Total Maximum Daily Loads of Fecal Coliform in the Restricted Shellfish Harvesting Areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River in Calvert and St. Mary's Counties, Maryland

FINAL

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List of Abbreviations

ARA	Antibiotic Resistance Analysis
BMP	Best Management Practice
BST	Bacteria Source Tracking
CBP	Chesapeake Bay Program
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
CWP	Center for Watershed Protection
EPA	Environmental Protection Agency
FDA	Food and Drug Administration
GIS	Geographic Information System
LA	Load Allocation
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
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollution Discharge Elimination System
NSSP	National Shellfish Sanitation Program
PCBs	Polychlorinated Biphenyls
T^{-1}	Per Tidal Cycle
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WLA	Wasteload Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WQS	Water Quality Standards
WWTP	Waste Water Treatment Plant

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency (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 (WQSs). For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) for the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2017a). This document, upon approval by the U.S. EPA, establishes TMDL for fecal coliform in the restricted shellfish areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River in Maryland.

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2017a). The Maryland Department of the Environment (MDE) has identified the waters of Patuxent River Mesohaline Chesapeake Bay Segment (Integrated Report Assessment Unit ID: MD-PAXMH) on the State's 2016 Integrated Report as impaired by polychlorinated biphenyls (PCBs) in fish tissue (2008) and fecal coliform in the restricted shellfish harvesting areas in Battle Creek (MD-PAXMH-Battle_Creek-2) in 2010 and MD-PAXMH-Battle_Creek-3 in 2014), Buzzard Island Creek (MD-PAXMH-Buzzard_Island_Creek in 2012) and Hog Neck Creek (MD-PAXMH-Hog Neck_Creek in 2014). The TMDLs established herein by MDE will address the fecal coliform listings for the restricted shellfish harvesting areas in Battle Creek, Buzzard Island Creek and Hog Neck Creek, for which a data solicitation was conducted, and all readily available data have been considered. The water quality criteria for shellfish harvesting areas is more stringent than the criteria for water contact recreation. Therefore, the endpoint for this TMDL is also protective of the water contact recreation use. Note that this report does not address the downstream portion of Battle Creek, MD-PAXMH-Battle_Creek, which is not listed as impaired on the 2016 Integrated Report. This document will use the name "Battle Creek" to describe the impaired sections MD-PAXMH-Battle_Creek-2 and PAXMH-Battle_Creek-3, which constitute a majority of the Creek.

Fecal coliforms are found in the intestinal tract of humans and other warm-blooded animals. Fecal coliform may occur in surface waters from point and nonpoint sources. Few fecal coliform are pathogenic; however, the presence of elevated levels of fecal coliform in shellfish waters may indicate recent sources of pollution. Some common waterborne diseases associated with the consumption of raw clams and oysters harvested from polluted water include viral and bacterial gastroenteritis and hepatitis A.

Water quality criteria for shellfish waters are established under the National Shellfish Sanitation Program (NSSP), a cooperative program that involves states, industry, academic and federal agencies, with oversight by the US Food and Drug Administration (FDA). Fecal coliforms are indicator organisms used in water quality monitoring in shellfish waters to indicate fresh sources of pollution from human and other animal wastes. When the water quality standard for fecal coliform in shellfish waters is exceeded, waters are closed to shellfish harvesting to protect human health due to the potential risk from consuming raw molluscan shellfish from contaminated waters.

The overall objective of the fecal coliform TMDLs established in this document is to ensure that the "shellfish harvesting" designated use, which is protective of human health related to the consumption of shellfish from these harvesting areas, is supported. Field observations collected between 2014 and 2017 and a steady-state tidal prism model were used to estimate the current fecal coliform load based on volume and concentration, and to establish allowable loads for these three restricted shellfish harvesting areas in the Lower Patuxent River Basin. The tidal prism model incorporates influences of freshwater discharge, tidal transport, and fecal coliform decay, thereby representing the fate and transport of fecal coliform in these restricted shellfish harvesting areas. The loadings from non-point sources (human, livestock, pets, and wildlife) were quantified through bacteria source tracking (BST) analysis using data collected in the Lower Patuxent River over a one-year period. There are no point sources identified within the drainage areas of the three restricted shellfish harvesting areas addressed in this document.

The allowable loads for the restricted shellfish harvesting areas were computed using both the median concentration water quality criterion for shellfish harvesting use of 14 Most Probable Number (MPN) of fecal coliform per 100ml (MPN/100ml), and the 90th percentile criterion concentration of 49 MPN/100ml for a three-tube decimal dilution. An implicit Margin of Safety (MOS) was incorporated into the analysis to account for uncertainty.

The goal in setting TMDL allocations is to determine the maximum allowable load for 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 criterion requiring the largest percent reductions - here the 90th - percentile criterion for these three restricted shellfish harvesting areas. Reductions by each source category were assigned by first managing controllable sources (human, livestock and pets) and then determining if the TMDL could be achieved. If the total required reduction was not achieved, then the wildlife source was also reduced.

Summaries of the baseline loads, TMDL allocations and reductions for the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River are presented in Table ES-1. It is important to note that the TMDLs presented herein should be applied as a three year averaging period consistent with the water quality standard.

Table ES-1: Summary of Fecal Coliform Baseline Loads, TMDL Allocations, Load Reductions for the Restricted Shellfish Harvesting Areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River

<table>
<tr><th colspan="5">Battle Creek</th></tr>
<tr><th>Source</th><th>Baseline Load (Counts/day)</th><th>Baseline Load (%)</th><th>TMDL (Counts/day)</th><th>TMDL Reduction (%)</th></tr>
<tr><td>Human</td><td>4.45E+11</td><td>17%</td><td>0</td><td>100%</td></tr>
<tr><td>Livestock</td><td>7.86E+11</td><td>30%</td><td>0</td><td>100%</td></tr>
<tr><td>Wildlife</td><td>9.96E+11</td><td>38%</td><td>1.62E+11</td><td>84%</td></tr>
<tr><td>Pets</td><td>3.93E+11</td><td>15%</td><td>0</td><td>100%</td></tr>
<tr><td><i>Nonpoint Sources</i></td><td>2.62E+12</td><td>100%</td><td>1.62E+11</td><td>94%</td></tr>
<tr><td><i>Point Sources</i></td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td><i>MOS</i></td><td>-</td><td>-</td><td>Implicit</td><td>-</td></tr>
<tr><td>Total</td><td>2.62E+12</td><td>100%</td><td>1.62E+11</td><td>94%</td></tr>
<tr><th colspan="5">Buzzard Island Creek</th></tr>
<tr><th>Source</th><th>Baseline Load (Counts/day)</th><th>Baseline Load (%)</th><th>TMDL (Counts/day)</th><th>TMDL Reduction (%)</th></tr>
<tr><td>Human</td><td>1.64E+10</td><td>17%</td><td>5.71E+09</td><td>65%</td></tr>
<tr><td>Livestock</td><td>2.90E+10</td><td>30%</td><td>1.01E+10</td><td>65%</td></tr>
<tr><td>Wildlife</td><td>3.67E+10</td><td>38%</td><td>3.67E+10</td><td>0%</td></tr>
<tr><td>Pets</td><td>1.45E+10</td><td>15%</td><td>5.04E+09</td><td>65%</td></tr>
<tr><td><i>Nonpoint Sources</i></td><td>9.65E+10</td><td>100%</td><td>5.75E+10</td><td>40%</td></tr>
<tr><td><i>Point Sources</i></td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td><i>MOS</i></td><td>-</td><td>-</td><td>Implicit</td><td>-</td></tr>
<tr><td>Total</td><td>9.65E+10</td><td>100%</td><td>5.75E+10</td><td>40%</td></tr>
<tr><th colspan="5">Hog Neck Creek</th></tr>
<tr><th>Source</th><th>Baseline Load (Counts/day)</th><th>Baseline Load (%)</th><th>TMDL (Counts/day)</th><th>TMDL Reduction (%)</th></tr>
<tr><td>Human</td><td>6.20E+09</td><td>11%</td><td>3.81E+09</td><td>39%</td></tr>
<tr><td>Livestock</td><td>1.69E+10</td><td>30%</td><td>1.04E+10</td><td>39%</td></tr>
<tr><td>Wildlife</td><td>2.37E+10</td><td>42%</td><td>2.37E+10</td><td>0%</td></tr>
<tr><td>Pets</td><td>9.59E+09</td><td>17%</td><td>5.89E+09</td><td>39%</td></tr>
<tr><td><i>Nonpoint Sources</i></td><td>5.64E+10</td><td>100%</td><td>4.38E+10</td><td>22%</td></tr>
<tr><td><i>Point Sources</i></td><td>NA</td><td>NA</td><td>NA</td><td>NA</td></tr>
<tr><td><i>MOS</i></td><td>-</td><td>-</td><td>Implicit</td><td>-</td></tr>
<tr><td>Total</td><td>5.64E+10</td><td>100%</td><td>4.38E+10</td><td>22%</td></tr>
</table>

Federal regulations require that TMDL analysis take into account the impact of critical conditions and seasonality on water quality (CFR 2017b). The intent of these requirements is to ensure that load reductions required by this TMDL, when implemented, will produce water quality conditions supportive of the designated use at all times. The 90^{th}-percentile concentration is the concentration exceeded only 10% of the time. Since data collected during the most recent three-year period was used to calculate the 90^{th}-percentile, the critical condition is implicitly included in the value of the 90^{th}-percentile. Similar to the critical condition, seasonality is also implicitly included in the analysis due to the averaging required in the water quality standards. The MDE shellfish-monitoring program uses a systematic random sampling design that was developed to cover inter-annual variability. The monitoring design and the statistical analysis used to evaluate water quality attainment therefore implicitly include the effect of seasonality.

Once USEPA has approved this 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 TMDL reductions to be implemented in an iterative process that first addresses those sources with the largest impact to water quality, with consideration given to cost of implementation. The source contributions estimated from the BST results may be used as a tool to target and prioritize initial implementation efforts. Continued monitoring will be undertaken by MDE's Shellfish Certification Division, and the data will be used to assess the effectiveness of the Department's implementation efforts on an ongoing basis.
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1.0 INTRODUCTION

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency (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 (WQSs). For each WQLS, the State is to either establish a TMDL for the specified substance that the waterbody can receive without violating WQSs, or demonstrate that WQSs are being met (CFR 2017a). This document, upon approval by the U.S. EPA, establishes Total Maximum Daily Loads (TMDL) for fecal coliform in the restricted shellfish areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River in Maryland.

TMDLs are established to determine the maximum pollutant load at which WQSs are met. A WQS 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, protection of aquatic life, fish and shellfish propagation and harvesting. 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.

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2017a). The Maryland Department of the Environment (MDE) has identified the waters of Lower Patuxent River Mesohaline Chesapeake Bay Segment (Integrated Report Assessment Unit ID: MD-PAXMH) on the State's 2016 Integrated Report as impaired by polychlorinated biphenyls (PCBs) in fish tissue (2008) and fecal coliform in the restricted shellfish harvesting areas in Battle Creek (MD-PAXMH-Battle_Creek-2, in 2010, and MD-PAXMH-Battle_Creek-3, in 2014), Buzzard Island Creek (MD-PAXMH-Buzzard_Island_Creek, in 2012) and Hog Neck Creek (MD-PAXMH-Hog Neck_Creek, in 2014). The TMDLs established herein by MDE will address the fecal coliform listings for the restricted shellfish harvesting areas in Battle Creek, Buzzard Island Creek and Hog Neck Creek, for which a data solicitation was conducted, and all readily available data have been considered. The water quality criteria for shellfish harvesting areas is more stringent than the criteria for water contact recreation. Therefore, the endpoint for this TMDL is also protective of the water contact recreation use. Note that this report does not address the downstream portion of Battle Creek, MD-PAXMH-Battle_Creek, which is not listed as impaired on the 2016 Integrated Report. This document will use the name "Battle Creek" to describe the impaired sections MD-PAXMH-Battle_Creek-2 and PAXMH-Battle_Creek-3, which constitute a majority of the Creek.

