Total Maximum Daily Loads of Total Nitrogen for Assawoman and Little Mosquito Creeks in Accomack County, Virginia

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List of Abbreviations

ASAE	American Society of Agricultural Engineers
BOD	Biochemical Oxygen Demand
BMP	Best Management Practice
CFR	Code of Federal Regulations
Chl-a	Chlorophyll *a*
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DIN	Dissolved Inorganic Nitrogen
DO	Dissolved Oxygen
DOC	Dissolved Organic Carbon
DSS	Division of Shellfish Sanitation
EFDC	Environmental Fluid Dynamics Computer Code
EPA	Environmental Protection Agency
FA	Future Allocation
GIS	Geographic Information System
LA	Load Allocation
LSPC	Loading Simulation Program C^{++}
MOS	Margin of Safety
MOU	Memorandum of Understanding
MS4s	Municipal Separate Storm Sewer Systems
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OC	Organic Carbon
ON	Organic Nitrogen
SOD	Sediment Oxygen Demand
SWCB	State Water Control Board
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USDA	United States Department of Agriculture
USGS	United States Geological Survey
VA-DCR	Virginia Department of Conservation and Recreation
VA-DEQ	Virginia Department of Environmental Quality
VADGIF	Virginia Department of Game and Inland Fisheries
VDH	Virginia Department of Health
VPDES	Virginia Pollutant Discharge Elimination System
WLA	Wasteload Allocation
WQAIR	Water Quality Assessment Integrated Report
WQC	Water Quality Criteria

WQLS	Water Quality Limited Segments
WQMIRA	Water Quality Monitoring, Information, and Restoration Act
WQMP	Water Quality Management Plan
WQS	Water Quality Standard

EXECUTIVE SUMMARY

Introduction

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop total maximum daily loads (TMDLs) for waterbodies that are exceeding water quality standards (WQS). TMDLs represent the total pollutant loading that a waterbody can receive without violating WQS. The TMDL process establishes the allowable loadings of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish controls based on water quality conditions to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

Assawoman Creek and Little Mosquito Creek are located in Accomack County, Virginia, along the Eastern Shore of the Delmarva Peninsula. Assawoman Creek drains east to Womans Bay, which drains to the Atlantic Ocean. Little Mosquito Creek drains east to the Horntown Bay, which then drains to the Atlantic Ocean (see Figure E1). Assawoman Creek-Upper (VAT-D02E_ ASW01A00) and Assawoman Creek-Lower (VAT-D02E_ ASW02A00, VAT-D02E_ ASW02B12) were listed on the 2006 and 2010 Virginia 305(b)/303(d) Water Quality Assessment Integrated Report (WQAIR, VA-DEQ, 2006; 2010) as having failed to support their aquatic life designated use due to violations of Virginia's Dissolved Oxygen (DO) criteria (Figure E2). Little Mosquito Creek-Upper (VAT-D01E_LTM01A06) and Little Mosquito Creek-Lower (VAT-D01E_LTM02A04 were listed on the 2006 and 2010 Virginia 305(b)/303(d) WQAIR (VA-DEQ, 2006; 2010) as having failed to support their aquatic life designated use due to violations of Virginia's DO criteria (Figure E3). TMDLs have been developed to meet DO standards for both creeks. This document, upon approval of EPA, establishes TMDLs of DO for the five-listed segments in the Assawoman Creek and Little Mosquito Creek.

Assessment Unit	Water Name	Location Description	Cause Category	Cause Name	Size (miles^2)
1 VAT-D01E_ LTM01A06	Little Mosquito Creek - Upper	From headwaters downstream to confluence of Snead Branch. Area of Division of Shellfish Sanitation (DSS) Prohibited (ADMINISTRATIVE-due to VPDES outfall @ VA0024457) condemnation # 100-032 B (effective 2010-11-08).	5A	Dissolved Oxygen	0.07
2 VAT-D01E_ LTM02A04	Little Mosquito Creek - Lower	South shore trib. to mainstem Back R. Adjacent to Fox Hill area. DSS shellfish condemnation # 054-215 A (effective 20101115). CBP Segment MOBPH.	5A	Dissolved Oxygen	0.14

3 VAT-D02E_ ASW01A00	Assawoman Creek - Upper	From headwaters downstream to confluence of Pettit Branch (RM 3.4). Portion of DSS shellfish direct harvesting condemnation # 099-135A (effective 2005-12-12).	5A	Dissolved Oxygen	0.07
4 VAT-D02E_ ASW02A00	Assawoman Creek - Lower	From confluence of Pettit Branch downstream to end of Shellfish Condemnation. Portion of DSS shellfish direct harvesting condemnation # 099-135 (effective date 2009-10-22).	5A	Dissolved Oxygen	0.05
5 VAT-D02E_ ASW02B12	Assawoman Creek - Lower	From end of condemnation to mouth. Portion of DSS shellfish direct harvesting condemnation # OPEN 099-135 (effective date 2009-10-22).	5A	Dissolved Oxygen	0.01

Sources of Nutrients

Based on data analysis and field surveys, the low DO that occurred in the two creeks was caused by excessive nutrient inputs, which stimulated the excessive growth of algae. Algae death and decomposition lead to an excessive consumption of DO. Therefore, this document proposes to establish TMDLs for the nutrients. Besides the impact of surface runoff of excessive nutrients, the groundwater contributes high inputs of nutrients to the system. The marsh and wetland environment often causes low DO during rainy days that add additional pressure to these systems. The watershed approach was applied to conduct nutrient source assessment. A large portion of the source assessment estimation comes from stakeholders' inputs. There are two point sources, Accomack County North Landfill Leachate Treatment Facility (VA0091529) and Accomack County Northern Landfill (VAR051367), in the Assawoman Creek watershed. There is one point source, U.S. NASA-Wallops Flight Facility (VA0024457), in the Little Mosquito watershed. The excessive nutrients are mainly due to nonpoint sources through both surface and subsurface inflows, including fertilizer, poultry manure application, livestock, wildlife, and failing septic systems and uncontrolled discharges. Atmosphere deposition and high nutrients inputs from the groundwater are additional sources for these creeks.

Modeling Approach

A system of numerical models was applied to simulate the loadings of organic matter and nutrients from the Assawoman Creek and Little Mosquito Creek watersheds, and the resulting response of in-stream water quality variables. The watershed model, Loading Simulation Program in C^{++} (LSPC), developed by the USEPA, was selected to simulate the watershed hydrology and nutrient loads to both creeks. The Environmental Fluid Dynamics Computer Code (EFDC) was used to simulate the eutrophication processes in the receiving water. The water column processes were coupled to the sediment diagenesis

model, which simulates the mineralization of particulate organic matters deposited from the overlying water column and the resulting fluxes of inorganic substances, and the sediment oxygen demand (SOD) back to the water column.

Endpoints

The numerical criteria for DO for Assawoman-Upper and -Lower and Little Mosquito Creek-Upper and -Lower are a minimum of 4.0 mg/L and a daily average of 5.0 mg/L (9VAC25-260-50). The endpoints were established based on the aquatic life designated use.

Load Allocation Scenarios

Calibrated model simulation results were used to establish the existing loads in the system. The loads that are necessary to meet WQS were established for the TMDLs. The difference between the TMDL and the existing loading (annual base loading) represents the necessary level of reduction. The maximum reductions of total nitrogen (TN) discharged from the watershed to meet the DO WQS are approximately 50% and 40%, respectively, for Assawoman Creek and Little Mosquito Creek. TMDLs for nitrogen are summarized below:

Daily load of TN (lbs/day) Summary:

Impairment	WLA****	LA	MOS	TMDL
Assawoman	8.5	287.4	15.6	311.4
VA0091529	*1.3**			
VAR051367	*4.1***			
Future load (1%)	*3.1*			
Little Mosquito	12.2	433.8	23.5	469.4
VA0024457	*7.5****			
Future load (1%)	*4.7*			

*The WLA for VA0091529 for TKN is 0.5 lbs/day) and NH_3 (0.8 lbs/day)
**The WLA for VAR0051367 is for NH_3
***The WLA for VA0024457 is for TKN (7.5 lbs/day)
****The discharge for each of these permits, with permitted parameters and limits listed in Table 3.3, are to be consistent with the assumptions and requirements of this TMDL.

Annual load of TN (lbs/year) Summary:

Impairment	WLA****	LA	MOS	TMDL
Assawoman	2,487.0	47,205.8	2,615.4	52,308.2
VA0091529	*474.5**			
VAR051367	*1,489.4***			
Future load (1%)	*523.1*			
Little Mosquito	3538.8	72584.3	4006.5	80129.6
VA0024457	2737.5***			
Future load (1%)	*801.3*			

*The WLA for VA0091529 is for TKN (182.5 lbs/year) and NH_3 (292.0 lbs/year)
**The WLA for VAR051367 is for NH_3
***The WLA for VA0024457 is for TKN (2737.6 lbs/year)
****The discharge for each of these permits, with permitted parameters and limits listed in Table 3.3, are to be consistent with the assumptions and requirements of this TMDL

Where:

TMDL =Total Maximum Daily Load
LA = Load Allocation (Nonpoint source)
WLA =Wasteload Allocation (Point source)
FA =Future Allocation (1% of the TMDL)
MOS =Margin of Safety

Point Source and Future Growth

A review of measured discharges from point sources indicates that total nitrogen loading from point sources is less than 2 % of the total nitrogen loading from watershed. As a conservative measure, loading from point sources was calculated using permitted design flow and nitrogen concentrations. These results indicated that point source loads account for less than 3.8% of the total allowable loading from each of the two watersheds. Therefore, no reductions are applied to the three point sources (VA0024457, VA0091529, and VAR051367). A future growth component was added to the WLA to account for any additional permits that may be given in the future. A portion of 1% of the total allowable load is assigned to future growth as WLA.

Margin of Safety

EPA regulations at 40 CFR 130.7 (c)(1) require TMDL reports to take into account critical conditions for stream flow, loading, and water quality parameters. This was done in this study by using long-term water quality data that cover different flow regimes and temperatures, and a long-term simulation to estimate the current nutrient loads and load

reduction targets. To allocate loads while protecting the aquatic environment, a margin of safety (MOS) needs to be considered. For Assawoman Creek and Little Mosquito Creek, an explicit MOS of 5% was included in the TMDLs.

Recommendations for TMDL Implementation

The goal of this TMDL is to develop an allocation plan that achieves WQS during the implementation phase. Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (WQMIRA) states, in Section 62.1-44.19.7, that the "Board shall develop and implement a plan to achieve fully supporting status for impaired waters."

To facilitate the phased IP approach to meet the DO WQS, the required reduction of TN discharged from the watershed is 50% for Assawoman and 40% for Little Mosquito. Examples of the reduction scenarios for each source are listed below.

Allocation I and TN Reduction for Each Landuse for Assawoman Creek

Land Use Name	**Current Condition (lbs/Year)**	**Percent**	**Allocation (lbs/Year)**	**Percent Reduction**
Barren	6.9	0.0%	6.9	0.0%
Cropland	33,957.1	32.5%	5,093.6	85.0%
Forest	1,958.4	1.9%	1,958.4	0.0%
Pasture	2,548.6	2.4%	382.3	85.0%
Urban Pervious	527.8	0.5%	79.2	85.0%
Wetlands	2,702.2	2.6%	2,702.2	0.0%
Urban Impervious	404.3	0.4%	60.7	85.0%
Sum	42,105.3	40.2%	10,283.1	75.6%
Groundwater	60,547.3	57.9%	40,061.2	33.8%
Point source	1963.9461	1.9%	1963.9	0.0%
Total	104,616.5	100.0%	52,308.2	50.0%

Allocation II and TN Reduction for Each Landuse for Assawoman Creek

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	6.9	0.0%	6.9	0.0%
Cropland	33,957.1	32.5%	16,978.6	50.0%
Forest	1,958.4	1.9%	1,958.4	0.0%
Pasture	2,548.6	2.4%	1,274.3	50.0%
Urban Pervious	527.8	0.5%	263.9	50.0%
Wetlands	2,702.2	2.6%	2,702.2	0.0%
Urban Impervious	404.3	0.4%	202.2	50.0%

Sum of surface runoff	42,105.3	40.2%	23,386.4	44.5%
Groundwater	60,547.3	57.9%	26,957.9	55.5%
Point Source	1963.9461	1.9%	1963.9	0.0%
Total	104,616.5	100.0%	52,308.2	50.0%

Allocation I and TN Reduction for Each Landuse for Little Mosquito Creek

Land Use Name	Current Condition (lbs/Year)	Percent	Allocation (lbs/Year)	Percent Reduction
Barren	2.8	0.0%	2.8	0.0%
Cropland	48,278.1	36.2%	7,241.7	85.0%
Forest	3,928.3	2.9%	3,928.3	0.0%
Pasture	1,909.4	1.4%	286.4	85.0%
Urban Pervious	1,680.3	1.3%	252.0	85.0%
Wetlands	6,756.9	5.1%	6,756.9	0.0%
Urban Impervious	1,481.3	1.1%	222.2	85.0%
Sum	64,037.2	48.0%	18,690.4	70.8%
Groundwater	66,774.7	50.0%	58,701.7	12.1%
Point Source	2,737.5	2.0%	2,737.5	0.0%
Total	133,549.3	100.0%	80,129.6	40.0%

Allocation II and TN Reduction for Each Landuse for Little Mosquito Creek

Land Use Name	Current Condition (lbs/Year)	Percent	Allocation (lbs/Year)	Percent Reduction
Barren	2.8	0.0%	2.8	0.0%
Cropland	48,278.1	36.2%	24,139.1	50.0%
Forest	3,928.3	2.9%	3,928.3	0.0%
Pasture	1,909.4	1.4%	954.7	50.0%
Urban Pervious	1,680.3	1.3%	840.2	50.0%
Wetlands	6,756.9	5.1%	6,756.9	0.0%
Urban Impervious	1,481.3	1.1%	740.7	50.0%
Sum	64,037.2	48.0%	37,362.6	41.7%
Groundwater	66,774.7	50.0%	40,029.5	40.1%
Point Source	2,737.5	2.0%	2,737.5	0.0%
Total	133,549.3	100.0%	80,129.6	40.0%

The TMDLs developed for the Assawoman Creek and Little Mosquito Creek watersheds provide allocation scenarios that will be a starting point for developing implementation strategies. The human impact due to failing septic systems should be eliminated due to health implication. Currently, nitrogen loading from surface runoff amounts to less than 10% of the nitrogen that is applied to the land. The runoff can be reduced using newly developed technology such as the installation of best management practices. Because a large portion of nutrients is discharged to both creeks through groundwater, the reduction of nitrogen from surface application will take a long period to affect the groundwater discharge. The allocation scenarios presented provide two options to stakeholders; both of which allow for attainment of water quality standards. Scenario I for both creeks calls for a reduction of 85% from surface runoff from cropland, pasture, and impervious urban areas which requires a smaller reduction of TN from groundwater. Scenario II for both creeks provides an option wherein there are greater reductions of TN required for groundwater. This approach requires reduction of nitrogen loading input to the watershed and the improvement of practices of nutrient application. By doing this, the nutrients leaching to the groundwater can be reduced gradually and the WQS will be attained in the future. Additional monitoring aimed at targeting the necessary reductions is critical to implementation development. Once established, continued monitoring will aid in tracking success toward meeting water quality milestones.

Public participation is critical to the implementation process. Reductions in non-point source loading are a crucial factor in addressing the problem. These sources cannot be addressed without public understanding of, and support for, the implementation process. Stakeholder input will be critical from the onset of the implementation process in order to develop an implementation plan that will be truly effective.

Reasonable Assurance

The reduction required for the attainment of WQs is based on the model simulations, which takes into consideration the seasonal and interannual variation of hydrological processes. Because of the influence of the groundwater in this region, the load reduction is challenged. Two recommendations are provided to design the nutrient reduction plan. The runoff can be reduced using a newly developed technology such as the installation of best management practices. Because a large portion of nutrients is discharged to both creeks through groundwater, the reduction of nitrogen from surface application will take a long period to affect the groundwater discharge. There is a reasonable assurance that the load reductions will be met when the implementation strategies are employed. Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program, and use these data to evaluate reductions in pollutants, the effectiveness of the TMDL in attaining and maintaining WQSs, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

Public Participation

Public participation was elicited at every stage of the TMDL development in order to receive inputs from stakeholders and to apprise the stakeholders of the progress made. Two public meetings were organized for this purpose. A kick-off Work Group meeting was held on June 23, 2015 at the Accomack-Northampton Planning District Commission (ANPDC), to inform the stakeholders of the TMDL development process and to obtain feedback. A second Work Group meeting was held August 26, 2015 to update source estimates in the watersheds. Results of the hydrologic calibration, nutrients source estimates, water quality model, model calibration, and TMDL development were discussed at the second public meeting, which was held on October 15, 2015 at Chincoteague BFS on Wallops Island, VA. Updated nutrient loadings and TMDL results were presented and discussed at the final public meeting held on March 10, 2016 at the ANPDC.

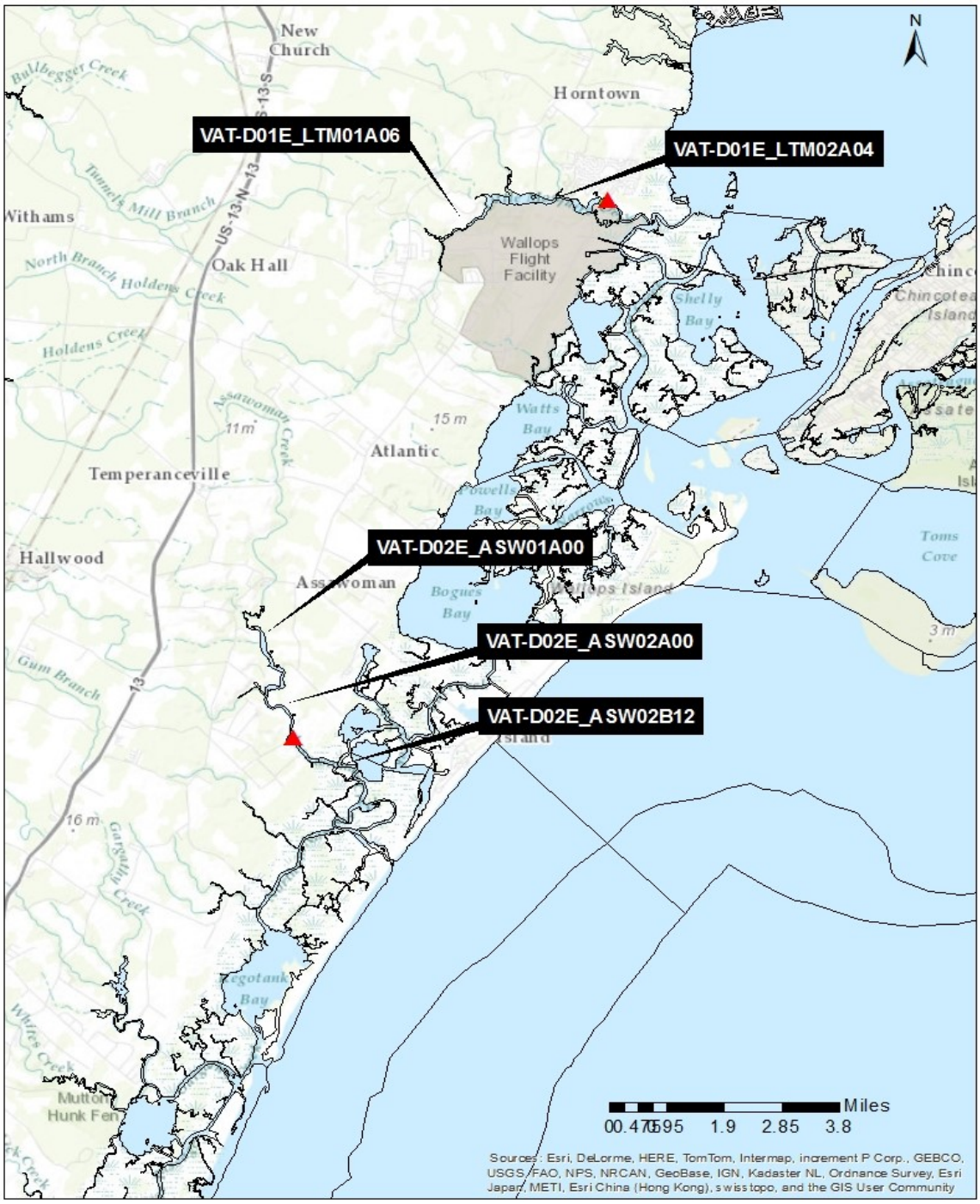


Figure E1: Location Map of Impacted Segments of Assawoman and Little Mosquito Creeks along Eastern Shore, VA

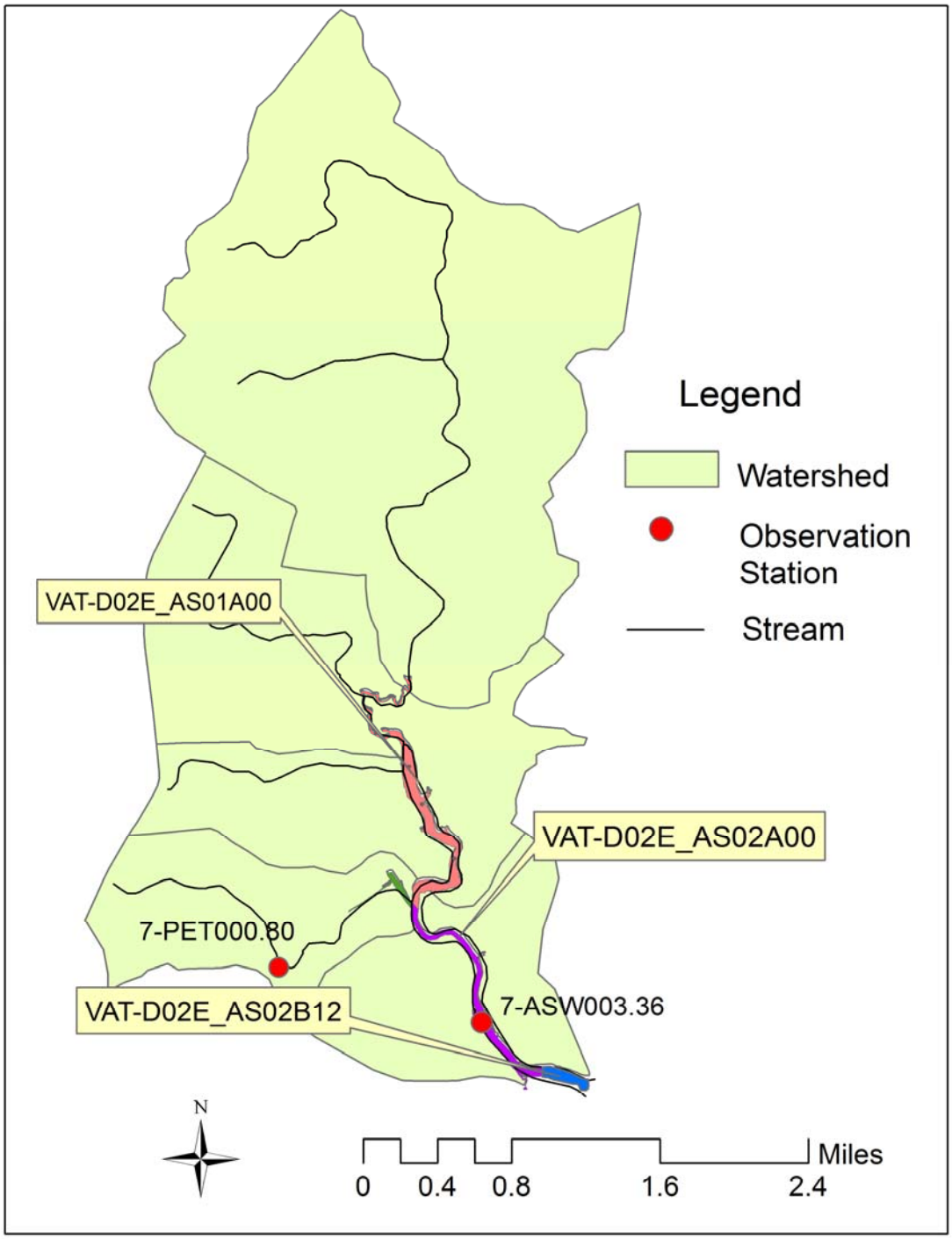


Figure E2: Delineation of the Impaired Waterbodies of the Assawoman Creek Watershed

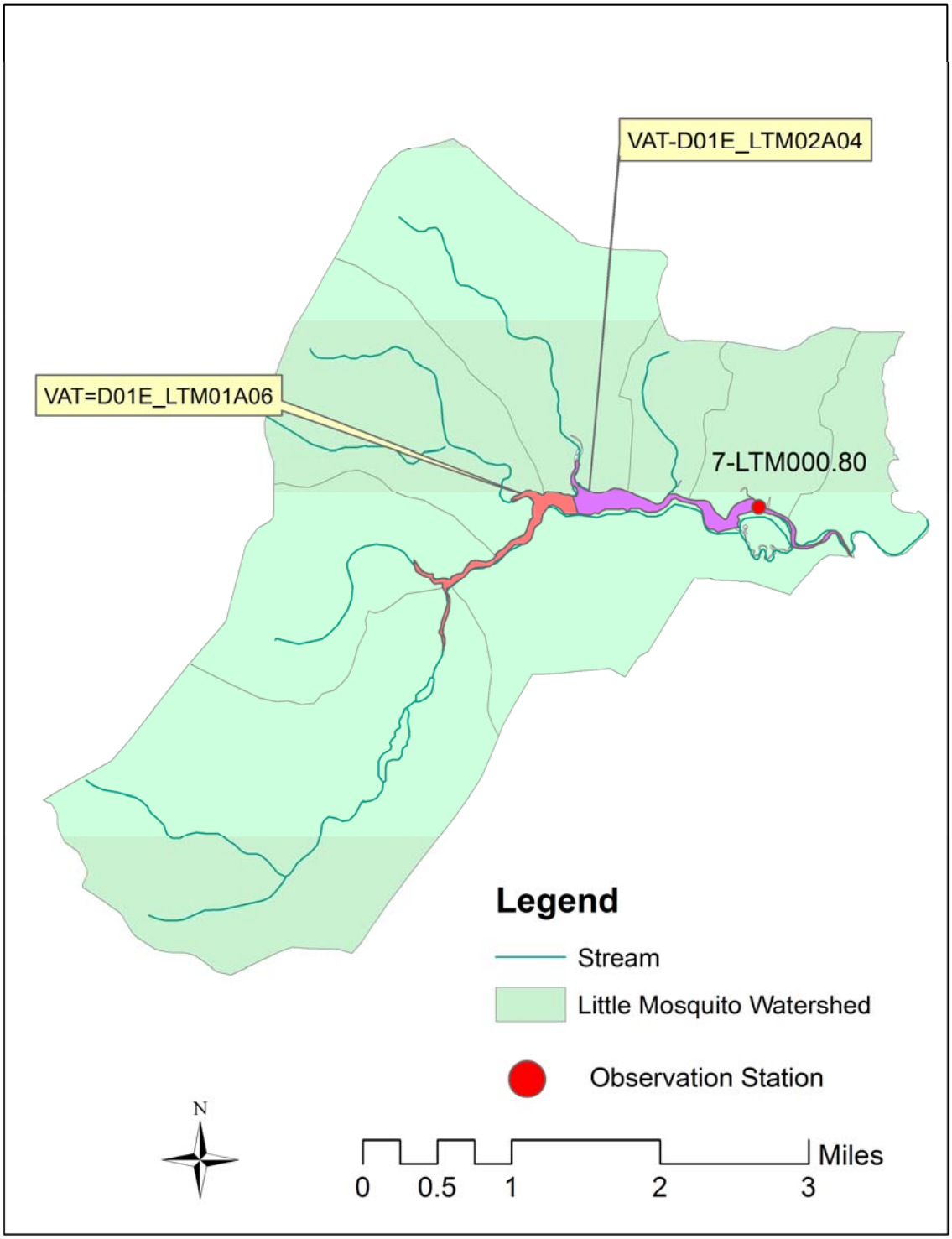


Figure E3: Delineation of the Impaired Waterbodies of the Little Mosquito Creek Watershed

1.0 INTRODUCTION

1.1 Background

Section 303(d) of the Clean Water Act (CWA) and the United States Environmental Protection Agency's (USEPA's) Water Quality Planning and Management Regulations (40 CFR Part 130) requires states to develop Total Maximum Daily Loads (TMDLs) for waterbodies that are exceeding Water Quality Standards (WQS). TMDLs represent the total pollutant loading that a waterbody can receive without violating WQS. The TMDL process establishes the allowable loadings of pollutants for a waterbody that the waterbody can receive without violating WQS. By following the TMDL process, states can establish controls based on water quality conditions to reduce pollution from both point and nonpoint sources to restore and maintain the quality of their water resources.

Assawoman Creek and Little Mosquito Creek are located in Accomack County, Virginia, along the Eastern Shore of the Delmarva Peninsula. The Assawoman Creek drains east to Womans Bay, which drains to the Atlantic Ocean. Little Mosquito Creek drains east to Horntown Bay, which also drains to the Atlantic Ocean. Assawoman Creek-Upper (VAT-D02E_ ASW01A00) and Assawoman Creek-Lower (VAT-D02E_ ASW02A00, VAT-D02E_ ASW02B12) were listed on the 2006 and 2010 Virginia 305(b)/303(d) Water Quality Assessment Integrated Report (WQAIR, VA-DEQ, 2006; 2010) as having failed to support their aquatic life designated use due to violations of Virginia's Dissolved Oxygen (DO) criteria. Little Mosquito Creek-Upper (VAT-D01E_LTM01A06) and Little Mosquito Creek-Lower (VAT-D01E_LTM02A04 were listed on the 2006 and 2010 Virginia 305(b)/303(d) WQAIR (VA-DEQ, 2006; 2010) as having failed to support their aquatic life designated use due to violations of Virginia's DO criteria. Detailed listing information for the creeks is listed in Table 1.1. TMDLs have been developed to meet DO standards. This document, upon approval of EPA, establishes TMDLs of DO for five-listed segments in the Assawoman Creek and Little Mosquito Creek.

Table 1.1: Impaired Segments in Assawoman Creek and Little Mosquito Creek

Assessment Unit	Water Name	Location Description	Cause Category	Cause Name	Size (miles^2)
1 VAT-D01E_ LTM01A06	Little Mosquito Creek - Upper	From headwaters downstream to confluence of Snead Branch. Area of DSS Prohibited (ADMINISTRATIVE-due to VPDES outfall @ VA0024457) condemnation # 100-032 B (effective 2010-11-08).	5A	Dissolved Oxygen	0.07
2 VAT-D01E_ LTM02A04	Little Mosquito Creek - Lower	South shore trib. to mainstem Back R. Adjacent to Fox Hill area. DSS shellfish condemnation # 054-215 A (effective 2010-11-15). CBP Segment MOBPH.	5A	Dissolved Oxygen	0.14

3 VAT-D02E_ ASW01A00	Assawoman Creek - Upper	From headwaters downstream to confluence of Pettit Branch (RM 3.4). Portion of DSS shellfish direct harvesting condemnation # 099-135A (effective 2005-12-12).	5A	Dissolved Oxygen	0.07
4 VAT-D02E_ ASW02A00	Assawoman Creek - Lower	From confluence of Pettit Branch downstream to end of Shellfish Condemnation. Portion of DSS shellfish direct harvesting condemnation # 099-135 (effective date 2009-10-22).	5A	Dissolved Oxygen	0.05
5 VAT-D02E_ ASW02B12	Assawoman Creek - Lower	From end of condemnation to mouth. Portion of DSS shellfish direct harvesting condemnation # OPEN 099-135 (effective date 2009-10-22).	5A	Dissolved Oxygen	0.01

1.2 Listing of Waterbodies under the CWA

WQS are regulations based on federal or state law that set numeric or narrative limits on pollutants. Water quality monitoring is performed to measure pollutants and determine if the measured levels are within the bounds of the limits set for the uses designated for the waterbody. Waterbodies with pollutant levels that exceed the designated standards are considered impaired for the corresponding designated use (e.g. swimming, drinking, shellfish harvesting, etc.). Under the provisions of §303 (d) of the CWA, impaired waterways are placed on the list reported to the EPA. The impaired water list is included in the biennial 305(b)/ 303(d) WQAIR (VA-DEQ, 2010). Those waters placed on the list require the development of a TMDL and corresponding implementation plan intended to eliminate the impairment and bring the water into compliance with the designated standards.

1.3 Watershed Location and Description

Assawoman Creek and Little Mosquito Creek are located in Accomack County, along the Eastern Shore of the Delmarva Peninsula (Figure 1.1). The Assawoman Creek watershed is approximately 6,775 acres. It is mainly made up of forest, agricultural land, pasture, and wetland. Agricultural land is approximately 53% of the watershed. The forest and wetland is about 39% of the watershed. The Little Mosquito Creek watershed is similar to the Assawoman Creek watershed and is approximately 9,577 acres. The agricultural land, and forest and wetlands are approximately 38% and 47% of the total landuse, respectively. Assawoman Creek can be delineated to two portions, which are Assawoman Creek-Upper and Assawoman Creek-Lower. Little Mosquito Creek can be delineated to Little Mosquito Creek-Upper and Little Mosquito Creek-Lower. Assawoman Creek drains east to the Womans Bay, which drains to the Atlantic Ocean. Little Mosquito Creek drains east to the Horntown Bay, which also drains to the Atlantic Ocean (Figure 1.1).

