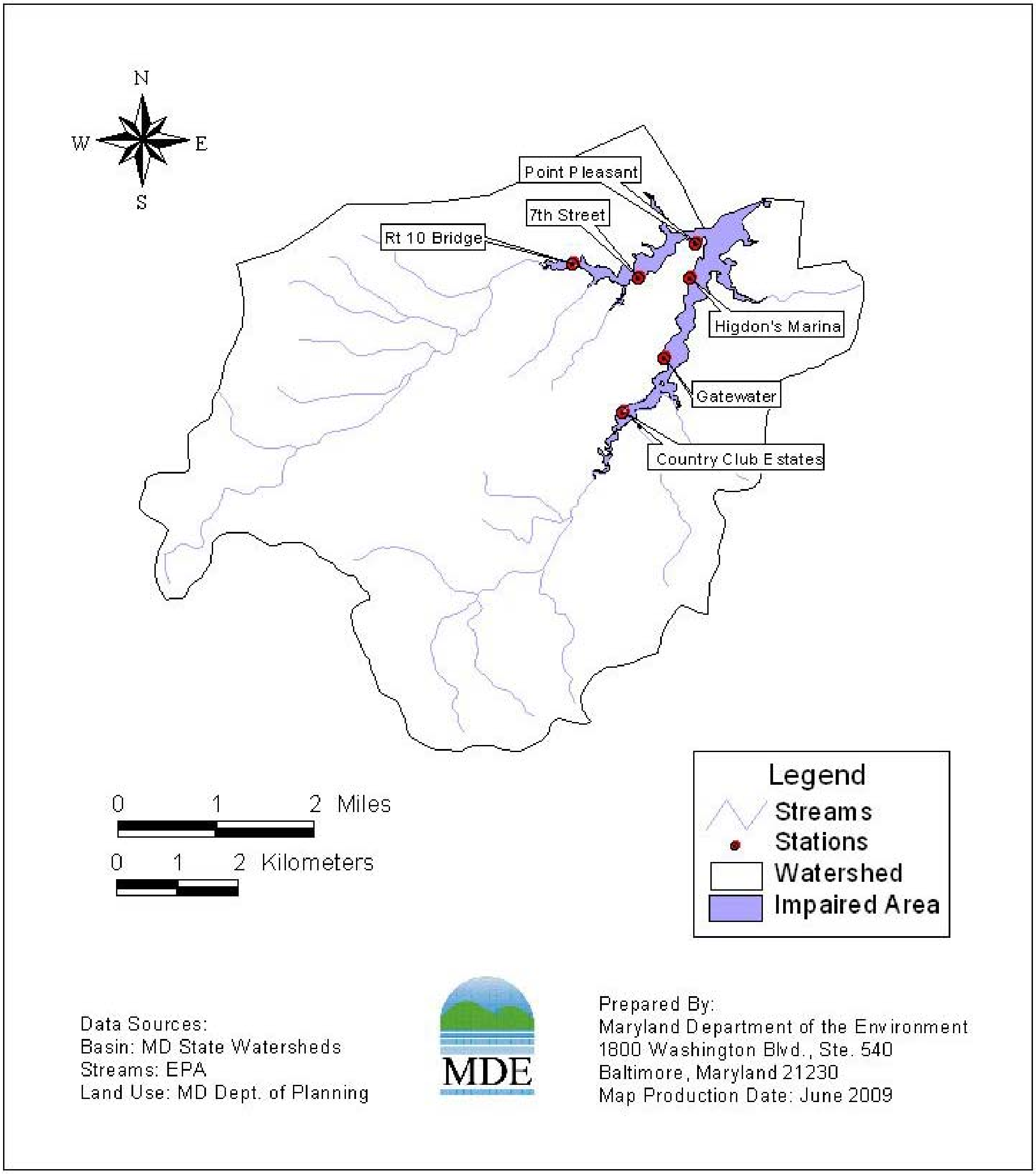

Figure 2.2.1: Enterococci Monitoring Stations in Marley Creek and Furnace Creek Impaired Recreational Area

Table 2.2.1: Locations of the Monitoring Stations in Marley Creek and Furnace Creek

Station Location	Station ID	Station Name	Total Obs. (2005-2008)	Latitude	Longitude
Marley Creek	AAMFCCE	Country Club	24	39.1606	-76.5958
	AAMFGat	Gatewater	24	39.1686	-76.5879
	AAMFHig	Higdons Marina	24	39.1802	-76.5831
Furnace Creek	AAMFPoint	Point Pleasant	12	39.1853	-76.5821
	AAMFRt10	Route 10 Bridge	6	39.1825	-76.6052
	AAMF7th	7th Street	24	39.1803	-76.5929