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Water quality criteria for shellfish waters are established under the National Shellfish Sanitation Program (NSSP), a cooperative program that involves states, industry, academic and federal agencies, with oversight by the US Food and Drug Administration (FDA). Fecal coliforms are indicator organisms used in water quality monitoring in shellfish waters to indicate fresh sources of pollution from human and other animal wastes. When the water quality standard for fecal coliform in shellfish waters is exceeded, waters are closed to shellfish harvesting to protect human health due to the potential risk from consuming raw molluscan shellfish from contaminated waters.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

Three restricted shellfish harvesting areas in the Lower Patuxent River Mesohaline are addressed in this report: Battle Creek, Buzzard Island Creek and Hog Neck Creek. Battle Creek and Buzzard Island Creek are located on the eastern shoreline of the Lower Patuxent River. Hog Neck Creek is located along the western shoreline. The Patuxent River, which drains directly to the Chesapeake Bay, is located on Maryland's western shore. Shellfish harvesting waters in the Patuxent River extend from Ferry Landing, which is south of Jug Bay, to the mouth of the river where it discharges into the Chesapeake Bay.

The Lower Patuxent River, shown in Figure 1, is located in the Atlantic Coastal Plain Eco-region. The basin has irregular topography, and the majority of the area near the receiving waters consists of low-lying, poorly drained land combined with a high (although variable) water table. The dominant tide in this region is the lunar semi-diurnal (M_2) tide with a tidal range of 0.5 m [National Oceanic and Atmospheric Administration (NOAA) 2017]. Table 1 presents the mean volumes and mean water depths of the three restricted shellfish harvesting areas. The location of the restricted areas and its corresponding drainage areas are shown on Figure 1. The drainage area for each restricted shellfish harvesting area was derived using online United States Geological Survey (USGS) StreamStats tool (USGS 2017).

Table 1: Physical Characteristics of the Restricted Shellfish Harvesting Areas

Restricted Shellfish Harvesting Area	Mean Water Volume in m^3	Mean Water Depth in m
Battle Creek	413,907	0.37
Buzzard Island Creek	160,062	0.52
Hog Neck Creek	126,246	2.12

Land Use

MDE edited Chesapeake Conservancy land cover data (Chesapeake Conservancy 2018) was used to estimate the land use information for the drainage areas of the three restricted shellfish harvesting areas. The land use percentage distributions for each area are shown in Table 2 to Table 4 and Figure 2 to Figure 4.

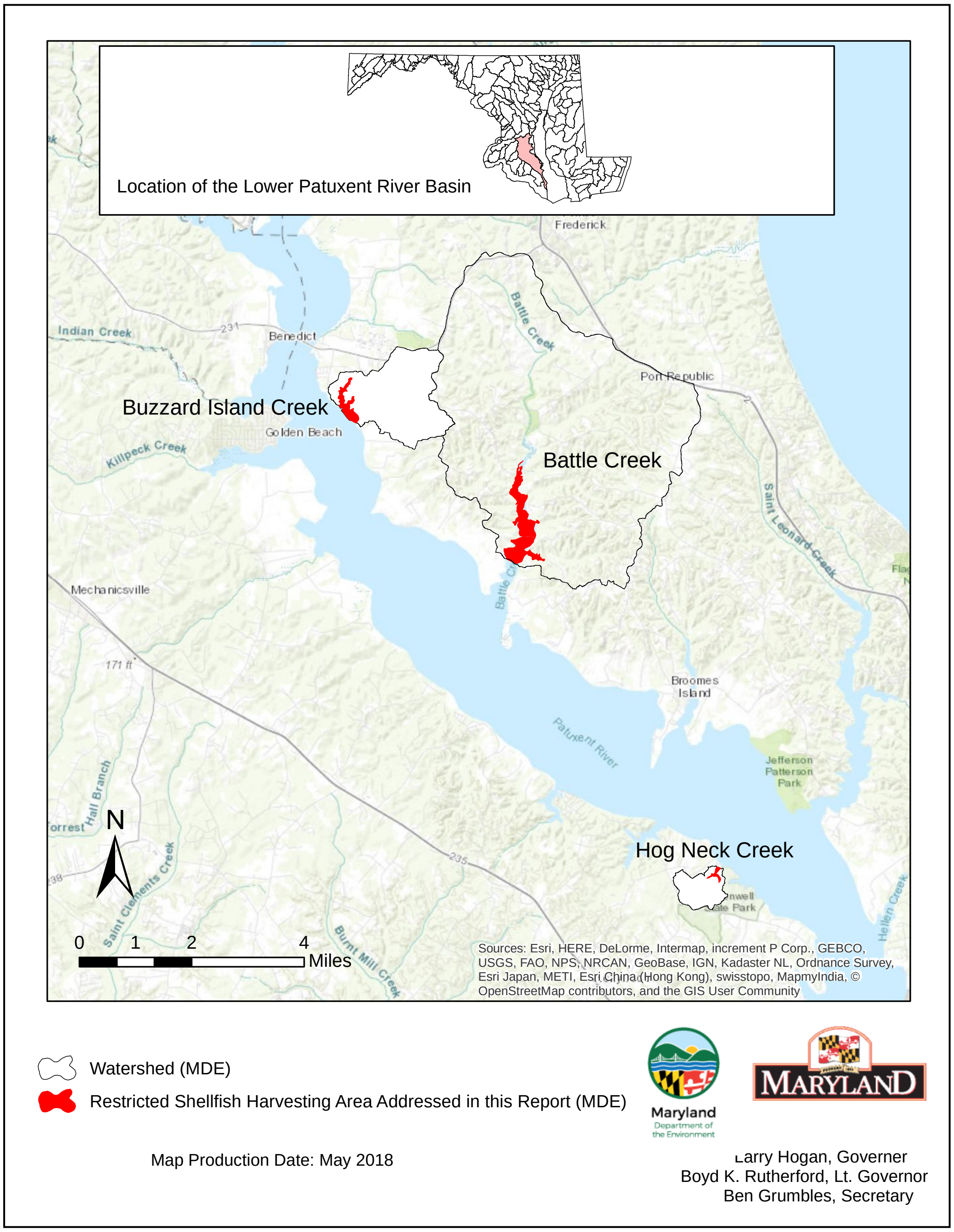

Figure 1: Location Map of the Restricted Shellfish Harvesting Areas and their Drainage Areas in the Lower Patuxent River Basin

Table 2: Land Use Percentage Distribution for Battle Creek Watershed

Land Use	Acreage	Percentage
Water/Wetland	371	3%
Forest	8,177	72%
Agriculture	1,275	11%
Urban	1,613	14%
Totals	11,436	100%

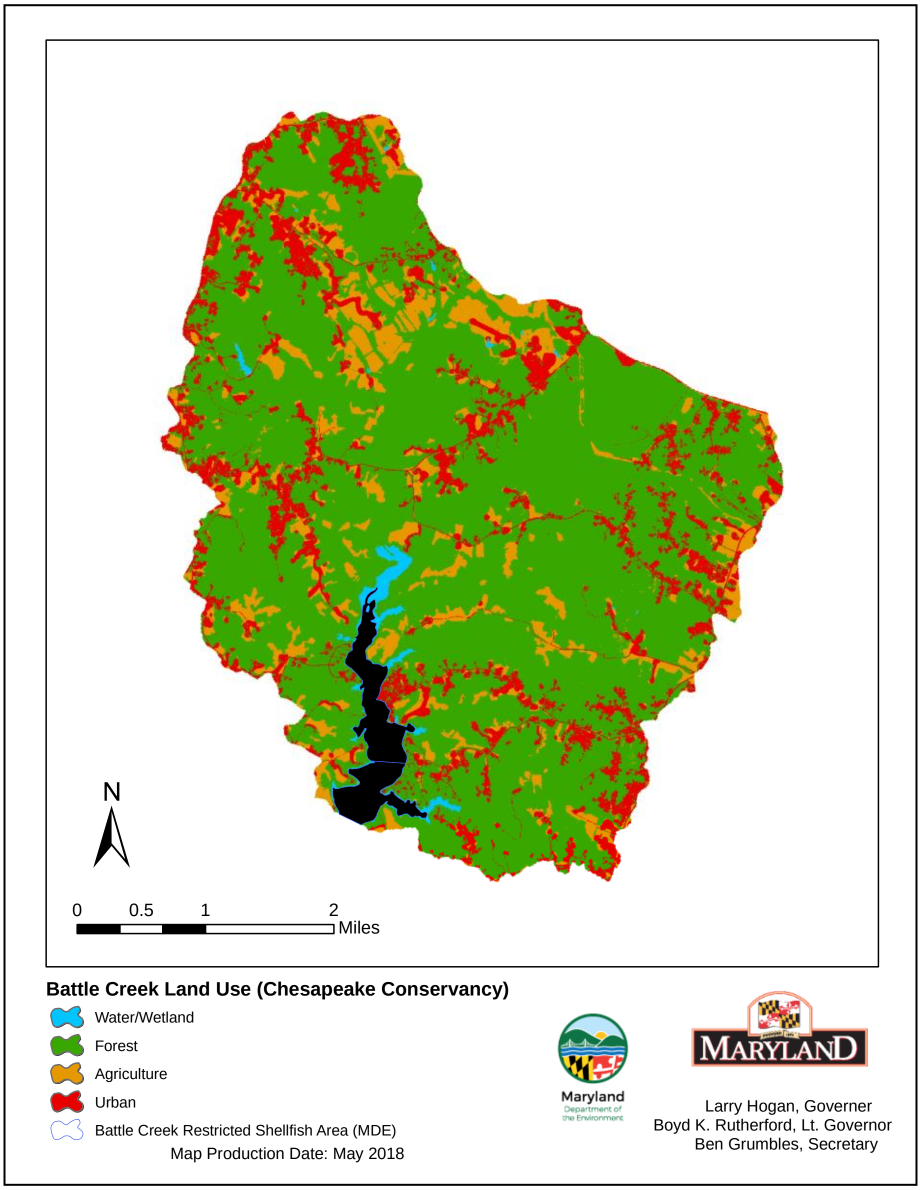

Figure 2: Land Use in the Battle Creek Drainage Area

Table 3: Land Use Percentage Distribution for Buzzard Island Creek Watershed

Land Use	Acreage	Percentage
Water/Wetland	96	6%
Forest	584	39%
Agriculture	522	34%
Urban	312	21%
Totals	1,514	100%