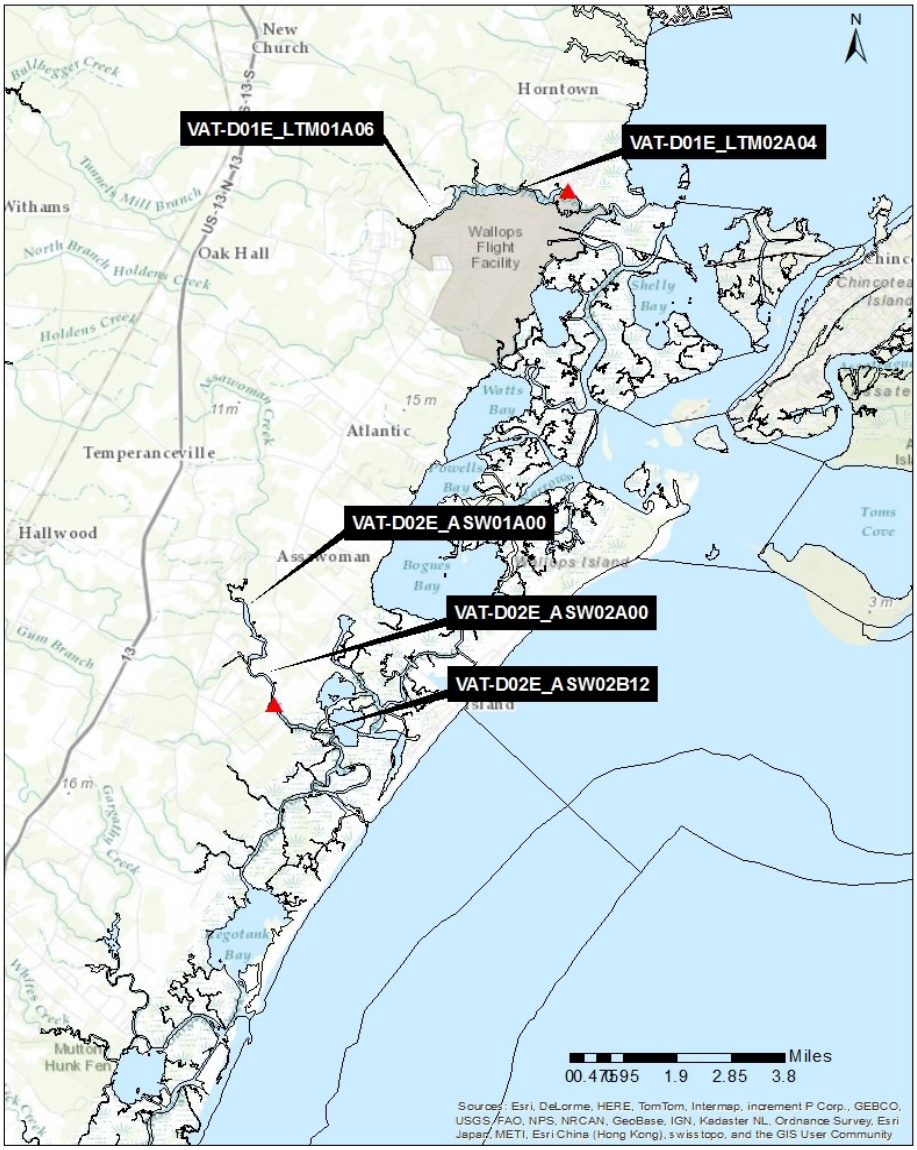


Figure 1.1: Location Map of Impacted Segments of Assawoman and Little Mosquito Creeks along Eastern Shore, VA

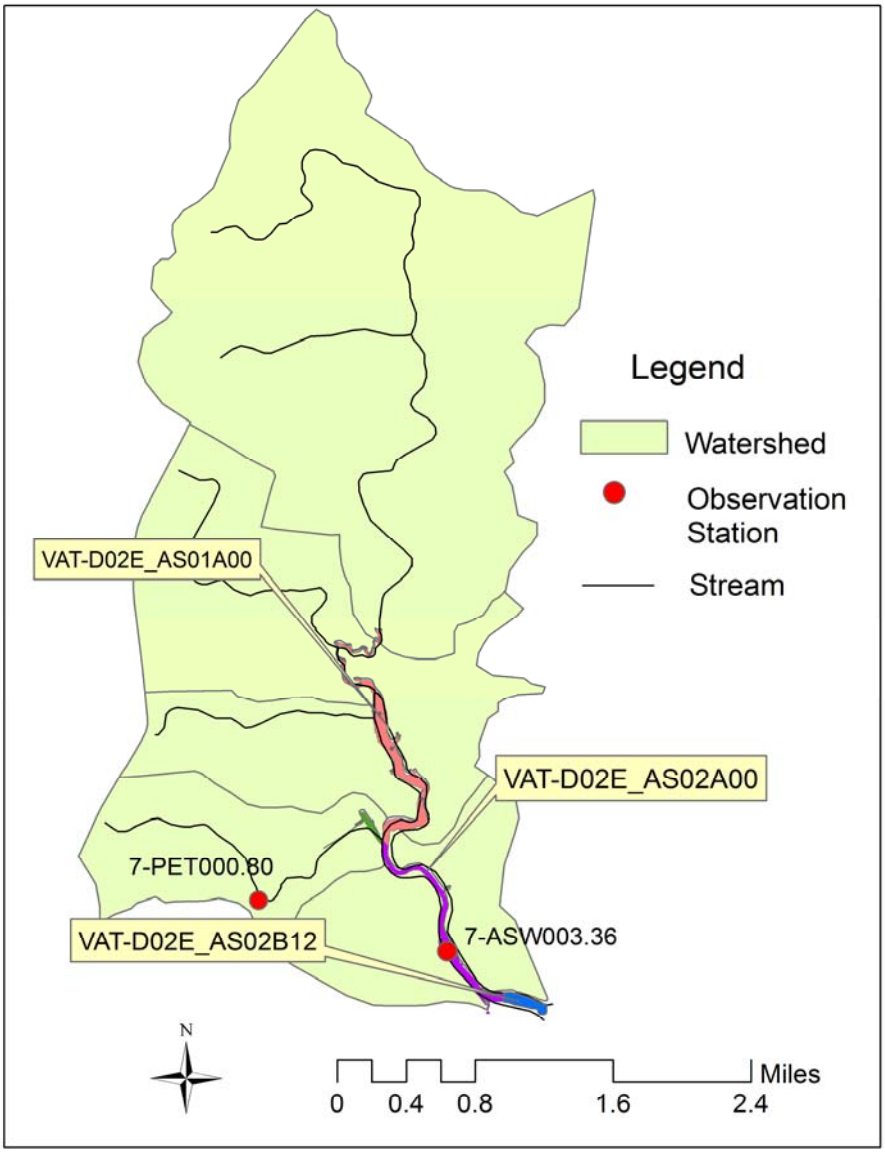


Figure 1.2: Delineation of the Impaired Waterbodies of the Assawoman Creek Watershed

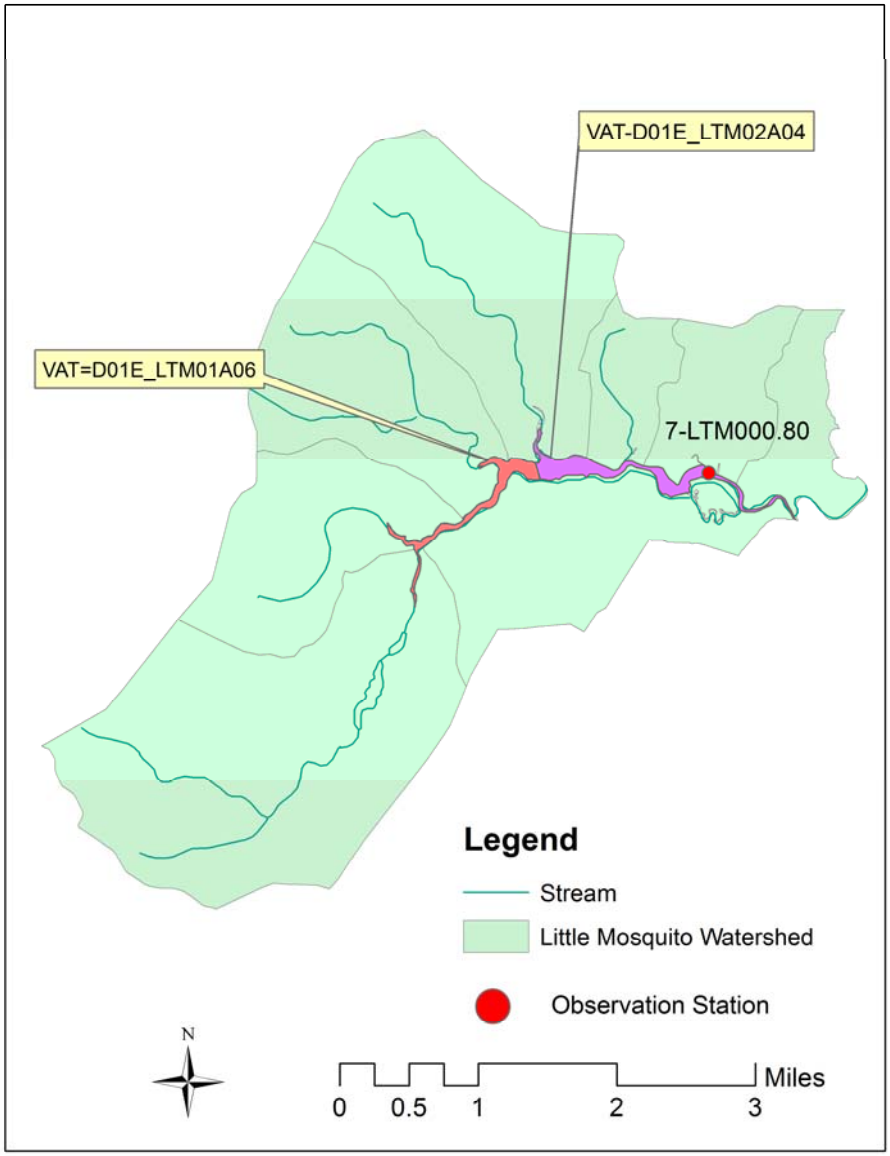


Figure 1.3: Delineation of the Impaired Waterbodies of the Little Mosquito Creek Watershed

1.4 Designated Uses and Applicable Water Quality Standards

1.4.1 Designation of Uses

According to Virginia WQS (9VAC25-260-10):

"All State waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to

inhabit them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish."

The state promulgates standards to protect waters to ensure that the uses designated for those waters are met. In Virginia's WQS, certain standards are assigned by water class, while other standards are assigned to specifically described waterbodies/waterways to protect designated uses of those waters. Virginia has seven water classes (I through VII) with DO, pH, and temperature criteria for each class (9VAC25-260-50). The identification of waters by class is found in the river basins section tables. The tables delineate the class of waters to which the basin section belongs in accordance with the class descriptions given in 9VAC25-260-50. By finding the class of waters for a basin section in the classification column and referring to 9VAC25-260-50, the DO, pH, and maximum temperature criteria can be found for each basin section. Both Assawoman Creek and Little Mosquito Creek are considered as Class II waters, "Estuarine Water (Tidal Water-Coastal Zone to Fall Line)" (9VAC25-260-50).

Figure 1.1 illustrates the impaired segments. The upper and lower portions of Assawoman Creek (Assawoman Creek-Upper and Assawoman Creek-Lower) and Little Mosquito Creek (Little Mosquito Creek-Upper and Little Mosquito Creek-Lower) do not support the aquatic life designated use due to violations of the DO criteria. Figures 1.2 and 1.3 show the watershed delineation for the impaired segments.

1.4.2 DO Criteria

DO is a basic requirement for a healthy aquatic ecosystem. Most fish and beneficial aquatic insects "breathe" oxygen dissolved in the water column. Most desirable fish species suffer if DO concentrations fall below 3 to 4 mg/L. Many fish and other aquatic organisms can recover from short periods of low DO availability. When oxygen drops to about 4 mg/L, fish will begin to feel stressed and move away from the area. Below 3 mg/L, fish kills may be observed and shellfish begin to shut down. At about 2 mg/L or lower, animals living in the sediments will start to die. Exposure to less than 2 mg/L oxygen for prolonged episodes may kill most organisms, leaving only air-breathing insects and anaerobic organisms. When a body of water experiences low levels of oxygen, the condition is known as hypoxia. When oxygen levels drop to virtually none, the condition is called anoxia.

According to 9VAC25-260-50, the numerical criterion for DO for Class II waters is a minimum of 4.0 mg/L and a daily average of 5.0 mg/L.

1.5 Impairment Listing

The VA-DEQ has two water quality stations (7-ASW003.36 and 7-PET000.80) in the Assawoman Creek and one station (7-LTM000.80) in the Little Mosquito Creek-Upper (see Figures 1.2 and 1.3 for station locations). There is insufficient data for Station 7-PET000.80. Sufficient exceedances of Virginia's WQS for DO minimum were recorded at the Stations 7-ASW003.36 and 7-LTM000.80 to assess the segments of Assawoman

Creek and Little Mosquito Creek, respectively, as not supporting the aquatic life designated use (Table 1.2). The designated uses, impairments, and criteria for listed segments in the two Creeks are summarized in Table 1.3.

Table 1.2: Exceedances of the WQC (2000-2014) of Assawoman Creek and Little Mosquito Creek

Stream Name	Station ID	Impairment	Number of Samples	Number of Exceedances	Percentage Exceedance
Assawoman Creek	7ASW003.36	DO	87	16	18.5%
Little Mosquito Creek	7-LTM000.80	DO	81	12	14.8%

Table 1.3: The Water Types, Designated Uses, Impairments, WQC, and List Years for Assawoman Creek and Little Mosquito Creek

Stream Name	Water Type	Designated Use	Impairment	Criteria	List Year
Assawoman Creek-Upper	Tidal	Aquatic life	DO	Minimum >4 (mg/L)	2006 ~2011
Assawoman Creek-Lower	Tidal	Aquatic life	DO	Minimum >4 (mg/L)	1994 ~2011
Little Mosquito Creek-Upper	Tidal	Aquatic life	DO	Minimum >4 (mg/L)	2006 ~2011
Little Mosquito Creek-Lower	Tidal	Aquatic life	DO	Minimum >4 (mg/L)	2006 ~2011

2.0 WATERSHED CHARACTERIZATION

2.1 Topology, Soil, and Climate

The Assawoman Creek and Little Mosquito Creek watersheds located along Virginia's Eastern Shore, are in the lowland sub-province of the Coastal Plain province. Latest Tertiary and Quaternary sand, silt, and clay, which cover much of the Coastal Plain, were deposited during interglacial highstands of the sea under conditions similar to those that exist in the modern Chesapeake Bay and its tidal tributaries (http://web.wm.edu/geology/virginia/provinces/coastalplain/coastal_plain.html). The soils in the watershed range from moderately drained to slow infiltration rate.

As part of the Tidewater Climate Region, both watersheds experience average January temperatures of 35-48 ^{o}F and average July temperatures of 71-85 ^{o}F. Average annual precipitation is 41.3 inches. This precipitation is influenced by stream discharge, groundwater seepage, and surface runoff.

2.2 Landuse

The landuse characterization for the Assawoman Creek and Little Mosquito Creek watersheds was based on the land cover data from the National Land Cover Data (NLCD) 2010 Landuse Dataset (Figures 2.1a and 2.1b). The brief descriptions of landuse classifications in the watershed, land area, and percentage are presented in Tables 2.1a and 2.1b, respectively, for Assawoman Creek and Little Mosquito Creek. Dominant landuses for Assawoman in the watershed were found to be agricultural (53%) and forest and wetland (39%), which account for 92% of the total land area in the watershed (Figure 2.2). Dominant landuses for Little Mosquito Creek watershed were found to be agricultural (38%) and forest and wetland (47%), which account for 85% of the total land area in the watershed (Figure 2.2).

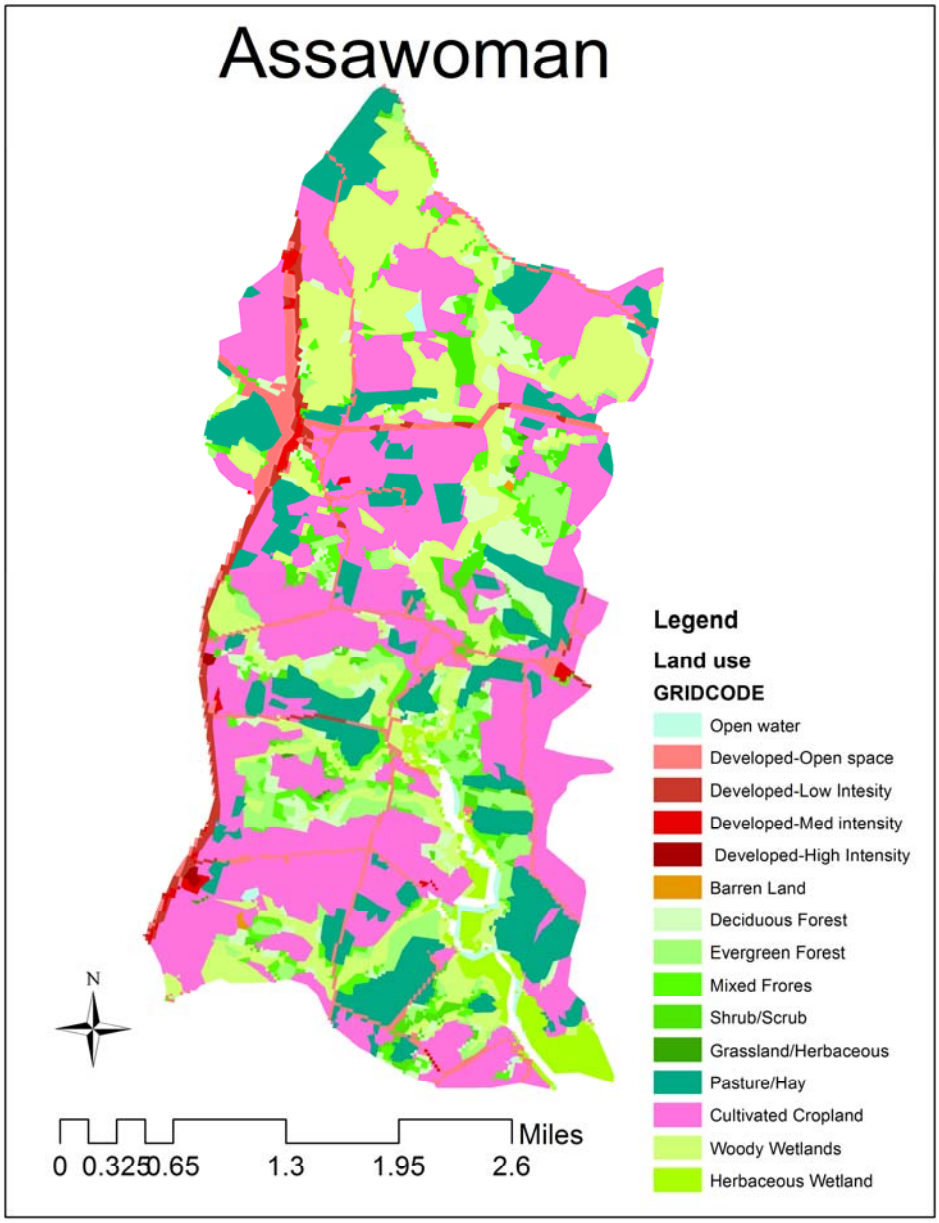


Figure 2.1a: Landuse of Assawoman Creek Watershed

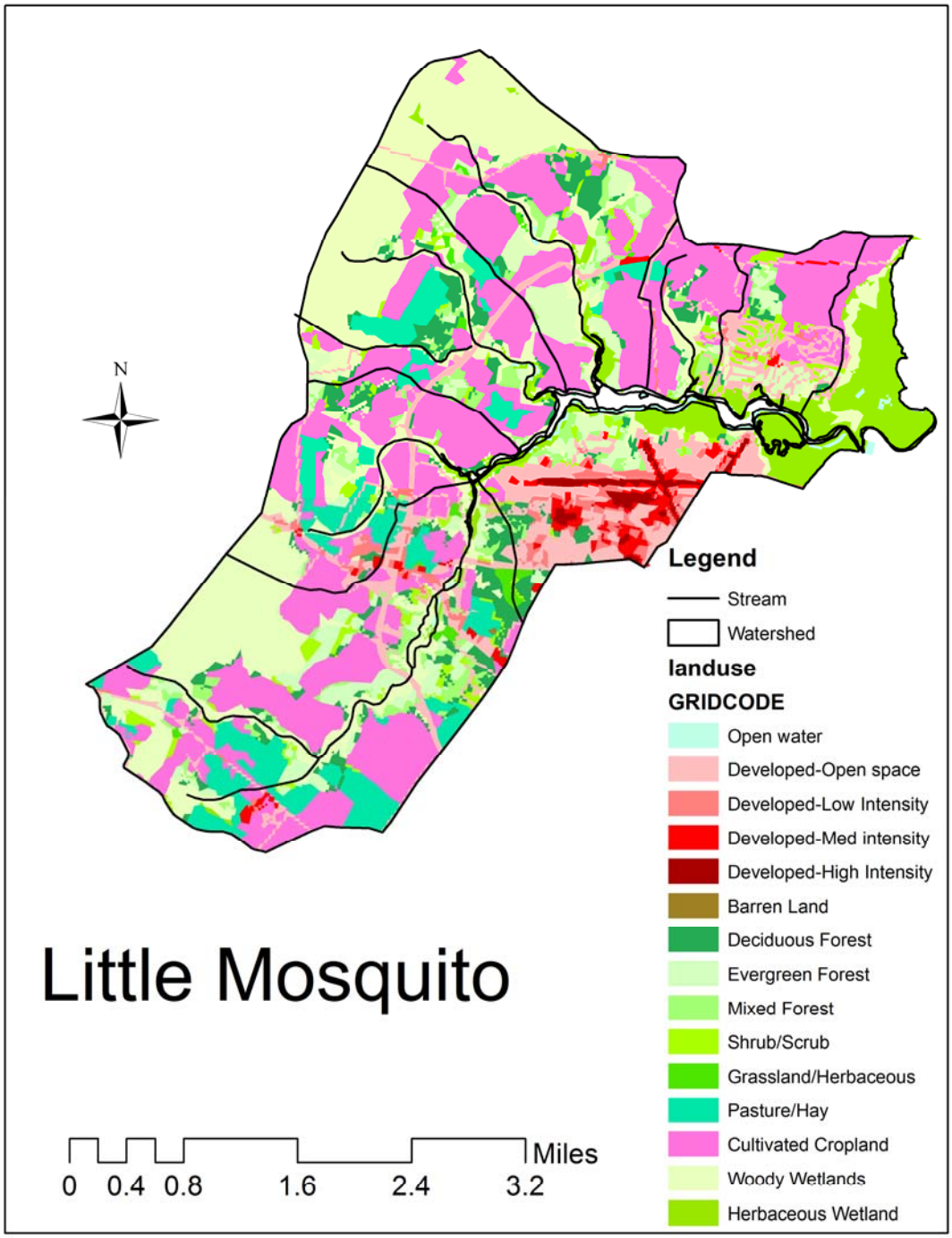


Figure 2.1b: Landuse of Little Mosquito Creek Watershed

Table 2.1a: Landuse Descriptions and Percentages of the Assawoman Creek Watershed

Land use	Area (Ac)	% of Watershed
Open Water	37.58	0.55
Developed-Open Space	357.39	5.28
Developed-Low Intensity	107.86	1.59
Developed-Med Intensity	40.03	0.59
Developed-High Intensity	7.34	0.11
Barren Land	4.45	0.07
Deciduous Forest	389.63	5.75
Evergreen Forest	372.29	5.50
Mixed Forest	241.30	3.56
Shrub/Scrub	194.59	2.87
Grassland/Herbaceous	7.34	0.11
Pasture/Hay	1025.24	15.13
Cultivated Cropland	2569.76	37.93
Woody Wetlands	1237.18	18.26
Herbaceous Wetland	182.59	2.70
Total	6774.6	100.0

Table 2.1b: Landuse Descriptions and Percentages of the Little Mosquito Creek Watershed

Land use	Area (Ac)	% of Watershed
Open Water	58.27	0.61
Developed-Open Space	921.38	9.62
Developed-Low Intensity	196.82	2.06
Developed-Med Intensity	151.45	1.58
Developed-High Intensity	78.28	0.82
Barren Land	1.33	0.01
Deciduous Forest	525.29	5.48
Evergreen Forest	649.84	6.79
Mixed Forest	343.15	3.58
Shrub/Scrub	232.62	2.43
Grassland/Herbaceous	57.16	0.60
Pasture/Hay	700.54	7.31
Cultivated Cropland	2836.19	29.61
Woody Wetlands	2205.48	23.03
Herbaceous Wetland	619.59	6.47
Total	9577.4	100.0

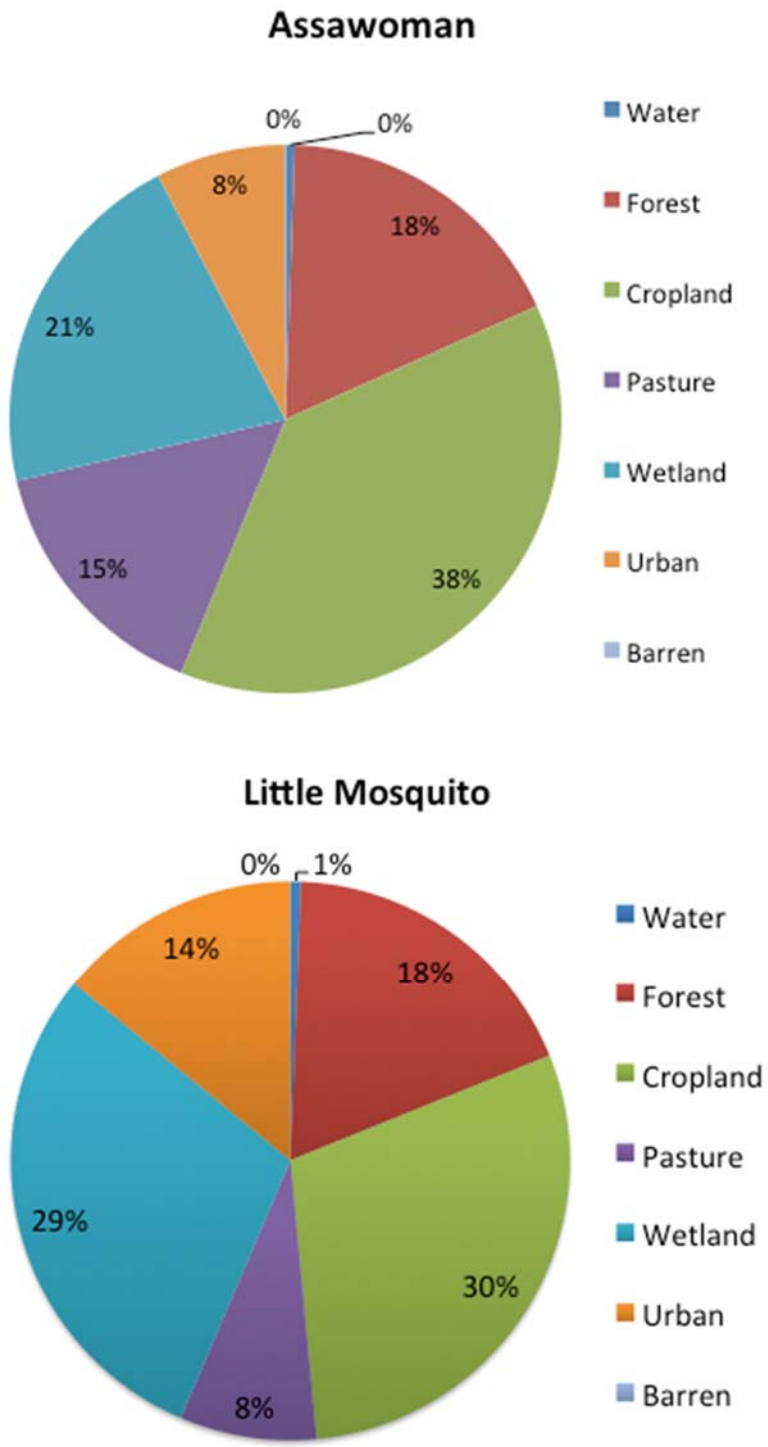


Figure 2.2: Percentage Landuse Groups of the Assawoman Creek and Little Mosquito Creek Watersheds

2.3 Water Quality Conditions

The VA-DEQ performs water quality monitoring throughout Virginia to determine if WQS are being met for the designated uses of the corresponding waters. Samples have been taken at two water quality monitoring stations in Assawoman Creek since 2000. But the observation station of 7-PET000.80 does not have enough data for analysis and modeling. Not all nutrient species were observed every year. The analysis will use data observed at 7-ASW003.36. The location of the observation station is shown in Figure 1.2. There is one observation station (i.e., 7-LTM000.80) in Little Mosquito Creek (Figure 1.3). A summary of the data is listed in Table 2.2.

Table 2.2: Water Quality Observations in Assawoman and Little Mosquito Creeks

Station	Latitude	Longitude	Parameter	Date	# of Observations
7-ASW003.36	37°50'34.28"N	75°31'31.09"W	DO	2000-2015	87
			TN	2000-2015	88
			NH_4^+	2000-2008	49
			NO_{23}^-	2000-2008	48
			TP	2000-2015	87
			PO_4^{3-}	2000-2008	48
			BOD_5	2000-2001	10
			pH	2000-2015	87
			Chl-a	2000-2015	78
7-LTM000.80	37°57'0.09"N	75°27'1.99"W	DO	2000-2015	81
			TN	2000-2015	86
			NH_4^+	2000-2008	20
			NO_{23}^-	2000-2008	20
			TP	2000-2015	60
			PO_4^{3-}	2000-2008	23
			BOD_5	2000-2001	8
			pH	2000-2015	86
			Chl-a	2000-2015	78

2.3.1 Dissolved Oxygen

Oxygen concentrations in a water column fluctuate under hydrological conditions. Severe oxygen depletion may result from activities that introduce large quantities of nutrients into surface waters that promote the excessive growth of algae. When the algae die, or other organic material gets introduced to the system, the bacteria decomposition process consumes large quantities of oxygen, which can result in a net decline in DO concentrations in the water. Other factors (such as temperature) influence the amount of

oxygen dissolved in water as well. The process of nutrient enrichment in aquatic ecosystems is called eutrophication. Human activities can greatly accelerate eutrophication by increasing the rate at which nutrients and organic substances enter aquatic ecosystems from their surrounding watersheds. Agricultural runoff, urban runoff, leaking septic systems, sewage discharges, eroded stream banks, and similar sources can increase the flow of nutrients and organic substances into aquatic systems.

For Assawoman Creek, most of the DO samples were collected bi-monthly at Station 7-ASW003.36, from 2000-2014. Figure 2.3a shows all the available DO observations from 2000 to 2014 at Station 7-ASW003.36. There are 16 observations below the water quality criterion of 4 mg/L minimum. Figure 2.4a shows the bi-monthly distribution of DO at this station. It shows that low DO occurs in summer and the lowest DO occurs in July. Correlation analysis between DO and nutrients, algae, and temperature show that DO is highly correlated to temperature (Figure 2.5a). It is moderately correlated to phosphorus (r=0.5). The correlation of DO and total phosphorus (TP) is mainly due to high inputs of TP during spring. There is a weak correlation of DO and total Kjeldahl nitrogen (TKN, r=0.30). There is no significant correlation between algae and DO, or total nitrogen (TN) and DO. This indicates that low DO is highly controlled by nonpoint sources and bottom sediment oxygen demand (SOD). The measurement location is surrounded by salt marshes. Organic materials and relatively low DO water output from salt marsh due to higher respiration also add pressure to low DO conditions of the Creek (Layman *et al*., 2000; Smith and Able, 2003). The groundwater contribution of organic carbon (OC) and nutrients are highest in the Eastern Shore region (Stanhope *et al*., 2009), which contributes to the occurrence of low DO.

For Little Mosquito Creek, most of the DO samples were collected bi-monthly at Station 7-LTM000.80, from 2000-2014. Figure 2.3b shows all the available DO observations from 2000 to 2014 at Station 7-LTM000.80. There are 12 observations below the water quality criterion of 4 mg/L minimum. Figure 2.4b shows the monthly distribution of DO at this station. It shows that low DO occurs in summer and the lowest DO occurs in August. Correlation analysis between DO and nutrients, algae, and temperature show that DO is highly correlated to temperature (r=0.9) (Figure 2.5b). It is correlated to phosphorus (r=0.64). There is a weak correlation of DO and TKN (r=0.38). There are no significant correlations between algae and DO, or TN and DO. The characteristic of Little Mosquito Creek is similar to that of Assawoman Creek. This indicates that low DO is highly controlled by nonpoint sources and SOD. The measurement location is surrounded by salt marshes. Organic materials and relatively low DO water output from salt marsh areas due to higher respiration and groundwater contribute to the low DO in the Creek.