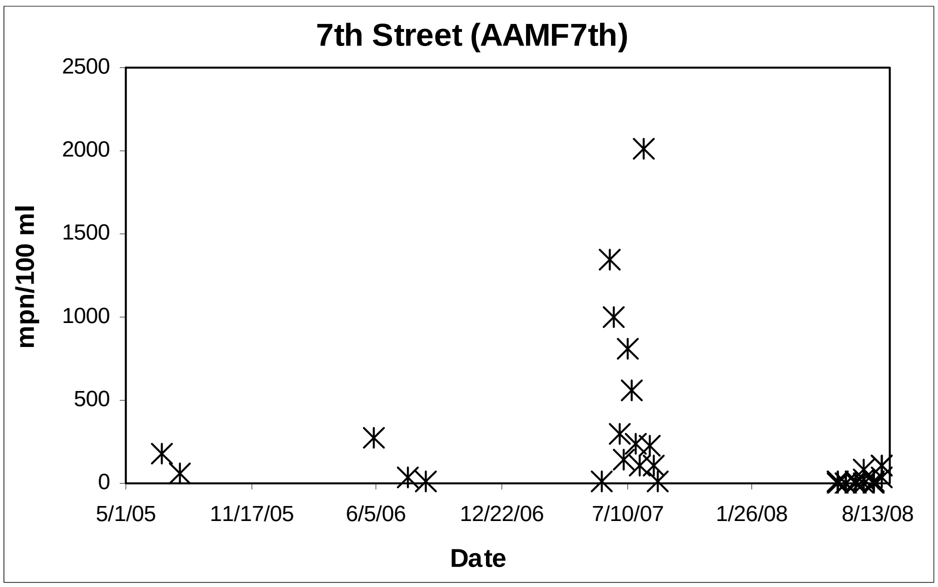

Figure 2.2.2: Observed Enterococci Concentrations at Station AAMF7th

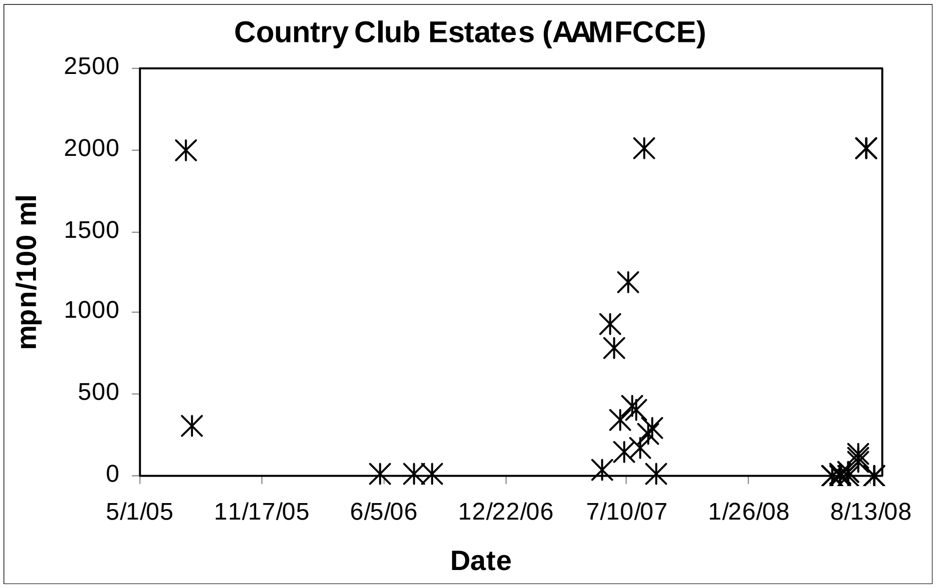

Figure 2.2.3: Observed Enterococci Concentrations at Station AAMFCCE

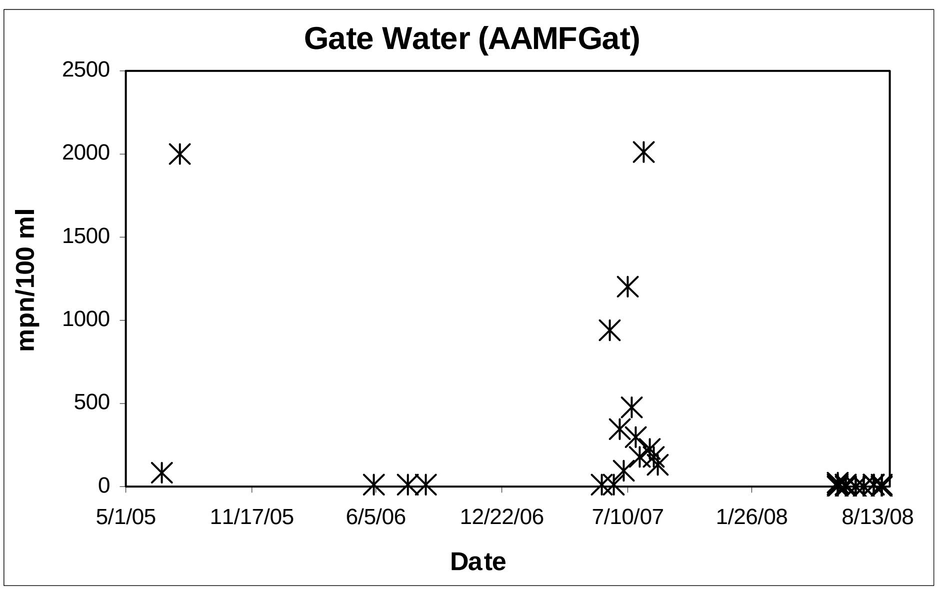

Figure 2.2.4: Observed Enterococci Concentrations at Station AAMFGat

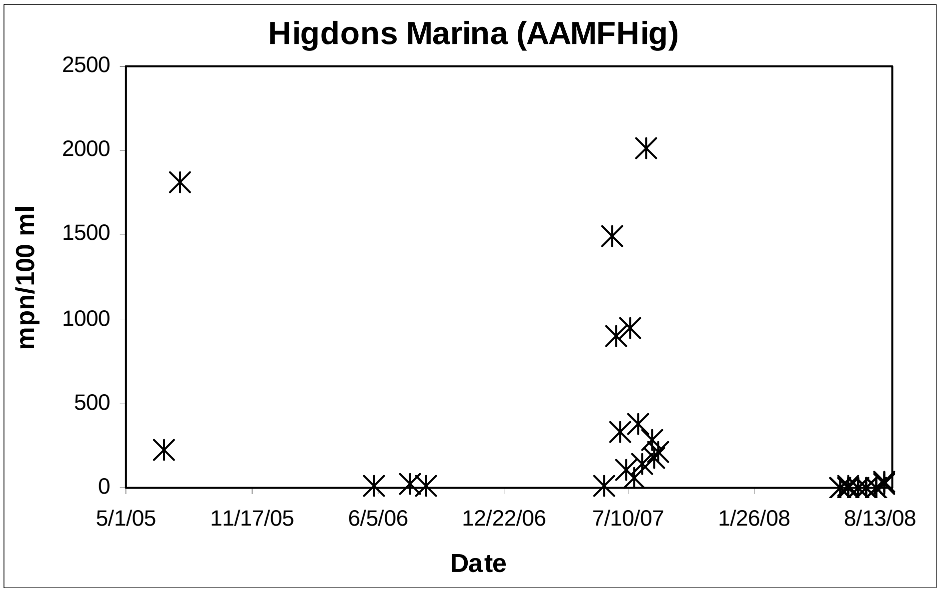

Figure 2.2.5: Observed Enterococci Concentrations at Station AAMFHig

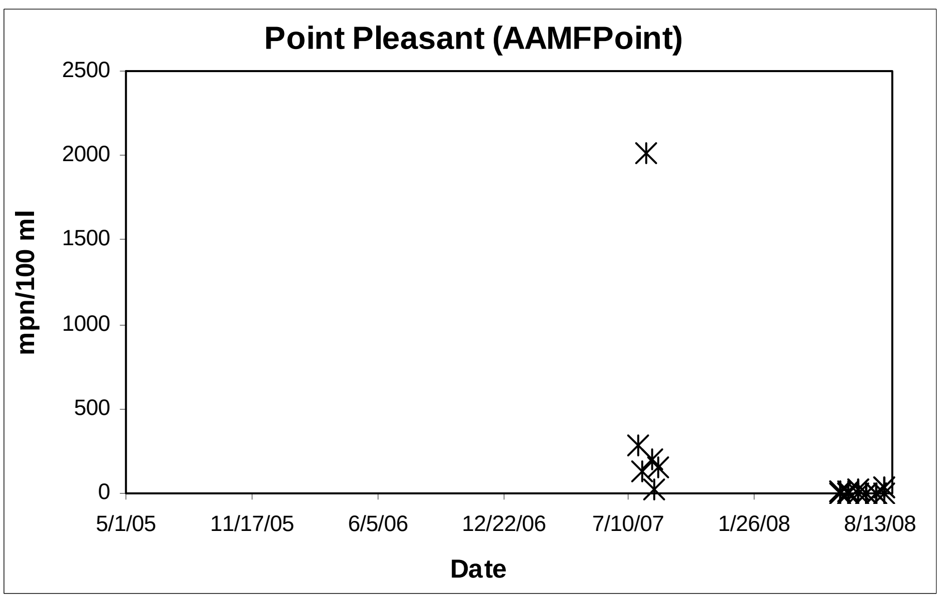

Figure 2.2.6: Observed Enterococci Concentrations at Station AAMFPoint

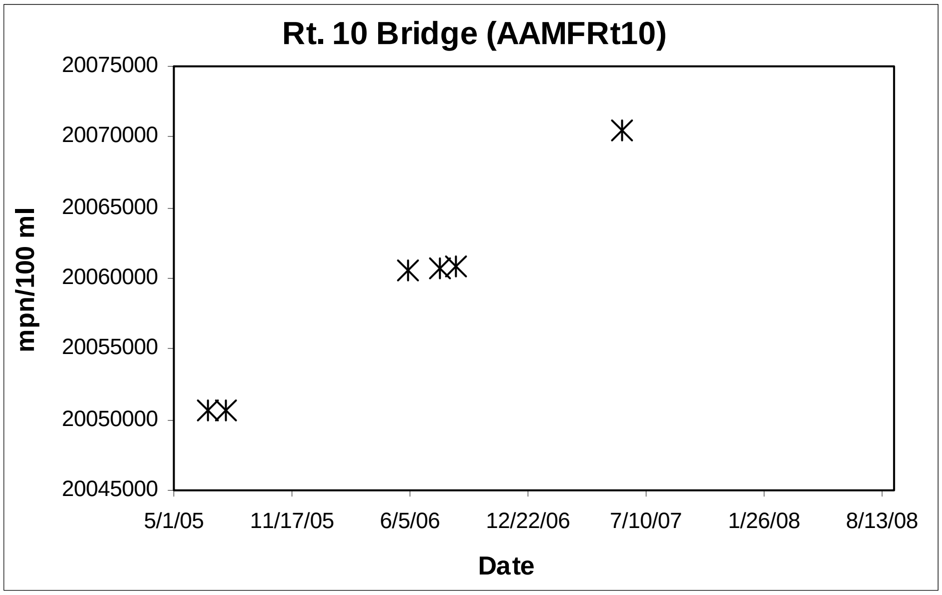

Figure 2.2.7: Observed Enterococci Concentrations at Station AAMFRt10

2.3 Designated Uses and Water Quality Standard

The Maryland water quality standard's Surface Water Use Designation for Marley Creek and Furnace Creek is Use I: Water Contact Recreation, Protection of Nontidal Warmwater Aquatic Life (COMAR 26.08.02.02). Both Marley Creek and Furnace Creek were listed on Maryland's 1998 303(d) List as impaired by bacteria (MDE 2008) due to elevated bacteria concentrations.

Water Quality Criteria

As per EPA's guidance, Maryland adopted *E. coli* and enterococci as indicators for Use I waters. The Maryland water quality standard for bacteria (enterococci) used in this study is as follows:

Table 2.3.1: Water Quality Criterion for Marley Creek and Furnace Creek

Indicator (Salt Water)	Steady-State Geometric Mean Indicator Density
Enterococci	35 cfu/100ml

When presenting the water quality standards, laboratory results, and model results, it is important to understand the definition of the reported units. In the laboratory analysis of fecal indicator bacteria, using membrane filtration analysis, plate counts are direct counts of living organisms (e.g. *E. coli* or enterococci) to estimate bacteria counts and are expressed in Colony Forming Units (cfu), the bacteria units presented in COMAR. The laboratory technique used for all the observations in this report is the IDEXX Enterolert ™ method to estimate bacteria counts. The results are the number of positives referenced to a most probable number table. The data collected for this report are reported in MPN/100 ml and are directly compared to the water quality standard presented in cfu/100 ml. Because both cfu and MPN are estimating bacteria counts, the TMDL is reported in counts/day.

The listing of impaired recreational waters requires analysis of data collected from the previous two to five years (MDE 2008 IR). The data for the calculation of the geometric mean should be from samples collected during steady-state, dry weather conditions and during the beach season (Memorial Day through Labor Day) to be representative of the critical condition (highest use).

Water Quality Assessment

The bacteria impairment addressed in this analysis was determined with reference to Maryland's Classification of Use I Waters and water quality criteria in Use I waters. For this analysis, MDE used steady-state monitoring data collected during beach seasons from 2005 to 2008. The maximum two-year-rolling geometric means of enterococci concentration from 2005 to 2008 for Marley Creek and Furnace Creek were chosen to estimate the baseline load (current load) for conservative purposes. Descriptive statistics of the monitoring data are shown in Table 2.3.2.

Table 2.3.2: Marley Creek and Furnace Creek Enterococci Statistics (Summer Data from 2005-2008)

Creek	Station ID	Geometric Mean (mpn/100 mL)		
		2005-2006	2006-2007	2007-2008
Marley Creek	AAMFCCE	57	153	50
	AAMFGat	49	121	17
	AAMFHig	60	148	15
Furnace Creek	AAMFPoint	NA	NA	8
	AAMFRt10	83	134	NA
	AAMF7th	65	171	30

2.4 Source Assessment

Nonpoint Source Assessment

Nonpoint sources of fecal bacteria do not have a single discharge point, but rather occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in watersheds. The possible introductions of fecal bacteria to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, excretions from pets and wildlife, and recreational activities. As the runoff occurs during rain events, surface runoff transports water and fecal bacteria over the land surface and into surface waters. The direct deposition of non-human fecal bacteria may occur when livestock or wildlife have direct access to a waterbody. Nonpoint source contributions from human activities generally arise from failing septic systems and their associated drain fields as well as through pollution from recreational vessel discharges. The potential transport of fecal bacteria from land surfaces to a waterbody is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to better identify potential sources of bacterial contamination that may be impacting the water quality of Marley Creek and Furnace Creek, MDE conducted a fecal pollution source identification survey in the area from December 2007 to November 2008 (Frana and Venso 2009, Appendix B). Bacterial Source Tracking (BST) technology was used to distinguish the origins of bacteria found in environmental waters. Under the premise that bacteria isolated from different hosts can be discriminated based on differences in the selective pressure of microbial populations found in the gastrointestinal tract of the hosts, i.e., humans, livestock, pets, and wildlife (Wiggins 1996), a biochemical method called Antibiotic Resistance Analysis (ARA) was used. In ARA, microbial isolates collected from water samples are tested and their resistance results are recorded and compared with library isolates. Finally, a statistical analysis can predict the likely host source of the water isolates (Hagedorn 1999, Price *et al.* 2006, Wiggins 1999).

Based on the ARA results, the largest category of potential sources in Furnace Creek was wildlife, followed by human and pet. The largest category of potential sources in Marley Creek was pet, followed by human and wildlife. The detailed BST results can be found in Appendix B.