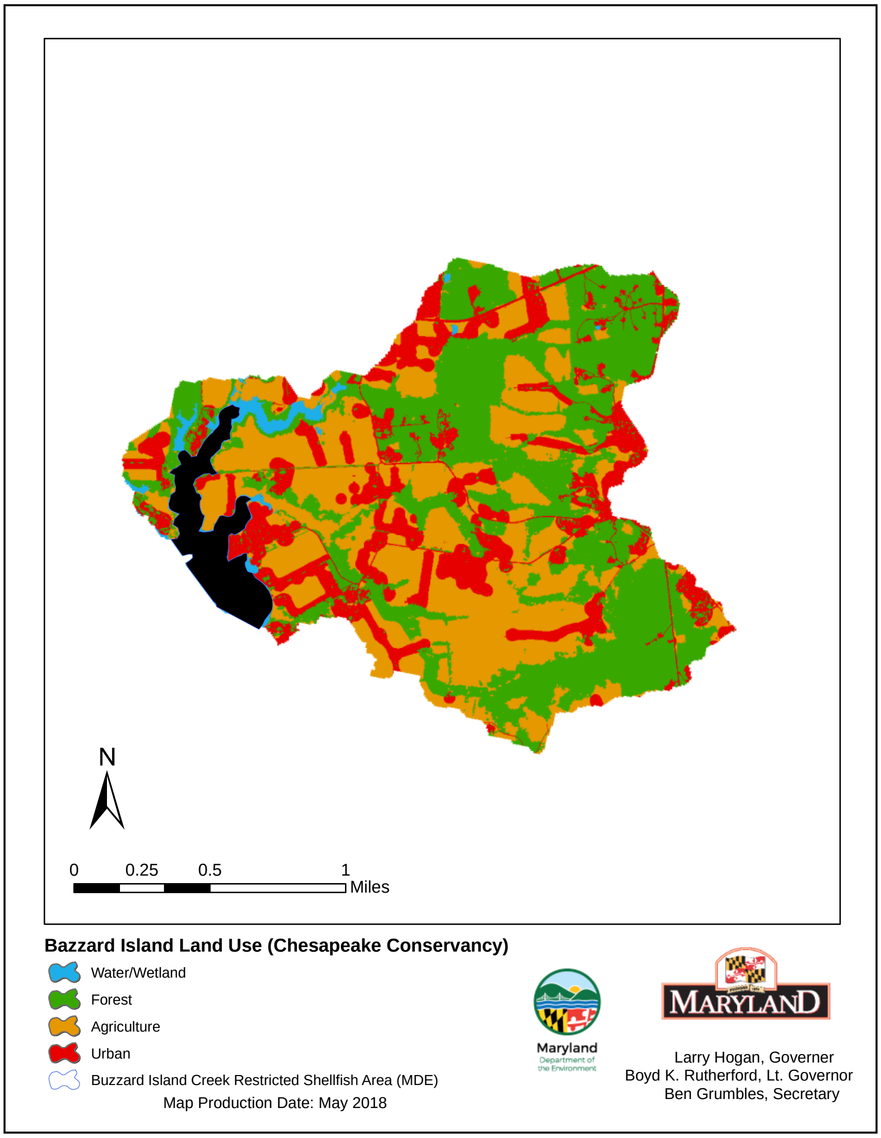

Figure 3: Land Use in the Buzzard Island Creek Drainage Area

Table 4: Land Use Percentage Distribution for Hog Neck Creek Watershed

Land Use	Acreage	Percentage
Water/Wetland	20	6%
Forest	193	59%
Agriculture	99	30%
Urban	18	5%
Totals	330	100%

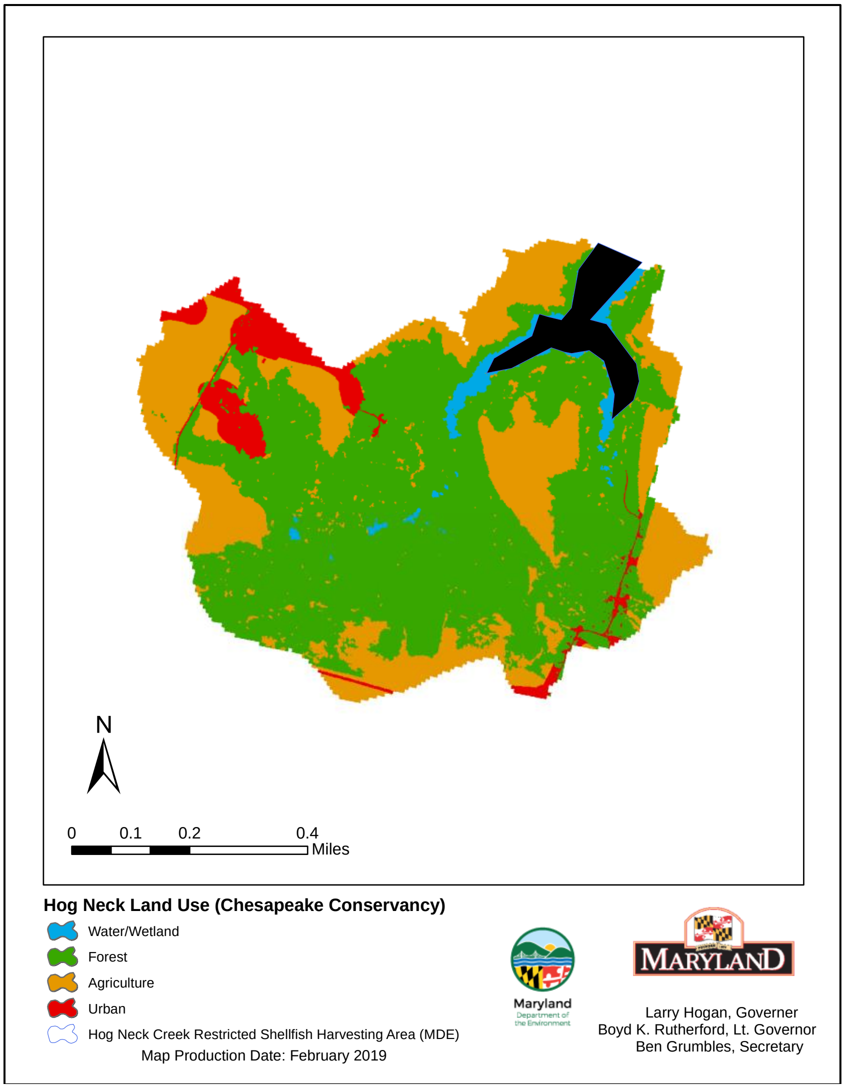

Figure 4: Land Use in the Hog Neck Creek Drainage Area

2.2 Water Quality Characterization and Impairment

Maryland WQSs specify that all surface waters of the State shall be protected for water contact recreation, fishing, and protection of aquatic life and wildlife (COMAR 2017a). The designated use of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek is Use II – *Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting* (COMAR 2017b). The water quality criteria for shellfish harvesting areas is more stringent than the criteria for water contact recreation. Therefore, the endpoint for this TMDL is also protective of the water contact recreation use. There are no "high quality," or Tier II, stream segments (Benthic Index of Biotic Integrity [BIBI] and Fish Index of Biotic Integrity [FIBI] aquatic life assessment scores > 4 [scale 1-5]) located within the drainage areas of the Battle Creek, Buzzard Island Creek or Hog Neck Creek restricted shellfish harvesting areas (COMAR 2017c).

MDE's Shellfish Certification Program is responsible for classifying shellfish harvesting waters to ensure oysters and clams are safe for human consumption. As discussed in Section 1, MDE adheres to the requirements of the NSSP, with oversight by FDA. MDE conducts shoreline surveys and collects routine bacteria water quality samples in the shellfish waters of Maryland to assure that Maryland's shellfish waters are properly classified.

MDE's Shellfish Certification Division has monitored shellfish growing regions throughout Maryland. The shellfish monitoring stations in the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek are shown in Figure 5.

The fecal coliform impairments addressed in this document were determined with reference to Maryland's Classification of Use II Waters (Support of Estuarine and Marine Aquatic Life and Shellfish Harvesting) in the Code of Maryland Regulations (COMAR), Surface Water Quality Criteria 26.08.02.03-3.C(2), which states:

> Classification of Use II Waters for Harvesting.
>
> (a) Approved classification means that the median fecal coliform MPN of at least 30 water sample results taken over a 3-year period to incorporate inter-annual variability does not exceed 14 per 100 milliliters; and:
>
> (i) In areas affected by point source discharges, not more than 10 percent of the samples exceed an MPN of 43 per 100 milliliters for a five tube decimal dilution test or 49 MPN per 100 milliliters for a three tube decimal dilution test; or
>
> (ii) In other areas, the 90th percentile of water sample results does not exceed an MPN of 43 per 100 milliliters for a five tube decimal dilution test or 49 MPN per 100 milliliters for a three tube decimal dilution test (COMAR 2017d).[1]

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[1] Note that Maryland uses the three-tube decimal dilution test for fecal coliform bacteria monitoring purposes.

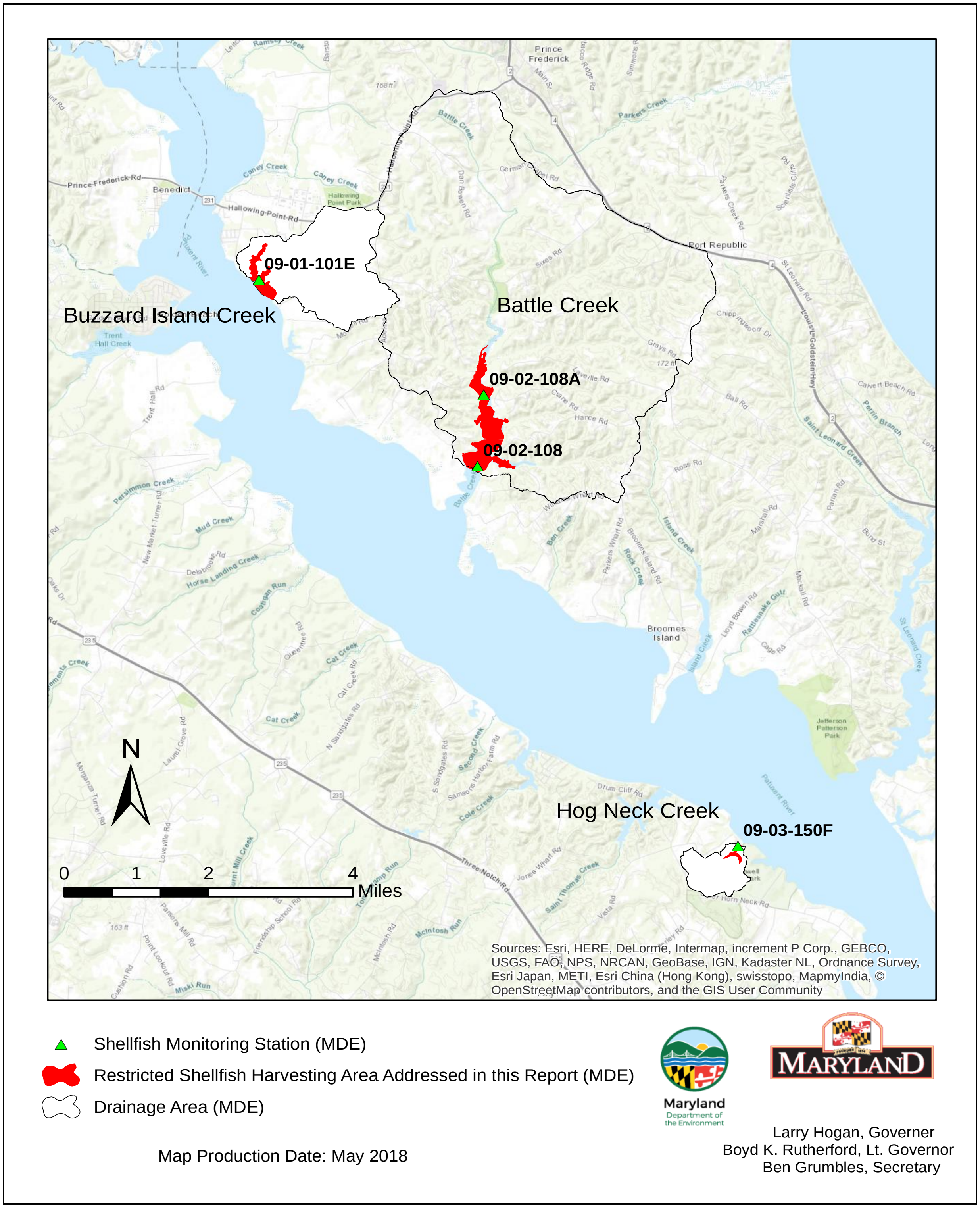

Figure 5: Shellfish Monitoring Stations in the Restricted Shellfish Harvesting Areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek

For this report, the water quality impairment was assessed based on the most recent three-year median and 90th percentile concentrations from June 2014 to June 2017. Descriptive statistics of the monitoring data at the stations for the three restricted shellfish harvesting areas and the water quality criterion are shown in Table 5. Results from this analysis confirm water quality impairments in the restricted shellfish harvesting areas of Battle Creek (violating both criteria), Buzzard Island Creek (violating 90th percentile criterion) and Hog Neck Creek (violating 90th percentile criterion).

