Total Maximum Daily Loads of Fecal Coliform for the Restricted Shellfish Harvesting Area in the Lower Wicomico River Basin in Wicomico and Somerset Counties, Maryland

FINAL

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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
EPA	Environmental Protection Agency
FA	Future Allocation
FDA	U.S. Food and Drug Administration
GIS	Geographic Information System
HEM-3D	Hydrodynamic and Eutrophication Model in 3 Dimensions
km	Kilometer
LA	Load Allocation
L_D	Load From Diffuse Sources
m	Meter
M_2	Lunar semi-diurnal tidal constituent
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
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NSSP	National Shellfish Sanitation Program
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

EXECUTIVE SUMMARY

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (EPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2006c).

Lower Wicomico River (basin number 02130301) was first identified on the 1996 303(d) List submitted to U.S. Environmental Protection Agency by the Maryland Department of the Environment (MDE). The designated uses in Lower Wicomico River were listed as impaired by sediments (1996, 2002), nutrients (1996), and fecal coliform in tidal portions of the basin (1996), and impacts to biological communities in the non-tidal portions (2002). In 2004, the fecal coliform listing was refined by identifying one restricted shellfish harvesting area within the basin (MDE 2006). The assessment unit listing code for this area in Maryland's 303(d) List is MD-WICMH-WICOMICO_RIVER. This document, upon EPA approval, establishes a TMDL of fecal coliform that will allow for the attainment of the shellfish harvesting designated use in the one restricted shellfish harvesting area of the Lower Wicomico River basin: the Lower Wicomico River mainstem. A TMDL for nutrients was completed in 2001. The listings for sediments and impact to biological communities within the Lower Wicomico River basin will be addressed at a future date.

An inverse three-dimensional model was used to estimate current fecal coliform loads and to establish allowable loads for the one restricted shellfish harvesting area in the Lower Wicomico River watershed. The inverse model incorporates influences of freshwater discharge, tidal and density-induced transport, and fecal coliform decay, thereby representing the fate and transport of fecal coliform in the restricted shellfish harvesting area. The loadings from potential sources (human, livestock, pets, and wildlife) are quantified based on analysis of the Bacteria Source Tracking (BST) data collected in the Lower Wicomico River over a one-year period.

The entire Wicomico River has a length of approximately 33 km whereas the Lower Wicomico River has a length of approximately 6.2 km. Because of the decay of fecal coliform, large amounts of bacteria discharged from the river's upstream region are lost during the transport. Numerical model simulation results show that bacterial loads discharged into the watershed upstream of Simms Wharf have minimal impact on the restricted area downstream because the concentration in the restricted area will be reduced by a factor of 10,000. Model sensitivity tests further confirm that the fecal coliform concentration in the restricted area does not depend significantly on the load from the watershed upstream of Simms Wharf. Therefore, this TMDL will be established for those downstream watersheds that have significant influence on the restricted area.

The allowable loads for the restricted shellfish harvesting area were computed using both the median concentration water quality criterion for shellfish harvesting use of 14 Most Probable

Number (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 TMDLs developed for the restricted shellfish harvesting area of the Lower Wicomico River Basin for fecal coliform are as follows:

Waterbody	**Fecal Coliform TMDL [counts per day]**	
	based on Median Criterion	**based on 90th Percentile Criterion**
Lower Wicomico River mainstem	1.513×10^{12}	4.821×10^{12}

The goal of TMDL allocation is to determine the maximum allowable loads 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. The TMDL requires a reduction of approximately 37.62% for the Lower Wicomico River mainstem.

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 while giving consideration to the relative ease of implementation and cost. The source contributions estimated from the BST data 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.

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 2006c). 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.

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. 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.

Fecal coliform 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 U.S. Food and Drug Administration (FDA), rather than EPA, is responsible for food safety. 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 FDA. The NSSP continues to use fecal coliform as the indicator organism to assess shellfish harvesting waters (FDA 2003). The water quality goal of this TMDL is to reduce high fecal coliform concentrations to levels that meet the criteria associated with the shellfish harvesting designated use.

In both the 1996 and 1998 Maryland 303(d) Lists of Impaired Waterbodies, many shellfish listings were identified on a broad 8-digit watershed scale. These listings were further refined in the 2004 303(d) List. Since 2004, the listings that are based on the shellfish water quality monitoring data are limited to the specific currently restricted shellfish harvesting areas within an 8-digit watershed (MDE 2006).

Lower Wicomico River (basin number 02130301) was first identified on the 1996 303(d) List submitted to EPA by the Maryland Department of the Environment (MDE). The designated uses in Lower Wicomico River were listed as impaired by sediments (1996, 2002), nutrients

(1996), fecal coliform in tidal portions of the basin (1996), and impact to biological communities in the non-tidal portions (2002). In 2004, the fecal coliform listing was refined by identifying one restricted shellfish harvesting area within the basin: the Lower Wicomico River mainstem (MDE 2006). The assessment unit listing code for this area in Maryland's 303(d) List is MD-WICMH-WICOMICO_RIVER. This document, upon EPA approval, establishes TMDLs for fecal coliform for the Lower Wicomico River mainstem. The designated use for shellfish harvesting in the Lower Wicomico River includes all the waters south of Whitehaven, MD. Waters north of Whitehaven are not designated for shellfish harvesting or propagation. A TMDL for nutrients was completed in 2001. The listings for sediments and impact to biological communities within the Lower Wicomico River basin will be addressed at a future date.

The basis of the shellfish harvesting area closure is fecal coliform data from the shellfish water quality monitoring program that exceeded water quality criteria, and therefore resulted in the areas being classified as "restricted" or closed to direct harvest. The criteria include both a median and a 90^{th} percentile concentration requirements (COMAR 2006).

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

One restricted shellfish harvesting area in the Lower Wicomico River basin is addressed in this report: Lower Wicomico River mainstem. Lower Wicomico River is located on Maryland's Eastern Shore in Wicomico and Somerset Counties, as shown in Figure 2.1.1. The Lower Wicomico River mainstem is in the lower portion of the Wicomico River. Wicomico River has a length of approximately 33 km and its width ranges from 130 to 180 m upstream and approximately 1.6 km at its mouth (where it flows into Chesapeake Bay just south of Nanticoke River). The Lower Wicomico River restricted shellfish harvesting area has length of 6.2 km and a drainage area of 124,790.4 acres (505.01 km^2).

The topography of the watershed is generally flat to slightly rolling and the soils are relatively well-drained with a low water table and fairly good percolation. The soils mainly consist of sand, silt, and clay (USDA 2006). It can be characterized as moderate to low runoff. The dominant tide in this region is the lunar semi-diurnal (M_2) tide, with a tidal range of 0.71 m in the restricted portion of the Lower Wicomico River with a tidal period of 12.42 hours (NOAA 2006). Please refer to Table 2.1.1 for the mean volume and mean water depth of this restricted shellfish harvesting area.

Table 2.1.1: Physical Characteristics of the Lower Wicomico River Restricted Shellfish Harvesting Area

Restricted Shellfish Harvesting Area	Mean Water Volume [m^3]	Mean Water Depth [m]
Lower Wicomico River Mainstem	14,847,573	2.97

The 2000 Maryland Department of Planning (MDP) land use/land cover data show that the watershed can be characterized as primarily rural for the Lower Wicomico River, with nearly 30% of the area being cropland and more than 36% being forest. The land use information for the restricted shellfish harvesting area in the Lower Wicomico River Basin is shown in Table 2.1.2 and Figure 2.1.2. Residential urban land use identified in Table 2.1.2 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.

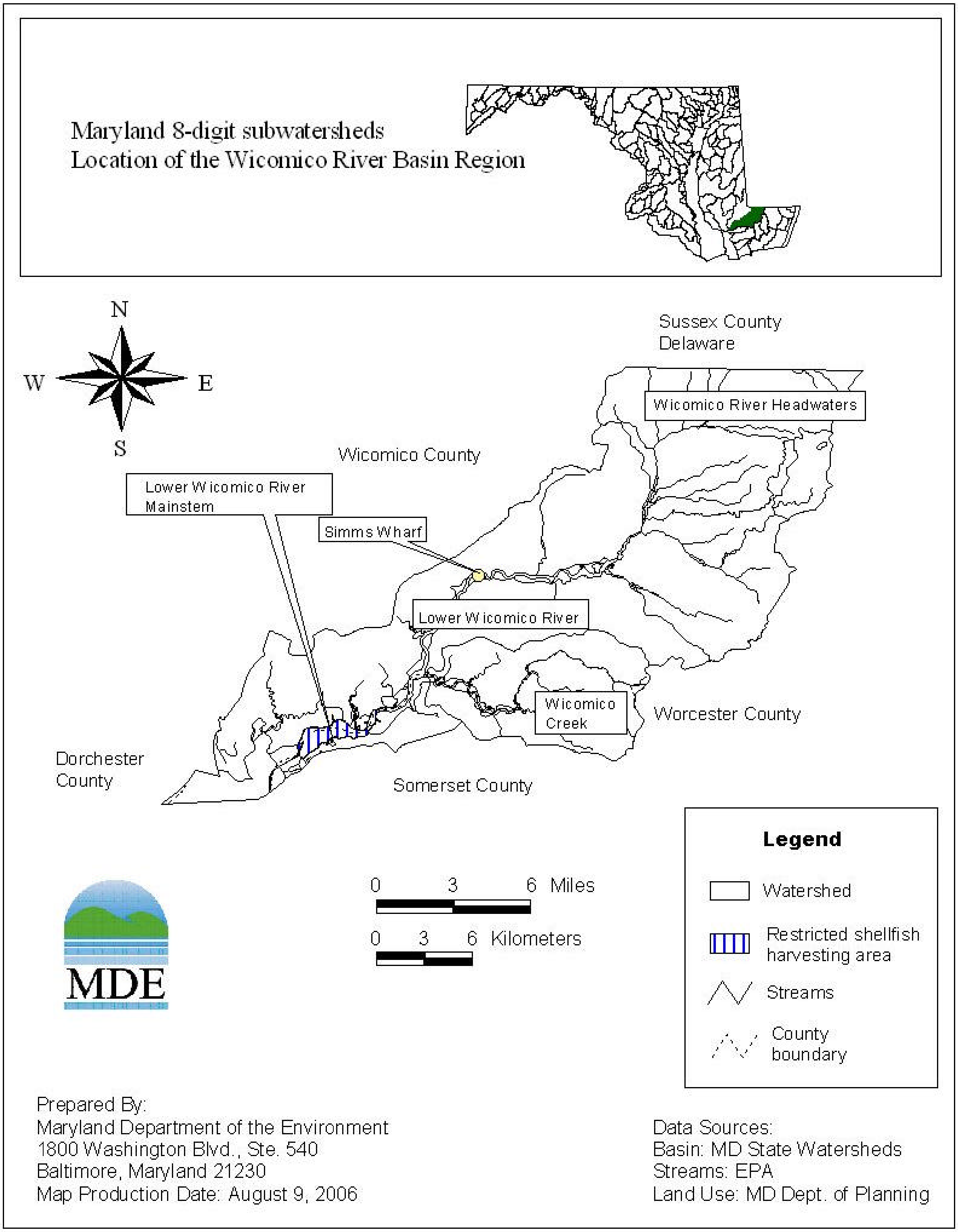

Figure 2.1.1: Location Map of the Lower Wicomico River Basin

Table 2.1.2: Land Use Percentage Distribution for Lower Wicomico River

Land Type	Acreage	Percentage
Residential urban[1]	17,629.8	14.13
Non-Residential urban[2]	7,233.5	5.80
Cropland	36,941.4	29.60
Pasture	616.2	0.49
Feedlot	1,028.3	0.82
Forest	45,496.3	36.46
Water	7,761.9	6.22
Wetlands	7,899.1	6.33
Barren	183.2	0.15
Transportation	0.7	0.00
Totals	**124,790.4**	**100.00**

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

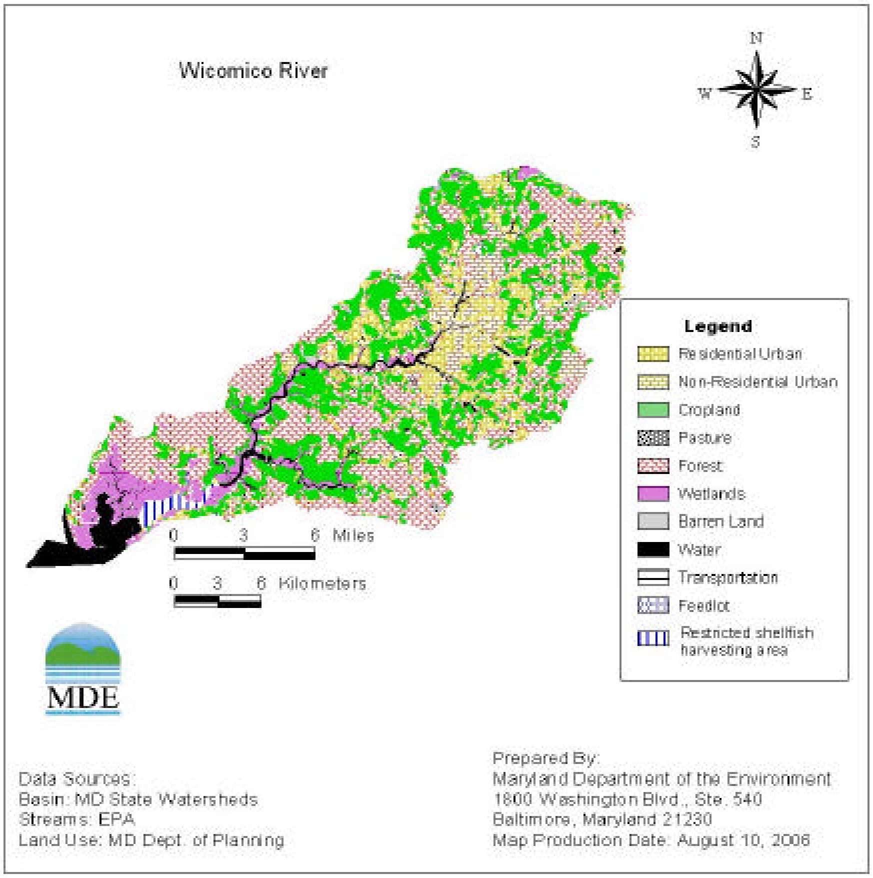

Figure 2.1.2: Land Use in the Lower Wicomico River Basin

2.2 Water Quality Characterization

MDE's Shellfish Certification Program is responsible for classifying shellfish harvesting waters to ensure oysters and clams are safe for human consumption. As discussed above, MDE adheres to the requirements of the National Shellfish Sanitation Program, with oversight by the U.S. Food and Drug Administration. 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 Program monitors shellfish waters throughout Maryland. There are five shellfish monitoring stations in the restricted shellfish harvesting area addressed in this report. The station identification and observations recorded during the period of July 2000 – July 2005, except Stations 14-06-007T and 14-06-008, are provided in Table 2.2.1 and Figure 2.2.1 through Figure 2.2.6. For Stations 14-06-007T and 14-06-008, data for the period of November 2002 to July 2005 were recorded. Tabulations of observed fecal coliform values at the monitoring stations included in this report are provided in Appendix D.

