Total Maximum Daily Load of Phosphorus in the Non-tidal Upper Pocomoke River Watershed, Wicomico and Worcester Counties, Maryland

FINAL

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List of Abbreviations

BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
BSID	Biological Stressor Identification
CAFO	Confined Animal Feeding Operation
CBLCD	Chesapeake Bay Watershed Land Cover Data
CBP P5.3.2	Chesapeake Bay Program Phase 5.3.2.2
CCAP	Coastal Change Analysis Program
cfs	Cubic Feet per Second
CFR	Code of Federal Regulations
COMAR	Code of Maryland Regulations
CNMP	Comprehensive Nutrient Management Plan
CV	Coefficient of Variation
CWA	Clean Water Act
CWAP	Clean Water Action Plan
DE	Delaware
DNR	Maryland Department of Natural Resources
DNREC	Delaware Department of Natural Resources and Environmental Control
DO	Dissolved Oxygen
EFDC	Environmental Fluid Dynamic Code
ENR	Enhanced Nutrient Reduction
EOS	Edge-of-Stream
EPA	Environmental Protection Agency
EPSC	Environmental Permit Service Center
EPT	*Ephemeroptera*, *Plecoptera*, and *Trichoptera*
FIBI	Fish Index of Biologic Integrity
GIS	Geographic Information System
HSPF	Hydrological Simulation Program Fortran
IBI	Index of Biotic Integrity
LA	Load Allocation
lbs	Pounds
lbs/ac/yr	Pounds Per Acre Per Year
lbs/day	Pounds Per Day
lbs/yr	Pound Per Year

MAFO	Maryland Animal Feeding Operation
MBSS	Maryland Biological Stream Survey
MD	Maryland
MDE	Maryland Department of the Environment
MDL	Maximum Daily Load
MGD	Millions of Gallons per Day
mg/l	Milligrams per liter
MOS	Margin of Safety
MRLC	Multi-Resolution Land Characteristics
MS4	Municipal Separate Stormwater System
NOI	Notice of Intent
NLCD	National Land Cover Data
NOAA	National Oceanic and Atmospheric Administration
NPS	Nonpoint Source
NPDES	National Pollutant Discharge Elimination System
OC	Organic Carbon
PS	Point Source
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USGS	United States Geological Survey
WIP	Watershed Implementation Plan
WLA	Waste Load Allocation
WQIA	Water Quality Improvement Act
WQLS	Water Quality Limited Segment
WWTP	Wastewater Treatment Plant

EXECUTIVE SUMMARY

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for total phosphorus (TP) in the non-tidal Upper Pocomoke River watershed (basin number 02130203) (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-02130203). Section 303(d) of the federal Clean Water Act (CWA) and EPA's implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS, the State is required to either establish a TMDL of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate that water quality standards are being met (CFR 2011a).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the non-tidal Upper Pocomoke River is Use I: *Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life*. The Maryland Department of the Environment (MDE) has identified the non-tidal waters of the Upper Pocomoke River (basin number 02130203) on the 2010 Integrated Report under Category 5 as impaired by nutrients (1996 listing), suspended sediment (1996 listing) and impacts to biological communities –1^{st} through 4^{th} order streams (2002 listing) (MDE 2010a). The 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. Similarly, the 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Consequently, for the purpose of this report the terms "nutrients" and "phosphorus" will be used interchangeably. The phosphorus TMDL established herein by MDE will address the 1996 nutrient listing, for which a data solicitation was conducted in 2011, and all readily available data from the past five years have been considered. A TMDL for sediments and phosphorus for the Adkins Pond impoundment was approved by EPA in 2002. A TMDL is currently under development to address the listing for total suspended solids. The listing for impacts to biological communities will be addressed separately at a future date.

Currently in Maryland, there are no specific numeric criteria that quantify the impact of nutrients on the aquatic health of non-tidal stream systems. Nutrients including phosphorus typically do not have a direct impact on aquatic life; rather, they mediate impacts through excessive algal growth leading to low dissolved oxygen (DO). Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient related parameters (i.e., dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair designated uses in the non-tidal Upper Pocomoke River. Maryland's water quality standards include general narrative criteria prohibiting the pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 2012g), and a numeric DO criterion for Use I waters requiring a minimum DO concentration of 5.0 mg/l at any time (COMAR 2012a). Attainment of the numeric DO criterion, as assessed in this study, is the TMDL endpoint.

In 2009, MDE developed a biological stressor identification (BSID) methodology to identify the most probable cause(s) of biological impairments in 1st through 4th order streams in Maryland 8-digit watersheds based on the suite of available physical, chemical, and land use data (MDE 2009). The BSID analysis for the Upper Pocomoke River watershed (MDE 2011) identified that both high total phosphorus and high orthophosphorus have statistically significant association with degraded biological conditions in the 1st through 4th order streams of the Upper Pocomoke River, confirming the 2008 impairment listing for phosphorus. Approximately 37% of the biologically impacted stream miles in the watershed are associated with high total phosphorus and 68% are associated with high orthophosphate concentrations. The BSID analysis also identified that low DO concentrations are associated with degraded biological conditions in the 1st through 4th order streams of the watershed and that 86% of the biologically impacted stream miles in the watershed are associated with DO concentrations below 5 mg/l.

The BSID analysis applies only to 1st through 4th order streams in a watershed. Therefore, water quality conditions in the Upper Pocomoke River mainstem are assessed using Maryland Department of Natural Resources (DNR) CORE/TREND program data. The biological monitoring data results from the DNR CORE/TREND station located in the mainstem of the Upper Pocomoke River indicate that the mainstem is meeting its Aquatic Life designated use. However, an analysis based on MDE water quality monitoring data from 1997 to 2010 shows that both the non-tidal Upper Pocomoke mainstem and tributaries have low DO conditions.

The phosphorus TMDL was established at a level that will achieve the DO criterion in the waterbody, as assessed in this study. The objective of the TMDL established herein is to ensure that there will be no nutrient impacts affecting aquatic health, thereby establishing phosphorus loads that support the Use I designation in the waters of the non-tidal Upper Pocomoke River.

The computational framework for this TMDL development is the three dimensional Environmental Fluid Dynamics Code (EFDC) water quality model. The model simulates the effects of water transport and eutrophication processes in the receiving river upon received flow and loading discharges from the surface and sub-surface of adjacent watersheds. Modeled variables include algae, DO, nitrogen, phosphorus, and organic carbon. The model simulates algal and DO dynamics, nutrients transport, settling, uptake, and recycling. The instream eutrophication model is coupled with a sediment process model, which simulates mineralization of nutrients, nutrient fluxes and sediment oxygen demand (SOD).

The watershed loading inputs to the EFDC water quality model are from the Chesapeake Bay Program Phase 5.3.2 (CBP P5.3.2) Watershed Model outputs that simulated flow and nutrient loadings in the non-tidal Upper Pocomoke River watershed. Loads from 1996 to 1998, a time period which includes wet, dry and mean hydrological conditions, were used as the baseline loads. The spatial domain of the Phase 5.3.2 Watershed Model segmentation aggregates to the Maryland 8-digit watersheds, which is consistent with the scale of the impairment listing.

EPA's regulations require TMDLs to take into account seasonality and critical conditions for stream flow, loading, and water quality parameters (CFR 2011b). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable. The EFDC eutrophication model was used to assess the attainment of water quality standards. The model is a continuous simulation model that was calibrated using data that captured seasonal variability. The loading rates used in the TMDL were determined using the Hydrological Simulation Program Fortran (HSPF) model, which is a continuous simulation model with a simulation of daily variations in loadings. Moreover, the simulation span of the watershed and in-stream water quality models is from 1996 through 1998, a period that included very wet-, dry-, and mean-hydrological years. Thus, both seasonal variation and critical conditions are addressed.

TMDLs must include a margin of safety (MOS) to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2011b). For this TMDL, the MOS is incorporated in the analysis by accounting for critical conditions captured in the hydrological return period selected for the dynamic model long term simulation. The simulation period selected for establishing the phosphorus allowable loads, includes a very wet year (1996), a dry year (1997), and a typical mean flow year (1998). In general, during dry years, the system can experience higher water temperatures combined with low flows. During wet years, higher flows and consequently increased pollutant loadings are expected. A wet year followed by a dry year combines both higher pollutant loadings to the system and higher temperatures, leading to lower DO levels due to increased primary production and bacterial decomposition. Incorporation of this critical period and the corresponding conservative assumptions in the modeling used to develop the TMDL supports the assertion of an implicit MOS. Therefore, a MOS that accounts for uncertainties in the analysis of water quality conditions in the non-tidal Upper Pocomoke River is considered as implicitly included in the model simulation and, consequently, in the TMDL.

TMDLs also need to be presented as a sum of waste load allocations (WLAs) for permitted point sources and load allocations (LAs) for nonpoint sources generated within the assessment unit, including natural background and human influence. The MD 8-digit Upper Pocomoke River Average Annual TMDL of Phosphorus is 43,592 lbs/yr. The TMDL consists of: (1) an Upstream Load Allocation (LA_{DE}) of 2,227 lbs/yr, attributed to loads generated outside the MD assessment unit from sources in the Delaware (DE) portion of the watershed; and (2) allocations attributed to loads generated within the assessment unit consisting of a MD 8-digit Upper Pocomoke River Watershed TMDL Contribution of 41,364 lbs/yr. The MD 8-digit Upper Pocomoke River TMDL Contribution is further subdivided into point and nonpoint source allocations and is comprised of a Load Allocation (LA_{UPR}), a CAFO Wasteload Allocation (CAFO WLA_{UPR}), a NPDES Stormwater Wasteload Allocation (NPDES Stormwater WLA_{UPR}), and a Process Water Wasteload Allocation (Process Water WLA_{UPR}) (see Table ES-1).

Table ES-1: MD 8-digit Upper Pocomoke River Average Annual TMDL of Phosphorus (lbs/yr)

TMDL (lbs/yr)		**LA**					+	**WLA**					+	**MOS**
	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**		**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**		
43,592	=	2,227		35,494	+	0	+	4,339	+	11	+	1,520	+	Implicit

Upstream Load Allocation[2] (under LA_{DE})

MD 8-digit Upper Pocomoke River Watershed TMDL Contribution (under LA_{UPR} through Process Water WLA_{UPR})

[1] The LA_{DE} was determined based on a DE TMDL that is expressed in lbs/day and converted herein to an annual loading by multiplying by 365 (DNREC 2005). The LA_{DE} meets Maryland water quality standards within the MD 8-digit Upper Pocomoke River watershed. It accounts for the upstream load from DE entering MD waters.

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

In addition to the average annual TMDL values, a Maximum Daily Load (MDL) for phosphorus is also presented in this document. The calculation of the MDL is based on USEPA guidelines with consideration of pre-defined 95th probability, and is derived from the TMDL average annual load (see Table ES-2).

Table ES-2: MD 8-digit Upper Pocomoke River Maximum Daily Load of Phosphorus (lbs/day)

TMDL (lbs/day)		**LA**					+	**WLA**					+	**MOS**
	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**		**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**		
392.2	=	6.1		370.02	+	0	+	11.9	+	0.03	+	4.2	+	Implicit

Upstream Load Allocation[2] (under LA_{DE})

MD 8-digit Upper Pocomoke RiverWatershed TMDL Contribution (under LA_{UPR} through Process Water WLA_{UPR})

[1] The LA_{DE} is based on the DE TMDL (DNREC 2005).

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

The total phosphorus baseline load, TMDL and required reduction for the Maryland 8-digit Upper Pocomoke River watershed are provided in Table ES-3.

Table ES-3: MD 8-Digit Upper Pocomoke River Baseline Phosphorus Load, TMDL, and Total Reduction Percentage

Baseline Load (lbs/yr)	**TMDL (lbs/yr)**	**Total Reduction (%)**
55,163	**41,364**	**25**

Overall, this TMDL will ensure that phosphorus loads and resulting effects are at a level that supports the Use I designation for the non-tidal Upper Pocomoke River watershed, and which the watershed can sustain without causing any nutrient related impacts to aquatic health. However, the TMDL will not completely resolve the impairment to biological communities within the watershed. Because the BSID watershed analysis identifies other possible stressors (e.g., sediment) as impacting biological conditions, this impairment remains to be fully addressed through the Integrated Report listing process and the TMDL development process, such that all impairing substances identified as impacting biological communities in the watershed are reduced to levels that will meet water quality standards, as established in future TMDLs for those substances (MDE 2009a).

This TMDL sets phosphorus load limits designed to result in attainment of DO levels that support the aquatic life use in the non-tidal Upper Pocomoke River. However, the data analysis and model scenario run results determined that, while nutrient enrichment is the primary cause of low DO conditions in some smaller streams, excessive organic carbon (OC) exported from watershed is the primary reason for low DO conditions in the mainstem of the Upper Pocomoke River. The river originates in the Great Cypress Swamp on the Delaware-Maryland border, one of the major sources of OC in the mainstem Upper Pocomoke River and in the downstream tidal portion (DNR 2010). Also, the watershed is dominated by natural wetlands and forest, both sources of rich organic matter. Thus, the low DO conditions in the non-tidal Upper Pocomoke River are caused by both natural conditions and human impacts. The TMDL analysis presented in this report demonstrates that, because of the high correlation between phosphorus and organic carbon, the reduction of phosphorus loads required to implement the TMDL will result in a proportional reduction of OC as well, which will further ensure DO attainment.

It is worth noting that, because of seasonal lower DO concentrations due to natural oxygen-depleting processes present in the extensive surrounding tidal wetlands, Maryland adopted a site-specific criterion of a 30-day mean DO greater than or equal to 4 mg/l in the tidal upper and middle Pocomoke River, approved by EPA on December 27, 2010. This site-specific criterion, which is lower than the general Use I criterion (DO not less than 5mg/l at any time), underscores the need to consider the influence of natural conditions in forest- and wetland-dominated environments like the Upper Pocomoke watershed.

Once EPA has approved this TMDL and it is known what measures must be taken to reduce pollution levels, implementation of best management practices (BMPs) are expected to take place. Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and wasteload allocations can and will be implemented. The Upper Pocomoke River phosphorus TMDL is expected to be implemented in a staged process. Reductions of phosphorus loads will be required to meet the Chesapeake Bay TMDL recently established by EPA (US EPA 2010). These reductions are necessary to meet water quality standards to protect the designated uses of the Chesapeake Bay and its tidal tributaries, independent of any additional nutrient reductions that may be required to meet existing water quality standards designed to protect aquatic life in local non-tidal waterbodies.

MDE expects that the first stage of implementation of the Upper Pocomoke River phosphorus TMDL shall be the achievement of the nutrient reductions needed within the Upper Pocomoke River watershed in order to meet target loads consistent with the Chesapeake Bay TMDL, which is expected to be fully implemented in Maryland by 2025. Once the Bay TMDL nutrient target loads for the Upper Pocomoke River watershed have been met, MDE will revisit the status of nutrient impacts on aquatic life in the non-tidal waters of Upper Pocomoke River, based on any additional monitoring data available and any improvements in the scientific understanding of the impacts of nutrients on aquatic life in free-flowing streams.

1.0 INTRODUCTION

This document, upon approval by the U.S. Environmental Protection Agency (EPA), establishes a Total Maximum Daily Load (TMDL) for total phosphorus (TP) in the non-tidal Upper Pocomoke River (basin number 02130203) (2010 *Integrated Report of Surface Water Quality in Maryland* Assessment Unit ID: MD-02130203). Section 303(d)(1)(C) of the federal Clean Water Act (CWA) and the EPA's implementing regulations direct each state to develop a TMDL for each impaired water quality limited segment (WQLS) on the Section 303(d) List, taking into account seasonal variations, critical conditions, and a protective margin of safety (MOS) to account for uncertainty (CFR 2011b). A TMDL reflects the total pollutant loading of the impairing substance a waterbody can receive and still meet water quality standards.

TMDLs are established to determine the pollutant load reductions needed to achieve and maintain water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include activities such as swimming, drinking water supply, protection of aquatic life, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. Criteria may differ among waters with different designated uses.

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for the non-tidal Upper Pocomoke River is Use I: *Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life*. The Maryland Department of the Environment (MDE) has identified the non-tidal waters of the Upper Pocomoke River (basin number 02130203) on the 2010 Integrated Report under Category 5 as impaired by nutrients (1996 listing), suspended sediment (1996 listing) and impacts to biological communities –1st through 4th order streams (2002 listing) (MDE 2010). The 1996 suspended sediment listing was refined in the 2008 Integrated Report to a listing for total suspended solids. Similarly, the 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. Consequently, for the purpose of this report the terms "nutrients" and "phosphorus" will be used interchangeably. The phosphorus TMDL established herein by MDE will address the 1996 nutrient listing, for which a data solicitation was conducted in 2011, and all readily available data from the past five years have been considered. A TMDL for sediments and phosphorus for the Adkins Pond impoundment was approved by EPA in 2002. A TMDL is currently under development to address the listing for total suspended solids. The listing for impacts to biological communities will be addressed separately at a future date.

The objective of the TMDL established herein is to ensure that there will be no nutrient impacts affecting aquatic health, thereby establishing nutrient loads that support the Use I designation for the non-tidal waters of the Upper Pocomoke River. A Biological Stressor Identification (BSID) analysis of the Upper Pocomoke River watershed (MDE 2011) shows that phosphorus is associated with biological impairments in the 1st through 4th order streams of the Upper Pocomoke River; therefore, a TMDL will be established for phosphorus.

Currently in Maryland, there are no specific numeric criteria that quantify the impact of phosphorus on the aquatic health of non-tidal stream systems. Nutrients typically do not have a direct impact on aquatic life; rather, they mediate impacts through excessive algal growth leading to low dissolved oxygen (DO). Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient related parameters (i.e., dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair designated uses in the non-tidal Upper Pocomoke River. Maryland's water quality standards include general narrative criteria prohibiting the pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 2012g), and a numeric DO criterion for Use I waters requiring a minimum DO concentration of 5.0 mg/l at any time (COMAR 2012a). Attainment of the numeric DO criterion, as assessed in this study, is the TMDL endpoint. The Chesapeake Bay Program Phase 5.3.2 (CBP P5.3.2) Watershed Model is used to determine the phosphorus loads from non-tidal Upper Pocomoke River watershed and the Environmental Fluid Dynamics Code (EFDC) water quality model is used to simulate the eutrophication processes in the main channel and tributaries to establish this phosphorus TMDL for the non-tidal Upper Pocomoke River watershed.

2.0 SETTING AND WATER QUALITY DESCRIPTION

2.1 General Setting

Location

The Pocomoke River originates in the Great Cypress Swamp on the Delaware-Maryland border and flows for approximately sixty miles through Maryland into Pocomoke Sound at the Chesapeake Bay (LESHC 1994). Streams are mostly non-tidal, with some tidal influence in the lowest reach of the Upper Pocomoke mainstem. The watershed is situated in Wicomico and Worcester Counties and drains approximately 122 stream miles (Figure 1). The largest towns within the watershed are Willards and Pittsville.

Geography/Soils

The Upper Pocomoke River watershed lies in the Coastal Plain physiographic province. The Coastal Plain province is characterized by flat or gently rolling topography and elevations rising from sea level to about 100 feet (DNR 2009a). The Coastal Plain Province is underlain by a wedge of unconsolidated sediments including gravel, sand, silt, and clay (MGS 2009). The predominant soils in the watershed are level to nearly level, poorly drained soils in the Pocomoke-Fallsington and Othello-Fallsington-Portsmouth Associations (SCS 1970, SCS 1973).

The Upper Pocomoke River is located in the Delmarva Peninsula region of the Coastal Plain. The Delmarva Peninsula contains a series of confined aquifers that are overlain by an extensive surficial (unconfined) aquifer. The typically sandy unconfined surficial aquifer on the Peninsula is vulnerable to anthropogenic contamination from a variety of sources, including septic system discharges and applications of fertilizer, pesticides, lime, and manure (Ator, Denver and Brayton 2005). Groundwater flow paths generally are shorter than a few miles in length, and in areas with a high density of streams or drainage ditches, groundwater flow paths commonly are shorter than a few hundred feet (Hamilton et al. 1993). Hydrologic studies conducted within the non-tidal Pocomoke watershed indicate that groundwater is a significant hydrologic transport pathway, and that periods of significant overland flow occur mainly during large storm events (Ator, Denver and Brayton 2005).

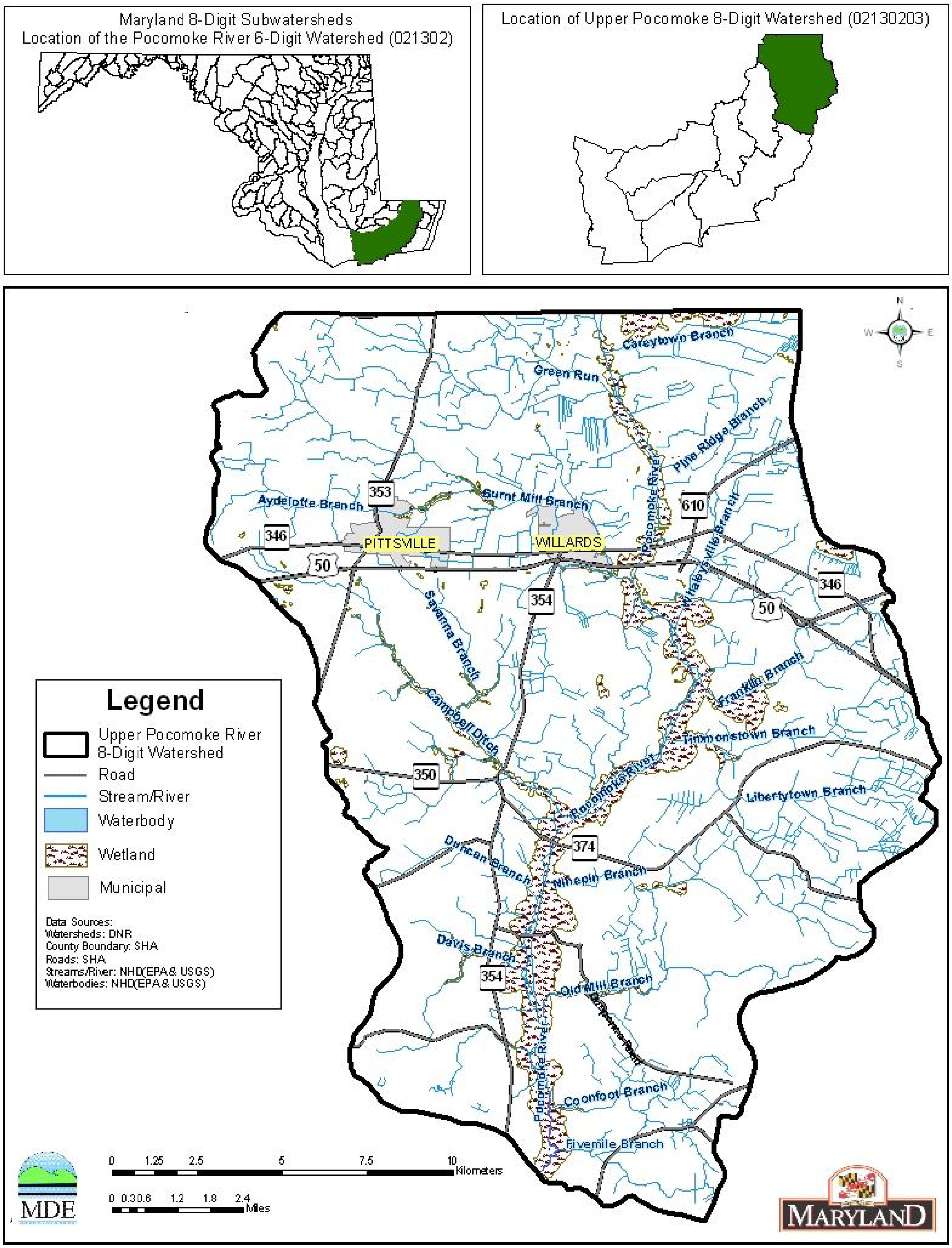

Figure 1: Location Map of Upper Pocomoke River Watershed in Wicomico and Worcester Counties, Maryland

2.1.1 Land Use

Land Use Methodology

The land use framework used to develop this TMDL was originally developed for the Chesapeake Bay Program Phase 5.3.2 (CBP P5.3.2) Watershed Model.[1] The CBP P5.3.2 land use was based on two distinct stages of development.

The first stage consists of the development of the Chesapeake Bay Watershed Land Cover Data (CBLCD) series of Geographic Information System (GIS) datasets. These datasets provide a 30 meter resolution raster representation of land cover in the Chesapeake Bay watershed, based on sixteen Anderson Level 2 land cover classes. The CBLCD basemap, representing 2001 conditions, was primarily derived from the Multi-Resolution Land Characteristics (MRLC) Consortium's National Land Cover Data (NLCD) and the National Oceanic and Atmospheric Administration's (NOAA) Coastal Change Analysis Program's (CCAP) Land Cover Data. By applying Cross Correlation Analysis to Landsat 5 Thematic Mapper and Landsat 7 Enhanced Thematic Mapper satellite imagery, USGS's contractor, MDA Federal, generated CBLCD datasets for 1984, 1992, and 2006 from the 2001 baseline dataset. The "*Chesapeake Bay Phase 5.3 Community Watershed Model*" (US EPA 2010b) describes the development of the CBLCD series in more detail. USGS and NOAA also developed an impervious cover dataset from Landsat satellite imagery for the CBLCD basemap, which was used to estimate the percent impervious cover associated with CBLCD developed land use classes.