Table 2.4.1: Marley Creek and Furnace Creek Host Source Distribution

Source	Marley Creek	Furnace Creek
Human	34.2%	32.5%
Livestock	0.0%	0.0%
Pet	34.6%	29.4%
Wildlife	31.2%	38.1%
Total	**100%**	**100%**

<u>Point Source Assessment</u>

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

There are no NPDES process water facilities with permits regulating the discharge of bacteria directly into the impaired section of Marley Creek and Furnace Creek. There are four NPDES permitted process water point sources discharging bacteria to the downstream of Marley Creek and Furnace Creek: two individual industrial permits - Baltimore City Composting facility (MD0061875) and US Gypsum Company (MD0001457); and two individual municipal permits - MD0021661 - Cox Creek Water Reclamation Facility and MD0021601 - Patapsco Wastewater Treatment Plant (WWTP). The locations of these point source facilities are illustrated in Figure 2.4.1. Model tests indicate that impact to the bacteria impairments upstream from these point source discharges are negligible, therefore the loads from theses facilities are not included in the WLA portion of the TMDL.

NPDES regulated stormwater discharges are considered point sources subject to assignment to the waste load allocation (WLA). Stormwater runoff is an important source of water pollution, including bacterial pollution. For example, domestic animal and wildlife waste may be transported through an MS4 conveyance system, or some other regulated stormwater conveyance system. These may include roads with drainage systems, municipal streets, catch basins, curbs, gutters, ditches, man-made channels, storm drains, best management practices (BMPs), and environmental site design (ESD), designed or used for collecting and conveying, or treating and reducing, stormwater before delivering it to a waterbody. MS4 stormwater management programs are designed to reduce the amount of pollution that enters a waterbody from storm sewer systems to the maximum extent practicable.

Bacteria loads attributable to MS4 Phase I and Phase II NPDES-regulated stormwater entities in the watershed, including the Anne Arundel County Phase I MS4, the MD State Highway Administration (SHA) Phase I MS4, Phase II State and federal MS4s, and industrial stormwater permittees, are combined in aggregate stormwater waste load allocations (SW-WLAs) in this TMDL. The NPDES Phase I or Phase II stormwater permits identified throughout the Marley Creek and Furnace Creek watershed are regulated based on BMPs and do not include bacteria limits. The stormwater loads are addressed in Section 4.7 and Appendix C.

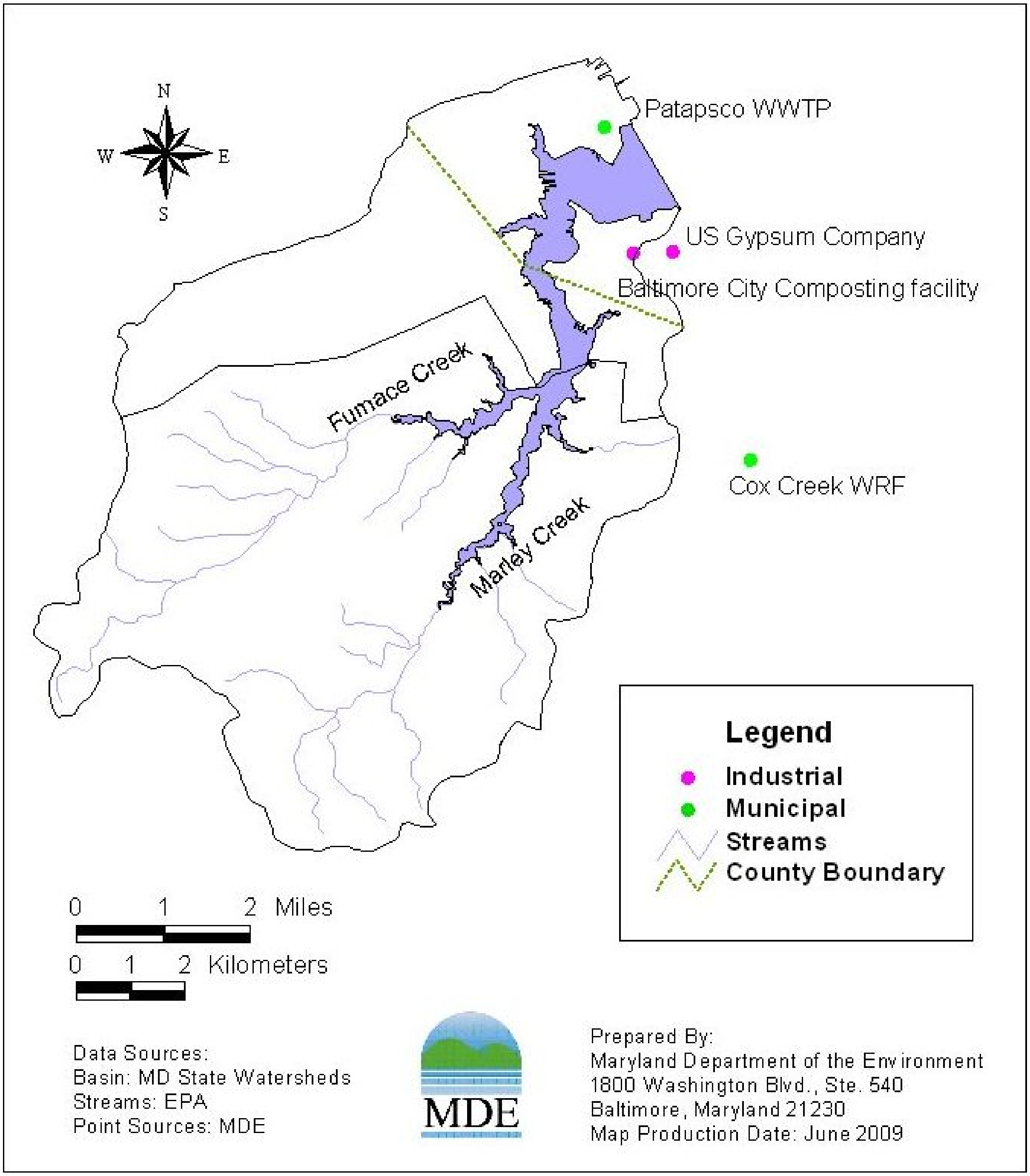

Figure 2.4.1: Locations of the Point Source Facilities

3.0 TARGETED WATER QUALITY GOAL

The overall objective of the bacteria TMDLs summarized in this document is to establish the maximum loading allowable to ensure attainment of water quality standard in the impaired area in Marley Creek and Furnace Creek. The standard is described fully in Section 2.3, Designated Uses and Water Quality Standard.

4.0 TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATION

4.1 Overview

This section documents the detailed enterococci TMDL and load allocation development for Marley Creek and Furnace Creek in Baltimore Harbor watershed. The required load reduction was determined based on data collected from June 2005 to August 2008. The TMDL is presented as counts per day. Section 4.2 describes the analysis framework for simulating enterococci concentration in the impaired area. Section 4.3 addresses critical conditions and seasonality. The TMDL calculations are presented in Section 4.4. Section 4.5 provides a summary of baseline loads and Section 4.6 discusses TMDL loading caps. Section 4.7 provides the description of the waste load and load allocations. The MOS is discussed in Section 4.8. Finally, the TMDL equation is summarized in Section 4.9.

A TMDL is the total amount of a pollutant that a waterbody can receive and still meet water quality criteria, which in this case is Maryland's water quality criteria for Use I waters. A TMDL may be expressed as a "mass per unit time, toxicity, or other appropriate measure" (CFR 2006b). These loads are based on an averaging period that is defined by the specific water quality criteria for Use I waters. The averaging period used for development of the TMDL requires data collected from the previous two (2) to five (5) years, for computing a steady state geometric mean to establish current condition.

A TMDL is the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a MOS that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, when applicable, the TMDL may include a future allocation (FA) when necessary. This definition is denoted by the following equation:

$$TMDL = WLAs + LAs + MOS + (FA, \text{ where applicable})$$

4.2 Analysis Framework

In general, tidal waters are exchanged through their connecting boundaries. The tide and amount of freshwater discharged into the impaired area are the dominant forces that influence the transport of bacteria. The impaired area is influenced by both tidal and freshwater input. The current distribution in the system varies as tidal and freshwater discharges change. In order to simulate the transport and fate of bacteria in the Marley Creek and Furnace Creek accurately, a 3-dimensional hydrodynamic model, the Environmental Fluid Dynamics Code (EFDC) model, are used for this study. The EFDC model is a general 3-Dimensional (3-D) model for environmental studies. The model simulates density and topographically induced circulation as well as tidal and wind-driven flows, and spatial and temporal distributions of salinity, temperature, and suspended sediment concentration, conservative tracers, eutrophication processes, and fecal bacteria. For a detailed model description, the reader is referred to Hamrick (1992a, 1992b) and Park *et al.* (1995).

In order to account for bacteria transport from both upstream and downstream, the entire Marley Creek, Furnace Creek, and Curtis Creek at their downstream embayment are simulated. The modeling area was represented by horizontal model grid cells. There are a total of 227 model grid cells in the modeling domain. To better simulate the stratification effect, three layers are used in the vertical direction. For this study, the model was calibrated for the tide and salinity distribution. In order to address the loading corresponding to geometric mean bacteria concentrations, an inverse approach was adopted to estimate the loads from the watershed (Sisson *et. al*, 2008). The watershed is divided into 22 subwatersheds. The loads from each subwatershed are discharged into the creeks from their tributaries.

The model was forced by 6 major tidal constituents, namely M_2, S_2, K_1, O_1, K_2, and N_2 (see abbreviations list for descriptions), and the mean salinity concentration at the river's mouth. The long-term mean freshwater input estimate is based on data from United States Geological Survey (USGS) gauge station 01589500 at Sawmill Creek at Glen Burnie. The discharges from subwatersheds are estimated based on the ratio of subwatershed area to the total drainage basin of the USGS station. The inverse method is used to estimate the existing load discharged from each subwatershed based on geometric mean concentration of bacteria obtained from the observations. The model is also used to establish the allowable loads. Detailed modeling procedures are described in Appendix A.

4.3 Critical Condition and Seasonality

EPA's regulations require TMDLs to be "established at levels necessary to attain and maintain the applicable narrative and numerical WQS [water quality standards] with *seasonal variations* and a *margin of safety* . . . Determinations of TMDLs shall take into account *critical conditions* for stream flow, loading, and water quality parameters" (CFR 2006c). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The critical condition accounts for the hydrologic variation in the watershed over many sampling years, whereas the critical period is the time during which a waterbody is most likely to violate the water quality standard.

The data used in the development of this TMDL were collected during beach season (Memorial Day through Labor Day) and during steady-state, dry weather conditions, to be representative of the critical condition, when maximum water contact is expected. Therefore, the seasonality and critical condition are included in the monitoring data requirement for recreational waters.

