Total Maximum Daily Load for Dissolved Oxygen in Mill Creek, Northampton County, Virginia

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List of Abbreviations

BOD	Biochemical Oxygen Demand
CFR	Code of Federal Regulations
COD	Chemical Oxygen Demand
CWA	Clean Water Act
DO	Dissolved Oxygen
EFDC	Environmental Fluid Dynamics Computer Code
EPA	Environmental Protection Agency
GIS	Geographic Information System
LA	Load Allocation
LSPC	Loading Simulation Program C^{++}
MOS	Margin of Safety
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
OC	Organic Carbon
SOD	Sediment Oxygen Demand
SWCB	State Water Control Board
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
VA-DEQ	Virginia Department of Environmental Quality
VA-DCR	Virginia Department of Conservation and Recreation
VPDES	Virginia Pollutant Discharge Elimination System
WLA	Wasteload Allocation
WQC	Water Quality Criteria
WQLS	Water Quality Limited Segments
WQMIRA	Water Quality Monitoring, Information, and Restoration Act
WQMP	Water Quality Management Plans
WQS	Water Quality Standard

EXECUTIVE SUMMARY

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

The Mill Creek, which is located on the Eastern Shore in Northampton County, Virginia (VAT-D06R-01), was initially listed in the 1998 303(d) TMDL Priority List & Report as it failed to support its aquatic life designated use due to violations of Virginia's Dissolved Oxygen (DO) criteria. It was also included in the 2008 Virginia 305(b)/303(d) Water Quality Integrated Report. This document, upon approval of EPA, establishes a TMDL of DO for the Mill Creek.

The numerical criteria for DO for the Mill Creek are a minimum of 4.0 mg/L and a daily average of 5.0 mg/L. The analysis of the available Virginia Department of Environmental Quality (VA-DEQ) water quality monitoring data showed that the low DO at the sampling site is due to a combination of natural conditions (e.g., the minimal re-aeration, wildlife wastes, and the decaying vegetation) and human influence (e.g., agricultural runoff and leaking septic systems). The data analysis and field survey, as well as the model sensitivity test indicated that reducing nutrients and organic carbon that discharge to the stream will improve the DO condition.

A system of numerical models was applied to simulate the loadings of organic matter and nutrients from the Mill Creek watershed, 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 the receiving waterbody. The Environmental Fluid Dynamics Code model (EFDC) was used to simulate the transport of pollutants and eutrophication processes in the receiving water. The water column processes are coupled to the sediment diagenesis, which simulates the changes of particulate organic matter deposited from the overlying water column and the resulting fluxes of inorganic substances, and the sediment oxygen demand (SOD) back to the water column.

EPA regulations at 40 CFR 130.7 (c)(1) require TMDLs 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 Mill Creek, an explicitly MOS of 5% was include in this TMDL. To consider the further development in this area, 1% of the load is allocated to future growth.

The TMDLs (lb/day) for Mill Creek are summarized as follows:

	TMDL	**=**	**LA**	**+**	**WLA**	**+**	**FA**	**+**	**MOS**
TC	30.53	=	28.69	+	N/A	+	0.31	+	1.53
TN	10.07	=	9.47	+	N/A	+	0.10	+	0.50

Where:

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

Several factors provide assurance that the TMDLs will be implemented. 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. DEQ will make every effort to continue to monitor the impaired stream in accordance with its ambient monitoring program. A TMDL implementation plan addressing at a minimum the Water Quality Monitoring, Information, and Restoration Act (WQMIRA) requirements will be developed. 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. The first public meeting was held on February 24, 2009 in Northampton County. Basic information of the TMDL process and the agencies involved were available for public review. A final public meeting was held on April 30, 2009.

1.0 INTRODUCTION

1.1 Background

Section 303(d) of the CWA and the USEPA's Water Quality Planning and Management Regulations (40 CFR Part 130) require states to develop TMDLs for waterbodies which are exceeding WQSs. TMDLs represent the total pollutant loading that a waterbody can receive without violating WQSs. 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.

The Mill Creek (VAT-D06R-01) in Northampton County was first listed as impaired due to violations of Virginia's DO criteria in the 1998 303(d) TMDL Priority List and Report. A 2.04-mile segment of the Mill Creek was impaired. This document, upon approval of EPA, establishes a TMDL of DO for the Mill Creek.

1.2 Listing of Waterbodies under the CWA

WQSs 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 harvest, 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) Water Quality Assessment Integrated Report (WQAIR, DEQ 2008). 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 Designated Uses and Applicable Criteria

1.3.1 Designated Uses

According to Virginia WQSs (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 the uses designated for those waters are met. In Virginia's WQSs, 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. The Mill Creek is considered a Class III water, "Nontidal Waters Coastal and Piedmont Zones" as of January, 2009 (9VAC25-260-50).

1.3.2 Applicable 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 III waters is a minimum of 4.0 mg/L and a daily average of 5.0 mg/L.

1.4 Impairment Listing

DEQ's Tidewater Regional Office has one water quality monitoring station (7-MCR002.00) at Mill Creek. Sufficient exceedances of Virginia's WQSs for DO minimum were recorded at the station to assess the segment of Mill Creek as not supporting of the CWA's aquatic life use support goal (Table 1.1).

Table 1.1: Exceedances of the Water Quality Criterion (1997-2003) of Mill Creek

Station ID	Number of Samples	Number of Exceedances	Percentage Exceedance
7-MCR002.00	34	13	38%

2.0 WATERSHED CHARACTERIZATION

2.1 Landuse

The Mill Creek watershed is located in Northampton County of the Eastern Shore of Virginia. The watershed occupies a landscape position (Figure 2.1). The drainage area of the watershed is approximately 1094 acres.

A map displaying the landuse in the Mill Creek area is shown in Figure 2.2. Table 2.1 lists the landuse percentages of the watershed. It can be seen that the watershed is dominated by agriculture (63.4%, including raw crops and pasture/hay) and forest (27.9%, including deciduous, evergreen, and mixed forest).

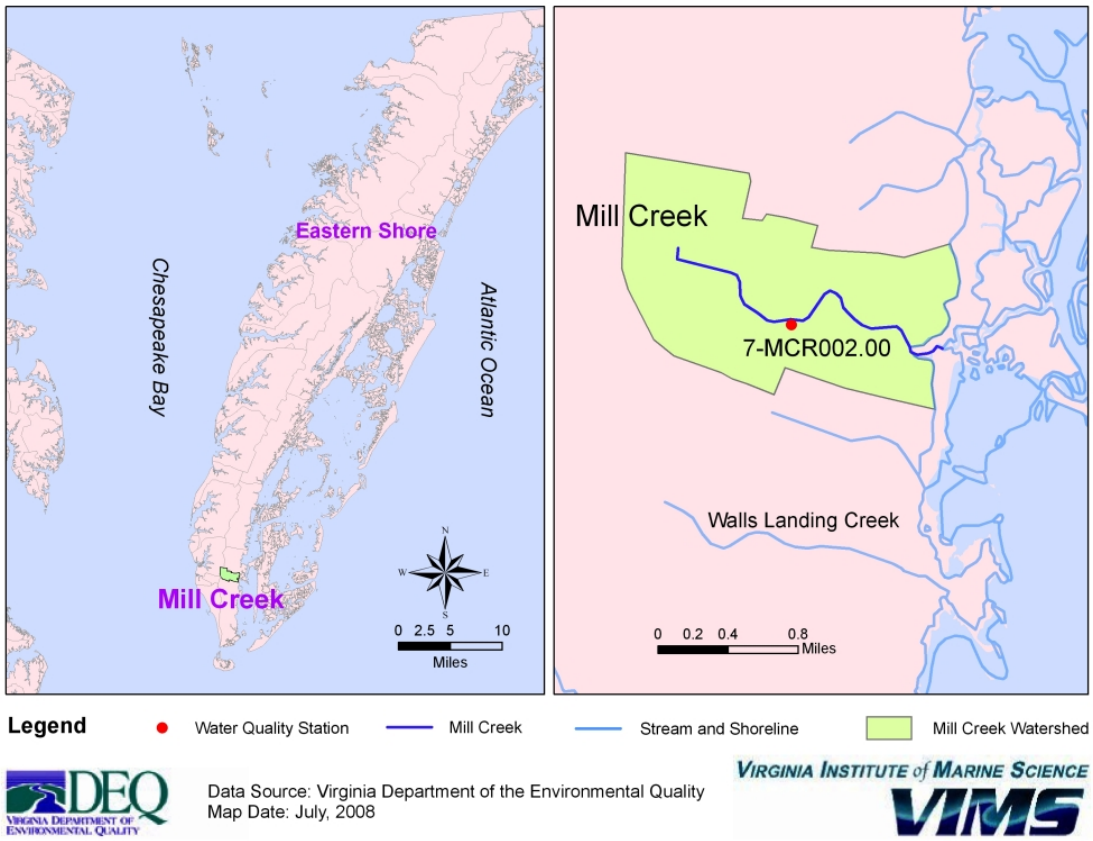

Figure 2.1: Locations of the Mill Creek Watershed, the Impaired Segment, and the DEQ Water Quality Station 7- MCR002.00

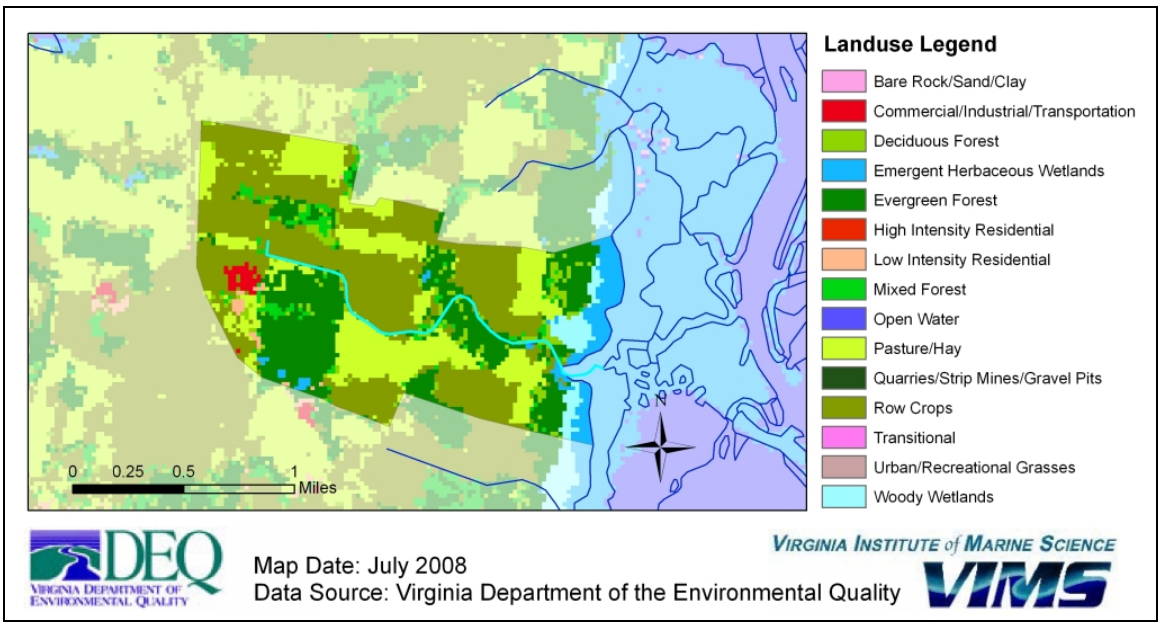

Figure 2.2: Landuse of the Mill Creek Watershed

Table 2.1: Landuse Categories for the Mill Creek Watershed

Landuses	Acres	Percentage
Open Water	0.22	0.02%
Low Intensity Residential	6.00	0.55%
Commercial/Industrial/Transportation	9.56	0.87%
Deciduous Forest	45.39	4.15%
Evergreen Forest	228.40	20.89%
Mixed Forest	31.14	2.85%
Pasture/Hay	239.74	21.92%
Row Crops	453.46	41.47%
Woody Wetlands	28.24	2.58%
Emergent Herbaceous Wetlands	51.37	4.70%
Totals	**1,094**	**100%**

2.2 Geology and Soils

Located at Virginia's Eastern Shore, the Mill Creek watershed is 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://www.wm.edu/geology/virginia/provinces/coastalplain/coastal_plain.html)

2.3 Climate and Hydrology

As part of the Tidewater Climate Region, the Mill Creek watershed experiences average January temperatures of 35-48° F and average July temperatures of 71-85° F. Annual precipitation is 41.32 inches. High precipitation occurs in late summer and March (Figure 2.3). Mill Creek is non-tidal and it is also influenced by stream discharge, groundwater seepage, and surface runoff.