The second stage consists of using ancillary information for: 1) the creation of a modified 2006 CBLCD raster dataset, and 2) the subsequent development of the CBP P5.3.2 land use framework in tabular format. Estimates of the urban footprint in the 2006 CBLCD were extensively modified using supplemental datasets. NAVTEQ street data (secondary and primary roads) and institutional delineations were overlayed with the 2006 CBLCD land cover and used to reclassify underlying pixels. Certain areas adjacent to the secondary road network were also reclassified based on assumptions developed by USGS researchers, in order to capture residential development (*i.e*., subdivisions not being picked up by the satellite in the CBLCD). In addition to spatially modifying the 2006 CBLCD, the following datasets were used to supplement the developed land cover data in the final CBP P5.3.2 land use framework: U.S. Census housing unit data, Maryland Department of Planning (MDP) Property View data, and estimates of impervious coefficients for rural residential properties (determined via a sampling of these properties using aerial photography). This additional information was used to estimate the extent of impervious area in roadways and residential lots. Acres of construction and extractive land uses were determined independently (Claggett *et al*. 2012). Finally, in order to develop accurate agricultural land use acreages, the CBP P5.3.2 incorporated county level U.S. Agricultural Census data (USDA 1982, 1987, 1992, 1997, 2002). The "*Chesapeake Bay Phase 5.3 Community Watershed Model*" (US EPA 2010b) describes these modifications in more detail.

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[1] The EPA Chesapeake Bay Program developed the first watershed model in 1982. There have been many upgrades since the first phase of this model. The latest version, CBP P5.3.2, was developed to estimate flow, nutrients, and sediment loads to the Bay.

The result of these second stage modifications is that CBP P5.3.2 land use does not exist in a single GIS coverage; instead it is only available in a tabular format. The CBP P5.3.2 watershed model is comprised of 30 land uses. Most of these land uses are differentiated only by their nitrogen and phosphorus loading rates. Table 1 summarizes the acreage of CBP P5.3.2 by sector in the Upper Pocomoke River watershed. The land use acreage is based on the CBP P5.3.2 2010 Progress Scenario, which is the P5.3.2 scenario that represents current conditions.

Upper Pocomoke River Watershed Land Use Distribution

The land use distribution in the Upper Pocomoke River watershed consists mostly of forest (62.6%) and crop (29.1%), followed by non-regulated urban (5.4%), pasture (1.7%), and harvested forest (0.6%), regulated urban (0.38%), nurseries (0.12%), water (0.02%), concentrated animal feeding operations (0.02%), and animal feeding operations (< 0.01) make up the remaining land use acres. A summary of the watershed land use areas is presented in Table 1.

Table 1: Land Use Distribution for the Upper Pocomoke River Watershed

General Land Use	Area (acres)	Percent (%)
Forest	59,753	62.57%
Harvested Forest	601	0.63%
AFOs	3	0.00%
CAFOs	19	0.02%
Pasture	1,626	1.70%
Crop	27,823	29.14%
Nursery	111	0.12%
Non-Regulated Urban	5,183	5.43%
Regulated Urban	359	0.38%
Water	19	0.02%
Total	95,495	100.00%

2.2 Source Assessment

2.2.1 Nonpoint Sources (NPS) Assessment

Nonpoint source nutrient loads in the Upper Pocomoke River watershed are estimated based on the edge-of-stream (EOS) loading rates from the CBP P5.3.2 Model for the simulation period 1991-2000. The 2010 Progress Scenario represents current (2010) land use, loading rates, and BMP implementation, simulated using precipitation and other meteorological inputs from the period 1991-2000 to represent variable hydrological conditions. The period 1991-2000 is the baseline hydrological period for the Chesapeake Bay TMDL.

EOS loads in the P5.3.2 model are determined by three factors: (1) the median of land use-specific loading rates found in the scientific literature; (2) the adjustment of the median loading rate based on the excess nutrient inputs applied to agricultural land use to determine EOS targets by land segment and land use; and (3) the application of regional factors in the river calibration.

Literature Review

Using Beaulac and Reckhow's (1982) literature survey as a starting point, CBP staff conducted a survey of the scientific literature to determine the range of observed nutrient loading rates from land uses. Most of these estimates were made from observations on small, homogeneous watersheds and thus represent edge-of-stream, rather than edge-of-field, nutrient loads**.** Phosphorus loads for developed land uses are based on the median phosphorus concentration in urban stormwater determined by Pitt et. al. (2005) in their study of monitoring data collected by jurisdictions for their Municipal Separate Storm Sewer System (MS4) permits. See "*Chesapeake Bay Phase 5.3 Community Watershed Model"* (US EPA 2010b) for further discussion of loading rates found in the scientific literature.

EOS Calibration Targets

Land processes in the P5.3.2 model are simulated by land use and land segment. Land segments are counties or, in some cases, sections of counties where precipitation is expected to vary because of orographic uplift.

The median literature loading rate is the starting point for determining calibration targets for EOS loads in the P5.3.2 model. For developed land uses, the target load is the product of average annual simulated runoff in the land segment and the median phosphorus concentration in urban stormwater, 0.27 mg/l, as determined by Pitt *et. al.* (2005). For agricultural land uses, median rates were adjusted upwards or downwards depending how much the amount of nutrients applied to a land use in a land segment exceeded the needs of the vegetation on that land use, compared to the average Chesapeake Bay segment. In other words, land segment calibration targets were distributed around the median literature value in proportion to the excess nutrients applied to the segments.

CBP calculated the nutrient loading rates for manure, fertilizer, and atmospheric deposition, as well as crop and vegetative uptake, for each land use and land segment. These calculations were based on the agricultural census, the expert opinion of local and state agronomists, statistics on fertilizer sales, and a mass balance of animal waste based on animal population estimates. See "*Chesapeake Bay Phase 5.3 Community Watershed Model"* (US EPA 2010b) for further details on the calculation of loading rates. For land uses with nutrient management, EOS loads are determined by reducing nutrient inputs to their agronomic rates on the corresponding land use without nutrient management.

Regional Factors

The use of literature loading rates and their adjustment according to the excess nutrients applied to the land can be expected to provide a good estimate of land use loading rates relative to each other. To further reduce uncertainty in loading rates, CBP applies a multiplicative regional factor to the simulated land segment loading rate. Regional factors are calculated in the calibration of river segments where simulated output is compared to observed monitoring data.

2.2.2 Point Source (PS) Assessment

A list of active permitted point sources that contribute to the phosphorus load in the non-tidal Pocomoke River watershed was compiled using MDE's Environmental Permit Service Center (EPSC) database. The types of permits identified include individual industrial, individual municipal, general mineral mining, general industrial stormwater, and general Concentrated Animal Feeding Operations (CAFOs). Table 2 lists all permitted entities identified in the EPSC in the non-tidal Upper Pocomoke River watershed.

Table 2: Active Permitted Point Source in Upper Pocomoke River Watershed

Permit #	NPDES	Facility	County	City	Type	Category
10DP3688	MD0070742	DEER RUN CAMPGROUND & RECREATION FACILITY	WORCESTER	BERLIN	Process Water	Industrial
10DP2085	MD0060348	PITTSVILLE WWTP	WICOMICO	PITTSVILLE	Process Water	Municipal
09DP1058	MD0051632	WILLARDS WWTP	WICOMICO	WILLARDS	Process Water	Municipal
10M9796	MDG499796	HARKINS READY MIX	WICOMICO	PITTSVILLE	Process Water	Industrail
08DP3601	MD0069957	CROPPER BROTHERS LUMBER COMPANY, INC.	WICOMICO	WILLARDS	Storm Water	Industrail
02SW1672	N/A	FOREST PRODUCTS, INC.	WICOMICO	PITTSVILLE	Storm Water	Industrail
TBA	N/A	NEWARK VOLUNTEER FIRE COMPANY, INC.	WORCESTER	NEWARK	Storm Water	Industrail

These permits can be grouped into two categories, process water and stormwater. There are two municipal WWTPs (Pittsville and Willards) permitted to discharge phosphorus in the watershed, both are minor facilities. There are also two minor industrial facilities capable of discharging phosphorus: Deer Run and Harkins facilities. The Deer Run facility is for construction dewatering at the campground with no nutrient discharge. The Pittsville, Willards, and Harkins facilities are represented in the Phase 5.3.2 Watershed Model and their estimated phosphorus loads for the 2010 Progress Scenario will be the point source baseline loads for these facilities. Baseline phosphorus loads for minor municipal WWTPs are based on DMR data, while current loads for minor industrial facilities were based either from monitoring required by their permits or professional judgment. The total estimated 2010 MD process water TP load is about 991 lbs/yr.

The urban stormwater loads are calculated using the developed land use area in the watershed. Urban stormwater nutrient loads in more heavily developed watersheds are primarily regulated under the NPDES MS4 program and as such are considered point source loads. Since there are no individual or general Phase I or II MS4 permitted jurisdictions or state/federal entities within the watershed, the only applicable NPDES regulated stormwater permits within the basin are facilities with an industrial stormwater permit. There are three NPDES stormwater permits identified within the MD 8-Digit Upper Pocomoke River watershed. The industrial stormwater permits do not include nutrient limits, but are regulated instead based on BMPs. The total estimated 2010 MD regulated stormwater TP load is 15 lbs/yr based on the CBP P5.3.2 watershed model 2010 scenario results. Most of the urban stormwater in the Upper Pocomoke River watershed is not regulated under the NPDES program and is therefore included in the nonpoint source loads.

Starting in 2009, Maryland began the process of permitting Concentrated Animal Feeding Operations (CAFOs). CAFOs are medium to large animal feeding operations that discharges or proposes to discharge to surface waters of the State. Recent EPA regulations require CAFOs to have a NPDES permit. Maryland also designates large animal feeding operations that do not discharge or propose to discharge as "Maryland Animal Feeding Operations" (MAFOs). It is anticipated that on review many MAFOs will require CAFO permits.

There are 69 operators in the Upper Pocomoke River watershed that have filed notices of intent to apply for permits under Maryland's CAFO or MAFO regulations. Based on the Notices of Intent (NOIs) filed by the reporting deadline of February, 2009, CBP estimates that the current average annual phosphorus load from CAFOs in the Maryland portion of Upper Pocomoke River watershed is 6,026.7 lb/yr.

The Upper Pocomoke River watershed is a very rural area with numerous septic systems within the watershed. Figure 2 shows the distribution of septic systems in this area. Phosphorus loads from septic systems are considered negligible.

The Berlin Wastewater Treatment Facility (permit number 11-DP-2864) has two spray irrigation sites within the Upper Pocomoke Watershed: Lee Road Spray Irrigation site and Bounds Property Spray Irrigation site. For the Lee Road site, there is complete nitrogen uptake by vegetation during the growing season (April to November) and no nitrogen is discharged to groundwater during the four month storage period. The Bounds Property site discharges directly to the tidal portion of the river. Therefore, nutrient loads from these spray irrigation sites have no effect on water quality in the non-tidal waters of the Upper Pocomoke River.

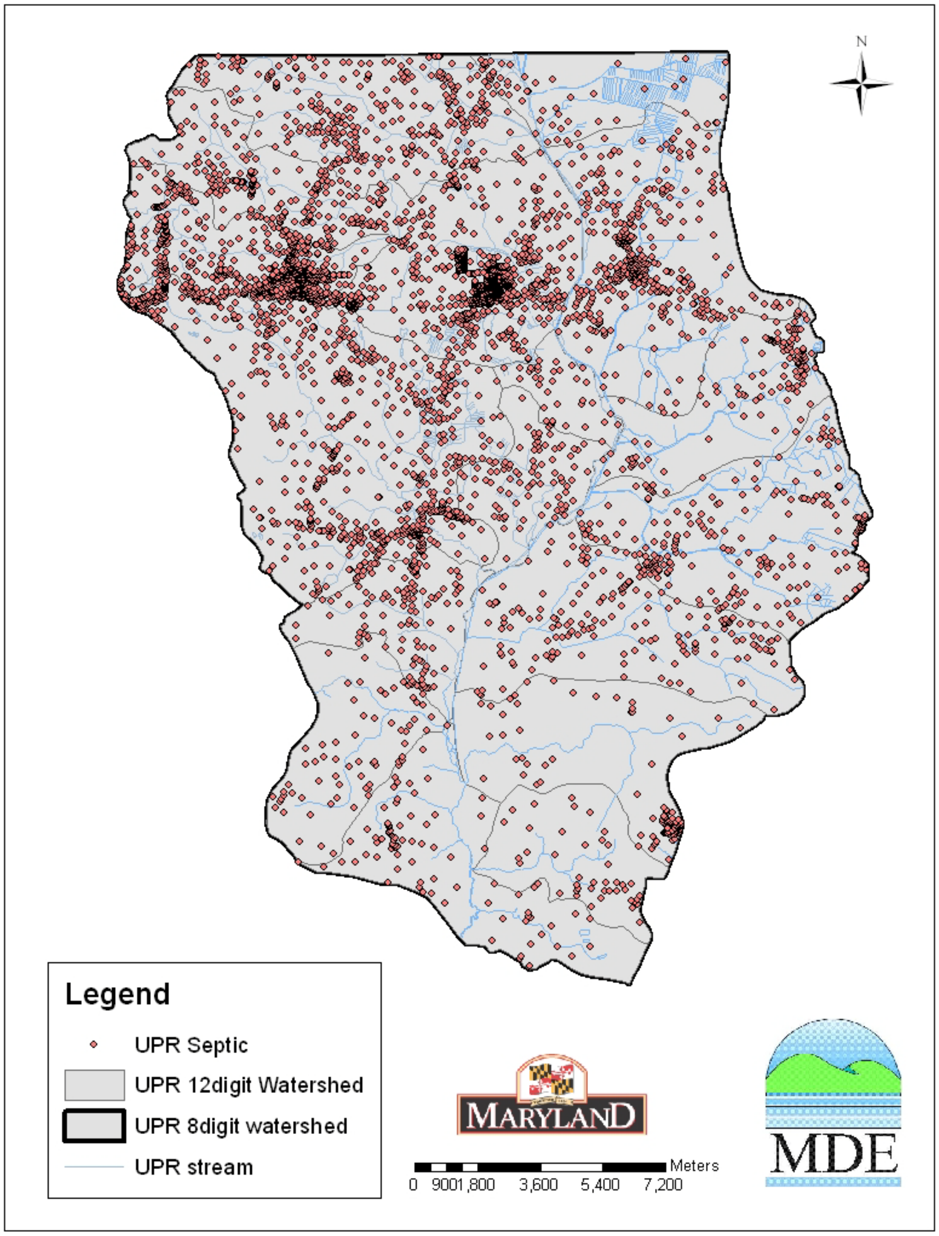

Figure 2: Septic Distributions in the Upper Pocomoke River Watershed

2.2.3 Overall Phosphorus Budget

Table 3 lists the current overall phosphorus budget for the Upper Pocomoke River watershed in Maryland and Delaware. These loads are derived from the P5.3.2 2010 Progress Scenario, which simulates 2010 land uses, BMP implementation, and point source loads over the hydrological period 1991-2000. The baseline loads are calculated from the 1996-1998 period. In Maryland, the largest source of phosphorus is agriculture (87.7%), followed by forest (5.3%), stormwater

(5.0%) and wastewater (1.8%). There are no combined sewer overflows (CSOs) in the watershed, and phosphorus loads from septic systems are negligible. Table 3 summarizes the MD 8-digit Upper Pocomoke River Baseline Phosphorus Loads for the MD 8-digit Load Contribution (Maryland) and the Upstream Baseline Loads (Delaware), in pounds per year (lbs/yr), for nonpoint and point source loadings.

Table 3: Upper Pocomoke River Watershed Detailed Baseline Total Phosphorus Loads

Source Sector	Landuse	Maryland		Delaware	
		2010 Progress	Percentage	2010 Progress	Percentage
Agriculture	AFO	125.8	0.2	4,356	21.66
	CAFO	6,026.7	10.9	1,662	8.27
	Crop	35,247.1	63.9	12,708	63.21
	Nursery	4,759.8	8.6	254	1.26
	Pasture	2,231.3	4.0	225	1.12
	Subtotal	***48,391***	87.7	***19,204***	95.52
Forest	Harvested	123	0.2	10	0.05
	Natural	2,812	5.1	359	1.78
	Subtotal	***2,935***	5.3	***368***	1.83
Non-Tidal Atm	Non-Tidal Atm	66	0.1	1	0.01
	Subtotal	***66***	0.1	***1***	0.01
Septic*	Septic	0	0.0	-	0.00
	Subtotal	***0***	0.0	***-***	0.00
Stormwater	CSS	0	0.0	-	0.00
	Construction	397	0.7	-	0.00
	Extractive	28	0.1	38	0.19
	Non-Regulated Developed	2,341	4.2	471	2.34
	Regulated Developed	15	0.0	23	0.11
	Subtotal	***2,781***	5.0	***532***	2.64
Wastewater	CSO	0	0.0	-	0.00
	Industrial	0	0.0	-	0.00
	Municipal	991	1.8	-	0.00
	Subtotal	***991***	1.8	***-***	0.00
	Total	***55,163***	100.0	***20,105***	100.00

***** It is assumed the drain fields reduce 100% of the TP discharged from septic systems

2.3 Water Quality Characterization

The non-tidal Upper Pocomoke River watershed was originally listed on Maryland's 1996 303(d) List as impaired by nutrients, using low DO as the indicator of nutrient over-enrichment. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance

A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Maryland water quality standards surface water use designation for the non-tidal Upper Pocomoke River is Use I: *Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life* (COMAR 2012b,c,d,e,f).

Currently, there are no specific numeric criteria for nutrients in Maryland's water quality standards for the protection of aquatic life in free-flowing non-tidal waters. Low levels of dissolved oxygen are often associated with the decay of excess primary production and therefore nutrient over-enrichment. Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient-related parameters (i.e., dissolved oxygen levels and/or chlorophyll *a* concentrations) are found to impair the designated uses of the non-tidal Upper Pocomoke River. Maryland's water quality standards include general narrative criteria prohibiting the pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 2012g), and a numeric DO criterion for Use I waters requiring a minimum DO concentration of 5.0 mg/l at any time (COMAR 2012a).

MDE has developed a biological stressor identification (BSID) analysis to identify potential stressors of aquatic life, including nutrients, in 1^{st} through 4^{th} order streams assessed by the Maryland Biological Stream Survey (MBSS). The impact of eutrophication on smaller-order streams in the watershed will be evaluated on the basis of the BSID analysis, which provides necessary and sufficient conditions for determining whether phosphorus is a potential stressor of the biological community in smaller-order streams.

A data solicitation for nutrients was conducted by MDE in April 2011 and all readily available data from 1997 to 2010 have been considered. All available resources, including Department of the Environment (MDE), Department of Natural Resources (DNR), U.S. Geological Survey (USGS), and the Chesapeake Bay Program (CBP), were also investigated to determine if there were other available data in the Upper Pocomoke River watershed. MDE collected water quality data in the Upper Pocomoke River from 1997 to 2005 and in 2010 at different sets of stations. Maryland Biological Stream Survey (MBSS) samplings conducted by DNR were in 1997 and 2001. DNR's CORE/TREND program also collected data from 1976 to 2006. The station information and monitoring year is presented in Table 4. Appendix B lists MDE water quality monitoring data from 1997 to 2010 in the Upper Pocomoke River.

Upper Pocomoke River Watershed Monitoring Stations

A total of 60 water quality monitoring stations were used to characterize the Upper Pocomoke River watershed. There were 37 biological/physical habitat monitoring stations from the MBSS program and 1 biological monitoring station from the Maryland Core/Trend monitoring network. MDE also sampled at the Core/Trend Stations and at 22 additional locations. The stations are presented in Figure 3 and listed in Table 4.