Steady-state data collected over the previous 4 beach seasons from 2005 to 2008 were used to develop the TMDL for the impaired waters of Marley Creek and Furnace Creek. The TMDL allocation is developed based on the scenario in which the greatest reduction is needed to meet the water quality standard, in this case, the scenario using the maximum two-year-rolling geometric mean concentration of enterococci (see Table 2.3.2). Therefore, the critical conditions requirement is met for the TMDL development in this document.

4.4 TMDL Computation

The simulated watershed is segmented into 22 subwatersheds and the load from each subwatershed was discharged into its corresponding segment of the river. The inverse method was used to compute the watershed loads discharged into the river based on the least-square criterion between the observations and model simulation of bacteria concentrations in the river. There are six monitoring stations located within the impaired area. The monitoring data from these stations from 2005 to 2008 were used to determine the existing loads. Detailed computation is presented in Appendix A. Detailed results by subwatershed are also listed in Appendix A.

According to the water quality standards for bacteria in Use I waters, the computation of a TMDL and load reduction requires analyses of steady-state geometric mean from the previous two to five years' data. For Marley Creek and Furnace Creek, the available steady-state beach season data are from 2005 to 2008. For conservative purposes, the load estimation scenario using the maximum two-year-rolling geometric mean concentration of enterococci was chosen for the baseline load, since this scenario will require the greatest reduction to meet water quality criteria. As shown in Table 2.3.2, the maximum steady-state geometric mean values of enterococci from two-year-rolling data is 171 MPN/100ml for the period 2006-2007 for Furnace Creek, and 153 MPN/100ml for the period 2006-2007 for Marley Creek. Therefore, the baseline loads (current load) from the watersheds are estimated based on concentrations of 2006-2007 period for Furnace Creek and Marley Creek, respectively.

The allowable load is calculated using the water quality criterion of a geometric mean bacteria density, i.e., enterococci of 35 cfu/100ml. The 3-D model was used to compute the allowable load for each subwatershed by reducing the existing loads from the watershed so that the bacteria concentrations in the receiving water meet the appropriate water quality standards. The total load discharged into Furnace Creek or Marley Creek is the summation of loads discharged from its subwatershed. The load reduction needed for the attainment of the criteria is determined as follows:

$$\textbf{Load Reduction} = \frac{\textbf{Current Load} - \textbf{Allowable Load}}{\textbf{Current Load}} \times 100\,\%$$

For complete details of the TMDL calculations, please see Appendix A.

4.5 Summary of Baseline Loads

For the TMDL analysis period, the calculated baseline (current) loads of enterococci from all sources in the listed area of the Marley Creek and Furnace Creek in Baltimore Harbor basin are summarized in Table 4.5.1.

Table 4.5.1: Summary of Baseline Loads

Waterbody	Enterococci Baseline Loads [counts per day]
	Geometric Mean Analysis Scenario
Marley Creek	6.19×10^{12}
Furnace Creek	3.66×10^{12}

4.6 TMDL Loading Caps

This section presents the TMDLs that would meet the geometric mean criterion. Seasonal variability is addressed implicitly through the interpretation of the water quality standards (see Section 4.3). The geometric mean criterion based TMDL for the Marley Creek and Furnace Creek of the Baltimore Harbor basin is summarized in Table 4.6.1.

Table 4.6.1: Summary of TMDL Loading Caps

Waterbody	Enterococci TMDL [counts per day]
	Based on steady-state Geometric Mean
Marley Creek	1.50×10^{12}
Furnace Creek	8.14×10^{11}

A two-year rolling period was used to develop the bacteria TMDLs for Marley Creek and Furnace Creek. When allocating loads among sources, the scenario that requires the greatest overall reductions is based on data analysis of the two-year rolling period from 2005 to 2008. The TMDL allocations are based on reductions from scenarios using the 2006 to 2007 data. Table 4.7.1 below summarizes the necessary load reductions by area.

4.7 Load Allocations and Percent Reductions

The purpose of this section is to allocate the TMDLs between point (WLA) and nonpoint (LA) sources. The load reduction scenario results in a load allocation by which the TMDL can be implemented to achieve water quality standards. The State reserves the right to revise these allocations, provided the allocations are consistent with the achievement of water quality standards. The load reduction is shown in Table 4.7.1.

Table 4.7.1: Load Reductions

Waterbody	Required Reduction
Marley Creek	75.75%
Furnace Creek	77.79%

Since the load reduction applied to this watershed was based on the geometric mean water quality standard during the beach season, it targets only those critical events that occur during the year. Therefore, the load reduction established is not a literal daily reduction, but rather an indicator that the control of measures for bacterial loads is needed for these more extreme events. Extreme events are often a result of hydrologic variability, land use practices, water recreation uses, or wildlife activities.

The WLA in Marley Creek and Furnace Creek watershed includes loads from municipal separate storm sewer systems (MS4). The remaining loads are allocated to the LA part of the TMDL (see Section 4.9). In the future, when more detailed data and information become available, MDE may revise the WLAs and LAs accordingly. The overall TMDL reductions will not change.

Municipal and Industrial Point Source Facilities

There are no NPDES facilities with permits regulating the discharge of bacteria directly into the impaired section of Marley Creek and Furnace Creek. There are four NPDES facilities with permits regulating bacteria discharges to areas downstream of Marley Creek and Furnace Creek: two industrial point sources - Baltimore City Composting facility (MD0061875) and US Gypsum Company (MD0001457); and two municipal point sources - Cox Creek Water Reclamation Facility (MD0021661) and Patapsco WWTP (MD0021601). The locations of these point source facilities are illustrated in Figure 2.4.1. Model tests indicate that impact to the bacteria impairments upstream from these point source discharges are negligible, therefore the loads from theses facilities are not included in the WLA portion of the TMDL.

NPDES Regulated Stormwater

The Department applies EPA's requirement that "stormwater discharges that are regulated under Phase I or Phase II of the NPDES storm water program are point sources that must be included in the WLA portion of a TMDL" (USEPA 2002). Phase I and II NPDES stormwater permits can include the following types of discharges:

- Small, medium, and large MS4s – these can be owned by local jurisdictions, municipalities, and state and federal entities (e.g., departments of transportation, hospitals, military bases),
- Industrial facilities regulated for stormwater discharges, and
- Small and large construction sites.

EPA recognizes that available data and information are usually not detailed enough to determine WLAs for NPDES regulated stormwater discharges on an outfall-specific basis (USEPA 2002).

Therefore, in the Marley Creek and Furnace Creek watershed, bacteria loads from all regulated NPDES stormwater outfalls are expressed as a single stormwater wasteload allocation. Upon approval of the TMDL, NPDES-regulated "storm water discharge effluent limits should be expressed as best management practices or other similar requirements, rather than as numeric effluent limits" (USEPA 2002).

Given the variability among sources, runoff volumes, and pollutant loads over time, it is difficult to accurately estimate stormwater bacteria load contributions to a particular waterbody. The accuracy of the bacteria source load estimation is largely confounded by the uncertainty related to nonpoint sources, including human, wildlife and pets. In addition, these contributions can be highly variable. Consequently, it was determined that WLA loads will be estimated assuming equitably diffuse loads from all land use categories. The estimated stormwater load will be calculated by multiplying the diffuse load (L_D) to the specific area by the proportion of urban land.

$$WLA_i = L_D * ULU_i$$

where
WLA_i = NPDES regulated stormwater load from jurisdiction i
L_D = Load from diffuse sources to impaired area, including stormwater
ULU_i = Percentage of urban land use within jurisdiction i

The stormwater load is calculated based on MDP land use and is included in the WLA of the TMDL. Bacteria loads attributable to MS4 Phase I and Phase II NPDES-regulated stormwater entities in the watershed, including the Anne Arundel County Phase I MS4, the MD State Highway Administration (SHA) Phase I MS4, Phase II State and federal MS4s, and industrial facilities regulated for stormwater discharges are combined in aggregate stormwater waste load allocations (WLAs) in this TMDL. The NPDES Phase I or Phase II stormwater permits identified throughout the Marley Creek and Furnace Creek watershed are regulated based on BMPs and do not include bacteria limits. In the absence of bacteria limits, the NPDES regulated stormwater WLA is calculated using methods described above and detailed calculations appear in Appendix C. A detailed list of the permits appears in Appendix D. The load allocated to the stormwater permitted areas is calculated as 60.5% for Marley Creek and 75.5% for Furnace Creek, respectively, of the diffuse load.

4.8 Margin of Safety

A MOS is required as part of a TMDL in recognition of many uncertainties in the understanding and simulation of water quality in natural systems. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of the pollutants on the chemical and biological quality of complex, natural waterbodies. The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection.

For TMDL development, the MOS needs to be incorporated to account for uncertainty due to model parameter selection. The decay rate is one of the most sensitive parameters in the model. For a given system, the higher the decay rate, the higher the assimilative capacity. The value of the decay rate varies from 0.7 to 3.0 per day in salt water (Mancini 1978, Thomann and Mueller 1987). A decay rate of 0.7 per day was used as a conservative estimate in the TMDL calculation. Further literature review supports this assumption as a conservative estimate of the decay rate (MDE 2004). Therefore the MOS is implicitly included in the calculation.

4.9 Summary of Total Maximum Daily Loads

The enterococci loads are allocated to either the MS4 (a component of WLA) or the LA. The TMDLs are summarized as follows:

Table 4.9.1: Summary of Enterococci TMDL (Counts per Day) Based on the Geometric Mean Criterion

Area	TMDL	=	LA	+	WLA	+	FA	+	MOS
Marley Creek	1.50×10^{12}	=	5.93×10^{11}	+	9.08×10^{11}	+	N/A	+	Implicit
Furnace Creek	8.14×10^{11}	=	1.99×10^{11}	+	6.15×10^{11}	+	N/A	+	Implicit

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Source)
WLA = Waste Load Allocation (Point Source)
FA = Future Allocation
MOS = Margin of Safety

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurance that the bacteria TMDLs will be achieved and maintained. The appropriate measures to reduce pollution levels include, where appropriate, the use of better treatment technology or installation of best management practices. Details of these methods are to be described in the implementation plan.

In general, MDE intends for the required reductions to be implemented in an iterative process that first addresses those sources with the greatest impact on water quality, with consideration given to ease of implementation and cost. The potential source contributions from the BST (Appendix B) may be used as a tool to target and prioritize initial implementation efforts. The iterative approach towards best management practice (BMP) implementation throughout the watershed will help to ensure that the most cost-effective practices are implemented first. The success of BMP implementation will be evaluated and tracked through follow-up stream monitoring.