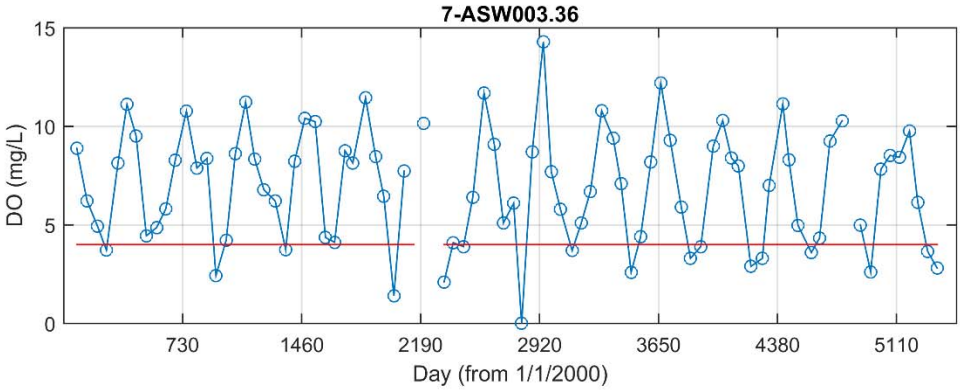


Figure 2.3a: DO Observations from 2000 to 2014 at Station 7-ASW003.36 Located in Assawoman Creek-Lower. (Red Line denotes the WQC of DO Minimum).

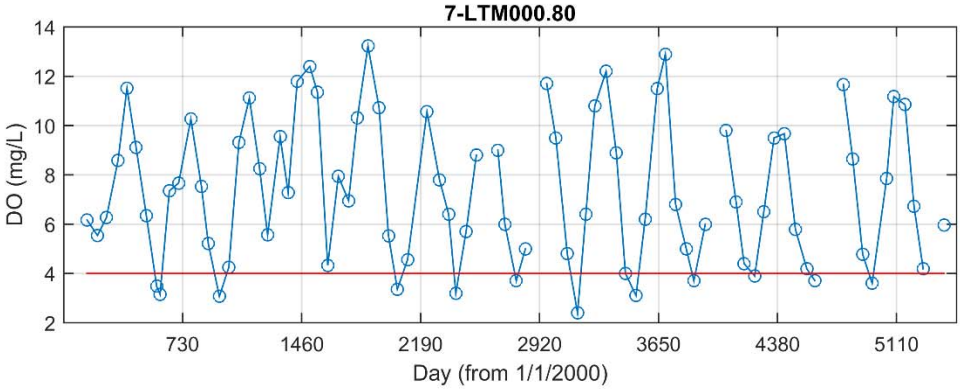


Figure 2.3b: DO Observations from 2000 to 2014 at Station 7-LTM000.80 Located in Little Mosquito Creek-Lower. (Red Line denotes the WQC of DO Minimum).

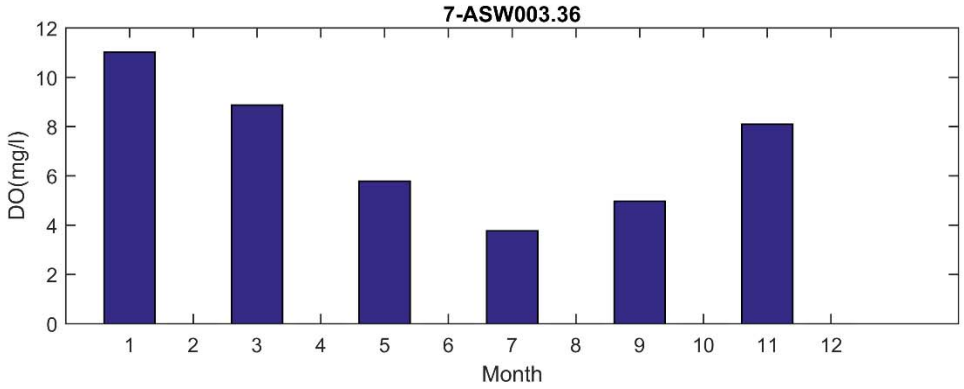


Figure 2.4a: Averaged Bimonthly DO at Station 7-ASW003.36 in Assawoman Creek (2000-2014)

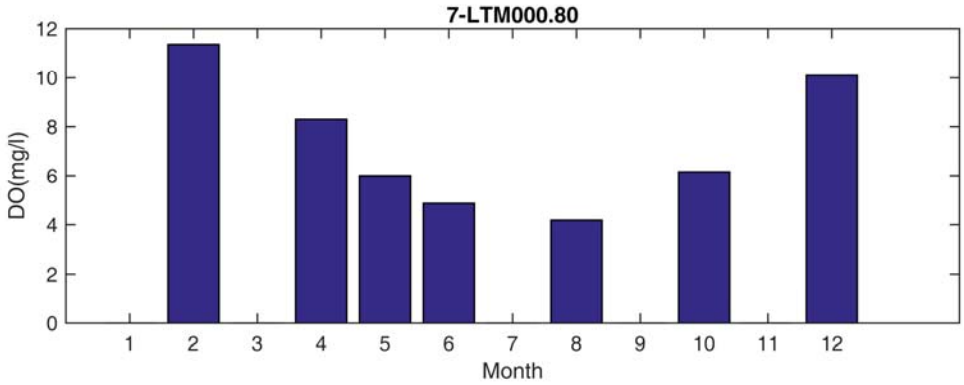


Figure 2.4b: Averaged Bimonthly DO at Station 7-LTM000.80 in Little Mosquito Creek (2000-2014)

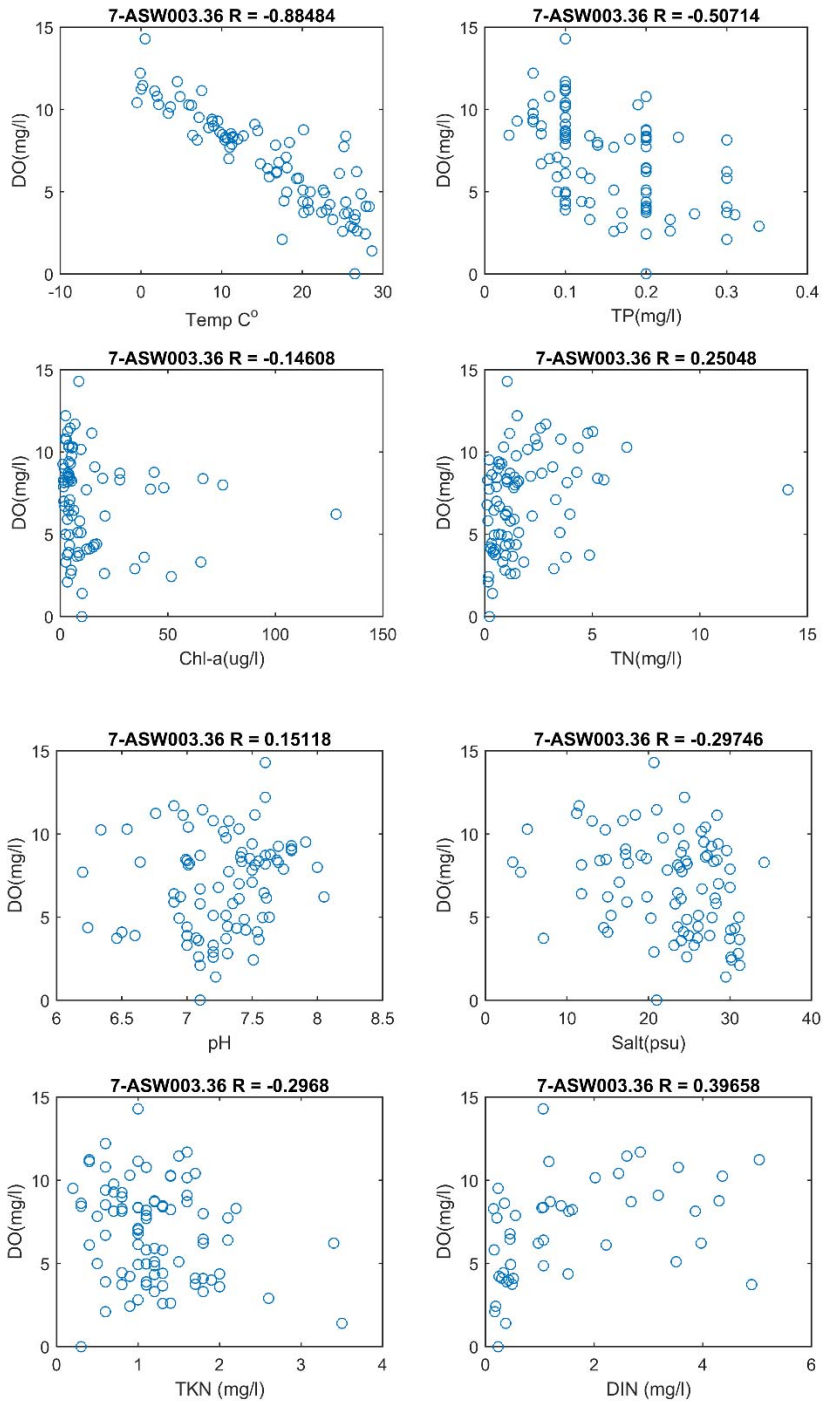


Figure 2.5a: DO Correlation Analysis Results for Assawoman Creek

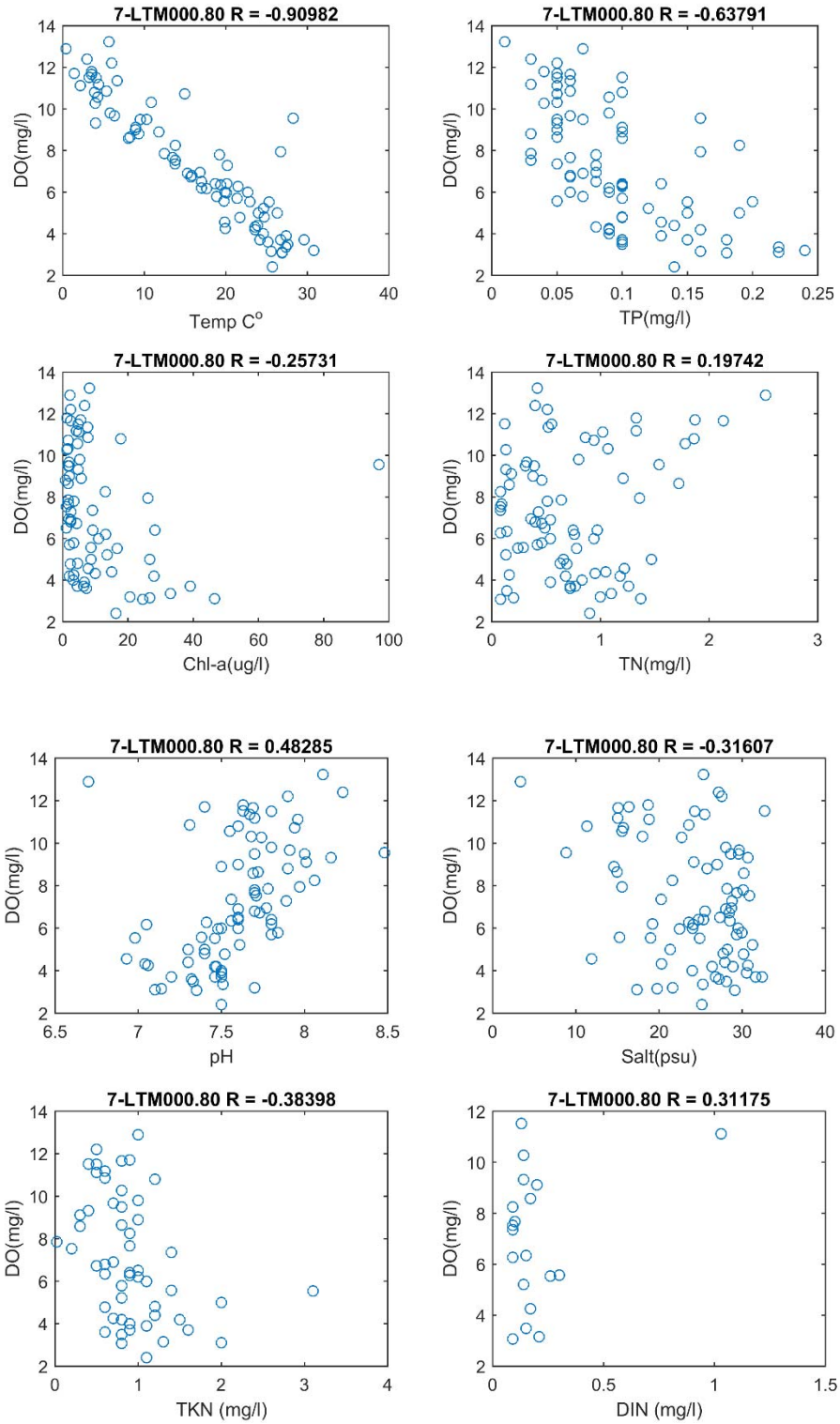


Figure 2.5b: DO Correlation Analysis Results for Little Mosquito Creek

2.3.2 Biological Oxygen Demand and Chemical Oxygen Demand

Biochemical oxygen demand, BOD, is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. BOD is used as an indirect measure of the concentration of biologically degradable material present. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic matter. The test is considered to represent the amount of OC available in the sample, but may include some nitrogenous-based organic material unless the consumption of these materials is chemically inhibited.

BOD can also be used as an indicator of the pollutant level, where the greater the BOD, the greater the degree of pollution. BOD concentrations in streams depend on the natural environment and dynamic conditions of a waterbody. In natural, unpolluted waterbodies, the BOD can be less than 5 mg/L (Boyd, 2000). Limited BOD samples (10 samples) were collected bi-monthly during 2000-2001 at the one monitoring station in Assawoman Creek (Figure 2.6a). Three observations were larger than 5 mg/L. The observed BOD value that corresponds to OC concentrations that range from 0.4-3.56 mg/L. These OC values are on the same order of magnitude as the concentration measured in this Creek. The average OC concentration from the groundwater in Assawoman Creek ranges from 3.2-7.9 mg/L (Stanhope *et al*., 2009). A 3 mg/L OC can result in a BOD concentration of 5 mg/L. The high OC concentration in this Creek can result in a high BOD. As OC decays in the Creek, it will consume DO. BOD indicates that OC contributes to the low DO.

The BOD distribution at Station 7-LTM000.80 in the Little Mosquito Creek is similar to that in Assawoman Creek. The observation data are very limited. The highest concentration is about 4 mg/L (Figure 2.6b).

Chemical oxygen demand (COD) is a measure of the total amount of oxygen required to oxidize organic matter to carbon dioxide and water. It is determined by oxidation of the organic matter with potassium dichromate and sulfuric acid. It is often used as a rapid way to assess BOD. The BOD and COD are roughly equal to each other in a waterbody characterized by highly decomposable organic matter. On the other hand, COD may be significantly higher than BOD in an environment with organic matter that is resistant to quick decay. At Stations 7-ASW003.36 and 7-LTM000.80 in both Assawoman Creek and Little Mosquito Creek, no COD measurements have been collected.

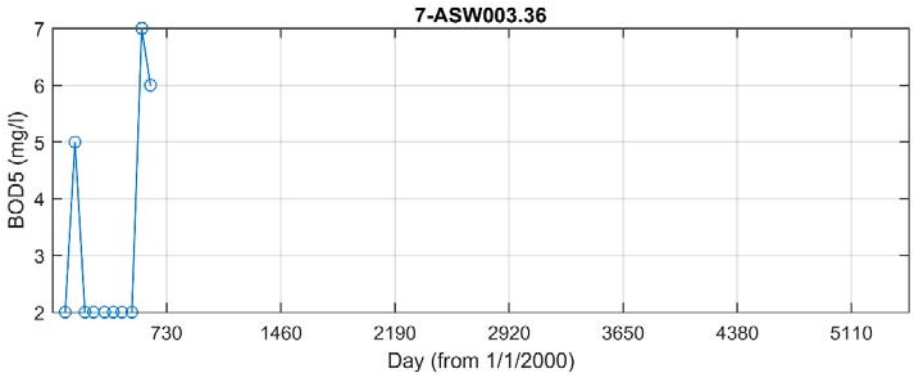


Figure 2.6a: BOD Observations from 2000 to 2001 at Station 7-ASW003.36 in Assawoman Creek

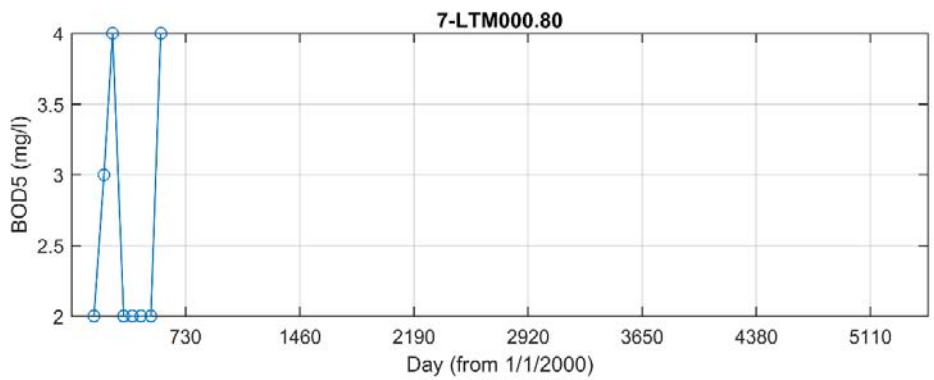


Figure 2.6b: BOD Observations from 2000 to 2001 at Station 7-LTM000.80 in Little Mosquito Creek

2.3.3 Chlorophyll *a*

Chlorophyll *a* (Chl-a) is a green pigment found in most algae and cyanobacteria, allowing them to convert sunlight into organic compounds in the process of photosynthesis. Its abundance is a good indicator of the amount of algae present in water. Excessive quantities of Chl-a can indicate the presence of algae blooms, in which unconsumed algae sink to the bottom and decay, using up the oxygen required by other plants and benthic organisms. As Chl-a levels increase, the amount of sunlight reaching underwater grasses declines as well. Figure 2.7a shows the available observations of Chl-a concentrations and monthly Chl-a distribution for Assawoman Creek. In general, the concentrations were between 1 and 70 μg/L, and values higher than 50 μg/L were often observed. The highest value was about 120 μg/L, which usually indicates that nutrients have an impact on algae in the tidal portion of the Creek. The highest concentration occurred in July.

For Little Mosquito Creek, observations of Chl-a at Station 7-LTM000.80 has been conducted from 2000-2014. Figure 2.7b shows the available observations of Chl-a concentrations and monthly Chl-a distribution for Little Mosquito Creek. Chl-a concentration ranges from 1 to 30 μg/L in general. Occasionally, high Chl-a concentrations of about 40 μg/L were observed (Figure 2.7b). The highest concentration occurred in August.

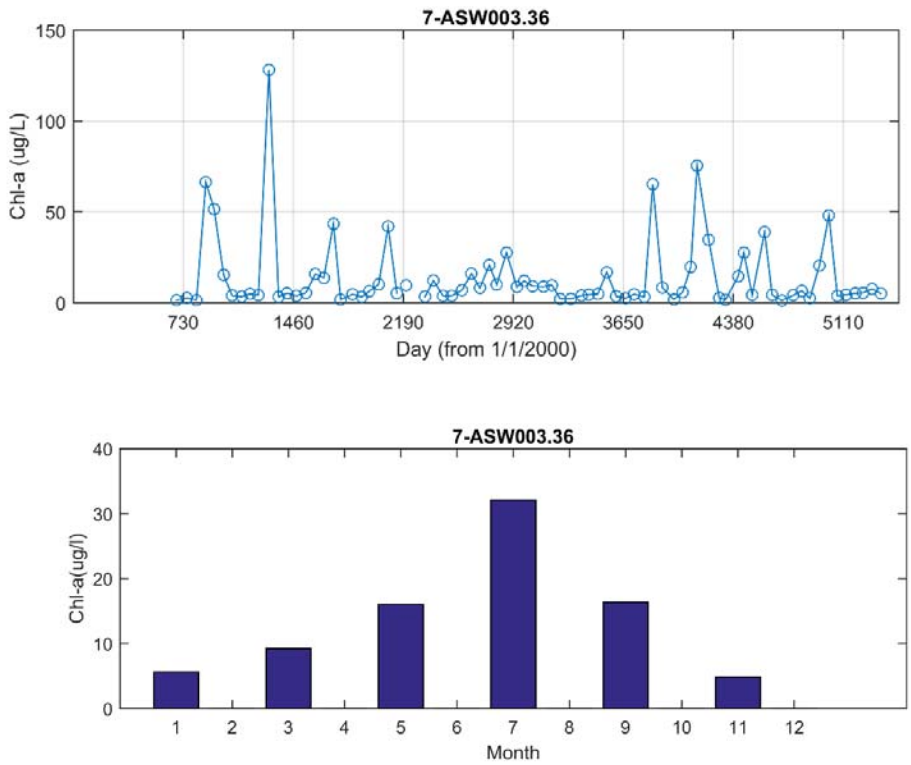
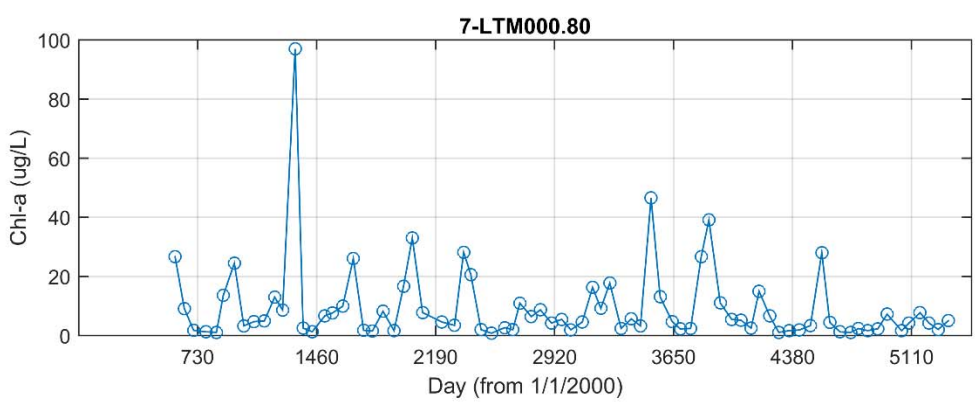


Figure 2.7a: Chl-a Concentrations at Station 7-ASW003.36 Located in the Assawoman Creek-Lower



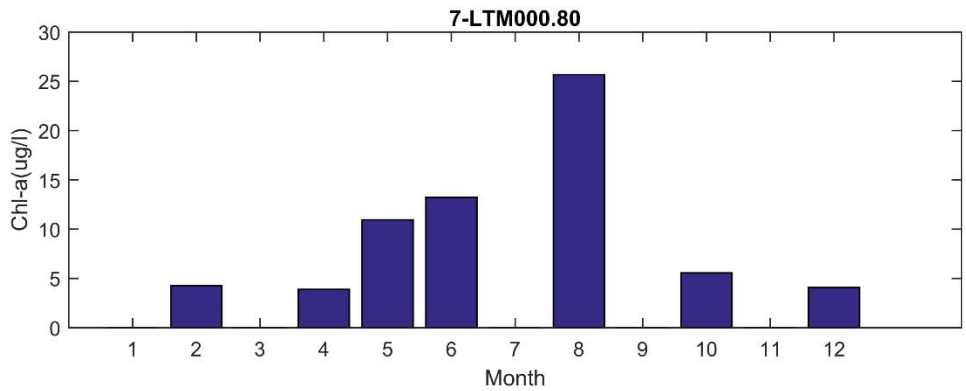


Figure 2.7b: Chl-a Concentrations at Station 7-LTM000.80 Located in the Little Mosquito Creek-Lower

2.3.4 Nutrients

The nutrients, nitrogen and phosphorus, are elements, and are essential building blocks for plant and animal growth. The measurement frequencies of the nitrogen and phosphate are the same as DO at the three monitoring stations.

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Total dissolved inorganic nitrogen (DIN, which includes NO_3^-, NO_2^-, NH_4^+, and NH_3) is a measure of all forms of DIN present in a water sample, which are essential nutrients for plants to uptake. On the other hand, organic nitrogen is undergoing ammonification to become NH_4^+, which oxidizes to NO_2^-. For Assawoman Creek, the distributions of each nutrient species at Station 7-ASW003.36 are shown in Figure 2.8a. TN ranges from 0.5-14.5 mg/L and NH_4^+ ranges from 0.05-0.4 mg/L. NO_{23} ranges from 0.05-5 mg/L at Station 7-ASW003.36. TN is higher than other creeks of the Eastern Shore. Organic nitrogen plus ammonium (TKN) ranges from 0.2-3.5 mg/L. NO_{23} is very high and a large portion of TN is comprised by NO_{23}. Higher NO_{23} concentration is often associated with groundwater discharge. It can be seen that a large portion of nitrogen can be discharged into the stream from the watershed through leaching and infiltration. A large amount of DO can be consumed through the nitrogen oxidation process by oxidizing ammonia to nitrite when organic and ammonia nitrogen exists in the nonpoint sources.

For Little Mosquito Creek, the nutrient distributions of TN, NH_4, NO_{23}, and TKN at Station 7-LTM000.80 are shown in Figure 2.8b. TN ranges from 0.1-2.5 mg/L. Both NH_4 and NO_{23} ranges from 0.05-0.1 mg/L. TKN ranges from 0.1-3 mg/L. It can be seen that the nitrogen concentration is lower than that observed in Assawoman Creek, especially NO_{23}.

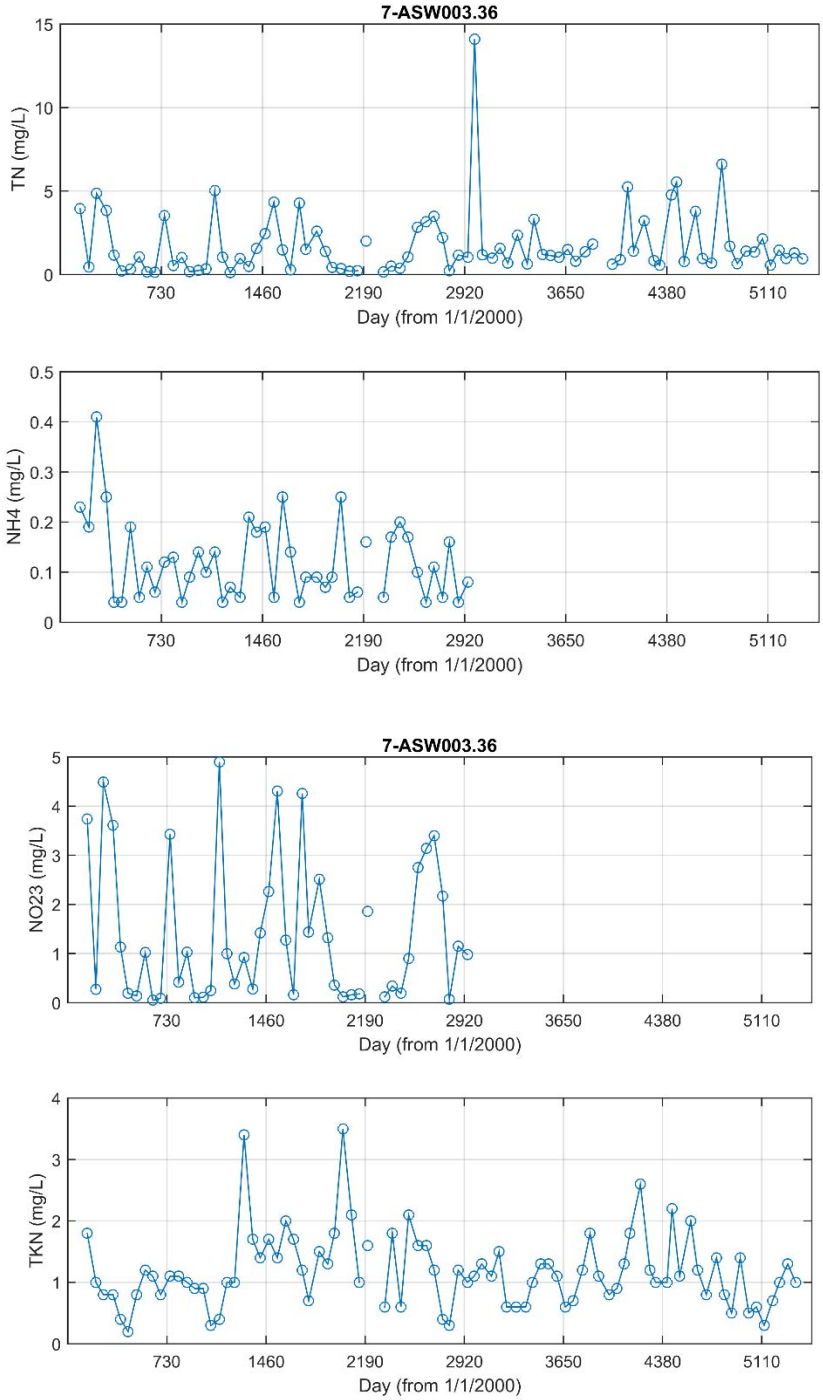


Figure 2.8a: TN, NH_4, NO_{23}, and TKN Distributions in Assawoman Creek-Lower

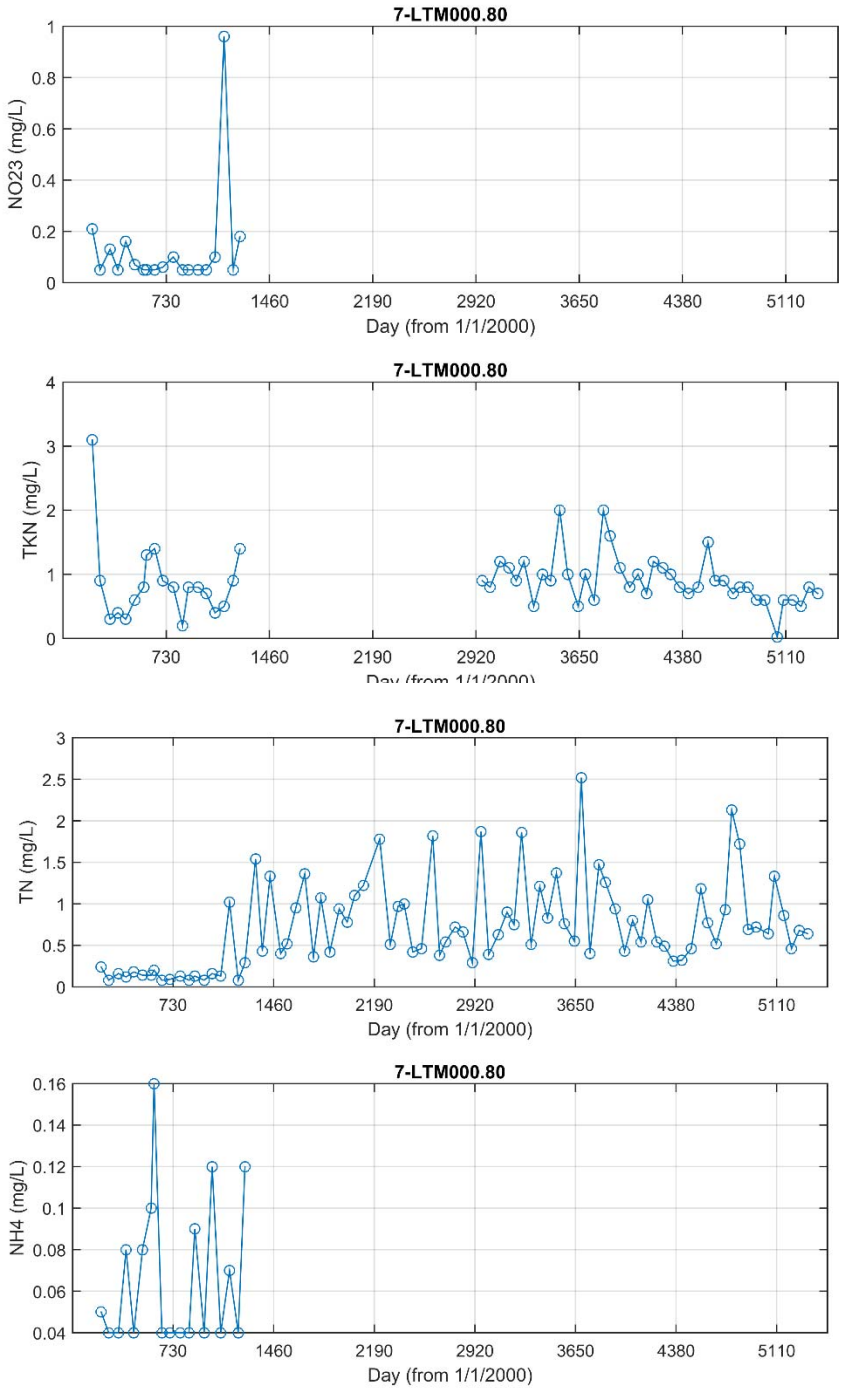


Figure 2.8b: TN, NH_4, NO_{23}, and TKN Distributions in Little Mosquito Creek-Lower

Phosphorus is found in nucleic acids and certain fats (phospholipids). It is a common element of igneous rocks. It is found in waterbodies in dissolved and particulate forms. TP is a measure of all the various forms of phosphorus (dissolved and particulate) found in water. For a mesotrophic waterbody, TP ranges from 10 to 20 mg/L (Thomann and Mueller, 1987). Figure 2.9a shows the TP concentration at Station 7-ASW003.36 in Assawoman Creek-Lower. TP ranges from 0.1-0.35 mg/L and PO_4 ranges from 0.02-0.13 mg/L. The highest TP concentration did not exceed 0.4 mg/L.