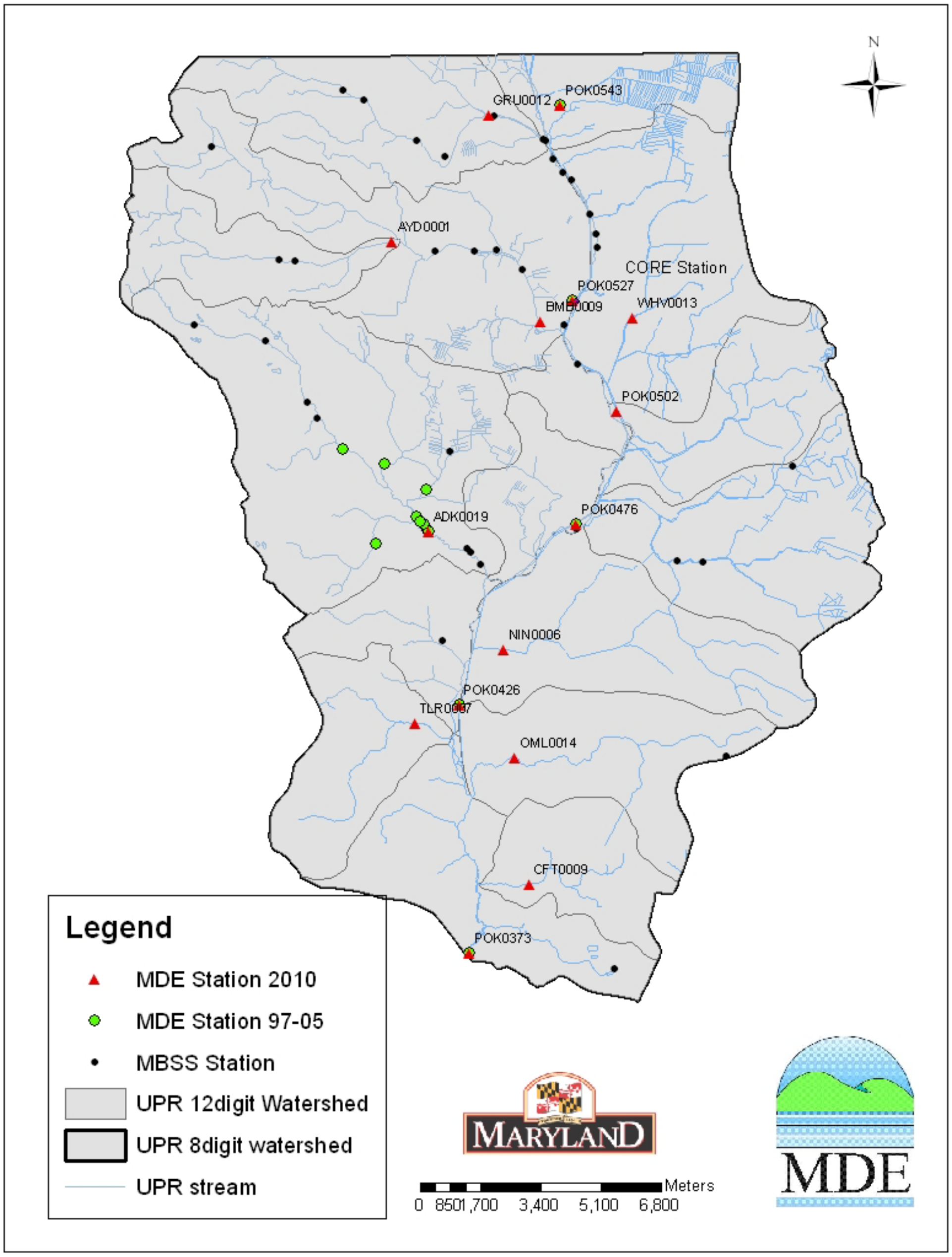

Figure 3: Monitoring Stations in the Upper Pocomoke River Watershed

Table 4: Monitoring Stations in the Upper Pocomoke River Watershed

Station Name	Sponsor	Site Type	Station Location	Latitude	Longitude	Data Year
ADK0017	MDE	WQ	Adkins Pond	38.33	75.37	2001
ADK0019	MDE	WQ	Adkins Race	38.33	75.37	97-98,2000-2001, 2004-2005, 2010
ADK0020	MDE	WQ	Adkins Pond	38.33	75.37	2001
ADK0021	MDE	WQ	Adkins Pond	38.33	75.38	2001
ADK0023	MDE	WQ	Adkins Pond	38.33	75.38	2001
AYD0001	MDE	WQ	Aydylotte Branch	38.41	75.38	2010
BMB0009	MDE	WQ	Burnt Mill Branch	38.38	75.34	2010
CFT0009	MDE	WQ	Coonfoot Branch	38.24	75.34	2010
CMP0016	MDE	WQ	Campbells Ditch	38.35	75.40	2000-2001
GIV0012	MDE	WQ	Givens Branch	38.33	75.39	2000-2001
GRU0012	MDE	WQ	Green Run	38.44	75.35	2010
NIN0006	MDE	WQ	Ninepin Branch	38.30	75.35	2010
OML0014	MDE	WQ	Old Mill Branch	38.27	75.35	2010
POK0373	MDE	WQ	Pocomoke River	38.22	75.36	2004-2005, 2010
POK0426	MDE	WQ	Pocomoke River	38.29	75.36	97-98, 2004-2005, 2010
POK0476	MDE	WQ	Pocomoke River	38.33	75.33	97-98, 2010
POK0502	MDE	WQ	Pocomoke River	38.36	75.31	2010
POK0527	MDE	WQ	Pocomoke River	38.39	75.33	97-99,2000-2005, 2010
POK0543	MDE	WQ	Pocomoke River	38.44	75.33	97-99, 2000-2002,2004-2005, 2010
SAA0005	MDE	WQ	Savanna Branch	38.35	75.39	2000-2001
TLR0007	MDE	WQ	Tighlman Race	38.28	75.38	2010
TUI0006	MDE	WQ	Truitt Branch	38.34	75.37	2000-2001
WHV0013	MDE	WQ	Whaleyville Branch	38.38	75.31	2010
POK0527	DNR	CORE/TREND	UPRmainstem	38.39	75.33	1976-2006
UPPC-101-R-2001	DNR	MBSS	Massey Branch	38.27	75.27	2001
UPPC-103-R-2001	DNR	MBSS	South Fork Green Run	38.44	75.39	2001
UPPC-105-R-2001	DNR	MBSS	Campbell Ditch	38.36	75.41	2001
UPPC-106-R-2001	DNR	MBSS	Timmonstown Branch	38.34	75.25	2001
UPPC-107-R-2001	DNR	MBSS	Aydylotte Branch	38.40	75.41	2001
UPPC-113-R-2001	DNR	MBSS	Campbell Ditch	38.36	75.40	2001
UPPC-114-R-2001	DNR	MBSS	Aydylotte Branch	38.40	75.42	2001
UPPC-115-R-2001	DNR	MBSS	Campbell Ditch	38.38	75.44	2001
UPPC-117-R-2001	DNR	MBSS	Fivemile Branch	38.21	75.31	2001
UPPC-118-R-2001	DNR	MBSS	South Fork Green Run	38.44	75.39	2001
UPPC-204-R-2001	DNR	MBSS	Libertytown Branch	38.32	75.29	2001
UPPC-216-R-2001	DNR	MBSS	Libertytown Branch	38.32	75.28	2001
UPPC-410-R-2001	DNR	MBSS	Pocomoke River	38.42	75.32	2001
WI-S-019-208-97	DNR	MBSS	South Fork Green Run	38.43	75.37	1997
WI-S-019-217-97	DNR	MBSS	South Fork Green Run	38.42	75.36	1997
WI-S-037-210-97	DNR	MBSS	Burnt Mill Branch	38.39	75.34	1997
WI-S-055-303-97	DNR	MBSS	Pocomoke River	38.33	75.32	1997
WI-S-057-309-97	DNR	MBSS	Adkins Race	38.32	75.36	1997
WI-S-057-311-97	DNR	MBSS	Adkins Race	38.32	75.35	1997
WI-S-057-319-97	DNR	MBSS	Adkins Race	38.32	75.35	1997
WI-S-059-106-97	DNR	MBSS	Truitt Branch	38.35	75.36	1997
WI-S-061-104-97	DNR	MBSS	Burnt Mill Branch UT1	38.43	75.44	1997
WI-S-067-207-97	DNR	MBSS	Burnt Mill Branch	38.40	75.36	1997
WI-S-067-219-97	DNR	MBSS	Burnt Mill Branch	38.40	75.35	1997
WI-S-074-103-97	DNR	MBSS	Murray Branch	38.40	75.34	1997
WI-S-084-107-97	DNR	MBSS	Campbell Ditch	38.38	75.42	1997
WI-S-999-114-97	DNR	MBSS	Duncan Ditch	38.30	75.36	1997
WO-S-003-306-97	DNR	MBSS	Pocomoke River	38.40	75.31	1997
WO-S-003-308-97	DNR	MBSS	Pocomoke River	38.40	75.31	1997
WO-S-003-312-97	DNR	MBSS	Pocomoke River	38.42	75.32	1997
WO-S-003-314-97	DNR	MBSS	Pocomoke River	38.38	75.32	1997
WO-S-003-320-97	DNR	MBSS	Pocomoke River	38.41	75.31	1997
WO-S-005-315-97	DNR	MBSS	Pocomoke River	38.37	75.32	1997
WO-S-008-305-97	DNR	MBSS	Pocomoke River	38.43	75.33	1997
WO-S-019-318-97	DNR	MBSS	Pocomoke River	38.42	75.33	1997
WO-S-061-205-97	DNR	MBSS	Green Run	38.43	75.33	1997
WO-S-061-206-97	DNR	MBSS	Green Run	38.43	75.34	1997

2.3.1 Biological Stressor Identification (BSID) Analysis

MDE has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings in the State's Integrated Report.

The BSID methodology uses data available from the statewide Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS). The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological stressors to Integrated Report categories.

The BSID analysis for the Upper Pocomoke River watershed identified phosphorus as a potential stressor. Both total phosphorus and orthophosphate show a significant association with degraded biological conditions. As much as 37% of the biologically impacted stream miles in the watershed are associated with high total phosphorus and 68% are associated with high orthophosphate. Based on the results of the analysis, the BSID report concludes that phosphorus is associated with impairments to aquatic life or biological communities in the 1st through 4th order streams of the Upper Pocomoke River watershed.

The BSID analysis also examines whether low DO concentrations are associated with degraded biological conditions in the 1st through 4th order streams of the watershed. The analysis of the Upper Pocomoke River watershed concludes that 86% of the biologically impacted stream miles in the watershed are associated with DO concentrations below 5 mg/l. Low DO concentrations may indicate nutrient over-enrichment and organic matter pollution due to excessive oxygen demand, which may stress aquatic organisms. Low (< 60%) DO saturation was identified as significantly associated with degraded biological conditions. The BSID analysis identified 62% of the impacted stream miles associated with low DO saturation in the lower order streams of the Upper Pocomoke River watershed.

For details on the BSID analysis, please refer to the document "Watershed Report for Biological Impairment of the Upper Pocomoke River Watershed in Wicomico and Worchester Counties, Maryland - Biological Stressor Identification Analysis Results and Interpretation" (MDE 2011).

2.3.2 Dissolved Oxygen and Chlorophyll *a*

DNR MBSS samples were taken in the Upper Pocomoke River watershed in 1997 and in 2001 and there is only one monitoring data for each station. MDE samples were taken from 1997 through 2005, and in year 2010 in different sets of stations. Figure 4 shows all the MDE DO monitoring data from 1997 to 2010. The DO values range from 0.8 to 12.1 mg/l with about 17% of the DO values below 5mg/l, indicating DO criterion is not met in the non-tidal waters of Upper Pocomoke River. Figure 5 and Figure 7 present the DO and chlorophyll *a* data in the mainstem Upper Pocomoke River. DO levels have a clear seasonal trend with low DO in the summer at the mainstem stations in the Upper Pocomoke River. However, the chlorophyll *a* concentrations are all below 5 µg/l at these mainstem stations. These low chlorophyll levels

suggest that low DO conditions in the mainstem waters are not due to eutrophication. Field surveys in these waters also confirm low algal growth due to light limitation.
For stations located in the tributaries, DO values show no apparent pattern, with low DO observed in spring, summer and/or fall at different stations (Figure 6). Some tributaries have one algae bloom in summer; others have two blooms (Figure 8). At some stations, chlorophyll *a* concentrations are as high as 90 µg/l, indicating nutrient over-enrichment at these sites.

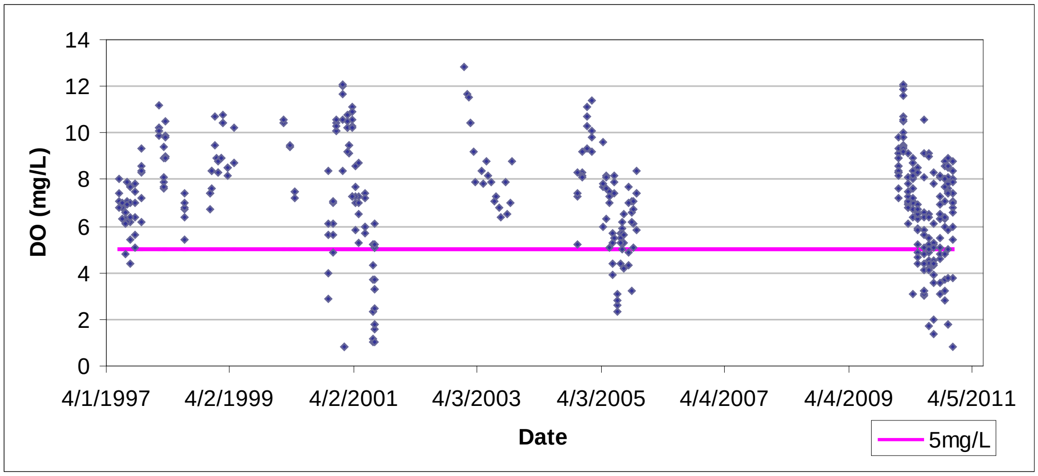

Figure 4: MDE Dissolved Oxygen Data from 1997 through 2010 in the non-tidal Upper Pocomoke River Watershed

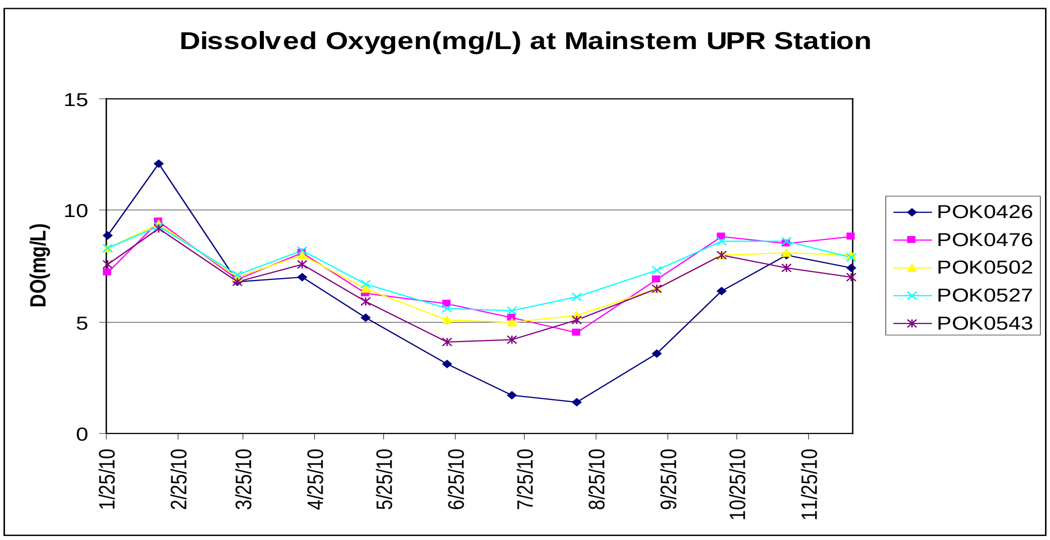

Figure 5: MDE 2010 Dissolved Oxygen Data in the non-tidal Upper Pocomoke River Mainstem Stations

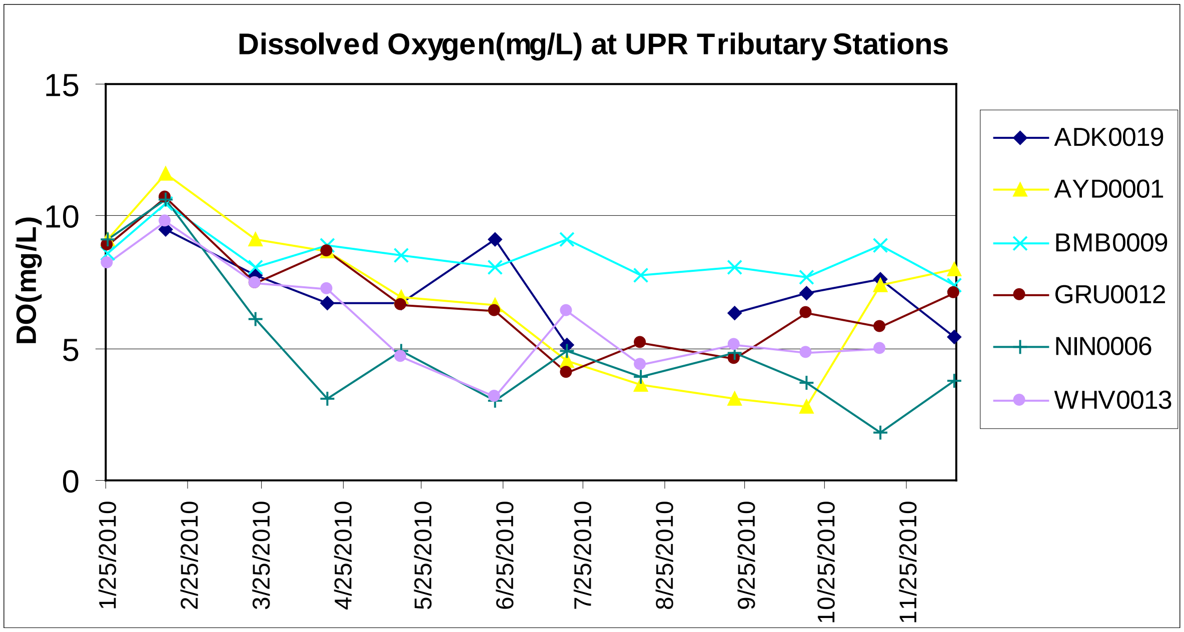

Figure 6: MDE 2010 Dissolved Oxygen Data in the non-tidal Upper Pocomoke River Tributary Stations

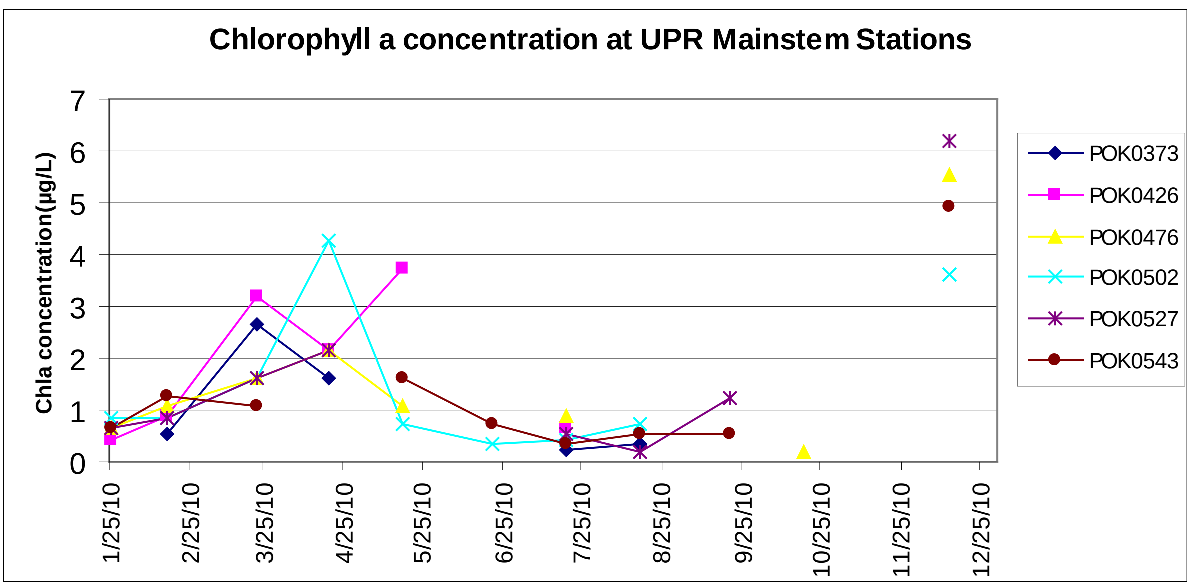

Figure 7: MDE 2010 Chlorophyll *a* Data in the non-tidal Upper Pocomoke River Mainstem Stations

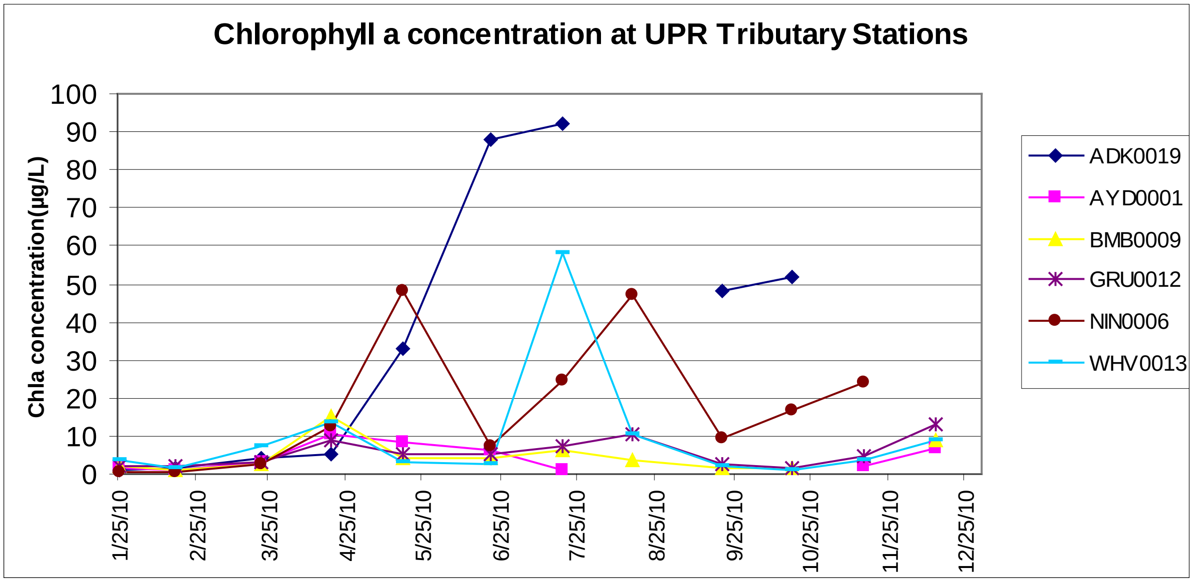

Figure 8: MDE 2010 Chlorophyll *a* Data in the non-tidal Upper Pocomoke River Tributary Stations

2.3.3 Nutrients

In the absence of State water quality standards with specific numeric limits for nutrients, evaluation of potentially eutrophic conditions is based on whether nutrient-related parameters (i.e., dissolved oxygen levels and chlorophyll *a* concentrations) are found to impair the designated uses in the Upper Pocomoke River (in this case protection of *Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life*). Consequently, the nutrients data presented in this section are for informational purposes only.

Total nitrogen (TN) and total phosphorus (TP) data for the Upper Pocomoke River have been collected as part of this study and the results are presented here for informational purposes. From 1997 to 2010, MDE data have total nitrogen (TN) concentrations ranging from 0.3 to 12.5 mg/l, except two extreme data with TN values around 50 mg/l. For total phosphorus (TP), concentrations ranging from 0.01 to 1.11 mg/l, except two extreme data with TP value at 23 mg/l. These data are presented graphically in Figures 9 and 10.

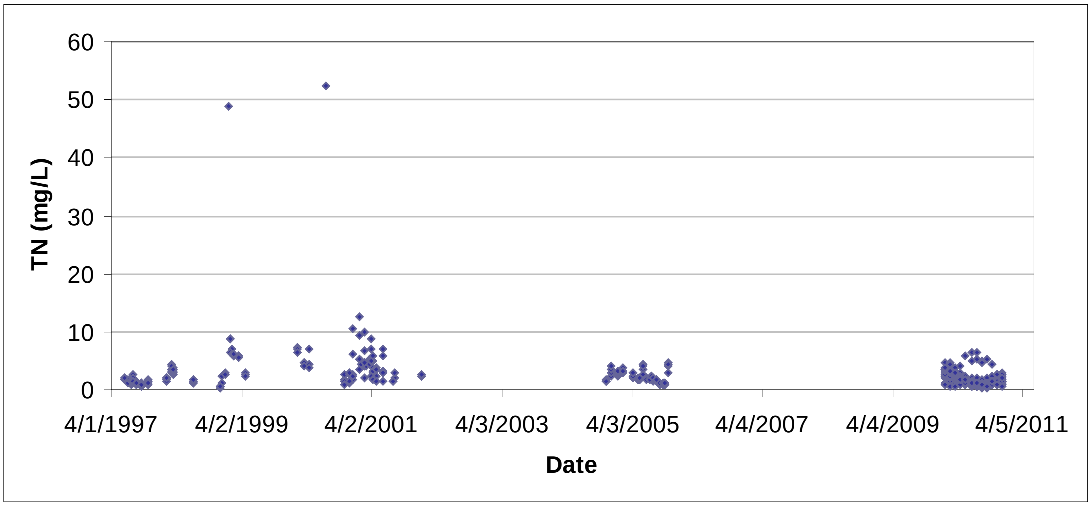

Figure 9: MDE Total Nitrogen (TN) Data from 1997 through 2010 in the non-tidal Upper Pocomoke River Watershed

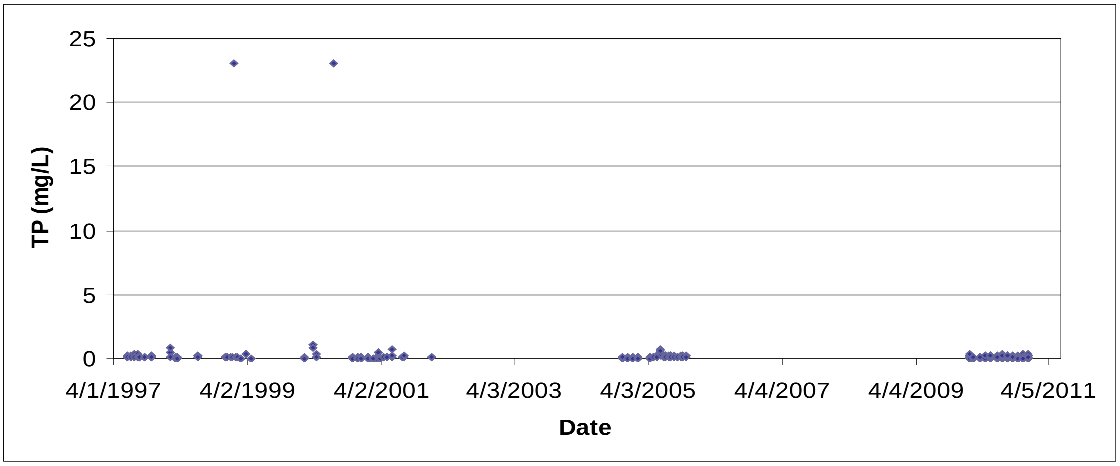

Figure 10: MDE Total Phosphorus Data from 1997 through 2010 in the non-tidal Upper Pocomoke River Watershed

2.3.4 Nutrient Limitation

Nitrogen and phosphorus are essential nutrients for algae growth. If one nutrient is available in great abundance relative to the other, then the nutrient that is less available limits the amount of plant matter that can be produced; this is known as the "limiting nutrient." The amount of the abundant nutrient does not matter because both nutrients are needed for algae growth. In general, a Nitrogen:Phosphorus (TN:TP) ratio in the range of 5:1 to 10:1 by mass is associated with plant growth being limited by neither phosphorus nor nitrogen. If the TN:TP ratio is greater than 10:1, phosphorus tends to be limiting; if the TN:TP ratio is less than 5:1, nitrogen tends to be limiting (Chiandani and Vighi 1974).

More than 68% of the samples collected in the Upper Pocomoke River watershed since 1997 have TN:TP ratios above 10 and less than 10% had TN:TP ratios below 5. The median ratio was 16. The observed data indicate that the streams in the non-tidal Upper Pocomoke River watershed are primarily phosphorus limited.

2.3.5 Upper Pocomoke River Benthic Macroinvertebrate Monitoring Stations

Biological data for the Upper Pocomoke River were also obtained from the DNR CORE/TREND program. The program collected benthic macroinvertebrate data between 1976 and 2006. The data were used to calculate four benthic community measures: total number of taxa, Shannon-Weiner diversity index, modified Hilsenhoff biotic index, and percent *Ephemeroptera*, *Plecoptera*, and *Trichoptera* (EPT). DNR has extensive monitoring data at one station (POK0527) on the non-tidal waters of the Upper Pocomoke River through the CORE/TREND program. The location of station POK0527 is shown in Figure 4. A summary of the results for this TREND station is presented in Table 5 (DNR 2009).

Table 5: Non-tidal Upper Pocomoke River CORE/TREND Data

Site Number	Current Water Quality Status	Trend Since 1970s
POK0527	Good	Improvement

Statistical analysis of the DNR long-term CORE/TREND biological data at the non-tidal Upper Pocomoke River station indicates that water quality has improved since 1976 and the non-tidal water is ranked as having good water quality based on percent EPT, taxa number, biotic index, and diversity index. However, Station POK0527 is the only CORE/TREND station in the non-tidal Upper Pocomoke River and is located in the mainstem of the River. CORE/TREND stations are not intended to assess 1^{st}-4^{th} order streams.

2.4 Water Quality Impairment

The Maryland water quality standards surface water use designation for the non-tidal waters of Upper Pocomoke is Use I (*Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life*) (COMAR 2012b,c,d). The nutrient water quality impairment of the non-tidal Upper Pocomoke River watershed addressed by this TMDL is caused by elevated nutrient loads beyond a level that is supportive of aquatic health, and phosphorus was identified as the specific impairing substance, with DO as the indicator of nutrient over-enrichment.

In Section 2.3.1, the BSID analysis using DNR MBSS data has identified that phosphorus is associated with impairments to aquatic life or biological communities in the 1^{st} through 4^{th} order streams of the Upper Pocomoke River watershed. The BSID analysis also identified that 86% of the biologically impacted stream miles in the watershed are associated with DO concentrations below 5 mg/l. In Section 2.3.2, the MDE DO data analysis shows that 17% of DO values are below 5 mg/l, therefore the DO water quality criterion applicable to the designated uses of the non-tidal Upper Pocomoke River is not being met. Water quality data also suggest that phosphorus contributes to low DO conditions in some tributaries, as indicated by high chlorophyll *a* concentrations in these streams. However, low chlorophyll *a* concentrations found in the mainstem of the river suggests that low DO conditions in the mainstem are caused by excessive organic carbon generated in the watershed.