Existing Funding and Regulatory Framework

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 MS4 permits for stormwater discharges. Subsequently, other entities and jurisdictions were added to the list of regulated stormwater entities. The Marley Creek and Furnace Creek watershed is managed under NPDES Phase I and II stormwater permits for the Anne Arundel County Phase I MS4, the MD State Highway Administration Phase I MS4, Phase II State and federal MS4s, and industrial facilities regulated for stormwater discharges. This provides regulatory assurances that urban stormwater sources will be managed to the maximum extent practicable. Stormwater BMPs and programs implemented as required by MS4 permits shall be consistent with available WLAs developed under the TMDL. Where fecal bacteria are transported through an MS4 conveyance system, stormwater BMPs implemented to control urban runoff should help in reducing fecal bacteria loads in the Marley Creek and Furnace Creek watershed.

Funding sources for implementation include low interest loans are available to property owners with failing septic systems through MDE's Linked Deposit Program. It is also anticipated that the Bay Restoration Fund will provide funding to upgrade onsite sewage disposal systems with priority given to failing systems and holding tanks in the Chesapeake and Atlantic Coastal Bays Critical Areas. Local governments can utilize funding from the State Water Quality Revolving Loan Fund and the Stormwater Pollution Cost Share Program. Although there is a small portion of agricultural land within the watershed, another potential funding sources for implementation include Maryland's Agricultural Cost Share Program (MACS), which provides grants to farmers to help protect natural resources, and the Environmental Quality and Incentives Program, which focuses on implementing conservation practices and BMPs on land utilized for livestock and agricultural production. Details of these programs and additional funding sources can be found at http://www.dnr.state.md.us/bay/services/summaries.html.

Maryland law requires the following types of facilities to have pumpout stations: existing marinas wishing to expand to a total of 11 or more slips that are capable of berthing vessels that are 22 feet or larger; new marinas with more than 10 slips capable of berthing vessels that are 22 feet or larger; and marinas with 50 or more slips and that berth any vessel over 22 feet in length (Maryland 1996). Any public or private marina in Maryland is eligible to apply for up to $15,000 in grant funds to install a pumpout station through the Maryland Department of Natural Resources. Also, although not directly linked, it is assumed that the nutrient management plans from the Water Quality Improvement Act of 1998 (WQIA) will result in some reduction of bacteria from manure application practices.

Implementation and Wildlife Sources

It is expected that, due to significant wildlife bacteria contribution, some waterbodies will not be able to meet water quality standards even after all anthropogenic sources are controlled. Neither the State of Maryland nor EPA is proposing the elimination of wildlife to allow for the attainment of water quality standards. This is considered to be an impracticable and undesirable action. While managing the overpopulation of wildlife remains an option for State and local stakeholders, the reduction of wildlife or the changing of a natural background condition is not the intended goal of a TMDL.

MDE envisions an iterative approach to TMDL implementation, which first addresses the controllable sources (i.e., human, livestock, and pets), especially those that have the largest impacts on water quality and create the greatest risks to human health, with consideration given to ease the cost of implementation. It is expected that the best management practices applied to controllable sources may also result in reduction of some wildlife sources. Following the initial implementation stage, MDE expects to re-assess the water quality to determine if the designated use is being attained. If the water quality standards are not attained, other sources may need to be controlled. However, if the required controls go beyond maximum practical reductions, MDE might consider developing either a risk-based adjusted water quality assessment or a Use Attainability Analysis to reflect the presence of naturally high bacteria levels from uncontrollable (natural) sources.

REFERENCES

Bertsekas, D.P. 1995. *Nonlinear Programming*. Belmont, MA: Athena Scientific.

CFR (Code of Federal Regulations). 2006a. *40 CFR 130.7(c)(1)*. http://www.gpoaccess.gov/cfr/index.html (Accessed December, 2009).

_________. 2006b. *40 CFR 130.2 (i)*. http://www.gpoaccess.gov/cfr/index.html (Accessed December, 2009).

_________. 2006c. *40 CFR 122.26 (b).* http://www.gpoaccess.gov/cfr/index.html (Accessed December, 2009).

COMAR (Code of Maryland Regulations). 2009. *26.08.02.02*. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.02.htm (Accessed December 2009).

Frana, M.F. and Venso, E.A. 2009. Identifying Sources of Fecal Pollution in Shellfish and Nontidal Waters in Maryland Watersheds. Salisbury University, Salisbury, MD 21801.

Hagedorn, C., Robinson, S.L., Filtz, J.R., Grubbs, S.M., Angier, T.A. and 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(12):5522-5531.

Hamrick, J.M. 1992a. Estuarine Environmental Impact Assessment Using a Three-Dimensional Circulation and Transport Model. In *Estuarine and Coastal Modeling, Proceedings of the 2nd International Conference*, edited by M. L. Spaulding, K. Bedford, and A. F. Blumberg. New York: American Society of Civil Engineers.

_________. 1992b. A Three-Dimensional Environmental Fluid Dynamics Code: Theoretical and Computational Aspects. *Special Report in Applied Marine Science and Ocean Engineering* No. 317. 63 pp.

Hong, B., Panday, N., Shen, J., Wang, H.V., Gong, W. and Soehl, A. 2010. Modeling water exchange between Baltimore Harbor and Chesapeake Bay using artificial tracers: seasonal variations (submitted to *Mari. Environ. Res*)

Mancini, J.L. 1978. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. *J. Water Pollut. Control Fed.* 50(11):2477-2484.

Maryland. 1996. Environment: 9-333. Marinas. *The Annotated Code of Maryland*. Charlottesville, VA: Reed Elsevier Inc.

MDP (Maryland Department of Planning). 2000. *Land Use/Land Cover for Maryland*. Planning Data Services, Maryland Department of Planning, Baltimore, MD.

MDE (Maryland Department of the Environment). 2004. *Technical Memorandum: Literature Survey of Bacteria Decay Rates*. Baltimore, MD: Maryland Department of the Environment.

_________. 2005. *Total Maximum Daily Loads of Fecal Coliform for Restricted Shellfish Harvesting Areas in the Potomac River Lower Tidal Basin in St. Mary's County, Maryland*. Baltimore, MD: Maryland Department of the Environment. Also Available at http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/ApprovedFinalTMDL/index.asp.

_________. 2008. The 2008 Integrated Report of Surface Water Quality in Maryland http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland%20303%20dlist/2008_Final_303d_list.asp (Accessed December, 2009).

NOAA (National Oceanic and Atmospheric Administration). 2009. *Tides Online*. http://tidesonline.nos.noaa.gov/ (Accessed December, 2009).

Park, K., Kuo, A.Y., Shen, J., and Hamrick, J.M. 1995. A Three Dimensional Hydrodynamic Eutrophication Model: Description of Water Quality and Sediment Process Submodels. Special Report in Applied Marine Science and Ocean Engineering No. 327. 98 pp.

Price, B., Venso, E.A., Frana. M.F., Greenberg, J., Ware, A., and Currey, L. 2006. A Classification Tree Method for Bacterial Source Tracking with Antibiotic Resistance Analysis Data. *Appl. Environ. Microb.* 72(5):3468-3475.

Reinelta, L.E., and Richard R.H. 1995. Pollutant Removal from Stormwater Runoff by Palustrine Wetlands Based on Comprehensive Budgets. *Ecol. Eng.* 4(2):77-97

Shen, J., Boon, J. and Kuo, A.Y. 1999. A Numerical Study of a Tidal Intrusion Front and Its Impact on Larval Dispersion in the James River Estuary, Virginia. *Estuary* 22 (3):681-692.

Shen, J., Wang, H., Sisson, M., and Gong, W. 2006. Storm Tide Simulation in the Chesapeake Bay Using an Unstructured Grid Model. *Estuar. Coast. Shelf S* 68(1-2):1-16.

Shen, J. 2006. Optimal Estimation of Parameters for an Estuarine Eutrophication Model. *Ecol. Model.* 191(3-4):521-537.

Shen, J., Jia, J., and Sisson, M. 2006. Inverse Estimation of Nonpoint Sources of Fecal Coliform for Establishing Allowable Load for Wye River, Maryland, *Water Res.* 40(18): 3333-3342.

Sisson, G.M., Jin, Z., Currey, L., Shen, J., and Jia, J. 2008. Developing a Cost-Effective Methodology to Manage Fecal Coliform Loading in Shellfish Harvesting Areas of Upper Chesapeake Bay, Maryland. *Proceedings of the 10th International Conference on Estuarine and Coastal Modeling*, 2007, Rhode Island, USA. Malcolm L. Spaulding, (editor), pp. 543-560.

Sun, N.Z., and Yeh, W.W.G. 1990. Coupled Inverse Problems in Groundwater Modeling 1. Sensitivity Analysis and Parameter Identification. *Water Resour. Res.* 20(10):2507-2525.

Thomann, R.V. and Mueller, J. 1987. *Principles of Surface Water Quality Modeling and Control*. New York: Harper Collins Publishers.

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

__________. 2002. Memorandum: Establishing Total Maximum Daily Load (TMDL) Wasteload Allocations (WLA) for Stormwater Sources and NPDES Permit Requirements Based on Those WLAs. Washington, DC: U.S. Environmental Protection Agency.

Weiskel, P., Howes, B., and Heufelder, G. 1996. Coliform Contamination of a Coastal Embayment: Sources and Transport Pathways. Environmental Science and Technology. 30(6):1872-1881.

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(11):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., and Zimmerman, M.E. 1999. Use of Antibiotic Resistance Analysis to Identify Nonpoint Sources of Fecal Pollution. *Appl. Environ. Microbiol.* 65(8):3483-3486.

VIMS (Virginia Institute of Marine Sciences). 2004. *Technical Memorandum for Fecal Coliform TMDL of Shellfish Harvesting Areas*. Gloucester Point, VA: Virginia Institute of Marine Sciences.