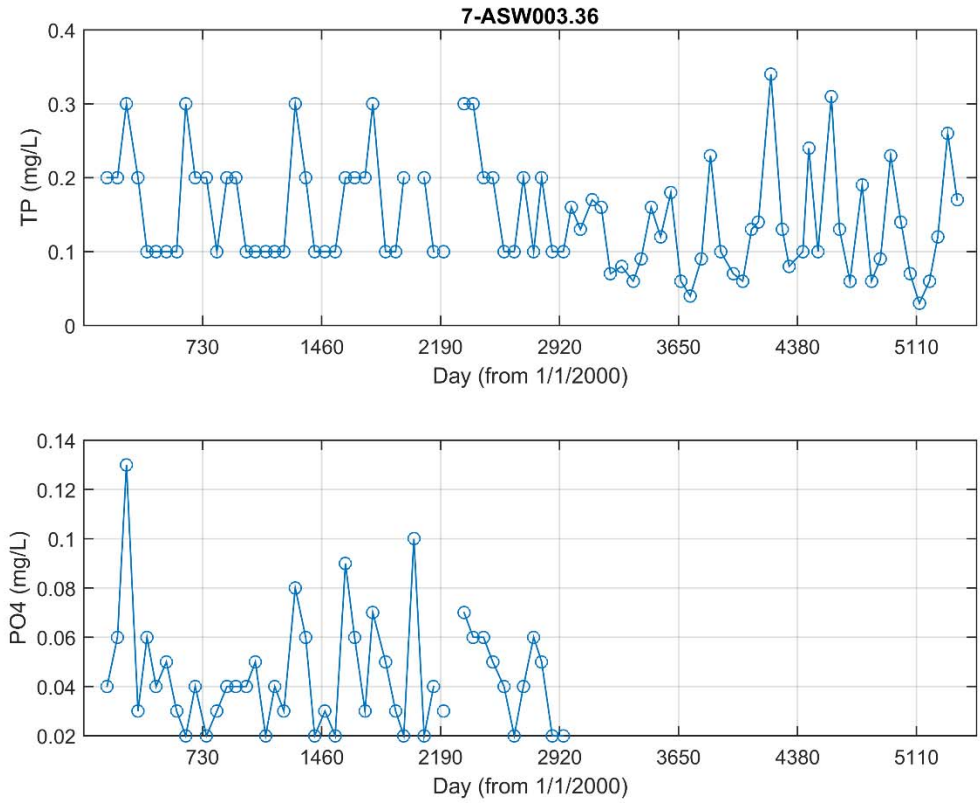


Figure 2.9a: TP Concentrations at Station 7-ASW003.36 in Assawoman Creek-Lower

For Little Mosquito Creek, Figure 2.9b shows the TP concentration at Station 7-LTM000.80. TP ranges from 0.1-0.25 mg/L and PO_4 ranges from 0.02-0.06 mg/L. The highest TP concentration did not exceed 0.4 mg/L.

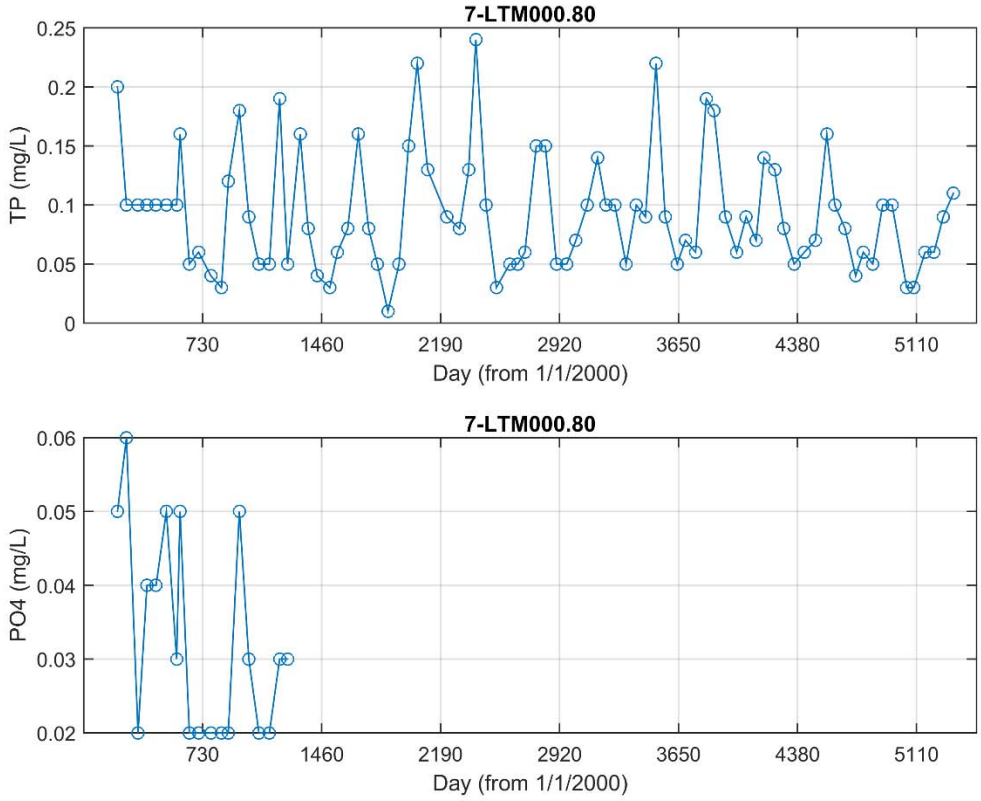


Figure 2.9b: TP Concentrations at Station 7-LTM000.80 in Little Mosquito Creek-Lower

2.3.5 Temperature, Salinity, and pH

Salinity, pH, and temperature values for Assawoman Creek at Station 7-ASW003.36 are shown in Figures 2.10a. A wide seasonal temperature variation is typical in the stream. Summer temperatures reached 30 degrees C and winter low temperatures were about 0 degrees C. The high temperature corresponded to the low DO in summer (Figure 2.5a). The salinity value in the lower reach of Assawoman Creek can be above 30 psu (Figure 2.10a), indicating it is highly influenced by tide. The pH values varied between 7.0 and 8.2 in Assawoman Creek, which is within the optimum range of 6.5-9.0 for fish and other aquatic life (Figure 2.10a).

For Little Mosquito Creek, salinity, pH, and temperature values at Station 7-LTM000.80 are shown in Figures 2.10b. The distributions are very similar to those of Assawoman Creek. The salinity value in the lower reach of Little Mosquito Creek can be above 30 psu (Figure 2.10b), indicating that it is highly influenced by tide.

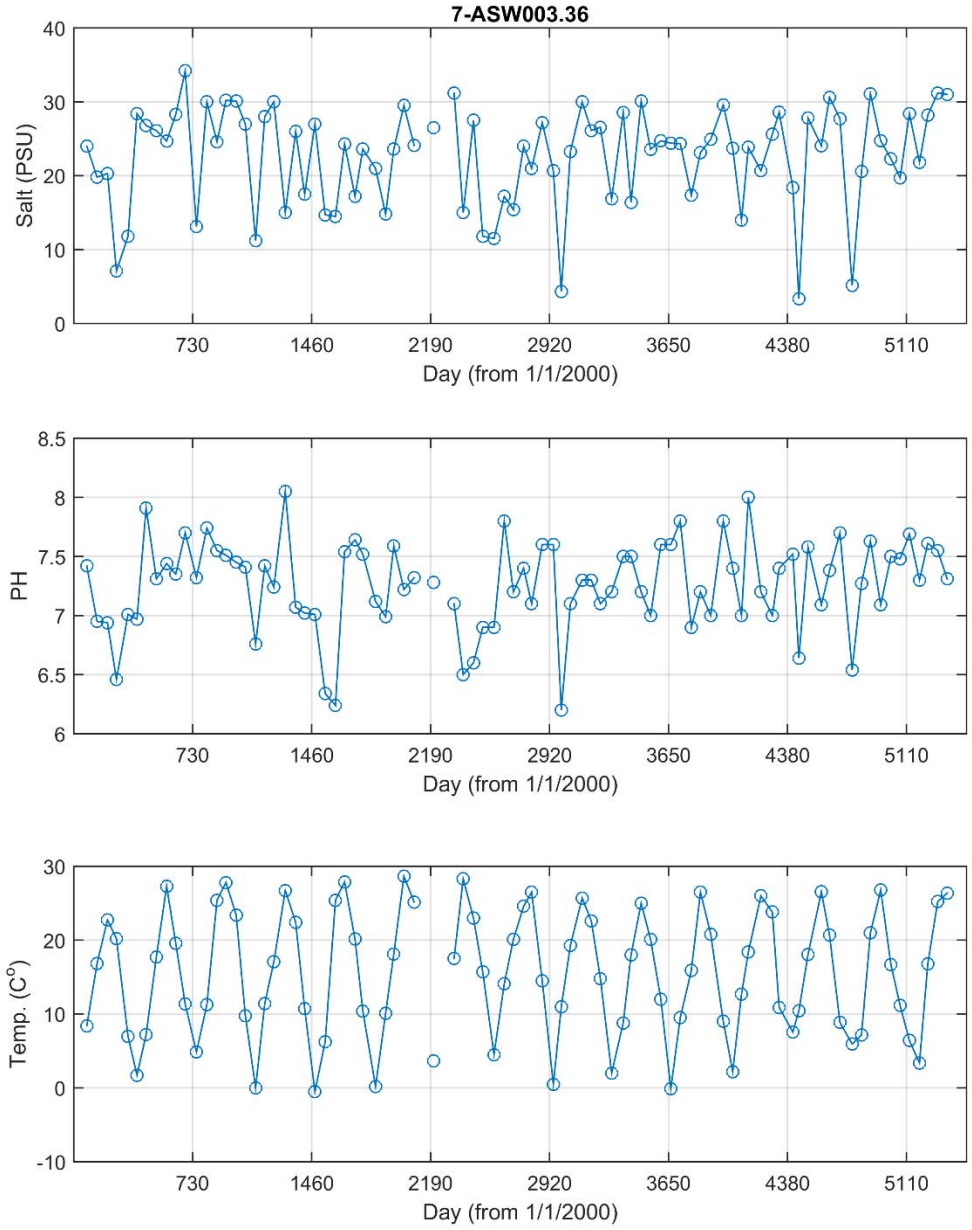


Figure 2.10a: Salinity, pH, and Temperature Variations in Assawoman Creek-Lower

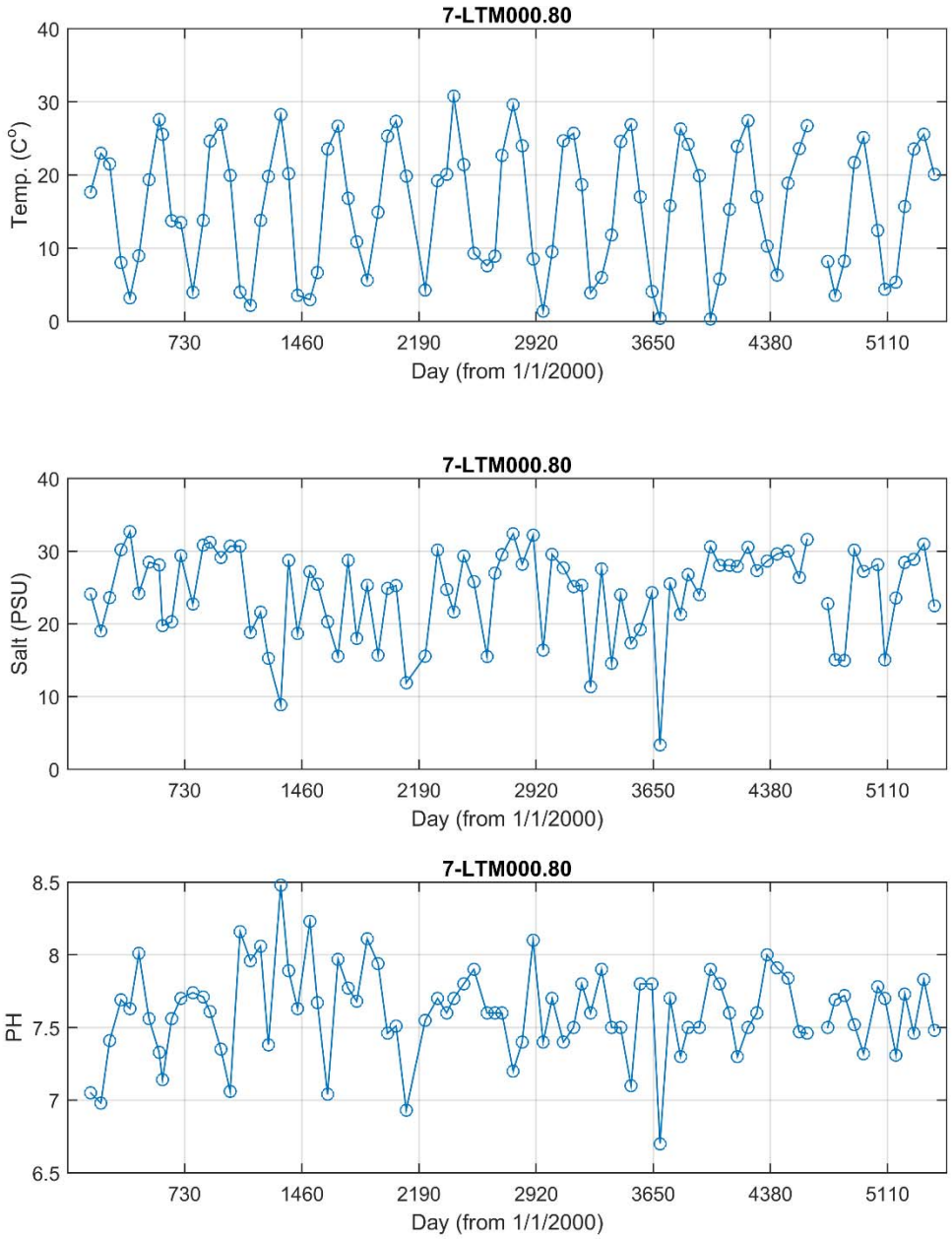


Figure 2.10b: Salinity and pH Variations in Little Mosquito Creek -Lower

2.3.6 Summary of Data Analysis

Assawoman Creek and Little Mosquito Creek are narrow streams, which are influenced by both tide and freshwater. Stratification can occur when freshwater discharge is large. When stratification occurs, it will result in a low DO in these coastal creeks (Shen *et al*.,

2008). The stream is surrounded by forest and agricultural land with large adjacent marshes. Runoff from adjacent farmlands, forestland, and marshes can discharge to the stream. There are two point source facilities with permitted nutrient levels that directly discharge to Assawoman Creek. Because of the influence of tide, a large amount of carbon and nutrients transported from upstream and the adjacent watershed will be deposited to the bottom. The light condition appears sufficient for algae growth. As algae die and deposit to the bottom, the DO consumption in summer will increase.

A summary of the statistics for water quality parameters for the Assawoman Creek is listed in Table 2.3a. In general, the averaged TN and TP were 1.75 and 0.15 mg/L. Both are higher than the EPA-recommended nutrient levels of 0.7 mg/L and 0.03 mg/L, respectively. The nitrogen inputs appear very high. Both TN and TP were higher than the screening level of water quality assessment guideline for Class VII, Swamp Water. The averaged pH value is 7.3. The results indicate that low DO in the Creek could be caused by the deposition of organic matter, which are discharged from watershed and deposition of algae from water column resulting in high SOD. Large marsh areas near the mouth of the Creek also add pressure for the Creek due to high respiration in the marsh and diurnal DO fluctuation, which is caused by photosynthesis of benthic algae, phytoplankton and submerged aquatic vegetation during daytime, and decreases after nightfall when high respiration occurs and DO consumption becomes high (Smith and Able, 2003; Layman *et al*., 2000). The OC from groundwater is another important component. According to the measurement of base flow in Assawoman Creek, the averaged dissolved organic carbon (DOC) ranges from 3.2-7.9 mg/L, which is higher than compared to other creeks in this region. The average concentration of DIN from groundwater ranges from 3.1-7.9 mg/L (Stanhope *et al*., 2009).

Figure 2.11a shows the TN:TP ratio distribution. The mean N:P value is 13.87. About 60% of observations of N:P exceed 7.4, a theoretical N:P ratio for phytoplankton. It appears that P is more limited in the Creek. However, as high algal concentration occurred in summer when nutrients are low, N limiting can occur as phosphorus is often available in a marine environment from the sediment and can be transported into the estuary.

Little Mosquito Creek is very similar to Assawoman Creek, as it is a narrow creek influenced by both freshwater discharge and tide. Stratification can occur when freshwater discharge is large. A summary of the statistics for water quality parameters for the Little Mosquito Creek is listed in Table 2.3b. In general, the averaged TN and TP were 0.72 and 0.09 mg/L. Both are above the EPA-recommended nutrient levels of 0.7 mg/L and 0.03 mg/L, respectively. The nitrogen values higher than 1.0 mg/L are often observed. TN, TP, and NO_{23}^{-} values are higher than the screening level (background Value for Natural Condition) of the water quality assessment guideline for Class VII, Swamp Water. The averaged pH value is 7.6. The results indicate that low DO in the Creek could be caused by the deposition of organic matter, which are discharged from watershed and deposition of algae from water column resulting in high SOD. The Creek has a similar landscape as that of Assawoman Creek. Large marsh areas near the mouth of the Creek also add pressure for the Creek due to high respiration in the marsh and diurnal DO

fluctuation, which is caused by photosynthesis of benthic algae, phytoplankton, and submerged aquatic vegetation during daytime, and decreases after nightfall when high respiration occurs and DO consumption becomes high. The OC from groundwater is another important component. According to the measurement of base flow in Little Mosquito Creek, the average ranges from 3.68-6.36 mg/L. The average concentration of DIN from groundwater ranges from 1.24-4.49 mg/L (Stanhope *et al*., 2009). The groundwater inputs of DIN and DOC are on the same order as those of Assawoman Creek.

Figure 2.11b shows the TN:TP ratio distribution of Little Mosquito Creek. The mean N:P value is 10.14. About 45% of the observations of N:P are larger than 7.4, the theoretical N:P ratio for phytoplankton. It appears that both N and P are limited in the Creek.

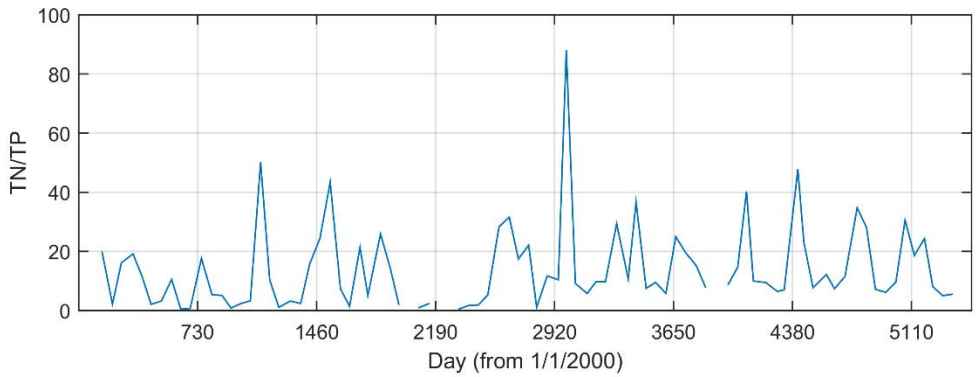


Figure 2.11a: Distribution of TN/TP Ratio in Assawoman Creek-Lower

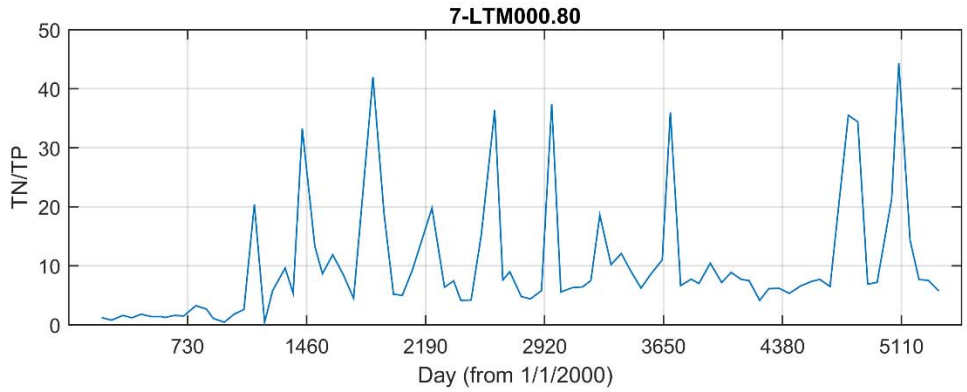


Figure 2.11b: Distribution of TN/TP Ratio in Little Mosquito Creek-Lower

Table 2.3a: Summary of Water Quality Parameters at Station 7-ASW003.36 in Assawoman Creek

Station	Parameter	Mean	Standard Deviation	[1]Background Value for Natural Condition	Values EPA Recommended
7-ASW003.36	DO (mg/L)	6.95	2.83		
	TN (mg/L)	1.75	1.99	<1.0	0.71
	NH_4^+ (mg/L)	0.15	0.08		
	NO_{23}^- (mg/L)	1.40	1.44	<0.6	
	TP (mg/L)	0.15	0.07	<0.1	0.03
	PO_4^{3-} (mg/L)	0.04	0.02		
	BOD_5 (mg/L)	3.2	1.99		
	Chl *a* (µg /L)	13.97	20.71		
	pH	7.26	0.38		

[1]Water Quality Assessment Guidance Manual, VA-DEQ, 2014, http://www.deq.virginia.gov/portals/0/deq/water/guidance/142005.pdf

Table 2.3b: Summary of Water Quality Parameters at Station 7-LTM000.80 in Little Mosquito Creek

Station	Parameter	Mean	Standard Deviation	[1]Background Value for Natural Condition	Values EPA Recommended
7-LTM000.80	DO (mg/L)	7.30	2.91		
	TN (mg/L)	0.72	0.53	<1.0	0.71
	NH_4^+ (mg/L)	0.07	0.04		
	NO_3^- (mg/L)	0.13	0.20	<0.6	
	TP (mg/L)	0.09	0.06	<0.1	0.03
	PO_4^{3-} (mg/L)	0.06	0.14		
	BOD_5 (mg/L)	2.63	0.92		
	Chl *a* (µg/L)	9.70	13.83		
	pH	7.61	0.14		

[1]Water Quality Assessment Guidance Manual, VA-DEQ, 2014, http://www.deq.virginia.gov/portals/0/deq/water/guidance/142005.pdf

3.0 SOURCE ASSESSMENT

3.1 General

All aquatic plants and algae require nutrients for growth. In aquatic environments, nutrient availability usually limits algal growth. When these nutrients are introduced into the estuary at higher rates, aquatic plant and algae productivity may increase dramatically. This in return results in more organic materials being added to the system, which eventually die and decay. The decaying organic matter depletes the oxygen supply available to aquatic organisms. This process, referred to as eutrophication, may adversely affect the suitability of the water for other uses. Depleted oxygen levels, especially in bottom waters where dead organic matter tends to accumulate, can reduce the quality of fish habitat and encourage the propagation of fish that are adapted to less oxygenated environments or the migration of fish to surface waters.

A primary component of DO TMDLs development for Assawoman Creek and Little Mosquito Creek is the evaluation of potential sources of nutrients in the watersheds. The watershed approach was applied for the source assessment. Landuse data together with human population, wildlife, fertilizer application, atmospheric deposition, manure application, etc. were used for the assessment. Sources of information that were used in evaluating potential pollutant sources included the VA-DEQ, the Virginia Department of Conservation and Recreation (VA-DCR), the Virginia Department of Game and Inland Fisheries (VADGIF), the Virginia Department of Health (VDH), US Department of Agriculture (USDA) agriculture census data, public participation, watershed studies, stream monitoring, published information, and best professional judgment. Many source assessments, including animal counts information, are contributed by stakeholders.

The potential pollutant sources in the watershed can be broken down into point and nonpoint sources. Point sources are permitted pollutant loads derived from individual sources and discharged at specific locations. There are two point sources in the Assawoman Creek watershed and one point source in the Little Mosquito Creek watershed. Nonpoint sources are from various sources over a relatively large land area, which are the dominant pollutant sources in the watersheds.

3.2 Human, Wildlife, and Livestock Contributions

Human Population and pets

Population numbers for humans and pets are shown in Table 3.1. The human population can be derived from US Census Bureau data (USCB, 2010) and estimated based on watershed area and landuses for the Assawoman Creek and Little Mosquito Creek watersheds with respect to the county watershed area for urban landuse. For a more accurate estimation of human population, the 911 addresses were used to estimate the number of households and the county-averaged persons per household was used to estimate population. There are 2,652 properties in the Trail's End Campground located along Little Mosquito Creek. Occupancy is seasonal and difficult to estimate. The

average occupancy is estimated as 25%. The average population is about 1,492. For the remainder of the Little Mosquito Creek, the estimated population is about 2,261.

Wildlife

Wildlife contribution is estimated based on the abundant wildlife density and local survey data and feedback from stakeholders. The population number calculation details are described in Appendix B. The densities used for estimate wildlife are based on those of the Hungars-Mattawoman IP study, a nearby watershed with similar landuse in the Eastern Shore region. The density used to estimate wildlife population is listed in Table 3.1. Considering birds are the dominant contribution of wildlife along the Eastern Shore and high bird populations exist during peak of migration season (local information), a relatively high density number is used to estimate peak-season geese and duck populations. Results are listed in Table 3.2.

Livestock

There are 2 permitted poultry farms in the Little Mosquito Creek watershed and 9 permitted poultry farms in the Assawoman Creek watershed. The estimation of chickens and other livestock can be achieved by using USDA county census data. However, the approach may not be accurate as livestock are not often distributed evenly. VDH-DSS has routinely conducted shoreline surveys. The shoreline survey data and input from local residents are used to better characterize the distribution of livestock. Figure 3.1 shows the distribution of livestock on the watershed. The population is listed in Table 3.2. Although there are many chickens in the watersheds, this is not likely a significant nutrient contributor because of requirements for proper nutrient management and storage of litter as prescribed by the Virginia Pollution Abatement permits. Additionally, most of the chicken litter that is produced is not land applied locally.

Table 3.1: Densities Used for Estimating Wildlife in Assawoman Creek and Little Mosquito Creek

Wildlife Type	Population Density	Habitat Requirements
Deer	0.1032 animals/acre	Entire watershed
Raccoons	0.0703 animals/acre	Entire watershed
Muskrats	0.3128 animals/acre	300-foot buffer for primary habitat/600-foot buffer for secondary habitat (season peak)
Geese	0.032 animals/acre	300-foot buffer for primary habitat /600-foot buffer for secondary habit
Ducks	0.0652 animals/acre	300-foot buffer for primary habitat/600-foot buffer for secondary habitat (season peak)

Table 3.2: Human, Dog, Livestock, and Wildlife Populations in Assawoman Creek and Little Mosquito Creek

		Assawoman Creek	Little Mosquito Creek
Human	**Population**	1073	3753*
	Septic system	477	1005 663**
	Dogs	279	587*
Livestock	**Horses**	30	12
	Cattle	100	0
	Goats	4	5
	Chickens	1,620,900	51204
	Geese	0	0
Wildlife	**Deer**	695	982
	Raccoons	474	669
	Muskrats	2618	2978
	Geese	242	264
	Ducks	493	539
	Geese (peak season)	435	476
	Ducks (peak season)	887	970

*Population includes Trail's End Campground. ** Septic for Trail's End Campground is estimated based on seasonal 25% occupancy.

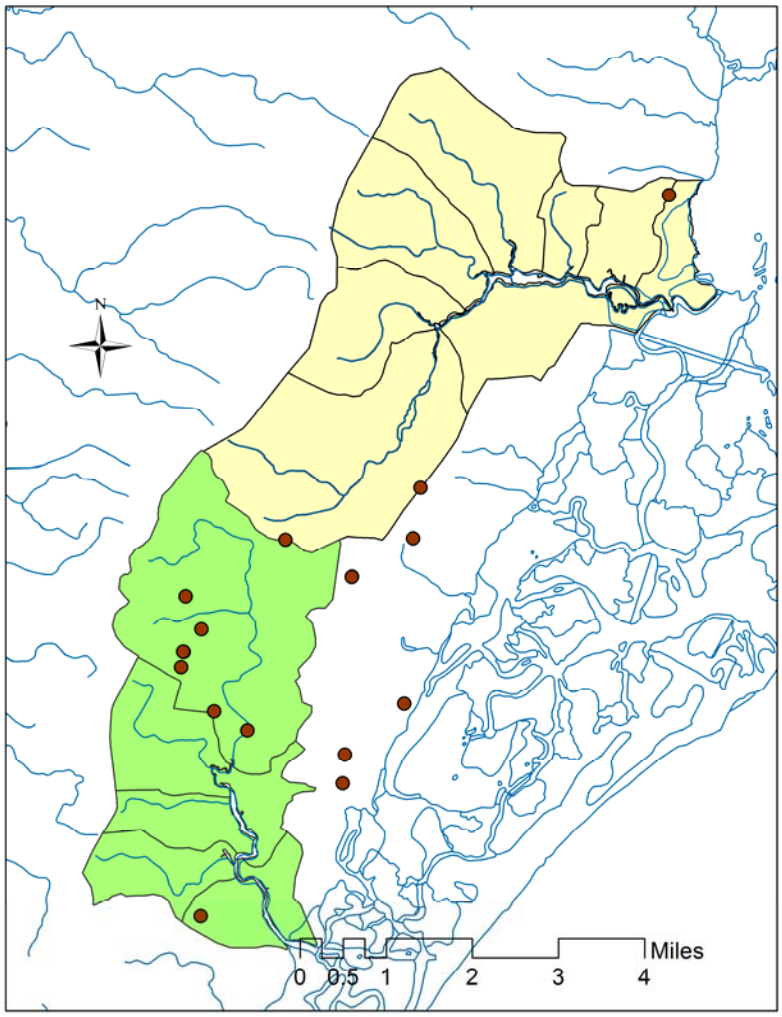


Figure 3.1: Location of Potential Causes of Problems Due to Livestock in Assawoman Creek (green shading area) and Little Mosquito Creek (yellow shading area)

3.3 Septic System Inputs

Conventional septic tank systems are only effective where the soil is adequately porous to allow percolation of liquids, and the groundwater level is low enough to avoid contamination. Leaking pipes or treatment tanks (i.e., leakage losses) can allow wastewater to return to the groundwater, or discharge to the surface, without adequate treatment. Leaking septic systems are a source of nutrients and bacteria. We used 911 addresses and converted them to a georeferenced Geographic Information System (GIS) layer to estimate the number of total households. This method provides a more accurate estimation of septic systems. As there are no houses located within the NASA urban land, the nutrient contribution from failing septic systems is only associated with urban areas

with population. There are totals of 477 and 3657 septic systems in the Assawoman Creek and Little Mosquito Creek watersheds, respectively (Figure 3.2). The occupancy of Trail's End Campground is about 25%. The active septic systems in Little Mosquito Creek is about 1668. Because the occupancy of each property in the campground is difficult to estimate, we use an estimated population and a failure rate of 5% to estimate the waste water for the Trail's End Campground. Using a failure rate of 5% based on the local VDH and the Hungars-Mattawoman IP report, the number of failed systems is approximately 24 and 83, respectively, for Assawoman Creek and Little Mosquito Creek watersheds. The nutrient concentration and flow used for the estimation of loading (USEPA TMDL tool) are nitrogen 60 mg/L, phosphorus 23.5 mg/L, BOD 290.0 mg/L, and flow 70 gallons/person/day.