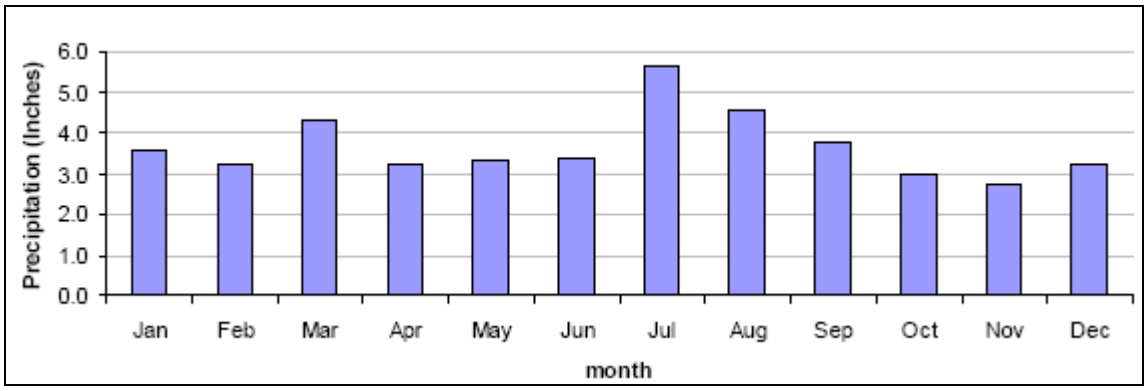

Figure 2.3: Annual Precipitation of the Mill Creek Watershed

2.4 Water Quality Conditions

The VA-DEQ performs water quality monitoring throughout Virginia to determine if WQSs are being met for the designated uses of the corresponding waters. Samples have been taken at the water quality monitoring station in Mill Creek (Figure 2.1) since 1994: however, the data reported here represent sampling from 1997 to 2003.

Oxygen concentrations in a water column fluctuate under hydrological conditions. Severe oxygen depletion may result from activities that introduce large quantities of organic carbon (OC) and nutrients into surface waters. Excessive nutrient input promotes the growth of algae and macroalgae, which introduce organic materials to both water column and the bottom sediment. 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.

2.4.1 Dissolved Oxygen

Most of the DO samples were collected bi-monthly. The observations show that the instantaneous DO levels fell below the water quality criterion of 4 mg/L minimum repeatedly throughout the period of 1997-2003 (Figure 2.4). The lowest DO value of 1.12 mg/L was recorded on June 2000. The monthly averaged DO concentrations at the station are shown in Figure 2.5 (data were not available every month). It can be seen that there is a strong seasonal variation of the DO with the lowest values often occurring in summer and fall.

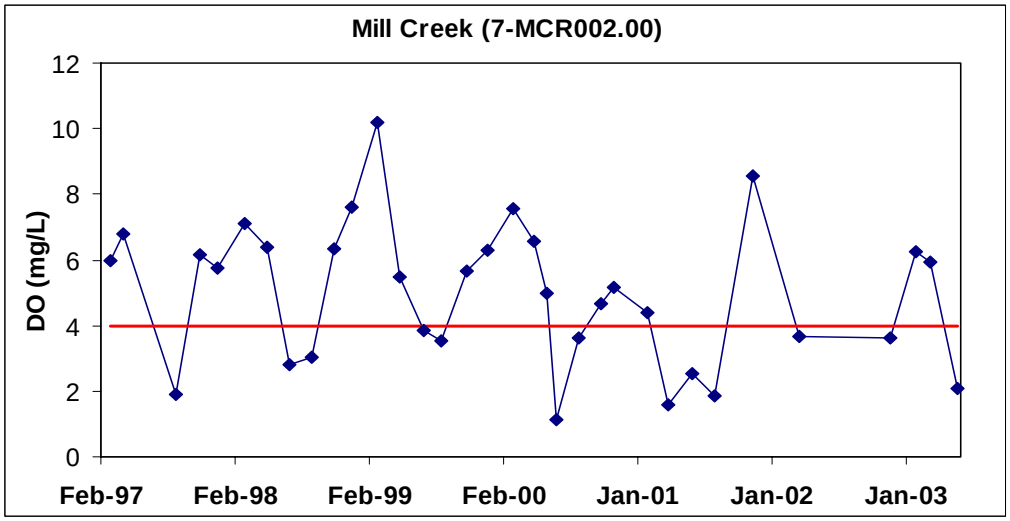

Figure 2.4: DO Observations in Mill Creek. The Horizontal Line Denotes the 4 mg/L Minimum Water Quality Criterion

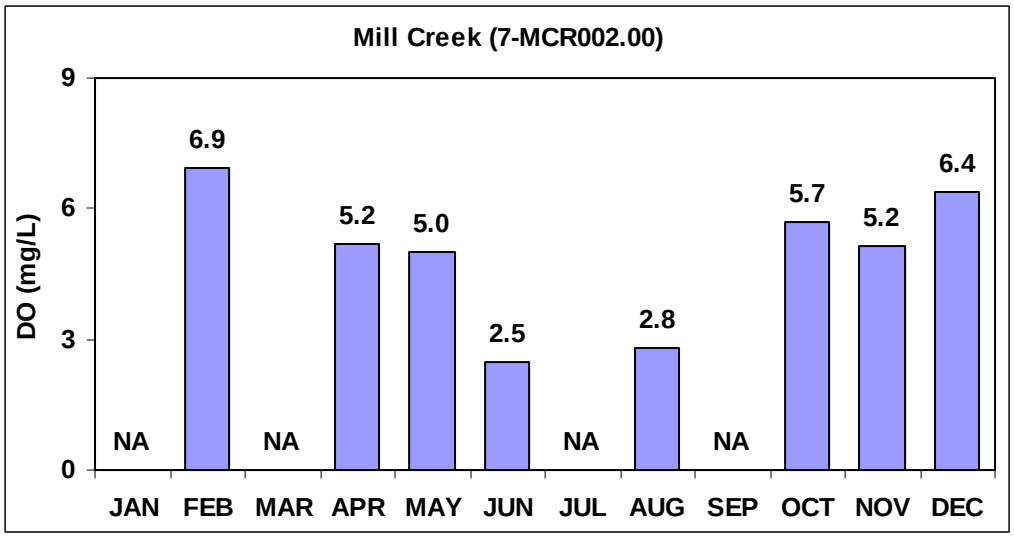

Figure 2.5: Averaged Monthly DO in Mill Creek (1997-2003)

2.4.2 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 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). Twenty six BOD samples were collected bi-monthly from 1997 to 2001 (Figure 2.6). Most of the observations were below the detection limit of 2 mg/L, indicating a low level of short term bio-degradable organics in the waterbody.

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 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 resistant to quick decay. DEQ has 14 COD measurements from 1997 to 1999 (Figure 2.6). They were an order of magnitude higher than the BODs during the same period. This indicates that the waterbody may have a large amount of organic matter resistant to quick decay.

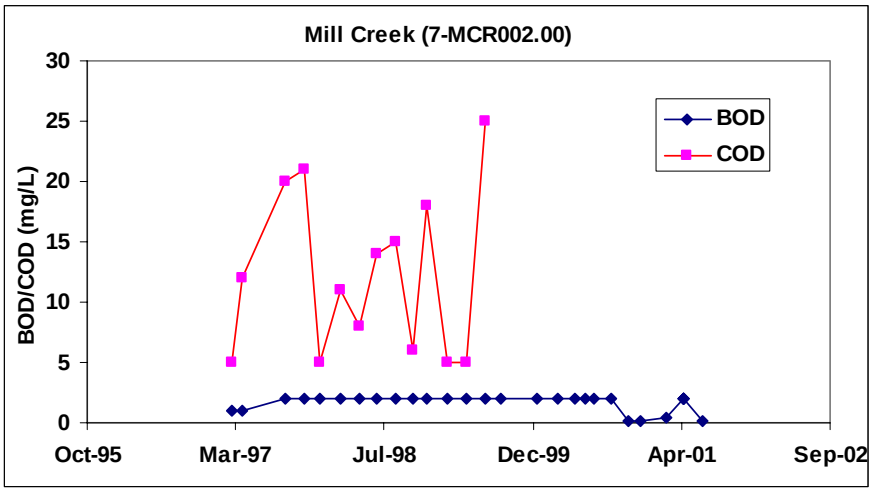

Figure 2.6: BOD and COD in Mill Creek

2.4.3 Chlorophyll *a*

Chlorophyll *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 chlorophyll *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 chlorophyll *a* levels increase, the amount of sunlight reaching underwater grasses declines as well. Figure 2.7 is the available chlorophyll *a* concentrations of Mill Creek. In general, the concentrations were between 1 and 5 ug/l, which usually indicates a low biomass of phytoplankton and a mesotrophic waterbody (Boyd, 2000). The low algae concentration also indicates that the light condition is not favorable for algae to grow in the creek.

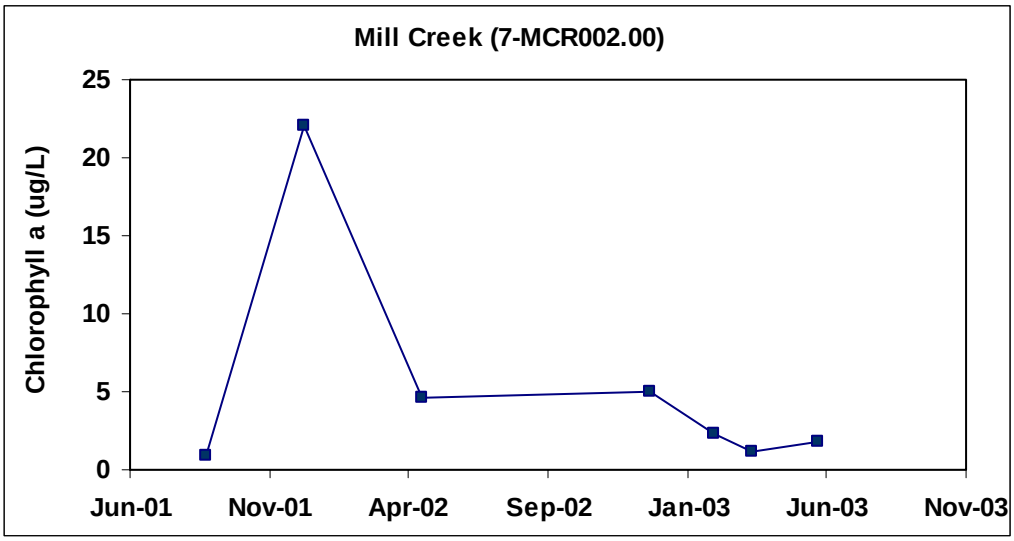

Figure 2.7: Chlorophyll *a* Concentrations in Mill Creek

2.4.4 Nutrients

The nutrients, nitrogen and phosphorus, are elements, and are essential building blocks for plant growth. Most of the water samples of nitrogen and phosphorus were bi-monthly collected in Mill Creek.

Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Total dissolved inorganic nitrogen (DIN, 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 plant to uptake. High concentrations can be observed for the stream with point source discharging nitrogen. The DIN values in Mill Creek were very high. The maximum concentration reached 10.7 mg/L in December 1998 (Figure 2.8). The dominant DIN

species is NO_3^- (Figure 2.9), while the NH_3 concentration is less then 1 mg/L. A large portion of DIN 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.