Table 2.2.1: Locations of the Shellfish Monitoring Stations in Lower Wicomico River Mainstem

Station Location	Shellfish Monitoring Station	Obs. Period	Total Obs.	LATITUDE Deg-min-sec	LONGITUDE Deg-min-sec
Lower Wicomico River Mainstem	14-06-004	2000-2005	66	38 14 40.0	75 50 34.0
	14-06-007	2000-2005	66	38 15 14.0	75 48 10.0
	14-06-007T	2002-2005	36	38 15 28.1	75 49 40.8
	14-06-008	2002-2005	35	38 15 10.8	75 48 21.9
	14-06-211	2000-2005	65	38 15 08.0	75 50 06.0

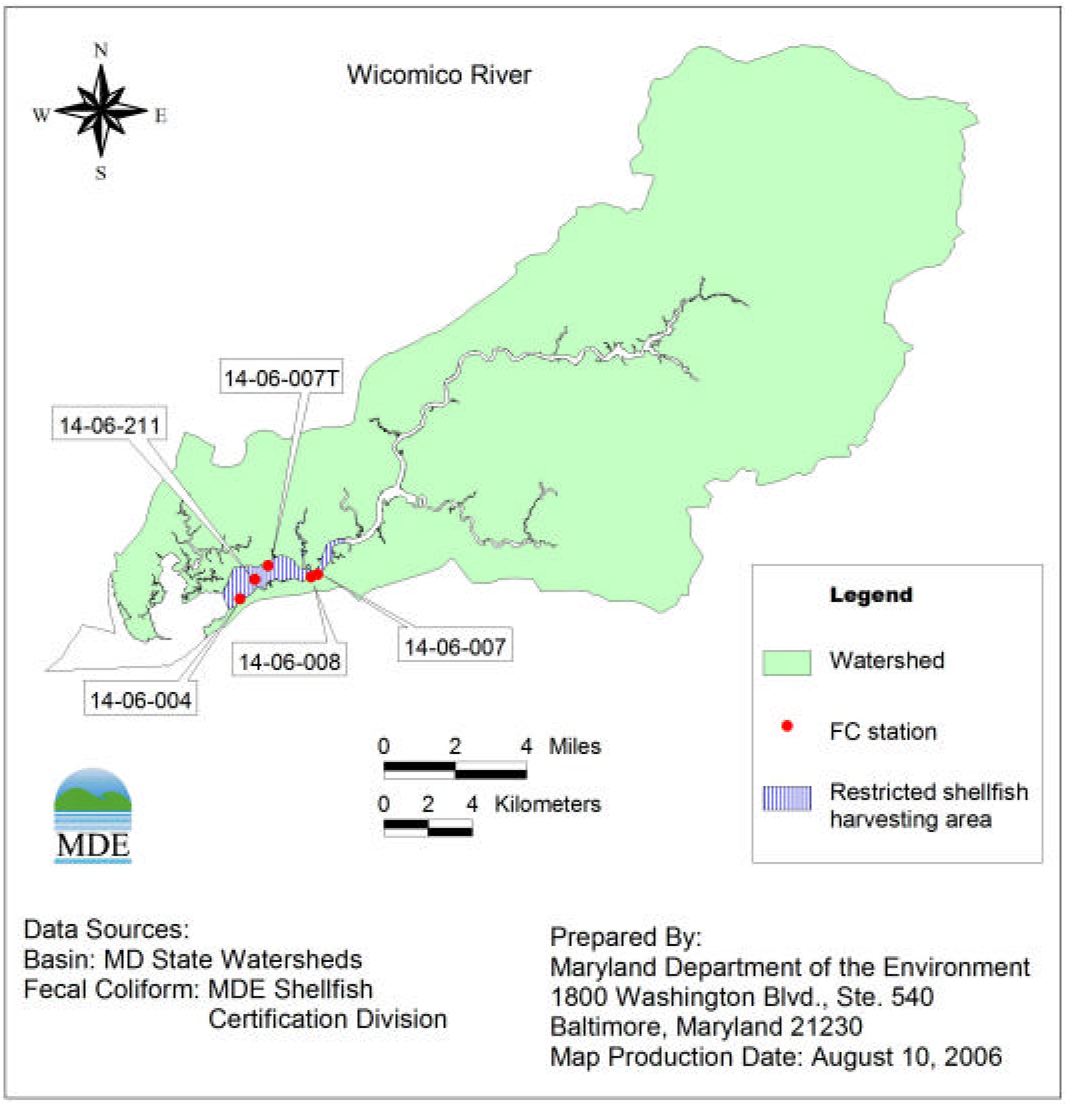

Figure 2.2.1: Shellfish Monitoring Stations in Lower Wicomico River Mainstem

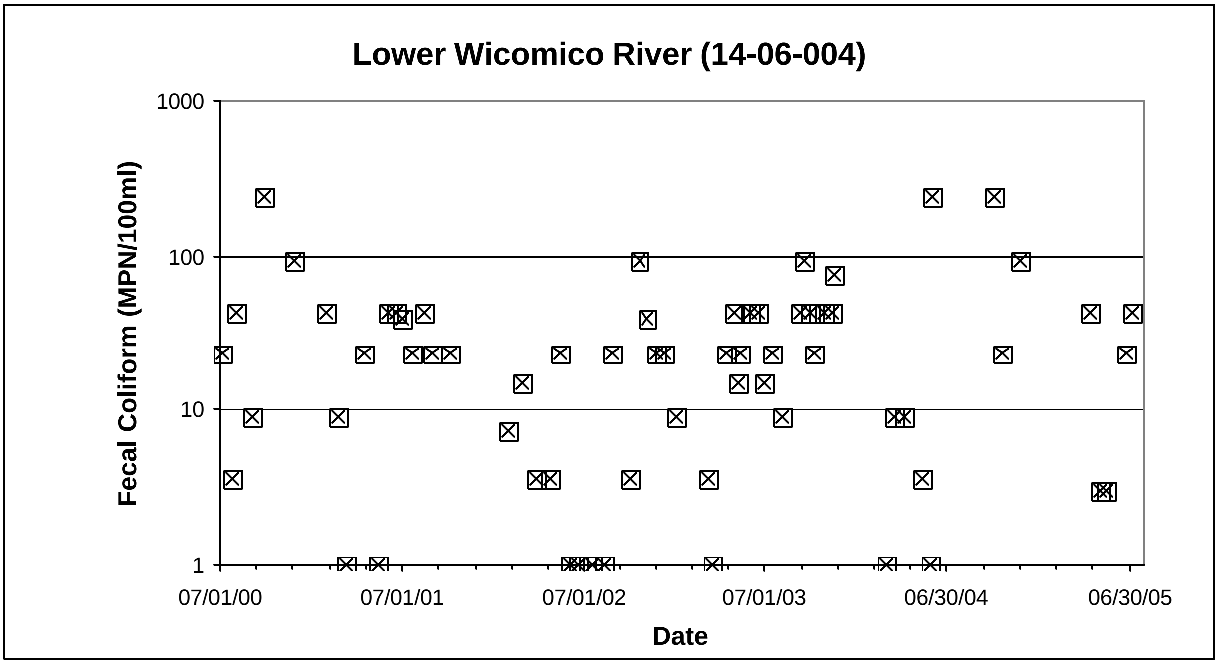

Figure 2.2.2: Observed Fecal Coliform Concentrations at Station 14-06-004

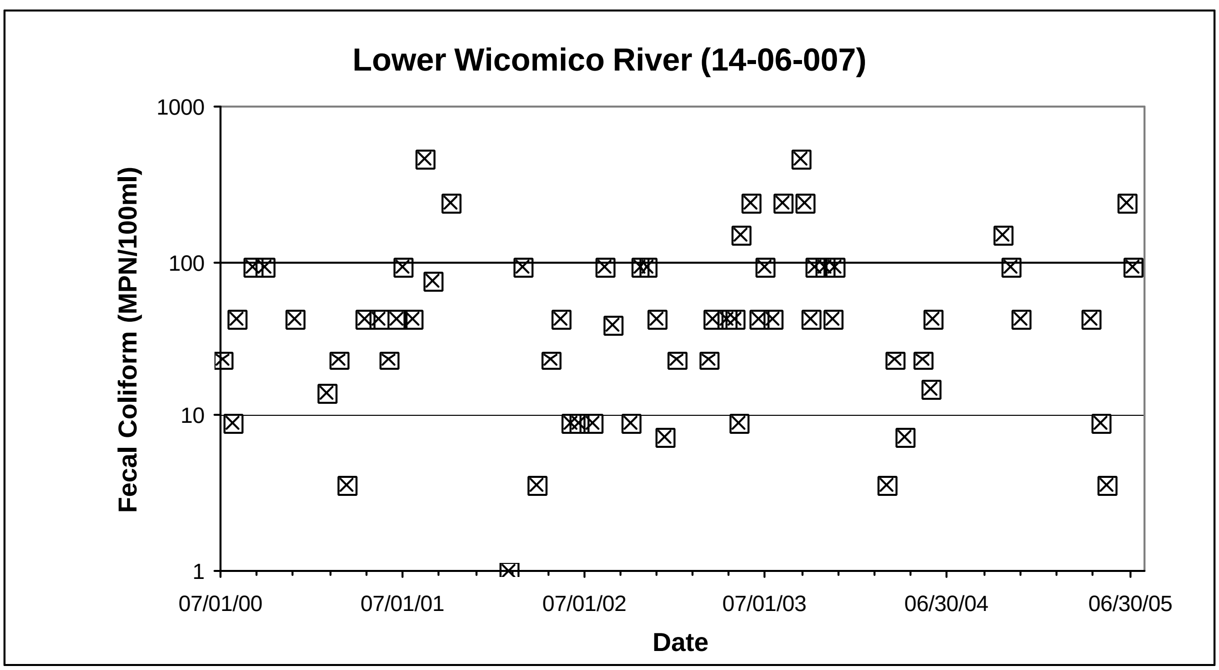

Figure 2.2.3: Observed Fecal Coliform Concentrations at Station 14-06-007

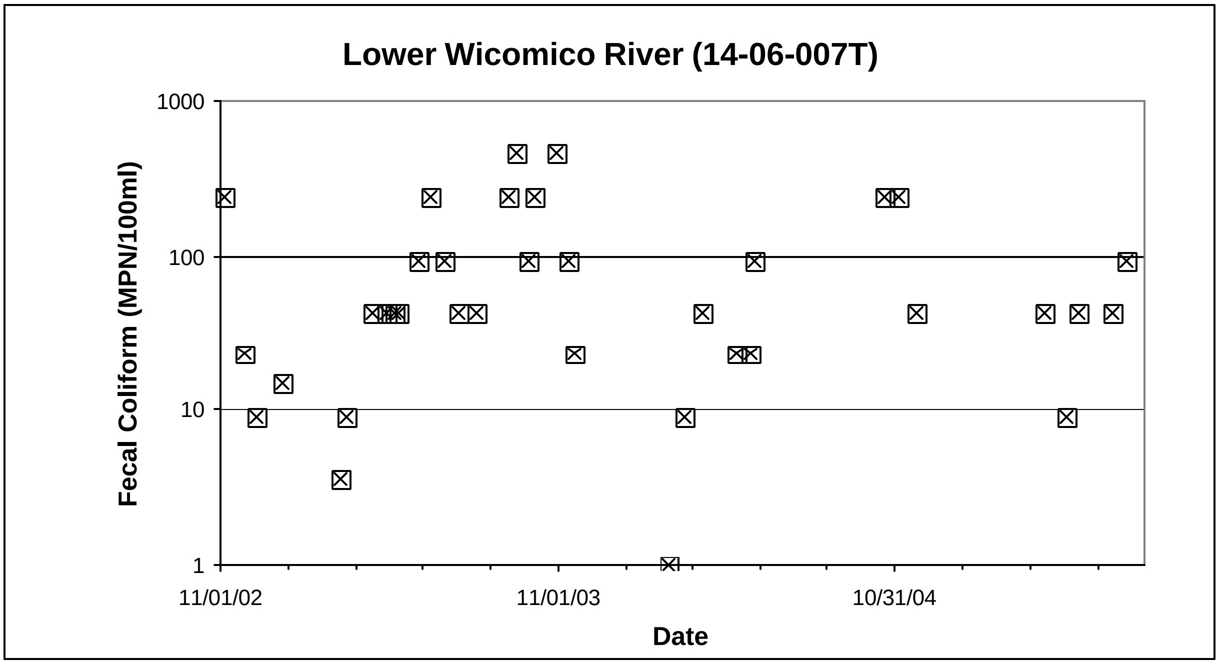

Figure 2.2.4: Observed Fecal Coliform Concentrations at Station 14-06-007T

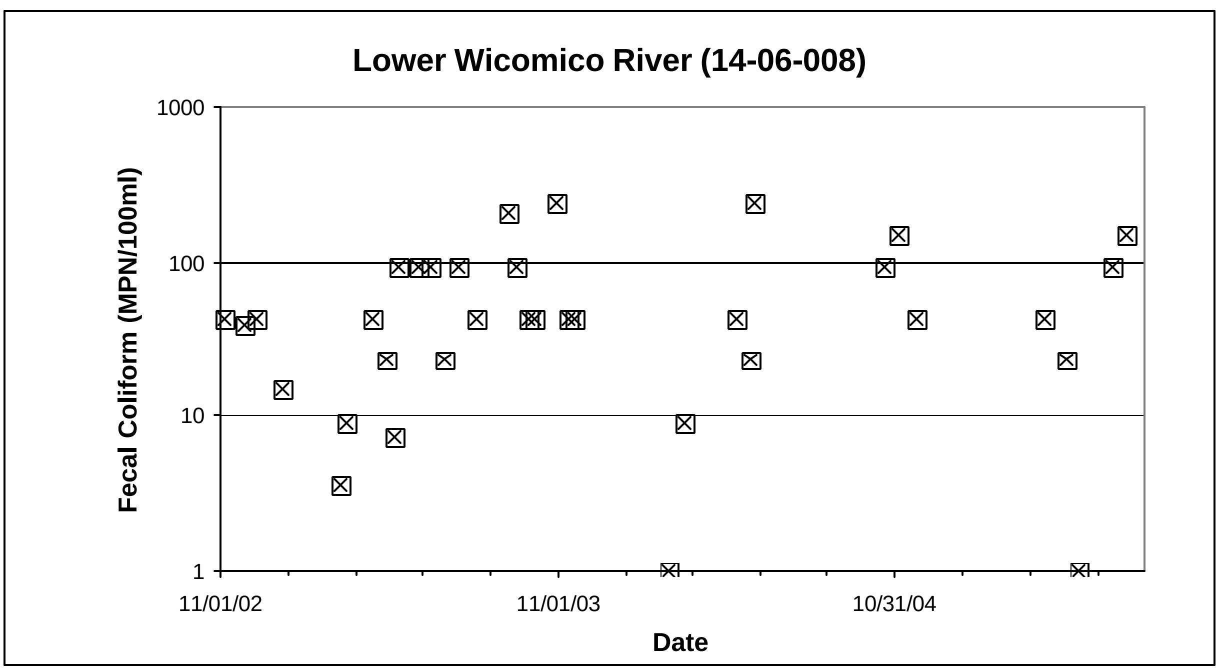

Figure 2.2.5: Observed Fecal Coliform Concentrations at Station 14-06-008

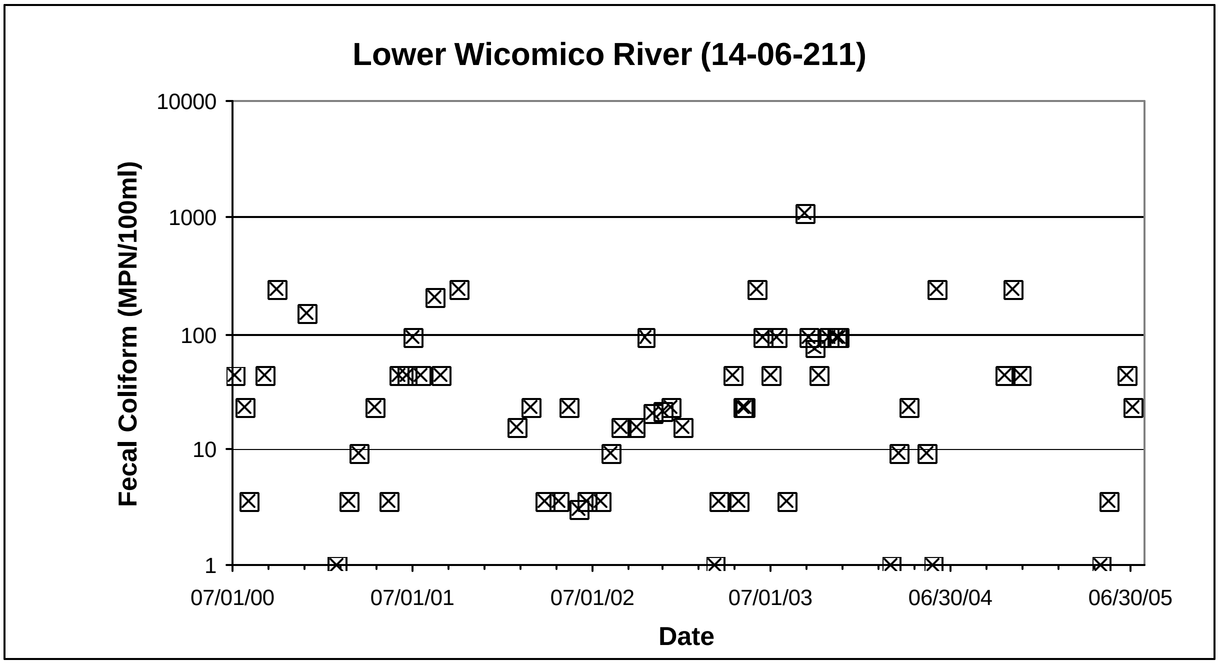

Figure 2.2.6: Observed Fecal Coliform Concentrations at Station 14-06-211

2.3 Water Quality Impairment

The fecal coliform impairment addressed in this analysis was 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:

> 2) 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 2006).[1]

MDE updated and promulgated water quality criteria for shellfish waters in June 2004. Although bacteriological criteria for shellfish harvesting waters were unchanged, the update included the classification criteria required under the NSSP that previously was not included in COMAR. In 2005, MDE revised the use designations in COMAR as part of the Chesapeake Bay Program revision to reflect living resources based habitat needs, but did not change the fecal coliform criteria for shellfish harvesting waters or shellfish harvesting use designations.

Maryland water quality standards explicitly state the fecal coliform criteria as a median and 90th percentile of at least 30 water sample results taken over a 3-year period. Therefore, a requirement for a daily TMDL value is not appropriate. Rather, the TMDL refers to a load that will ensure that the more stringent of the two criteria is met.

For this analysis, MDE is using routine monitoring data collected over a five-year period between July 2000 and July 2005. Most shellfish harvesting areas have been monitored routinely since before 1950 and, due to an emerging oyster aquaculture industry, there are a few shellfish harvesting areas that have less than five years worth of data. For the purpose of classifying shellfish harvesting areas, a minimum of 30 samples is required. For TMDL development, if fewer than 30 samples are available, current loads are estimated based on all of the most recent data. The assimilative capacity will be based on the approved classification requirements of a median concentration of 14 MPN/100 ml and a 90th percentile concentration of less than 49 MPN/100 ml.

Lower Wicomico River was first listed on the 1996 Integrated 303(d) List as impaired by fecal coliform. This listing was further refined in 2004 and specified the following shellfish

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

harvesting waters as impaired by fecal coliform: Lower Wicomico River mainstem. The water quality impairment in the Lower Wicomico River mainstem was assessed as not meeting either the median criterion or the 90th percentile criterion at any of its five monitoring stations. Descriptive statistics of the monitoring data and the requirements for the approved classification are shown in Table 2.3.1.

Table 2.3.1: Lower Wicomico River Fecal Coliform Statistics (data from 2000-2005)

Area Name	Station	Median		90th Percentile	
		Monitoring Data	Criterion	Monitoring Data	Criterion
		MPN/100ml	MPN/100ml	MPN/100ml	MPN/100ml
Lower Wicomico River Mainstem	14-06-004	23	14	102	49
	14-06-007	43	14	189	49
	14-06-007T	43	14	272	49
	14-06-008	43	14	200	49
	14-06-211	23	14	171	49

2.4 Source Assessment

Nonpoint Source Assessment

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

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 sampling over a one-year period in the Lower Wicomico River watershed using 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 Wicomico 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. The watershed is predominately cropland and forest. According to land use information, wildlife could be the dominant source. Pet contributions usually occur through runoff from streets and land. Human sources mainly result from failure of septic systems. Figure 2.1.2 shows the land use categories in the watershed. Based on the analysis of BST data, wildlife is the predominant bacteria source followed by livestock, human, and pet sources. Twenty percent (20%) of the water isolates are unknown (unclassified). Table 2.4.1 summarizes the source distribution based on BST data analysis. Detailed results of BST analysis are presented in Appendix B.

Table 2.4.1: Source Distribution Based on BST Data Analysis

Human	Livestock	Wildlife	Pets	Unknown
20.1%	9.5%	44.1 %	5.9%	20.4%

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 20.4% unknown sources for BST analysis are those where no match was identified in the known library. They do not represent unknown sources in the sense that they cannot be identified, rather they represent a portion of the statistical analysis where no matches to the BST library were found (see Appendix B for details on BST used for this report).