Appendix A. Model Development

Since the water quality criterion for bacteria applicable in this watershed is expressed in terms of the geometric mean concentration, the modeling task is to estimate daily bacteria loading corresponding to the geometric mean concentration. For a relatively small waterbody, the tidal prism model has been used to estimate the loads based on the observations and water quality standards using the inverse method (or back calculation) (MDE 2005). The 3-dimensional Environmental Fluid Dynamic Code model (EFDC, which is also referred to as "HEM3D" in VIMS) (park *et al.*, 1995) has been used for this study. The EFDC model is a general 3D model for environmental studies. The model simulates density and topographically induced circulation as well as tidal and wind-driven flows, spatial and temporal distributions of salinity, temperature, and suspended sediment concentrations, conservative tracers, eutrophication processes, and bacteria. The purpose of the inverse modeling is to estimate the long-term average daily loads corresponding to the geometric mean concentrations in the waterbody. Therefore, the bacteria daily loads from each subwatershed can be considered as constant model parameters. The inverse methods have been used for many environmental problems to estimate point source loads and model parameters (Sun and Yeh 1990, Shen 2006, Sisson *et al.* 2008). The model has been applied for varieties of environmental problems in estuaries (Hamrick 1992a, Shen *et al.* 1999). For a detailed discussion of the model theory, readers are referred to Hamrick (1992b) and Park *et al.* (1995).

Marley Creek, Furnace Creek, and downstream Curtis Creek are tidal rivers. The dominant tidal constituent is M_2 (lunar semi-diurnal tide). There is no tidal gauge located inside the creeks and a direct model calibration of tide is not feasible. However, the length of the creeks including downstream Curtis Creek is less than 8 km, which is much shorter than a quarter of the M_2 tidal length. The tide in the creek shows typical standing wave characteristics which indicates that the tide rises and fall inside the creeks almost simultaneously with the variation of the tide at the mouth. The model was forced by 6 tidal constituents, namely M_2, S_2, K_1, O_1, K_2, and N_2, at the model open boundary based on the National Oceanic and Atmospheric Administration (NOAA) data at Fort Carroll station and the large domain Chesapeake Bay model (Shen *et al.* 2006). The Chesapeake Bay model simulates the tide of entire Chesapeake Bay and the model partially covers the Marley Creek and the Patapsco River. A harmonic analysis of the model results was conducted for the tidal constituents at 6 stations and compared to the large model results at the junction of Marley Creek and Furnace Creek and NOAA nearby tidal gauge stations. The tidal simulation comparison is listed in Table A-1. It demonstrates the standing wave characteristics of the tide in the creeks.

Table A-1: Comparison of Modeled and NOAA Predicted Tide

Tidal Constituents	Point Pleasant	7th Street	Route 10 Bridge	Higdons Marina	Gatewater	Country Club	Fort Carrol (NOAA)	Large Domain Model
M2	0.162	0.162	0.162	0.162	0.162	0.162	0.159	0.163
S2	0.023	0.023	0.023	0.023	0.023	0.024	0.023	0.030
K1	0.069	0.069	0.069	0.069	0.069	0.069	0.069	0.070
O1	0.056	0.056	0.056	0.056	0.056	0.056	0.056	0.060
N2	0.035	0.035	0.035	0.035	0.035	0.035	0.034	0.040

The quantity of freshwater discharged from each subwatershed was estimated according to the average long-term flow from the USGS gauge 01589500. The flow of each subwatershed was estimated based on the ratio of the subwatershed area to the drainage basin area of the USGS gauge. The mean flows used for the model are listed in Table A-2 for the subwatersheds shown in Figure A-1. The salinity at the model boundary is specified based on the mean salinity of the 3D model in the Baltimore Harbor (Hong *et al.* 2010). During the 2009 sample collection, a set of salinity data were obtained at the monitoring stations shown in Figure 2.2.1. As salinity changes with time, the model was calibrated to match the modeled mean salinity to these measurements in a qualitative way and model results are listed in Table A-3.

Table A-2: Estimated Mean Flows of Subwatersheds in Marley Creek and Furnace Creek

Subwatershed	Mean Flow (cfs)
1	1.46
2	2.96
3	5.48
4	9.84
5	8.65
6	1.72
7	0.81
8	0.40
9	0.08
10	0.52
11	0.88
12	0.67
13	0.88
14	2.12
15	1.33
16	0.64
17	0.82
18	1.27
19	1.69
20	0.21
21	0.63
22	0.21

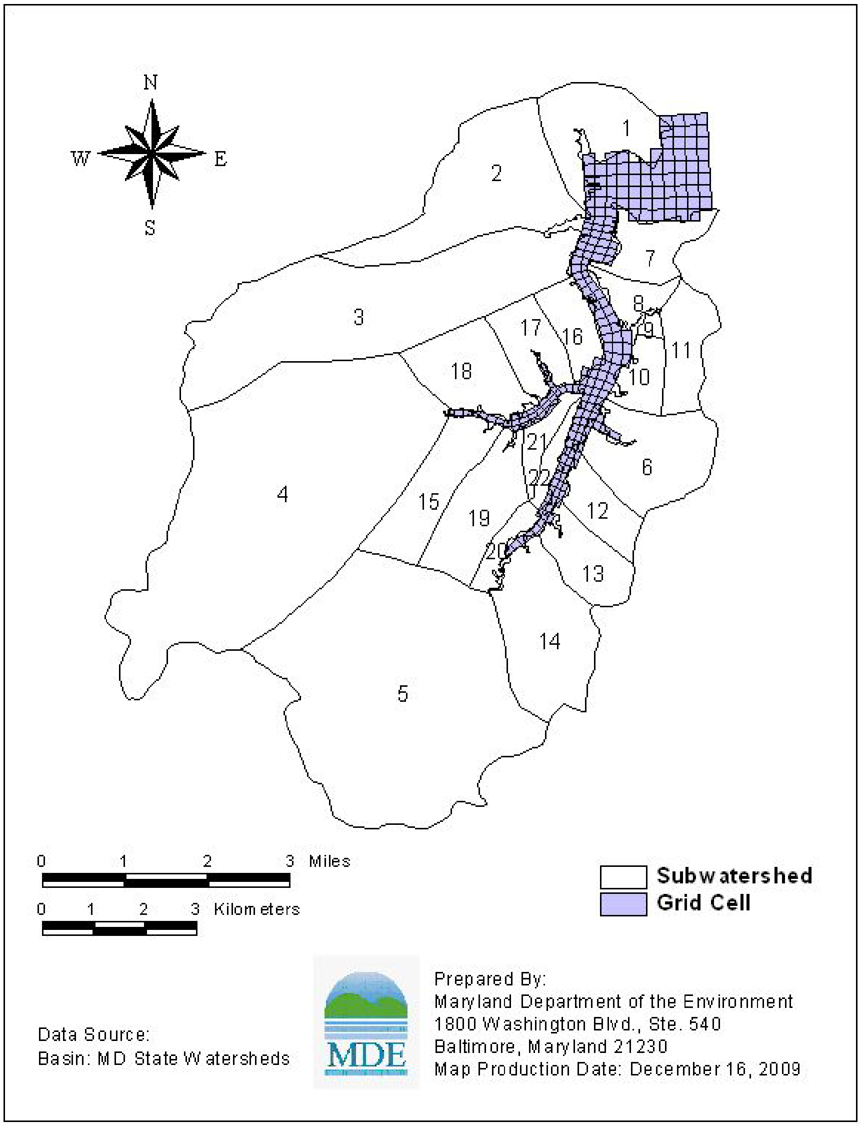

Figure A-1: Model Grid Cells and Subwatersheds in Marley Creek and Furnace Creek

Table A-3: Comparison of Measured and Calculated Salinities

Station	Measured (ppt)	Modeled (ppt)
Pt. Pleasant	14.27	14.30
7th Street	14.03	14.00
Rt 10 bridge	14.89	13.40
Higdon Marina	13.90	14.20
Gatewater	13.58	13.80
County Club	13.07	13.20

The problem of loads estimation can be treated as an inverse problem: to find a set of loads such that a defined goal function (or cost function), which measures the data misfit between the model predictions and the observations, becomes minimal. It can be presented as follows:

$$J(\mathbf{C};\boldsymbol{\beta}^*) = \min J(\mathbf{C};\boldsymbol{\beta}) \tag{1}$$

subject to:

$$\boldsymbol{\beta}^* \in \boldsymbol{\beta}_0 \tag{2}$$
$$\mathbf{F} = 0 \tag{3}$$

where $\boldsymbol{J}$ is a goal or cost function; $\boldsymbol{\beta}^* = (\beta_1, \beta_2, \ldots, \beta_m)$ is the optimal parameter (*i.e.*, loads); $\boldsymbol{\beta_0}$ is an acceptable set of loads. **F** is transport function. Different methods can be used to characterize the noninferior solutions. Choosing a weighted least-square criterion to measure the data misfit, the scalar cost function is then defined as follows:

$$J(\mathbf{C};\boldsymbol{\beta}) = \int_{T_N} \iint_{\Omega} \frac{w}{2}(C(x,z,t) - C^0(x,z,t))^2 d\Omega dt \tag{4}$$

where C and C^0 are modeled and measured bacteria concentration in the river, Ω is the spatial domain in the x- and z- directions, T_N is time later than the last date when the prototype observations are available, and w is the weight. In our case, let $C_m(x)$ be the geometric mean obtained from the observations at location (x). If we choose:

$$C_m(x) = \max(\overline{C}(x,t)) \qquad \textit{for} \quad T_0 < t < T_N \tag{5}$$

where $\overline{C}(x,t)$ is the vertical mean bacteria concentration. Equation (4) can be written as:

$$J(\mathbf{C};\boldsymbol{\beta}) = \int_X \frac{w}{2}(C_m(x,t) - C^0(x))^2 dx \tag{6}$$

The algorithm can be constructed as a sequence of the unconstrained minimization problem. Many authors have studied the solution of the optimization problem extensively. Several different methods can be used to solve the problem including the Gradient method, Conjugate direction method, and the Variational method (Bertsekas 1995). For this study, the modified Newton method was used to solve the optimization problem (Shen 2006).