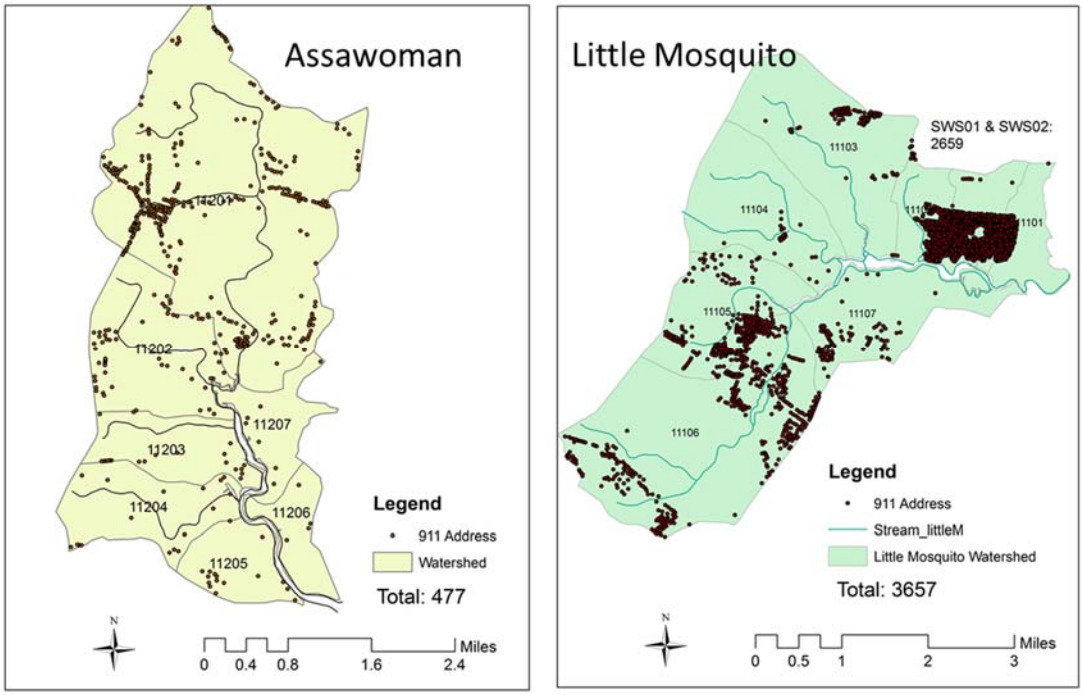


Figure 3.2: Septic System Locations in the Assawoman Creek and Little Mosquito Creek Watersheds

3.4 Manure/Litter/Fertilizer Applications

Farming practices are a source of nutrient contributions to the stream. Organic manure and litter and inorganic fertilizer are applied to croplands. When they are applied in excess or just before a rain event, nutrients can be washed into aquatic ecosystems. For the purposes of developing a value for the potential source of nutrients from fertilizer application to croplands, we assumed one application rate for the entire watershed. Based on local information, the estimated amount of N-fertilizer applied to the cropland is 125 lbs/acre/year in general. According to the recent NMP manure spreading summary since 2011, only 2 farms had poultry litter application, which were about 4 tons over 50 acres in the Assawoman Creek watershed. An estimation of percentages of N, P, and C is

approximately 15%, 5% and 89% of poultry litter, respectively.

3.5 Point Sources

There are two point sources that discharge to Assawoman Creek and one point source that discharges to Little Mosquito Creek. Permitted design flows and nutrient concentrations are listed in Table 3.3. Figure 3.3 shows the point source discharge of flow, BOD, and nutrients. In general the discharge is lower than designed flow and nutrients are within permitted concentration, except VA0091529. High discharge concentrations of TKN and BOD were observed for VA0091529. The concentrations have decreased in recent years. Discharged flow is less than 0.02 MGD and total loading of TKN is low. The estimated loadings (Table 3.4) are based on permitted design flow and parameters listed in Table 3.3. The accrual discharged loading based on monitoring data is lower than the permitted loading, except VA0091529.

Table 3.3: List of Point Source Permits

Permit	Facility Name	Creek	Design Flow (MGD)	BOD (mg/L)	TKN (mg/L)	NH3 (mg/L)
VA0024457	U.S. NASA-Wallops Flight Facility	Little Mosquito Creek	0.3	10	3	
VA0091529	Accomack County Leachate Treatment Facility	Assawoman Creek	0.02	10	3	4.9
VAR051367	Accomack County Northern Landfill	Assawoman Creek	0.1*	37		4.9
*estimated based 150 ac						

Table 3.4: List of Estimated Loadings for Point Source Permits

Permit	Facility Name	Creek	Design flow (MGD)	BOD (lbs/day)	TKN (lbs/day)	NH3 (lbs/day)
VA0024457	U.S. NASA-Wallops Flight Facility	Little Mosquito Creek	0.3	25.0	7.5	NA
VA0091529	Accomack County Leachate	Assawoman	0.02	1.7	0.5	0.8

	Treatment Facility					
VAR051367	Accomack County Northern Landfill	Assawoman	0.1	30.9	NA	4.1

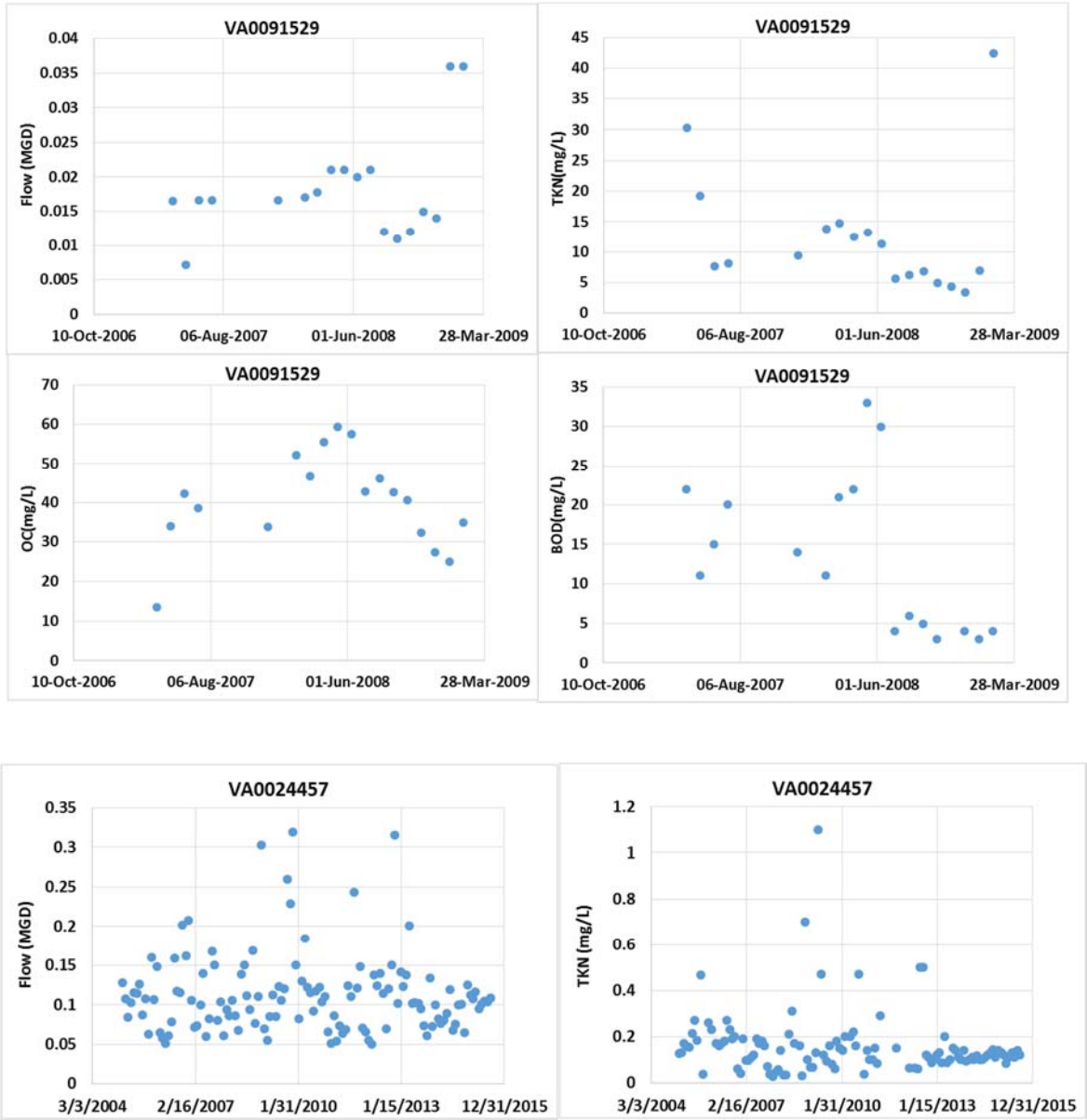


Figure 3.3: Distribution of Flow BOD and Nutrients for Point Source Discharges

3.6 Other Sources

Atmospheric deposition of air-borne nutrients has been estimated using the value from the literature for the Chesapeake Bay region shown in Table 3.5.

Table 3.5: Nutrient Contribution from Atmospheric Deposition

Nutrient	Loading (lbs/acre/year)
TN	11.48
TP	0.71

The EPA estimates that the average lawn fertilizer application in the Chesapeake Bay area ranges from 44-321 lbs/year. As less people may apply lawn fertilizer in this region, the low end of this range (44 lbs/yr) was estimated. This could be slightly over-estimated in this region. Because urban land use comprises a small percentage in this region, lawn application is a minor contribution in the watershed.

Inputs from groundwater are another significant source of nutrients to this region. Soil characteristics in the watershed can affect the groundwater nitrogen concentrations. In the Coastal Plain, riparian forests typically have poorly drained soils, which can potentially facilitate the removal of N from groundwater via plant uptake and denitrification. A study in Cherrystone Inlet and other locations of the Eastern Shore provide a TN range of 2.0 - 7.0 mg/L and a TP range of 0.02 - 0.03 mg/L (Reay, 1996). Stanhope *et al*. (2009) conducted an extensive study of the base-flow of nutrient loading along the Eastern Shore region. Streams were sampled monthly from May 2001 through April 2002. To exclude interference from surface water, base flow samples were collected only when there was at least a 48-hr antecedent period of no precipitation (Stanhope *et al*., 2009). The annual based-flow weighted concentrations of DIN, DIP, and DOC are 2.90, 0.013. 5.03 mg/L, respectively, for Little Mosquito Creek. The concentration of DIN, DIP, and DOC are 5.63, 0.09. 5.55 mg/L, respectively, for Assawoman Creek. Average concentrations for DIN, DIP, and DOC based on measurement from 14 creeks in the Eastern Shore region are 2.44, 0.024, and 4.2 mg/L, respectively. It can be seen that the large amount of nutrients originate from groundwater. The estimated loading of NO_3 ranges from 5.1-6.1 kg/ha/yr (4.5-5.4 lbs/ac/yr) and DOC ranges from 5.5-6.2 kg/ha/yr (4.5-5.52 lbs/ac/yr) in the Assawoman Creek and Little Mosquito Creek watershed regions. According to our watershed model simulation, the groundwater contribution of nitrogen and OC is on the same order of magnitude as the surface runoff.

The observation stations in both Creeks are located near the mouth. DO can be affected by conditions outside of the Creeks. Station 7-LTM000.80 is connected to the Maryland Coastal Bay. Figure 3.4 shows the comparison of DO observations collected at the 2 stations in the Coastal Bay near the Virginia side (~8 km). It can be seen that 2 stations inside the Coastal Bay have similar DO distribution and DO measured inside the Coastal

Bay is lower than saturation DO by 2.25 O_2 mg/L. Another station located near the shore shows that DO below 5 mg/L are frequently occurred in the Coastal Bay (Wang *et al*., 2014,http://www.mde.state.md.us/programs/Water/TMDL/ApprovedFinalTMDLs/Documents/MD_Coastal_Bays_nutrient_TMDL/WQM_report_031114_final.pdf). Low DO values can be observed during rainy days in the environment with high density of submerged aquatic vegetation (SAV) and macroalgae. Figure 3.5 shows that DOC concentration in Maryland Coastal Bay is also high between 2-6 mg/L. High DOC at Station XBM1301 occurred during summer, which corresponded to low DO at Station LTM000.80. Organic materials and relatively low DO water output from salt marsh due to higher respiration (Layman *et al*., 2000; Smith and Able, 2003) also add pressure to low DO conditions of the Creeks.

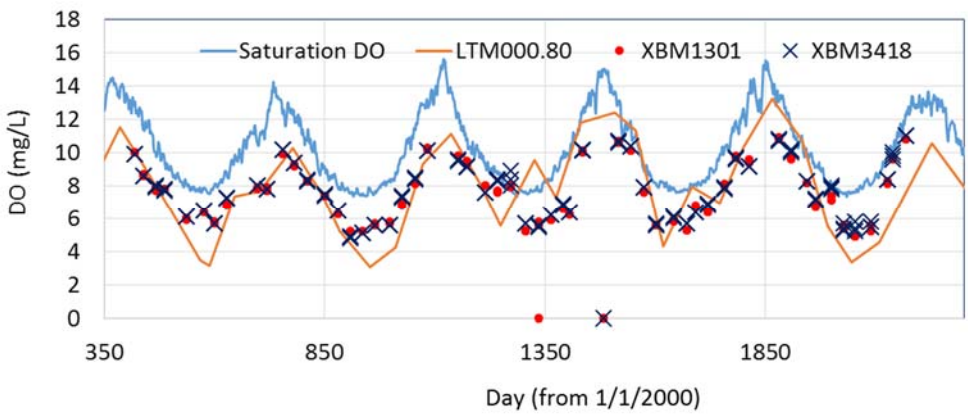


Figure 3.4: Comparison of observed DO in the Little Mosquito and Observations in the Maryland Coastal Bay and Saturation DO

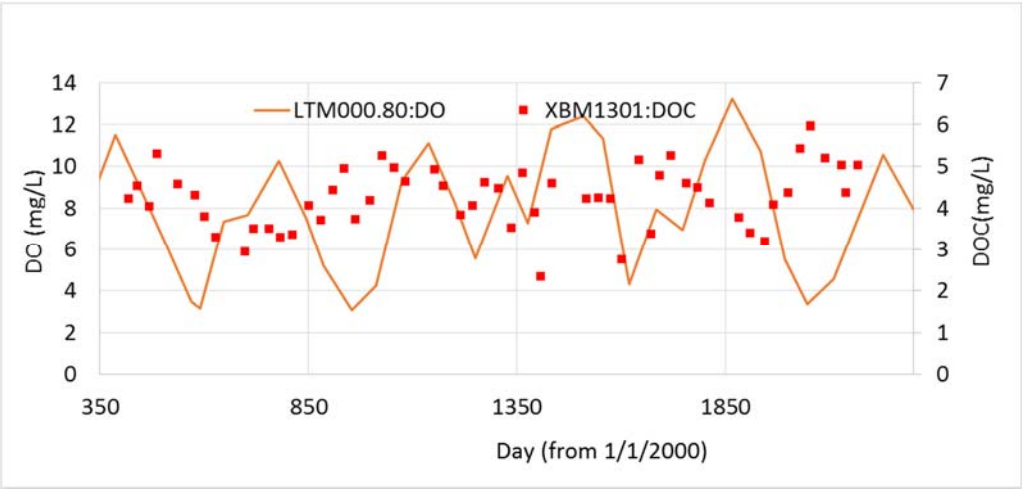


Figure 3.5: Distribution DO in the Little Mosquito Creek and Observed DOC in the Maryland Coastal Bay

3.7 Nutrient and BOD/Carbon Loads Summary

As building blocks for biotic production, N, P, and C are utilized in the process of algal growth, and then become available again as the algae die and decay. The natural processes of biotic decay result in the consumption of oxygen. However, excessive levels of decaying material will result in unacceptably low levels of DO. Nitrogen and phosphorus backgrounds, or natural levels, can vary depending upon the location, hydrology, and geology of the watershed. The critical determination in identifying the necessity and amount of nutrient reductions is defining the relationship between the nutrients and the target levels for DO. Quantifying the total loads for nutrients is necessary to understand the effects of various nutrient loads on DO. They are also needed to develop scenarios to model reductions in nutrient inputs to analyze the effect of the reduction on DO. The goal is to identify the nutrient loads that result in ambient concentrations that support the DO target.

The nutrient loads contributed from livestock and wildlife were estimated based on nutrient productions per animal per day. The production rates for livestock were based on data compiled by the American Society of Agricultural Engineers (ASAE, 1994). For wildlife, the nutrient production rates were estimated based on the animal rates that have similar sizes. The contributions from failure of septic systems were estimated based on nutrient concentrations and typical septic overcharge flow rate per person. A value of 70 gal/day/person was assumed and the concentrations for TN, TP, and BOD were 60 mg/L, 23.5 mg/L, and 290.0 mg/L, respectively.

For OC, which is both naturally produced on land and a potential pollutant in the waterway, the accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of C/N obtained from monitoring data during wet-dry seasonal sampling instead of directly surveyed field data. The ratio of TC/TN of the wet-dry seasonal measurement in Onancock Creek, a watershed with similar hydrology and land use features, is from 3 to 7 (Shen *et al*., 2008). The ratio of DOC and dissolved nitrogen is about 2 in Assawoman Creek and Little Mosquito Creek. The nutrient and carbon concentrations for interflow and groundwater were derived from the base flow study conducted by Stanhope *et al*. (2009) in the Assawoman Creek and Little Mosquito Creek. The total loads for TN, TP, and OC on the surface were estimated based on land use distribution. Load contributions from manure/litter/fertilizer applications were applied to agricultural land uses, those from atmospheric deposition were distributed to all landuse categories. Wildlife of birds and deer were distributed to all land uses. Other wildlife were distributed to landuses except urban. Those from failure of septic systems were applied to low-intensity residential landuses.

As estimation of inputs of nitrogen to each landuse together with point source is summarized in Table 3.6. Point source loadings are estimated based on the permitted concentration and design flow. It should be noted that not all nutrients applied on the watershed will be discharged to the stream. For example, a large amount of nutrients applied to the cropland will be taken up by the plants. A portion of nitrogen will be leached to the groundwater and some will be lost due to denitrification.

Table 3.6: Total Nitrogen Deposited on Land and Point Sources Discharged to Stream

	Assawoman		**Little Mosquito**	
Category	TN (lb/Year)	Percentage	TN (lb/Year)	Percentage
Barren	51.2	0.02%	15.4	0.00%
Cropland	252,859.3	80.52%	261,981.4	74.80%
Forest	14,583.2	4.64%	21,317.0	6.09%
Pasture	18,978.0	6.04%	10,361.3	2.96%
Urban Pervious	3,929.9	1.25%	9,118.3	2.60%
Wetlands	20,121.5	6.41%	36,666.1	10.47%
Urban Impervious	3,010.9	0.96%	8,038.5	2.30%
Point Source	480.6	0.15%	2,737.6	0.78%
Total	314,014.6	100.00%	350,235.5	100.00%

4.0 TMDL DEVELOPMENT

4.1 Overview

A TMDL is the total amount of a pollutant that a waterbody can receive and still meet WQS. A TMDL may be expressed as a "mass per unit time, toxicity, or other appropriate measure" (CFR, 2006). These loads are based on an averaging period that is defined by the specific WQS. A TMDL is the sum of individual wasteload allocations (WLAs) for point sources and load allocations (LAs) for nonpoint sources, incorporating natural background levels. The TMDL must, either implicitly or explicitly, include a margin of safety (MOS) that accounts for the uncertainty in the relationship between pollutant loads and the quality of the receiving waterbody, and in the scientific and technical understanding of water quality in natural systems. In addition, when applicable, the TMDL may include a future allocation (FA) when necessary. This definition is denoted by the following equation:

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

This section documents the detailed DO TMDLs and LA development for Assawoman Creek and Little Mosquito Creek.

4.2 Selection of TMDL Endpoints

An important step in developing a TMDL is the establishment of in-stream numerical endpoints, which are used to evaluate the attainment of acceptable water quality and allowable loading capacity. According to WQS 9VAC25-260-50, the numerical criteria for DO for Class II waters are a minimum of 4.0 mg/L and a daily average of 5.0 mg/L. Based on data analysis and field surveys, as well as model sensitivity tests, it is evident that high temperature and low re-aeration, together with the high SOD resulting from the accumulation of organic matter, are the dominant causes of low DO. Reducing nutrients and OC discharge to the Creek will improve the DO condition.

4.3 Model Development for Computing TMDL

Numerical models are a widely used approach for TMDL and other water quality studies. In this study, a system of numerical models was applied to simulate the loadings of organic matter and nutrients from the watershed, and the resulting response of in-stream water quality variables such as DO, algae, and nutrients. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model Loading Simulation Program in C^{++} (LSPC), developed by the USEPA (Shen *et al.*, 2005), was selected to simulate the watershed hydrology and nutrient loads to Assawoman Creek and Little Mosquito Creek. Figure 4.1 shows a diagram of the modeling system. The Environmental Fluid Dynamics Computer Code (EFDC) (Park *et al.*, 1995) recommended by EPA was used to simulate the water quality of the receiving water. A detailed model description, model setup, model calibration, and scenario runs are presented in Appendix A.

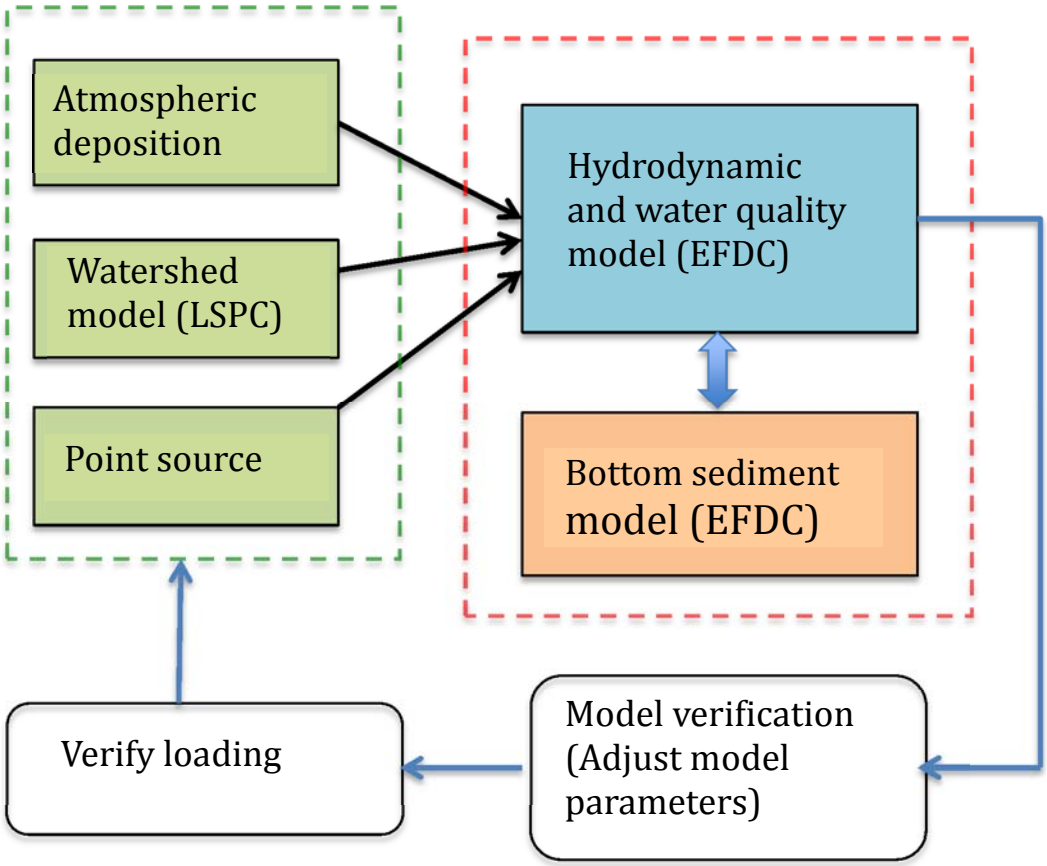


Figure 4.1: Diagram of the Structure of Modeling System

The LSPC model is driven by hourly precipitation and was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (nitrogen, phosphorus, and OC) loadings from each sub-watershed were fed into the adjacent water quality model segments. The EFDC model simulates the transport of pollutants and eutrophication processes in the Creek. In order to predict primary production and DO, a large suite of model state variables controlling nutrient and DO dynamics were simulated in the model, including:

1. Algae (green)
2. OC (particulates and dissolved)
3. Organic phosphorus (particulates and dissolved)
4. Phosphate
5. Organic nitrogen (particulates and dissolved)
6. Inorganic nitrogen (ammonium and nitrate)
7. DO

The water column processes are coupled to the sediment diagenesis, which is a group of chemical processes in sediment causing mineralization of organic matters after they have been deposited. The sediment diagenesis model simulates the changes of particulate organic matter deposited from the overlying water column and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate, and sulfite), and the SOD back to the water column.

The flow simulated by the watershed model was calibrated using United States Geological Survey (USGS) gauging data at Gage 01484800 in Guy Creek near Nassawadox, VA, located approximately 50 km south of the Assawoman Creek watershed, which is the only USGS station located along the Eastern Shore. An example of model calibration of the flow is shown in Figure 4.2. Detailed modeling processes and the calibration procedure are presented in Appendix A.

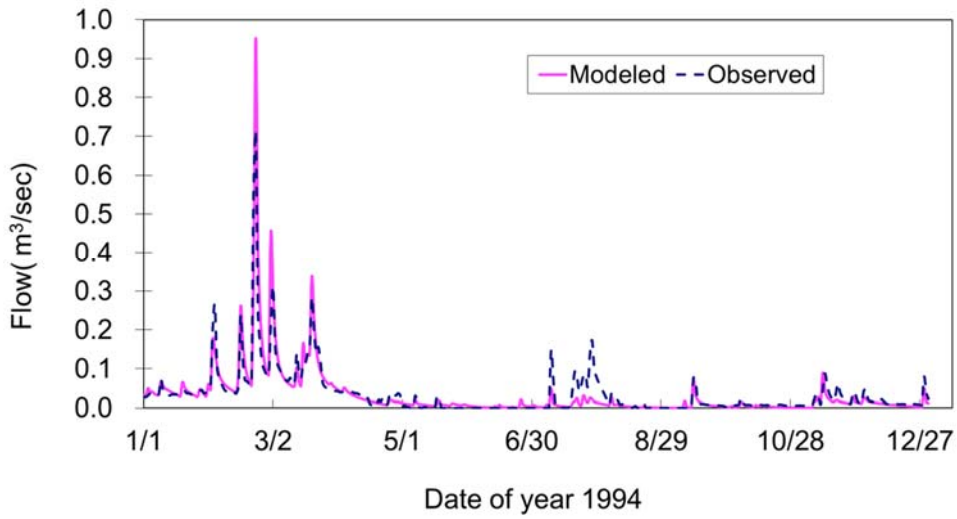


Figure 4.2: Time Series Comparison of Daily Stream Flow between Model Simulation and Observations from USGS Stream Gage 01484800 in 1994

Because the nutrient observation data in the Guy Creek watershed were not available, a linked watershed-in stream model approach was used for the model calibration based on the observations in the receiving water. The water quality model was calibrated in Assawoman Creek using the observation data collected in the Creek for a 13-year simulation period (2000-2013). The selection of this period was due to the observation of nutrient species data availability and occurrence of low DO measurements. The model was calibrated based on algae (Chl a), TN and TP, phosphate, ammonium, nitrate, and DO. The computed average nitrogen and phosphorus loadings are 104,623.4 and 2,807 lbs per year, respectively, for the Assawoman watershed and 133,549.3 and 2,128.8 lbs per year, respectively, for the Little Mosquito Creek watershed.

A comparison of model results against observations for DO and phytoplankton from 2000-2011 is shown in Figures 4.3 and 4.4 for Assawoman and Little Mosquito Creeks,

respectively. It can be seen that the model simulated the seasonal DO and algae variation and low DO during this period well. Sometimes, the algal concentration can be very high, which is typical in this environment. The model is calibrated to the seasonal and interannual variation, rather than to catch the peaks. The model predicted low DO in 2002 and 2005, but missed low DO in 2006 for Assawoman Creek. The DO calibration is satisfactory overall. There are several factors that will affect the model performance. Both outside conditions of DO and DOC concentrations have a large impact on the DO inside the estuaries, which will be discussed in the Appendix. The detailed model setup and calibration processes and model sensitivity runs are presented in Appendix A.

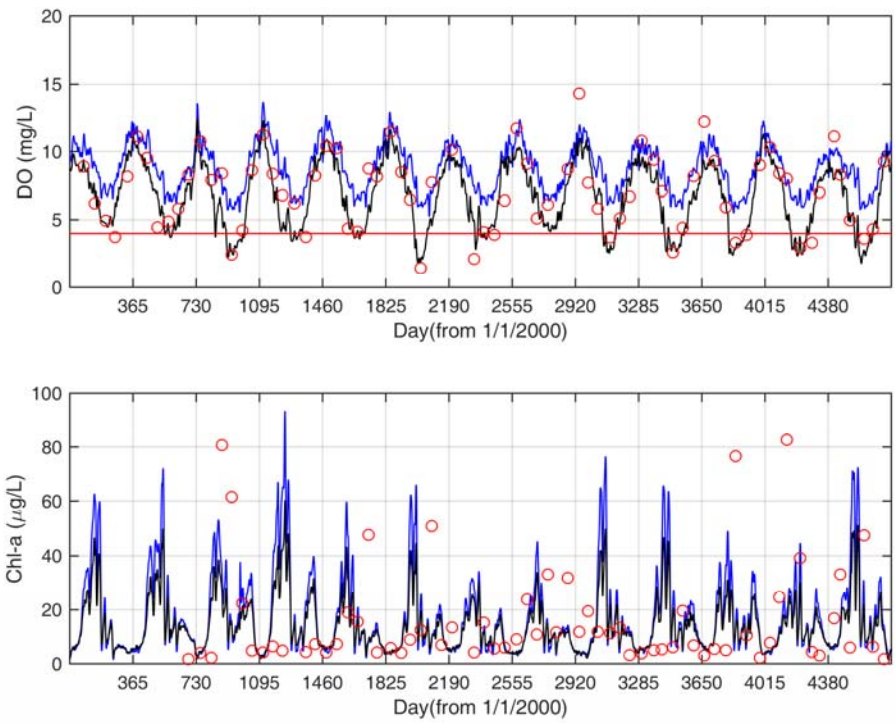


Figure 4.3: Time Series Comparison of DO and Chl-a between Model Simulation and Observation from 2000 to 2011 at Station 7-ASW003.36 in the Assawoman Creek-Lower (Blue Lines Are Modeled Daily Mean, Black Lines Are Modeled Daily Maximum, and Red Circles Are Observations)

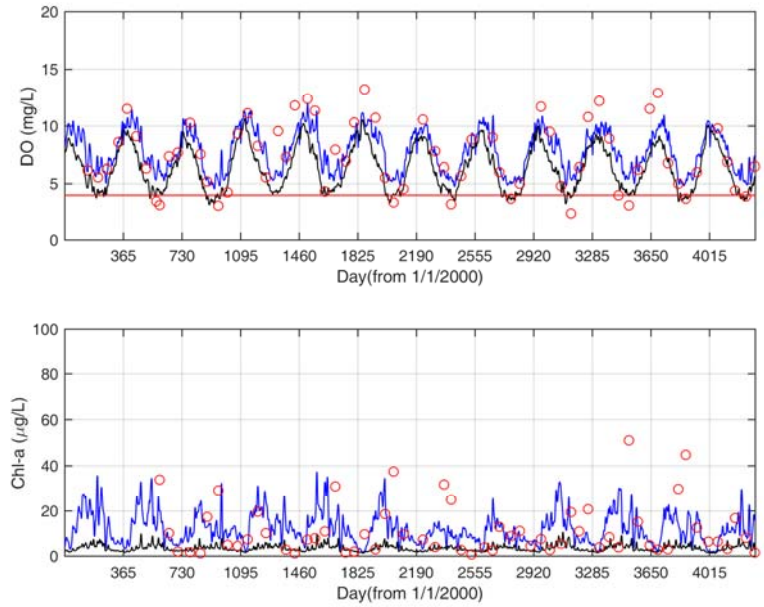


Figure 4.4: Time Series Comparison of DO and Chl-a between Model Simulation and Observation from 2000 to 2011 at Station 7-LTM000.80 in the Little Mosquito Creek-Lower (Blue Lines Are Daily Mean, Black Lines Are Daily Maximum, and Red Circles are Observations)

4.4 Consideration of Critical Conditions and Seasonal Variation

EPA regulations at 40 CFR 130.7 (c)(1) require TMDL studies to take into account critical conditions for stream flow, loading, and water quality parameters. The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when they are most vulnerable. Critical conditions are important because they describe the factors that combine to cause a violation of WQS and help to identify the actions that may have to be undertaken to meet WQS.

The current loadings to the waterbody were determined using a long-term record of water quality monitoring (observation) data and watershed model from 2000-2014. The period of record spans different flow regimes and temperatures. The selection of the period represents the occurrence of the lowest DO and available observations data for nutrient species. The eutrophication model was calibrated based on multiple water quality parameters including TN and TP, phosphate, ammonium, nitrate, algae, ON, and DO. The resulting estimate is quite robust. Seasonal variations involved changes in surface runoff, stream flow, and water quality as a result of hydrologic and climatologic patterns. These are accounted for by the use of this long-term simulation to estimate the current load and reduction targets.