Point Source Assessment

There are no industrial facilities with permits regulating the discharging fecal coliform to the Lower Wicomico River. The four municipal sewage treatment facilities that have permits regulating the discharge of fecal coliform to the Wicomico River or its tributaries are: Delmar Waste Water Treatment Plant (WWTP) with National Pollution Discharge Elimination System (NPDES) permit number MD0020532, Salisbury WWTP (NPDES number MD0021571), Fruitland WWTP (NPDES number MD0052990), and Hearrne-Meadows, LLC WWTP (NPDES number MD0063282). Their permits specify limitations of 200 MPN/100ml monthly log mean fecal coliform concentration with respective flows of 0.85, 10.2, 0.49, and 0.0046 million gallons per day (mgd). Detailed information about the fecal coliform permits and loads for these point sources are summarized in Appendix E. The allocation of the permitted load from these point source facilities will be addressed in Section 4.7.

3.0 TARGETED WATER QUALITY GOAL

The overall objective of the fecal coliform TMDLs summarized in this document is to establish the maximum loading needed to ensure attainment of water quality standards in the restricted shellfish harvesting area in the Lower Wicomico River basin. These standards are described fully in Section 2.3, Water Quality Impairment.

4.0 TOTAL MAXIMUM DAILY LOADS AND LOAD ALLOCATION

4.1 Overview

This section documents the detailed fecal coliform TMDLs and load allocation development for the restricted shellfish harvesting waters in the Lower Wicomico River watershed. The required load reduction was determined based on data collected from July 2000 to July 2005. The TMDLs are presented as counts/day. Section 4.2 describes the analysis framework for simulating fecal coliform concentration in restricted shellfish harvesting waters in the Lower Wicomico River basin. Section 4.3 addresses critical conditions and seasonality. The TMDL calculations are presented in Section 4.4. Section 4.5 summarizes baseline loads, Section 4.6 discusses TMDL loading caps, and Section 4.7 provides the description of the waste load and load allocations and percent reductions. The margin of safety 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 the case of this document would be Maryland's water quality criteria for shellfish harvesting 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 shellfish harvesting waters. The averaging period used for development of these TMDLs requires at least 30 samples and uses a five-year window of data to identify current baseline conditions.

A TMDL is the sum of individual wasteload allocations (WLAs) for point sources, load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a margin of safety 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:

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

4.2 Analysis Framework

In general, tidal waters are exchanged through their connecting boundaries. The tide and amount of freshwater discharged into the restricted shellfish harvesting area are the dominant forces that influence the transport of fecal coliform. The Lower Wicomico River is the downstream 6.2-km portion of the 33-km Wicomico River, a tributary of the Chesapeake Bay, where it flows into Chesapeake Bay just south of Nanticoke River. The current distribution in the system varies as tidal and freshwater discharges change. In order to simulate the transport processes in the Lower Wicomico River accurately, the 3-dimensional hydrodynamic and eutrophication model (HEM-3D) has been used for this study. The HEM-3D 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, and spatial and temporal distributions of: salinity, temperature, and suspended sediment concentrations, conservative tracers, eutrophication processes and fecal coliform. For a detailed model description, the reader is referred to Park et al. (1995).

The Wicomico River is represented by a horizontal model of Cartesian grid cells. There are a total of 315 grid cells in the modeling domain. To better simulate the stratification effect, three layers are used in the vertical. For this study, the model was calibrated for the tide and long-term mean salinity distribution. In order to address the standards of the median and 90th percentile fecal coliform concentrations, an inverse approach has been adopted here to estimate the loads from the watershed. The watershed is divided into 17 subwatersheds. The loads from each subwatershed are discharged into the river from small creeks connected to the river.

The model was forced by the M_2 constituent of the tide and the mean salinity concentration at the river's mouth. The long-term mean freshwater input estimated based on data from the United States Geological Survey (USGS) gage station 01485500 was used. 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 median and 90th percentile fecal coliform data obtained from observations. The model is also used to establish the allowable loads for the Lower Wicomico River mainstem restricted shellfish harvesting area. 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 90th percentile concentration is the concentration that exceeded water quality criterion only 10% of the time. Since the data used were collected over a five-year period, the critical condition requirement is implicitly included in the 90th percentile value. Given the length of the monitoring record used and the limited applicability of best management practices (BMPs) to extreme conditions, the 90th percentile concentration is utilized instead of the absolute maximum.