3.0 TARGETED WATER QUALITY GOAL

A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life, primary or secondary contact recreation, drinking water supply, and shellfish propagation and harvest. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Designated Use for the non-tidal Upper Pocomoke River is Use I: *Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life* (COMAR 2012b,c,d,e,f). The objective of the phosphorus TMDL established herein is to reduce phosphorus loads, and subsequent effects on aquatic health, in the non-tidal waters of Upper Pocomoke River watershed to levels that support the Use I designation (*Water Contact Recreation, and Protection of Non-tidal Warmwater Aquatic Life*.

The non-tidal Upper Pocomoke River watershed was originally listed on Maryland's 1996 303(d) List as impaired by nutrients, with low DO as the indicator. The 1996 nutrient listing was refined in the 2008 Integrated Report and phosphorus was identified as the specific impairing substance. The Integrated Report nutrients listing methodology uses DO concentrations in the water column as the indicator to assess nutrient-related water quality in streams. Low levels of DO are sometimes associated with the decay of excess primary production and resulting nutrient over-enrichment, or eutrophication; for this reason, the potential nutrient-related impact on water quality is best measured during the growing season, May through October. The water quality analysis must demonstrate that either the water quality standards for DO are met or that nutrients are not the cause of the violation of the standards.

Currently, there are no specific numeric criteria for nutrients in Maryland's water quality standards for the protection of aquatic life in free-flowing non-tidal waters. Therefore, the evaluation of potentially eutrophic conditions due to nutrient over-enrichment will be based on whether nutrient-related parameters (i.e., dissolved oxygen (DO) levels and chlorophyll *a* concentrations) are found to impair the designated uses of the non-tidal Upper Pocomoke River.

Maryland's water quality standards include general narrative criteria prohibiting the pollution of waters of the State by any material in amounts sufficient to create a nuisance or interfere directly or indirectly with designated uses (COMAR 2012g), and a numeric DO criterion for Use I waters requiring a minimum DO concentration of 5.0 mg/l at any time (COMAR 2012a). Attainment of the numeric DO criterion is the endpoint of the TMDL. For this study, an allowance of up to 10% non-attainment for any 30-day period was applied to assess attainment of the DO criterion, to account for environmental variability from extreme or unusual conditions, and the uncertainties that tend to increase under such conditions in the modeling tools used to simulate water systems. EPA guidance has recommended making non-attainment decisions with respect to conventional pollutants, including nitrogen and phosphorus, when more than 10% of measurements exceed the water quality criterion (Regas 2005).

The non-tidal waters of the Upper Pocomoke River are located upstream of the tidal waters, and both portions of the river have in common a surrounding wetland/marsh environment. It is worth noting that, because of seasonal lower DO concentrations due to natural oxygen-depleting processes present in the extensive surrounding tidal wetlands, Maryland adopted a site-specific criterion of a 30-day mean DO greater than or equal to 4 mg/l in the tidal waters of the Upper and Middle Pocomoke River, approved by EPA on December 27, 2010. This site-specific criterion, which is lower than the general Use I criterion (DO not less than 5 mg/l at any time), underscores the need to consider the influence of natural conditions in forest- and wetland-dominated environments like the Upper Pocomoke watershed.

Overall, this TMDL will ensure that the phosphorus loads and resulting effects are at a level to support the Use I designation for the non-tidal Upper Pocomoke watershed, and more specifically, at a level the watershed can sustain without causing any nutrient related impacts to aquatic health. The TMDL, however, will not completely resolve the impairment to biological communities within the watershed. Because the BSID watershed analysis identifies other possible stressors (e.g., sediments) as impacting the biological conditions, this impairment remains to be fully addressed through the Integrated Report listing process and the TMDL development process, such that all impairing substances or stressors identified as impacting biological communities in the watershed are reduced to levels that will meet water quality standards, as established in future TMDLs for those substances (MDE 2009a).

4.0 TOTAL MAXIMUM DAILY LOADS AND SOURCE ALLOCATION

4.1 Overview

This section describes how the phosphorus TMDL and load allocations (LA) were developed for non-tidal Upper Pocomoke River Watershed. Section 4.2 describes the analysis framework for estimating phosphorus loading rates and the assimilative capacity of the watershed stream system. Section 4.3 summarizes the scenarios that were used in the analysis and presents results. Section 4.4 discusses critical conditions and seasonality. Section 4.5 explains the calculations of TMDL loading caps. Section 4.6 details the load allocations, and Section 4.7 explains the rationale for the margin of safety. Finally, Section 4.8 summarizes the TMDL.

4.2 Analysis Framework

For this TMDL development, the Chesapeake Bay Program Phase 5.3.2 (CBP P5.3.2) Watershed Model 2010 progress scenario loading outputs in the Upper Pocomoke River watershed was used as the baseline loads. A three dimensional Environmental Fluid Dynamics Code (EFDC) water quality model is used to simulate the eutrophication processes in the non-tidal waters of Upper Pocomoke River. The phosphorus TMDL was set at a level that will meet the stated DO criterion (see Section 3.0).

Watershed Model

The P5.3.2 model is a Hydrological Simulation Program FORTRAN (HSPF) model of the Maryland, Virginia, and the portions of Pennsylvania, Delaware, New York, and West Virginia in the Chesapeake Bay basin. Its primary purposes are: (1) to determine the sources of nitrogen, phosphorus, and sediment to the Chesapeake Bay; (2) to calculate nutrient and sediment loads to the Chesapeake Bay for use in the CBP Water Quality and Sediment Transport Model; and (3) to estimate load allocations in nutrient and sediment TMDLs for impaired Chesapeake Bay water quality segments. Generally, river reaches that have average annual flows greater than 100 cfs are represented in the model, but MDE has worked with CBP to ensure that all of MD's 8-digit watersheds, the unit of water quality assessment in MD, are represented in the model.

Bicknell et al. (2001) describe the HSPF model in greater detail. US EPA (2010b) documents the development of the Phase 5 Watershed Model.

An important aspect of the P5.3.2 model is that it imposes a uniform and consistent methodology for calculating nutrient input loads to land segments. The P5.3.2 model also uses automated calibration procedures to determine land and river parameters as well as the regional factors for EOS loads discussed in Section 2.2.1. This ensures that the land and river segments are simulated in a consistent manner and therefore that the allocation of loads is equitable. The P5.3.2 model was used to assign load and wasteload allocations for the Chesapeake Bay TMDLs. The load estimates from the P5.3.2 model will therefore shape water quality management in Maryland for the foreseeable future. The results of the model will impact point source and MS4 permits, as well as nonpoint source management programs for agriculture, silvaculture, and stream restoration. Using the P5.3.2 model as the basis enables Maryland to integrate its non-tidal nutrient TMDLs into the management framework for the Chesapeake Bay. It also provides a consistent and equitable way to determine the load contribution from neighboring states.

The P5.3.2 Watershed Model 2010 Progress scenario is based on 2010 land use and BMPs with actual precipitation. The five watershed model land-river segments used in this study are A10005EL2-5110-5270 (from Delaware), A24045EL2-5110-5270, A24045EL2-5270-0001, A24047EL2-5110-5270 and A24047EL2-5270-0001. The point source facilities included in this scenario and their associated load information are listed in Table 8 in Section 4.6 below.

Water Quality Model

The EFDC water quality model was used to simulate the eutrophication processes in the non-tidal waters of Upper Pocomoke River. The EFDC model is a general 3-Dimensional (3-D) model for environmental studies. The model simulates density and topographically induced circulation as well as tidal and wind-driven flows, and spatial and temporal distributions of salinity, temperature, and suspended sediment concentration, conservative tracers, eutrophication processes, and fecal bacteria. For a detailed model description, the reader is referred to Hamrick (1992a, 1992b) and Park *et al.* (1995).

The model domain encompasses the mainstem of the Upper Pocomoke River and the tributaries where low DO and elevated levels of nutrients were observed. The model simulates water transport and eutrophication processes in the receiving river as a function of flow and loading discharges from the surface and sub-surface of adjacent watersheds. Modeled variables include algae, DO, nitrogen, phosphorus, and organic carbon. The model simulates algal and DO dynamics, and nutrients transport, settling, uptake, and recycling. The instream eutrophication model is coupled with a sediment process model, which simulates minimization of nutrients, nutrient fluxes and sediment oxygen demand (SOD). Details of the model development, model calibration, and verification are presented in Appendix A.

MDE 2010 in-stream water quality data was chosen for the water quality model calibration. There is one monitoring station located within each 12-digit watershed. These stations are located in the mainstem and some of the tributaries as shown in Figure 4. Monthly water quality data were collected in each station through the year 2010. Because the current CBP watershed model simulation period ends in 2005, the 2010 watershed loads were estimated based on the USGS flow and the load-flow regression relationship derived from the P5.3.2 2010 scenario watershed model outputs. The MDE 2010 water quality dataset was selected for the calibration because the data were collected in both the mainstem and tributaries. The method for deriving the 2010 watershed loads and model calibration results are presented in the model calibration section of Appendix A.

4.3 Scenario Descriptions and Results

The following analyses allow a comparison of baseline conditions (under which water quality problems exist) with future conditions, which project the water quality response to various simulated phosphorus load reductions. The analyses are grouped according to baseline conditions and future conditions associated with TMDL.

Baseline Conditions

The baseline conditions are intended to provide a point of reference by which to compare the future scenario that simulates conditions of a TMDL. The baseline conditions typically reflect an approximation of nonpoint source loads during the monitoring time frame, as well as estimated point source loads for the same period.

The non-tidal Upper Pocomoke River watershed baseline nutrient loads are estimated using the CBP P5.3.2 2010 Progress Scenario model outputs. The 2010 Progress Scenario represents current land use (2010 land use), loading rates, and BMP implementation simulated using actual precipitation and other meteorological inputs from the period 1991-2000 to represent variable hydrological conditions. The period 1991-2000 is the baseline hydrological period for the Chesapeake Bay TMDL. For this study, loading outputs for the period of 1996 to 1998 from the 2010 Progress Scenario were used as the baseline loads. The years 1996, 1997 and 1998 represent very wet, dry and mean hydrological conditions, respectively, as shown in Figure 11.

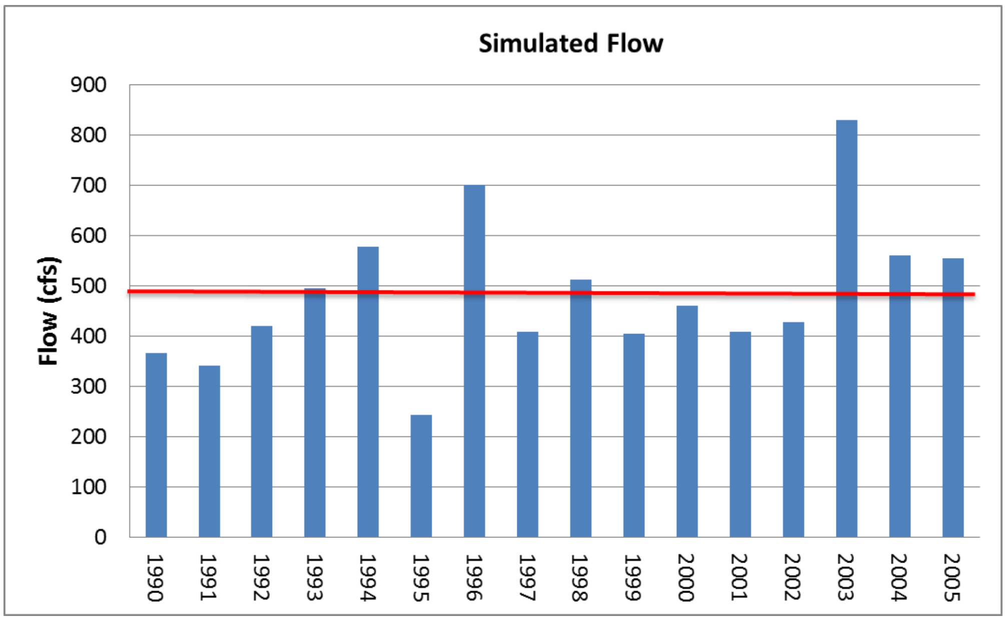

Figure 11: Chesapeake Bay Model Simulation of Annual Mean Flow Distribution from 1990 to 2005 in the non-tidal Upper Pocomoke River Watershed

Watershed loading calculations were based on the CBP P5.3.2 segmentation scheme within each MD 8-digit watershed and corresponding 12-digigt MD segments by redistributing Bay watershed model loads for each landuse category to small MD 12-digit watersheds based on the proportion of different land uses within each subwatershed. The phosphorus loads from these segments are combined to represent the baseline condition. The MD point source phosphorus loads are estimated based on the point source facilities loads included in CBP P5.3.2 model. Details of these loading estimates can be found in Table 8 in Section 4.6. The total baseline phosphorus load from the DE portion of the Upper Pocomoke River watershed is 20,105 lbs per year; the load from the MD portion is 55,163 lbs per year.

TMDL Conditions

This scenario represents the future conditions of maximum allowable phosphorus loads whereby there will be no phosphorus-related impacts affecting aquatic health. In the TMDL calculation, the allowable load for the impaired watershed is calculated as the reduction of the baseline load necessary to meet the stated DO criterion (see Section 3.0) for the entire model domain of this study. In order to apply an allowance of up to 10% non-attainment for any 30-day period to the current DO criterion, a 30-day moving average of the percentage of non-attainment of 5mg/l is calculated for every cell of the model domain until no more than 10% of non-attainment for any 30-day period is achieved. The resulting load is considered the maximum allowable load the watershed can sustain without causing nutrient-related impacts to aquatic health. (For details refer to Appendix A.) Model calibration becomes more uncertain in extreme high and extreme low flow conditions; therefore, it is important to apply averaging to prevent extreme or unlikely events and anomalies from driving and potentially skewing results. In the present case, instead of averaging, the TMDL model evaluation of attainment provides a 90% confidence level that DO values will be above 5 mg/l for any given 30-day period in the simulation.

The TMDL loadings and associated reductions are averaged at the MD 8-digit watershed scale, which is consistent with the original listing scale. It is important to recognize that some subwatersheds may require higher reductions than others, depending on the distribution of the land use.

The established phosphorus TMDLs in the upstream Delaware (DE) portion of the Upper Pocomoke River and in the Adkins Pond sub-watershed are both applied to this TMDL scenario. In 2005, DE developed nutrient TMDLs in the Pocomoke River watershed within their state, which requires 55% reductions of TN and TP loads to meet DE's DO criteria (5.5 mg/l daily average and 4mg/l minimum at all time) and a TP target value of 0.2mg/l (DNREC 2005). DE's TMDL development used QUAL2K water quality model and their nutrient criteria are different from those used in this study. The QUAL2K model simulation and TMDL were based on the summer low flow condition that resulted in a phosphorous TMDL of 6.1 lbs per day. Because the DE phosphorus TMDL is more stringent than the DE loading estimated in this study as necessary to meet water quality in the MD portion of the River, and because the drainage area of the DE TMDL is identical to the DE portion of the Upper Pocomoke watershed in this study, the MD phosphorus TMDL load allocation for the upstream DE portion of the watershed is based on the DE TMDL.

The Adkins Pond average annual phosphorus TMDL of 2,505 lb/yr, which was developed by MDE to be protective of water quality standards within the impoundment and approved by EPA in 2002, still applies as the target phosphorus loading capacity within the pond's drainage area, located in the mid-western portion of the Upper Pocomoke River watershed (MDE 2002). The attainment of water quality standards within the MD 8-digit Upper Pocomoke River watershed and Adkins Pond impoundment can only be achieved by meeting the average annual TMDL of phosphorus specified for the MD 8-digit watershed within this report as well as the specific TMDL for the Adkins Pond drainage basin established by MDE in 2002. Furthermore, both the baseline phosphorus loading and TMDL for the impoundment are implicitly included within the Upper Pocomoke River nonpoint source baseline loads and TMDL load allocation, respectively, due to the spatial resolution of the CBP P5.3.2 Watershed Model segmentation.

Using the modeling framework described in this report, the model simulation of future conditions that will achieve the stated DO criterion resulted in the following TMDL loads:

The MD 8-digit Upper Pocomoke River Average Annual TMDL of phosphorus is 43,592 lbs/yr. The TMDL consists of: (1) an Upstream Load Allocation (LA_{DE}) of 2,227 lbs/yr, attributed to loads generated outside the MD assessment unit from sources in the Delaware (DE) portion of the watershed; and (2) allocations attributed to loads generated within the assessment unit consisting of a MD 8-digit Upper Pocomoke River Watershed TMDL Contribution of 41,364 lbs/yr. The TMDL represents an overall 25% reduction of the baseline loads.

This TMDL sets phosphorus load limits designed to result in attainment of DO levels that support the aquatic life use in the non-tidal Upper Pocomoke River. However, the data analysis and model scenario run results determined that, while nutrient enrichment is the primary cause of low DO conditions in some smaller streams, excessive organic carbon (OC) exported from watershed is the primary reason for low DO conditions in the mainstem of the Upper Pocomoke River. The river originates in the Great Cypress Swamp on the Delaware-Maryland border, one of the major sources of OC in the mainstem Upper Pocomoke River and in the downstream tidal portion (DNR, 2010). Also, the watershed is dominated by natural wetlands and forest, both sources of rich organic matter. Thus, the low DO conditions in the non-tidal Upper Pocomoke River are caused by both natural conditions and human impacts. The TMDL analysis presented in this report demonstrates that, because of the high correlation between phosphorus and organic carbon, the reduction of phosphorus loads required to implement the TMDL will result in a proportional reduction of OC as well, which will further ensure DO attainment.

4.4 Critical Conditions and Seasonality

EPA's regulations require TMDLs to take into account critical conditions and seasonality for stream flow, loading, and water quality parameters (CFR 2011a). The intent of this requirement is to ensure that the water quality of the waterbody is protected during times when it is most vulnerable.

To ensure that the TMDL accounts for seasonal hydrological variations and the attainment of the DO criterion in the non-tidal Upper Pocomoke River is met during critical conditions, a three-year period from 1996-1998 was selected for the model simulations upon which the TMDL was based. 1996 was a very wet year, 1997 a dry year, and 1998 was a typical mean flow year. The selection of this three-year period represents variable hydrological conditions and captures high and low flow events. It inherently includes critical conditions and seasonal variations. Therefore, the phosphorus loading limit established by the numerical model ensures that the DO criterion is met.

Seasonality is captured in two components. First, it is implicitly included through the use of monitoring data for water quality assessment and model calibration. For example, MDE's 2010 water quality monitoring data was collected once every month throughout 2010. Second, the loading rates used in the TMDL were determined using the HSPF model, which is a continuous simulation model based on daily perception. The three dimensional receiving water model simulation spans a three-year period which covers wet-, dry-, and mean-flow years. This 3-year simulation encompasses seasonal variations and a range of hydrological and meteorological conditions.

4.5 TMDL Loading Caps

This section presents the average annual TMDL of phosphorus for the Upper Pocomoke River watershed. These loads are considered the maximum allowable long-term average annual load the watershed can sustain without causing any nutrient-related impacts to aquatic health.

As explained in Section 4.3, DE established TN and TP TMDLs in the Pocomoke River in 2005. These TMDLs are protective of the DE portion of the Pocomoke River and are more stringent than the DE loading estimated in this study as necessary to meet water quality in the MD portion of the River. Therefore, the TMDL established by DE applies as the target phosphorus loading capacity for the upstream DE portion of the watershed in this TMDL.

The long-term average annual TMDL was calculated for the MD 8-digit watershed based on model simulations and the DO criterion. In order to attain the TMDL loading cap calculated for the watershed, reductions will be applied to the controllable sources. According to the Chesapeake Bay TMDL established by the EPA on December 31, 2010, a 24% reduction of phosphorus will be required in the Upper Pocomoke River watershed in Maryland to meet the phosphorus allocations assigned to the Pocomoke Tidal Fresh Bay Water Quality Segment. However, the phosphorus TMDL presented in this report was developed to meet DO water quality criteria in the non-tidal portion of the River, and requires a higher reduction of phosphorus loads. To ensure consistency with the Bay TMDL, and efficiency in the reduction of phosphorus loads, reductions will be applied to the same controllable sources identified in Maryland's Watershed Implementation Plan (WIP) for the Bay TMDL. The predominant controllable sources typically include: (1) regulated and non-regulated developed land; (2) high till crops, low till crops, hay, and pasture; and (3) municipal and industrial wastewater treatment plants. Additional sources might need to be controlled in order to ensure that water quality standards are attained in the Chesapeake Bay as well as in the non-tidal Upper Pocomoke River.

An overall reduction of 25% of phosphorus loads from the MD 8-digit Upper Pocomoke River watershed will be required to meet TMDL allocations and attain DO criterion set by this study. The baseline and TMDL scenario loads for the Upper Pocomoke River watershed are presented in Table 6. For the DE portion of the watershed, the baseline load is based on CBP P5.3.2 model output and the TMDL scenario load is derived from the phosphorus TMDL established by DE in 2005. Therefore, the loads from DE are presented for informational purposes only, and the reduction is not applicable.

Table 6: Upper Pocomoke River Watershed TMDL for Phosphorus

	Baseline Load (lbs/yr)	TMDL Scenario Load (lbs/yr)	Reduction (%)
DE*	**20,105***	**2,227***	**NA**
MD 8-digit	**55,163**	**41,364**	**25%**

*DE baseline load is from CBP P5.3.2 model output and TMDL for DE portion is established by DE in 2005

4.6 Load Allocations Between Point and Nonpoint Sources

Per EPA regulation, all TMDLs need to be presented as a sum of waste load allocations (WLAs) for point sources and load allocations (LAs) for nonpoint source loads generated within the assessment unit, as well as natural background, tributary, and adjacent segment loads (CFR 2011b). Consequently, the Upper Pocomoke River watershed TMDL allocations are presented in terms of WLAs (i.e., point source loads identified within the watershed) and LAs (i.e., the nonpoint source loads within the watershed and loads from upstream watersheds). The State reserves the right to allocate the TMDL among different sources in any manner that is reasonably calculated to protect aquatic life from nutrient-related impacts.

Table 7 summarizes the TMDL scenario results for phosphorus. There are no CSOs in the Upper Pocomoke River watershed and phosphorus loads from septic systems are negligible. Equal reductions were applied to the controllable loads. Controllable loads were determined in accordance with the Chesapeake Bay TMDL (US EPA 2010a). In this watershed, crop, pasture, nursery, urban land, CAFOs and AFOs, and municipal WWTPs were identified as the predominant controllable sources. Forest is the primary non-controllable source, as it represents the most natural condition in the watershed. Atmospheric deposition will be reduced by existing state and federal programs and thus is not addressed in this TMDL.

Urban stormwater nutrient loads are primarily regulated under the NPDES MS4 program and therefore included in the WLA. However, most urban stormwater sources in the Upper Pocomoke River watershed are unregulated and the loads are included in the LA. Loads from regulated urban sources are negligible.

The Upper Pocomoke River Phosphorus TMDL requires a 25% reduction in phosphorus loads from nonpoint sources in MD's 8-digit watershed (See Table 7). For more detailed information regarding the Upper Pocomoke River Watershed TMDL Contribution nonpoint source allocations, please see Appendix A.

Table 7: MD 8-digit Upper Pocomoke River TMDL Phosphorus TMDL by Source

	Baseline Load Source Categories		Baseline Load (lbs/yr)	TMDL Components	TMDL (lbs/yr)	Reduction (%)
Upper Pocomoke River Contribution	**Nonpoint Source**	Forest	2,935	**LA**	2,935	0%
		AFOs	126		91	28%
		Pasture	2,231		1,607	28%
		Crop	35,247		25,378	28%
		Nursery	4,760		3,427	28%
		Septic	0		0	0%
		Non-Regulated Urban	2,766		1,991	28%
		Atmospheric Deposition	66		66	0%
		Sub-total	**48,130**		**35,494**	26%
	Point Source	CAFOs	6,027	**WLA**	4,339	28%
		Regulated Urban	15		11	28%
		WWT	991		1,520	-53%**
		CSO	0		0	0%
		Sub-total	**7,033**		**5,870**	17%
	Total MD 8-digit		**55,163**		**41,364**	**25%**
Upstream	**Delaware***		**20,102***	**Upstream**	**2,227***	**NA**

* The DE TMDL shown here is based on DE's 2005 phosphorus TMDL (DNREC 2005) and the baseline load is from CBP P5.3.2 model output. Therefore, the reduction is not applicable.
** The phosphorus WLA for process waters are larger than the baseline load because WLAs for the municipal facilities were calculated using their design flows, which are the maximum flow capacities these facilities could discharge. This is represented by the negative reduction.

The wasteload allocation (WLA) of the Upper Pocomoke River watershed is allocated in three categories: Process Water WLA, NPDES Stormwater WLA, and CAFO WLA. The categories are described below.