Table 5: Summary of Fecal Coliform Data for the Restricted Shellfish Harvesting Areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek from June 2014 to June 2017

Area Name	Station	Median		90th Percentile	
		Monitoring Data	Criterion	Monitoring Data	Criterion
		MPN/100ml	MPN/100ml	MPN/100ml	MPN/100ml
Battle Creek	09-02-108	7.3	14	43.0	49
	09-02-108A	39.0	14	328.0	49
Buzzard Island Creek	09-01-101E	9.1	14	82.2	49
Hog Neck Creek	09-03-150F	9.1	14	63.0	49

2.3 Source Assessment

Fecal coliform are found in the intestinal tract of humans and other warm-blooded animals. Fecal coliform may occur in surface waters from point and nonpoint sources. This section provides a summary of the sources that have been identified as contributing fecal coliform loads to the restricted shellfish areas addressed in this document.

2.3.1. Nonpoint Sources

Nonpoint sources of fecal coliform do not have one discharge point but occur over the entire length of a stream or waterbody. There are many types of nonpoint sources in watersheds draining to restricted shellfish harvesting areas. The possible introductions of fecal coliform to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. During rain events, surface runoff can transport fecal coliform from the land surface and to the restricted shellfish harvesting area. The transport of fecal coliform from land surface to the restricted shellfish harvesting area is dictated by the hydrology, soil type, land use, and topography of the watershed. Deposition of non-human fecal coliform directly to a restricted shellfish harvesting area can occur when livestock or wildlife have direct access to the waterbody. Nonpoint source contributions to the bacterial levels from human activities generally arise from failing septic systems and their associated drain fields as well as through pollution from recreation vessel discharges.

In order to determine the sources of fecal coliform contribution and reduction needed to achieve water quality criteria and to allocate fecal coliform loads among these sources, it is necessary to identify all existing sources. MDE conducted scat and water column sampling over a one-year period in the shellfish harvesting areas of Lower Patuxent River watershed to use bacteria source tracking (BST) to identify sources of fecal coliform. The nonpoint source assessment was conducted by analyzing BST results to quantify source loadings from humans, livestock, pets, and wildlife.

In the Lower Patuxent River basin, wildlife contributions, both mammalian and avian, are considered natural conditions and may represent a background level of bacterial loading. Livestock contributions, such as those from mammalian and avian livestock, mainly result from surface runoff. Pet contributions usually occur through runoff from streets and land. Human sources mainly result from failure of septic systems. Table 6 summarizes the source distribution based on BST data analysis for the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek. A detailed description of the BST analysis is presented in Appendix B.

Table 6: Source Distribution Based on BST Data Analysis

Area	Human	Livestock	Wildlife	Pets
Battle Creek	17%	30%	38%	15%
Buzzard Island Creek	17%	30%	38%	15%
Hog Neck Creek	11%	30%	42%	17%

BST data analysis includes a statistical comparison of known sources collected in the watershed and compared with unknown source samples collected over the study period. The fecal coliform sources in water samples are unknown until matched with the library of known sources. The dominant source is from wildlife for the three restricted areas. The source distributions from the BST analysis for the above restricted shellfish areas appear consistent with the land use information of each corresponding drainage areas as shown on Tables 2 to 4, in that the watersheds are primarily forested with significant agricultural acreage.

2.3.2. Point Sources

There are no National Pollutant Discharge Elimination System (NPDES)-regulated municipal wastewater treatment plants (WWTPs), industrial process water facilities and regulated stormwater discharges under Phase I or Phase II of the NPDES stormwater program within the drainage areas of any of the restricted shellfish harvesting areas. Therefore, there are no point source allocations for fecal coliform loads from the drainage areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek.

2.3.3. Source Assessment Summary

From this source assessment, all known point and nonpoint sources of fecal coliform to the restricted areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in Lower Patuxent River watershed have been identified and characterized. The nonpoint sources of fecal coliform are from four categories: human, livestock, wildlife and pets. There are no point sources with permits regulating the discharge of fecal coliform load identified for any of the restricted shellfish areas. Estimated fecal coliform loads from these nonpoint sources represent the baseline conditions for the drainage areas of the restricted shellfish harvest areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek.

3.0 TARGETED WATER QUALITY GOAL

As described in Section 2.2, MDE evaluates whether a waterbody is restricted for shellfish harvesting based on both the median fecal coliform concentration of 14 MPN/100ml and 90th percentile fecal coliform concentration of 49MPN/100ml of at least 30 samples taken over a three-year period. The overall objective of the fecal coliform TMDLs established in this document is to meet these criteria, ensuring that the “shellfish harvest” designated use, which is protective of human health related to the consumption of shellfish, is supported.

4.0 TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATION

4.1 Overview

A TMDL is the total amount of an impairing substance that a waterbody can receive and still meet WQSs. The TMDL may be expressed as a mass per unit time, toxicity, or other appropriate measure and should be presented in terms of wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, and either an implicit or explicit margin of safety (MOS) (CFR 2017a):

$$\text{TMDL} = \text{WLAs} + \text{LAs} + \text{MOS} \qquad \text{(Equation 5.1)}$$

This section describes how the fecal coliform TMDL and the corresponding LAs and WLAs have been developed for the drainage areas of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River.

4.2 Analysis Framework

In general, tidal waters are exchanged through their connecting boundaries. The tide and amount of freshwater discharge into the embayment are the dominant influences on the transport of fecal coliform. The methodology used assumes that freshwater input, tidal range, and the first-order decay of fecal coliform are all constant. The TMDL is calculated based on the steady state tidal prism model. Compared to the volumetric method (EPA Shellfish Workshop 2002), the steady state tidal prism model provides improvements incorporating the influences of tidal induced transport, freshwater, and decay of fecal coliform in the embayment. A detailed description of the model is presented in Appendix A.

Using the steady state tidal prism model, the loads can be estimated according to the equation as follows (see also Appendix A):

$$L = \left[C\left(Q_b + kV\right) - Q_0 C_0\right] \times Cf \qquad \text{(Equation 5.2)}$$

where:
L = fecal coliform load (counts per day)
C = fecal coliform concentration (MPN /100ml) of embayment
Q_b = the quantity of mixed water that leaves the embayment on the ebb tide that did not enter the embayment on the previous flood tide (m^3 per tidal cycle)
k = the fecal coliform decay rate (per tidal cycle)
V = the mean volume of the embayment (m^3)
Q_0 = the quantity of water that enters the embayment on the flood tide through the ocean boundary that did not flow out of the embayment on the previous ebb tide (m^3 per tidal cycle)
C_0 = the fecal coliform concentration (MPN/100ml) at the oceanside boundary
Cf = the unit conversion factor
Q_b and Q_0 are estimated based on the steady state condition as follows:

$$Q_b = Q_0 + Q_f$$

where Q_f is mean freshwater discharge during the tidal cycle

$$Q_0 = \beta Q_T$$

where β is an exchange ratio and Q_T is the total ocean water entering the bay on the flood tide, which is calculated based on tidal range. The dominant tide in this region is the lunar semi-diurnal (M_2) tide with a tidal period of 12.42 hours; therefore, the M_2 tide is used for the representative tidal cycle. In general, the exchange ratio varies from 0.3 to 0.7, based on the previous model tests in Virginia coastal embayments (Kuo et al. 1998; Shen et al. 2002). The observed salinity data were also used to estimate the exchange ratio. The estimated values range from 0.3-0.8; therefore, a value of 0.5 is used for the exchange ratio.

The stream flow used for the estimation of Q_f was based on the flows of the USGS gage # 01661050, located nearby in St. Mary's County, MD. For each restricted shellfish area, the average of three-year (June 2014 to June 2017) monthly average flow for this USGS gage (i.e., 17.84 cfs) was adjusted by the ratio of the drainage area to that of the gage's drainage basin (11,840 acres) to derive estimates of the long-term flows. The estimated freshwater flows to each restricted shellfish areas are listed in Table 7.

Table 7: Average Long Term Flows from the Drainage Areas of the Restricted Areas

Restricted Shellfish Harvesting Area	Drainage Area in Acres	Average Long-Term Flow in cfs
Battle Creek	11,161	16.82
Buzzard Island Creek	1,444	2.18
Hog Neck Creek	315	0.48

Baseline Conditions

The most recent three-year (June 2014 to June 2017) median and 90th percentile fecal coliform concentrations in each restricted shellfish harvesting area were used to characterize the current (baseline) conditions. If there is only one monitoring station in the restricted shellfish harvesting area, the fecal coliform concentration of this station will be used as both the embayment and boundary condition. Baseline concentrations for median and 90th percentile scenarios and the estimated baseline loads from the drainage areas of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek are presented in Table 8.

Table 8: Baseline Loads Estimated for the Restricted Shellfish Harvesting Areas

Median Scenario					
Restricted Shellfish Harvesting Area	**Embayment Median Fecal Coliform Concentration (MPN/100mL)**	**Boundary Median Fecal Coliform Concentration. (MPN/100mL)**	**Decay Rate Per Tidal Cycle**	**Estimated Residence Time* (day)**	**Baseline Load (Counts/day)**
Battle Creek	39.0	7.3	0.36	0.7	3.00E+11
Buzzard Island Creek	9.1	9.1	0.36	1.0	1.07E+10
Hog Neck Creek	9.1	9.1	0.36	4.2	8.15E+09

90th Percentile Scenario					
Restricted Shellfish Harvesting Area	**Embayment 90th percentile Fecal Coliform Concentration (MPN/100mL)**	**Boundary 90th percentile Fecal Coliform Concentration. (MPN/100mL)**	**Decay Rate Per Tidal Cycle**	**Estimated Residence Time* (day)**	**Baseline Load (Counts/day)**
Battle Creek	328.0	43.0	0.36	0.7	2.62E+12
Buzzard Island Creek	82.2	82.2	0.36	1.0	9.65E+10
Hog Neck Creek	63.0	63.0	0.36	4.2	5.64E+10

* See Appendix A for more details.

TMDL Scenarios

TMDL scenarios were run to estimate the maximum allowable loads the restricted shellfish harvesting areas could receive from the responding drainage areas in order to assure that the fecal coliform concentrations within the embayments would not exceed the criteria. The allowable loads are calculated using the water quality criteria for the fecal coliform concentrations both in the embayment and at the boundary. The estimated allowable loads from the drainage areas of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek are presented in Table 9.