A comparison of the median values and the 90th percentile values against the water quality criteria determines which represents the more critical condition or higher percent reduction. If the median values dictate the higher reduction, this suggests that, on average, water sample counts are high with limited variation around the mean. If the 90th percentile criterion requires a higher reduction, this suggests an occurrence of high fecal coliform due to the variation of hydrological conditions.

The seasonal fecal coliform distributions for the five applicable monitoring stations are presented in Appendix C. The results show the seasonal variability of fecal coliform concentrations; high concentrations occur between June and November in the Lower Wicomico River restricted shellfish harvesting area. The large standard deviations correspond to the high variability in concentration at each station, resulting in high 90th percentile concentrations, which indicate that exceedances may occur only during a few months of the year.

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. By examining the seasonal variability of fecal coliform, the highest fecal coliform concentration often occurs during the few months of the year that correspond to the critical condition. If loads under the critical condition can be controlled, water quality attainment can be achieved.

4.4 TMDL Computation

Because the water quality standards for fecal coliform in shellfish waters include both the median and 90th percentile criteria, TMDLs are calculated against both criteria and the criterian requiring the greatest percent reduction is selected for the TMDL.

Routine monitoring data were used to estimate the current loads. Both the median and the 90th percentile analyses have been performed. The restricted shellfish harvesting area in the Lower Wicomico River has five shellfish monitoring stations. As stated above, in order to estimate accurately the load with consideration of available monitoring data, the watershed was segmented into 17 subwatersheds (see Figure A-1). The load for each subwatershed was discharged into its corresponding receiving water model. The inverse method was used to compute the watershed loads discharged into the river based on the best match of observations and model simulation of fecal coliform concentrations in the river. The total loads are reported in Table 4.4.1 and Table 4.4.2. Detailed results by subwatershed are also listed in Appendix A.

The allowable load is calculated using the water quality criteria of a median of 14 MPN/100ml and a 90th percentile of 49 MPN/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 fecal coliform concentrations in the receiving water meet the appropriate water quality standards. The total loads discharged into the river are the summation of loads discharged from each subwatershed. For the Lower Wicomico River mainstem, neither the median nor the 90th percentile criteria are met at any of the five stations. The load reduction needed for the attainment of the criteria is determined as follows:

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

The TMDL calculations are presented in Appendix A. The calculated results are listed in Table 4.4.1 and Table 4.4.2.

Table 4.4.1: Median Analysis of Loads and Estimated Load Reduction

Area	Mean Volume M^3	Fecal Coliform Median Criterion MPN/100mL	Current Load counts/day	Allowable Load counts/day	Required Percent Reduction (%)
Lower Wicomico River mainstem	14,847,573	14	2.288E+12	1.513E+12	33.87

Table 4.4.2: 90th Percentile Analysis of Loads and Estimated Load Reduction

Area	Mean Volume M^3	Fecal Coliform 90th Percentile Criterion MPN/100mL	Current Load counts/day	Allowable Load counts/day	Required Percent Reduction (%)
Lower Wicomico River mainstem	14,847,573	49	7.729E+12	4.821E+12	37.62

4.5 Summary of Baseline Loads

For the TMDL analysis period, from July 2000 to July 2005, the calculated baseline (current) loads of fecal coliform from all sources in the restricted shellfish harvesting area of the Lower Wicomico River basin are summarized in Table 4.5.1 (see also Table 4.4.1 and Table 4.4.2 above).

Table 4.5.1: Summary of Baseline Loads

Watershed	Fecal Coliform Baseline Loads [counts per day]	
	Median Analysis Scenario	90th Percentile Analysis Scenario
Lower Wicomico River	2.288×10^{12}	7.729×10^{12}

4.6 TMDL Loading Caps

This section presents the TMDLs that would meet the median and 90th percentile criteria. Seasonal variability is addressed implicitly through the interpretation of the water quality standards (see Section 4.3). The median and 90th percentile based TMDLs for the restricted shellfish harvesting waters of the Lower Wicomico River basin are summarized in Table 4.6.1:

Table 4.6.1: Summary of TMDL Loading Caps

Watershed	Fecal Coliform TMDL [counts per day]	
	based on Median Criterion	based on 90^{th} Percentile Criterion*
Lower Wicomico River	1.513×10^{12}	4.821×10^{12}

* The comparison of the reductions required based on the median and 90th percentile criteria indicated that the 90th percentile scenario requires the largest percent reductions. Therefore, reductions required to meet the 90th percentile criterion provide the basis for the TMDL allocations.

A five-year averaging period was used to develop the fecal coliform TMDLs for the shellfish harvesting area in the Lower Wicomico River basin. This specific averaging period was chosen based on the water quality criteria, which requires at least 30 samples (COMAR 2006). When allocating loads among sources, the scenario that requires the greatest overall reductions (here the 90^{th} percentile scenario) was applied. Table 4.7.1 below summarizes the necessary load reductions by area.

4.7 TMDL Allocations and Percent Reduction

The purpose of this section is to allocate the TMDLs between point (WLA) and nonpoint (LA) sources. As stated in Section 2.4, there are four point source facilities in the reported restricted shellfish harvesting area that have permits to discharge fecal coliform to the Wicomico River (or its tributaries) and the fecal coliform load from these point sources is approximately 2.84×10^{11} counts per day and will be included in the WLA. The remaining loads assimilative capacity will be allocated to the load allocation.

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 calculated in this document was based on the 90^{th} percentile water quality criterion, which is shown in Table 4.7.1 for the restricted shellfish harvesting area of the Lower Wicomico River watershed.

Table 4.7.1: Load Reduction

Restricted Shellfish Harvesting Area	Required Reduction
Lower Wicomico River mainstem	**37.62%**

Since the load reduction applied to this watershed was based on the 90^{th} percentile water quality standard, it targets only those critical events that occur less frequently. 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.

4.8 Margin of Safety

A margin of safety 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

There are four municipal sewage treatment facilities with permits regulating the discharge of fecal coliform, Delmar WWTP (NPDES permit number MD0020532), Salisbury WWTP (NPDES permit number MD0021571), Fruitland WWTP (NPDES permit number MD0052990), and Hearrne-Meadows, LLC WWTP (NPDES permit number MD0063282) that discharge into waters of the Wicomico River upstream of shellfish waters. The total permitted fecal coliform loads from these point sources are approximately 2.84×10^{11} counts per day and will be included in the WLA. The remaining loads, calculated based on the most stringent criterion (i.e., the 90th percentile), will be allocated to the LA. The TMDL is summarized as follows:

Fecal coliform TMDL (counts per day) based on 90th percentile criterion:

Area	**TMDL**	**=**	**LA**	**+**	**WLA**	**+**	**FA**	**+**	**MOS**
Lower Wicomico River mainstem	**4.82×10^{12}**	**=**	**4.54×10^{12}**	**+**	**2.84×10^{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 assurances that the fecal coliform TMDLs 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. 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 source contributions estimated from BST analysis (see Table 2.4.1) may be used as a tool to target and prioritize initial implementation efforts. The iterative approach towards 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

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. 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. 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.

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 responsibilities under 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 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 MDE may place administrative restrictions or restrictions required by the NSSP. 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

ASAE (American Society of Agricultural Engineers). 1998. *ASAE Standards, 45th Edition: Standards, Engineering Practices, Data.* St. Joseph, MI: American Society of Agricultural Engineers.

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

Brodie, H., and L. Lawrence. 1996. *Nutrient Sources on Agricultural Lands in Maryland: Final Report of Project NPS 6*. Annapolis, MD: Chesapeake Bay Research Consortium.

CFR (Code of Federal Regulations). 2006a. *40 CFR 122.26 (b).* http://www.gpoaccess.gov/cfr/index.html (Accessed August, 2006).

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

_________. 2006c. *40 CFR 130.7(c)(1)*. http://www.gpoaccess.gov/cfr/index.html (Accessed August, 2006).

COMAR (Code of Maryland Regulations). 2006. *26.08.02.03-3C(2)*. http://www.dsd.state.md.us/comar/26/26.08.02.03-3.htm (Accessed August, 2006).

De Walle, F. B. 1981. Failure Analysis of Large Septic Tank Systems. *Journal of Environmental Engineering Division* 107:229-240.

DNR (Maryland Department of Natural Resources). 2003. *2002-2003 Game Program Annual Report*. Annapolis, MD: Maryland Department of Natural Resources, Wildlife and Heritage Services.

_________. 2004. Personal Communication with Douglas Horton.

_________. 2005. Personal Communication with Larry Hindman.

FDA (Food and Drug Administration). 2003. Chapter IV: Shellstock Growing Areas. In *National Shellfish Sanitation Program: Guide for the Control of Molluscan Shellfish*. Rockville, MD: Food and Drug Administration, Department of Health and Human Services. Also Available at http://www.cfsan.fda.gov/~ear/nss2-toc.html.

Frana, M.F. and E. A. Venso. 2006. Bacterial Source Tracking Report: Identifying Sources of Fecal Pollution in the Wicomico River Shellfish Harvesting Waters, Maryland. 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, 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.

Kator, H., and M. W. Rhodes. 1996. Identification of Pollutant Sources Contributing to Degraded Sanitary Water Quality in Taskinas Creek National Estuarine Research Reserve, Virginia. *Special Report in Applied Marine Science and Ocean Engineering* No. 336. 47 pp.

Mancini, J. L. 1978. Numerical Estimates of Coliform Mortality Rates Under Various Conditions. *Journal - Water Pollution Control Federation* 50 (November):2477-2484.

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

MDA (Maryland Department of Agriculture). 2002a. *Agriculture in Maryland 2002 Summary*. Annapolis, MD: Maryland Department of Agriculture, Maryland Agricultural Statistics Services. Also Available at http://www.nass.usda.gov/md/Ag%20in%20Maryland%202002.pdf.

_________. 2002b. *Maryland Equine: Results of the 2002 Maryland Equine Census*. Annapolis, MD: Maryland Department of Agriculture, Maryland Agricultural Statistics Services, and The Maryland Horse Industry Board. Also Available at http://www.marylandhorseindustry.org/census2.htm.

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.

__________. 2006. *2004 303(d) List Searchable Database*. http://www.mde.state.md.us/Programs/WaterPrograms/TMDL/Maryland 303 dlist/303d_search/ (Accessed August, 2006).

MDP (Maryland Department of Planning). 2000. *2000 Land Use Data.* Baltimore, MD: Maryland Department of Planning.

__________. 2003. *Estimates of Septic Systems.* Baltimore, MD: Maryland Department of Planning, Comprehensive Planning Unit.

__________. 2004. *Maryland Department. of Natural Resources 12 Digit Watershed GIS Coverage*. Baltimore, MD: Maryland Department of Planning.

NOAA (National Oceanic and Atmospheric Administration). 2006. *Tides Online*. http://tidesonline.nos.noaa.gov/ (Accessed August, 2006).

Park, K., A. Y. Kuo, J. Shen, and J. M. Hamrick. 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.

Shen, J. 2006. Optimal Estimation of Parameters for a Estuarine Eutrophication Model. *Ecological Modeling* 191:521-537.

Shen, J., and A. Y. Kuo. 1996. Inverse Estimation of Parameters for an Estuarine Eutrophication Model. *Journal of Environmental Engineering* 122 (11):1031-1040.

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

Shen, J., J. Boon, and A. Y. Kuo. 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.

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

Swann, C. 1999. *A Survey of Residential Nutrient Behaviors in the Chesapeake Bay*. Ellicott City, MD: Widener Burrows Inc, Chesapeake Bay Research Consortium, and the Center for Watershed Protection.

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

USDA (U.S. Department of Agriculture). 1997a. Maryland State Level Data. In *1997 Census of Agriculture*. Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service. Also Available at http://www.nass.usda.gov/census/census97/volume1/md-20/toc97.htm.

__________. 1997b. Maryland County Level Data. In *1997 Census of Agriculture*. Washington, DC: U.S. Department of Agriculture, National Agricultural Statistics Service. Also Available at http://www.nass.usda.gov/census/census97/volume1/md-20/toc297.htm.

__________. 2006. *State Soil Geographic (STATSGO) Database for Maryland*. http://www.ncgc.nrcs.usda.gov/products/datasets/statsgo/index.html (Accessed August, 2006).

USDOC (U.S. Department of Commerce). 2000. *United States 2000 Census Data.* Washington, DC: U.S. Department of Commerce, U.S. Census Bureau. http://www.census.gov/main/www/cen2000.html.

USEPA (U.S. Environmental Protection Agency). 1994. *Chesapeake Bay Program Watershed Model Application to Calculate Bay Nutrient Loadings: Final Findings and Recommendations*. Annapolis, MD: U.S. Environmental Protection Agency, Chesapeake Bay Program. Also Available at http://www.chesapeakebay.net/pubs/subcommittee/mdsc/doc-nutrientloadings-7-16-1994.pdf.

__________. 2000. *Bacteria Indicator Tool User's Guide*. Washington, DC: U.S. Environmental Protection Agency, Office of Water.

__________. 2001. *Protocol for Developing Pathogen TMDLs*. Washington, DC: U.S. Environmental Protection Agency, Office of Water. Also Available at http://nepis.epa.gov/pubtitleOW.htm.

__________. 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.

__________. 2006. *Stormwater Manager Resource Center*. http://www.stormwatercenter.net/ (Accessed August, 2006).

VADEQ (Virginia Department of Environmental Quality). 2002. *Fecal Coliform TMDL for Dodd Creek Watershed, Virginia.* Washington, DC: The Louis Berger Group, Inc. Also Available at http://www.deq.virginia.gov/tmdl/apptmdls/newrvr/dodd.pdf.