The bacteria loads discharged to the waterbody originate from 22 subwatersheds, as shown in Figure A-1. There are 6 routine monitoring stations located in Marley Creek and Furnace Creek. Because both bacteria loadings from upstream and downstream watersheds can affect this region due to tidal induced transport, the model domain encompasses the impaired area and their downstream tidal river. The model was forced by six tidal constituents and mean salinity at the mouth. The mean freshwater inflows from the subwatersheds are discharged into the river. A set of initial loads from 22 subwatersheds was estimated and discharged to the river. The initial loads are estimated based on the event mean concentration associated with land use types based on literature values (Reinelt and Horner, 1995; Weiskel et al. 1996) and drainage area, and mean precipitation. The model was run for 60 days to reach dynamic equilibrium. The maximum concentration for the last 15 days, which covers spring-neap tidal cycle, was computed and used to calculate the cost function (Eq. 4) for the optimization. The modified Newton method was used to update the loads until the cost function is minimal. The water quality assessment requires analysis of the steady-state geometric mean of previous two to five year period. For Marley Creek and Furnace Creek, the available steady-state beach season data is from 2005 to 2008. For conservative purposes, the load estimation scenario using the maximum two-year-rolling geometric mean concentrations of enterococci were chosen for the baseline load, since this scenario will require the greatest reduction to meet water quality criteria. According to Table 2.3.2, the maximum steady-state geometric mean values of enterococci from two-year-rolling data is during the period 2006-2007 for Furnace Creek and Marley Creek. Because the two-year-rolling geometric mean values at Station Point Pleasant is not available from 2006-2007 period, a mean ratio of geometric mean values between Point Pleasant and the 7th street in 2007 and 2008 was computed. The geometric mean value in 2006-2007 periods at Point Pleasant station was estimated using the estimated ratio and 2007 geometric mean value. This estimated value was also used in the inverse model to obtain loadings, but giving low weight (See Eq. 4) and used as a reference. Figure A-2 shows the inverse model results. The correlation between observed and modeled (R^2) is 0.95. It can be seen that the model results are satisfactory. The estimated loading is listed in Table A-4.

For the TMDL calculation, the baseline loads from the watershed adjacent to the creeks and the watershed upstream were reduced so that the model simulated bacteria concentrations in the creeks meet the geometric mean concentration of water quality standard. The resultant loads are the allowable loads for the creeks. With the use of baseline loads and TMDLs, the percentage reduction can be estimated for each subwatershed. The baseline and allowable loads are listed in Table A-4. Note that a different reduction scenario can be obtained from the subwatersheds located on the northern and southern banks of the creeks as loadings from both sides have the same contribution to the creeks. The model sensitivity tests indicate that the bacteria concentration in Marley Creek and Furnace Creek highly depends on the loadings from upstream and the adjacent watersheds, while the loadings discharged to the downstream estuary (Subwatersheds 1-3, 7-9, and 11) have minor impact on the upstream impaired area. A ten-fold increase of the bacteria loading in these downstream subwatersheds will only cause an increase of fewer than 10 counts/100ml bacteria concentration in the impaired area. Therefore, the final TMDL calculation excluded loads from these downstream watersheds.

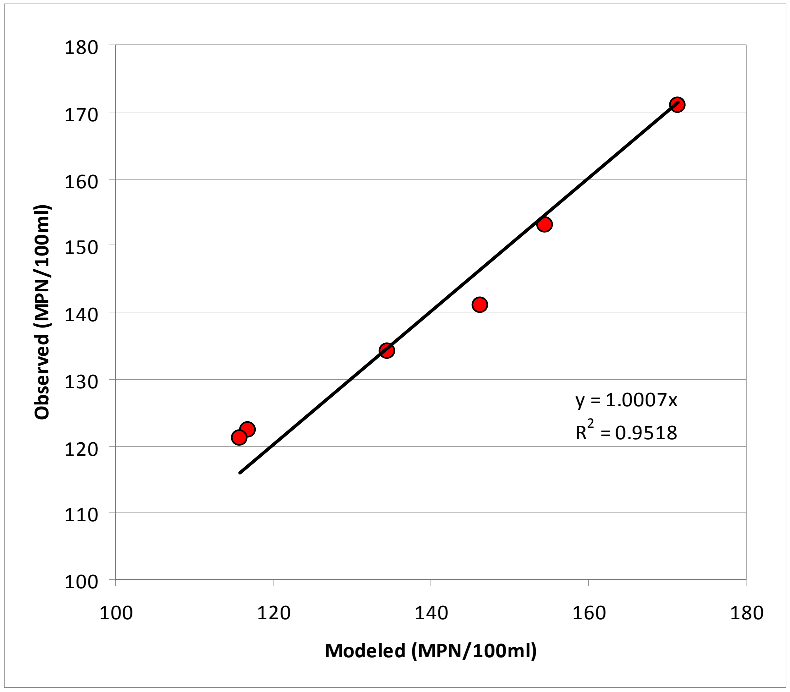

Figure A-2: Comparison of Measured and Modeled Bacteria Concentrations

Table A-4: TMDL Calculation Results for Each Subwatershed

Area	Subwatershed	Geometric Mean		
		Current Load Counts/day	Allowable Load Counts/day	Percent Reduction
Furnace Creek	4	1.283E+11	2.566E+10	80%
	15	1.737E+11	3.474E+10	80%
	16	2.491E+11	6.227E+10	75%
	17	1.370E+12	3.424E+11	75%
	18	3.194E+10	6.388E+09	80%
	19	4.045E+11	8.090E+10	80%
	21	1.307E+12	2.614E+11	80%
	Total	**3.66E+12**	**8.14E+11**	**78%**
Marley Creek	5	1.478E+11	3.696E+10	75%
	6	3.770E+12	9.425E+11	75%
	10	8.011E+11	2.003E+11	75%
	12	5.704E+11	1.426E+11	75%
	13	5.273E+11	1.055E+11	80%
	14	3.072E+09	6.144E+08	80%
	20	5.187E+10	2.593E+10	50%
	22	3.212E+11	4.769E+10	85%
	Total	**6.19E+12**	**1.50E+12**	**76%**
Downstream	1-3, 7-9, 11	1.428E+12	1.428E +12	0%

Appendix B. Identifying Sources of Fecal Pollution in Marley Creek and Furnace Creek

Introduction

In order to better identify potential sources of bacterial contamination that may be impacting the water quality of Marley Creek and Furnace Creek area, MDE conducted a fecal pollution source identification survey in the area from December 2007 to November 2008 (Frana and Venso 2009). BST (bacterial source tracking) technology was used to distinguish the origins of bacteria found in environmental waters. One of the biochemical BST methods, Antibiotic Resistance Analysis (ARA), was used in the survey with *Enterococcus* spp. as the indicator organism. The premise of this method is that bacteria isolated from different hosts can be discriminated based on differences in the selective pressure of microbial populations found in the gastrointestinal tract of the hosts, i.e., humans, livestock, pets, and wildlife (Wiggins 1996). In ARA, microbial isolates collected from water samples are tested and their resistance results are recorded and compared with library isolates from known sources. A statistical analysis can predict the likely host source of the water isolates (Hagedorn 1999, Price *et al.* 2006, Wiggins 1999).

<u>Furnace Creek Watershed BST Results</u>

A 565 known-source isolate library was constructed from sources in the Furnace Creek Watershed. The number of unique antibiotic resistance patterns was calculated, and the known sources in the library were grouped into four categories: human, livestock (none), pet (dog), and wildlife (deer, fox, rabbit, raccoon). Water samples were obtained from one monitoring station in Furnace Creek. A total of 258 enterococcus isolates were analyzed by statistical analysis. The BST results are shown in Figure B-1 and Table B-1. The largest category of potential sources in Furnace Creek watershed was wildlife (38%), followed by human (33%) and pet (29%) (from Frana and Venso 2009).

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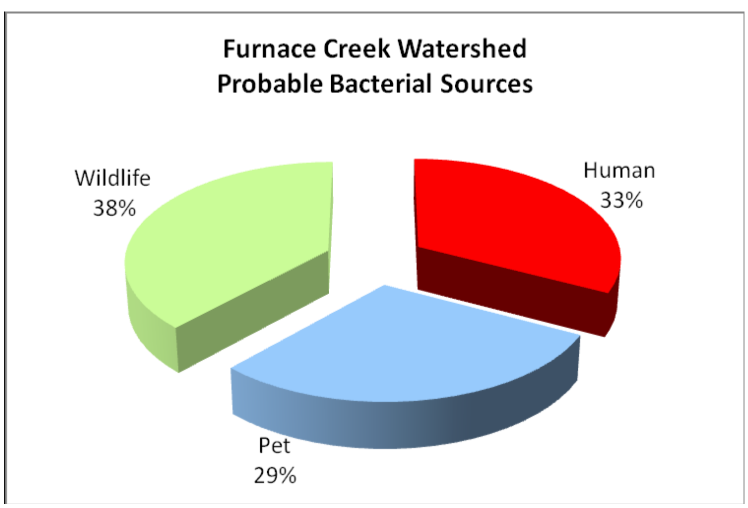

Figure B-1: Furnace Creek Watershed Relative Contributions by Probable Sources of Enterococcus Contamination

Table B-1: Furnace Creek Predicted Host Source Distribution

Source	Distribution
Human	32.5%
Livestock	0.0%
Pet	29.4%
Wildlife	38.1%
Total	**100.0%**

Marley Creek Watershed BST Results

A 473 known-source isolate library was constructed from sources in the Marley Creek watershed. The number of unique antibiotic resistance patterns was calculated, and the known sources in the library were grouped into four categories: human, livestock (none), pet (dog), and wildlife (beaver, deer, fox). Water samples were obtained from one monitoring station in Marley Creek. A total of 135 enterococcus isolates were analyzed by statistical analysis. The BST results are shown in Figure B-2 and Table B-2. The largest category of potential sources in Marley watershed was pet (35%), followed by human (34%), and then wildlife (31%) (from Frana and Venso 2009)
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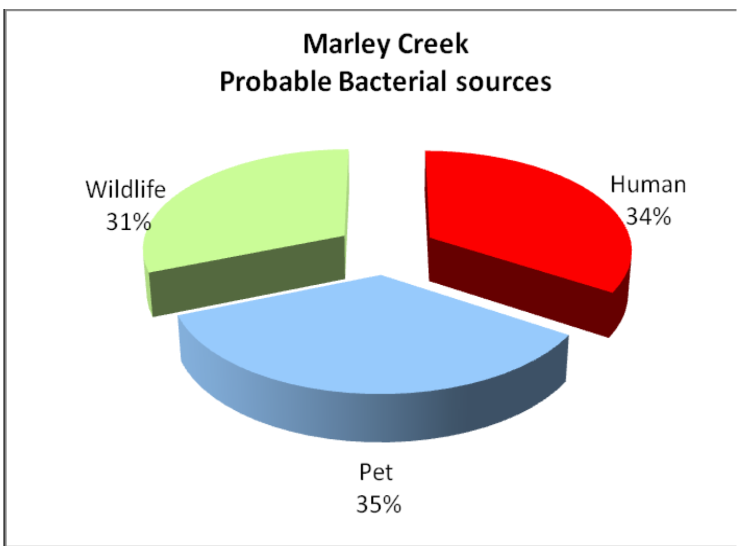

Figure B-2: Marley Creek Watershed Relative Contributions by Probable Sources of Enterococcus Contamination

Table B-2: Marley Creek Predicted Host Source Distribution

Source	Distribution
Human	34.2%
Livestock	0.0%
Pet	34.6%
Wildlife	31.2%
Total	**100.0%**

Appendix C. Stormwater Allocation Procedure

The stormwater wasteload allocation is estimated based on the proportion of urban land within the permitted county in the watershed. To estimate this load, the load from diffuse sources is multiplied by the proportion of urban land, and the resulting value is assigned to the stormwater WLA.