Table 9: Allowable Loads Estimated for the Restricted Shellfish Harvesting Areas

<table>
<tr><th colspan="6">Median Scenario</th></tr>
<tr><th>Restricted Shellfish Harvesting Area</th><th>Embayment Median Fecal Coliform Concentration (MPN/100mL)</th><th>Boundary Median Fecal Coliform Concentration. (MPN/100mL)</th><th>Decay Rate Per Tidal Cycle</th><th>Estimated Residence Time* (day)</th><th>Allowable Load (Counts/day)</th></tr>
<tr><td>Battle Creek</td><td>14.0</td><td>14.0</td><td>0.36</td><td>0.7</td><td>4.63E+10</td></tr>
<tr><td>Buzzard Island Creek</td><td>14.0</td><td>14.0</td><td>0.36</td><td>1.0</td><td>1.64E+10</td></tr>
<tr><td>Hog Neck Creek</td><td>14.0</td><td>14.0</td><td>0.36</td><td>4.2</td><td>1.25E+10</td></tr>
<tr><th colspan="6">90th Percentile Scenario</th></tr>
<tr><th>Restricted Shellfish Harvesting Area</th><th>Embayment 90th percentile Fecal Coliform Concentration (MPN/100mL)</th><th>Boundary 90th percentile Fecal Coliform Concentration. (MPN/100mL)</th><th>Decay Rate Per Tidal Cycle</th><th>Estimated Residence Time* (day)</th><th>Allowable Load (Counts/day)</th></tr>
<tr><td>Battle Creek</td><td>49.0</td><td>49.0</td><td>0.36</td><td>0.7</td><td>1.62E+11</td></tr>
<tr><td>Buzzard Island Creek</td><td>49.0</td><td>49.0</td><td>0.36</td><td>1.0</td><td>5.75E+10</td></tr>
<tr><td>Hog Neck Creek</td><td>49.0</td><td>49.0</td><td>0.36</td><td>4.2</td><td>4.38E+10</td></tr>
</table>

* See Appendix A for more details.

4.3 Critical Condition and Seasonality

Federal regulations require TMDL analysis to take into account the impact of critical conditions and seasonality on water quality (CFR 2017a). The intent of this requirement is to ensure that water quality is protected when it is most vulnerable.

The 90th percentile concentration is the concentration exceeded only 10% of the time. Since data collected during the most recent three-year period was used to calculate the 90th percentile, the critical condition during that period is implicitly included in the value of the 90th percentile.

Similar to the critical condition, seasonality is also implicitly included in the analysis due to the duration of the period for which water quality standards are applied. The monitoring design and the statistical analysis used to evaluate water quality attainment therefore implicitly include the effect of seasonality.

4.4 TMDL Allocations and Reductions

All TMDLs need to be presented as a sum of WLAs for point sources and LAs for nonpoint source loads generated within the assessment unit, and if applicable, LAs for the natural background, tributary, and adjacent segment loads (CFR 2017b). The State reserves the right to revise these allocations provided the revisions are consistent with achieving WQSs. The allocations described in this section summarize the fecal coliform TMDLs established to meet the shellfish harvesting designated use in the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River Basin.

In Section 5.2, the baseline loads and allowable loads were estimated for the three restricted areas. The load reductions needed for the attainment of the criteria for median and 90th percentile scenarios are determined by subtracting the allowable loads from the current loads and the results are listed in Table 10.

$$\%\ \text{Reduction in Load} = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\%$$

Table 10: Load Reductions for the Restricted Shellfish Harvesting Areas

Median Scenario			
Restricted Shellfish Harvesting Area	**Current Load (Counts/day)**	**Allowable Load (Counts/day)**	**Required Reduction (%)**
Battle Creek	3.00E+11	4.63E+10	85%
Buzzard Island Creek	1.07E+10	1.64E+10	0%
Hog Neck Creek	8.15E+09	1.25E+10	0%
90th Percentile Scenario			
Restricted Shellfish Harvesting Area	**Current Load (Counts/day)**	**Allowable Load (Counts/day)**	**Required Reduction (%)**
Battle Creek	2.62E+12	1.62E+11	94%
Buzzard Island Creek	9.65E+10	5.75E+10	40%
Hog Neck Creek	5.64E+10	4.38E+10	22%

When comparing the median and the 90th percentile scenario results, the loads from scenario with greater percent load reductions were chosen as the final TMDL loads and used for source allocation. For all the three restricted areas, the 90th percentile scenarios require greater percent reductions to meet the criterion, therefore, the 90th percentile scenario results are chosen as the final TMDLs and will be used for source allocation for these three restricted areas. It is also important to note that the TMDLs presented herein should be applied as a three year averaging period with a minimum of 30 samples collected consistent with the water quality standard.

According to Section 2.3.1, there are four nonpoint source categories of fecal coliform: human, livestock, wildlife and pets. Table 6 presents the percentage distribution from each category for the three restricted areas. Source reductions were assigned by first managing controllable sources (human, livestock and pets) and then determining if the TMDL could be achieved. Loads were assigned based on the source distribution determined using the BST analysis. If the total required reduction was not achieved, then the wildlife source was reduced. Based on these assumptions, the source allocation for the watershed for each of the major source categories is estimated. Results are presented in Table 11.

As stated in Section 2.3.2, there are no point sources with permits regulating the discharge of fecal coliform to the three restricted shellfish harvesting areas, therefore there is no WLA allocation and all the loads will be allocated to the nonpoint sources.

Table 11: Load Allocations and Reductions by Sources

Battle Creek				
Source	**Baseline Load (Counts/day)**	**Baseline Load (%)**	**TMDL (Counts/day)**	**TMDL Reduction (%)**
Human	4.45E+11	17%	0	100%
Livestock	7.86E+11	30%	0	100%
Wildlife	9.96E+11	38%	1.62E+11	84%
Pets	3.93E+11	15%	0	100%
Nonpoint Sources	2.62E+12	100%	1.62E+11	94%
Point Sources	NA	NA	NA	NA
Total	2.62E+12	100%	1.62E+11	94%
Buzzard Island Creek				
Source	**Baseline Load (Counts/day)**	**Baseline Load (%)**	**TMDL (Counts/day)**	**TMDL Reduction (%)**
Human	1.64E+10	17%	5.71E+09	65%
Livestock	2.90E+10	30%	1.01E+10	65%
Wildlife	3.67E+10	38%	3.67E+10	0%
Pets	1.45E+10	15%	5.04E+09	65%
Nonpoint Sources	9.65E+10	100%	5.75E+10	40%
Point Sources	NA	NA	NA	NA
Total	9.65E+10	100%	5.75E+10	40%

Hog Neck Creek				
Source	**Baseline Load (Counts/day)**	**Baseline Load (%)**	**TMDL (Counts/day)**	**TMDL Reduction (%)**
Human	6.20E+09	11%	3.81E+09	39%
Livestock	1.69E+10	30%	1.04E+10	39%
Wildlife	2.37E+10	42%	2.37E+10	0%
Pets	9.59E+09	17%	5.89E+09	39%
Nonpoint Sources	5.64E+10	100%	4.38E+10	22%
Point Sources	NA	NA	NA	NA
Total	5.64E+10	100%	4.38E+10	22%

4.5 Margin of Safety

All TMDLs must include a MOS to account for the lack of knowledge and the many uncertainties in the understanding and simulation of water quality parameters in natural systems (*i.e.*, the relationship between modeled loads and water quality). The MOS is intended to account for such uncertainties in a manner that is conservative from the standpoint of environmental protection. For example, knowledge is incomplete regarding the exact nature and magnitude of pollutant loads from various sources and the specific impacts of those pollutants on the chemical and biological quality of complex, natural water bodies.

For the TMDL development in this document, the MOS needs to be incorporated to account for uncertainty due to model parameter selection. Based on previous analysis (VIMS 2004), it was determined that the most sensitive parameter is the decay rate. 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.

4.6 TMDL Summary

Table 12 summarizes the fecal coliform baseline loads, TMDL allocations and load reductions for the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River basin.

Table 12: Summary of Fecal Coliform Baseline Loads, TMDL Allocations, Associated Percent Reductions for the Restricted Shellfish Harvesting Areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River Basin

Battle Creek

Source	Baseline Load (Counts/day)	Baseline Load (%)	TMDL (Counts/day)	TMDL Reduction (%)
Human	4.45E+11	17%	0	100%
Livestock	7.86E+11	30%	0	100%
Wildlife	9.96E+11	38%	1.62E+11	84%
Pets	3.93E+11	15%	0	100%
Nonpoint Sources	2.62E+12	100%	1.62E+11	94%
Point Sources	NA	NA	NA	NA
MOS	-	-	Implicit	-
Total	2.62E+12	100%	1.62E+11	94%

Buzzard Island Creek

Source	Baseline Load (Counts/day)	Baseline Load (%)	TMDL (Counts/day)	TMDL Reduction (%)
Human	1.64E+10	17%	5.71E+09	65%
Livestock	2.90E+10	30%	1.01E+10	65%
Wildlife	3.67E+10	38%	3.67E+10	0%
Pets	1.45E+10	15%	5.04E+09	65%
Nonpoint Sources	9.65E+10	100%	5.75E+10	40%
Point Sources	NA	NA	NA	NA
MOS	-	-	Implicit	-
Total	9.65E+10	100%	5.75E+10	40%

Hog Neck Creek

Source	Baseline Load (Counts/day)	Baseline Load (%)	TMDL (Counts/day)	TMDL Reduction (%)
Human	6.20E+09	11%	3.81E+09	39%
Livestock	1.69E+10	30%	1.04E+10	39%
Wildlife	2.37E+10	42%	2.37E+10	0%
Pets	9.59E+09	17%	5.89E+09	39%
Nonpoint Sources	5.64E+10	100%	4.38E+10	22%
Point Sources	NA	NA	NA	NA
MOS	-	-	Implicit	-
Total	5.64E+10	100%	4.38E+10	22%

5.0 ASSURANCE OF IMPLEMENTATION

This section provides the basis for reasonable assurances that the fecal coliform TMDL will be achieved and maintained. The appropriate measures to reduce pollution levels in the impaired segments include, where appropriate, the use of better treatment technology or installation of best management practices.

MDE anticipates that reductions in fecal coliform levels will be driven by a variety of state and county-level programs. These include programs that are intended to address bacteria sources directly, and ones that are intended to address other water quality concerns, such as nutrients, but that also impact bacteria loads. For example, practices put in place as part of a strategy for meeting the 2010 Chesapeake Bay TMDLs for nutrients and sediment, may also manage fecal coliform. Many of these practices are described in Maryland's Phase II Watershed Implementation Plan (WIP) for the Chesapeake Bay TMDL

Existing Funding and Regulatory Framework

As of June 2017, the Bay Restoration Fund had funded over 8,900 upgrades of septic systems to Best Available Technology (BAT) across the state, with nearly 5,490 of these upgrades occurring in Maryland's Critical Areas, defined as land within 1,000 feet of the State's tidal waters (BRFAC 2018). Although BAT upgrades are designed to reduce nitrogen loadings, the fund prioritizes grants for failing septic systems in the Critical Areas. Failing systems are more likely to discharge fecal coliform to the environment, and fecal coliform discharged close to tidal waters have a greater likelihood of being delivered into those waters. Replacing a failing system with a properly functioning one, BAT or otherwise, reduces the likelihood of fecal coliform loadings to shellfish harvesting areas.

Agricultural practices can reduce potential livestock sources of bacteria within watersheds. Many of these practices are being implemented as part of the WIP, and funded through federal and state cost-share programs. Stream protection, either using fencing or remote watering holes away from streams, prevents direct animal contact with surface waters. These measures can be funded through MDA's Maryland Agricultural Water Quality Cost-Share (MACS) Program and USDA's Environmental Quality Incentives Program (EQIP). These programs also fund animal waste management systems—structures at animal confinement operations that enable waste to be handled and stored correctly and which control runoff. Riparian forest and grass buffers, linear strips of vegetation between fields and streams that can filter pollutants, can receive funding through MACS and USDA's Conservation Reserve Enhancement Program (CREP). Other funding mechanisms, such as the Chesapeake Bay Targeted Watersheds Grant Program can be used for pasture management. At a county level, Soil Conservation Districts promote soil and water quality programs, by provide technical expertise to farmers related to agricultural BMPs. Implementation of the TMDL for the 2010 Chesapeake Bay nitrogen, phosphorus and sediment TMDL could also provide some reductions in fecal coliform. While the objectives of the two efforts differ, with the 2010 Bay TMDLs focused on nitrogen, phosphorus and sediment while this TMDL targeting fecal coliform, many of the reductions achieved through implementation activities for the Bay TMDL could result in progress toward both goals.