VIMS (Virginia Institute of Marine Sciences). 2002-2004. Personal Communication with Helen Woods.

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

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. Model Development

The 3-dimensional hydrodynamic and eutrophication model (HEM-3D) has been used for this study. The HEM-3D 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 fecal coliform. The model has been applied for varieties of environmental problems in estuaries (Hamrick 1992a; Shen, Boon, and Kuo 1999). For a detailed discussion of the model theory, readers are referred to Hamrick (1992b).

Figure A-1 is the model grid superimposed on the 17 subwatersheds of the Wicomico River. The modeling domain consists of 315 grid cells. Because the Wicomico River is a narrow estuary, a horizontal 2-dimensional curvilinear model grid was used in the downstream portion and a 1-dimensional grid was used in the upstream portion. To better simulate estuarine circulation, a total of 3 layers are used in the vertical. The fecal coliform is simulated using a conservative tracer with first-order decay. 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 this TMDL study.

The Lower Wicomico River is a tidal river. The dominant tidal constituent is M_2 (lunar semi-diurnal). To simulate tide correctly, a calibration of tide was conducted. The model was forced by seven tidal harmonic constituents at the river mouth. The tidal harmonic constituents at the mouth were obtained from the 3-dimensional Chesapeake Bay UnTRIM model developed at the Virginia Institute of Marine Science (VIMS) (Shen et al. 2006). The model results are compared with National Oceanic and Atmospheric Administration (NOAA) predicted tides at three stations inside the Wicomico River (NOAA 2006). The results are listed in Table A-1. The HEM-3D model results compare well against results from the NOAA predicted tides and the difference in the range of the dominant M_2 tide is less than 3 cm. Because there are no real-time observation data of stream flow, tide, and wind available in the Wicomico River, comparison of real-time salinity simulation against the observed salinity cannot be performed. Therefore, the model calibration for the mean condition of salinity distribution was performed to reproduce the averaged salinity distribution at 9 stations along the river. The locations of these stations are shown in Figure A-2. For the mean salinity calibration, the dominant M_2 tide was used as a forcing at the model open boundary. Mean salinity measured at the station nearest the mouth was used as the salinity boundary condition. The quantity of freshwater discharged from each subwatershed was estimated according to the average long-term flow from the USGS gage of 01485500 (Nassawango Creek near Snow Hill, MD). The flow of each subwatershed was estimated based on the ratio of the subwatershed area to the drainage basin area of the USGS gage. The mean flows used for the model calibration are listed in Table A-2 below for the subwatersheds shown in Figure A-1. A comparison of model results against observations is shown in Figure A-3. It can be seen that the model simulates salinity distribution well in the estuary.
Since the water quality criteria for fecal coliform are expressed in terms of the median and the

90th percentile concentrations, the modeling tasks are to estimate fecal coliform mean daily loads from the watershed corresponding to the median and 90th percentile, respectively. 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). For this study, an inverse modeling approach method built on the HEM-3D has been used to estimate fecal coliform loading from the watershed. The purpose of the inverse modeling is to estimate the long-term average daily loads corresponding to the median and 90th percentile concentrations in the waterbody. Therefore, the fecal coliform 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 (Shen and Kuo 1996; Sun and Yeh 1990; Shen 2006).

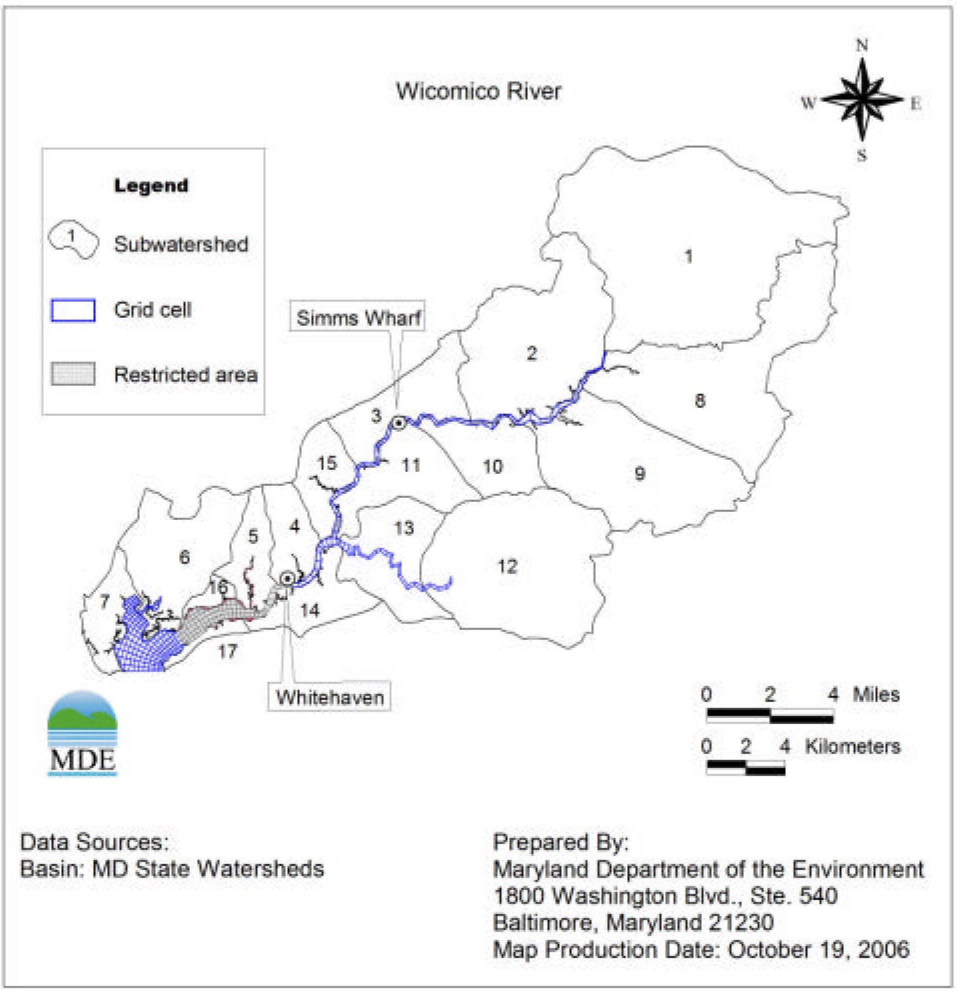

Figure A-1: HEM-3D Grid Cells and Subwatersheds in the Wicomico River

Table A-1: Comparison of Modeled and NOAA Predicted Mean Tidal Range

Station	Modeled Range (m)	NOAA Predicted Range (m)
Great Shoals Light, Monie Bay	0.708	0.701
Whitehaven	0.734	0.732
Salisbury	0.889	0.914

Table A-2: Estimated Mean Flows of Subwatersheds in the Wicomico River

Subwatershed	Mean Flow (cms)
1	0.905
2	0.431
3	0.169
4	0.094
5	0.094
6	0.255
7	0.088
8	0.534
9	0.432
10	0.148
11	0.176
12	0.529
13	0.202
14	0.114
15	0.101
16	0.023
17	0.022

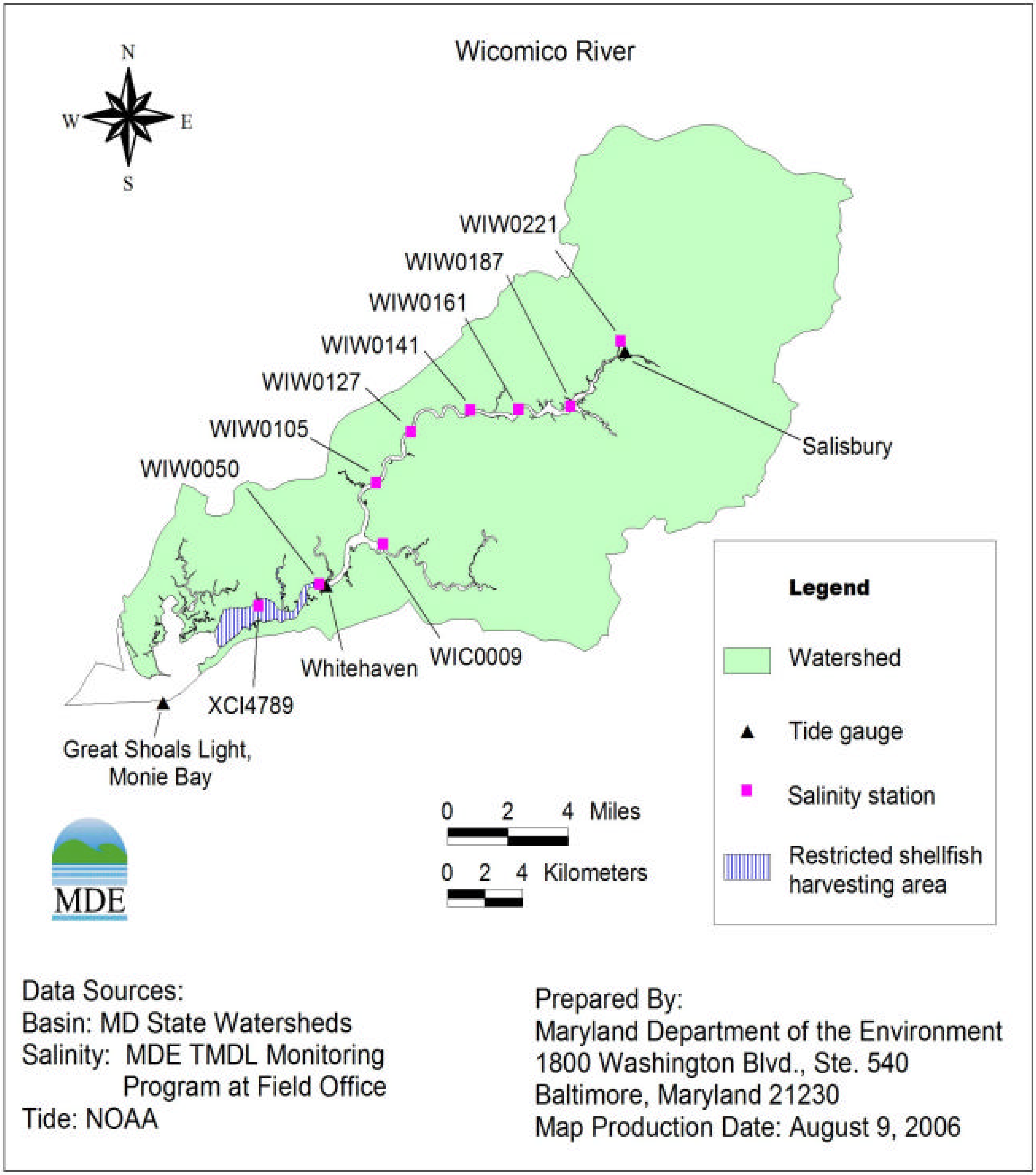

Figure A-2: Tide and Salinity Stations of the Wicomico River Used in Model Calibration

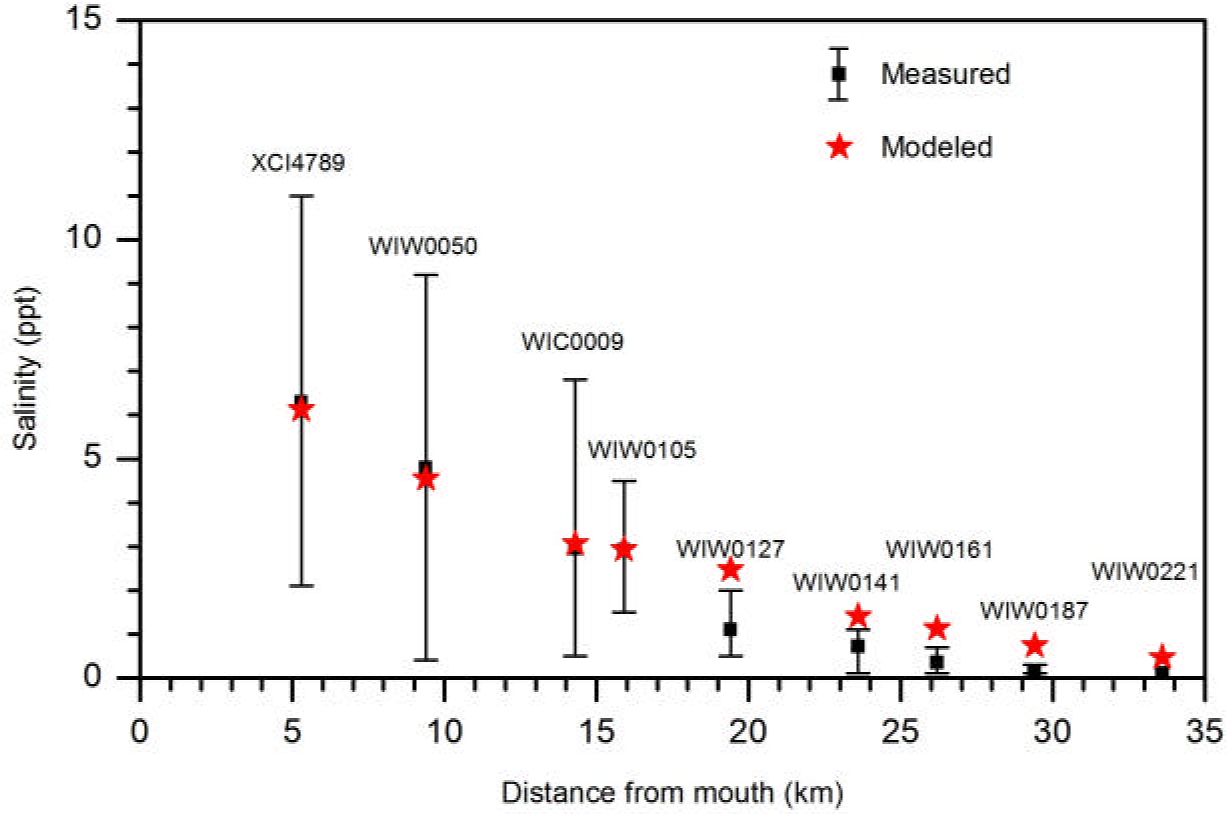

Figure A-3: Comparison of Measured and Calculated Salinities

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:

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

subject to:

$$\mathbf{\beta}^* \in \mathbf{\beta}_0 \qquad (2)$$

$$\mathbf{F} = 0 \qquad (3)$$

where ***J*** is a goal or cost function; $b^* = (\beta_1, \beta_2, ..., \beta_m)$ is the optimal parameter (*i.e.*, loads); $b_{\mathbf{0}}$ 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:

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

where C and C^0 are modeled and measured fecal coliform 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 $C^0_m(x)$ be the median or 90th percentile obtained from the observations at location (x). If we choose:

$$C_m(x) = \max(C(x,z,t)) \qquad for \quad T_0 < t < T_N \qquad (5)$$

Equation (4) can be written as:

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

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 fecal coliform loads discharged to the river originate from 17 subwatersheds, as shown in Figure A-1. For estimating of existing median loads, the model was forced by an M_2 tide and mean salinity at the mouth. The mean freshwater inflows from the subwatersheds are discharged into the river. A set of initial loads from 17 subwatersheds was estimated and discharged to the river. The initial loads are estimated based on the land use type and drainage sizes. The model was run for 20 days to reach equilibrium and the maximum concentration at the last day was used to calculate the cost function against the observed median along the river.