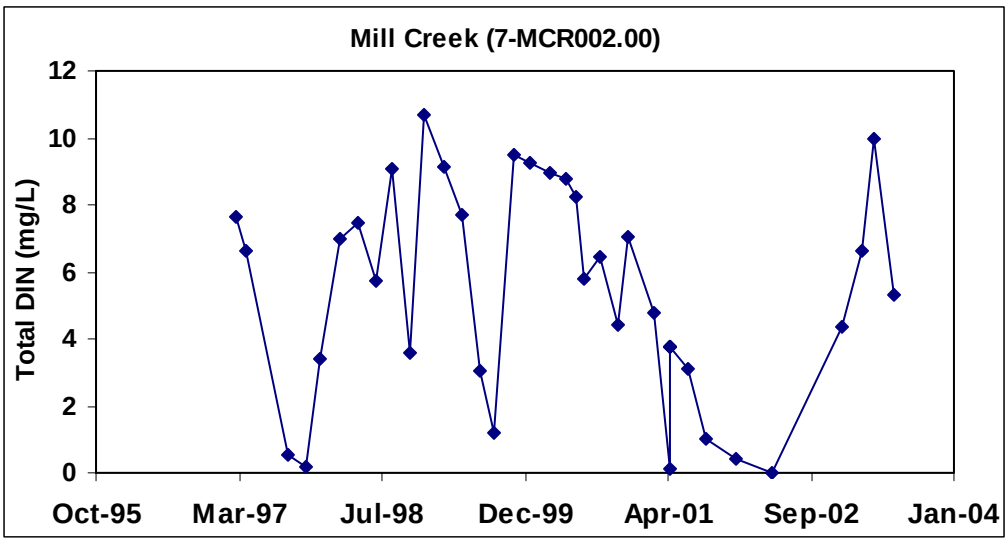

Figure 2.8: Total DIN in Mill Creek

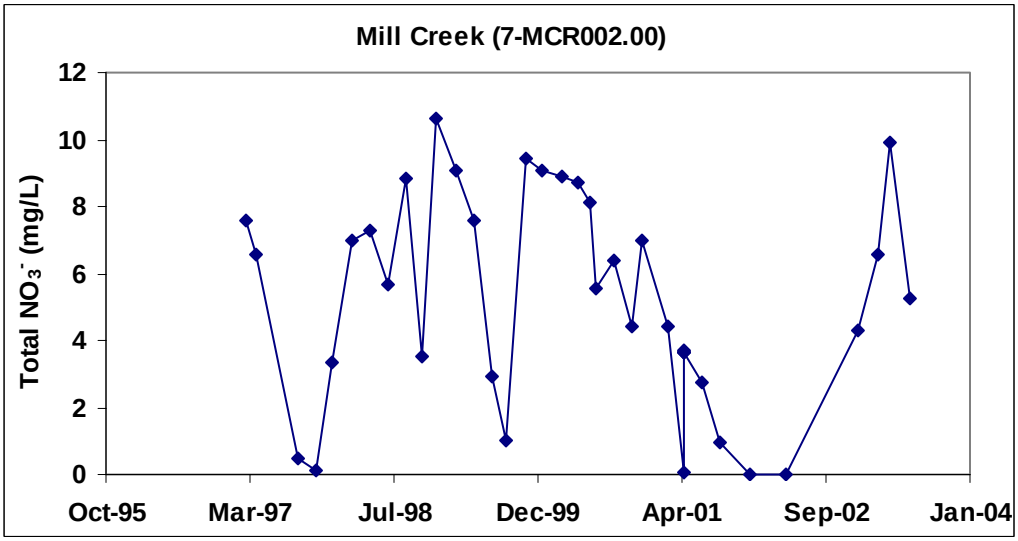

Figure 2.9: Total NO_3^- in Mill Creek

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. Total phosphorus (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). The highest TP concentration in Mill Creek did not exceed 1.1 mg/L, with other observations no higher than 0.5 mg/L (Figure 2.10).

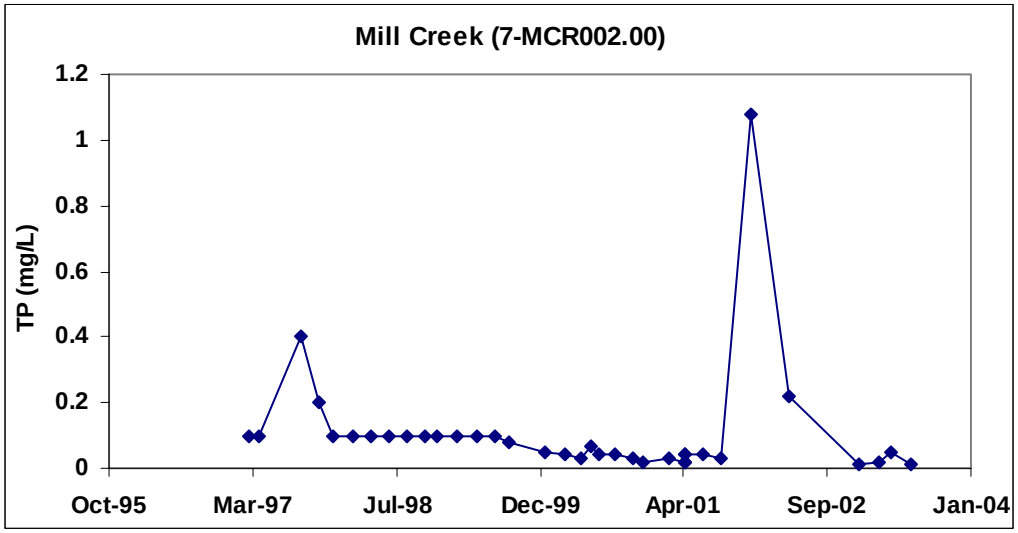

Figure 2.10: TP Concentrations in Mill Creek

2.4.5 Temperature, pH, and Salinity

Temperature and pH values for Mill Creek are shown in Figures 2.11 and 2.12, respectively. A wide seasonal temperature variation is typical in the stream. Summer temperatures reached 25°C and winter low temperatures were above 0°C. The high temperature corresponded to the low DO in summer. The pH values varied between 5.5 and 7.5, which exceeded the lower limit of optimum range of 6.5-9 for fish and other aquatic life, indicating that slowed growth of some species may occur (Boyd, 2000). Most of the salinities were between 0 and 0.2 ppt, indicating the influence of tide was very limited (Figure 2.13).

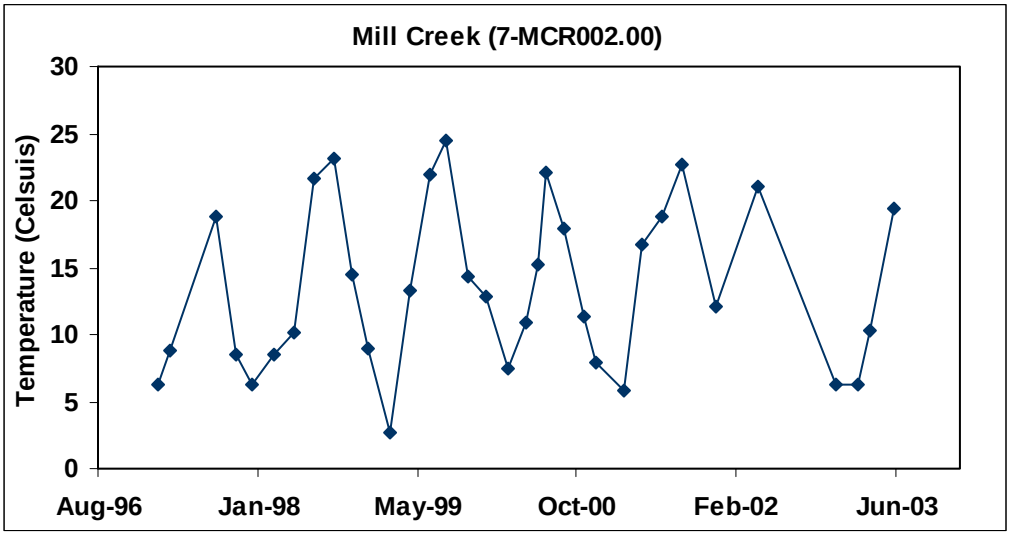

Figure 2.11: Temperature Variations in Mill Creek

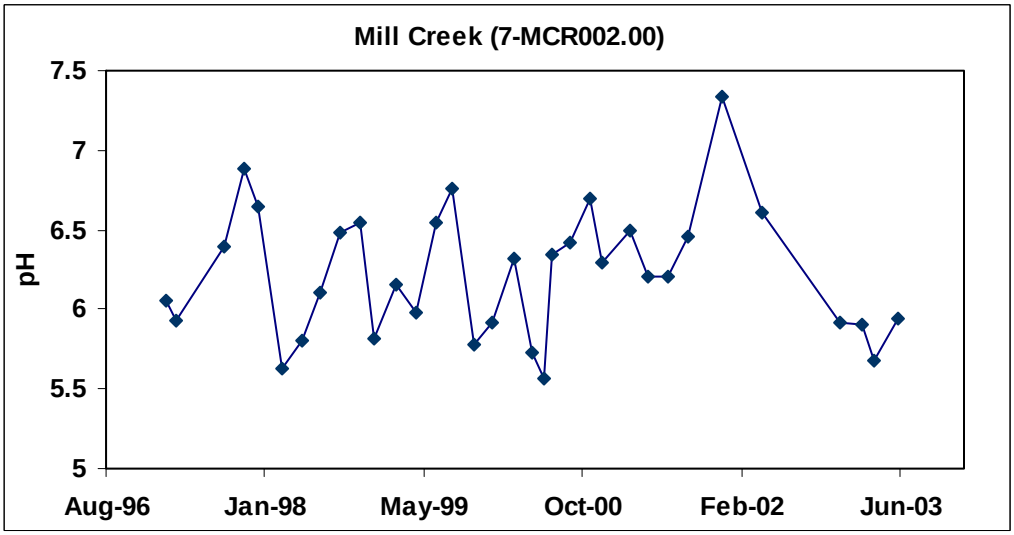

Figure 2.12: pH Values in Mill Creek

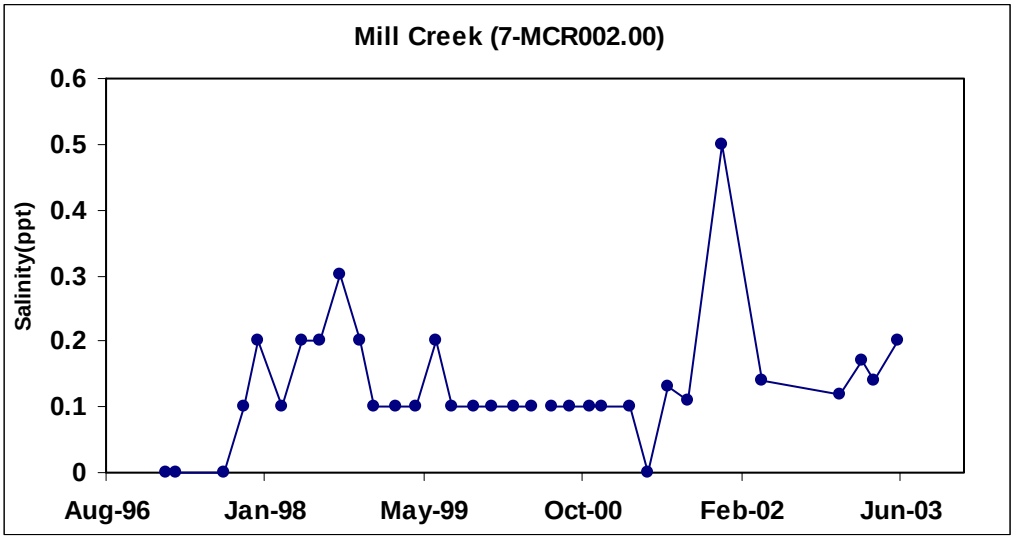

Figure 2.13: Salinities in Mill Creek

2.4.6 Summary of Data Analysis

The Mill Creek is a very narrow freshwater stream. It is surrounded by forest and agricultural land with a large wetland area adjacent to the stream. Runoff from adjacent farmlands can discharge to the stream through the drainage ditches connected to it. There is no point source facility with permitted nutrient levels that directly discharges to Mill Creek. The creek is characterized by low flows and minimal re-aeration under normal hydrological conditions. The flow is very low during dry season, and sometimes the creek can be completely dry for a couple of days. Large amount of carbon transported from upstream, as well as adjacent farmlands and wetlands, will be deposited inside the creek. The vegetation on the bank often covers a large portion of the stream during summer time, resulting in low re-aeration and low light in the creek. The low light condition is not favorable for algae growth, thus low algae concentrations were observed. A large quantity of decaying vegetation with high concentrations of organic acids (tannins, humic, and fulvic substances) can accumulate there. The averaged pH value was around 6.2 and 38% of the time the measured pH values were below 6. The level of acidity, as registered by pH in the waterbody, indicates the decay of vegetative material and buffering capacity. Very high nitrate concentrations were observed, and possibly most of them were discharged into the creek through ground water. The decay of OC and oxidization of ammonia in the subsurface also contribute to the DO consumption. These results indicate that low DO in the stream is caused by high inflow of nitrogen and OC, which also subsequently resulted in deposition of organic matters in the bottom. High temperature, low re-aeration, decay of organic materials and nitrogen oxidation, and the high SOD due to accumulated deposition of organic matters, are dominant causes of low DO.