The strategies for implementing the 2010 Bay TMDLs are described in Maryland's Phase I WIP (MDE 2010) and Phase II WIP (MDE 2012). The WIPs are the centerpieces of the State's "reasonable assurance" of implementation for the 2010 Bay TMDLs, and the strategies encompass a host of BMPs, pollution controls and other actions for all source sectors that cumulatively will result in meeting the State's 2025 targets. In particular, the implementation of practices to reduce nutrient and sediment loadings from the agricultural and urban stormwater sectors could result in decreased loads in fecal coliform.

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.

Portions of St. Mary's and Calvert Counties have a MS4 permit regulating stormwater. As part of the permit, there is a requirement for an education program for pet waste removal. It is anticipated that the program would be developed County-wide. In addition, both Counties have animal control laws that require the pick up of pet waste on public and private lands (Calvert County 2018; St. Mary's County 2018).

Regulatory enforcement of potential bacteria sources would be covered by MDE's routine sanitary surveys of shellfish growing areas and NPDES permitting activities. 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.

As part of Maryland's commitment to the NSSP, MDE's Shellfish Certification Program continues to monitor shellfish waters and classify shellfish harvesting areas as restricted, approved, or conditionally approved. A major component of MDE's responsibilities under the Shellfish Certification Program is to identify potential pollution sources and correct or eliminate them. Waters meeting shellfish water quality standards are reclassified as approved or conditionally approved harvesting areas. The removal of shellfish harvesting restrictions may serve as a tracking tool measuring water quality improvements. However, when performing such analyses, it is important to understand that, per FDA/NSSP requirements, areas located near point sources are expected to remain restricted. Existence of such restrictions does not necessarily mean that the area is not meeting water quality standards.

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

BRFAC (Bay Restoration Fund Advisory Committee). 2018. Maryland Bay Restoration Fund Advisory Committee Annual Status Report, January 2018. Available at: https://mde.maryland.gov/programs/Water/BayRestorationFund/Documents/2018%20BRF%20Report-Final%20Draft.pdf (Accessed August 2018).

Calvert County. 2018. Calvert County Chapter 7. Section 7-6-702 (C). Available at: https://www.co.cal.md.us/DocumentCenter/View/2275

Chesapeake Conservancy. 2018. *Chesapeake Conservancy Land Cover Data Project*. http://chesapeakeconservancy.org/conservation-innovation-center/high-resolution-data/land-cover-data-project (Accessed May, 2018).

CFR (Code of Federal Regulations). 2017a. 40 CFR 130.2. http://www.gpo.gov/fdsys/pkg/CFR-2002-title40-vol18/pdf/CFR-2002-title40-vol18-sec130-2.pdf (Accessed December, 2017).

_____________. 2017b. 40 CFR 130.7. http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol22/pdf/CFR-2011-title40-vol22-sec130-7.pdf (Accessed December, 2017).

_____________. 2017c. 40 CFR 122.44(k). http://www.gpo.gov/fdsys/pkg/CFR-2011-title40-vol22/pdf/CFR-2011-title40-vol22-sec122-44.pdf (Accessed December, 2017).

COMAR (Code of Maryland Regulations). 2017a. 26.08.02.07. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.07.htm (Accessed December, 2017).

_____________. 2017b. 26.08.02.08 M. http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.08.htm (Accessed December, 2017).

_____________. 2017c. 26.08.02.04-1.

http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.04-1.htm (Accessed December, 2017).

_____________. 2017d. 26.08.02.03-3 C(2). http://www.dsd.state.md.us/comar/comarhtml/26/26.08.02.03-3.htm (Accessed December, 2017).

Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J., and N.H. Brooks. 1979. Mixing in inland and coastal water, Academic Press, San Diego.

Frana, M. F. and E. A. Venso. 2006. Bacterial Source Tracking Report: Identifying Sources of Fecal Pollution in Shellfish and Nontidal Waters in Maryland Watersheds. Salisbury University, Salisbury, MD 21801.

Guo, Q. and G. P. Lordi. 2000. “Method for quantifying freshwater input and flushing time in an estuary.” J. of Environmental Engineering, vol. 126, No. 7, ASCE, 675-683.

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

Ketchum, B. H. 1951. “The exchanges of fresh and salt water in tidal estuaries.” J. of Marine Research, 10(1): 18-38.

Kuo, A. Y. and B. J. Neilson. 1988. A modified tidal prism model for water quality in small coastal embayments. Water Science Technology, 20 (6/7): 133-142.

Kuo, A., Butt, A., Kim, S. and J. Ling. 1998. Application of a tidal prism water quality model to Virginia Small Coastal Basins. SRAMSOE No. 348.

Mancini, J.L. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. Journal WPCF, November, 2477-2484.

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

NOAA (National Oceanic and Atmospheric Administration). 2017. https://tidesandcurrents.noaa.gov/ (Accessed December, 2017).

Shen, J., H. Wang, and M. Sisson. 2002. Application of an Integrated Watershed and Tidal prism Model to the Poquoson Coastal Embayment (submitted to Department of Environmental Quality, Commonwealth of Virginia). Virginia Institute of Marine Science Special Report 380, Gloucester Point, VA.

St. Mary’s County. 2018. St. Mary’s County Animal Control Regulations. §212.11(8) Available at: https://www.stmarysmd.com/docs/AnimalControlRegulations.pdf

Thomann, R. V. and J. Mueller. 1987. Principles of surface water quality modeling and control. Harper Collins Publishers.

US EPA Shellfish Workshop Document. 2002.

USGS (United States Geological Survey). 2014. 2006 National Land Cover Dataset Chesapeake Bay Area, Modified Version 2.0. Annapolis, MD: United States Geological Survey, Chesapeake Bay Program Office.

_____________. 2017. *USGS StreamStats*. https://streamstats.usgs.gov/ss (Accessed December, 2017).

VIMS, 2004: Technical Memo for Fecal Coliform TMDL of Shellfish Harvesting areas.

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.

Appendix A: Method Used to Estimate Fecal Coliform Load

A steady-state Tidal Prism Model was used to estimate the fecal coliform loads from the drainage areas of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River basin. A detailed description of the tidal flushing model is presented in this section. It is assumed that a single volume can represent a water body, and that the pollutant is well mixed in the water body system, as shown in Figure A-1.

The mass balance of water can be written as follows (Guo and Lordi 2000):

$$\frac{dV}{dT} = (Q_0 - Q_b + Q_f) \tag{1}$$

where Q_0 is the quantity of water that enters the embayment on the flood tide through the ocean boundary (m^3T^{-1}); Q_b is the quantity of mixed water that leaves the bay on the ebb tide that did not enter the bay on the previous flood tide (m^3 per tidal cycle); Q_f is total freshwater input over the tidal cycle (m^3); V is the volume of the bay (m^3); T is the dominant tidal period (hours).

It is further assumed that Q_0 is the pure ocean water that did not flow out of the embayment on the previous ebb tide, and that Q_b is the embayment water that did not enter into the system on the previous flood tide. The mass balance for the fecal coliform can then be written as follows:

$$\frac{dVC}{dT} = Q_0C_0 - Q_bC + L_f + L_l - kVC \tag{2}$$

where L_f is the loading from upstream; L_l is the additional loading from the local area within the tidal cycle, k is the fecal coliform decay rate (or a damped parameter for the net loss of fecal coliform), C is fecal coliform concentration in the embayment, and C_0 is the fecal coliform concentration from outside the embayment.

In a steady-state condition, the mass balance equations for the water and the fecal coliform concentration can be written as follows:

$$Q_b = Q_0 + Q_f \tag{3}$$

$$Q_bC + kVC = Q_0C_0 + L_f + L_l \tag{4}$$

The fecal coliform concentration in the embayment can be calculated as follows:

$$C = \frac{Q_0C_0 + L_f + L_l}{Q_b + kV} \tag{5}$$

From Equation (4), assuming $L_f + L_l = Load_t$ and letting C_c be the criterion of fecal coliform in the embayment, the loading capacity can be estimated as:

$$Load_T = C_c(Q_b + kV) - Q_0C_0 \tag{6}$$

The daily load can be estimated based on the dominant tidal period in the area. For the upper Chesapeake Bay the dominant tide is lunar semi-diurnal (M_2) tide with a tidal period of 12.42 hours. If fecal coliform concentration is in MPN/100ml, the daily load (counts day^{-1}) can be estimated as:

$$Load = Load_T \times \frac{24}{12.42} \times 10000 \tag{7}$$

In practice, one may not know Q_0 *a priori*. Instead, one is given the tidal range of the tidal embayment. From that, Q_T, the total ocean water entering the bay on the flood tide, can be calculated. From this, Q_0, the volume of new ocean water entering the embayment on the flood tide can be determined by the use of the ocean tidal exchange ratio β as:

$$Q_0 = \beta Q_T \tag{8}$$

where β is the exchange ratio and Q_T is the total ocean water entering the bay on the flood tide. The exchange ratio can be estimated from salinity data (Fischer et al., 1979):

$$\beta = \frac{S_f - S_e}{S_0 - S_e} \tag{9}$$

where S_f is the average salinity of ocean water entering the bay on the flood tide, S_e is the average salinity of the bay water leaving the bay, and S_0 is the salinity at the ocean side. The numerical value of β is usually smaller than 1, and it represents the fraction of new ocean water entering the embayment. Once Q_0 is known, then Q_b can be calculated from equation (3).

The residence time, T_L, is an estimate of time required to replace the existing pollutant concentration in a system; it can be calculated as follows:

$$T_L = \frac{V_b}{Q_b} \tag{10}$$

where V_b is mean volume of the embayment. From the definition, the denominator can either be Q_T or Q_b. However, using Q_T assumes that the ocean water enters into the embayment during the flood tide is 100% new, whereas using Q_b takes into consideration that a portion of water is not entirely new. It can be shown that the latter is more realistic. If Q_b is used in the residence time calculation, it will result in a longer time scale than if Q_T is used (Ketchum 1951; Guo and Lordi 2000).