Process Water WLA

As explained in Section 2.2.2, there are two minor municipal WWTPs in the Upper Pocomoke River watershed. Minor municipal WWTPs are assigned phosphorus WLAs based on their Maryland Tributary Strategy Cap flow and the permit limit; or if the facility does not have permit limits, it is assigned a WLA based on its Maryland Tributary Strategy Cap flow and an assumed maximum average annual concentration of 3 mg/l TP. The Tributary Strategy Cap flow is the design flow of the facility or the projected 2020 flow (projected from 2003 discharge flows and Maryland Department of Natural Resources growth rates by county), whichever is less.

One active minor industrial facility discharging process water in the Upper Pocomoke River watershed was judged to have the capacity to discharge TP in their process water. Under the Chesapeake Bay TMDL, industrial facilities capable of discharging phosphorus in their process water were given a WLA based on the results of monitoring required by their permits or professional judgment. In addition, allocations for minor municipal WWTPs (with design flows less than 0.5 MGD) and for minor industrial facilities are presented in the Chesapeake Bay TMDL as a watershed-wide aggregate WLA. A similar approach was adopted for the Upper Pocomoke River TMDL and all minor municipal and minor industrial process water facilities allocations are represented as a watershed-wide WLA.

Table 8 lists the facilities that are represented in the Phase 5.3.2 Watershed Model, and presents the total estimated baseline phosphorus loads and TP WLA for these facilities.

Table 8: Process Water WLA in the Upper Pocomoke River Watershed

NPDES	Facility	Process Water Baseline TP loads (lbs/yr)	Process Water TP WLA (lbs/yr)
MD0051632	WILLARDS WWTP	991	1520
MD0060348	PITTSVILLE WWTP		
MDG499796	HARKINS READY MIX		

* The phosphorus WLA for process waters are larger than the baseline load because WLAs for the municipal facilities were calculated using their design flows, which are the maximum flow capacities these facilities could discharge. This is represented by the negative reduction.

Stormwater WLA

Per EPA requirements, "stormwater discharges that are regulated under Phase I or Phase II of the National Pollutant Discharge Elimination System (NPDES) stormwater program are point sources that must be included in the WLA portion of a TMDL" (US EPA 2002). Phase I and II permits can include the following types of discharges:

- small, medium, and large MS4s – these can be owned by local jurisdictions, municipalities, and state and federal entities (i.e., departments of transportation, hospitals, military bases, etc.);
- general industrial stormwater permitted facilities; and
- small and large construction sites.

Urban stormwater nutrient loads are primarily regulated under the NPDES MS4 program and therefore included in the WLA. However, most urban stormwater in the Upper Pocomoke River watershed are unregulated and the loads are included in the LA. Loads from regulated urban are negligible (Table 9).

Table 9: Stormwater WLA in the Upper Pocomoke River Watershed

NPDES	Facility	Stormwater Baseline TP loads (lbs/yr)	Stormwater TP WLA loads (lbs/yr)
MD0069957	CROPPER BROTHERS LUMBER COMPANY, INC.	15	11
N/A	FOREST PRODUCTS, INC.		
N/A	NEWARK VOLUNTEER FIRE COMPANY, INC.		

CAFO WLA

Under the Clean Water Act, combined animal feeding operations (CAFOs) require NPDES permits for their discharges or potential discharges (CFR 2010c). In January, 2009, Maryland implemented new regulations governing CAFOs (COMAR 26.08.01, 26.08.03, and 26.08.04), which were approved by the EPA in January, 2010. Under these regulations, CAFOs are required to fulfill the conditions of a general permit. These conditions include instituting a Comprehensive Nutrient Management Plan (CNMP) which meets the Nine Minimum Standards to Protect Water Quality. The general permit also prohibits the discharge of pollutants, including nutrients, from CAFO production areas except as a result of event greater than the 25-year, 24-hour storm. The Upper Pocomoke River Phosphorus TMDL requires a 50% reduction in phosphorus loads from CAFOs.

4.7 Margin of Safety

All TMDLs must include a margin of safety to account for any lack of knowledge and uncertainty concerning the relationship between loads and water quality (CFR 2011a). For this TMDL, the MOS is incorporated in the analysis by accounting for critical conditions captured in the hydrological return period selected for the dynamic model long term simulation. The simulation period selected for establishing the phosphorus allowable loads, includes a very wet year (1996), a dry year (1997), and a typical mean flow year (1998). In general, during dry years, the system can experience higher water temperatures combined with low flows. During wet years, higher flows and consequently increased pollutant loadings are expected. A wet year followed by a dry year combines both higher pollutant loadings to the system and higher temperatures, leading to lower DO levels due to increased primary production and bacterial decomposition. Incorporation of this critical period and the corresponding conservative assumptions in the modeling used to develop the TMDL supports the assertion of an implicit MOS. Therefore, a MOS that accounts for uncertainties in the analysis of water quality conditions in the non-tidal Upper Pocomoke River is considered as implicitly included in the model simulation and, consequently, in the TMDL.

4.8 Summary of Total Maximum Daily Loads

The average annual phosphorus TMDL for the Maryland 8-digit Upper Pocomoke River watershed and Delaware streams draining to the watershed are summarized in Table 10. The Maximum Daily Loads are summarized in Table 11. (See Appendix C for more details).

Table 10: MD 8-digit Upper Pocomoke River Average Annual TMDL of Phosphorus (lbs/yr)

		LA						WLA						
TMDL (lbs/yr)	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**	+	**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**	+	**MOS**
43,592	=	2,227		35,494	+	0	+	4,339	+	11	+	1,520	+	Implicit

Upstream Load Allocation[2] — LA_{DE}; MD 8-digit Upper Pocomoke River Watershed TMDL Contribution — LA_{UPR} through Process Water WLA_{UPR}

[1] The LA_{DE} was determined based on a DE TMDL that is expressed in lbs/day and converted herein to an annual loading by multiplying by 365 (DNREC 2005). The LA_{DE} meets Maryland water quality standards within the MD 8-digit Upper Pocomoke River watershed. It accounts for the upstream load from DE entering MD waters.

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

Table 11: MD 8-digit Upper Pocomoke River Maximum Daily Loads of Phosphorus (lbs/day)

		LA						WLA						
TMDL (lbs/day)	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**	+	**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**	+	**MOS**
392.2	=	6.1		370.02	+	0	+	11.9	+	0.03	+	4.2	+	Implicit

Upstream Load Allocation[2] — LA_{DE}; MD 8-digit Upper Pocomoke River Watershed TMDL Contribution — LA_{UPR} through Process Water WLA_{UPR}

[1] LA_{DE} was based on the DE TMDL (DNREC, 2005).

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

5.0 ASSURANCE OF IMPLEMENTATION

Section 303(d) of the Clean Water Act and current EPA regulations require reasonable assurance that the TMDL load and wasteload allocations can and will be implemented. This section provides the basis for reasonable assurance that the phosphorus TMDL in the Upper Pocomoke River will be achieved and maintained.

The non-tidal Upper Pocomoke River phosphorus TMDL is expected to be implemented as part of a staged process recently developed by Maryland. This staged process is designed to achieve both the nutrient reductions needed within the Upper Pocomoke River watershed and to meet target loads consistent with the Chesapeake Bay TMDL, established by EPA in 2010 (US EPA 2010a) and scheduled for full implementation by 2025. The Bay TMDL requires reductions of nitrogen, phosphorus and sediment loads throughout the Bay watershed to meet water quality standards that protect the designated uses in the Bay and its tidal tributaries. The nutrient reductions for the Bay TMDL are independent of those needed to implement any TMDLs developed to address nutrient-related impairments in Maryland's non-tidal waterbodies, although their reduction goals and strategies do overlap. For example, the implementation planning framework, developed by the Bay watershed jurisdictions in partnership with EPA, provides a staged approach to achieving Bay TMDL nutrient reduction goals that is also applicable to implementation of nutrient TMDLs in local non-tidal watersheds. In short, nutrient reductions required to meet the Chesapeake Bay TMDL will also support the restoration and protection of local water quality.

Maryland's Phase I Watershed Implementation Plan (WIP) for the Chesapeake Bay TMDL, finalized in December 2010, identifies nutrient reduction targets by source sector for the Pocomoke Tidal Fresh segment-shed, which includes Upper Pocomoke River and a number of other Maryland 8-digit watersheds. EPA revised the nutrient and sediment load allocations for the Bay TMDL in August 2011, based on results of the updated Phase 5.3.2 Watershed Model. Maryland has been working with key local partners, including county and municipal staff, soil conservation managers, and a variety of stakeholder organizations and business interests, to help them develop local implementation plans at the county scale. These local plans are being incorporated into the basin-scale implementation plans in the Phase II WIP, which will be finalized in October 2012.

Maryland's Phase II WIP and the State's schedule of two-year milestones provide implementation strategies and a time line for achieving nutrient reductions across the State to meet Chesapeake Bay interim target loads by 2017, equivalent to 60% of the final target goals set for 2025 to fully implement the Chesapeake Bay TMDL in Maryland. A Phase III Plan will be developed in 2017 to address the additional reductions needed from 2018 through 2025 to meet the final targets. Prior to Phase III, the TMDL allocations may again be revised to reflect better data, a greater understanding of the natural systems, and to make use of enhanced analytical tools (such as updated watershed and water quality models). This iterative process provides an adaptive approach for achieving the Chesapeake Bay TMDL goals, as well as a framework and time line for the staged implementation of the Upper Pocomoke River non-tidal waters nutrient TMDL.

The proposed approach for achieving the Upper Pocomoke River reduction targets will be based on deployment of an appropriate selection of the comprehensive implementation strategies described in Maryland's Phase I WIP (MDE 2010b) and Phase II WIP (MDE 2012b), the centerpieces of the State's "reasonable assurance" of implementation for the Bay TMDL. The strategies encompass a host of best management practices, pollution controls and other actions for all source sectors that cumulatively will result in meeting the State's 2017 interim nutrient and sediment reduction targets, as verified by the Chesapeake Bay Water Quality Model.

Accounting, tracking and reporting are an important part of the overall WIP strategy, and progress will be closely monitored for the two-year milestones by tracking both implementation and water quality. The setting of 2017 interim targets and a schedule of two-year milestone commitments will allow for an iterative, adaptive management process with ongoing assessments of implementation progress, as well as periodic reevaluation of nutrient impacts on local water quality. This staged approach provides further assurance that the implementation of the Upper Pocomoke River phosphorus TMDL will be achieved through increased accountability and verification of water quality improvements over time.

Once the Bay TMDL nutrient target loads for the Upper Pocomoke River watershed have been met, MDE will revisit the status of nutrient impacts on aquatic life in the non-tidal waters of Upper Pocomoke River, based on any additional monitoring data available and any improvements in the scientific understanding of the impacts of nutrients on aquatic life in free-flowing streams. The results of this reassessment will determine whether additional phosphorus reductions are needed in the watershed, or whether the non-tidal Upper Pocomoke River phosphorus TMDL goals have in fact been met.

Maryland Legislative Actions and Funding Programs to Support TMDL Implementation

Maryland recently enacted significant new legislation that requires Phase I MS4 jurisdictions to establish, by July 1, 2013, an annual stormwater remediation fee and a local watershed protection and restoration fund to support implementation of local stormwater management plans. Maryland has made a commitment to include provisions in Phase I and II MS4 permits, due for issuance in 2012, to implement the State's WIP strategies to reduce nutrient and sediment loads from urban stormwater sources.

Maryland has also enacted significant new legislation to increase the Bay Restoration Fund to provide financing for wastewater treatment plant upgrades and on-site septic system improvements, as well as legislation to guide grown on central sewer and septic systems. These new laws will support local efforts to reduce nutrient loads in both non-tidal watersheds and in downstream tidal waters of the Chesapeake Bay.

In response to the WIP and the increased burden on local governments to achieve nutrient reduction goals, Maryland has continued to increase funding in the Chesapeake and Atlantic Coastal Bays Trust Fund. For Fiscal Year 2013, in addition to $25 million (pending) for the Trust Fund, $38 million in general obligation bonds were made available to local communities for implementation of stormwater capital improvements. These funds will not only kick start restoration at the local level, but also create and retain green jobs in Maryland's economy.

Funding was also increased to support implementation of natural filters on public lands ($9 million), and funding for Soil Conservation Districts from 16 to 39 positions ($2.2 million). In addition, funding for the cover crop program is at $12 million – a record level.

MD's Water Quality Improvement Act of 1998 (WQIA) requires that comprehensive and enforceable nutrient management plans be developed, approved and implemented for all agricultural lands throughout MD. This act specifically required such plans for nitrogen be developed and implemented by 2002, and plans for phosphorus be completed by 2005.

Additional potential funding sources for implementation include Maryland's Agricultural Cost Share Program (MACS) which provides grants to farmers to help protect natural resources, and the Environmental Quality and Incentives Program, which focuses on implementing conservation practices and BMPs on land involved with livestock and production.

For the 2012-2013 milestone period, Maryland is working to: restrict fall fertilization of small grain crops on soil testing above a given nitrate level thresholds; require incorporation of organic nutrient sources (with some exceptions); limit fall applications of organic nutrient sources; and, require a cover crop following fall applications of organic nutrient sources. Future changes: nutrient application setbacks of 10-35 feet (depending on application methods) will be required (2014); best management practices will be required for streams with adjacent livestock (2014); winter application of all organic nutrient sources will be prohibited (2016-2020).

Maryland is also working to adopt a revised Phosphorus Site Index (PSI) and incorporate the new PSI into nutrient management plans in preparation for the 2013 crop season (winter 2012-2013).

To enhance Urban Nutrient Management as a nutrient reduction strategy, the State is working to develop regulations to implement the Fertilizer Use Act. This will: limit nitrogen & phosphorus content in fertilizer content and use on non-agricultural land; require certification and training for non-agricultural applicators; require certain fertilizer product labeling; and require outreach and education programs for homeowner fertilizer use.

For more information on Maryland's implementation and funding strategies to achieve nutrient and sediment reductions throughout the State's portion of the Chesapeake Bay watershed, please see Maryland's Phase II Watershed Implementation Plan.

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Appendix A. Model Development and Calibration

A1. Model Development

The application of numerical models is a widely used approach for TMDL and other water quality studies. In this study, a numerical model was developed to simulate dissolved oxygen (DO) and algae dynamics and nutrients transport in the Upper Pocomoke River (UPR). The Environmental Fluid Dynamic Code (EFDC) model (Hamrick, 1992a, Park *et al*. 1995) was used to simulate the water quality of the receiving water.

A.1.1 Model Description

A.1.1.1 Hydrodynamic and Eutrophication Model

Hydrodynamic transport is the essential mechanism for driving the movement of dissolved and particulate substances in aquatic waters. Hydrodynamic models are used to represent transport processes in complex aquatic systems. For the Upper Pocomoke River phosphorus TMDL development, the EFDC model was selected to simulate the hydrodynamics of the system. The EFDC is a general purpose modeling package capable of 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 *et al.*, 1992b; Hong and Shen, 2012; MDE, 2011).

Inputs to the EFDC model for UPR include:

- Bathymetry
- Freshwater inputs (lateral and upstream) 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 the Upper Pocomoke River (UPR) was developed based on the high-resolution shoreline digital files from USEPA and USGS topographic maps. The grid covered many channels of the UPR including all the tributaries with observation stations. One grid cell is used to represent the channel. The width and depth were compiled using MDE field survey data. The total water depth was simulated using three vertical layers to model differences of oxygen levels between surface and bottom. Setting the model boundary well outside the model area of interest increased the model accuracy by reducing the influence of the boundary condition. Because there is no tide in the non-tidal waters of UPR, the downstream boundary condition will not affect the upstream condition. However, flow can be reversed in the tributary temporally during the high flow period when water elevation is high in the main channel. Figure A-1 shows the central location of the grid.

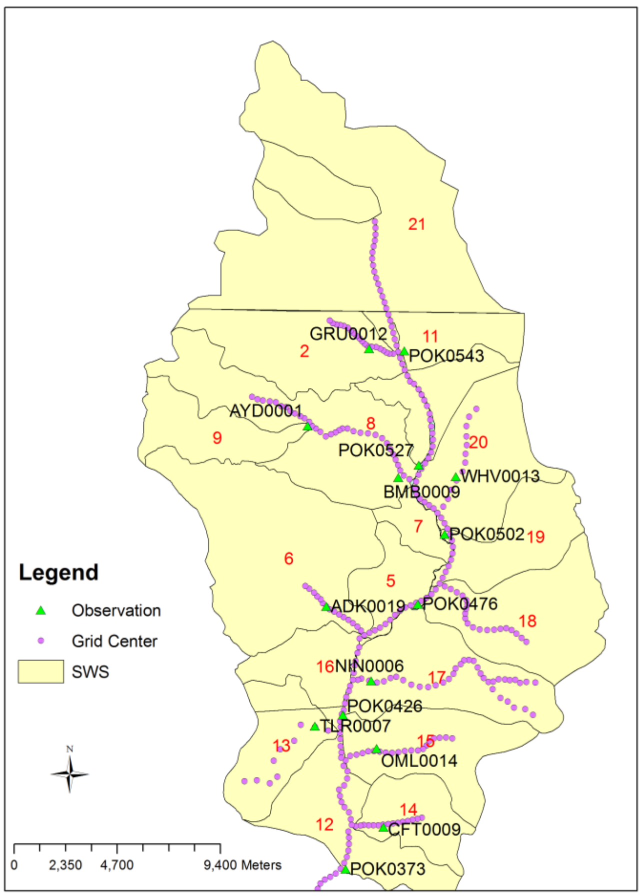

Figure A-1: A Map of Central Location of Model Grid

The EFDC water quality model has been integrated with a water column eutrophication component and a sediment diagenesis component (Park *et al*., 1995). The model is similar to the Chesapeake Bay eutrophication model. The integrated model simulates the spatial and temporal distributions of water quality state variables 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 is 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
- Organic Carbon (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
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

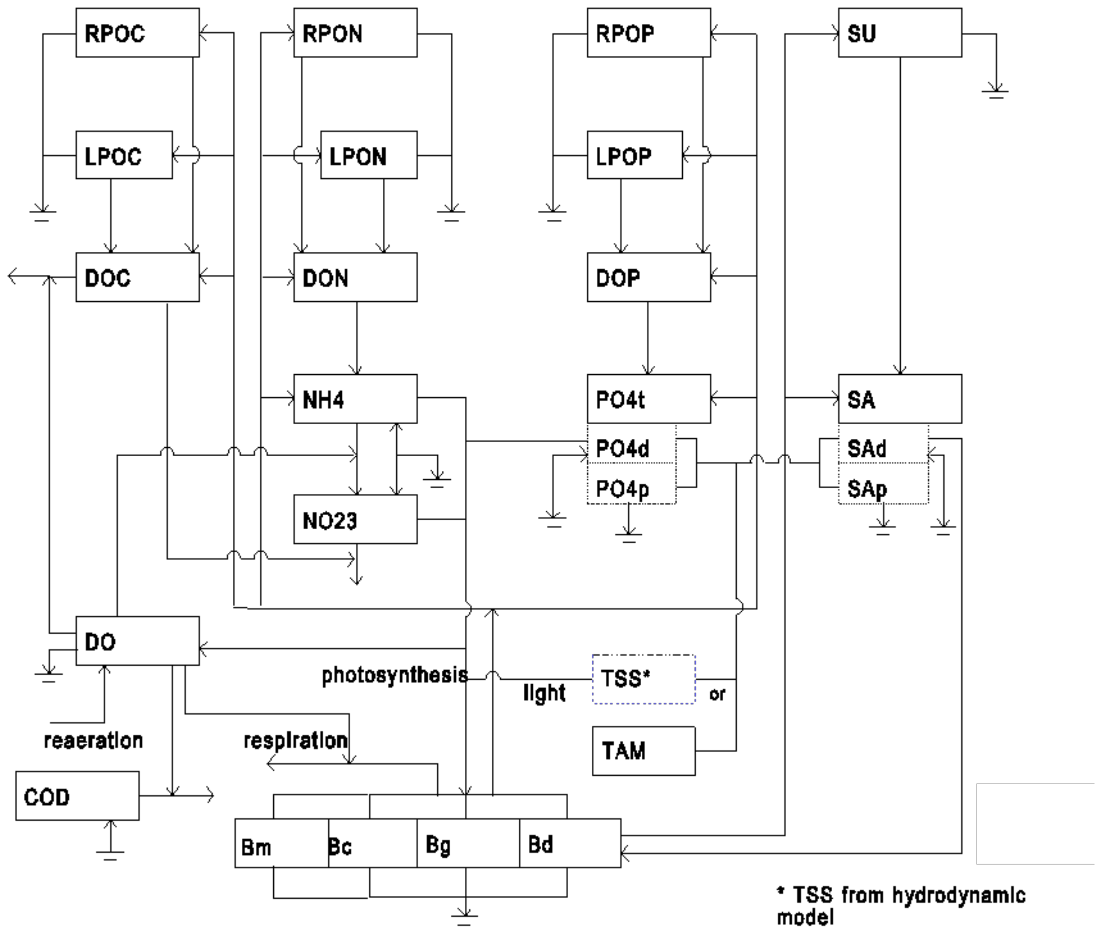

Figure A-2: Diagram of Water Quality Model State Variables.

Sediment diagenesis is a group of chemical processes in the 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.1.1.3 Watershed Loading and Model Linkage

The Chesapeake Bay Program Phase 5.3.2 watershed model outputs were used for the model inputs of flow, organic carbon, and nutrients loadings. P5.3.2 model has outputs in five segments in the UPR, one segment for the Delaware portion of the watershed, and four segments for the Maryland portion of the watershed. The watershed model provides daily loadings for flow, organic carbon (OC), organic phosphorus (OP), phosphate (PO_4), organic nitrogen (ON), ammonium (NH_3), and nitrate (NO_3) for each landuse type and point sources. There are a total of 31 landuse types. In order to obtain loadings for each tributary, the UPR watershed was segmented into 21 subwatersheds based on the Maryland 12-digit watershed segmentation (Figure A-1). The landuse area for each subwatershed was obtained using GIS tools based on GIS coverages of CBP 2010 landuse, land-river segment and MDE 8-digit and 12-digit watersheds. The Bay watershed model landuse types were regrouped into thirteen landuses for the purpose of computing loadings. The ratio of the landuse area of each 12-digit subwatershed and its corresponding Chesapeake Bay watershed model segment was computed. This ratio was used to obtain the loading for the 12-digit subwatershed landuse loading by multiplying the ratio of subwatershed landuse to the total daily loading of the Bay model outputs. The final flow and loadings for each 12-digit subwatershed was distributed to the tributary of the receiving water model.

A linkage between the Bay Program watershed model loadings and the EFDC model has been developed so that the daily freshwater discharges and loadings from the 12-digit watershed segmentation can be directly distributed and input into the receiving water model. All freshwater discharges and nonpoint source inputs were assigned to specific grid cells. A diagram of model linkage between watershed loadings and bottom sediment is shown in Figure A-3.

Table A-2: Landuse Category and Landuse Regroup

Landuse Category	CBP Model 2010 landuse Category	CBP Landuse Code
Water	water	Atdep
Pasture	nutrient management pasture	Npa
	pasture	Pas
	degraded riparian pasture	Trp
Crops	alfalfa	Alf
	hightill without manure	Hom
	hightill with manure	Hwm
	hay without nutrients	Hyo
	hay with nutrients	Hyw
	lowtill with manure	Lwm
	nutrient management alfalfa	Nal
	nutrient management hightill with manure	Nhi
	nutrient management hightill without manure	Nho
	nutrient management hay with nutrients	nhy
	nutrient management lowtill with manure	Nlo
Nursery	nursery	Urs
Forest	forest	For
Harvested Forest	harvested forest	Hvf
Regulated Urban	regulated impervious developed	Rid
	regulated pervious developed	Rpd
	regulated extractive	Rex
	regulated construction	Rcn
Unregulated Urban	nonregulated impervious developed	Nid
	nonregulated pervious developed	Npd

Landuse Category	CBP Model 2010 landuse Category	CBP Landuse Code
	nonregulated extractive	Nex
AFO	animal feeding operations	Afo
CAFO	concentrated animal feeding operations	Cfo
Septic	septic	Septic
CSO	cso	Cso
Point Source	Industrial Discharge	Indus
	Municipal-WWTP	Wwtp

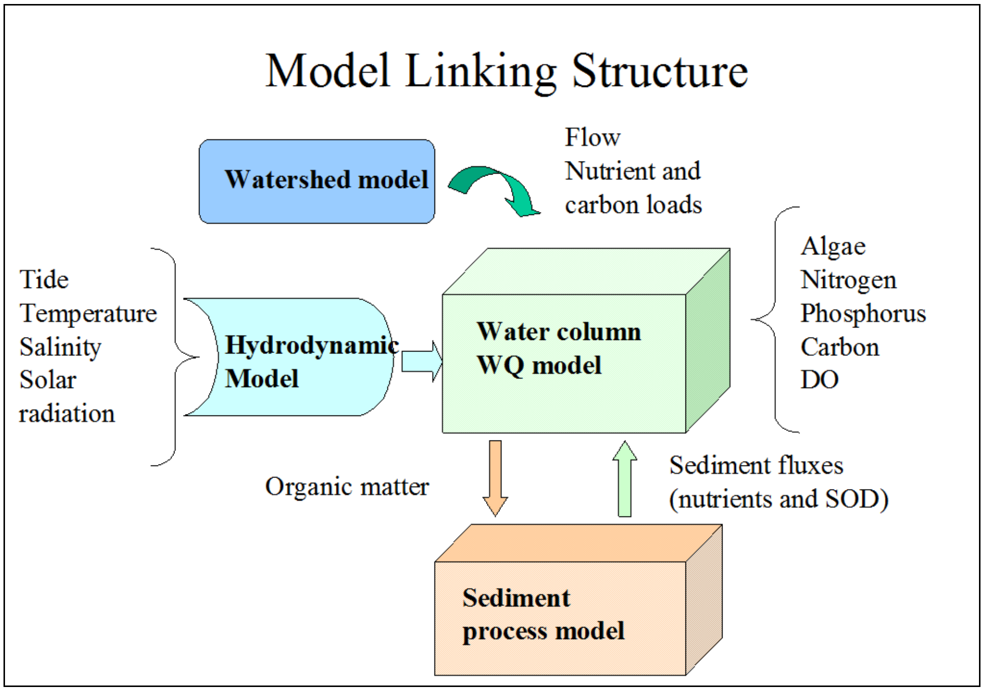

Figure A-3: Diagram of Model Linking Structure

A.1.2 Model Calibration and Verification

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 and bottom sediment. 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 the simulation of the eutrophication process and DO dynamics in the UPR are the nutrients and carbon loads from the watershed delivered via surface runoff or groundwater.