Because the observation data are only available in the downstream portion of the river, it is not feasible to use data collected in this downstream region and in turn use the inverse model to estimate loads from 17 subwatersheds. A monthly survey was conducted in the upstream region from September to November in 2005. The data analysis shows that the variation of the mean concentration of fecal coliform is not significant along the river, which indicates that sources of fecal coliform are discharged into the river from subwatersheds along the river. The mean concentration of fecal coliform along the upstream portion of the Wicomico River is in the same range as the 90th percentile concentration in the restricted area. Note that the distances from the headwaters of the river to Simms Wharf and the restricted area are approximately 17 km and 25 km, respectively. It can be expected that fecal coliform discharged from the upstream region will be lost due to decay before it reaches the downstream region.

One model sensitivity test of the change of downstream fecal coliform concentrations with respect to the change of upstream loading was conducted by discharging fecal coliform loads from these watersheds upstream of Simms Wharf. The fecal coliform distribution along the river is shown in Figure A-4. It shows that fecal coliform levels are reduced by a factor of 10,000 in the restricted area compared with the concentration at the headwaters. This result suggests that the downstream fecal coliform levels are not dependent on the loads from the upstream watershed. Therefore, the load allocation will only be established for downstream watersheds that influence the restricted areas significantly.

Based on the sensitivity test, the loads discharged from the subwatersheds upstream of Simms Wharf can be estimated independently from the loads discharged into the river from downstream segments. Therefore, the existing loads discharged upstream of the restricted areas (i.e., subwatersheds 1-3 and 8-10) were estimated based on mean and maximum values of three-month observation datasets. Although the number of samples and the limited time period for these available data do not allow us to estimate the 5-year median and 90th percentile, the estimated loads provided a reasonable estimation of current conditions.

The existing loads downstream were estimated based on the observed data collected within the restricted area of the Wicomico River using the inverse model. Station locations for these observed data are shown in Figure A-5, and the fecal coliform concentrations from these stations are shown in Table A-3. The modified Newton method was used to update the loads until the cost function attained a minimum. For estimating the existing loads for the 90th percentile, the same method was used except the existing 90th percentile concentrations were used to minimize the cost function.

Figures A-6 and A-7 show the model results of the simulated median and 90th percentile, respectively, along the river. It can be seen that the model results are satisfactory. The existing loads for each subwatershed are listed in Table A-4.

For TMDL calculation, the existing 90th percentile loads were reduced so that the model simulated fecal coliform values along the river to meet the median and 90th percentile criteria. The resultant loads are the allowable loads for the river. With the use of existing loads and TMDLs, the percentage reduction can be estimated. Comparing the reduction needed for both median and 90th percentile loads, the maximum reductions required for each watershed are used to establish the TMDLs. The existing and allowable loads are listed in Table A-3. Note that the current median and 90th percentile loads in the upstream portion of the river are used as allowable loads.

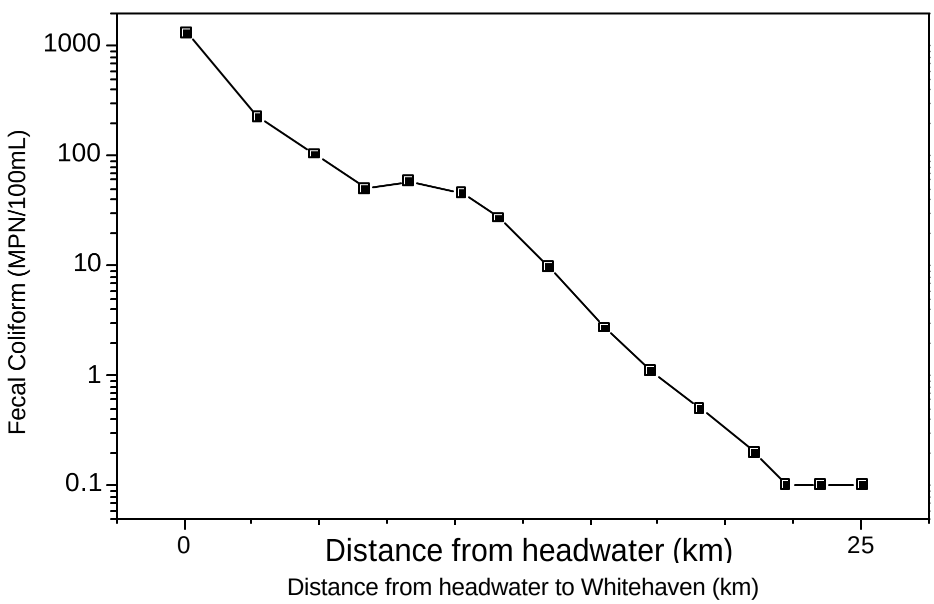

Figure A-4: Model Result of Sensitivity Test

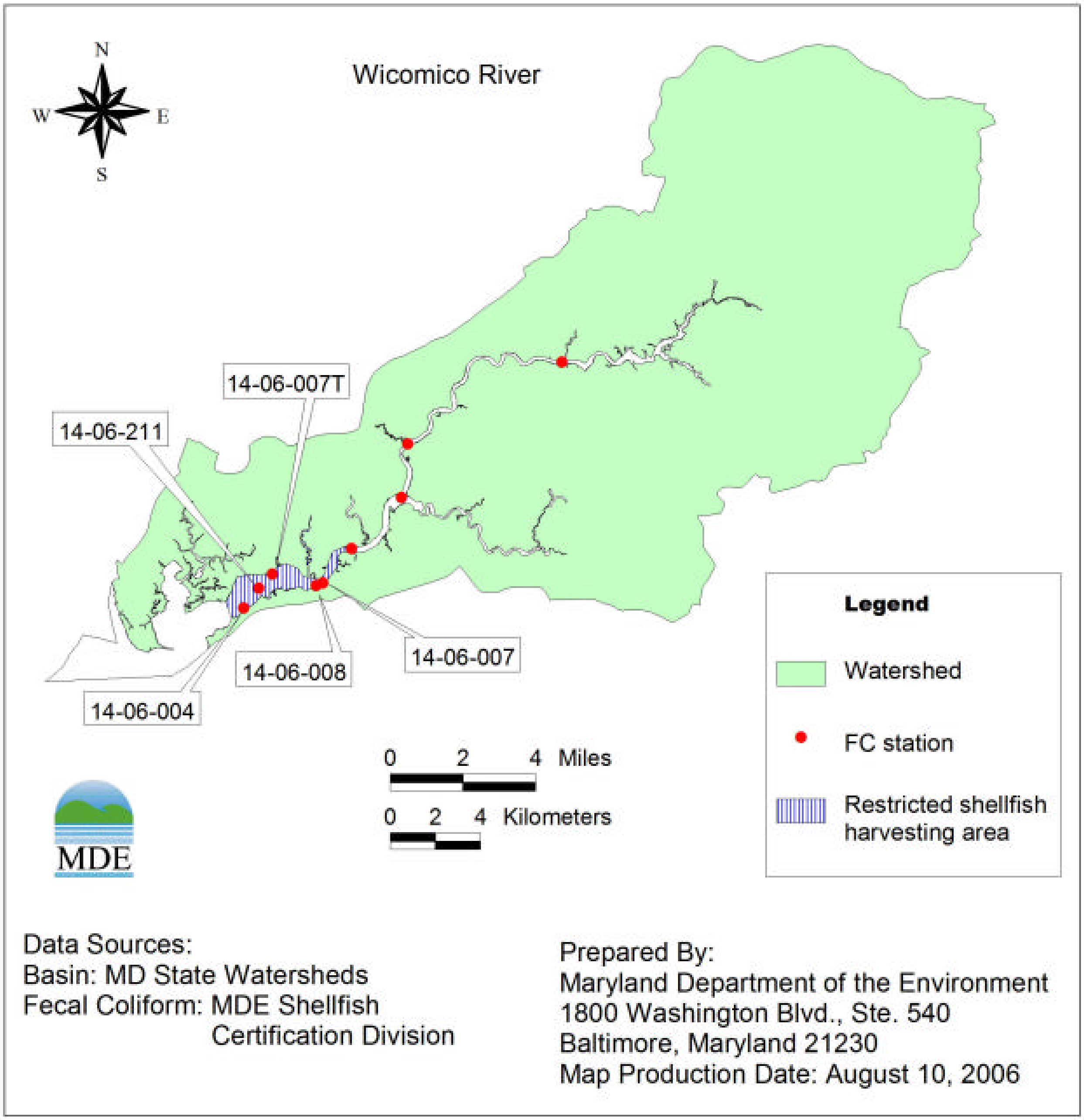

Figure A-5: Locations of Wicomico River Fecal Coliform Monitoring Stations

Table A-3: Lower Wicomico River Fecal Coliform Statistics (Data from 2000-2005)

Area Name	Station	Median		90th Percentile	
		Monitoring Data	Criterion	Monitoring Data	Criterion
		MPN/100ml	MPN/100ml	MPN/100ml	MPN/100ml
Lower Wicomico River	14-06-004	23.00	14	101.77	49
	14-06-007	43.00	14	188.65	49
	14-06-007T*	43.00	14	271.73	49
	14-06-008*	43.00	14	200.34	49
	14-06-211	23.00	14	171.10	49

*station data from November 2002 to July 2005

Table A-4: TMDL Calculation Results for Each Subwatershed

Subwatershed	Median			90th Percentile		
	Allowable Load*	Current Load	Percent Reduction	Allowable Load	Current Load	Percent Reduction
	Counts/day	Counts/day		Counts/day	Counts/day	
1-3,8-10	8.328E+11	8.328E+11	N/A	2.817E+12	2.817E+12	N/A
Other subwatersheds	6.805E+11	1.455E+12	53.23%	2.004E+12	4.912E+12	59.20%
TOTALS	1.513E+12	2.288E+12	33.87%	4.821E+12	7.729E+12	37.62%

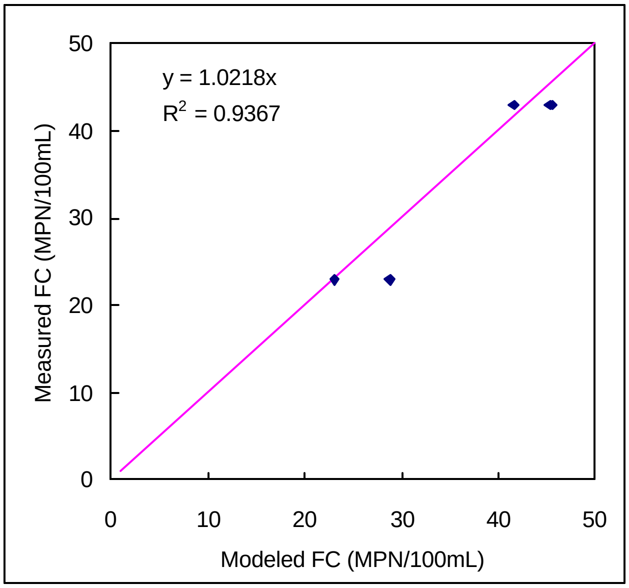

Figure A-6: Measured and Modeled Fecal Coliform for the Median Criterion

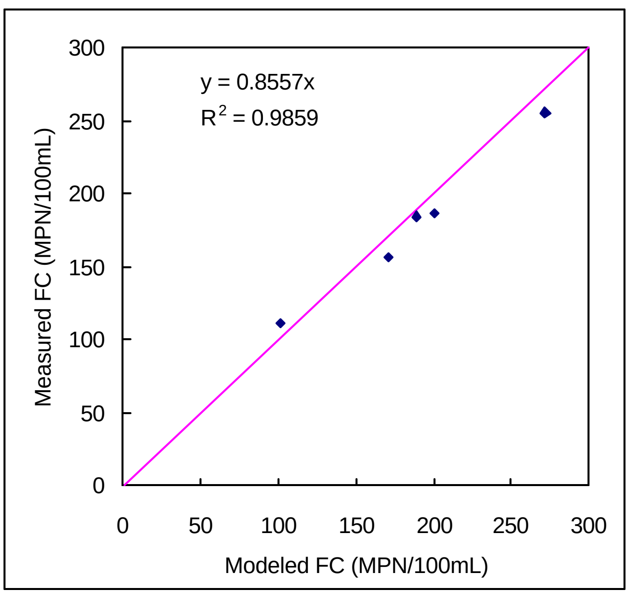

Figure A-7: Measured and Modeled Fecal Coliform for the 90th Percentile Criterion

By comparing the reductions required for the median and 90th percentile scenarios, one can see that the 90th percentile scenario requires the largest reduction. Therefore, the reduction required to meet the 90th percentile at each subwatershed are the overall reductions required for the subwatersheds. The allowable loads and required reductions for the watershed are listed in Table A-5.