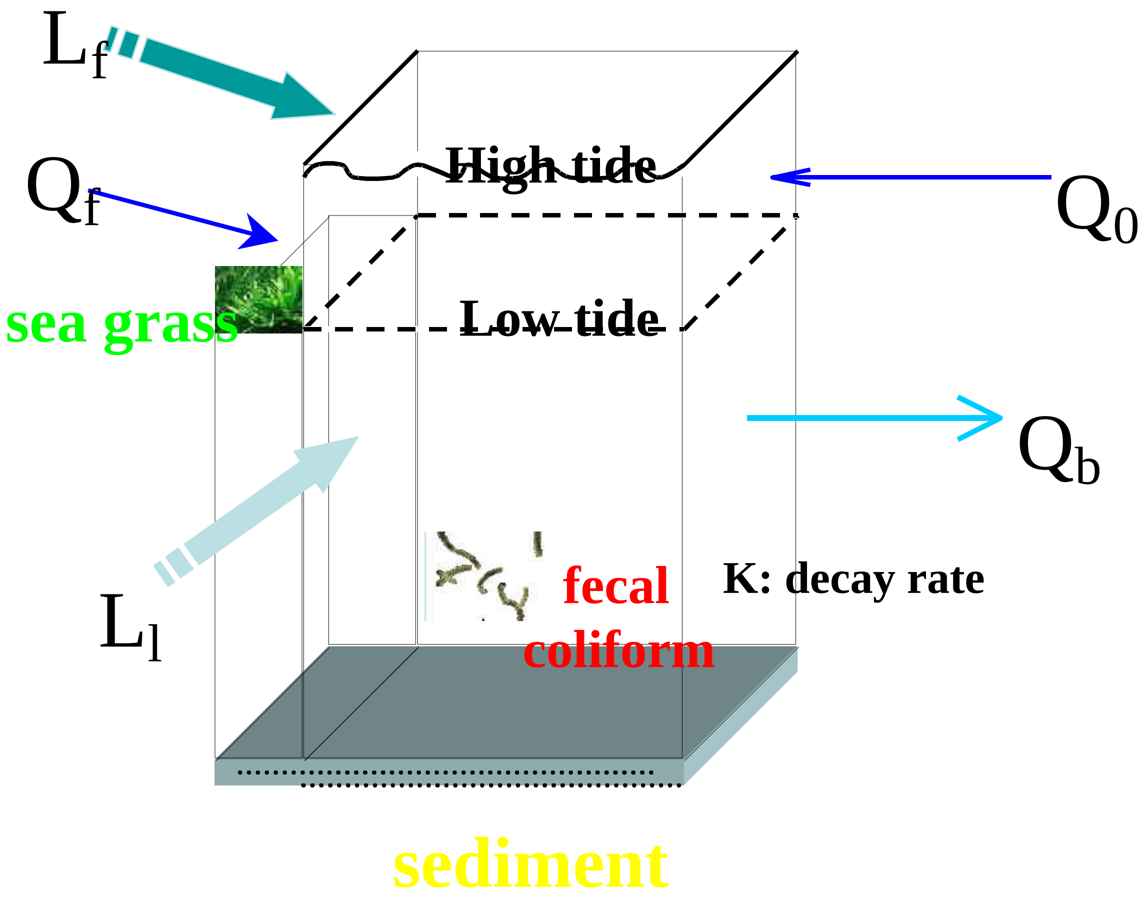

Figure A-1: The schematic diagram for the tidal prism model

The detailed calculations for the current loads and allowable loads from both median and 90th percentile scenarios for the drainage areas of the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in the Lower Patuxent River basin are listed below and the parameters needed for the load calculation are also presented.

A Tidal Prism Model Calculation for Battle Creek

Median Scenario: The most recent three-year fecal coliform median concentration is used. The median load calculation is illustrated as follows:

V = Mean volume of the embayment = 413907(m^3)
k = Fecal coliform decay rate =0.36(T^{-1})
Q_f = Freshwater discharge
= 16.815 × 0.0283×86400×12.42÷24 = 21277(m^3T^{-1})
Q_0 = 279318 (m^3T^{-1})
Q_b = 300595 ($m^3\ T^{-1}$)
C_c = water quality criterion = 14 MPN/100ml
C = current fecal coliform 3-year median concentration = 39.0 (MPN/100ml)
C_0 = fecal coliform 3-year median outside of the embayment = 7.3 (MPN/100ml)
T =tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 14 MPN/100ml). The fecal coliform concentration at the outside of the embayment also uses 14 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$= [14\times (300595 + 0.36\times413907) - 279318\times 14] \times24\div12.42\times10000$$

$$=4.632\times10^{10}$$

For the current load estimation, the most recent three-year median fecal coliform median concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$[39.0\times (300595 + 0.36\times413907) - 279318\times 7.3] \times24\div12.42\times10000$$

$$=3.001\times10^{11}$$

The load reduction is estimated as follows:

$$\text{Load Reduction } = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\% = 84.6\%$$

A Tidal Prism Model Calculation for Battle Creek (con't.)

90th percentile Scenario: The most recent three-year fecal coliform 90th percentile concentration is used. The 90th percentile load calculation is illustrated as follows:

V = Mean volume of the embayment = 413907(m^3)
k = Fecal coliform decay rate =0.36(T^{-1})
Q_f = Freshwater discharge
= 16.815 × 0.0283×86400×12.42÷24 = 21277 (m^3T^{-1})
Q_0 = 279318 (m^3T^{-1})
Q_b = 300595 ($m^3\ T^{-1}$)
C_c = water quality criterion = 49 MPN/100ml
C = current fecal coliform 3-year 90th percentile concentration = 328.0 (MPN/100ml)
C_0 = fecal coliform 3-year 90th percentile at the outside of the embayment
= 43.0 (MPN/100ml)
T = tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 49 MPN/100ml). The fecal coliform concentration at the outside of the embayment uses 49 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$= [49\times (300595 + 0.36\times 413907) - 279318\times 49] \times 24 \div 12.42 \times 10000$$

$$= 1.621\times 10^{11}$$

For the current load estimation, the most recent 3-year 90th percentile fecal coliform concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$[328.0\times (300595 + 0.36\times 413907) - 279318\times 43.0] \times 24 \div 12.42 \times 10000 = 2.623\times 10^{12}$$

The load reduction is estimated as follows:

$$\text{Load Reduction} = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\% = 93.8\%$$

A Tidal Prism Model Calculation for Buzzard Island Creek

Median Scenario: The most recent three-year fecal coliform median concentration is used. The median load calculation is illustrated as follows:

V = Mean volume of the embayment = 160062(m^3)
k = Fecal coliform decay rate =0.36(T^{-1})
Q_f = Freshwater discharge
= 2.176 × 0.0283×86400×12.42÷24 = 2753(m^3T^{-1})
Q_0 = 76592 (m^3T^{-1})
Q_b = 79345 (m^3 T^{-1})
C_c = water quality criterion = 14 MPN/100ml
C = current fecal coliform 3-year median concentration = 9.1 (MPN/100ml)
C_0 = fecal coliform 3-year median outside of the embayment = 9.1 (MPN/100ml)
T =tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 14 MPN/100ml). The fecal coliform concentration at the outside of the embayment also uses 14 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

= [14× (79345 +0.36×160062) - 76592× 14] ×24÷12.42×10000
=1.643×10^{10}

For the current load estimation, the most recent three-year median fecal coliform median concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

[9.1× (79345 +0.36×160062) - 76592× 9.1] ×24÷12.42×10000
=1.068×10^{10}

The load reduction is not needed for median scenario.

A Tidal Prism Model Calculation for Buzzard Island Creek (con't.)

90^{th} percentile Scenario: The most recent three-year fecal coliform 90^{th} percentile concentration is used. The 90^{th} percentile load calculation is illustrated as follows:

V = Mean volume of the embayment = $160062(m^3)$
k = Fecal coliform decay rate $=0.36(T^{-1})$
Q_f = Freshwater discharge
$= 2.176 \times 0.0283 \times 86400 \times 12.42 \div 24 = 2753\ (m^3T^{-1})$
$Q_0 = 76592\ (m^3T^{-1})$
$Q_b = 79345\ (m^3\ T^{-1})$
C_c = water quality criterion = 49 MPN/100ml
C = current fecal coliform 3-year 90^{th} percentile concentration = 82.2 (MPN/100ml)
C_0 = fecal coliform 3-year 90^{th} percentile at the outside of the embayment
= 82.2 (MPN/100ml)
T = tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 49 MPN/100ml). The fecal coliform concentration at the outside of the embayment uses 49 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$= [49 \times (79345 + 0.36 \times 160062) - 76592 \times 49] \times 24 \div 12.42 \times 10000$$

$$= 5.751 \times 10^{10}$$

For the current load estimation, the most recent 3-year 90^{th} percentile fecal coliform concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$[82.2 \times (79345 + 0.36 \times 160062) - 76592 \times 82.2] \times 24 \div 12.42 \times 10000 = 9.647 \times 10^{10}$$

The load reduction is estimated as follows:

$$\text{Load Reduction} = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\% = 40.4\%$$

A Tidal Prism Model Calculation for Hog Neck Creek

Median Scenario: The most recent three-year fecal coliform median concentration is used. The median load calculation is illustrated as follows:

V = Mean volume of the embayment = 126246(m^3)
k = Fecal coliform decay rate =0.36(T^{-1})
Q_f = Freshwater discharge
= 0.475 × 0.0283×86400×12.42÷24 = 601(m^3T^{-1})
Q_0 = 14860 (m^3T^{-1})
Q_b = 15460 (m^3 T^{-1})
C_c = water quality criterion = 14 MPN/100ml
C = current fecal coliform 3-year median concentration = 9.1 (MPN/100ml)
C_0 = fecal coliform 3-year median outside of the embayment = 9.1 (MPN/100ml)
T =tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 14 MPN/100ml). The fecal coliform concentration at the outside of the embayment also uses 14 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$= [14\times (15460 + 0.36\times 126246) - 14860\times 14] \times 24 \div 12.42 \times 10000$$

$$= 1.253\times 10^{10}$$

For the current load estimation, the most recent five-year median fecal coliform median concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$[9.1\times (15460 + 0.36\times 126246) - 14860 \times 9.1] \times 24 \div 12.42 \times 10000$$

$$= 8.148\times 10^{9}$$

The load reduction is not needed for median scenario.

A Tidal Prism Model Calculation for Hog Neck Creek (con't.)

90th percentile Scenario: The most recent three-year fecal coliform 90th percentile concentration is used. The 90th percentile load calculation is illustrated as follows:

V = Mean volume of the embayment = 126246(m^3)
k = Fecal coliform decay rate =0.36(T^{-1})
Q_f = Freshwater discharge
= 0.475 × 0.0283×86400×12.42÷24 = 601 (m^3T^{-1})
Q_0 = 14860 (m^3T^{-1})
Q_b = 15460 (m^3 T^{-1})
C_c = water quality criterion = 49 MPN/100ml
C = current fecal coliform 3-year 90th percentile concentration = 63.0 (MPN/100ml)
C_0 = fecal coliform 3-year 90th percentile at the outside of the embayment
= 63.0 (MPN/100ml)
T = tidal cycle =12.42 hours
Cf = the unit conversion factor

For allowable calculation, C_c is used as fecal coliform concentration (i.e., 49 MPN/100ml). The fecal coliform concentration at the outside of the embayment uses 49 MPN/100ml as well. The allowable load is calculated as follows:

Allowable Load =

$$Load = [C_c \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$= [14\times (15460 + 0.36\times 126246) - 14860 \times 14] \times 24 \div 12.42 \times 10000$$

$$= 4.387\times 10^{10}$$

For the current load estimation, the most recent 3-year 90th percentile fecal coliform concentration is used for the calculation. The current load is calculated as follows:

Current condition =

$$Load = [C \times (Q_b + kV) - Q_0 \times C_0] \times Cf$$

$$[63.0\times (15460 + 0.36\times 126246) - 14860 \times 63.0] \times 24 \div 12.42 \times 10000 = 5.641\times 10^{10}$$

The load reduction is estimated as follows:

$$\text{Load Reduction} = \frac{\text{Current Load} - \text{Allowable Load}}{\text{Current Load}} \times 100\% = 22.2\%$$

Appendix B. Bacteria Source Tracking

Nonpoint sources of fecal coliform do not have one discharge point and may occur over the entire length of a stream or waterbody. The possible introductions of fecal coliform bacteria from non-human activities to the land surface are through the manure spreading process, direct deposition from livestock during the grazing season, and excretions from pets and wildlife. As the runoff occurs during rain events, surface runoff transports water and fecal coliform over the land surface to surface waters. Nonpoint source contributions to the bacteria levels from human activities generally arise from failing septic systems from recreation vessel discharges. The transport of fecal coliform from land surface to shellfish harvesting areas is dictated by the hydrology, soil type, land use, and topography of the watershed.