Loading Estimation

By examining the observations obtained from the tributaries in 2010, it can be seen that there is great variability for the state variables. Algae blooms occurred in both spring and fall at Stations GRU0012 and NIN0006, while either spring or fall algal bloom occurred at other tributary stations. Algal concentration in the main channel is lower than 5 ug/L. More intensive observations of 2005 were available, but observations are only available in the main channel. Therefore the observations in 2010 were selected for the model calibration so that model can be better calibrated for both main channel and tributaries. However, the Bay Program simulated nonpoint source loading is only available until 2005. Therefore, the statistical method was used to obtain nonpoint source loading for 2010. A regression of 10-year flow of Bay model simulations against the USGS observations at USGS Station 01485000 was conducted using data from 1991 to 2000. Regressions for loadings of OC, OP, PO_4, ON, NH_3, and NO_3 at each 12-digit watershed were conducted to obtain loadings with respect to flow for the same 10-year periods. Different regression methods were tested starting with a linear function, a logarithmic function, a power function, and multiple variable regressions including periodical functions. Test runs showed that using either logarithmic or power functions between flow and loading can have satisfactory results. High correlations were achieved, indicating that loading obtained using regression methods is statistically sound. Flow of 2010 at each 12-digit watershed were obtained based on USGS station 2010 data using flow regression equations obtained from 10-year data analysis. The linear regression was used for the flow between each subwatershed and USGS flow stations. The resulting 2010 flow of each subwatershed was used to obtain loadings for that watershed using regressions results between flow and loadings. Selected flow regression results are shown in Figure A-4. Example of selected loading regression results of OC, PO_4, NH_3 are shown in Figures A-5 to A-7.

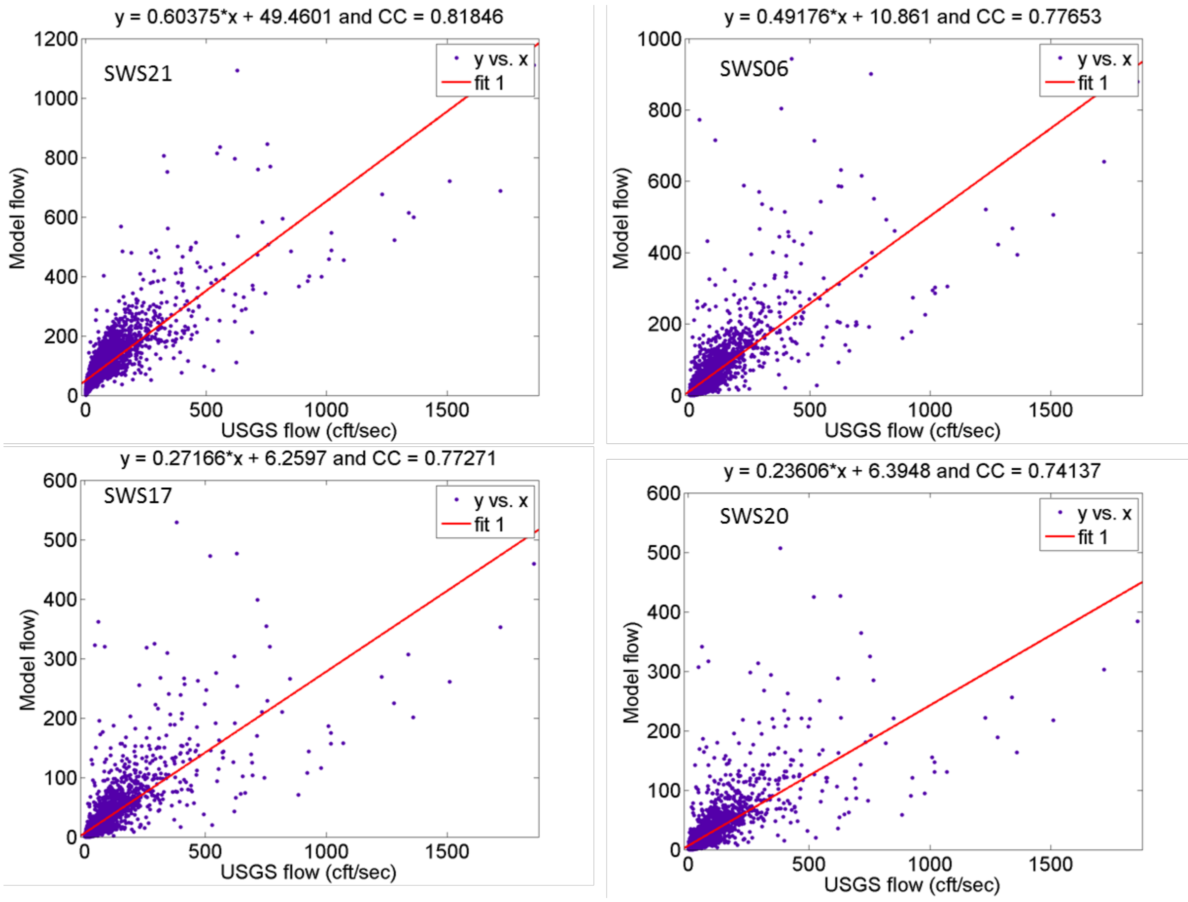

Figure A-4. Regression Results for Flow

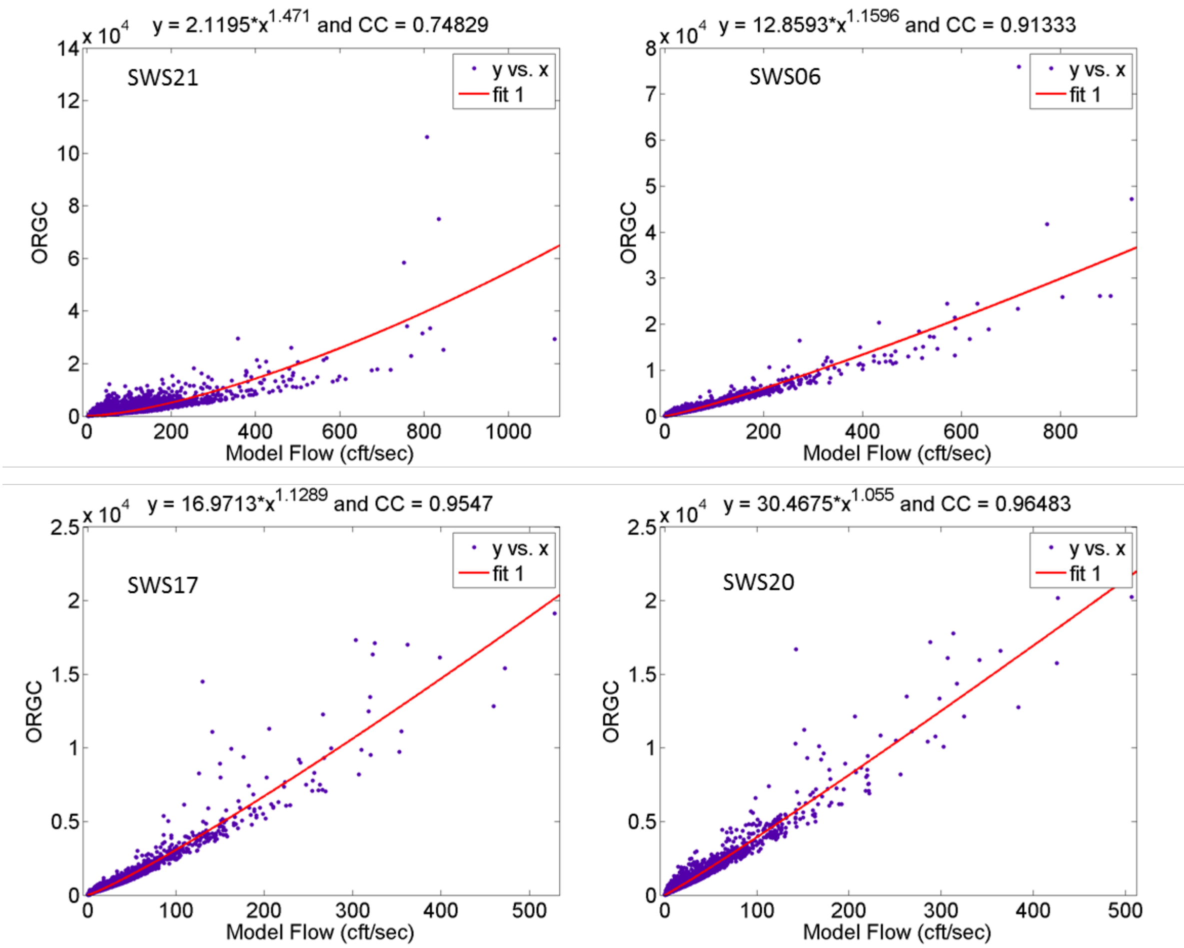

Figure A-5. Regression Results for Organic Carbon.

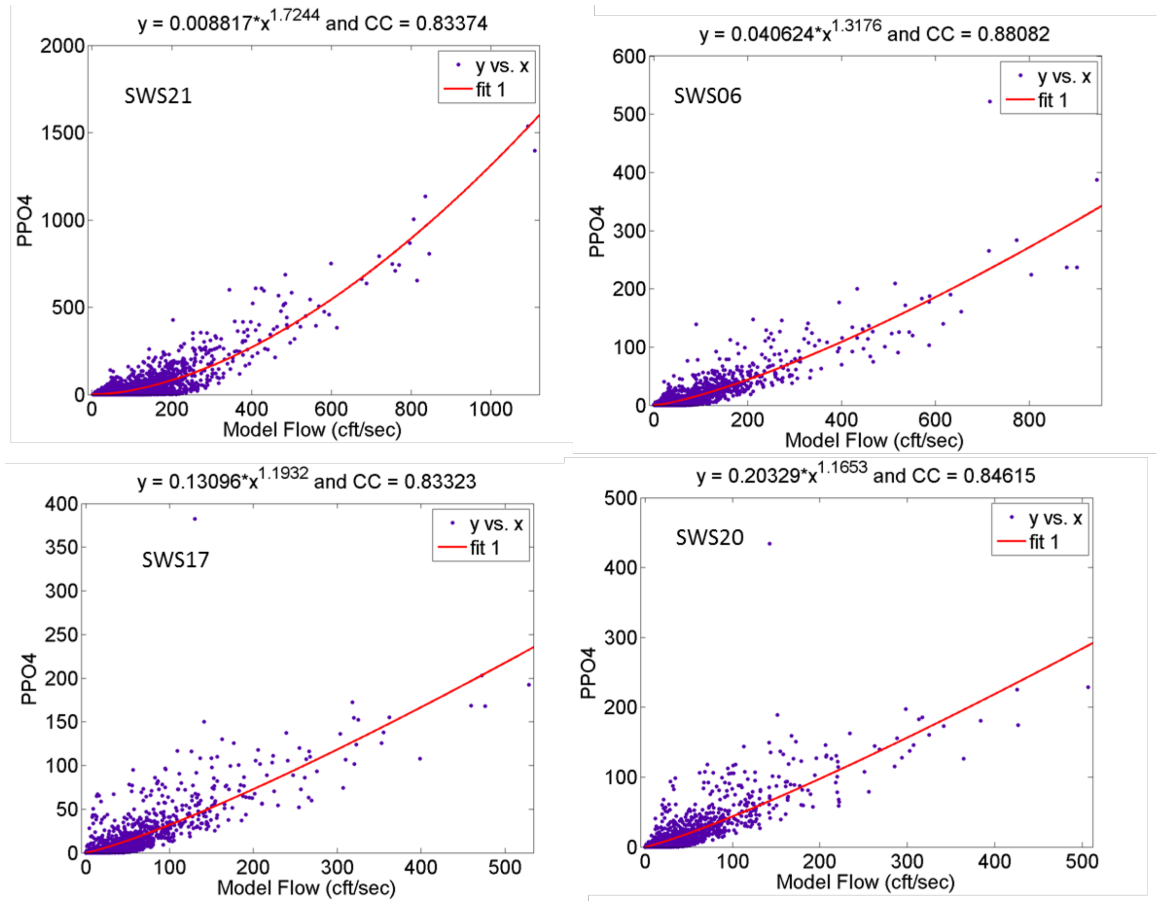

Figure A-6. Regression Results for PO_4.

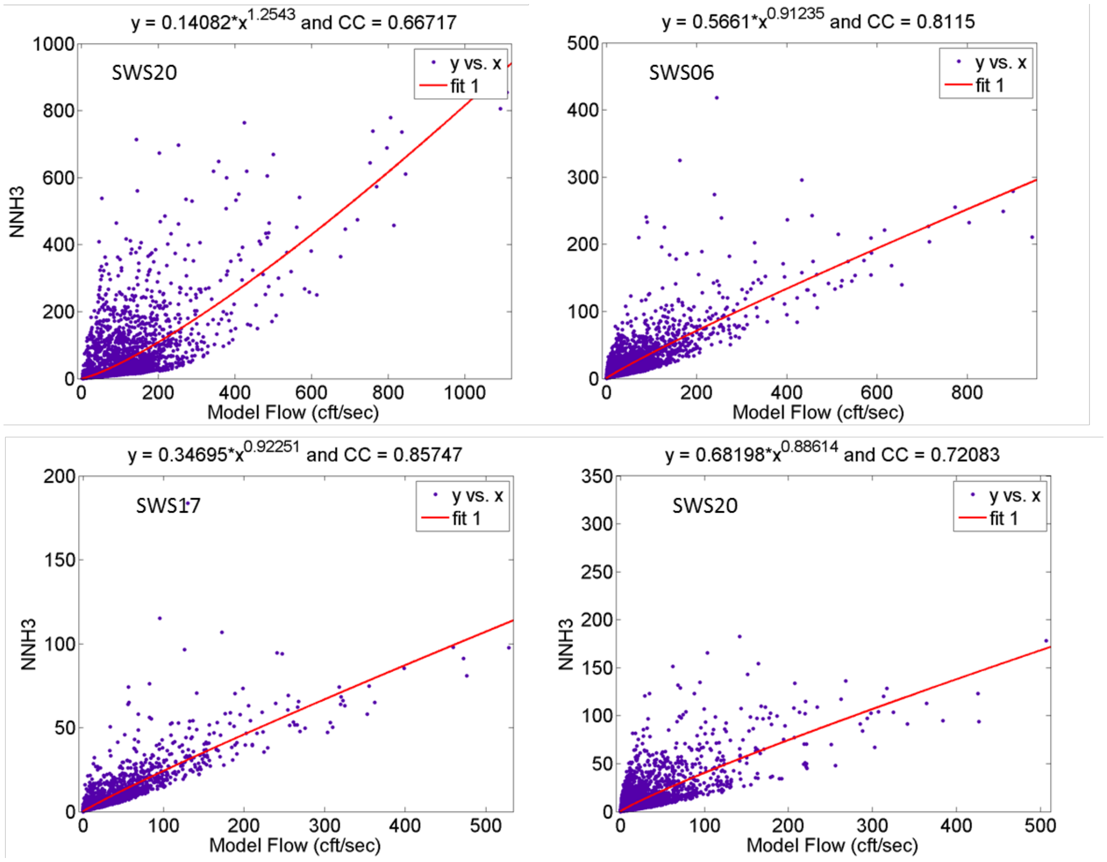

Figure A-7. Regression Results for NO_3.

For the Chesapeake Bay watershed model, a large portion of organic carbon is from algae (~49%). As the Bay watershed model only simulated 5 large sub-watersheds for the Upper Pocomoke River, the algae simulation is a representative of total algae throughout the entire watershed. As only a portion of streams in the watershed are simulated by the current 3-D water quality model and the Pocomoke mainsteam does not have enough light to support algal growth, a fraction of organic carbon generated by the Bay watershed model due to algal production should be removed. It is reasonable to assume that 25% of organic carbon generated by the Bay model is simulated by the current model, which should be removed, while the rest of the organic carbon was generated in watershed and streams that are not considered in the current model. By converting 25% loading of organic carbon to algae biomass, the mean algae Chla concentration is within the range of observations in the tributaries. Therefore, 25% of the organic carbon from Bay watershed model is removed from the watershed loading before input to the current 3D water quality model for all the model simulations.

<u>Model Calibration</u>

Using loadings obtained from the regression method, the model was run for 2010. The initial sediment condition was generated based on 3-year simulations using 1996-1998 Bay Program P5.3.2 model loading data. The selected period included wet, dry, and mean flow years. The model was run cyclically to attain a dynamic equilibrium condition. It is noted that the high deposition accumulated in the bottom sediment during the spring time was gradually used up during the summer and fall. Over a 3-year period, the bottom deposition nutrients and carbon can reach equilibrium, which can be used for the model initial condition. 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 and different values were used for main channel and tributaries based on model calibration. 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. Based on the observations, both spring and fall algal bloom frequently occurred in the tributaries. Therefore, two algae species, green algae and cyanobacteria were used for the model simulations to represent algae species in the Upper Pocomoke River. The key parameters of growth, respiration, mortality rates, and settling rates were calibrated for the model. The growth, respiration, and mortality rates are 2 -5.0, 0.05, and 0.01-0.03 per day, respectively. Model calibrations for each station are shown in Figures A-8 to A-20. In general, model results agree well for most of the state variables. Modeled DO concentrations agree well with observations. Nutrients and carbon predictions are close to the mean values. Because a regression method was used to obtain loading based on a 10-year regression, it is closest to the mean loadings. Algal concentration in the channel is relatively high compared with observations, but the overall algae concentration in the main channel is low. Overall, the model results are reliable.

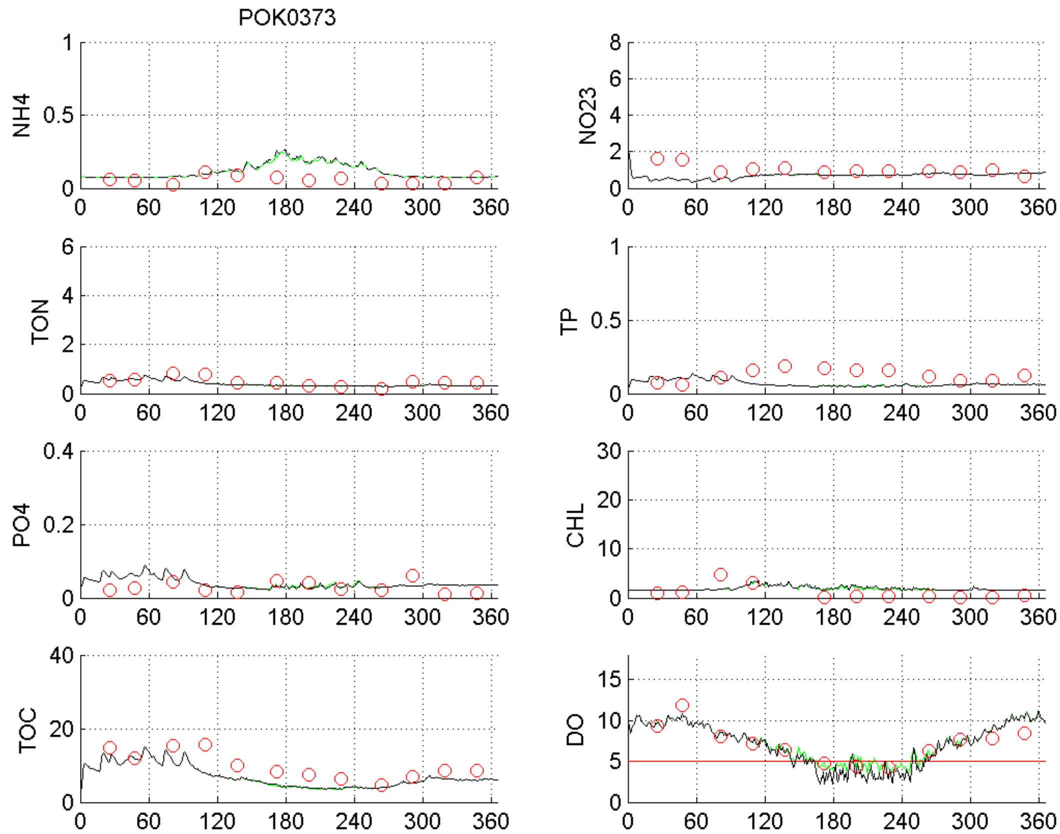

Figure A-8. Predictions versus observations for a suite of variables at Station POK0373 in 2010(Black lines are model simulation at bottom and green lines are near the surface, circles are observations)**.**

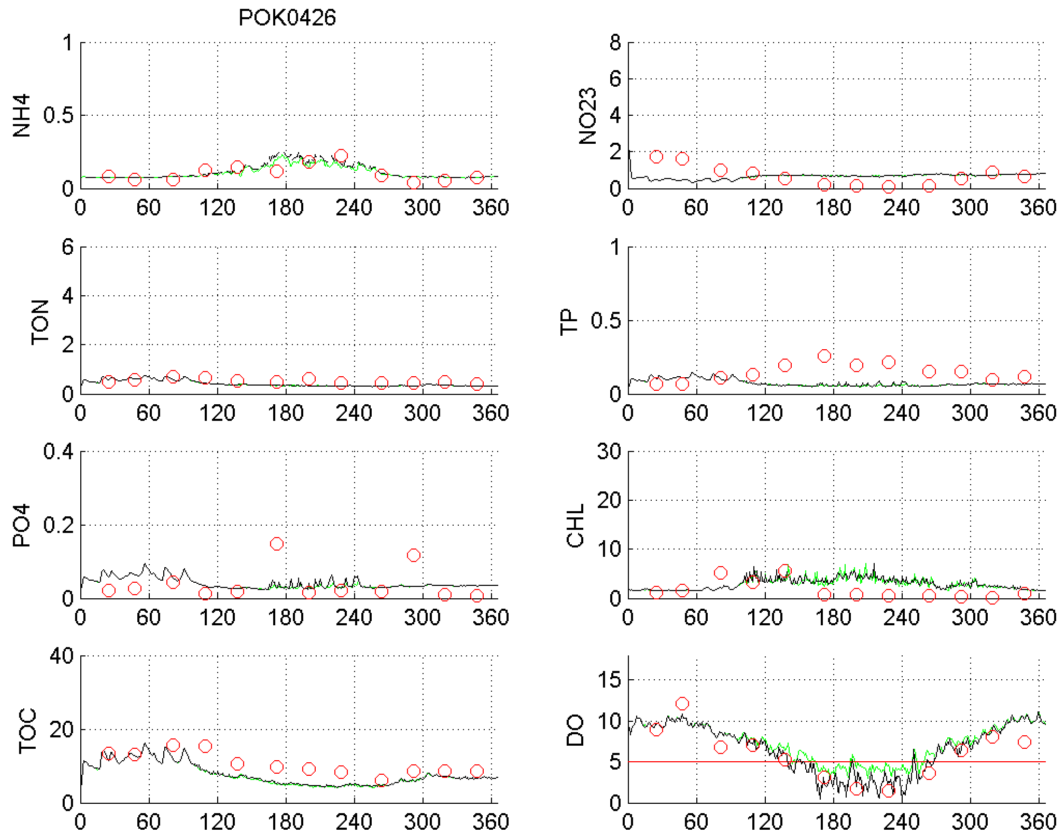

Figure A-9. Predictions versus observations for a suite of variables at Station POK0426 in 2010.