Table A-5: Load Allocation and Reduction by Subwatershed

Subwatershed	Load Allocation	Required Reduction
1-3, 8-10	2.817E+12	0.00%
Other subwatershed	2.004E+12	59.20%
TOTALS	**4.821E+12**	**37.62%**

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 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 and discharges to surface waters. Nonpoint source contributions to the bacteria levels from human activities generally arise from failing septic systems and from potential discharge from recreation vessel. 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.

In order to determine the sources of fecal coliform contribution 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.

Bacteria Source Tracking

In order to assess the potential fecal bacteria sources that contribute to the Lower Wicomico River, four routine monitoring stations in the Lower Wicomico River 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. Twelve months of sampling was conducted from November 2002 to October 2003. The Antibiotic Resistance Analysis (ARA) Approach was the chosen BST method used to determine the potential sources of fecal coliform discharged in the Lower Wicomico 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 Wicomico River, these sources included human, cat, dog, chicken, horse, cow, deer, rabbit, fox, and goose. 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 Wicomico River basin is located in Frana and Venso (2006) Appendix B.

Results

Water samples were collected mostly from the 4 stations in the Lower Wicomico 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 1015 enterococci isolates were analyzed by statistical analysis. Table B-1 below shows the BST results by category, the number of isolates and percent isolates classified at the 0.50 (50%) cutoff probability, as well as the percent classified overall. The seasonal distribution of water isolates from samples collected at each sampling station is shown below in Table B-2. According to the ARA, wildlife is the predominant bacteria source followed by Human. Twenty percent (20%) of the water isolates were from unknown (unclassified) probable sources.

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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.

Table B-1: Probable Host Sources of Water Isolates by Category, Number of Isolates, Percent Isolates Classified at Cutoff Probabilities of 50%

Category	No.	% Isolates Classified 50% Prob.
Pet	60	5.9%
Human	204	20.1%
Livestock	96	9.5%
Wildlife	448	44.1%
Unknown*	207	20.4%
Total w/ Complete Data	1015	
Total	1015	
% Classified		79.6%

* Unknown means that the library of known sources failed to classify for isolates from water samples collected

Table B-2: Number of enterococci Isolates from Water Collected and Analyzed by Season

Station	Fall	Winter	Spring	Summer	Total
14-06-007	69	59	70	72	270
14-06-007T	68	57	71	48	244
14-06-008	71	69	67	48	255
14-06-211	70	38	67	71	246

Appendix C. Seasonality Analysis

The Code of Federal Regulations requires that TMDL studies take into account critical conditions for stream flow, loading, and water quality parameters (CFR 2006c). The Environmental Protection Agency (EPA) also requires that these Total Maximum Daily Load (TMDL) studies take into account seasonal variations. The consideration of critical condition and seasonal variation is to account for the hydrologic and source variations. The intent of the requirements is to ensure that the water quality of the water body is protected during the most vulnerable times.

In the Chesapeake Bay region, both fecal coliform sources and delivery vary seasonally due to changes in hydrological conditions and land use practices. The most probable fecal coliform sources are runoff from wildlife, agricultural practices and livestock, and developed areas. Precipitation and temperature fluctuate seasonally, producing varied stream flow and surface runoff that serve as a delivery mechanism for fecal coliform, as well as seasonal changes in vegetation. Vegetation, particularly in pastureland and agricultural buffer zones, is very important for trapping and preventing fecal coliform from entering waters by decreasing surface runoff. Wildlife are active during summer and fall due to ample food supply, resulting in increased fecal coliform production, and the probability of their direct contact with receiving waters is comparatively high during warm seasons. The seasonal variation of fecal coliform concentrations in water not only results from activities of wildlife on forestland and wetland, but it is also related to agricultural activities. Fecal coliform deposition on a field by livestock can be transported into streams and rivers through surface runoff, and thus there tends to be an increase in fecal coliform concentrations during wet seasons. In croplands, fecal coliform discharge is often related to the timing of crop planting and fertilization. Improper application during crop planting may increase the risk of exceeding fecal coliform standards in the receiving water. Such seasonal changes in both the sources and the delivery mechanisms of fecal coliform may lead to obvious seasonal patterns in fecal coliform concentration in the shellfish growing areas.

A 5-year monthly mean fecal coliform concentration and its standard deviation were calculated for the five monitoring stations used in this report. The results are presented in Figure C-1 through Figure C-5. It shows that high concentrations occur between June and November in the Lower Wicomico River mainstem restricted shellfish harvesting area. Although seasonal distributions vary from one station to the next, a large standard deviation that corresponds to the high fecal coliform concentration variability at each station suggests that the violation, in regards to the criteria, may occur in a few months of the year.

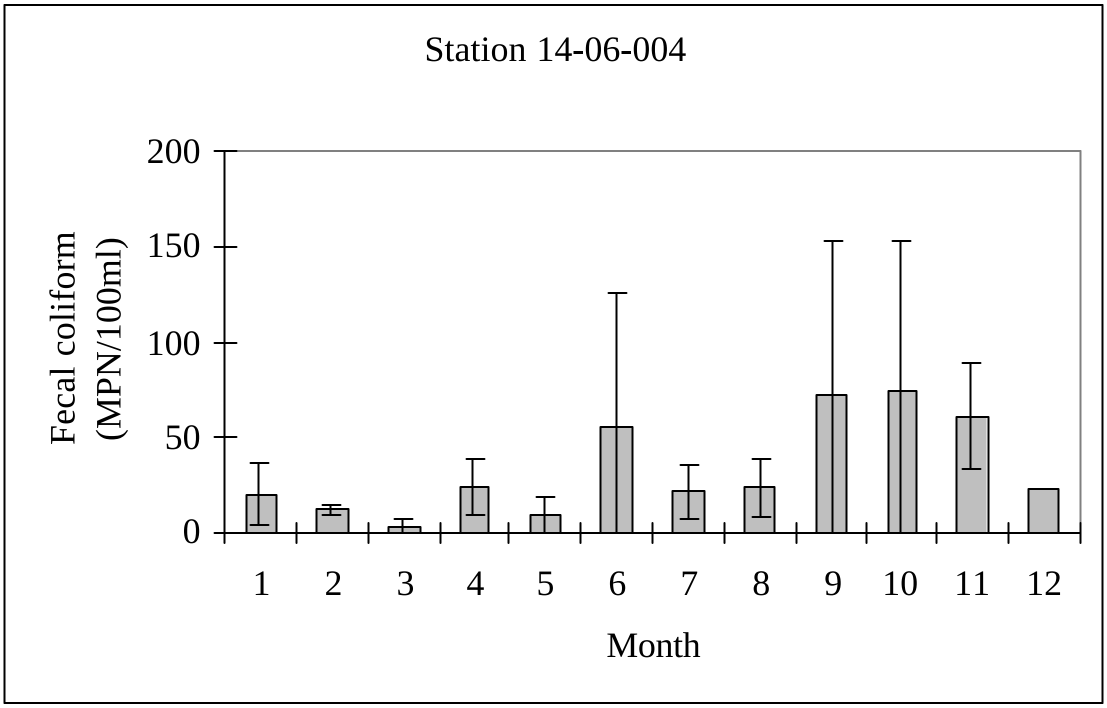

Figure C-1: Seasonality Analysis of Fecal Coliform at Lower Wicomico River Station 14-06-004

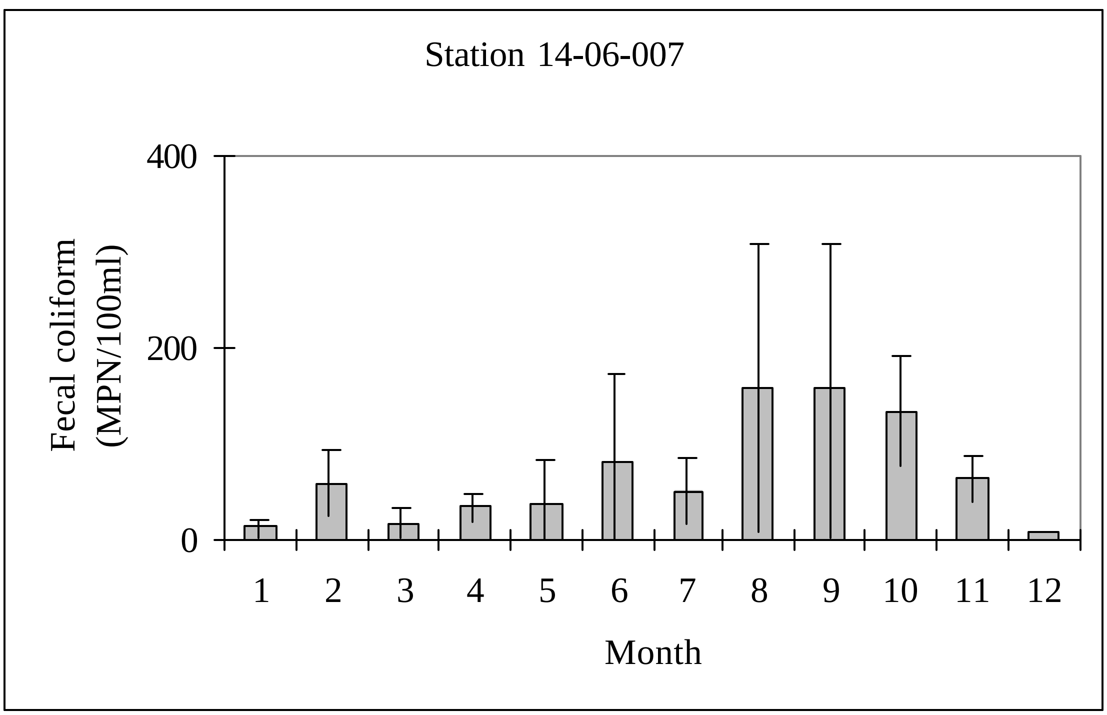

Figure C-2: Seasonality Analysis of Fecal Coliform at Lower Wicomico River Station 14-06-007

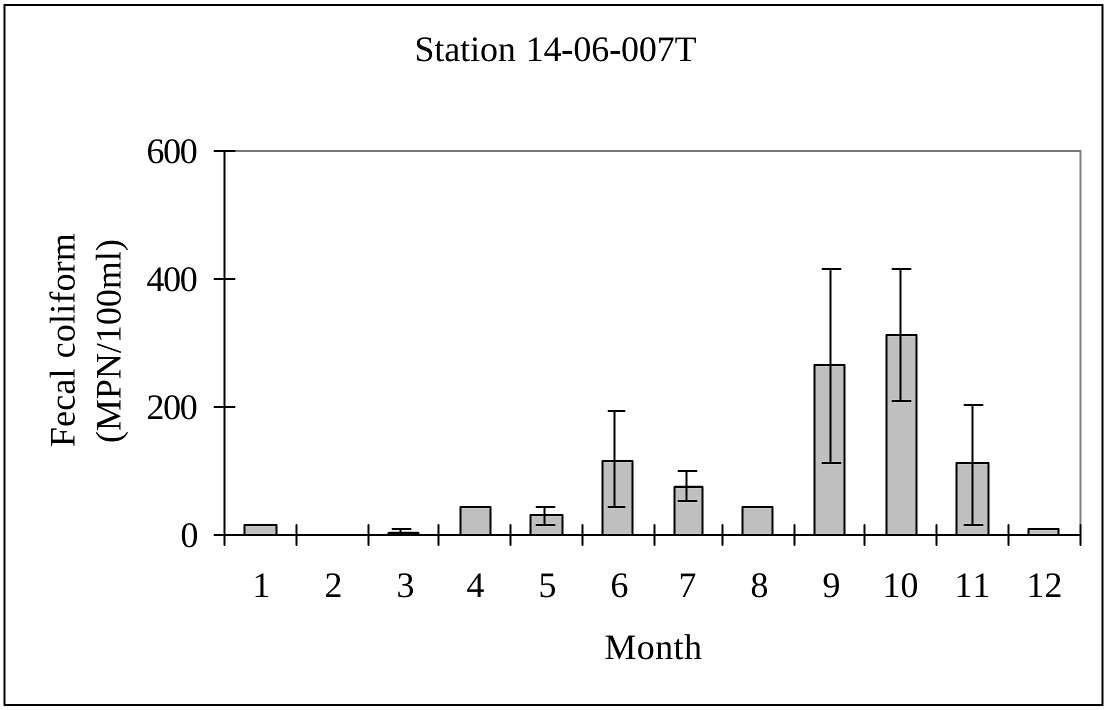

Figure C-3: Seasonality Analysis of Fecal Coliform at Lower Wicomico River Station 14-06-007T