4.5 Margin of Safety

To allocate loads while protecting the aquatic environment, a MOS needs to be considered. A MOS is typically expressed either as unallocated assimilative capacity or as conservative analytical assumptions used in establishing the TMDL (e.g., derivation of numeric targets, modeling assumptions or effectiveness of proposed controls). In the TMDL calculation, the MOS can either be explicitly stated as an additional separate quantity, or implicitly stated, as in conservative assumptions. For the Little Mosquito and Assawoman Creeks, an explicit MOS of 5% was included in the TMDLs.

4.6 TMDL Computation

According to the endpoints for DO for the established pollutant reduction target, the allowable nitrogen to meet the DO standards can be computed.

The load reduction needed for the attainment of the criteria was determined as follows:

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

Because the stations near the mouth for both Creeks are influenced by the outside condition, the assessments for the reduction is focused on the DO concentrations in the middle and upstream segments for both Creeks, which represents the current watershed condition. Model simulations of reductions of both TN and TP, and reduction of TN only were conducted, respectively, for Assawoman and Little Mosquito Creeks. It is found that, by reducing TN only, the attainment condition can be achieved, as nitrogen is often limited in the Creeks. Therefore, the TMDL is developed based on nitrogen reduction. For the model simulation, the organic carbon loading ranges from 1.25-1.5 of TN. Once nitrogen is reduced, OC is on the same order of TN and it will be reduced in proportion to nitrogen, as nitrogen is the essential element for plants for carbon fixation. The calculated results for TN are listed in Tables 4.1. Although nutrient inputs are similar in terms of acreage loading for Assawoman and Little Mosquito Creeks, more nutrient reduction is needed for the Assawoman due to the difference of dynamic conditions. A relatively larger residence time in the middle portion to the upstream portion of Assawoman Creek is found compared to that in Little Mosquito Creek, resulting in less nutrients being transported out of the system. Note the loads presented in the following tables are loads derived from runoff from watershed or from groundwater.

Table 4.1: Estimated Loads and Load Reductions for TN

Watershed	Pollutant	Current Load (lbs/year)	Allowable Load (lbs/year)	Allowable Load (lbs/day)	Required Reduction (%)
Assawoman Creek	TN	104,616.5	52,308.2	311.4	50%
Little Mosquito Creek	TN	133,549.3	80,129.6	469.4	40%

4.7 Summary of TMDL and Load Allocation

The daily allowable loads for these water bodies were computed based on annual loading with statistical adjustment (Appendix A4). The loads were then allocated to the WLA and LA. There are two permitted point sources in the Assawoman Creek watershed and one in the Little Mosquito watershed. The discharges for each of these permits, with permitted parameters and limits listed in Table 3.3, are to be considered consistent with the assumptions and requirements of this TMDL. The TMDLs are summarized below in Tables 4.2 and 4.3:

Table 4.2: Total Maximum Daily Load (lbs/day) of Nitrogen (TN) for Assawoman Creek and Little Mosquito Creek

Impairment	WLA****	LA	MOS	TMDL
Assawoman	8.5	287.4	15.6	311.4
VA0091529	*1.3**			
VAR051367	*4.1***			
Future load (1%)	*3.1*			
Little Mosquito	12.2	433.8	23.5	469.4
VA0024457	7.5***			
Future load (1%)	4.7			

*The WLA for VA0091529 is for TKN (0.5 lbs/day) and NH_3 (0.8 lbs/day)
**The WLA for VAR051367 is for NH_3
***The WLA for VA0024457 is for TKN (7.5 lbs/day)
****The discharge for each of these permits, with permitted parameters and limits listed in Table 3.3, are to be consistent with the assumptions and requirements of this TMDL.

Table 4.3: Total Maximum Annual Load (lbs/year) of Nitrogen (TN) for Assawoman Creek and Little Mosquito Creek

Impairment	WLA****	LA	MOS	TMDL
Assawoman	2,487	47,205.8	2,615.4	52,308.2
VA0091529	*474.5**			
VAR051367	1,489.4**			
Future load (1%)	*523.1*			
Little Mosquito	3538.8	72,584.2	4006.5	80,129.6
VA0024457	2737.5***			
Future load (1%)	801.3			

*The WLA for VA0091529 is for TKN (182.5 lbs/year) and NH_3 (292 lbs/year)
**The WLA for VAR051367 is for NH_3
***The WLA for VA0024457 is for TKN (2737.6 lbs/year)
****The discharge for each of these permits, with permitted parameters and limits listed in Table 3.3, are to be consistent with the assumptions and requirements of this TMDL.

Where:

TMDL = Total Maximum Daily Load
LA = Load Allocation (Nonpoint Sources)
WLA = Wasteload Allocation (Point Sources)
FA = Future Allocation (1% of the TMDL)
MOS = Margin of Safety

A review of measured discharges from point sources indicates that discharged loading of nitrogen is less than 2% of nitrogen discharged to the stream. As a conservative measure, the loading from point sources was calculated using permitted design flow and nitrogen concentrations. These results have indicated that point source loads account for less than 3.8% of the total allowable loading from each of the two watersheds. Therefore, no reductions are applied to the three point sources (VA0024457, VA0091529, and VAR051367). A future growth component was added to the WLA to account for any additional permits that may be given in the future. A portion of 1% of the total allowable load is assigned to future growth as WLA.

The allocation of reduction for each land use as annual loading is listed in Tables 4.4 and 4.5 for Assawoman and Little Mosquito. The reduction required for Assawoman is 52,308 lbs/year (current load of 104,616 lbs/year – allocated load of 52,308 lbs/year = required reduction of 52.308 lbs/year), while the current load from surface runoff is 42,105 lbs/year (Table 4.4a and b) for Assawoman. It can be seen that the current load from surface runoff in the Assawoman watershed is less than the required reduction. Therefore, the WQS cannot be achieved without reducing the groundwater loading for Assawoman. Table 4.4a shows that with a reduction of 85% from surface runoff from cropland, pasture, and urban pervious areas from Assawoman, the percent reduction required for groundwater is 33.8%. In order to provide implementation options, an alternative allocation scenario is presented which calls for reductions of surface runoff from cropland, pasture, and urban pervious areas by 50% and reductions of groundwater

by 55.5%. The rationale for this approach is that reducing input nitrogen to the land surface or improving the practice of nitrogen application would result in a gradual reduction of the leaching of nitrogen to the groundwater. Note that the runoff from the watershed is less than 10% of the nitrogen added to the land. A large portion of nitrogen is taken up by plants. The remaining portion of nitrogen is incorporated into the soil or is leached to the groundwater. With appropriate management of nitrogen application and runoff, the total runoff of nitrogen can be reduced and the groundwater level will be gradually improved.

Table 4.4a: Allocation I and TN Reduction for Each Landuse for Assawoman Creek

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	6.9	0.0%	6.9	0.0%
Cropland	33,957.1	32.5%	5,093.6	85.0%
Forest	1,958.4	1.9%	1,958.4	0.0%
Pasture	2,548.6	2.4%	382.3	85.0%
Urban Pervious	527.8	0.5%	79.2	85.0%
Wetlands	2,702.2	2.6%	2,702.2	0.0%
Urban Impervious	404.3	0.4%	60.7	85.0%
Sum of surface runoff	42,105.3	40.2%	10,283.1	75.6%
Ground	60,547.3	57.9%	40,061.2	33.8%
Point Source	1963.9461	1.9%	1963.9	0.0%
Total	104,616.5	100.0%	52,308.2	50.0%

Table 4.4b: Allocation II and TN Reduction for Each Landuse for Assawoman Creek

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	6.9	0.0%	6.9	0.0%
Cropland	33,957.1	32.5%	16,978.6	50.0%
Forest	1,958.4	1.9%	1,958.4	0.0%
Pasture	2,548.6	2.4%	1,274.3	50.0%
Urban Pervious	527.8	0.5%	263.9	50.0%
Wetlands	2,702.2	2.6%	2,702.2	0.0%
Urban Impervious	404.3	0.4%	202.2	50.0%
Sum of surface runoff	42,105.3	40.2%	23,386.4	44.5%
Ground	60,547.3	57.9%	26,957.9	55.5%
Point Source	1963.9461	1.9%	1963.9	0.0%
Total	104,616.5	100.0%	52,308.2	50.0%

Table 4.5a: Allocation I and TN Reduction for Each Landuse for Little Mosquito

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	2.8	0.0%	2.8	0.0%
Cropland	48,278.0	36.1%	7,241.7	85.0%
Forest	3,928.3	2.9%	3,928.3	0.0%
Pasture	1,909.4	1.4%	286.4	85.0%
Urban Pervious	1,680.3	1.3%	252.0	85.0%
Wetlands	6,756.8	5.1%	6,756.8	0.0%
Urban Impervious	1,481.3	1.1%	222.2	85.0%
Sum of surface runoff	64,037.1	48.0%	18,690.3	70.8%
Ground	66,774.7	50.0%	58,701.7	12.1%
Point Source	2737.6	2.0%	2737.6	0.0%
Total	133,549.3	100.0%	80,129.6	40.0%

Table 4.5b: Allocation II and TN Reduction for Each Landuse for Little Mosquito

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	2.8	0.0%	2.8	0.0%
Cropland	48,278.0	36.1%	24,139.0	50.0%
Forest	3,928.3	2.9%	3,928.3	0.0%
Pasture	1,909.4	1.4%	954.7	50.0%
Urban Pervious	1,680.3	1.3%	840.2	50.0%
Wetlands	6,756.8	5.1%	6,756.8	0.0%
Urban Impervious	1,481.3	1.1%	740.7	50.0%
Sum of surface runoff	64,037.1	48.0%	37,362.5	41.7%
Ground	66,774.7	50.0%	40,029.5	40.1%
Point Source	2737.6	2.0%	2737.6	0.0%
Total	133,549.3	100.0%	80,129.6	40.0%

5.0 IMPLEMENTATION AND PUBLIC PARTICIPATION

5.1 General

Once a TMDL has been approved by the EPA, measures must be taken to reduce pollution levels from both point and nonpoint sources in the stream. For point sources, all new or revised Virginia Pollutant Discharge Elimination System (VPDES)/National Pollutant Discharge Elimination System (NPDES) permits must be consistent with the TMDL WLA pursuant to 40 CFR '122.44 (d)(1)(vii)(B) and must be submitted to EPA for approval. The measures for nonpoint source reductions, which can include the use of better treatment technology and the installation of best management practices (BMPs), are implemented in an iterative process that is described along with specific BMPs in the implementation plan. The process for developing an implementation plan has been described in the "TMDL Implementation Plan Guidance Manual", published in July 2003 and available upon request from the DEQ and DCR TMDL project staff or at http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ImplementationPlans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the values of their land and water resources. Additionally, development of an approved implementation plan may enhance opportunities for obtaining financial and technical assistance during implementation.

5.2 Staged Implementation

In general, Virginia intends for the required nutrient reductions to be implemented in an iterative process that first addresses those sources with the largest impact on water quality. For example, in agricultural areas of the watershed, BMP technology can be used to reduce the runoff of nutrient discharging to the creeks.

Additionally, in both urban and rural areas, reducing the human loading from failing septic systems should be a primary implementation focus because of its health implications. This component could be implemented through education on septic tank pump-outs as well as a septic system repair/replacement program and the use of alternative waste treatment systems.

The iterative implementation of BMPs in the watershed has several benefits:

1. To enable tracking of water quality improvements following BMP implementation through follow-up stream monitoring;
2. To provide a measure of quality control, given the uncertainties inherent in computer simulation modeling;
3. To provide a mechanism for developing public support through periodic updates on BMP implementation and water quality improvements;
4. To help to ensure that the most cost-effective practices are implemented first; and
5. To allow for the evaluation of the adequacy of the TMDL in achieving WQS.

Watershed stakeholders will have the opportunity to participate in the development of the

TMDL implementation plan.

5.3 Reasonable Assurance for Implementation

5.3.1 Follow-Up Monitoring

Following the development of the TMDL, DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. DEQ's Ambient Watershed Monitoring Plan for conventional pollutants calls for watershed monitoring to take place on a rotating basis, bi-monthly for two consecutive years of a six-year cycle. In accordance with DEQ Guidance Memo No. 03-2004, during periods of reduced resources, monitoring can temporarily discontinue until the TMDL staff determines that implementation measures to address the source(s) of impairments are being installed. Monitoring can resume at the start of the following fiscal year, next scheduled monitoring station rotation, or where deemed necessary by the regional office or TMDL staff, as a new special study.

The purpose, location, parameters, frequency, and duration of the monitoring will be determined by the DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee, and local stakeholders. Whenever possible, the location of the follow-up monitoring station(s) will be the same as the listing station. At a minimum, the monitoring station must be representative of the original impaired segment. The details of the follow-up monitoring will be outlined in the Annual Water Monitoring Plan prepared by each DEQ Regional Office. Other agency personnel, watershed stakeholders, etc. may provide input on the Annual Water Monitoring Plan. These recommendations must be made to the DEQ regional TMDL coordinator by September 30 of each year.

DEQ staff, in cooperation with DCR staff, the Implementation Plan Steering Committee, and local stakeholders, will continue to use data from the ambient monitoring stations to evaluate reductions in pollutants ("water quality milestones" as established in the IP), the effectiveness of the TMDL in attaining and maintaining WQS, and the success of implementation efforts. Recommendations may then be made, when necessary, to target implementation efforts in specific areas and continue or discontinue monitoring at follow-up stations.

In some cases, watersheds will require monitoring above and beyond what is included in DEQ's standard monitoring plan. Ancillary monitoring by citizens, watershed groups, local government, or universities is an option that may be used in such cases. An effort should be made to ensure that ancillary monitoring follows established quality assurance/quality control (QA/QC) guidelines in order to maximize compatibility with DEQ monitoring data. In instances where citizens' monitoring data are not available and additional monitoring is needed to assess the effectiveness of targeting efforts, TMDL staff may request of the monitoring managers in each regional office an increase in the number of stations or that they monitor existing stations at a higher frequency in the watershed. The additional monitoring beyond the original bi-monthly single-station monitoring will be contingent on staff resources and available laboratory budget. More

information on citizen monitoring in Virginia and QA/QC guidelines is available at: http://www.deq.virginia.gov/Programs/Water/WaterQualityInformationTMDLs/WaterQualityMonitoring/CitizenMonitoring/Guidance.aspx.

To demonstrate that the watershed is meeting WQS in watersheds where corrective actions have taken place (whether or not a TMDL or TMDL Implementation Plan has been completed), DEQ must meet the minimum data requirements from the original listing station or a station representative of the originally listed segment. The minimum data requirement for conventional pollutants (bacteria, DO, etc.) is bi-monthly monitoring for two consecutive years. For biological monitoring, the minimum requirement is two consecutive samples (one in the spring and one in the fall) in a one-year period.

5.3.2 Regulatory Framework

While Section 303(d) of the CWA and current EPA regulations do not require the development of TMDL implementation plans as part of the TMDL process, they do require reasonable assurance that the LAs and WLAs can and will be implemented. EPA also requires that all new or revised NPDES permits must be consistent with the TMDL WLA pursuant to 40 CFR §122.44 (d)(1)(vii)(B). All such permits should be submitted to EPA for review.

Additionally, Virginia's 1997 Water Quality Monitoring, Information and Restoration Act (the "Act") directs the State Water Control Board to "develop and implement a plan to achieve fully supporting status for impaired waters" (Section 62.1-44.19.7). The Act also establishes that the implementation plan shall include the date of expected achievement of water quality objectives, measurable goals, corrective actions necessary and the associated costs, benefits and environmental impacts of addressing the impairments. EPA outlines the minimum elements of an approvable implementation plan in its 1999 "Guidance for Water Quality-Based Decisions: The TMDL Process." The listed elements include implementation actions/management measures, timelines, legal or regulatory controls, time required to attain WQS, monitoring plans, and milestones for attaining WQS.

For the implementation of the WLA component of the TMDL, the Commonwealth intends to utilize the VPDES program, which typically includes consideration of the WQMIRA requirements during the permitting process. Requirements of the permit process should not be duplicated in the TMDL process, and with the exception of stormwater-related permits, permitted sources are not usually addressed during the development of a TMDL implementation plan.

For the implementation of the TMDL's LA component, a TMDL implementation plan addressing at a minimum the WQMIRA requirements will be developed. An exception is the municipal separate storm sewer systems (MS4s) that are both covered by NPDES permits and expected to be included in TMDL implementation plans, as described in the water permit section below. Watershed stakeholders will have opportunities to provide input and to participate in the development of the TMDL implementation plan. Regional

and local offices of DEQ, DCR, and other cooperating agencies are technical resources to assist in this endeavor.

In response to a Memorandum of Understanding (MOU) between the EPA and DEQ, DEQ also submitted a draft Continuous Planning Process to EPA in which DEQ commits to regularly updating the Water Quality Management Plans (WQMPs). Thus, the WQMPs will be, among other things, the repository for all TMDLs and TMDL implementation plans developed within a river basin.

DEQ staff will present both EPA-approved TMDLs and TMDL implementation plans to the State Water Control Board for inclusion in the appropriate WQMP, in accordance with the CWA's Section 303(e) and Virginia's Public Participation Guidelines for Water Quality Management Planning. DEQ staff will also request that the State Water Control Board (SWCB) adopt TMDL WLAs as part of the Water Quality Management Planning Regulation (9VAC 25-720), except in those cases when permit limitations are equivalent to numeric criteria contained in the Virginia WQS. This regulatory action is in accordance with §2.2-4006A.4.c and §2.2-4006B of the Code of Virginia. SWCB actions relating to water quality management planning are described in the public participation guidelines referenced above and can be found on DEQ's website under http://www.deq.virginia.gov/Portals/0/DEQ/Water/TMDL/ppp.pdf

5.3.3 Implementation Funding Sources

Cooperating agencies, organizations, and stakeholders must identify potential funding sources available for implementation during the development of the implementation plan in accordance with the "Virginia Guidance Manual for Total Maximum Daily Load Implementation Plans." Potential sources for implementation may include the U.S. Department of Agriculture's Conservation Reserve Enhancement and Environmental Quality Incentive Programs, EPA Section 319 funds, the Virginia State Revolving Loan Program, Virginia Agricultural Best Management Practices Cost-Share Programs, the Virginia Water Quality Improvement Fund, tax credits and landowner contributions.

The TMDL Implementation Plan Guidance Manual contains additional information on funding sources, as well as government agencies that might support implementation efforts and suggestions for integrating TMDL implementation with other watershed planning efforts.

5.4 Public Participation

The development of the TMDL would not have been possible without public participation. A kick-off Work Group meeting was held on June 23, 2015 at the Accomack-Northampton Planning District Commission, to inform the stakeholders of TMDL development process and to obtain feedback. A second Work Group meeting was held August 25, 2015 to update source estimates in the watersheds. Results of the hydrologic calibration, nutrient source estimates, and TMDL development were discussed in the second public meeting which was held on October 15, 2015 at the Chincoteague

BFS on Wallops Island, VA. Updated nutrient loading and TMDL results were presented and discussed at the final public meeting held on March 10, 2016 at the ANPDC.

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Appendix A: Model Development

A.1 Model Development

Numerical models are a widely used approach for TMDL and other water quality studies. In this study, a system of numerical models was developed to simulate the loadings of organic matter and nutrients from the watershed, and the resulting response of in-stream water quality variables such as DO, algae, and nutrients. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model LSPC, developed by the USEPA, was selected to simulate the watershed hydrology and nutrient loads to the receiving waterbodies of Assawoman Creek and Little Mosquito Creek. The EFDC model (Park *et al*., 1995) was used to simulate the water quality of the receiving water. Figure A-1 shows a diagram of the modeling system.

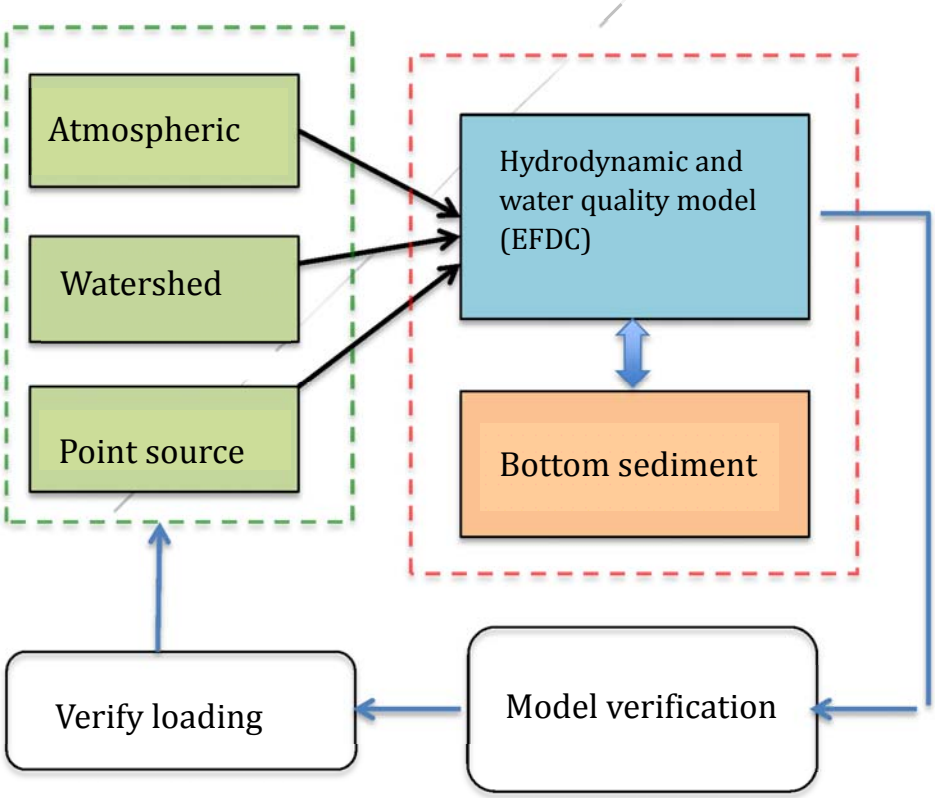


Figure A-1: Diagram of the Structure of Modeling System

A.1.1 Watershed Model

The LSPC model is a stand-alone, personal computer-based watershed modeling program developed in Microsoft C^{++} (Shen *et al*., 2005). It includes selected Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land, as well as a simplified stream transport model (USEPA, 2004; Shen *et al.*, 2002a, b; USEPA, 2001a, b). Like other watershed models, LSPC is a precipitation-driven model and requires necessary meteorological data as model input.

The LSPC model was configured for Assawoman Creek and Little Mosquito Creek watersheds to simulate these watersheds. The Assawoman Creek and Mosquito Creek watersheds are segmented, respectively, as 7 and 8 hydrologically connected subwatersheds (Figure A-2). The subwatersheds were used as modeling units for the simulation of flow, nutrient, and pathogen loads based on meteorology, land use, and nutrient application and pathogen deposition on the watershed. LSPC was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (nitrogen, phosphorus, OC, etc.) loadings for each subwatershed were fed into the adjacent water quality model segments. In simulating nonpoint source pollutants from the watershed, LSPC uses a traditional buildup and washoff approach. Pollutants from various sources (fertilizers, atmospheric deposition, wildlife, septic systems, etc.) accumulate on the land surface and are available for runoff during rain events. Different land uses are associated with various anthropogenic and natural processes that determine the potential pollutant load. The pollutants contributed by interflow and groundwater are also modeled in LSPC for each land use category. Pollutant loadings from surface runoff, interflow, and groundwater outflow are combined to form the final loading output from LSPC. For this watershed, a large amount of organic matter can be deposited on the mud flats and marshes with poor flushing. This organic matter can be washed to the stream during very high tide under certain wind conditions. However, the contributions of TN and OC are relatively low compared to the large surface runoff from agricultural land and groundwater. These regions were grouped to wetland and marsh land uses and simulated by the watershed model. In summary, nonpoint sources from the watershed are represented in the model as land-based runoff from the landuse categories to account for their contribution (USEPA, 2001a).

For this study, the watershed processes were simulated based on buildup and washoff processes. The final loads were converted to model accumulation rates (ACQOP, units of lbs/acre/day for nutrients or counts/acre/day for pathogens). The ACQOP can be calculated for each land use based on all sources contributing nutrients to the land surface. For example, croplands receive nutrients from fertilizer and manure application, atmospheric deposition, and feces from wildlife. Summarizing all these sources together can derive the accumulation rates for croplands. These loading

parameters were adjusted accordingly during model calibration. The loads discharged to the stream were estimated based on model simulation results (see model simulation section). The other two major parameters governing water quality simulation, the maximum storage limit (SQOLIM, unit in lbs/acre/day for nutrients or counts/acre/day) and the washoff rate (WSQOP, units of inches/hour), were specified based on soil characteristics and land use practices, and further adjusted during the model calibration. The WSQOP is defined as the rate of surface runoff that results in 90% removal of pollutants in one hour. The lower the value, the more easily washoff occurs.

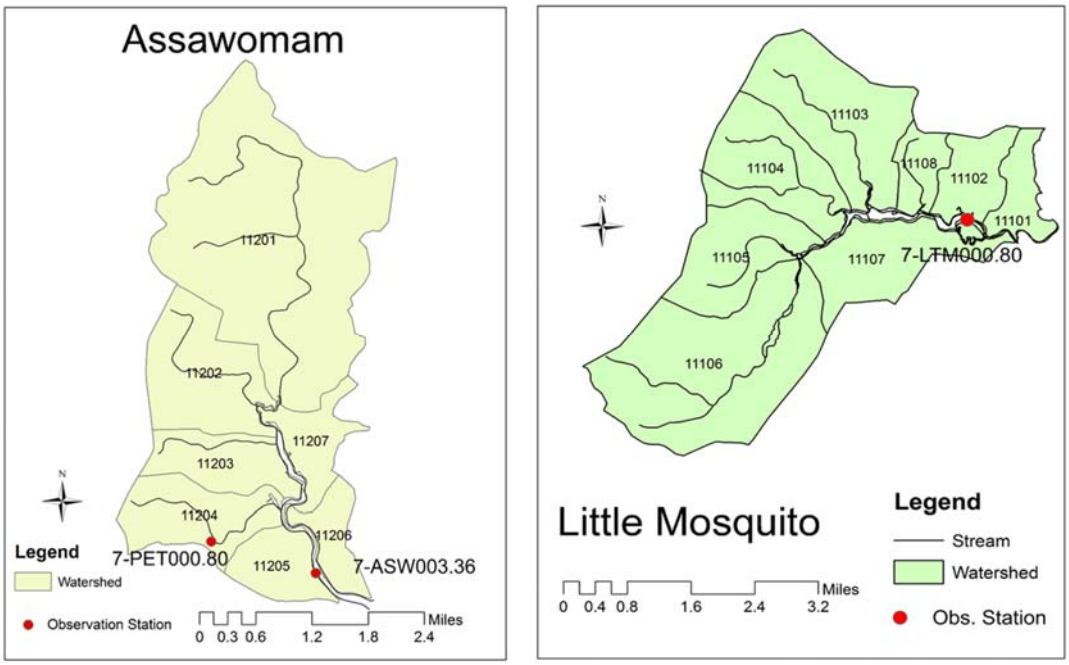


Figure A-2: Watershed segmentation for Assawoman Creek and Little Mosquito Creek watersheds.

A.1.2 Hydrodynamic Model

Hydrodynamic transport is the essential dynamic for driving the movement of dissolved and particulate substances in aquatic waters. Hydrodynamic models are used to represent transport patterns in complex aquatic systems. For this study, the EFDC model was selected to simulate hydrodynamics. EFDC is a general purpose modeling package for simulating 1-, 2-, and 3-dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands, and oceanic coastal regions. It was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software (Hamrick, 1992a). The model code has been extensively tested and documented. The EFDC model has been integrated into the EPA's TMDL Modeling

Toolbox for supporting TMDL development:

https://www.epa.gov/exposure-assessment-models/efdc

The EFDC model solves the continuity and momentum equations for surface elevation and horizontal and vertical velocities. The model simulates density and gravitationally induced circulation as well as tidal and wind-driven flows, spatial and temporal distributions of salinity, temperature, and suspended sediment concentration, and conservative tracers. The model uses the efficient numerical solution routines to improve the accuracy and efficiency of the model applications. The model has been applied to a wide range of environmental studies in the Chesapeake Bay system and other systems (e.g., Hamrick *et al.*, 1992b; Shen *et al.*, 1999; Shen and Kuo, 1999).

Inputs to the EFDC hydrodynamic model for Assawoman Creek and Little Mosquito Creek include:

- Bathymetry
- Freshwater inputs (lateral and up-stream) from watersheds
- Surface meteorological parameters (wind, atmospheric pressure, solar radiation, dry and wet temperature, humidity, and cloud cover)

The model uses a grid to represent the study area (Figure A-3). The grid is comprised of cells connected through the modeling process. The scale of the grid (cell size) determines the level of resolution in the model and the model efficiency from an operational perspective. The smaller the cell size, the higher the resolution and the lower the computational efficiency. Because both the Assawoman and Little Mosquito Creeks connect to coastal lagoons with complex geometry of small streams and embayments, the open boundary condition of tide and salinity are unknown. In order to obtain accurate tide and salinity boundary conditions for the Assawoman Creek and Little Mosquito Creek, a two-dimensional unstructured grid hydrodynamic model is applied to the Eastern Shore to simulate tide and salinity. The model grid is shown in Figure A-3. The unstructured grid model (referred to as the large domain model) is forced by freshwater discharge from the watershed and observed tide at the inlet boundary, and surface wind forcing, and simulates tide and salinity of the coastal lagoon. The output of hourly tide and salinity at the open boundaries of the Assawoman Creek and Little Mosquito Creek was used to force each model. The model grid used for Assawoman Creek and Little Mosquito Creek was developed based on the high-resolution shoreline digital files from USEPA and USGS topographic maps. The grid covers the entire Creeks and extends further outside so that the mouth of the Creeks can be used to set the boundary condition. Setting the model boundary well outside the model area of interest increases the model accuracy by reducing the influence of the boundary condition. There are totals of 423 and 400

cells in the horizontal, respectively, for the Assawoman Creek and Little Mosquito Creek. Four vertical layers were used in the model to simulate stratification for these shallow Creeks. The National Oceanic and Atmospheric Administration (NOAA) bathymetry data and NOAA chart were combined to obtain water depths for the model.

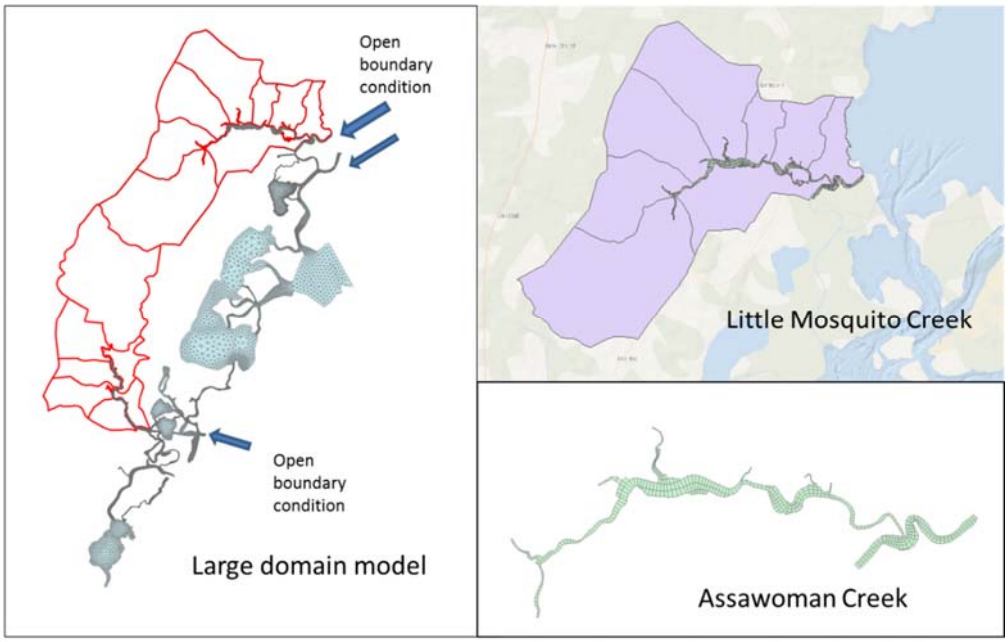


Figure A-3: Receiving water hydrodynamic model grids for the large domain model, the Assawoman Creek and Little Mosquito Creek grids

A.1.3 Water Quality Model

Central to the eutrophication component of the model is the relationship between algal primary production and the concentration of DO. In order to predict primary production and DO, a large suite of model state variables representing nutrient dynamics are simulated in the model (See Table A-1). The eutrophication model has the following water quality variable groups:

- Algae (green, cyanobacteria, and diatoms)
- Macro-algae
- OC (labile and refractory particulates, and dissolved)
- Organic phosphorus (labile and refractory particulates, and dissolved)
- Phosphate
- Organic nitrogen (labile and refractory particulates, and dissolved)
- Inorganic nitrogen (ammonium and nitrate)
- Silica (particulate and bio-available)

The eutrophication processes included in the EFDC were those described by Park *et al*. (1995). A diagram of model state variables and their relationship is demonstrated in Figure A-4. Each state variable is defined in Table A-1.