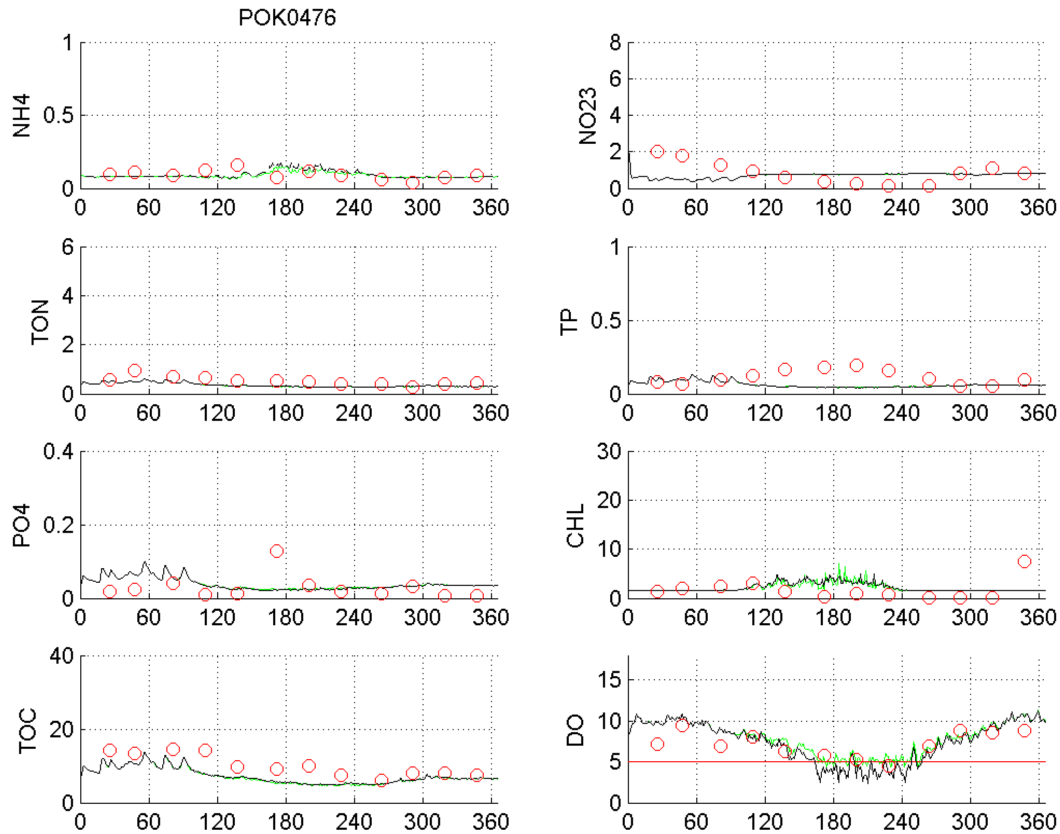

Figure A-10. Predictions versus observations for a suite of variables at Station POK0476 in 2010.

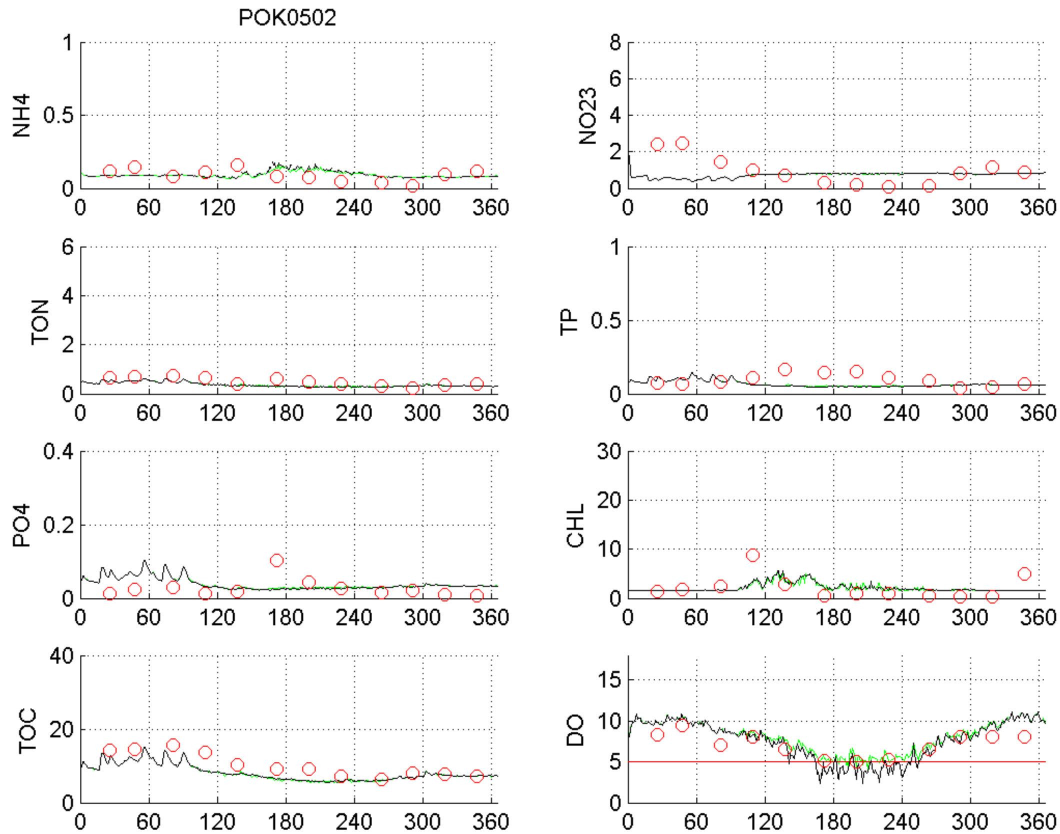

Figure A-11. Predictions versus observations for a suite of variables at Station POK0502 in 2010.

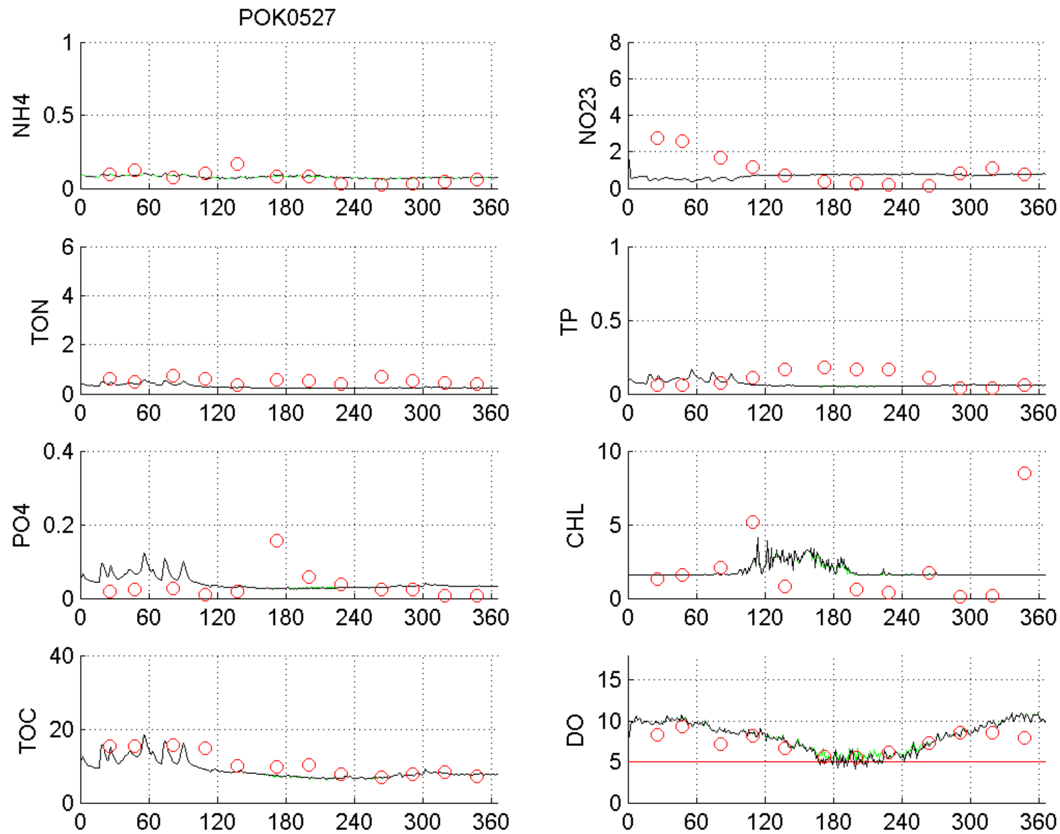

Figure A-12. Predictions versus observations for a suite of variables at Station POK0527 in 2010.

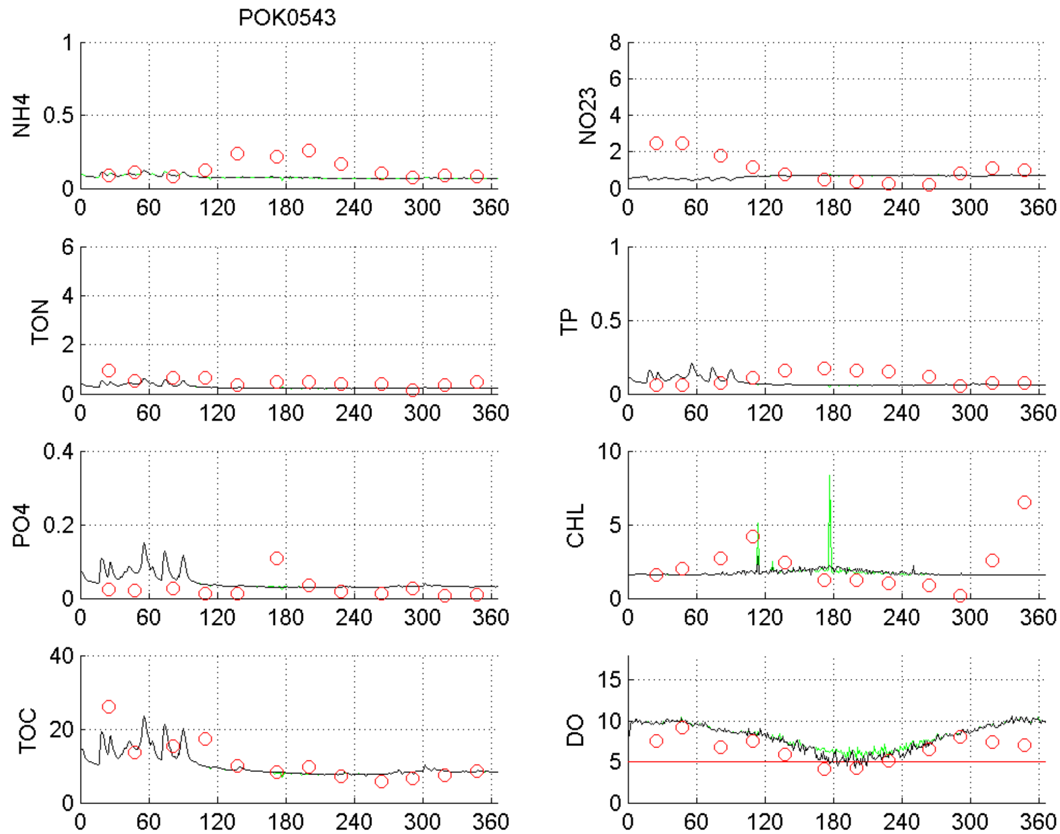

Figure A-13. Predictions versus observations for a suite of variables at Station POK0543 in 2010.

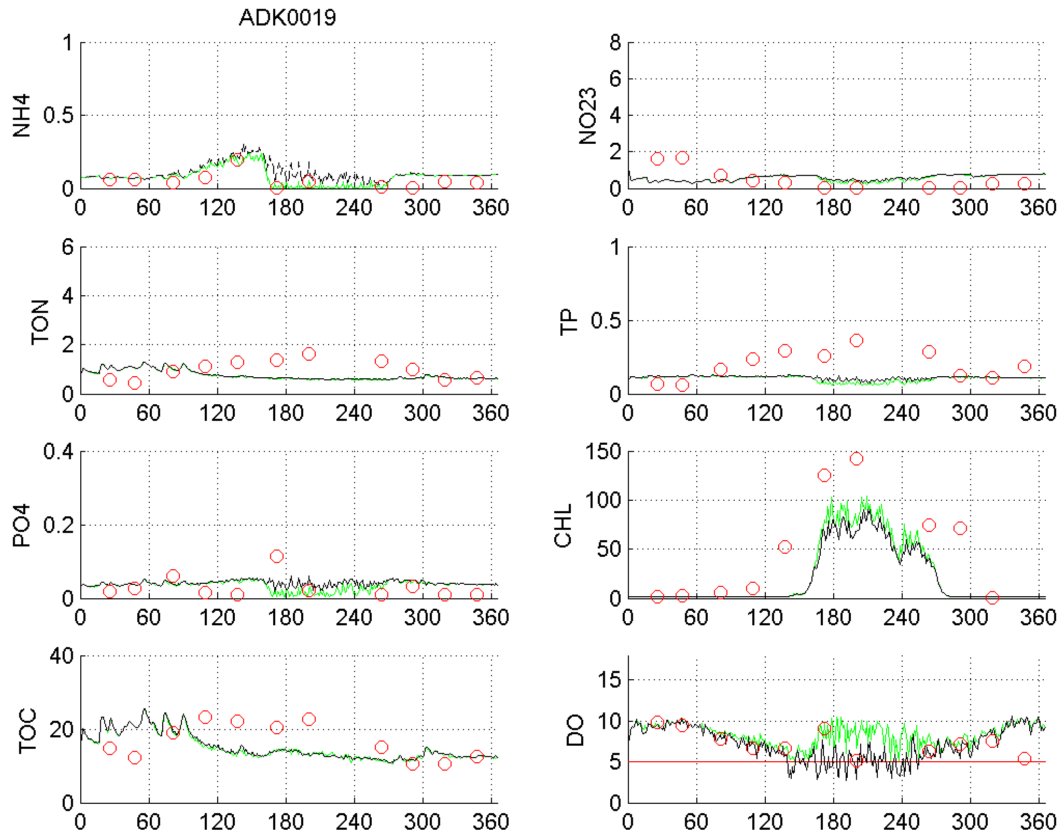

Figure A-14. Predictions versus observations for a suite of variables at Station ADK0019 in 2010.

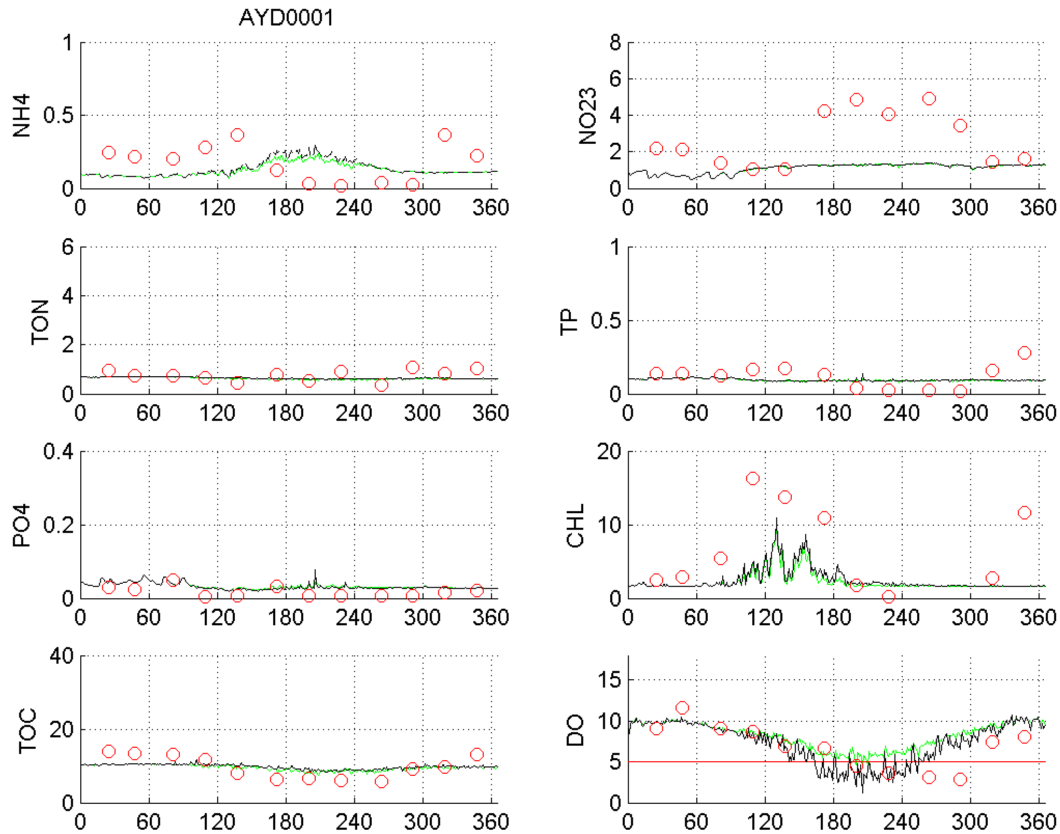

Figure A-15. Predictions versus observations for a suite of variables at Station AYD0001 in 2010.

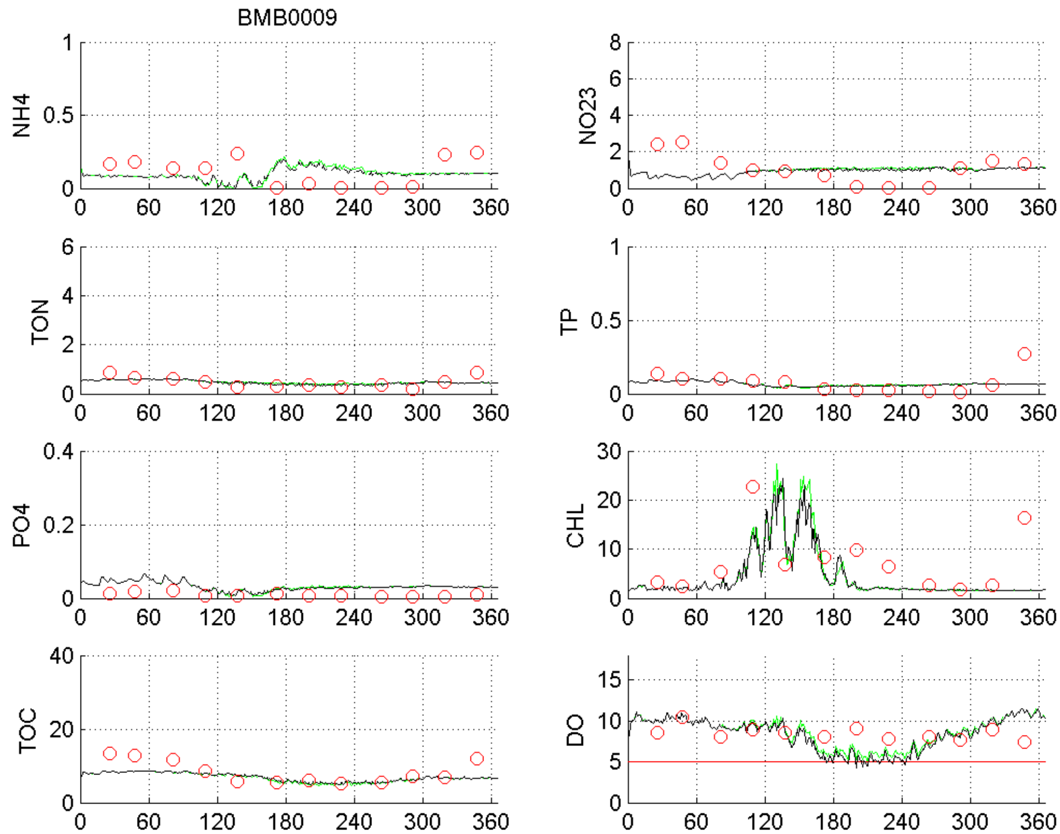

Figure A-16. Predictions versus observations for a suite of variables at Station BMB0009 in 2010.

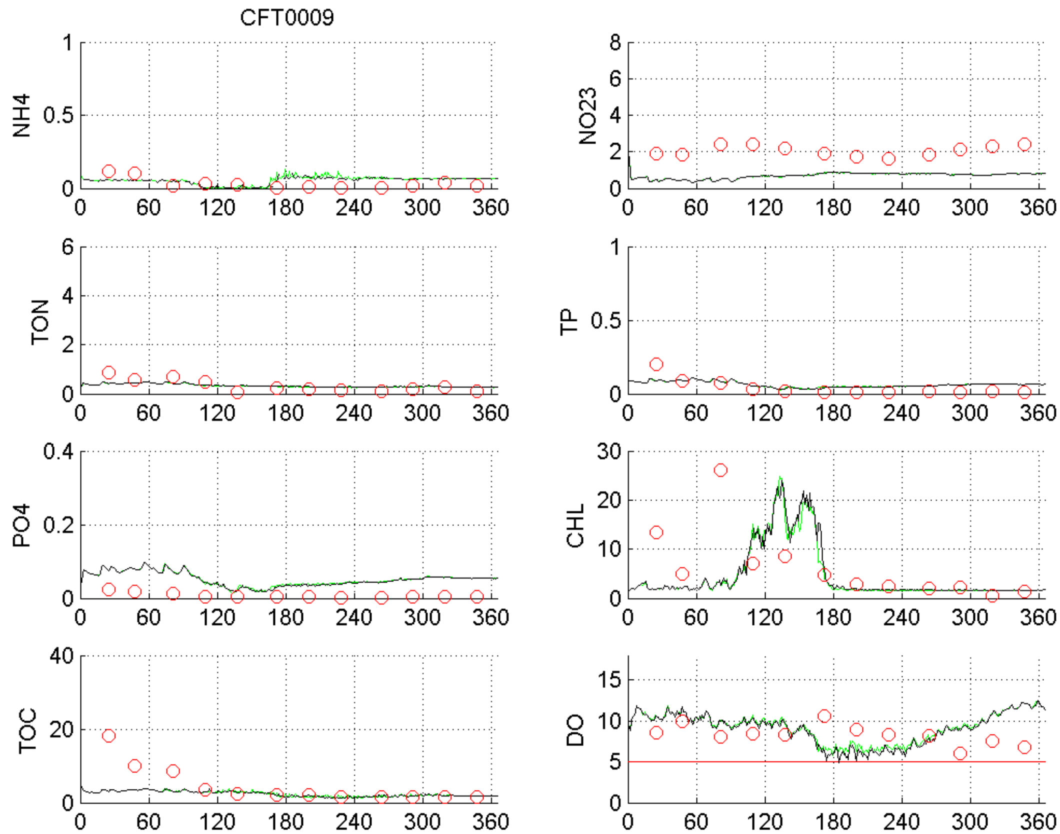

Figure A-17. Predictions versus observations for a suite of variables at Station CFT0009 in 2010.

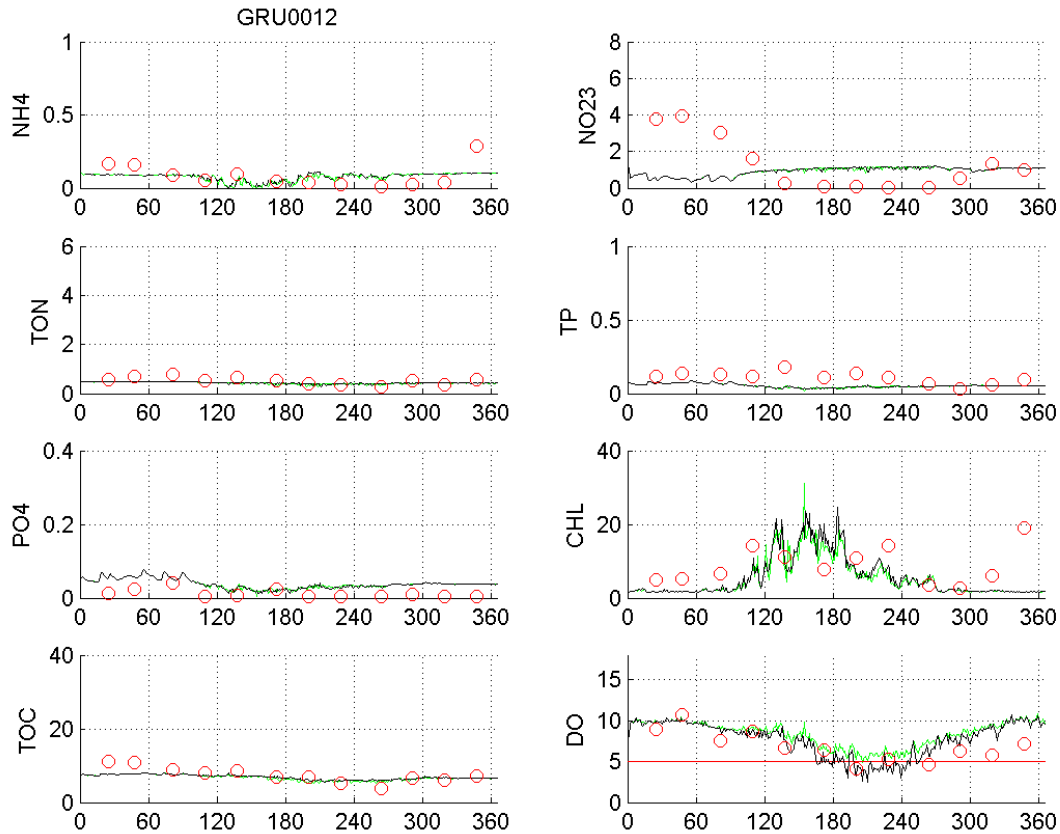

Figure A-18. Predictions versus observations for a suite of variables at Station GRU0012 in 2010.