A summary statistics of nutrients, BOD_5, and algae are listed in Table 2.2. In general, the average nitrate concentration was about 5.26 mg/L. The averaged total nitrogen (TN) and TP were 5.87 and 0.10 mg/L, and the former was 487% higher than the screening level of water quality assessment guideline for Class VII, Swamp Water. The TN and TP levels were 727% and 233% higher than the EPA recommended levels, respectively.

Table 2.2: Summary of Water Quality Parameters of Mill Creek

	Duration	Count	Mean	Standard Deviation	[1]Background Value for Natural Condition	Values EPA Recommended
DO (mg/L)	1997-2003	34	4.98	2.16		
TN (mg/L)	1997-2003	37	5.87	3.01	<1.0	0.71
NH_4^+ (mg/L)	1997-2003	38	0.06	0.07		
NO_{23}^- (mg/L)	1997-2003	38	5.26	3.15	<0.6	
TP (mg/L)	1997-2003	37	0.10	0.18	<0.1	0.03
BOD_5 (mg/L)	1997-2001	30	1.70	0.64		
Chl *a* (ug/L)	2001-2003	7	5.42	7.50		
pH	1997-2003	34	6.22	0.41	<6	

[1]Water Quality Assessment Guidance Manual, VA-DEQ, 2008, http://www.deq.virginia.gov/waterguidance/wqam.html

3.0 SOURCE ASSESSMENT

3.1 General

All plants require nutrients for growth. In aquatic environments, nutrient availability usually limits plant growth. When these nutrients are introduced into the estuary at higher rates, the productivity of aquatic plants, both floating and attached, 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 oxygen environment or the migration of fish to surface waters.

Potential sources of nutrients and organic matter to a waterbody include both permitted and non-permitted sources. Permitted sources can be individual facilities such as sewage treatment plants, or stormwater systems such as municipal storm sewer systems. In Mill Creek, there is no point source with permitted nutrient levels. Often referred to as non-point source pollution, non-permitted sources of nutrients are those that are diffuse and without a single identifiable point of origin. During rain events, surface runoff transports water and nutrients, and discharges to stream. Nutrients delivered via runoff may originate from all landuse categories. In residential landscape, nutrients may be introduced from residential landuse practices, i.e. fertilizer applications, failing septic systems, and pet wastes. In agricultural landscape, sources of nutrients include crop applications, and livestock and pet wastes. Contributions from wildlife, both mammalian and avian, are natural conditions associated primarily with undeveloped areas (forest and wetlands), but to some extent all landuses, and represent a background level of nutrient loading. There are some nutrient loads to the waterway from undeveloped lands, which are considered to be background level.

In order to better address the sources of pollutants and connect them with the model system, the Mill Creek watershed was divided to 4 sub-watersheds based on elevation data (e.g., United States Geological Survey (USGS) Digital Elevation Model and topographic maps) and local survey information (Figure 3.1). The information presented in this chapter serves as a reference for the nutrient loads determined for each landuse category as described in Section 4.0.

3.2 Population Number Summaries

Population numbers for humans, dogs, livestock, and wildlife are shown in Table 3.1. Data sources for human and livestock numbers and an explanation of the pet and wildlife numbers are found in Appendix B. Human population is derived from US Census Bureau

data and estimated based on watershed area and landuses. National Agriculture Statistics Survey data was used to calculate the livestock values (Appendix B).

Table 3.1: Humans, Dogs, Livestock, and Wildlife Populations by Sub-watershed

Sub-watershed		1	2	3	4
Human		58	26	27	26
Dog		14	6	7	6
Livestock	**Cattle**	<1	3	2	<1
	Swine	1	<1	<1	<1
	Horse	<1	<1	<1	<1
	Sheep	<1	<1	<1	<1
	Chicken*	<1	<1	<1	<1
Wildlife	**Duck**	36	16	17	16
	Geese	27	12	13	12
	Deer	16	7	8	7
	Raccoon	26	12	12	12
* The current data are not available. The numbers do not include new chicken farms be added in the watershed in recent 3 years.					

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 nitrogen from human wastes and phosphorus from machine dishwashing detergents and some chemical water conditioners. There are approximately 69 septic systems in the Mill Creek watershed (Figure 3.1). With a failure rate of 12% from literature, the estimated number of failed systems is approximately 8.

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 whole watershed. Based on local information, the estimated amount of N-fertilizer applied to the cropland is 125 lbs/acre/year and the chicken manure application rate is 1-2 tons/acre/year. Lawn fertilizer loading is 44 lbs/acre/year using a literature value for the Chesapeake Bay region (with a ratio of nutrients of N:P = 70:30).

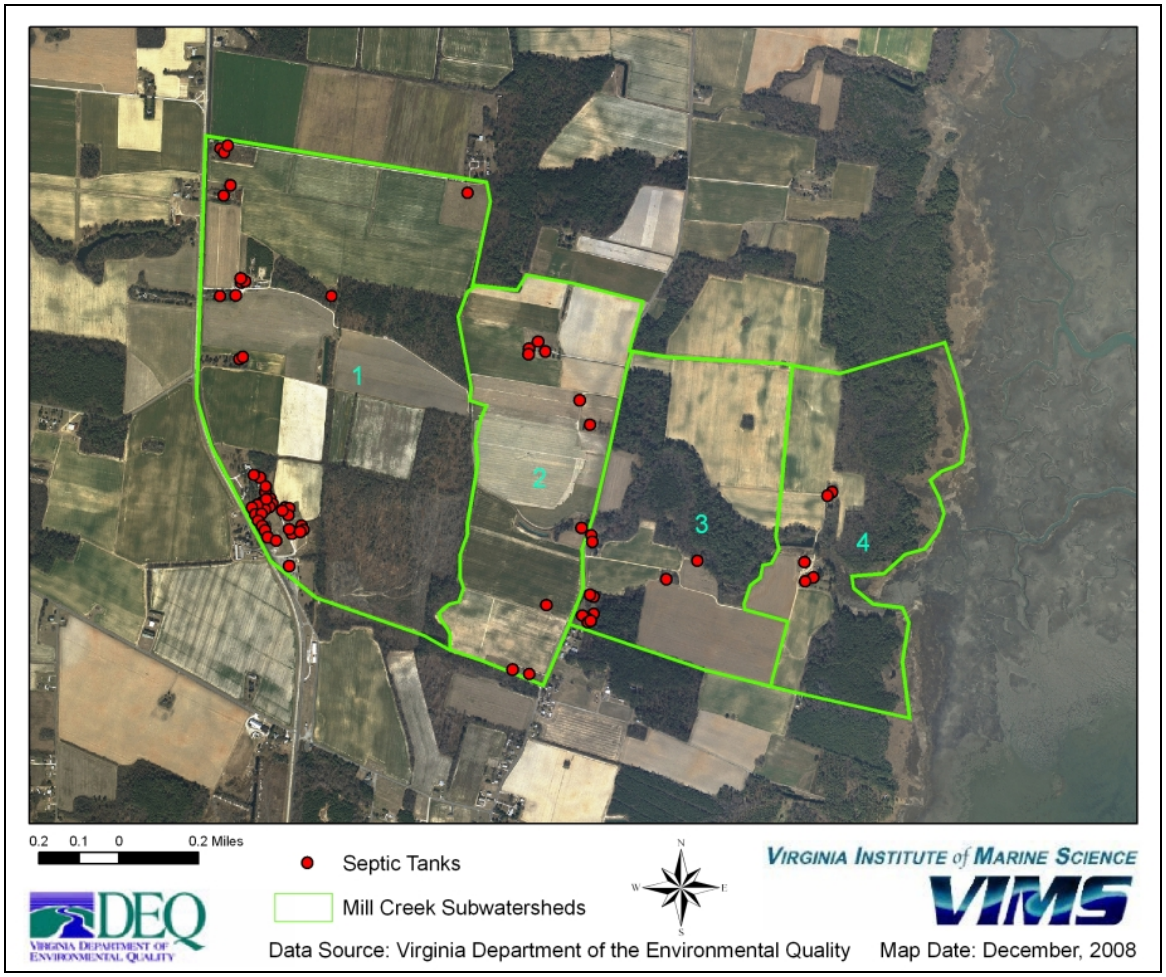

Figure 3.1: Sub-watersheds and Septic System Locations of Mill Creek

3.5 Other Sources

Inputs from groundwater is another source of nutrients to Mill Creek. Specific values are not available; however, a study in Cherrystone Inlet and other locations on the Eastern Shore provide a TN range of 2.0 - 7.0 mg/L and TP range of 0.02 - 0.03 mg/L (Reay, 1996).

Atmospheric deposition of air-borne nutrients has been estimated using the value from the literature for the Chesapeake Bay region shown in Table 3.2.

Table 3.2: Nutrient Contribution from Atmospheric Deposition

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

3.6 Nutrient and BOD/Carbon Loads Summary

As building blocks for biotic production, nitrogen, phosphorus, and carbon are utilized in the process of algal and vegetation growth in the stream, and then become available again as algae and vegetation 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 background, 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 which 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, 1998). 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, 23.5, and 240 mg/L, respectively.

For OC, which is both naturally-produced on land and a potential pollutant in the stream, the accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of C/N was obtained from storm water sampling monitoring instead of directly surveyed field data in the Eastern Shore watershed. Due to the absence of subsurface water quality measurements, pollutant concentrations for interflow and groundwater were derived from the reference data of Cherrystone Inlet (Reay, 1996). The total loads for TN, TP, and OC were estimated based on landuse distribution. Load contributions from manure/litter/fertilizer applications were applied to agricultural landuses, those from atmospheric deposition were distributed to all the landuses categories, those from wildlife were distributed to all the landuses accept urban, and those from failure of septic systems to low-intensity residential landuse.

4.0 TMDL DEVELOPMENT

4.1 Overview

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

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

This section documents the detailed DO TMDL and LA development for Mill Creek.

4.2 Selection of a TMDL End Point

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 III waters are a minimum of 4.0 mg/L and a daily average of 5.0 mg/L. Based on data analysis and field survey, as well as model sensitivity test, it is evident that the low DO occurring in Mill Creek is caused by a combination of natural condition and human impact. High temperature, low re-aeration, and decay of organic materials and nitrogen oxidation, together with the high SOD due to accumulated deposition of organic matters, are dominant causes of low DO. Reducing nutrients and OC discharge to the Creek will improve the DO condition. To evaluate the amount of nutrients and OC to be reduced, the DO water quality criteria of a minimum of 4.0 mg/L and a daily average of 5.0 mg/L were set as the endpoints to determine the allowable loadings.

4.3 Model Development for Computing TMDL

Numerical models are a widely used approach for TMDLs 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 LSPC, developed by the USEPA (Shen *et al.*, 2005), was selected to simulate the watershed hydrology and nutrient loads to the receiving waterbody of Mill Creek. Figure 4.1 shows a diagram of the modeling system. The EFDC developed by Park *et al.* (1995) and recommend 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.