Table A-1: Abbreviates and State Variables Used in the EFDC Water Quality Model

Abbreviates	State Variable
Bc	cyanobacteria
Bd	diatom algae
Bg	green algae
Bm	macroalgae
COD	chemical oxygen demand
DO	dissolved oxygen
DOC	dissolved organic carbon
DOP	dissolved organic phosphorus
DON	dissolved organic nitrogen
FC	fecal coliform bacteria
LPOC	labile particulate organic carbon
LPON	labile particulate organic nitrogen
LPOP	labile particulate organic phosphorus
NH_4^+	ammonia nitrogen
NO23	nitrate nitrogen
PO4t = PO4d+ PO4p	total phosphate=dissolved phosphate + particulate phosphate

RPOC	refractory particulate organic carbon
RPON	refractory particulate organic nitrogen
RPOP	refractory particulate organic phosphorus
Sad	dissolved available silica
Sap	particulate biogenic silica

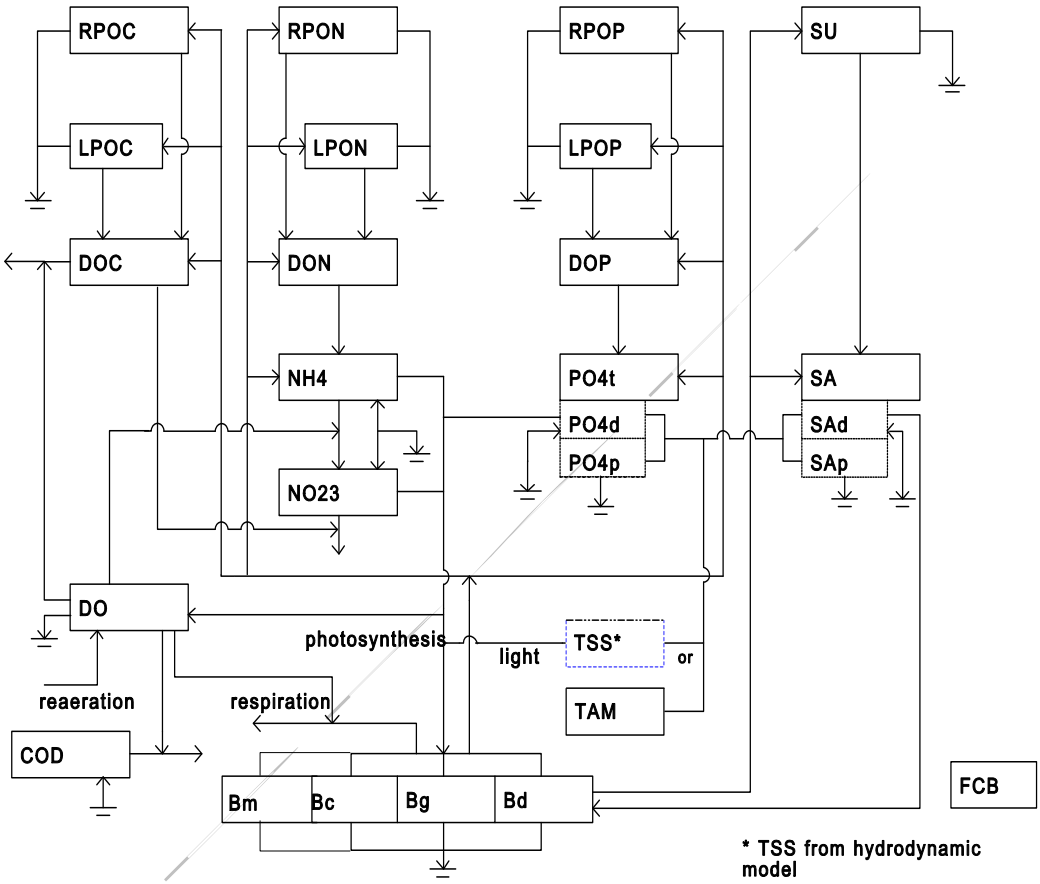


Figure A-4: Diagram of Water Quality Model State Variables and Their Relationship

Sediment diagenesis is a group of chemical processes in sediment causing mineralization of organic matters after they have been deposited. The sediment diagenesis model component simulates the changes of particulate organic matter deposited from the overlying water column and the resulting fluxes of inorganic substances (ammonium, nitrate, phosphate, and silica) and SOD back to the water column. The integration of the sediment processes component with the water quality model not only enhances the model's predictive capability of water quality parameters, but also enables it to simulate the long-term changes in water quality

conditions in response to changes in nutrient loadings.

A.2 Model Calibration and Verification

A.2.1 Model Calibration

The calibration process of watershed model involved adjustment of the model parameters used to represent the hydrologic processes until acceptable agreement between simulated flows and field measurements is achieved. Since there is no USGS gage or any other continuous flow data available in the Assawoman Creek and Little Mosquito Creek watersheds, a reference watershed was used for calibration. The USGS Gage 01484800 in Guy Creek near Nassawadox, VA, located approximately 49 km south of the Assawoman Creek Watershed, was used to calibrate the model parameters for hydrology simulation. Available data are from 1963-1996. The derived parameters were further verified with local flow data collected by the VADEQ in the Onancock Creek watershed (Shen *et al*., 2008). The Onancock Creek watershed has similar landuse, soil, and characteristics to those of Assawoman Creek. Figures A-5 and A-6 show the time series comparison of daily stream flow for years 1993 and 1994, respectively. Figure A-7 shows the 10-year daily stream flow frequency comparison between the model result and field data collected by the USGS gage. Based on the comparison, it can be seen that LSPC has reasonably reproduced the observed flow over a 10-year period.

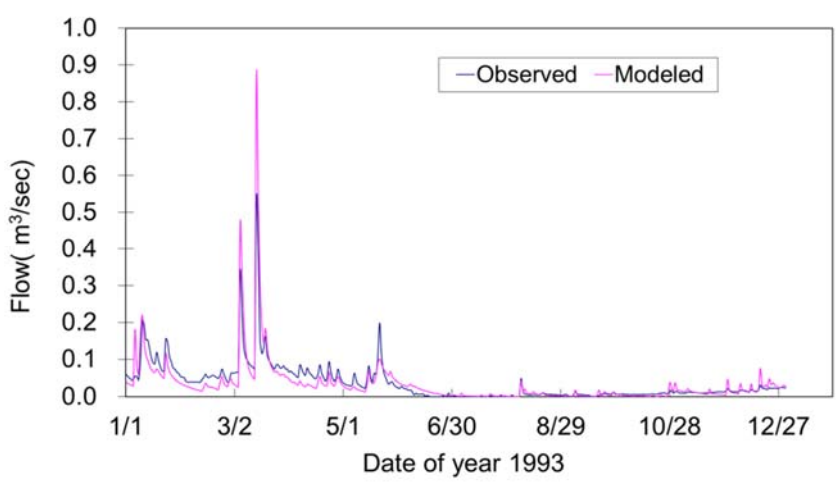


Figure A-5: Time Series Comparison of the Daily Stream Flow between Model Simulation and Observed Data from USGS Stream Gage 01484800 in 1993

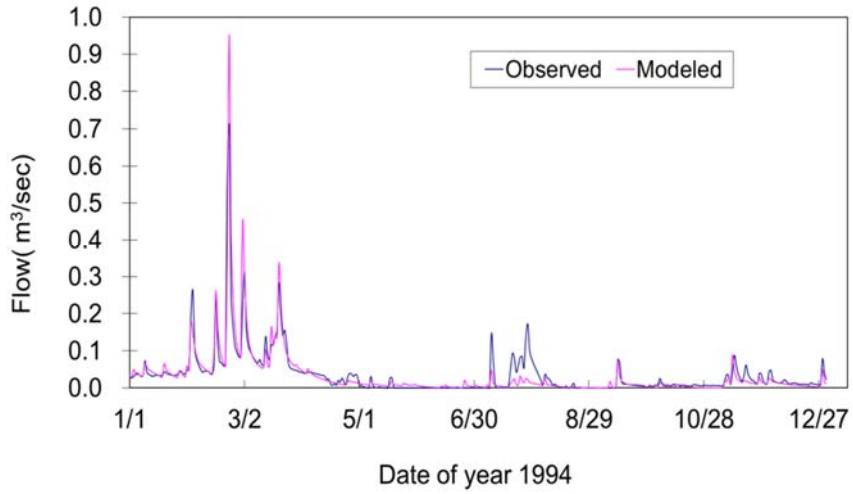


Figure A-6: Time Series Comparison of the Daily Stream Flow between Model Simulation and Observed Data from USGS Stream Gage 01484800 in 1994

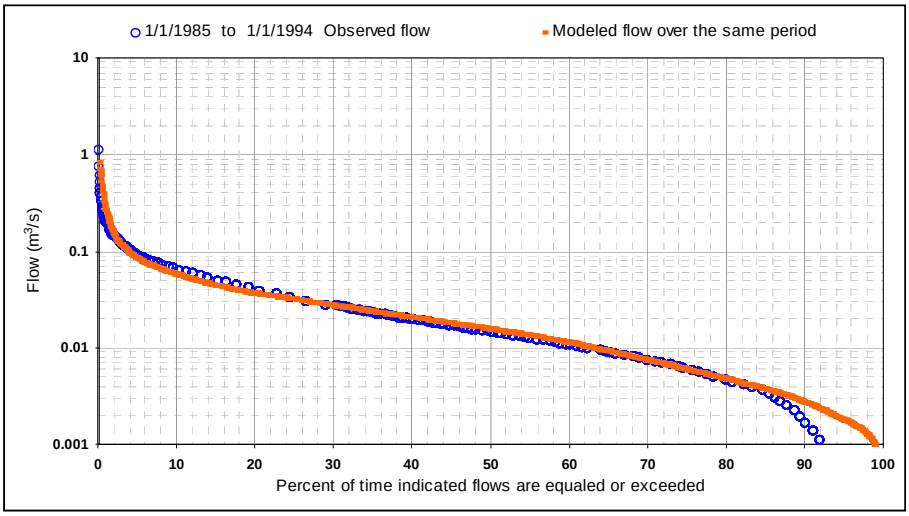


Figure A-7: 10-year Accumulated Daily Stream Flow Comparison between Model Simulation and the Reference Flow Station USGS 01484800

The watershed model parameters (accumulation and loss rates) for nitrogen and phosphate associated with surface runoff of each land use category were estimated on the basis of all available field survey data using USEPA-recommended loading production rates (USEPA, "NutrientTool.xls" program, 1998). For OC, which is both naturally produced on land and a potential pollutant in the waterway, accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of carbon to nitrogen was obtained from monitoring instead of directly surveyed

field data in the nearby watersheds. The measurement shows the ratio has a large range from 1 to 5. Due to the absence of subsurface water quality measurements in the Creeks, pollutant concentrations for interflow and groundwater were derived from reference data observed in the Assawoman and Little Mosquito Creeks (Stanhope *et al*., 2009). The initial loading output from LSPC was fed into the receiving water quality model. A fifteen-year watershed model simulation (2000-2014) was conducted. The selection of this period is due to the availability of the low DO occurrence and nutrient species at each station during this period. The comparison of modeled state variables and observations in the receiving water provided a reference for calibration of the watershed model. Because loading to the watershed was estimated from the current information and constant loadings were applied for this period, it may deviate from the current condition during this period. Based on the water quality model calibration, there is no statistically significant trend of change of nutrients that has been detected.

The hydrodynamics model calibration is mainly for salinity and temperature. Accurate simulation salinity is important for simulating estuarine circulation correctly. Correct simulation of temperature is important for accurately simulating biochemical processes. The model simulation results compared with observations for temperature and salinity for Assawoman Creek and Little Mosquito Creek are shown in Figures A-8 and A-9, respectively. Because there are only observations at the surface for salinity and temperature in both Creeks, observations of model simulation are compared to near-surface measurements. It can be seen that both temperature and salinity simulations perform well for both Creeks. The annual variation of temperature and salinity will change if runoff is well-simulated and the model is capable of water quality model simulations.

Calibration of water quality simulations are typically performed using water quality measurements from the watershed. Absent the necessary data from Assawoman Creek and Little Mosquito Creek watersheds, the calibration was performed on the observation data in both Creeks using an iterative approach between the watershed models and receiving water models.

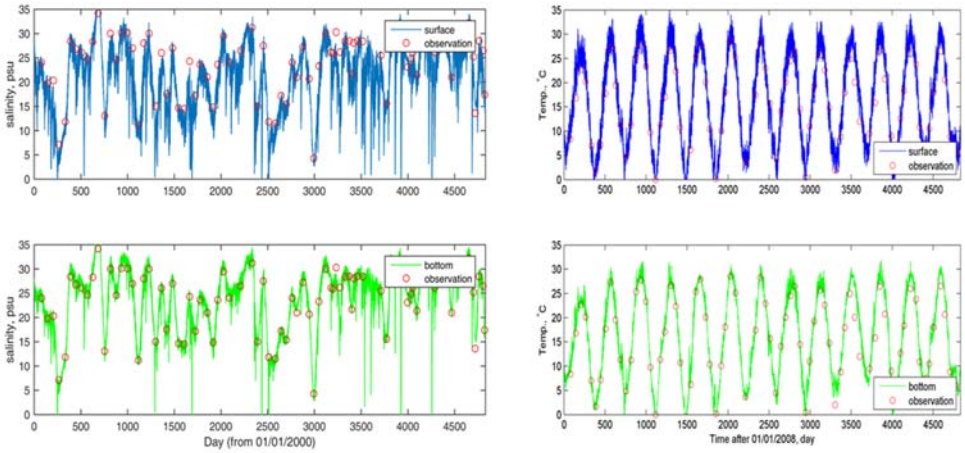


Figure A-8: Comparison of Modeled and Observed Temperature and Salinity at Station 7-ASW003.36 in Assawoman Creek

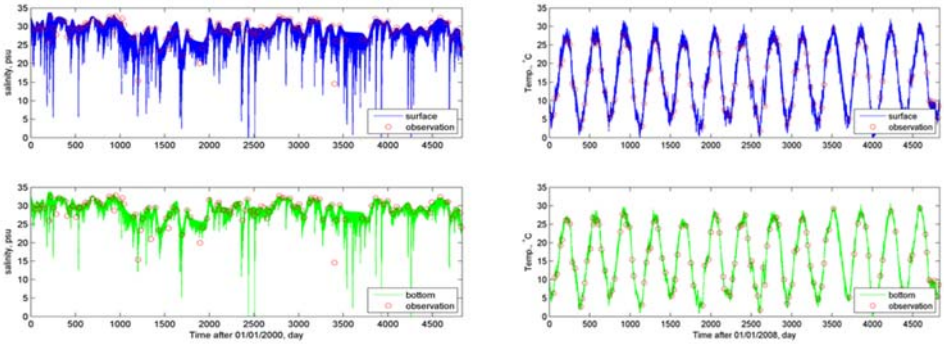


Figure A-9: Comparison of Modeled and Observed Temperature and Salinity at Station 7-LTM000.80 in Little Mosquito Creek

A.2.2 Water Quality Model Results

In the EFDC model, the eutrophication component of the receiving water model is coupled to the hydrodynamic model, so that the transport fields simulated by the hydrodynamic model drive the eutrophication component. The eutrophication model simulates dynamics of phytoplankton, DO, nitrogen, phosphorus, and carbon in the water column. The water temperature from the hydrodynamic model is used in the calculation of kinetic processes of the eutrophication model.

The most important input data for simulation of eutrophication process and DO in the Creeks are the nutrient and carbon loads from the watershed delivered via surface

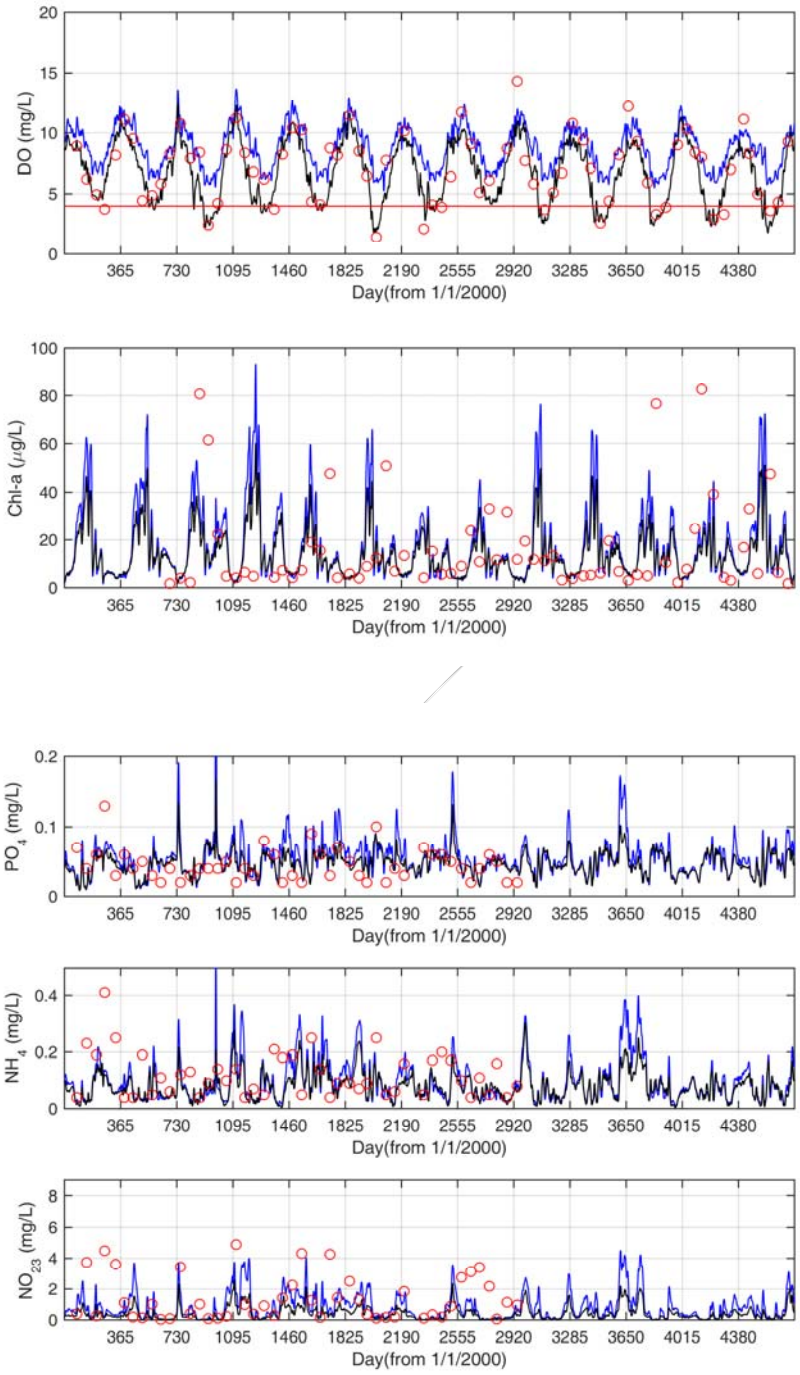
runoff and groundwater. The watershed model simulated TP, TN, and total carbon (TC). The loading discharge locations were identical to flow discharge locations along the banks of the Creeks. The TN, TP, and TC simulated by the watershed model were split into individual state variables for the eutrophication model component. The total organic nitrogen, phosphorus, and carbon were split into refractory, labile, and dissolved nitrogen, phosphorus, and carbon. The ratios used to split the variables were based on Chesapeake Bay modeling and eutrophication model applications in Onancock Creek, and adjusted during the model calibration.

In this study, a typical set of model kinetic parameters was initially used for the model setup. The set of model parameters originated from the Chesapeake Bay eutrophication model (Cerco and Cole, 1994; Park *et. al.*, 1995). Most of these kinetic parameters were used without any modification in this study. A few key model parameters, including growth, respiration, mortality, and settling rates, were further adjusted during the model calibration process. Literature values (Thomann and Mueller, 1987; Johnson *et al.*, 1985) were used as guidelines so that calibrated kinetic parameters were within the accepted ranges.

The sediment diagenesis was run iteratively for 3 years with the use of 2000 nutrient loads. The model results at the end of the second year were used as the initial condition for model simulation. It was found that after 3 years of iterative simulation, the water quality concentrations in the sediment bed approached a dynamic equilibrium.

The Little Mosquito connects to the Maryland Coastal Bay, a coastal bay with similar environment with abundant salt marshes. Observations of DO and OC measured in the Coastal Bay were used as the boundary conditions. As the nutrient levels are low, the low concentrations were used as background values.

A model calibration and validation time period for the simulation was from 1/1/2000 to 12/31/2012. The selection of this period was due to the available nutrient species (NH_4, N_{23}, PO_4) and boundary conditions that are only available in the early period and the lowest DO that occurred during this period. The model calibration was conducted by comparing model predictions against in-stream monitoring data. The model calibration results for the Assawoman Creek are shown from Figure A-10, and model calibration results for Little Mosquito Creek are shown in Figure A-11. It can be seen that the model captured seasonal variations for both DO and algae. The model simulated low DO for most of the time. Although the model missed a couple of very high algal bloom events, the overall model performances were satisfactory. The model simulation of nutrient species is in good agreement with observations. Considering the large uncertainties associated with the loading and the boundary condition, some discrepancies can be expected. The focus of the model calibration is to simulate seasonal variations and the range of the variations.


DO (mg/L)
Day(from 1/1/2000)
Chl-a (μg/L)
Day(from 1/1/2000)
PO4 (mg/L)
Day(from 1/1/2000)
NH4 (mg/L)
Day(from 1/1/2000)
NO23 (mg/L)
Day(from 1/1/2000)

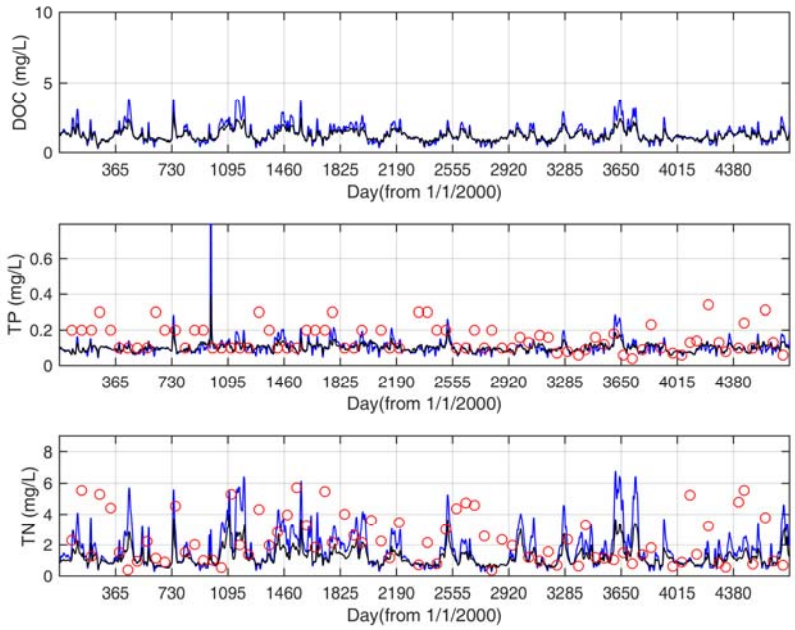
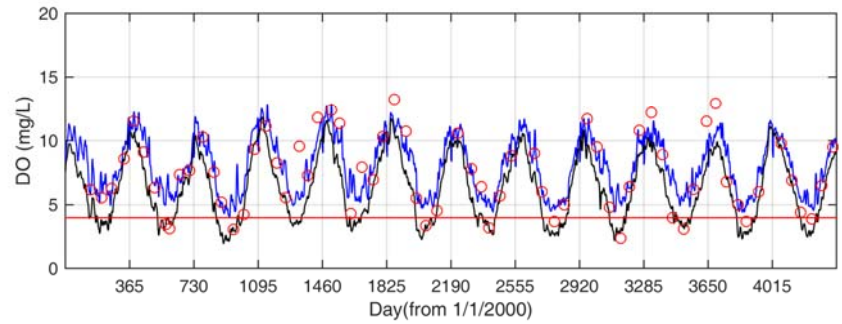
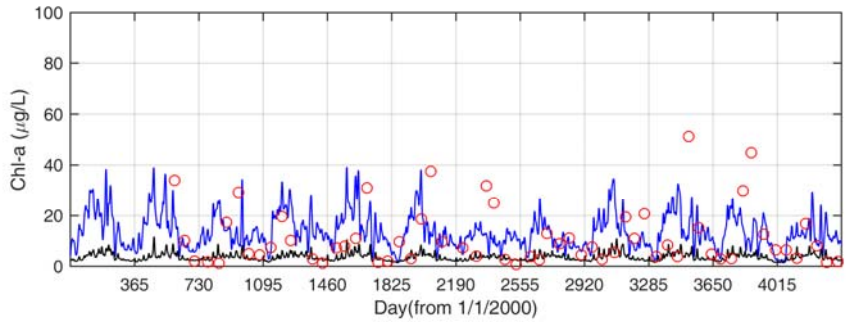
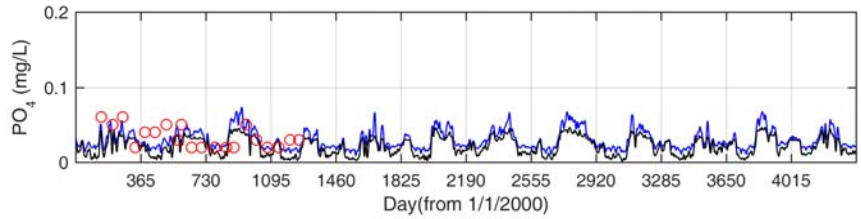
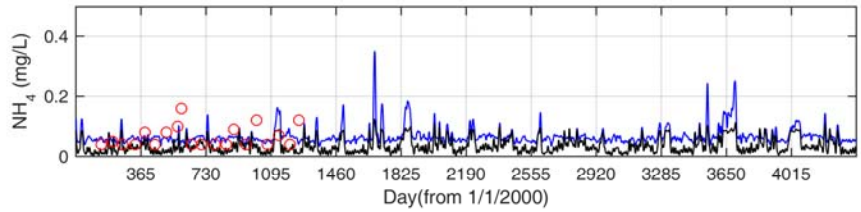


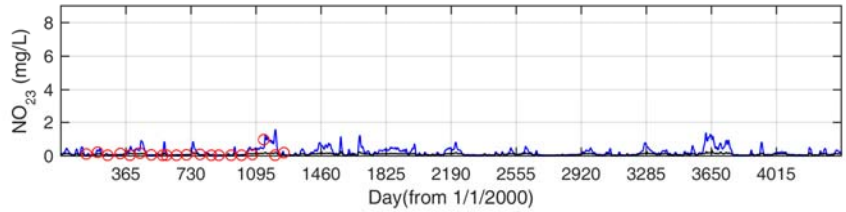
Figure A-10: Comparison of Modeled and Observed DO, Chl-a, NH_4, NO_{23}, PO_4, TP, and TN at Station 7-ASW003.36 in Assawoman Creek. (Blue Lines are Daily Average Concentration, Black Lines are Daily Minimum Concentrations, and Red Circles are Observations).


DO (mg/L)
Day(from 1/1/2000)


Chl-a (μg/L)
Day(from 1/1/2000)


PO4 (mg/L)
Day(from 1/1/2000)


NH4 (mg/L)
Day(from 1/1/2000)


NO23 (mg/L)
Day(from 1/1/2000)

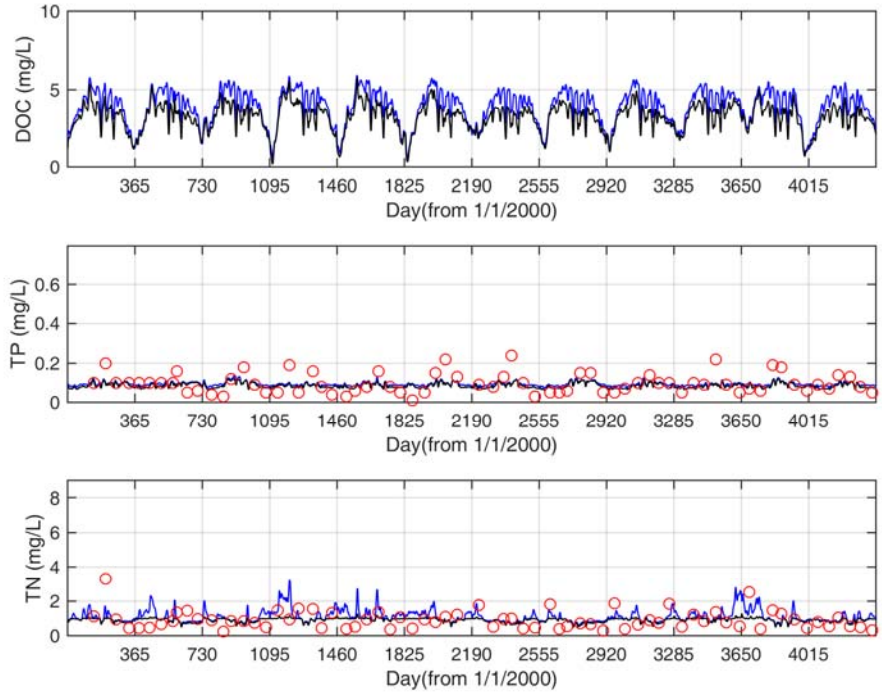


Figure A-11: Comparison of Modeled and Observed DO, Chl-a, NH_4, NO_{23}, TP, and TN at Station 7-LTM000.80 in Little Mosquito Creek. (Blue Lines are Daily Average Concentration, Black Lines are Daily Minimum Concentrations, and Red Circles are Observations).

A.2.3 Discussion of Model Results

Open boundary condition

In the source assessment section, it is shown that the environmental condition outside of the two Creeks can affect the DO condition. For shallow water with large saltmarsh and abundant macroalgae, high DOC output due to respiration can reduce the DO, especially during summer and rainy days when the light condition is not favorable for photosynthesis. The existence of the diurnal DO variation is a typical natural condition for these coastal environments (Smith *et al*., 2003; Shen *et al*., 2008). The groundwater has a high DOC content, which will also contribute to low DO in this region. Because both observation stations are located near the mouth adjacent to shallow lagoons with large salt marshes, low DO may not be caused fully due to eutrophication processes alone. To test the influence of the boundary condition on DO, a model sensitivity test was conducted using 90% of saturation DO at the mouth, and background DOC concentration of 1.2 mg/L, which can be considered as the base

condition. The model results of DO located at the observation station, mid-stream, and upstream are shown in Figures A-12 and A-13, respectively, for Assawoman and Little Mosquito Creeks. It can be seen that low DO has disappeared at observation stations located near the mouth, but low DO still occurred in the middle and upstream of the Creeks. However, an algal bloom can still exist inside the estuary. Algae settles to the bottom and undergoes decay, which will consume DO in the water column. The sensitivity results suggest that the outside condition can affect the DO near the mouth, but not upstream. The middle and upstream low DO indicates that runoff from the watershed will cause low DO in the Creek. The TMDL should be developed based on the attainment in the listed segments in the middle and upstream of these two Creeks.

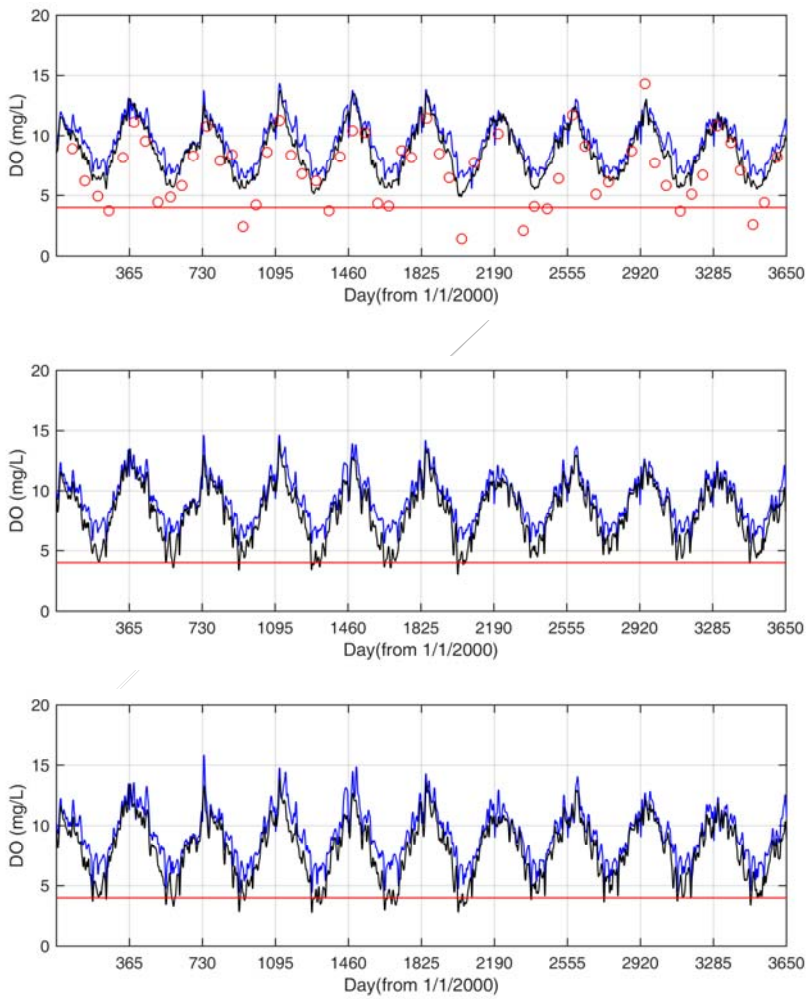


Figure A-12: Model Sensitivity Test of Impact of Open Boundary Condition on DO in the Assawoman Creek (Top, middle, and bottom panels are downstream, middle, and upstream, respectively).