In order to determine the significant sources of fecal coliform and reduction needed to achieve water quality criteria among these sources, it is necessary to identify all existing sources. The nonpoint source assessment was conducted using the fecal coliform monitoring data (provided by MDE Shellfish Certification Program) and bacteria source tracking analysis to quantify source loadings from humans, livestock, pets, and wildlife.

<u>Bacteria Source Tracking</u>

In order to assess the potential fecal bacteria sources those contribute to the restricted shellfish harvesting areas of Lower Patuxent River basin, 26 stations were selected to evaluate the source characterization through a process called Bacteria Source Tracking (BST). BST is used to provide evidence regarding contributions from anthropogenic sources (*i.e.*, human or livestock) as well as background sources, such as wildlife. Sampling was conducted over a twelve-month period from November 2003 through October 2004. Antibiotic Resistance Analysis (ARA) was the chosen BST method used to determine the potential sources of fecal coliform in the Lower Patuxent River. ARA uses enterococci or *Escherichia coli* (*E. coli*) and patterns of antibiotic resistance to identify sources. The premise is that the antibiotic resistance of bacteria isolated from different hosts can be discerned based upon differences in the selective pressure of microbial populations found in the gastrointestinal tract of those hosts (humans, livestock, pets, wildlife) (Wiggins 1996). Bacteria isolated from the fecal material of wildlife would be expected to have a much lower level of resistance to antibiotics than bacteria 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. Enterococci isolates were obtained from known source present in the watershed. For the Lower Patuxent River, these sources included pet (cat, dog), human, livestock (cow, chicken, donkey, goat, horse, pig, rabbit, sheep, turkey) and wildlife (deer, duck, fox, goose, groundhog, mouse, muskrat, otter, owl, rabbit, raccoon, seagull, squirrel, swan). Bacterial isolates collected from water samples are then tested and their resistance results are recorded. Based upon a comparison of resistance patterns of water and known library isolates, a statistical analysis can predict the likely host source of the water isolates (Hagedorn 1999; Wiggins 1999).

A tree classification method, [1]CART®, was applied 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 in order to maximize 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] The full BST report for the Lower Patuxent River basin is located in Frana and Venso (2006).

Results

Water samples were collected monthly from the 26 stations in the Lower Patuxent River. If weather conditions prevented sampling at a station, a second collection(s) in a later month was performed. The maximum number of enterococci isolates per water sample was 24, although the number of isolates that actually grew was sometimes fewer than 24. A total of 1615 enterococci isolates were analyzed by statistical analysis. Because of the size of the Lower Patuxent River shellfish harvesting areas, the basin was divided into six project areas. In addition, the library of known sources was divided into project area libraries according to the location where the scat was collected. The water sample isolates for the areas were then analyzed for BST using both the corresponding area library and the full library containing all known-source isolates from the Lower Patuxent River Shellfish Harvesting Area. After examining the data, it was determined that the use of the full library more often produced results consistent with field observations.

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

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

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

The ARA results by four categories (human, livestock, wildlife and pets) for Battle Creek, Buzzard Island Creek and Hog Neck Creek were chosen as the results of the nearest project areas.

Table B-1 below shows the source contributing results for Battle Creek, Buzzard Island Creek and Hog Neck Creek. According to the results, wildlife is the predominant bacteria source followed by livestock for each of the three restricted shellfish harvesting areas.

Table B-1: BST Source Distribution Results Based on ARA Analysis

Area	Human	Livestock	Wildlife	Pets
Battle Creek	17%	30%	38%	15%
Buzzard Island Creek	17%	30%	38%	15%
Hog Neck Creek	11%	30%	42%	17%

Appendix C. Fecal Coliform Monitoring Data

The fecal coliform monitoring data used to develop the fecal coliform TMDLs for the restricted shellfish harvesting areas of Battle Creek, Buzzard Island Creek and Hog Neck Creek in this document are provided in Tables C-1 through C-3.

Table C-1: Observed Fecal Coliform Data in Battle Creek

Station	Date	Fecal Coliform MPN/100 ml	Station	Date	Fecal Coliform MPN/100 ml
09-02-108	6/9/14	7.2	09-02-108A	6/9/14	93
09-02-108	6/24/14	23	09-02-108A	6/24/14	23
09-02-108	7/9/14	3.6	09-02-108A	7/9/14	23
09-02-108	8/11/14	1	09-02-108A	8/11/14	3.6
09-02-108	9/11/14	14	09-02-108A	9/11/14	150
09-02-108	10/8/14	7.3	09-02-108A	10/8/14	43
09-02-108	11/13/14	1	09-02-108A	11/13/14	39
09-02-108	12/8/14	3.6	09-02-108A	12/8/14	23
09-02-108	1/21/15	1	09-02-108A	1/21/15	3.6
09-02-108	3/19/15	1	09-02-108A	3/19/15	1
09-02-108	3/30/15	1	09-02-108A	3/30/15	3.6
09-02-108	4/9/15	9.1	09-02-108A	4/9/15	43
09-02-108	4/29/15	3.6	09-02-108A	4/29/15	23
09-02-108	5/13/15	23	09-02-108A	5/13/15	9.1
09-02-108	5/27/15	1	09-02-108A	5/27/15	43
09-02-108	6/8/15	23	09-02-108A	6/8/15	93
09-02-108	6/25/15	3	09-02-108A	6/23/15	23
09-02-108	7/13/15	3.6	09-02-108A	7/13/15	43
09-02-108	8/10/15	3.6	09-02-108A	8/10/15	93
09-02-108	8/25/15	1	09-02-108A	8/25/15	23
09-02-108	9/9/15	3.6	09-02-108A	9/9/15	23
09-02-108	9/29/15	43	09-02-108A	9/29/15	240
09-02-108	10/7/15	14	09-02-108A	10/7/15	93
09-02-108	10/27/15	93	09-02-108A	10/27/15	460
09-02-108	11/12/15	120	09-02-108A	11/12/15	460
09-02-108	11/30/15	9.1	09-02-108A	11/30/15	75
09-02-108	12/7/15	3.6	09-02-108A	12/7/15	21
09-02-108	12/21/15	39	09-02-108A	12/21/15	23

Station	Date	Fecal Coliform MPN/100 ml	Station	Date	Fecal Coliform MPN/100 ml
09-02-108	1/14/16	9.1	09-02-108A	1/14/16	9.1
09-02-108	2/18/16	3.6	09-02-108A	2/18/16	3.6
09-02-108	3/14/16	43	09-02-108A	3/14/16	43
09-02-108	4/11/16	3.6	09-02-108A	4/11/16	9.1
09-02-108	4/26/16	15	09-02-108A	4/26/16	240
09-02-108	5/9/16	21	09-02-108A	5/9/16	93
09-02-108	6/13/16	9.1	09-02-108A	6/13/16	23
09-02-108	6/28/16	3.6	09-02-108A	6/28/16	9.1
09-02-108	7/11/16	9.1	09-02-108A	7/11/16	15
09-02-108	8/8/16	23	09-02-108A	8/8/16	23
09-02-108	9/12/16	3.6	09-02-108A	9/12/16	39
09-02-108	10/19/16	43	09-02-108A	10/19/16	460
09-02-108	12/7/16	1100	09-02-108A	12/7/16	1100
09-02-108	1/26/17	23	09-02-108A	1/26/17	93
09-02-108	2/7/17	1	09-02-108A	2/7/17	1
09-02-108	3/23/17	1	09-02-108A	3/23/17	1
09-02-108	4/19/17	23	09-02-108A	4/19/17	43
09-02-108	5/23/17	240	09-02-108A	5/23/17	460
09-02-108	6/12/17	3.6	09-02-108A	6/12/17	43

Table C-2: Observed Fecal Coliform Data in Buzzard Island Creek

Station	Date	Fecal Coliform MPN/100 ml
09-01-101E	6/9/14	43
09-01-101E	6/24/14	9.1
09-01-101E	7/9/14	23
09-01-101E	8/11/14	23
09-01-101E	9/11/14	43
09-01-101E	10/8/14	15
09-01-101E	11/13/14	3.6
09-01-101E	12/8/14	3.6
09-01-101E	1/21/15	3.6
09-01-101E	3/19/15	1
09-01-101E	3/30/15	1

Station	Date	Fecal Coliform MPN/100 ml
09-01-101E	4/9/15	43
09-01-101E	4/29/15	1
09-01-101E	5/13/15	1
09-01-101E	5/27/15	1
09-01-101E	6/8/15	15
09-01-101E	6/23/15	15
09-01-101E	7/13/15	7.3
09-01-101E	8/10/15	23
09-01-101E	8/25/15	23
09-01-101E	9/9/15	3.6
09-01-101E	9/29/15	28
09-01-101E	10/7/15	23
09-01-101E	10/27/15	9.1
09-01-101E	11/12/15	43
09-01-101E	11/30/15	75
09-01-101E	12/7/15	3.6
09-01-101E	12/21/15	3.6
09-01-101E	1/14/16	15
09-01-101E	2/18/16	9.1
09-01-101E	3/14/16	9.1
09-01-101E	4/11/16	23
09-01-101E	4/26/16	240
09-01-101E	5/9/16	7.3
09-01-101E	6/13/16	3.6
09-01-101E	6/28/16	7.3
09-01-101E	7/11/16	93
09-01-101E	8/8/16	3.6
09-01-101E	9/12/16	3.6
09-01-101E	10/19/16	93
09-01-101E	12/7/16	150
09-01-101E	1/26/17	43
09-01-101E	2/7/17	1
09-01-101E	3/23/17	1
09-01-101E	4/19/17	3.6
09-01-101E	5/23/17	240
09-01-101E	6/12/17	9.1

Table C-3: Observed Fecal Coliform Data in Hog Neck Creek

Station	Date	Fecal Coliform MPN/100 ml
09-03-150F	6/5/14	43
09-03-150F	7/8/14	43
09-03-150F	8/7/14	9.1
09-03-150F	9/4/14	1
09-03-150F	9/22/14	23
09-03-150F	10/6/14	9.1
09-03-150F	11/12/14	3.6
09-03-150F	12/4/14	11
09-03-150F	1/15/15	9.1
09-03-150F	2/3/15	7.2
09-03-150F	3/17/15	1
09-03-150F	4/6/15	3.6
09-03-150F	5/18/15	3.6
09-03-150F	6/3/15	93
09-03-150F	6/17/15	9.1
09-03-150F	7/8/15	43
09-03-150F	7/22/15	23
09-03-150F	8/5/15	9.1
09-03-150F	9/29/15	43
09-03-150F	10/6/15	3.6
09-03-150F	11/4/15	3.6
09-03-150F	12/7/15	1
09-03-150F	1/27/16	3.6
09-03-150F	2/2/16	1
09-03-150F	3/14/16	43
09-03-150F	4/13/16	43
09-03-150F	4/20/16	93
09-03-150F	5/3/16	9.1
09-03-150F	5/17/16	9.1

Station	**Date**	**Fecal Coliform MPN/100 ml**
09-03-150F	6/2/16	9.1
09-03-150F	6/20/16	23
09-03-150F	7/6/16	1
09-03-150F	7/20/16	9.1
09-03-150F	8/16/16	150
09-03-150F	9/6/16	9.1
09-03-150F	9/20/16	460
09-03-150F	10/4/16	43
09-03-150F	10/26/16	23
09-03-150F	12/5/16	23
09-03-150F	1/4/17	3.6
09-03-150F	2/23/17	9.1
09-03-150F	2/24/17	1
09-03-150F	3/27/17	3.6
09-03-150F	4/5/17	1
09-03-150F	4/24/17	93
09-03-150F	6/6/17	23
09-03-150F	6/20/17	43