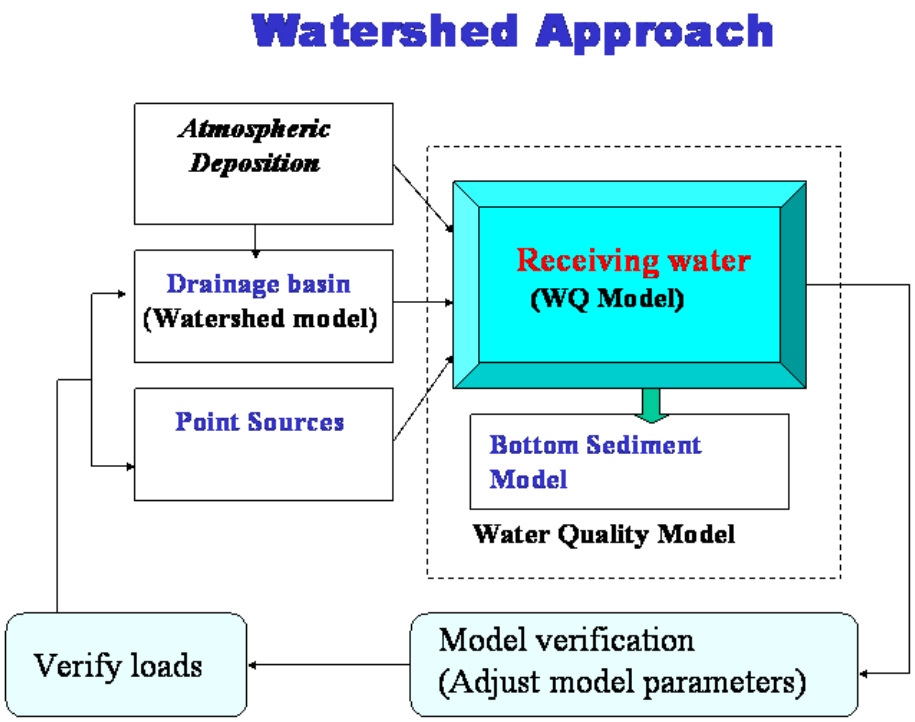

Figure 4.1: Diagram of the Structure of Modeling System

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 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 representing 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 is coupled to the sediment diagenesis (DiToro and Fitzpatrick, 1993), which 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 sulfite), and the SOD back to the water column.

The flow simulated by the watershed model was calibrated using USGS gaging data at Gage 01484800 in Guy Creek near Nassawadox, VA. The gage is located approximately 33 km north of the Mill Creek watershed and is the only station located in the Eastern Shore. The flow simulation was further verified with the local flow data collected by VA-DEQ in the Onancock Creek watershed (Wang, 2005). An example of model calibration of the flow is shown in Figure 4.2. Detailed modeling processes and calibration procedure is presented in Appendix A.

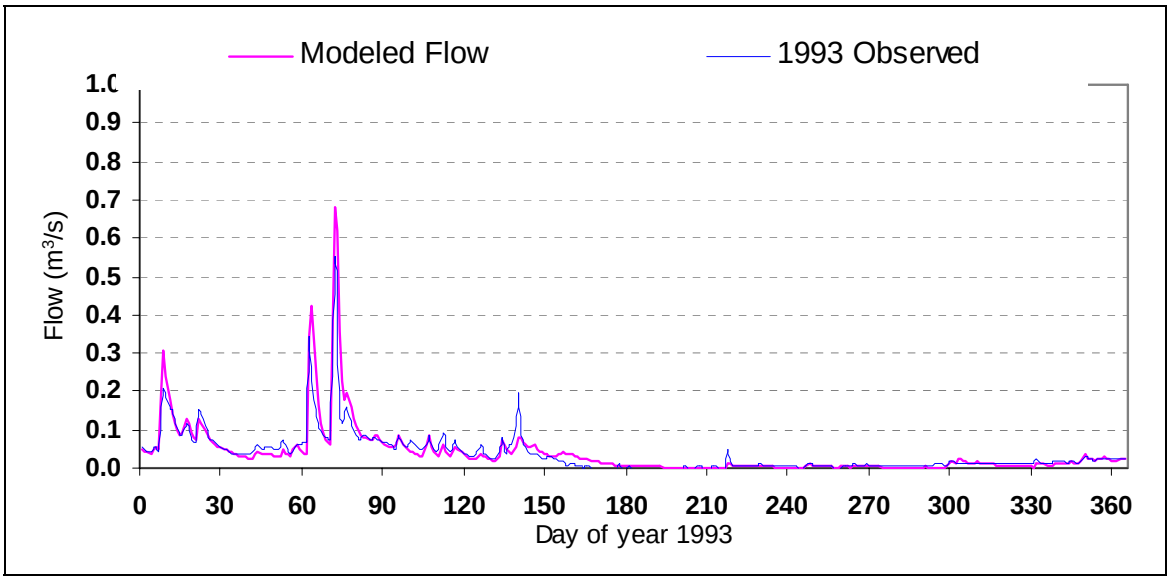

Figure 4.2: Time Series Comparison of Daily Stream Flow between Model Simulation and Observations from USGS Stream Gage 01484800 in 1993

Because the nutrients data in the watershed were not available, an interactive approach of calibration of watershed and in-stream water quality model was conducted using all available in-stream monitoring data. The water quality model was calibrated in Mill Creek using the observation data. A six-year model simulation (1998-2003) was conducted. The model was calibrated based on TN and TP, phosphate, ammonium, nitrate, total Kjehldahl nitrogen (TKN), and DO. The computed average nutrient and carbon for the existing condition is shown in Figure 4.3. A comparison of model results against observations from 1998 to 2003 is shown in Figure 4.4. It can be seen that the model simulated the seasonal DO variation and low DO during this period well. The detailed model setup and calibration processes are presented in Appendix A.

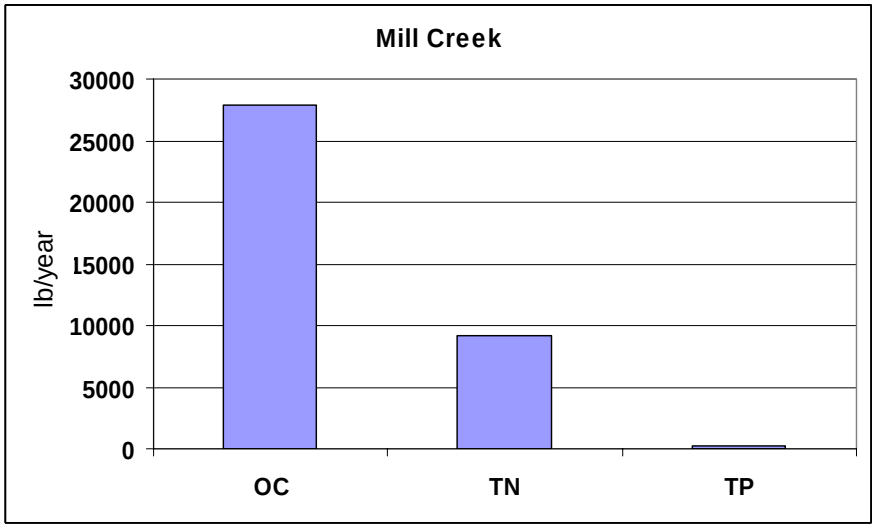

Figure 4.3: Estimated Average Annual Existing Nutrients and Carbon Loading to Mill Creek

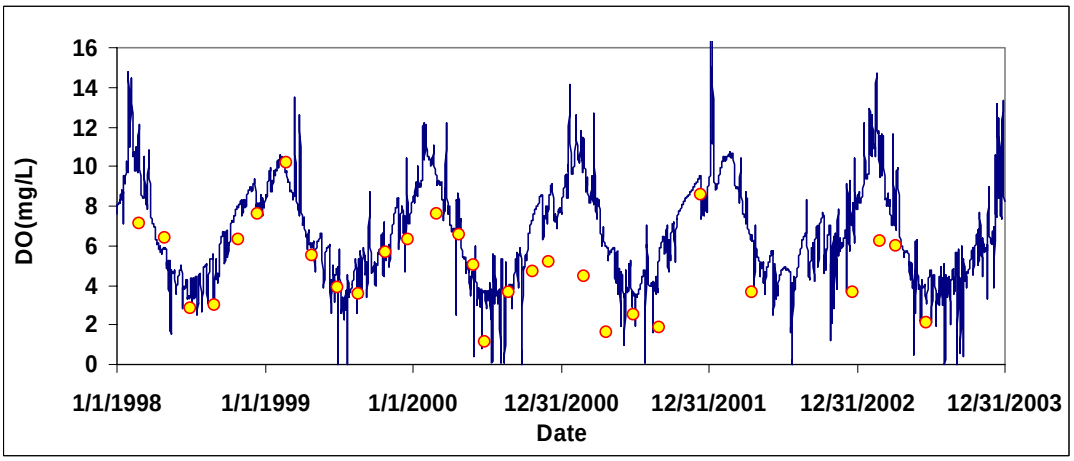

Figure 4.4: Time Series Comparison of Daily Mean DO between Model Simulation (the Line) and Observation (the Circles) from 1998 to 2003

4.4 Consideration of Critical Conditions and Seasonal Variation

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

The current loadings to the waterbody were determined using a long-term record of water quality monitoring (observation) data. The period of record for the data was 1998 to 2003, which spans different flow regimes and temperatures. A six-year model simulation (1998-2003) was conducted. The model was calibrated based on multiple water quality parameters including TN and TP, phosphate, ammonium, nitrate, TKN, and DO. The resulting estimate is quite robust. Seasonal variations involved changes in surface runoff, stream flow, and water quality condition as a result of hydrologic and climatologic patterns. These were 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 Mill Creek, an explicitly MOS of 5% was included in the TMDL.

4.6 TMDL Computation

According to the DO criteria, the allowable nutrients to the creek to meet the water quality standards can be computed. The allowable loads for organic carbon, total nitrogen and phosphorus were calculated using the DO water quality criteria of a minimum of 4.0 mg/L and a daily average of 5.0 mg/L.

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

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

The calculated results are listed in Table 4.1.

Table 4.1: Estimated Loads and Load Reductions for TOC, TN, and TP

Pollutant	Current Load (lb/day)	Allowable Load (lb/day)	Required Reduction (%)
TOC	76.34	30.53	60%
TN	25.18	10.07	60%
TP	0.77	0.77	0%

4.6 Summary of TMDL and Load Allocation

As there are no industrial or wastewater treatment facilities that are permitted to discharge nutrients in the watershed of Mill Creek, the loads were allocated to the LA. For consideration of future growth in this watershed, 1% of the total load is allocated to the future growth. The TMDLs are summarized in Table 4.2.

Table 4.2: TMDLs and Load Allocation (lb/day)

Nutrient	TMDL	=	LA	+	WLA	+	FA	+	MOS
TOC	30.53	=	28.69	+	N/A	+	0.31	+	1.53
TN	10.07	=	9.47	+	N/A	+	0.10	+	0.50

Where:

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

5.0 IMPLEMENTATION AND PUBLIC PARTICIPATION

5.1 General

Once a TMDL has been approved by 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/tmdl/implans/ipguide.pdf. With successful completion of implementation plans, local stakeholders will have a blueprint to restore impaired waters and enhance the value 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 Creek. The Mill Creek is connected to drainage ditches of farming land and the upper portion of the stream is covered by vegetation. Implementation of BMPs in the adjacent farmland and ground improvement of the stream can be useful for reducing nutrients to the stream and enhance re-aeration.

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 WQSs.

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 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.

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 is 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 bimonthly 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/cmonitor/.

To demonstrate that the watershed is meeting WQSs 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 WQSs, monitoring plans and milestones for attaining WQSs.

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 are the municipal separate storm sewer systems (MS4s) which are both covered by NPDES permits and expected to be included in TMDL implementation plans, as described in the stormwater 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 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 WQSs. 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.state.va.us/tmdl/pdf/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 of funding 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 first public meeting was held on February 24, 2009 in Kiptopeke Elementary School, Cape Charles of Eastern Shore Virginia. Local interested organizations and individuals, as well as state agency personnel can attend each meeting. The final meeting was held on April 30, 2009.

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Appendix A: Model Development

A.1 Model Development for DO

Numerical models are a widely used approach for TMDLs 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 Mill Creek. The EFDC modified by 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.