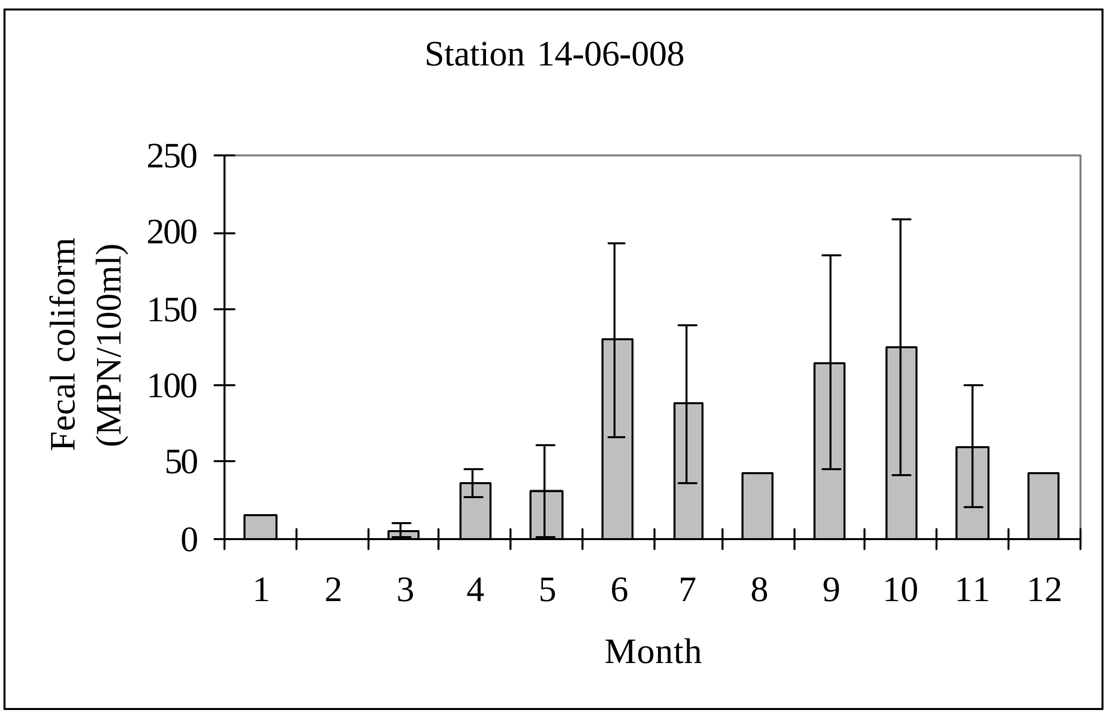

Figure C-4: Seasonality Analysis of Fecal Coliform at Lower Wicomico River Station 14-06-008

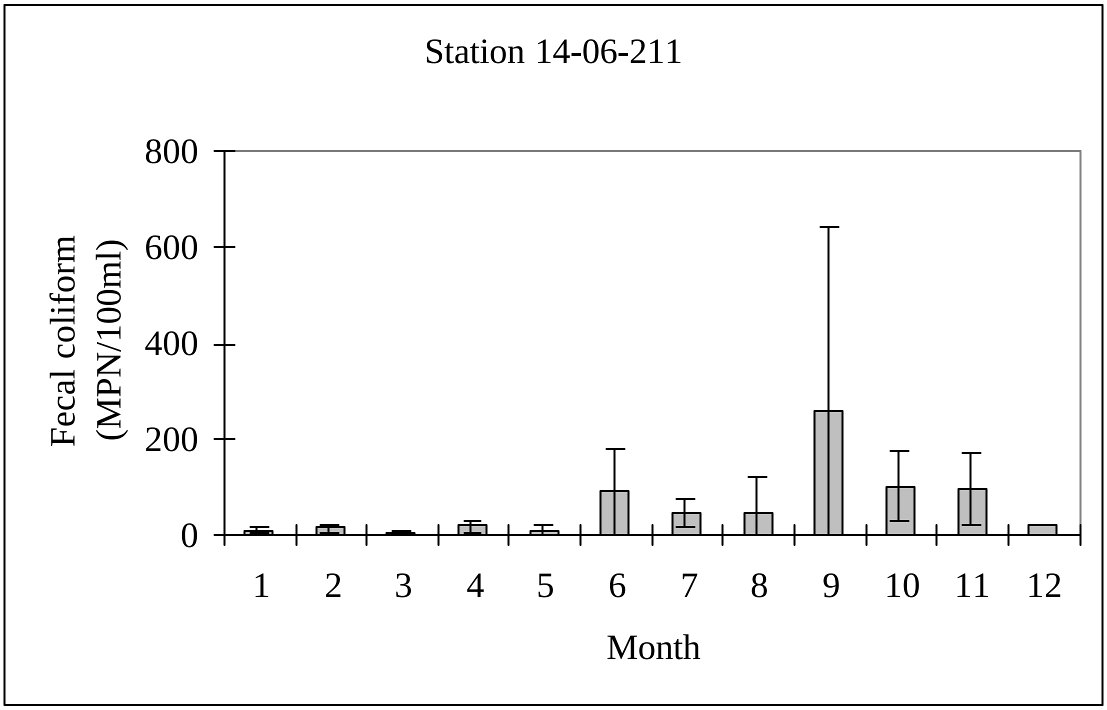

Figure C-5: Seasonality Analysis of Fecal Coliform at Lower Wicomico River Station 14-06-211

Appendix D. Tabulation of Fecal Coliform Data

This appendix provides a tabulation of fecal coliform values for the monitoring stations of the restricted shellfish harvesting area in the Lower Wicomico River mainstem of the Lower Wicomico River Basin in Tables D-1 through D-5. These data are plotted in Figures 2.2.2 through 2.2.6 of the main report.

Table D-1: Observed Fecal Coliform Data at Lower Wicomico River Station 14-06-004

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
7/5/2000	23	1/6/2003	9.1
7/25/2000	3.6	3/10/2003	3.6
8/1/2000	43	3/17/2003	1
9/5/2000	9.1	4/14/2003	23
9/27/2000	240	4/30/2003	43
11/27/2000	93	5/8/2003	15
1/29/2001	43	5/12/2003	23
2/21/2001	9.1	6/2/2003	43
3/12/2001	1	6/16/2003	43
4/16/2001	23	7/1/2003	15
5/14/2001	1	7/16/2003	23
6/4/2001	43	8/4/2003	9.1
6/18/2001	43	9/8/2003	43
7/2/2001	39	9/16/2003	93
7/19/2001	23	9/30/2003	43
8/13/2001	43	10/6/2003	23
8/28/2001	23	10/29/2003	43
10/4/2001	23	11/12/2003	43
1/28/2002	7.3	11/18/2003	75
2/27/2002	15	3/1/2004	1
3/25/2002	3.6	3/17/2004	9.1
4/22/2002	3.6	4/7/2004	9.1
5/13/2002	23	5/13/2004	3.6
6/4/2002	1	5/27/2004	1
6/19/2002	1	6/1/2004	240
7/17/2002	1	10/3/2004	240
8/8/2002	1	10/20/2004	23
8/26/2002	23	11/22/2004	93
9/30/2002	3.6	4/11/2005	43
10/21/2002	93	5/3/2005	3
11/6/2002	39	5/16/2005	3
11/26/2002	23	6/22/2005	23
12/10/2002	23	7/7/2005	43

Table D-2: Observed Fecal Coliform Data at Lower Wicomico River Station 14-06-007

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
7/5/2000	23	1/6/2003	23
7/25/2000	9.1	3/10/2003	23
8/1/2000	43	3/17/2003	43
9/5/2000	93	4/14/2003	43
9/27/2000	93	4/30/2003	43
11/27/2000	43	5/8/2003	9.1
1/29/2001	14	5/12/2003	150
2/21/2001	23	6/2/2003	240
3/12/2001	3.6	6/16/2003	43
4/16/2001	43	7/1/2003	93
5/14/2001	43	7/16/2003	43
6/4/2001	23	8/4/2003	240
6/18/2001	43	9/8/2003	460
7/2/2001	93	9/16/2003	240
7/19/2001	43	9/30/2003	43
8/13/2001	460	10/6/2003	93
8/28/2001	75	10/29/2003	93
10/4/2001	240	11/12/2003	43
1/28/2002	1	11/18/2003	93
2/27/2002	93	3/1/2004	3.6
3/25/2002	3.6	3/17/2004	23
4/22/2002	23	4/7/2004	7.3
5/13/2002	43	5/13/2004	23
6/4/2002	9.1	5/27/2004	15
6/19/2002	9.1	6/1/2004	43
7/17/2002	9.1	10/20/2004	150
8/8/2002	93	11/3/2004	93
8/26/2002	39	11/22/2004	43
9/30/2002	9.1	4/11/2005	43
10/21/2002	93	5/3/2005	9.1
11/6/2002	93	5/16/2005	3.6
11/26/2002	43	6/22/2005	240
12/10/2002	7.3	7/7/2005	93

Table D-3: Observed Fecal Coliform Data at Lower Wicomico River Station 14-06-007T

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
11/6/2002	240	10/6/2003	240
11/26/2002	23	10/29/2003	460
12/10/2002	9.1	11/12/2003	93
1/6/2003	15	11/18/2003	23
3/10/2003	3.6	3/1/2004	1
3/17/2003	9.1	3/17/2004	9.1
4/14/2003	43	4/7/2004	43
4/30/2003	43	5/13/2004	23
5/8/2003	43	5/27/2004	23
5/12/2003	43	6/1/2004	93
6/2/2003	93	10/20/2004	240
6/16/2003	240	11/3/2004	240
7/1/2003	93	11/22/2004	43
7/16/2003	43	4/11/2005	43
8/4/2003	43	5/3/2005	9.1
9/8/2003	240	5/16/2005	43
9/16/2003	460	6/22/2005	43
9/30/2003	93	7/7/2005	93

Table D-4: Observed Fecal Coliform Data at Lower Wicomico River Station 14-06-008

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
11/6/2002	43	10/6/2003	43
11/26/2002	39	10/29/2003	240
12/10/2002	43	11/12/2003	43
1/6/2003	15	11/18/2003	43
3/10/2003	3.6	3/1/2004	1
3/17/2003	9.1	3/17/2004	9.1
4/14/2003	43	5/13/2004	43
4/30/2003	23	5/27/2004	23
5/8/2003	7.3	6/1/2004	240
5/12/2003	93	10/20/2004	93
6/2/2003	93	11/3/2004	150
6/16/2003	93	11/22/2004	43
7/1/2003	23	4/11/2005	43
7/16/2003	93	5/3/2005	23
8/4/2003	43	5/16/2005	1
9/8/2003	210	6/22/2005	93
9/16/2003	93	7/7/2005	150
9/30/2003	43		

Table D-5: Observed Fecal Coliform Data at Lower Wicomico River Station 14-06-211

DATE	Fecal Coliform MPN/100 ml	DATE	Fecal Coliform MPN/100 ml
7/5/2000	43	1/6/2003	15
7/25/2000	23	3/10/2003	1
8/1/2000	3.6	3/17/2003	3.6
9/5/2000	43	4/14/2003	43
9/27/2000	240	4/30/2003	3.6
11/27/2000	150	5/8/2003	23
1/29/2001	1	5/12/2003	23
2/21/2001	3.6	6/2/2003	240
3/12/2001	9.1	6/16/2003	93
4/16/2001	23	7/1/2003	43
5/14/2001	3.6	7/16/2003	93
6/4/2001	43	8/4/2003	3.6
6/18/2001	43	9/8/2003	1100
7/2/2001	93	9/16/2003	93
7/19/2001	43	9/30/2003	75
8/13/2001	210	10/6/2003	43
8/28/2001	43	10/29/2003	93
10/4/2001	240	11/12/2003	93
1/28/2002	15	11/18/2003	93
2/27/2002	23	3/1/2004	1
3/25/2002	3.6	3/17/2004	9.1
4/22/2002	3.6	4/7/2004	23
5/13/2002	23	5/13/2004	9.1
6/4/2002	3	5/27/2004	1
6/19/2002	3.6	6/1/2004	240
7/17/2002	3.6	10/20/2004	43
8/8/2002	9.1	11/3/2004	240
8/26/2002	15	11/22/2004	43
9/30/2002	15	5/3/2005	1
10/21/2002	93	5/16/2005	3.6
11/6/2002	20	6/22/2005	43
11/26/2002	21	7/7/2005	23
12/10/2002	23		

Appendix E. Point Source Permits and Loads

There are no industrial facilities discharging fecal coliform to the Lower Wicomico River. The four municipal sewage treatment facilities that have permits regulating the discharge of fecal coliform to the Wicomico River or its tributaries are: Delmar Waste Water Treatment Plant (WWTP) with National Pollution Discharge Elimination System (NPDES) permit number MD0020532, Salisbury WWTP (NPDES number MD0021571), Fruitland WWTP (NPDES number MD0052990), and Hearrne-Meadows, LLC WWTP (NPDES number MD0063282). This appendix provides a tabulation of fecal coliform permits and loads information for the four municipal point sources listed above which have permits regulating the discharge of fecal coliform to the Lower Wicomico River (Table E-1).

Table E-1: A Summary of Point Source Facility Discharge

Facility Name	NPDES Permit Number	Design Flow (MGD)	Permitted FC Concentration in MPN/100ml	Permitted FC Loads in MPN/Day	
				Median	90th Percentile
Delmar WWTP	MD0020532	0.85	200 (monthly log mean)	6.44E+09	2.09E+10
Salisbury WWTP	MD0021571	10.2	200 (monthly log mean)	7.72E+10	2.51E+11
Fruitland WWTP	MD0052990	0.49	200 (monthly log mean)	3.71E+09	1.21E+10
Hearrne-Meadows, LLC WWTP	MD0063282	0.0046	200 (monthly log mean)	3.48E+07	1.13E+08
Total				8.74E+10	2.84E+11