$WLA_i = L_D * ULU_i$

Where
WLA_i = NPDES regulated stormwater load from jurisdiction i
L_D = Load from diffuse sources to impaired area, including stormwater
ULU_i = Percentage of urban land use within jurisdiction i

Stormwater Loading Estimates

Table C-1 to Table C-4 summarize the following information for each watershed: 1) the Maryland Department of Planning (MDP) land use distribution by land use code, 2) the urban/non-urban land use distribution by acres, 3) the urban/non-urban land use distribution by percentage, and 4) the stormwater waste load allocation.

Table C-1: MDP Land Use Distribution for Marley Creek and Furnace Creek

Classification	Marley Creek		Furnace Creek	
	Total (acres)	Area within Anne Arundel County (acres)	Total (acres)	Area within Anne Arundel County (acres)
Residential urban [1]	3770.6	3770.6	3004.7	3004.7
Non-Residential urban [2]	1301.4	1301.4	3295.0	3295.0
Cropland	154.6	154.6	183.4	183.4
Pasture	74.9	74.9	136.7	136.7
Feedlot	32.2	32.2	0.0	0.0
Forest	2771.1	2771.1	1410.4	1410.4
Water	3.2	3.2	9.8	9.8
Wetlands	6.1	6.1	0.0	0.0
Barren	268.5	268.5	305.8	305.8
Total	**8382.5**	**8382.5**	**8345.8**	**8345.8**

Notes: [1] Includes low-density residential, medium-density residential, and high-density residential.
[2] Includes commercial, industrial, institutional, extractive, and open urban land.

Table C-2: Urban/Non-urban Land Use Distribution at Marley Creek and Furnace Creek

Stormwater Class	Marley Creek		Furnace Creek	
	Total (acres)	Area within Anne Arundel County (acres)	Total (acres)	Area within Anne Arundel County (acres)
Non-urban	3310.5	3310.5	2046.1	2046.1
Urban	5071.9	5071.9	6299.7	6299.7
Total	**8382.5**	**8382.5**	**8345.8**	**8345.8**

Table C-3: Urban/Non-urban Land Use Distribution (Percentage) at Marley Creek and Furnace Creek

Stormwater Class	Marley Creek		Furnace Creek	
	Total (%)	Area within Anne Arundel County (%)	Total (%)	Area within Anne Arundel County (%)
Non-urban	39.5	39.5	24.5	24.5
Urban	60.5	60.5	75.5	75.5
Total	**100**	**100**	**100**	**100**

Table C-4: Stormwater Waste Load Allocation at Marley Creek and Furnace Creek

Creek	Loading (count/day)	Distribution		Allocation (Count/day)	
		Urban	Non-urban	Stormwater WLA	LA
Marley	1.50E+12	60.5%	39.5%	9.08E+11	5.93E+11
Furnace	8.14E+11	75.5%	24.5%	6.15E+11	1.99E+11

Appendix D. MDE Permit Information

Table D-1: Stormwater Permit Information

MDE PERMIT #	NPDES #	FACILITY	CITY	COUNTY	TYPE	TMDL
02SW1504		GABLE SIGNS & GRAPHICS, INC.	BALTIMORE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1283		EJ ENTERPRISES, INC.	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0925		J & R BUS SERVICE, INC.	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1285		MARYLAND RECYCLE COMPANY, INC. - GLEN BURNIE	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0692		DLA/DNSC CURTIS BAY DEPOT	BALTIMORE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0298		GLEN BURNIE LANDFILL AND CONVENIENCE CENTER	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0964		RELIABLE CONTRACTING COMPANY, INC.	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1080		INTERSTATE BRANDS CORP. - GLEN BURNIE	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0823		HUBERS BUS SERVICE, INC.	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0962		MAISEL BROTHERS, INC.	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW0625		SOLLEY ROAD SANITARY LANDFILL	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1332		SHA - GLEN BURNIE SHOP	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
02SW1951		MTA - CROMWELL LIGHT RAIL MAINTENANCE FACILITY	GLEN BURNIE	ANNE ARUNDEL	WMA5SW	Stormwater WLA
	MD0068306	ANNE ARUNDEL COUNTY MS4	COUNTY-WIDE	ANNE ARUNDEL	WMA6	Stormwater WLA
99DP3313	MD0068276	STATE HIGHWAY ADMINSTRATION MS4	ALL PHASE I	STATE-WIDE	WMA6	Stormwater WLA
		MDE GENERAL PERMIT TO CONSTRUCT	ALL	ALL		Stormwater WLA

Appendix E. Tabulation of Enterococci Data

This appendix provides a tabulation of enterococcus values (including all duplicates) for the monitoring stations of the Marley Creek and Furnace Creek impaired area in the Baltimore Harbor basin. These data are plotted in Figures 2.2.2-2.2.7 of the main report.

Table D-1: Enterococci Data in Marley Creek and Furnace Creek 2005-2007 (MPN/100 ml)

Station ID	Date	Enterococci	Station	Date	Enterococci
AAMFCCE	7/14/2005	2000	AAMFGat	6/29/2005	83
AAMFCCE	7/27/2005	310	AAMFGat	7/27/2005	2000
AAMFCCE	5/31/2006	10	AAMFGat	5/31/2006	10
AAMFCCE	7/26/2006	10	AAMFGat	7/26/2006	13
AAMFCCE	8/23/2006	10	AAMFGat	8/23/2006	13
AAMFCCE	5/31/2007	36	AAMFGat	5/31/2007	10
AAMFCCE	6/13/2007	936	AAMFGat	6/13/2007	943
AAMFCCE	6/20/2007	790	AAMFGat	6/20/2007	13
AAMFCCE	6/27/2007	340	AAMFGat	6/27/2007	343
AAMFCCE	7/5/2007	150	AAMFGat	7/5/2007	90
AAMFCCE	7/11/2007	1190	AAMFGat	7/11/2007	1200
AAMFCCE	7/18/2007	430	AAMFGat	7/18/2007	476
AAMFCCE	7/25/2007	403	AAMFGat	7/25/2007	300
AAMFCCE	7/30/2007	166	AAMFGat	7/30/2007	180
AAMFCCE	8/6/2007	2010	AAMFGat	8/6/2007	2010
AAMFCCE	8/15/2007	253	AAMFGat	8/15/2007	226
AAMFCCE	8/20/2007	300	AAMFGat	8/20/2007	180
AAMFCCE	8/27/2007	13	AAMFGat	8/27/2007	130
AAMFHig	6/29/2005	223	AAMF7th	6/29/2005	176
AAMFHig	7/27/2005	1816	AAMF7th	7/27/2005	63
AAMFHig	5/31/2006	10	AAMF7th	5/31/2006	270
AAMFHig	7/26/2006	20	AAMF7th	7/26/2006	40
AAMFHig	8/23/2006	10	AAMF7th	8/23/2006	10
AAMFHig	5/31/2007	10	AAMF7th	5/31/2007	16
AAMFHig	6/13/2007	1493	AAMF7th	6/13/2007	1350
AAMFHig	6/20/2007	900	AAMF7th	6/20/2007	996
AAMFHig	6/27/2007	330	AAMF7th	6/27/2007	296
AAMFHig	7/5/2007	103	AAMF7th	7/5/2007	143
AAMFHig	7/11/2007	950	AAMF7th	7/11/2007	810
AAMFHig	7/18/2007	56	AAMF7th	7/18/2007	556
AAMFHig	7/25/2007	376	AAMF7th	7/25/2007	243
AAMFHig	7/30/2007	143	AAMF7th	7/30/2007	106
AAMFHig	8/6/2007	2010	AAMF7th	8/6/2007	2010

AAMFHig	8/15/2007	280	AAMF7th	8/15/2007	230
AAMFHig	8/20/2007	173	AAMF7th	8/20/2007	103
AAMFHig	8/27/2007	210	AAMF7th	8/27/2007	10
AAMFPoint	7/25/2007	290	AAMFRt10	6/29/2005	143
AAMFPoint	7/30/2007	133	AAMFRt10	7/27/2005	140
AAMFPoint	8/6/2007	2010	AAMFRt10	5/31/2006	646
AAMFPoint	8/15/2007	203	AAMFRt10	7/26/2006	23
AAMFPoint	8/20/2007	20	AAMFRt10	8/23/2006	13
AAMFPoint	8/27/2007	153	AAMFRt10	5/31/2007	1656

Table D-2: Enterococci Data in Marley Creek and Furnace Creek in 2008 (MPN/100 ml)

Station	Date	Observation 1	Observation 2	Observation 3
AAMF7th	06/11/08	10	10	1
AAMF7th	06/24/08	1	1	1
AAMF7th	07/08/08	10	1	10
AAMF7th	07/23/08	20	1	80
AAMF7th	08/07/08	10	10	1
AAMF7th	08/19/08	110	110	40
AAMFCCE	06/11/08	1	1	1
AAMFCCE	06/24/08	1	10	10
AAMFCCE	07/08/08	20	20	1
AAMFCCE	07/23/08	90	140	NA
AAMFCCE	08/07/08	2010	2010	2010
AAMFCCE	08/19/08	1	1	1
AAMFGat	06/11/08	1	20	10
AAMFGat	06/24/08	10	10	1
AAMFGat	07/08/08	1	1	1
AAMFGat	07/23/08	1	1	1
AAMFGat	08/07/08	10	10	10
AAMFGat	08/19/08	1	10	1
AAMFHig	06/11/08	1	1	1
AAMFHig	06/24/08	1	10	1
AAMFHig	07/08/08	1	1	1
AAMFHig	07/23/08	1	1	1
AAMFHig	08/07/08	1	1	1
AAMFHig	08/19/08	20	30	40
AAMFPoint	06/11/08	10	1	10
AAMFPoint	06/24/08	1	1	10
AAMFPoint	07/08/08	20	1	20
AAMFPoint	07/23/08	1	1	1
AAMFPoint	08/07/08	1	1	1
AAMFPoint	08/19/08	1	30	30