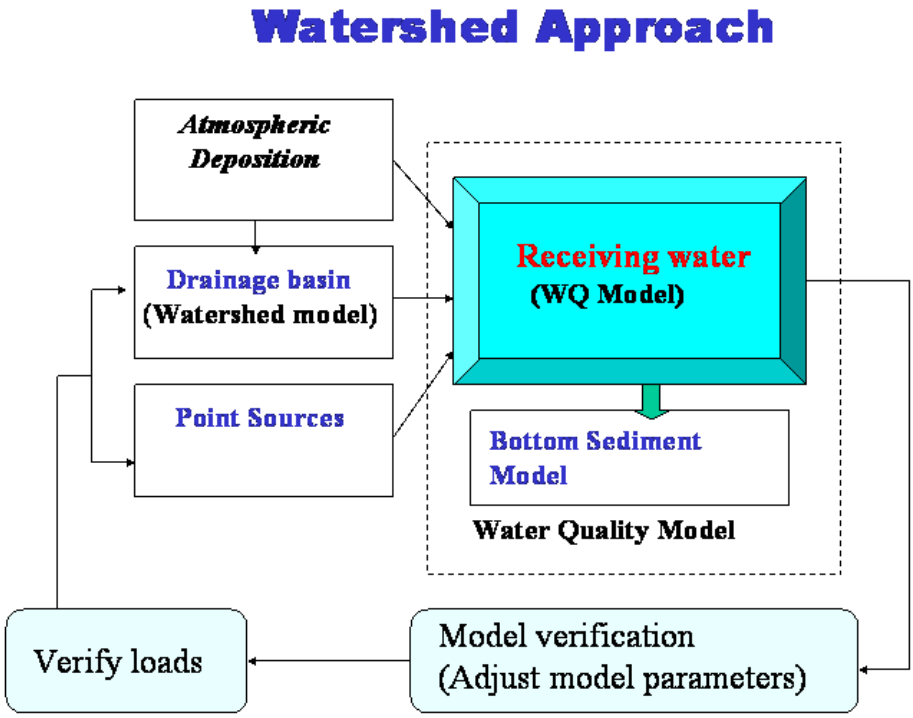

Figure A-1: Diagram of the Structure of Modeling System

A.1.1 Model Description

A.1.1.1 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.*, 2002; USEPA, 2001). Like other watershed models, LSPC is a precipitation-driven model and requires necessary meteorological data as model input.

The LSPC was configured for Mill Creek to simulate the watershed as 4 hydrologically connected sub-watersheds (Figure 3.1). The sub-watersheds were used as modeling units for the simulation of flow and nutrient loads based on meteorology, landuse, and nutrient application. The LSPC was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (nitrogen, phosphorus, and OC) loadings for each sub-watershed were fed into the adjacent water quality model segments of the receiving water model. In simulating nonpoint source pollutants from the watershed, LSPC uses a traditional buildup and washoff approach. Pollutants from various sources (fertilizer, atmospheric deposition, wildlife, etc.) accumulate on the land surface and are available for runoff during rain events. Different landuses 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 landuse category. Pollutant loadings from surface runoff, interflow, and groundwater outflow are combined to form the final loading output from LSPC. 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, 1998).

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 lb/acre/day). The ACQOP can be calculated for each landuse 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 lb/acre/day) and the washoff rate (WSQOP, unit in inches/hour), were specified based on soil characteristics and landuse 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.

A.1.1.2 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 the Mill Creek study, the EFDC model was selected to simulate hydrodynamics. The 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 (http://www.epa.gov/athens/wwqtsc/html/hydrodynamic_models.html).

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, 1992b; Shen *et al.*, 1999a, b).

Inputs to the EFDC model for Mill Creek include:

- Model grid and geometry
- Freshwater inputs (lateral and up-stream) from watersheds
- Surface meteorological parameters (wind, atmospheric pressure, solar radiation, dry and wet temperature, humidity, and cloud cover)
- Nutrient loadings from watershed

The model uses a grid to represent the study area. 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. The model grid used for Mill Creek was developed based on the shoreline digital files from USEPA and USGS Topographic Maps combined with the geometry from field survey. Because the stream is narrow, one dimensional model was used. As the stream at the headwater is very narrow, the model only simulates 1.5 miles of the stream with the width between 3-6 m. The entire stream was divided into 12 segments with the length of 200 m. The downstream boundary condition is based on the specification of outflow based on the slope and roughness of the stream. The upper wind scheme is used for transport pollutants out of the stream.

A.1.1.3 Model Linkage

A linkage between LSPC and EFDC has been developed so that the daily freshwater discharges from the watershed can be directly input into the receiving water model. All of the freshwater discharge or nonpoint source inputs were assigned to specific grid cells.

The EFDC has been integrated with a water column eutrophication component and a sediment diagenesis component (Park *et al*., 1995). The integrated model simulates the spatial and temporal distributions of water quality parameters including DO, algae, and various forms of carbon, nitrogen, phosphorus, and silica.

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-2. Each state variable is defined in Table A-1.

Table A-1: EFDC Model Water Quality State Variables

Abbreviates	State Variable
Bc	cyanobacteria
Bd	diatom algae
Bg	green algae
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

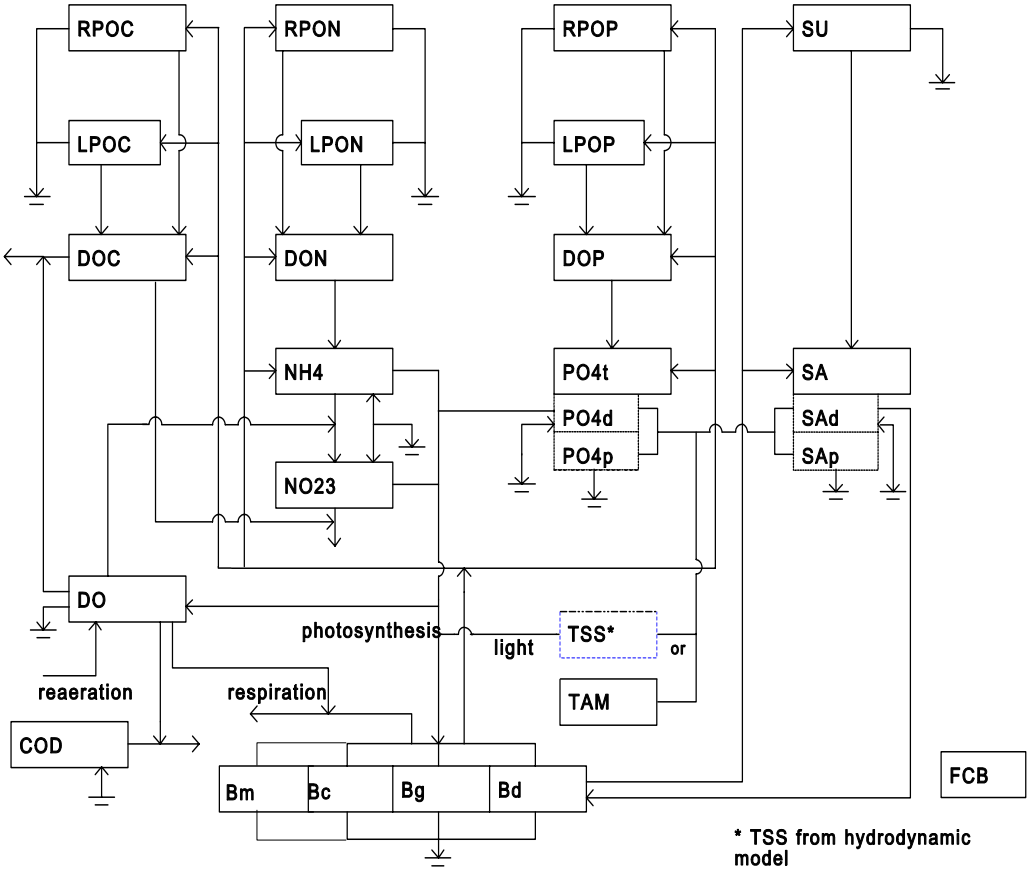

Figure A-2: Diagram of Water Quality Model State Variables and Their Relationships

As only green algae were simulated for Mill Creek, silica was not simulated. 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 model linkage is shown in Figure A-3.

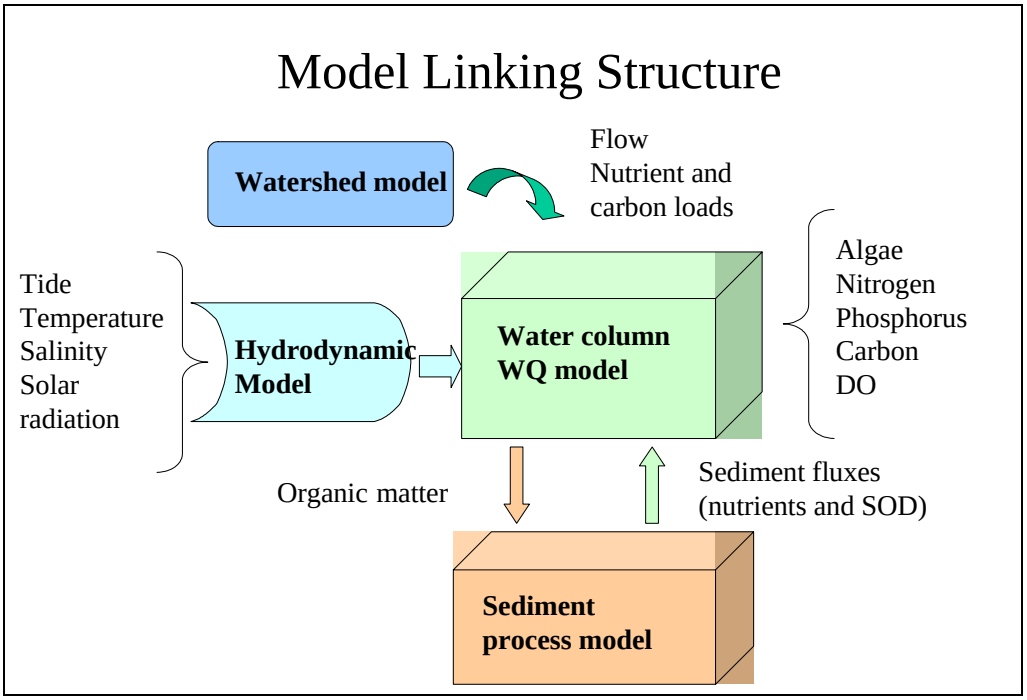

Figure A-3: Diagram of Model Linking Structure

A.1.2 Model Calibration and Verification

A.1.2.1 Watershed Model

The calibration process involved adjustment of the model parameters used to represent the hydrologic processes until acceptable agreement between simulated flows and field measurements were achieved. Since there is no USGS gage or any other continuous flow data available in the Mill Creek watershed, a reference watershed was used for calibration (Wang, 2005). The USGS Gage 01484800 in Guy Creek near Nassawadox, VA, located approximately 33 km north of the Mill Creek watershed, was used to calibrate the model parameters for hydrology simulation. Figure A-4 shows the time series comparison of daily stream flow for years 1993 and 1994. Figure A-5 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.