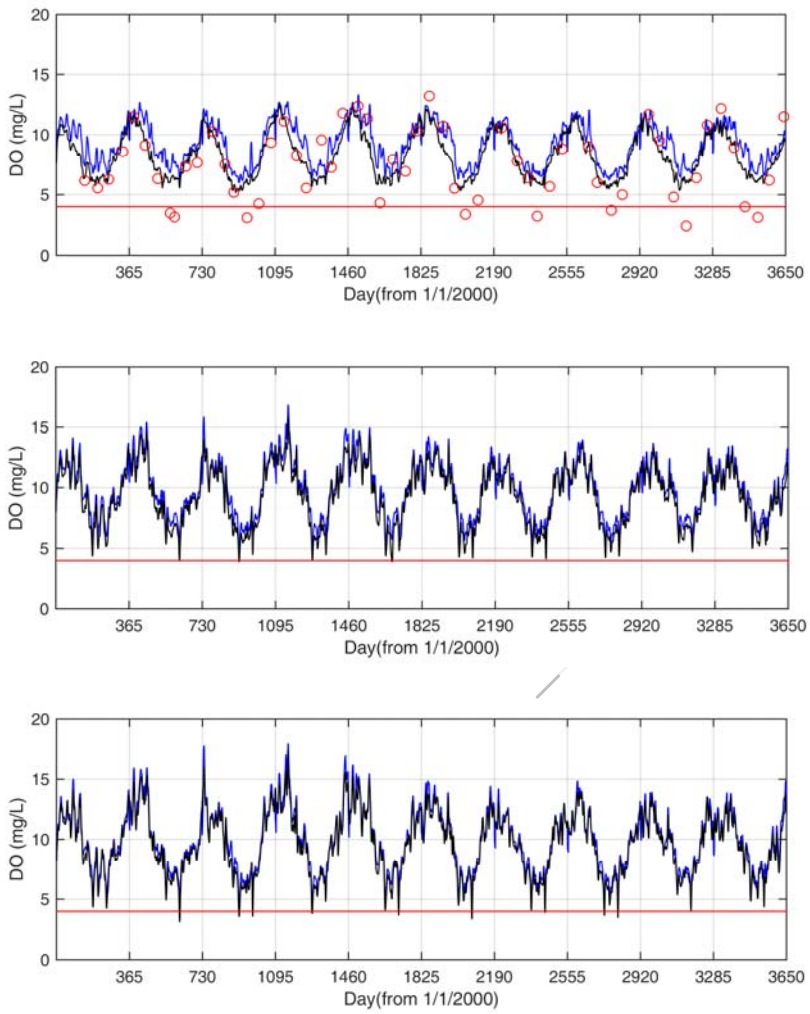


Figure A-13: Model Sensitivity Test Impact of Open Boundary Condition on DO in the Little Mosquito Creek Top, middle, and bottom panels are downstream, middle, and upstream, respectively).

Groundwater

The groundwater loading is very high in these 2 watersheds due to historical excessive nutrient applied on the surface and infiltrated to the ground. The observation of base flow (Stanhope et al., 2009) shows that the total nutrient inputs from the groundwater is about 50% of the total loading. However, unlike surface runoff, groundwater inputs are gradual and persistent, which is different from surface runoff. To test the influence of groundwater, a model sensitivity run was conducted by removing the groundwater inputs. For the sensitivity run, the open boundary condition were specified using 90% saturation DO. With the removal of groundwater, DO levels

in the middle and upstream still show the violation in the Assawoman Creek, but low DO levels have almost disappeared in the Little Mosquito Creek. Because the nutrient input was altered and because of the nonlinear dynamics of the system, the DO does not always show an improvement as shown in Assawoman Creek.

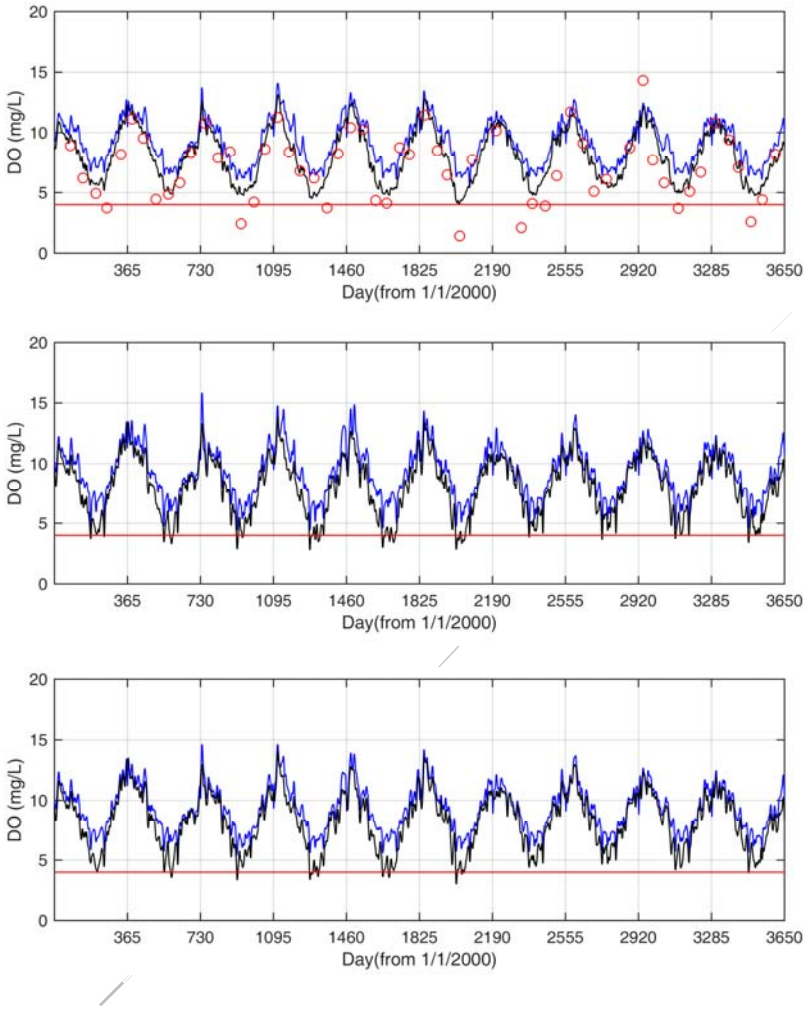


Figure A-14: Model Sensitivity Test of Groundwater in the Assawoman Creek

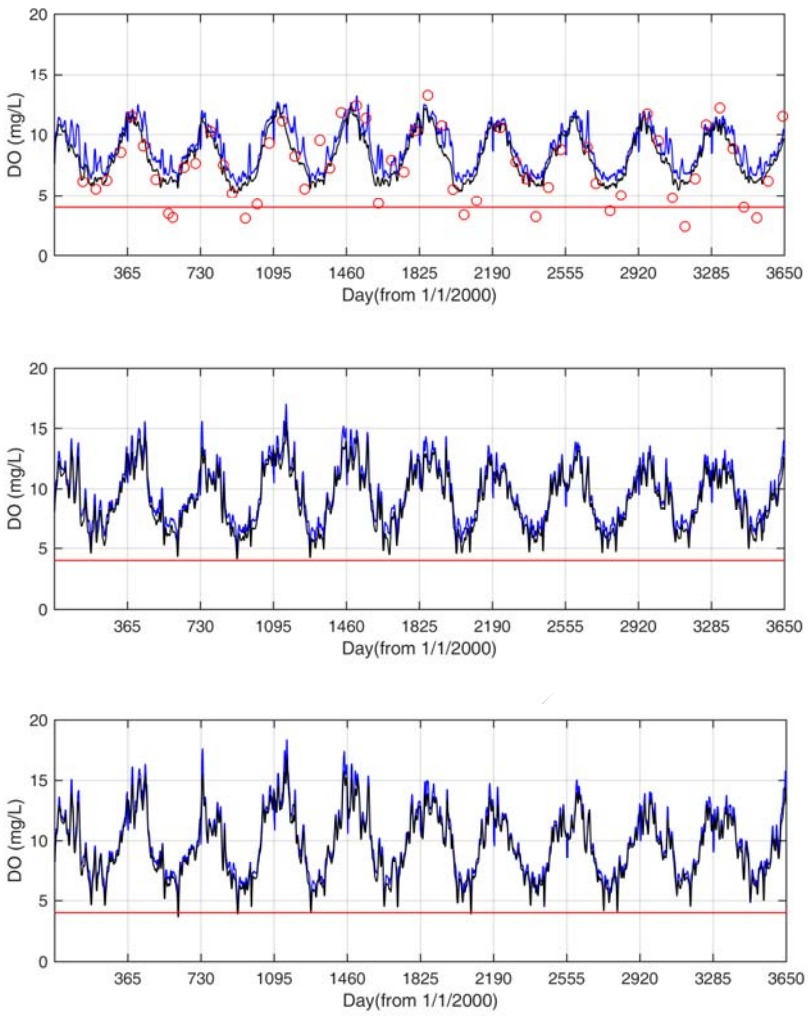


Figure A-15: Model Sensitivity Test of Groundwater Condition in the Little Mosquito Creek

Point Sources

There are two point sources in the Assawoman Creek and one point source in the Little Mosquito Creek. Loadings of nitrogen from point sources are low due to low discharge. An estimation of loading based on design flow shows that the total nitrogen loading is about 1.3 lbs/day and 7.5 lbs/day, respectively, for Assawoman Creek and Little Mosquito Creek. The loading is about 1% of the existing loading. The observed nutrient is lower than the loading estimated based on the design loading. As the point source discharge is persistent and similar to groundwater, it can be expected that the removal of point source discharge will not affect current conditions.

A.3 Allocable Load

A.3.1 Current Condition

The existing loading is estimated from watershed model outputs. The loadings that discharge to the stream are loadings from the edge watershed as surface runoff or from groundwater. Annual loads are shown in Figure A-16.

The cause of low DO is mainly due to the runoff and deposition of organic matter resulting in high sediment oxygen demand (SOD) during the summer and the influence of salt marshes that consume DO. The bottom fluxes of nutrients and SOD are high. The distributions of bottom flux at observation stations are shown in Figures A-17a and A-17b, respectively, for Assawoman and Little Mosquito.

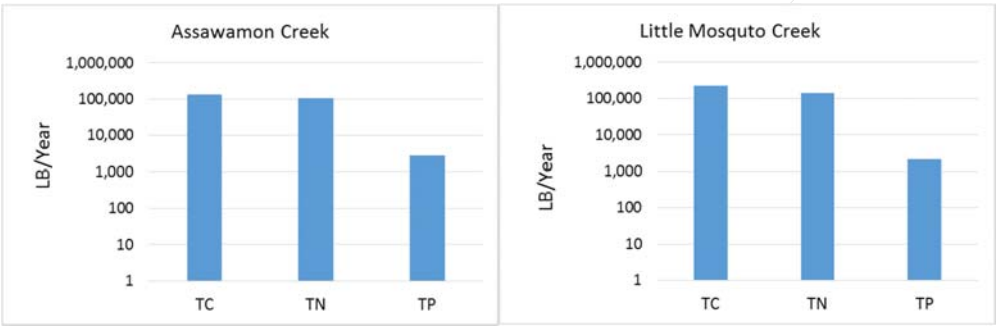


Figure A-16: Estimated Annual Loadings Discharged from Watersheds

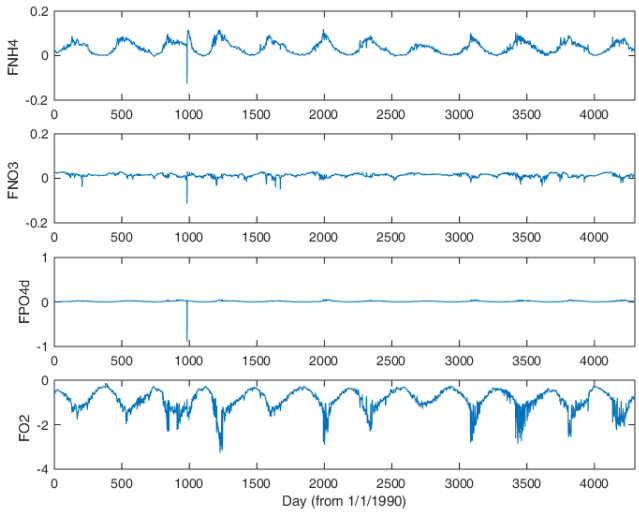


Figure A-17a: Benthic Flux of NH_4 (FNH_4), NO_3 (FNO_3), PO_4 (FPO_4d), and SOD (FO_2) at Station 7-ASW003.36. Units are in g/m^2/day.

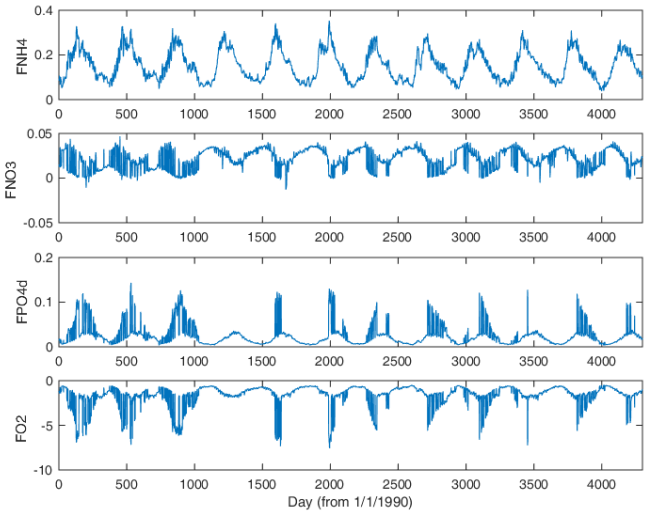


Figure A-17b: Benthic Flux of NH_4 (FNH_4), NO_3 (FNO_3), PO_4 (FPO_4d), and SOD (FO_2) at Station 7-LTM000.80. Units are in g/m^2/day.

A.3.2 Allowable Load

According to the DO endpoint, a series of nutrient reduction scenarios was conducted to find the allowable loads to evaluate the attainment of acceptable in-stream water quality because the downstream values of DO are affected by the outside condition of DO and DOC. The sensitivity run with a change of open boundary conditions indicates that the DO condition will meet the standards in the downstream of the Creek, but violation still occur in the middle to upstream impaired segments. It suggests that the downstream DO does not fully represent the condition of the Creek. Therefore, the reduction scenarios will be conducted using 90% of saturation DO as the open boundary condition to remove the influence from outside the Creeks and reduce nutrients to ensure the middle and upstream impaired segments meet the water quality standard. Model simulations were conducted by reducing both TN and TP, and by reducing TN only. For these simulations, we assumed that OC reduction is in proportion to TN as nitrogen is the essential nutrient needed by plants for carbon fixation. The model results show that, by reducing TN and OC, the DO can be attained without reducing TP, as nitrogen is often limited in these systems (especially during summer) and phosphorus is more limited during spring, associated with high runoff.

Several model simulations were conducted by reducing TN sources. Because the major sources of TN are from cropland and groundwater, the WQS cannot be achieved by reducing loadings from failing septic system, manure application, urban landuse runoff. The model runs that reduce loadings from cropland and groundwater by about 50% and 40%, respectively, cause the WQS to be achieved.

After reducing TN by 50% and 40%, respectively, for Assawoman and Little Mosquito Creek, attainment of the DO WQS can be achieved. Figures A-18 and A-19 show the results of DO distribution for Assawoman and Little Mosquito Creek.

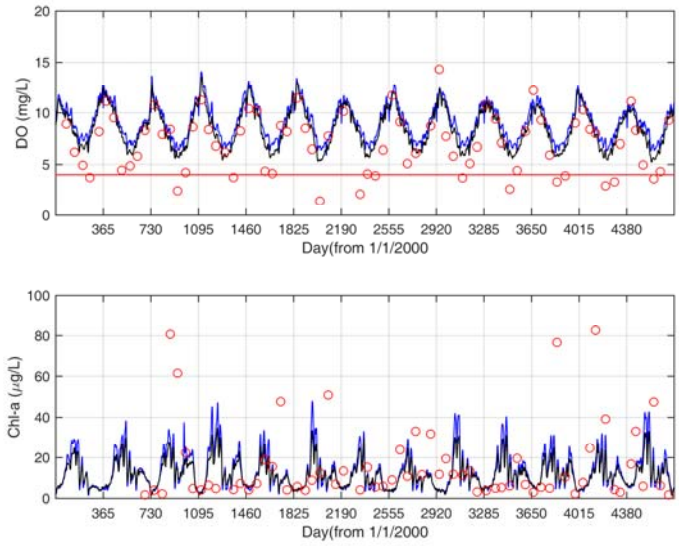


Figure A-18a: DO and Algae Distribution after 50% Reduction of TN in Assawoman Creek (Downstream)

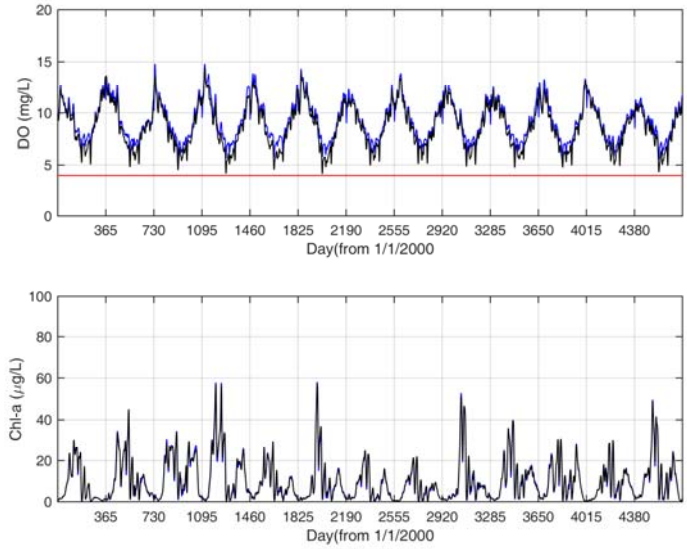


Figure A-18b: DO and Algae Distribution after 50% Reduction of TN in Assawoman Creek (Midstream)

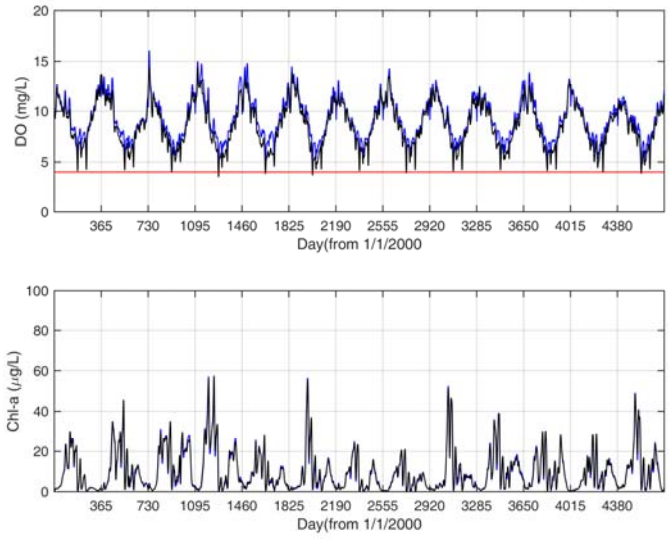


Figure A-18c: DO and Algae Distribution after 50% Reduction of TN in Assawoman Creek (Upstream)

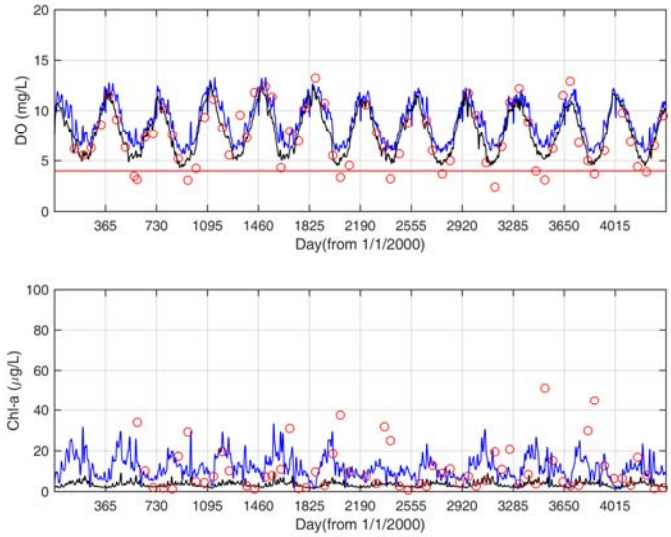


Figure A-19a: DO and Algae Distribution after 40% Reduction of TN in Little Mosquito Creek (Downstream)

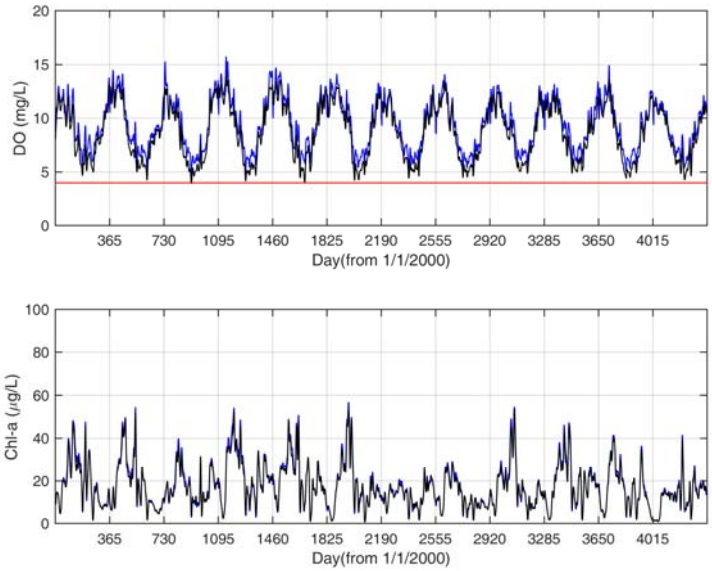


Figure A-19b: DO and Algae Distribution after 40% Reduction of TN in Little Mosquito Creek (Midstream)

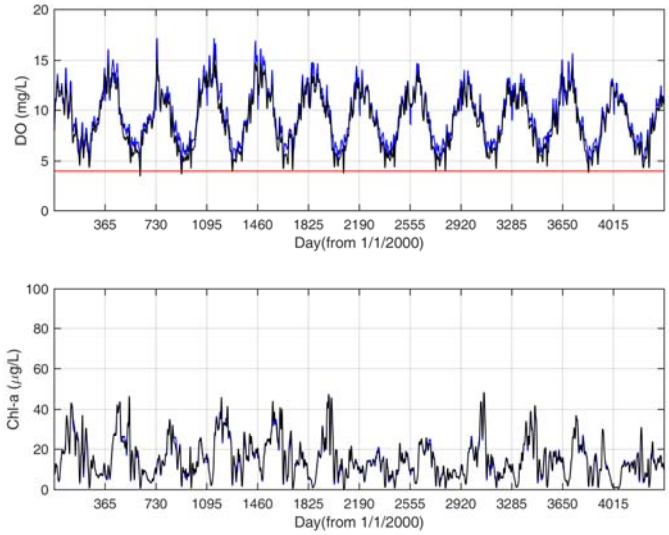


Figure A-20: DO and Algae Distribution after 40% Reduction of TN in Little Mosquito Creek (Upstream)

The load allocation for each land use is listed in Tables A-2 and A-3, for Assawoman and Little Mosquito Creeks, respectively. The reductions required for Assawoman to be 52,308 Lbs/year, while the current surface runoff is 42,105 Lbs/year for Assawoman. It can be seen that the current load from surface runoff from Assawoman is less than the required reduction. Therefore, the WQS cannot be achieved without reducing the groundwater loading for Assawoman. Table 4.4a shows that a reduction of 85% from the surface runoff from cropland, pasture, and urban pervious land use areas from Assawoman is required to reduce groundwater loading by 33%. Because it is a challenge to remove surface runoff completely, an alternative TMDL is presented to reduce runoff from cropland, pasture, and urban pervious land use areas by 50%. The rationale of this approach is to reduce input of nitrogen to the land surface through improved nitrogen application on land so that leaching of nitrogen to the groundwater will be gradually reduced. Note that the runoff from the watershed is less than 10% of the nitrogen added to the land. A large portion of nitrogen is taken up by plants. The remaining portion of nitrogen is incorporated into the soil or is leached to the groundwater. With the appropriate management of nitrogen application and runoff, the total runoff of nitrogen can be reduced and the groundwater level will be gradually improved. Although, the reduction of groundwater cannot be achieved short-term, the groundwater condition can be gradually improved through the implementation of surface runoff reductions.

Table A-2: Allocation and TN Reduction for Each Landuse for Assawoman

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	6.9	0.0%	6.9	0.0%
Cropland	33,957.1	32.5%	16,978.6	50.0%
Forest	1,958.4	1.9%	1,958.4	0.0%
Pasture	2,548.6	2.4%	1,274.3	50.0%
Urban Pervious	527.8	0.5%	263.9	50.0%
Wetlands	2,702.2	2.6%	2,702.2	0.0%
Urban Impervious	404.3	0.4%	202.2	50.0%
Sum of surface runoff	42,105.3	40.2%	23,386.4	44.5%
Ground	60,547.3	57.9%	26,957.9	55.5%
Point Source	1963.9461	1.9%	1963.9	0.0%
Total	104,616.5	100.0%	52,308.2	50.0%

Table A-3: Allocation and TN Reduction for Each Landuse for Little Mosquito

Land Use Name	Current Condition (Lbs/Year)	Percent	Allocation (Lbs/Year)	Percent Reduction
Barren	2.8	0.0%	2.8	0.0%
Cropland	48,278.0	36.1%	24,139.0	50.0%
Forest	3,928.3	2.9%	3,928.3	0.0%
Pasture	1,909.4	1.4%	954.7	50.0%
Urban Pervious	1,680.3	1.3%	840.2	50.0%
Wetlands	6,756.8	5.1%	6,756.8	0.0%
Urban Impervious	1,481.3	1.1%	740.7	50.0%
Sum of surface runoff	64,037.1	48.0%	37,362.5	41.7%
Ground	66,774.7	50.0%	40,029.5	40.1%
Point Source	2737.6	2.0%	2737.6	0.0%
Total	133,549.3	100.0%	80,129.6	40.0%

A.4 Computing Total Maximum Daily Load

The TMDL seeks to eliminate 100% of the human-derived component, regardless of the allowable load determined through the LA process. Human-derived forms are a serious concern in the estuarine environment and both state and federal law preclude the discharge of human waste. According to the preceding analysis (Fig 3.5), reduction of the controllable loads, human, livestock and pets, will not result in achievement of the WQS. The point source discharge account for about 1% of total loading. The dominant sources are due to nutrient application of the surface, groundwater and wildlife. The manure application on the watershed are very limited. The groundwater contributes high nutrient inputs from the watershed. Because nutrients in the ground are due to filtration of nutrients from the surface, by reducing nutrients from the surface, the nutrient level can be gradually reduced.

All TMDLs have some probability of being exceeded, with the probability being either explicitly specified or implicitly assumed. EPA guidance states that the probability component of a calculated maximum daily load (MDL) should be “based on a representative statistical measure” that is dependent upon the specific TMDL and best professional judgment of the developers (USEPA, 2007). This statistical measure represents how often the MDL is expected, or allowed, to be exceeded. The primary options for selecting this level of protection would be:

1. **The maximum daily load reflects some central tendency:** In this option, the maximum daily load is based upon the mean or median value of the range of loads expected to occur. The variability in the actual loads is not addressed.
2. **The maximum daily load reflects a level of protection implicitly provided by the selection of some "critical" period**: In this option, the maximum daily load is based upon the allowable load that is predicted to occur during some critical period examined during the analysis. The developer does not explicitly specify the probability of occurrence.
3. **The maximum daily load is a value that will be exceeded with a pre-defined probability:** In this option, a "reasonable" upper-bound percentile is selected for the maximum daily load based upon a characterization of the variability of daily loads. For example, selection of the 95th percentile value would result in a maximum daily load that would be exceeded 5% of the time.

Because time variable model simulations were conducted, daily loads vary significantly. Daily loading varies both seasonally and annually with respect to different hydrological years. Therefore, the MDL for this analysis is determined based on a pre-defined probability. The computed MDL is consistent with achieving the annual cumulative load target. A 90th percentile was selected as the pre-defined probability,. Because the loading distributions are better described by log-normal distributions in the Assawoman and Little Mosquito Creeks, the MDL is computed as follows (USEPA, 2007):

$$TMDL = LTA \cdot \exp(Z_p \sigma_y - 0.5\sigma_y^2)$$

Where Zp is pth percentage point of the standard normal distribution. For the 95th percentile, Zp = 1.28. LTA is long-term mean daily loading and σ_y is computed as:

$$\sigma_y = \sqrt{\ln(CV^2 + 1)}$$

where CV is coefficient of variation of the untransformed data, which equals to the standard deviation divided by the mean.

Using the method described above, *LTA* is the mean daily loading from model simulation. The results are summarized in Table A-4.

Table A-4: Current and Allowable Daily and Annual Loading

Watershed	Pollutant	Current Load (lbs/year)	Allowable Load (lbs/year)	Allowable Load* (lbs/day)	Required Reduction (%)
Assawoman Creek	TN	104,616.5	52,308.2	311.4	50%
Little Mosquito Creek	TN	133,549.3	80,129.6	469.4	40%

*with statistical adjustment.

Appendix B: Calculation of Population Numbers

The process used to generate population numbers used for the nonpoint source contribution analysis for the four source categories (human, livestock, pets, and wildlife) is described for each below.

B.1 Human

The number of people contributing nutrients from failing septic tanks were estimated in two ways and then compared to determine a final value.

1) Deficiencies (septic failures) from the DSS shoreline surveys were counted for each watershed and multiplied by 3 (average number of people per household).
2) Numbers of households in each watershed were determined using 911 addresses. The address was obtained for each household and geo-reference for each household was obtained and a GIS layer was created for accounting for the number.

The septic failure rate was estimated by dividing the number of deficiencies in the watershed by the total households in the watershed. For this TMDL, the average septic failure rate was 5% and this was used based on the previous study, public feedback and the Hungars-Mattawoman IP study.

B.2 Livestock

USCB data can be used to calculate the livestock values. The numbers for each type of livestock (cattle, swine, sheep, chickens (big and small), and horses) were reported by county. Each type of livestock was assigned to the landuse(s) it lives on, or contributes to by the application of manure, as follows:

Cattle	Cropland and Pastureland
Swine	Cropland
Sheep	Pastureland
Chickens	Cropland
Horses	Pastureland

The GIS methodology was used to overlay data layers for several steps:

1) The county boundaries and the landuses to get the area of each landuse in each county. The number of animals was divided by the area of each landuse for the county to get an animal density for each county.
2) The subwatershed boundaries and the landuses to get the area of each landuse in each subwatershed.
3) The county boundaries and the subwatershed boundaries to get the area of each county in each subwatershed.

Using the MS ACCESS database, for each type of livestock, the animal density by

county was multiplied by the area of each landuse by county in each subwatershed to get the number of animals in each subwatershed. The number of animals in each subwatershed was summed to get the total number of animals in each watershed.

For this study, a series of public meetings were held and feedback from these public meetings was used to estimate the livestock number. Combining inputs from stakeholders and DSS shoreline survey data, the total number was determined for this study.

B.3 Pets

The pet population was calculated using a formula for estimating the number of pets using national percentages, reported by the American Veterinary Association and previous study:
dogs = # of households ×36.5%× 1.6.
cats = # of households ×30.4%× 2.1.

B.4 Wildlife

For this study the density for wildlife specifically derived from public meeting feedback and results from the Hungars-Mattawoman IP study were used, which are listed below in Table B-1.

Table B-1: Densities Used for Estimating Wildlife in Assawoman and Little Mosquito Creeks

Wildlife Type	Population Density	Habitat Requirements
Deer	0.1032 animals/acre	Entire watershed
Raccoons	0.0703 animals/acre	Entire watershed
Muskrats	0.3128 animals/acre	300-foot buffer for primary habitat/600-foot buffer for secondary habitat
Geese	0.032 animals/acre	300-foot buffer for primary habitat /600-foot buffer for secondary habit
Ducks	0.0652 animals/acre	300-foot buffer for primary habitat/600-foot buffer for secondary habitat