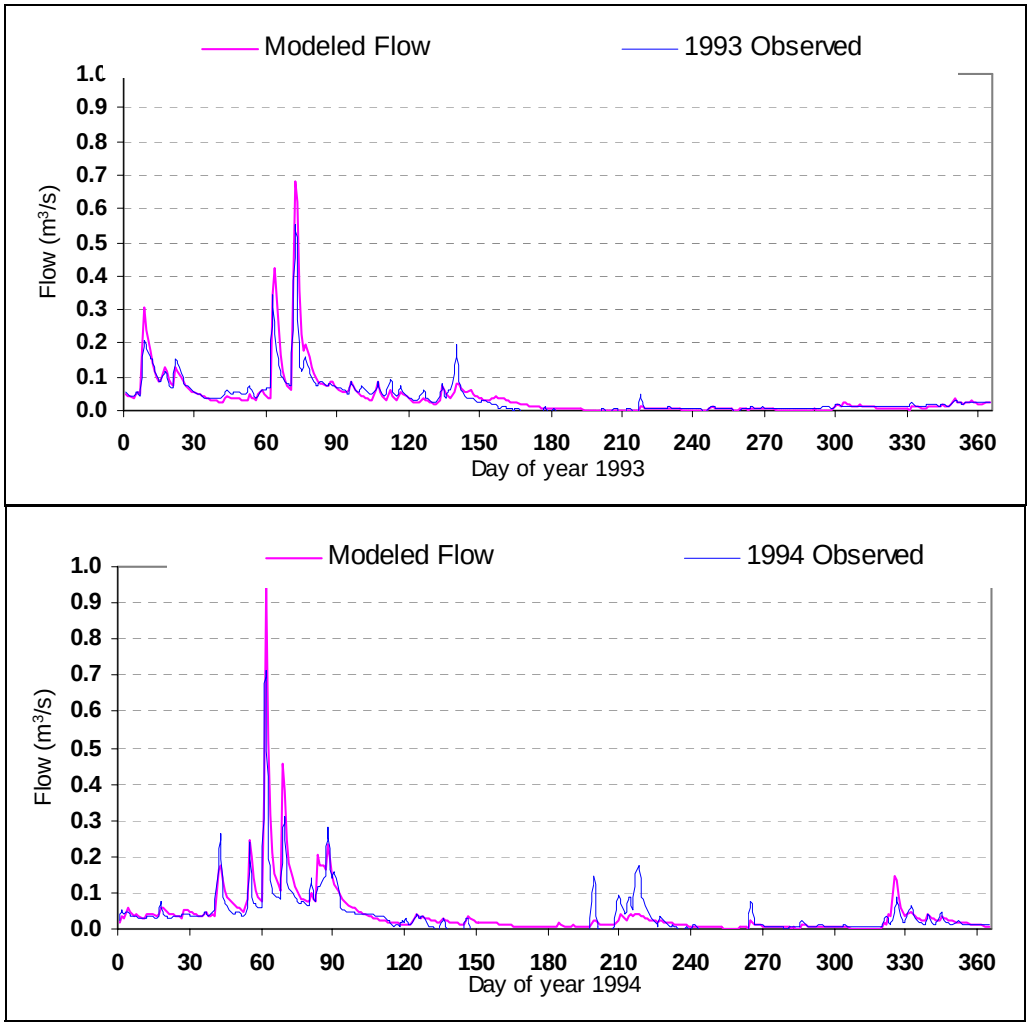

Figure A-4: Time Series Comparison of the Daily Stream Flow between Model Simulation and Observed Data from USGS Stream Gage 01484800 in 1993 and 1994

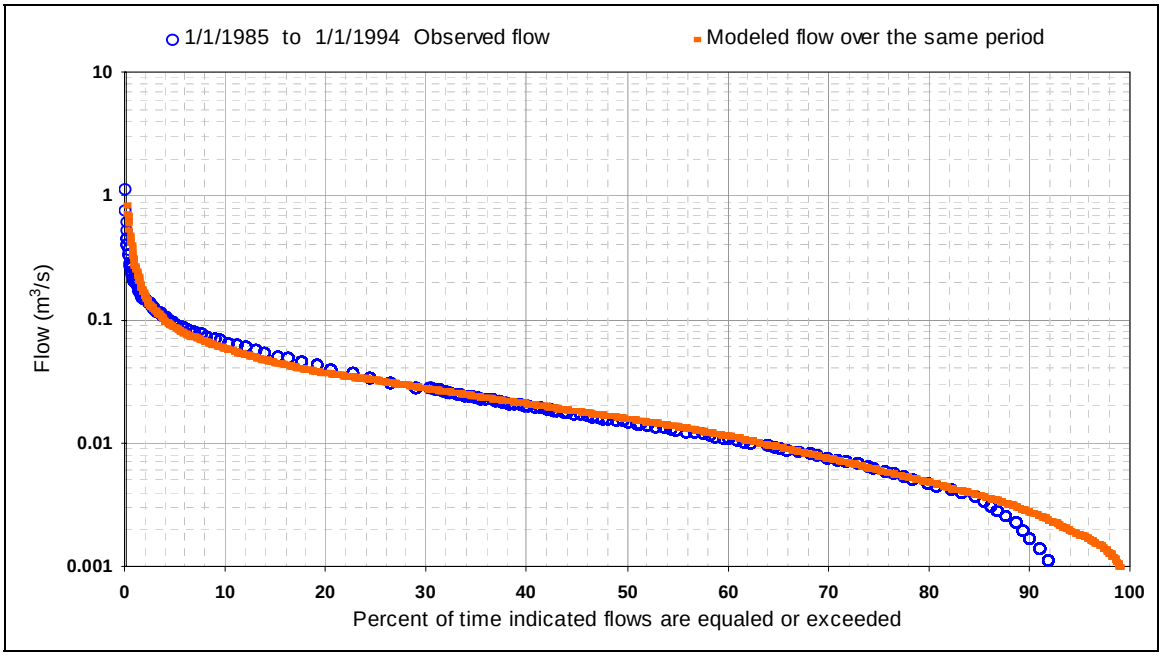

Figure A-5: 10-year Accumulated Daily Stream Flow Comparison between Model Simulation and the Reference Flow Station USGS 01484800

Calibration of water quality simulations is typically performed using water quality measurements from the watershed. Absent the necessary data from Mill Creek watershed, the calibration was performed on the observation data in Mill Creek using an iterative approach between the watershed model and receiving water model. The watershed model parameters (accumulation and lost rates) for nitrogen and phosphate associated with surface runoff of each landuse 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 storm water sampling monitoring instead of directly surveyed field data in the nearby watershed. The storm water measurement in the Eastern Shore shows the ratio is from 3 to 7. Due to the absence of subsurface water quality measurements in the Creek, pollutant concentrations for interflow and groundwater were derived from reference data from Cherrystone Inlet (Reay, 1996). The initial loading output from LSPC was fed into the receiving water quality model. A six-year model simulation (1998-2003) was conducted. The selection of this period is due to the availability perception data and lowest DO occurrence during this period. The initial ratio for particulate and dissolved phases was adjusted based on the model calibrations. The comparison of modeled state variables and observations in the receiving water provided a reference for calibration of the watershed model.

A.1.2.2 Receiving Water 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 Creek are the nutrient and carbon loads from the watershed delivered via surface runoff or ground water. The watershed model simulated TP, TN, and TOC. The loading discharge locations were identical to flow discharge locations along the bank of the Creek. The TN, TP, and TOC 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 labile, and dissolved nitrogen, phosphorus, and carbon. As there is no data for refractory phase of the nitrogen, phosphorus, and carbon, only one particulate phase was simulated for nitrogen, phosphorus, and carbon. The ratios used to split the variables were based on Chesapeake Bay modeling and eutrophication model applications in Onancock Creek (Wang, 2005), 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 a guideline so that calibrated kinetic parameters were within the accepted ranges. The key parameters of growth, respiration, and mortality rates for green algae used in the model were 3.6, 0.05, and 0.05 per day, respectively. The settling rates were 20 and 80 cm/day for algae and particulates, respectively.

The sediment diagenesis model (DiToro and Fitzpatrick, 1993) was coupled to the water column eutrophication model component to simulate nutrient exchanges on the water-sediment interface. The model was run iteratively for 2 years with the use of 1998 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 2 years of iterative simulation, the water quality concentrations in the sediment bed approached a dynamic equilibrium.

A model calibration and validation time period for the tidal simulation was from 1/1/1998 to 12/31/2003. The selection of this period was due to the availability precipitation data and lowest DO occurrence during this period. The model calibration was conducted by comparing the model prediction against in-stream monitoring data. The model calibration results are shown from Figure A-6 to Figure A-10.

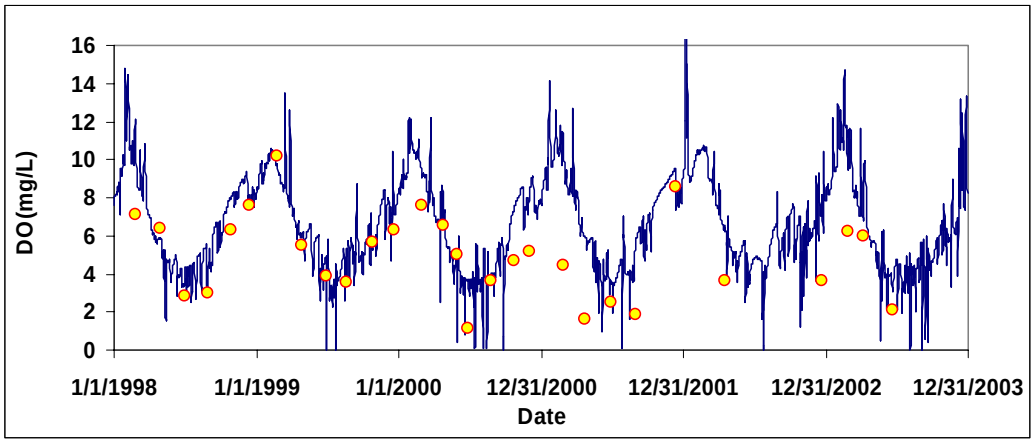

Figure A-6: Comparison of Modeled and Observed DO

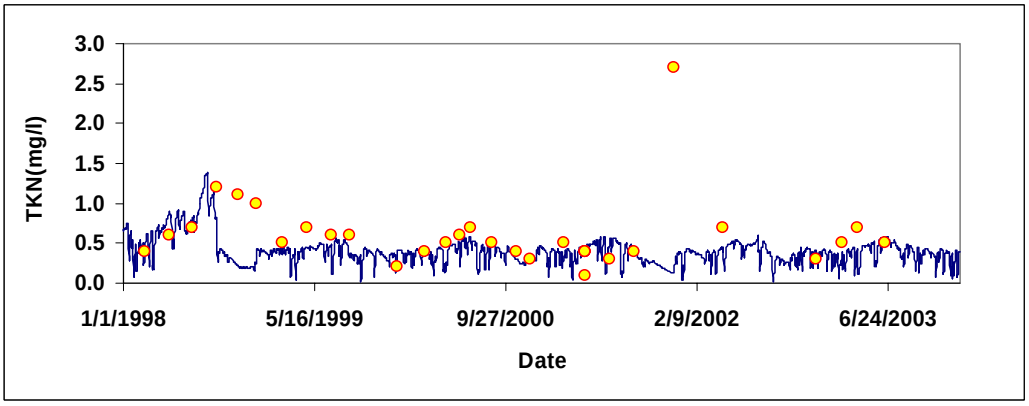

Figure A-7: Comparison of Modeled and Observed TKN

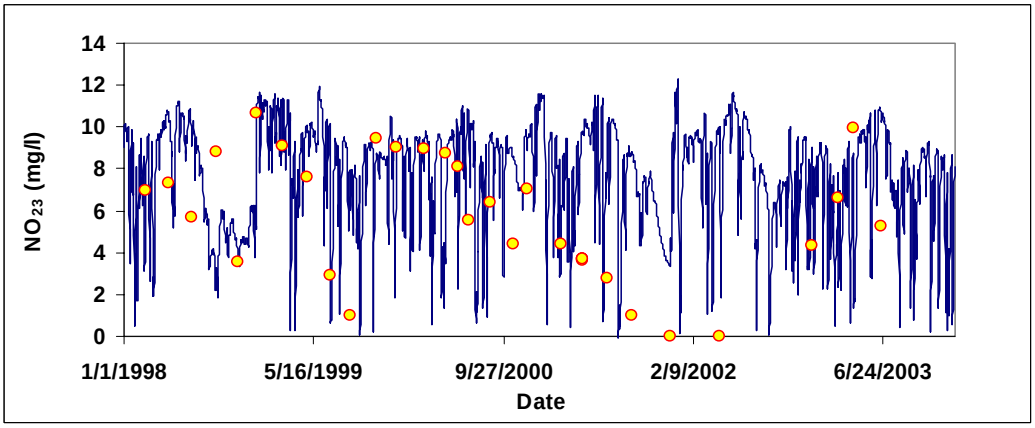

Figure A-8: Comparison of Modeled and Observed NO_{23}

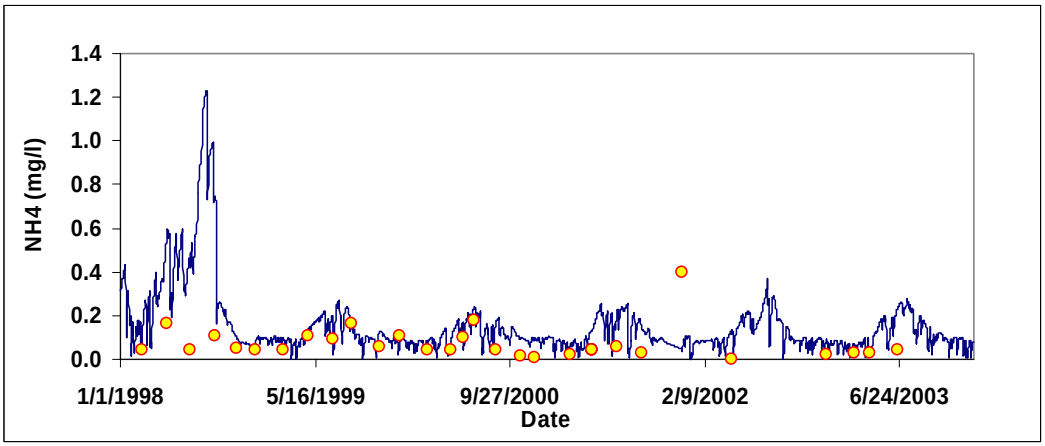

Figure A-9: Comparison of Modeled and Observed NH_4^+

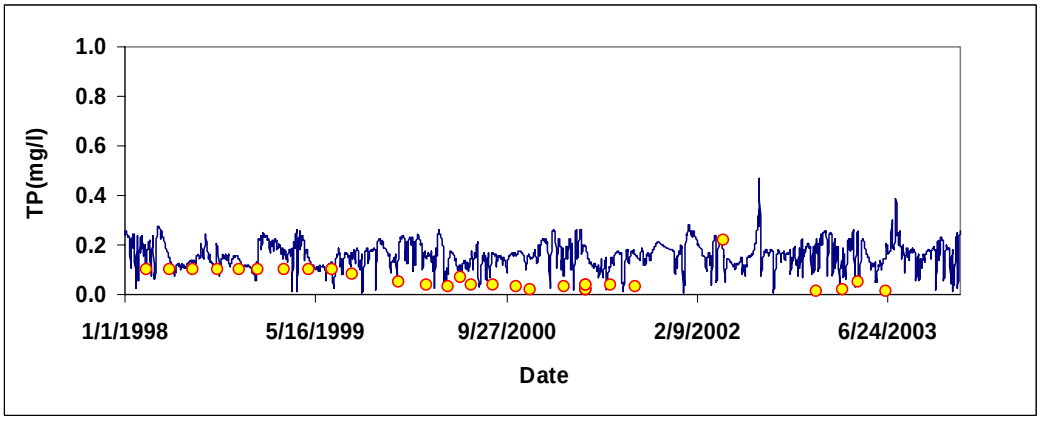

Figure A-10: Comparison of Modeled and Observed TP

A.2 Allocable Load

A.2.1 Current Condition

A six-year model simulation from 1998 to 2003 was selected to represent the current condition, which was the same period used for the model calibration. The selection of these six years captured a wet, a mean, and a dry meteorologic condition. The loads of nitrogen, phosphorus, and OC were generated by the LSPC model with calibrated model parameters. The loading and flow output from the watershed model were input to the receiving water model (EFDC) to simulate hydrodynamic and water quality condition in the Creek. Average annual loads were calculated for TN, TP, and TOC, respectably. Figure A-11 shows the annual loading distribution. The estimated loads were used to represent the existing condition.

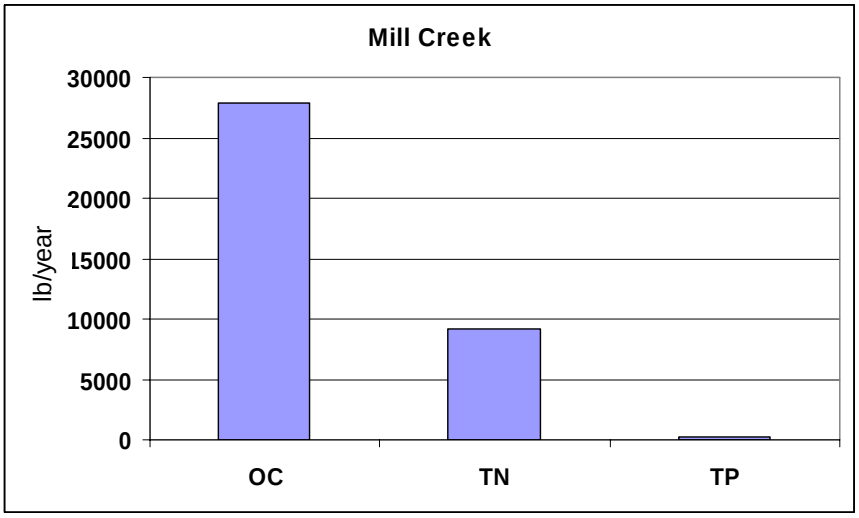

Figure A-11: Estimated Existing Annual Mean Nutrients Loading Discharged to Mill Creek

A.2.2 Allowable Load

According to the endpoint of numerical criteria for DO, a series of nutrient reduction scenarios were conducted to find the allowable loads to evaluate the attainment of acceptable in-stream water quality criteria. The results on average in-stream concentration for the scenarios of load reduction of 60% are listed in Table A-2. With a 60% reduction of TN and TOC, the in-stream DO concentration meets the water quality criteria. A DO distribution is shown in Figure A-12. It can be seen that the DO is improved with a 60% reduction of TN and TOC.

Table A-2: Summary of Existing Loads and Allowable Loads

Pollutant	Current Load (lb/day)	Allowable Load (lb/day)	Required Reduction (%)
TOC	76.34	30.53	60%
TN	25.18	10.07	60%
TP	0.77	0.77	0%

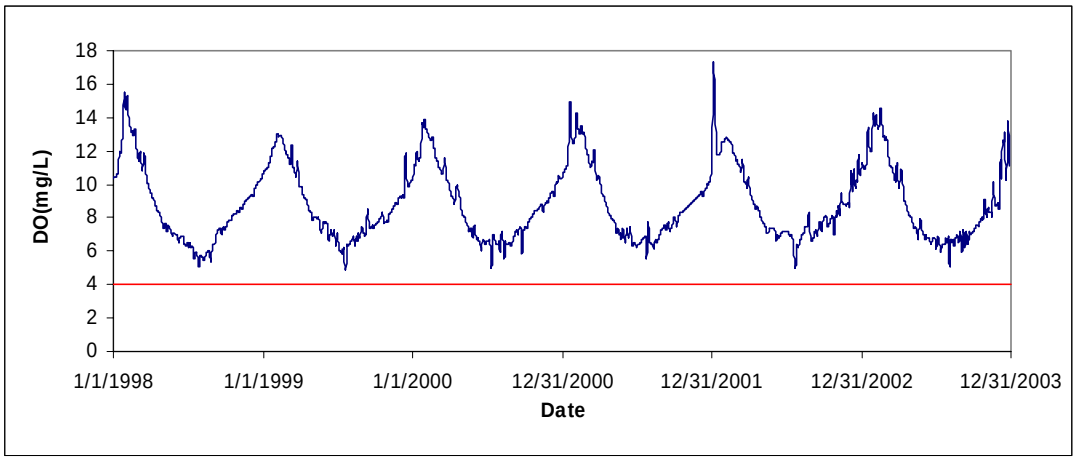

Figure A-12: DO Distribution after 60% Reduction of TN and TOC

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 below.

B.1 Human

The number of households was identified on the high resolution aerial photo. This number was multiplied by the septic failure rate[1] to get the total number of failed septic tanks in the watershed. Assuming the average number of people served by each septic system is 2.39, the number of people on failed septic system can be calculated.

B.2 Livestock

US Census Bureau data was 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

Geographic Information System (GIS) 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 sub-watershed boundaries and the landuses to get the area of each landuse in each sub-watershed.
3) The county boundaries and the sub-watershed boundaries to get the area of each county in each sub-watershed.

Using MS Access, for each type of livestock, the animal density by county was multiplied by the area of each landuse by county in each sub-watershed to get the number of animals in each sub-watershed. The number of animals in each sub-watershed was summed to get the total number of animals in each watershed.

[1] The septic failure rate was estimated by dividing the number of deficiencies in the watershed by the total households in the watershed. The average septic failure rate was 12% and this was used as the default unless the DSS data indicated that septic failure was higher.

B.3 Pets

The dog population was calculated using a formula for estimating the number of pets using national percentages, reported by the American Veterinary Association:
dogs = # of households * 0.58. US Census Bureau data provided the number of households by county. The number of dogs per county was divided by the area of the county to get a dog density per county. GIS was used to overlay the sub-watershed boundaries with the county boundaries to get the area of each county in a sub-watershed. Using MS Access, the area of each county in the sub-watershed was multiplied by the dog density per county to get the number of dogs per sub-watershed. The number of dogs in each sub-watershed was summed to get the total number of dogs in each watershed.

B.4 Wildlife

B.4.1 Deer

The numbers of deer were calculated using information supplied by DGIF, consisting of an average deer index by county and the formula:

$$\#deer/mile^2 \text{ of deer habitat} = (-0.64 + (7.74 * \text{average deer index}))$$

Deer habitat consists of forests, wetlands, and agricultural lands (crop and pasture). GIS was used to overlay data layers for the following steps:

1) The county boundaries and the sub-watershed boundaries to get the area of each county in each sub-watershed.
2) The sub-watershed boundaries and the deer habitat to get the area of deer habitat in each sub-watershed.

Using MS Access, number of deer in each sub-watershed was calculated by multiplying the $\#deer/mile^2$ of deer habitat times the area of deer habitat. The number of deer in each sub-watershed was summed to get the total number of deer in each watershed.

B.4.2 Ducks and Geese

The data for ducks and geese were divided into summer (April through September) and winter (October through March).

Summer

The summer numbers were obtained from the Breeding Bird Population Survey (US Fish and Wildlife Service) and consisted of bird densities (ducks and geese) for 3 regions: the southside of the James River, the rest of the tidal areas, and the salt marshes in both areas. The number of ducks and geese in the salt marshes were distributed into the other 2 regions based on the areal proportion of salt marshes in them using the National Wetland Inventory data and GIS.

Winter

The winter numbers were obtained from the Mid-Winter Waterfowl Survey (USFWS) and consisted of population numbers for ducks and geese in several different areas in the tidal region of Virginia. MS Access was used to calculate the total number of ducks and geese in each area and then these numbers were grouped to match the 2 final regions (Southside and the rest of tidal Virginia) for the summer waterfowl populations.

Data from DGIF showed the spatial distribution of ducks and geese for 1993 and 1994. Using this information and GIS a 250m buffer on each side of the shoreline was generated and contained 80% of the birds. Wider buffers did not incorporate significantly more birds, since they were located too far inland. GIS was used to overlay the buffer and the watershed boundaries to calculate the area of buffer in each watershed. To distribute this information into each sub-watershed, GIS was used to calculate the length of shoreline in each sub-watershed and the total length of shoreline in the watershed.
Dividing the length of shoreline in each sub-watershed by the total length of shoreline gives a ratio that was multiplied by the area of the watershed to get an estimate of the area of buffer in each sub-watershed. MS Excel was used to multiply the area of buffer in each sub-watershed times the total numbers of ducks and geese to get the numbers of ducks and geese in each sub-watershed. These numbers were summed to get the total number of ducks and geese in each watershed. To get annual populations, the totals then were divided by 2, since they represent only 6 months of habitation (this reduction underestimates the total annual input from ducks and geese, but is the easiest conservative method to use since the model does not have a way to incorporate the seasonal differences).

B.4.3 Raccoons

Estimates for raccoon densities were supplied by DGIF for 3 habitats—wetlands (including freshwater and saltwater, forested and herbaceous), along streams, and upland forests. GIS was used to generate a 600 ft buffer around the wetlands and streams, and then to overlay this buffer layer with the sub-watershed boundaries to get the area of the buffer in each sub-watershed. GIS was used to overlay the forest layer with the sub-watershed boundaries to get the area of forest in each sub-watershed. MS Access was used to multiply the raccoon densities for each habitat times the area of each habitat in each sub-watershed to get the number of raccoons in each habitat in each sub-watershed. The number of raccoons in each sub-watershed was summed to get the total number of raccoons in each watershed.