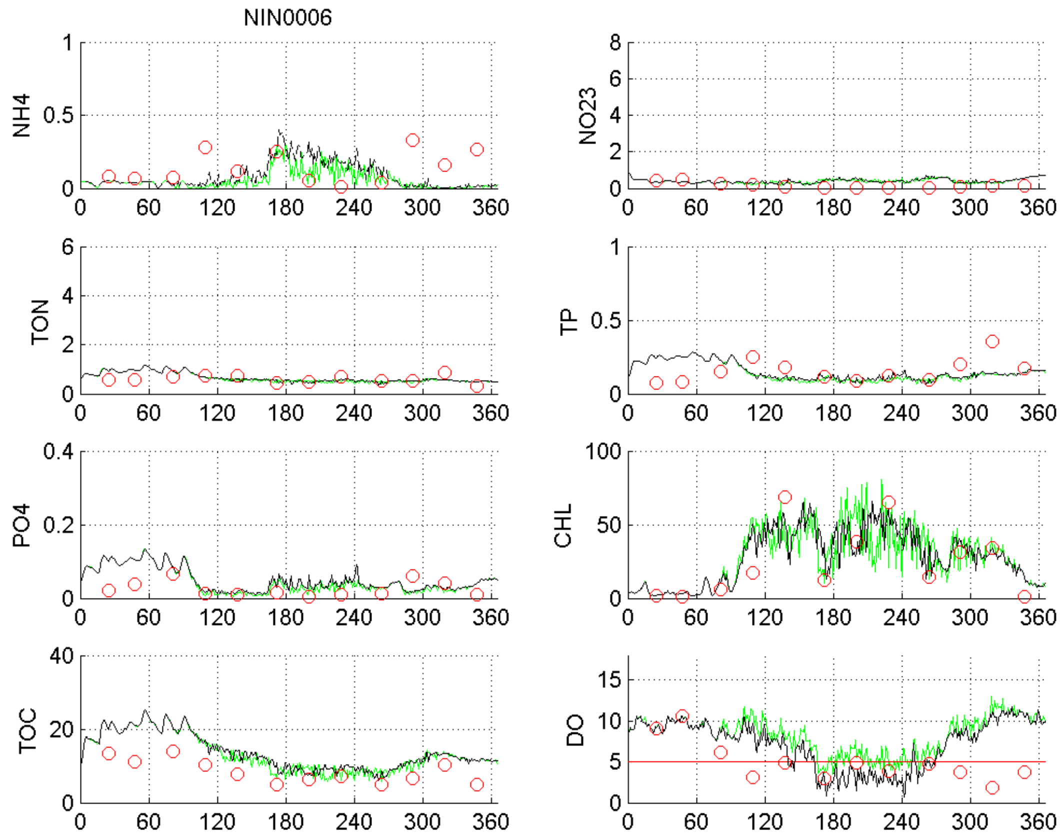

Figure A-19. Predictions versus observations for a suite of variables at Station NIN0006 in 2010.

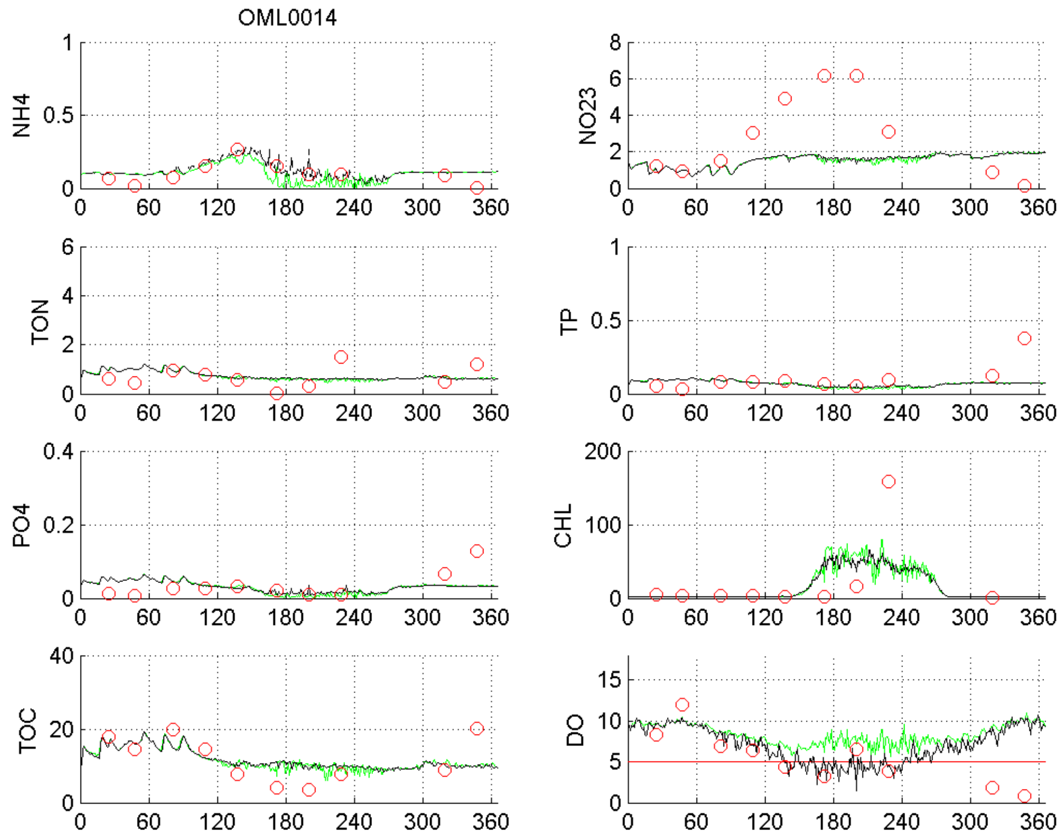

Figure A-20. Predictions versus observations for a suite of variables at Station OML0014 in 2010.

Model Verification

Model verification was conducted using 2005 observations. The Chesapeake Bay P5.3.2 watershed model output was used for the verification. All the kinetic parameters derived from model calibration were used for model verification. The results will demonstrate the robustness of the model performance and ensure the calibrated model is capable for long-term simulations Verification results at Stations POK0543, POK0527, and POK0426 are shown in Figures A-21 through A-25. It can be seen that the model simulation for DO is satisfactory and it can be used for TMDL development.

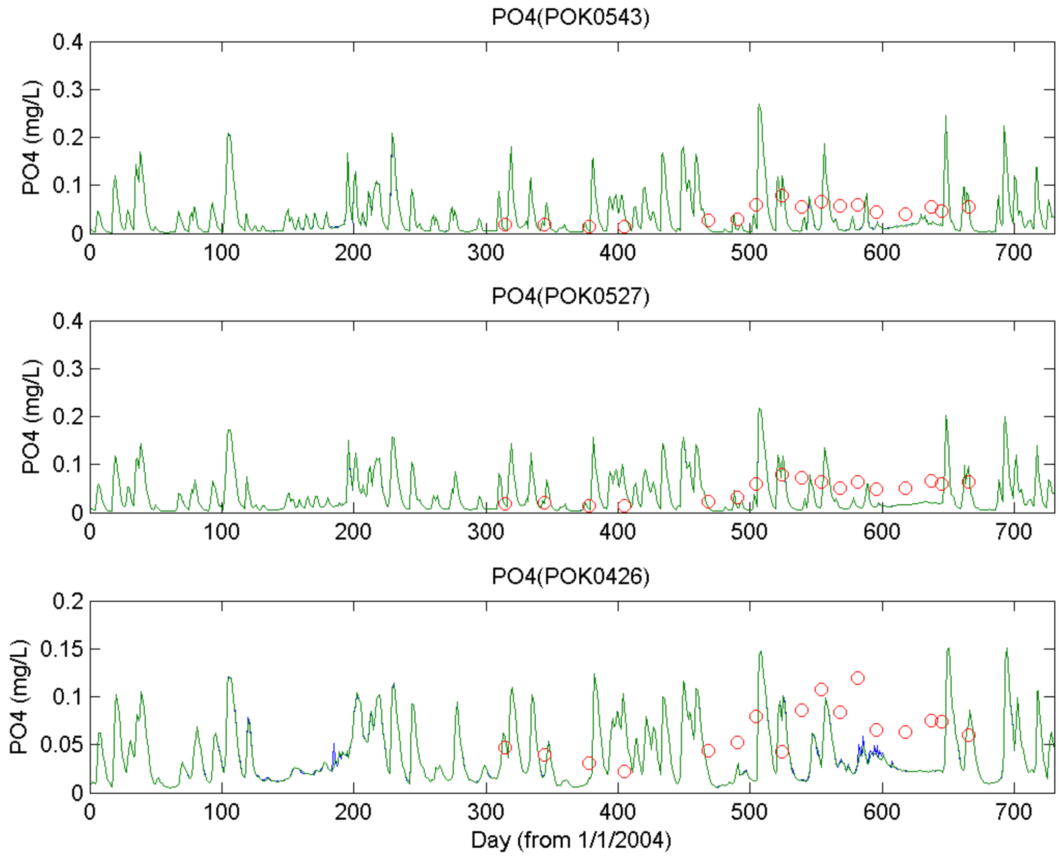

Figure A-21. Predictions versus observations for PO4 at Stations POK0543, POK0527, and POK0426 in 2005 (Green lines are model results near surface and blue lines are near bottom Circles are observations)**.**

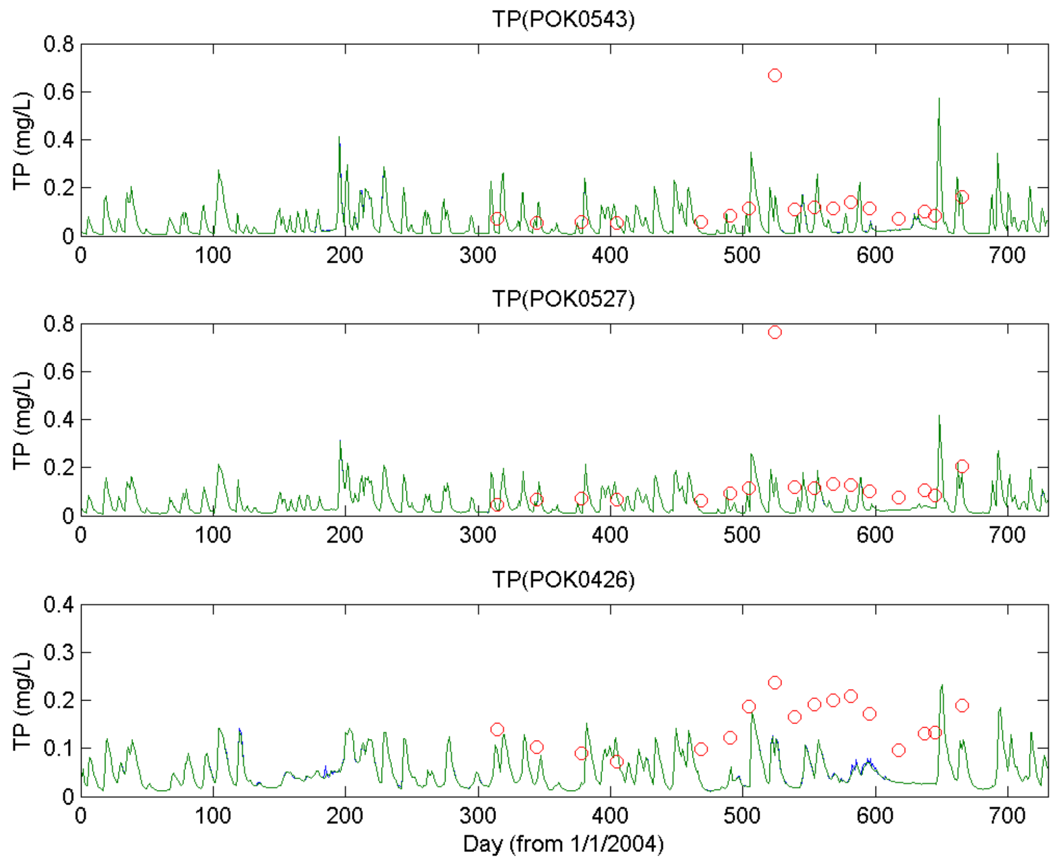

Figure A-22. Predictions versus observations for TP at Stations POK0543, POK0527, and POK0426 in 2005.

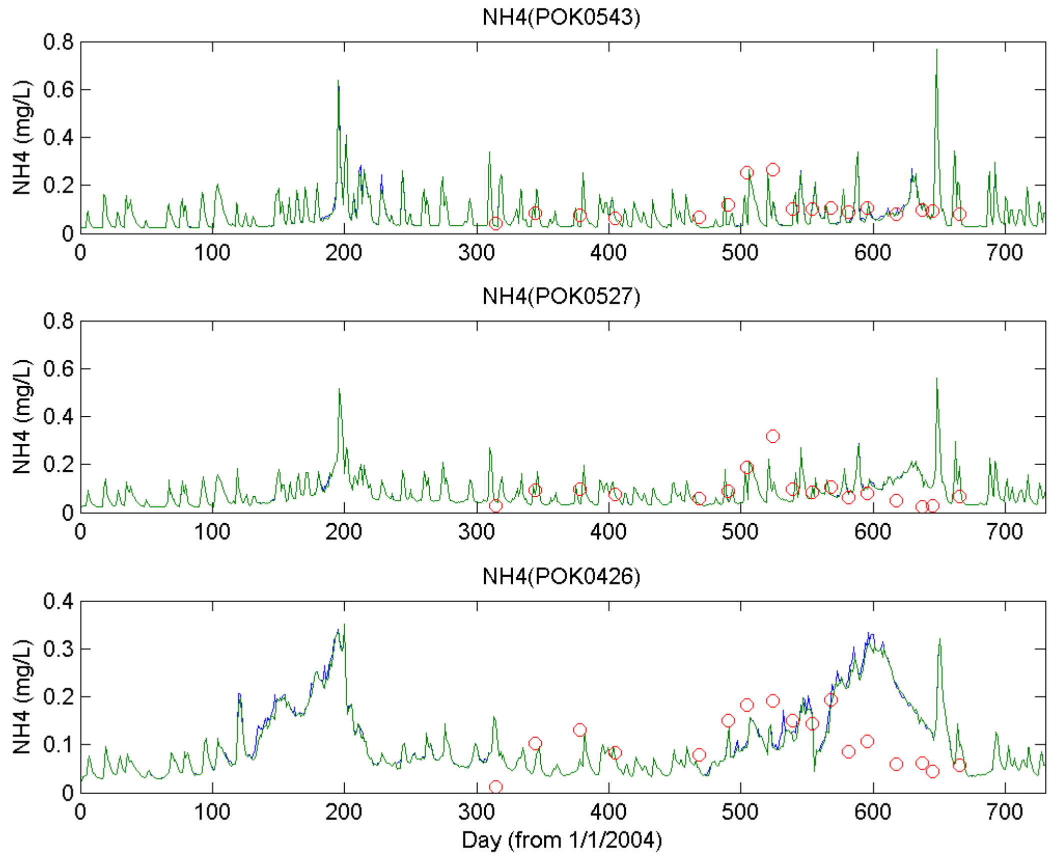

Figure A-23. Predictions versus observations for NH4 at Stations POK0543, POK0527, and POK0426 in 2005.

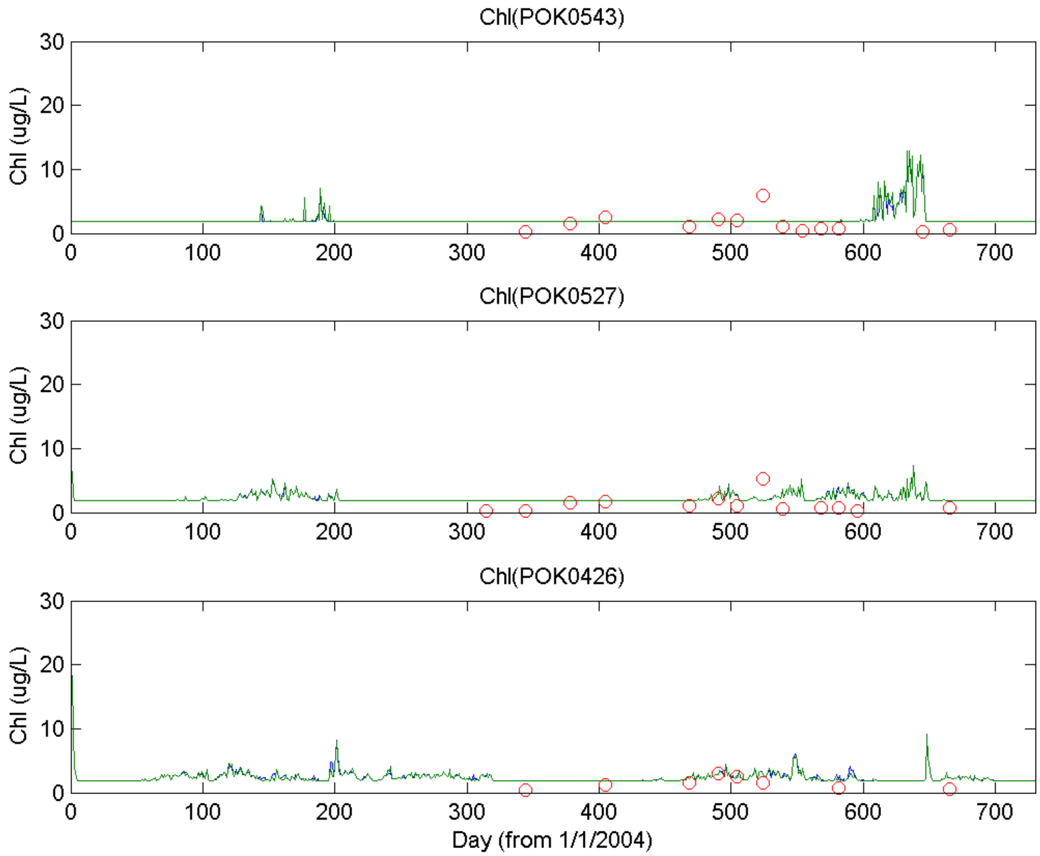

Figure A-24. Predictions versus observations for Chl at Stations POK0543, POK0527, and POK0426 in 2005.

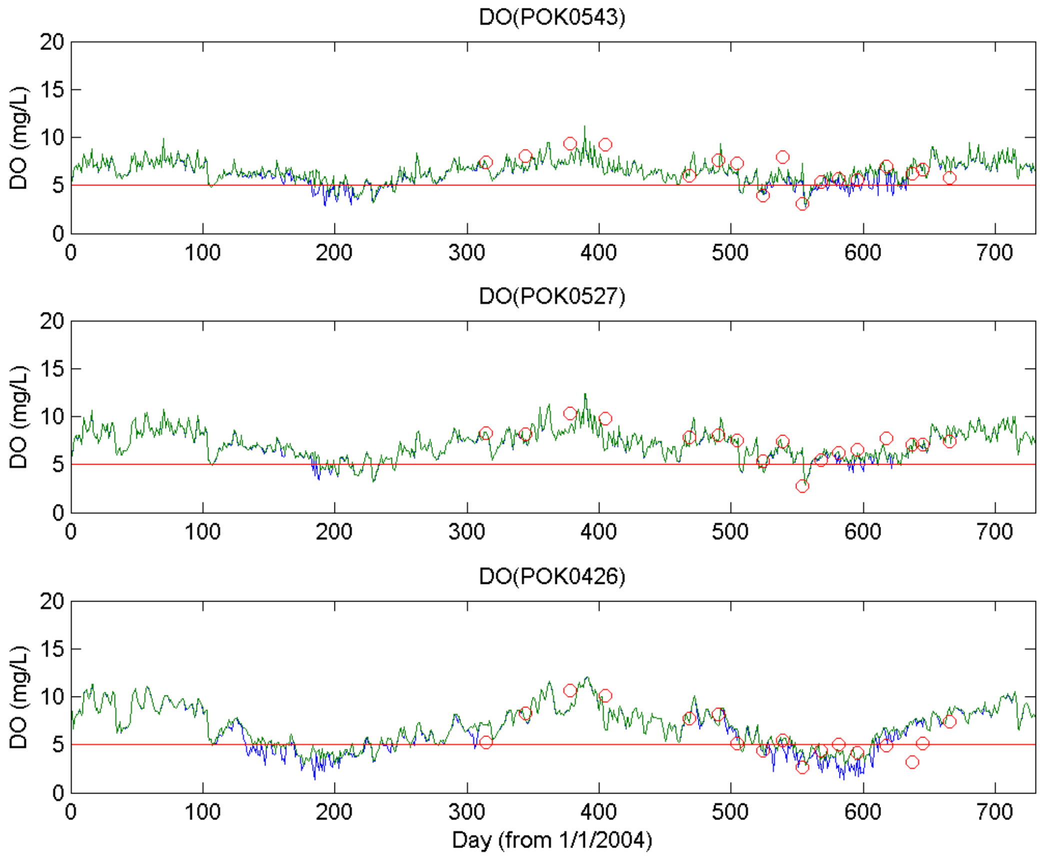

Figure A-25. Predictions versus observations for DO at Stations POK0543, POK0527, and POK0426 in 2005.

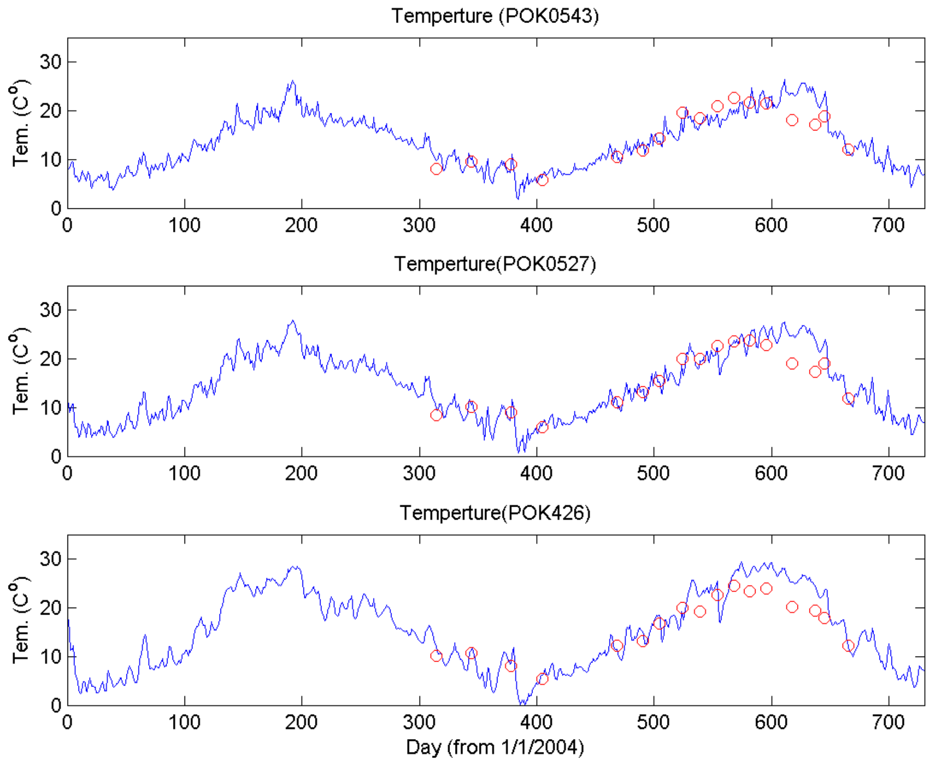

Figure A-26. Predictions versus observations for Temperature at Stations POK0543, POK0527, and POK0426 in 2005 (Blue lines are model results near surface and circles are observations).

A2. TMDL Development

The TMDL scenario represents the maximum allowable phosphorus loads whereby there will be no phosphorus related impacts affecting aquatic health. In the TMDL calculation, the allowable load for the impaired watershed is calculated so as to reduce the baseline loads to a level until model simulated DO meet the DO criterion for the entire model domain of this study.

The cause of low DO in the stream is contributed by both high organic carbon outputs from the watershed and from the deposition of algae that fix carbon in the streams. Observations show that large amounts of organic carbon are transported from the watershed to the downstream waters, while algae concentration is very low. Figure A-27 shows the plot of TOC and Chla concentration. It can be seen that there is a poor correlation between total organic carbon (TOC) and chlorophyll *a* (Chla) concentration. TOC concentration can be very high, while Chla concentration is below 20 ug/L. On the other hand, there is a good correlation between OC and TDP in the streams (Figure A-27). Algal biomass in streams is principally constrained by light limitation due to shading by the riparian canopy (VWRRC, 2006). Algal biomass is expected to be poorly correlated with stream nutrient concentrations in some streams because light limitation is the principal determinant of production. Another factor affecting algal growth is the transport time (Lucas et al., 2009). If algal growth rate is lower than transport rate, low algal biomass can be expected. Stream responses to nutrient enrichment will depend upon the co-occurrence of canopy disturbance and flow condition. The contribution of organic carbon from watershed is highly correlated to nutrient enrichment. Figure A-28 shows the correlation of organic carbon and phosphorus loadings from the Bay watershed model. It can be seen that there is a high correlation between OC and TP (r^2 =0.82). Therefore, it was assumed that OC loading from the watershed was also reduced by the phosphorus reduction percentage when developing TMDLs. This is consistent with previous Delaware TMDLs in the same region. For nutrient TMDL development in the Delaware portion of the Upper Pocomoke, the QUAL2K model was used. As part of each scenario modeled, prescribed sediment oxygen demand (SOD) was also reduced by the average nutrient reduction percent (DNREC, 2005), which accounted for the reduction of OC from the watershed as nutrients are removed.

Phosphorus TMDLs for waters upstream of the Maryland 8-digital watershed have been developed by the Delaware Department of Natural Resources and Environmental Control and approved by EPA (DNREC, 2005) and a Maryland TMDL for sediments and phosphorus for the Adkins Pond impoundment was approved by EPA in 2002. These established phosphorus TMDLs were applied to the current TMDL scenario for the upstream Delaware portion and for Adkins Pond sub-watershed. For the remainder of the watershed, an equal amount of phosphorus reduction was applied to each sub-watershed for the model simulations for TMDL development.

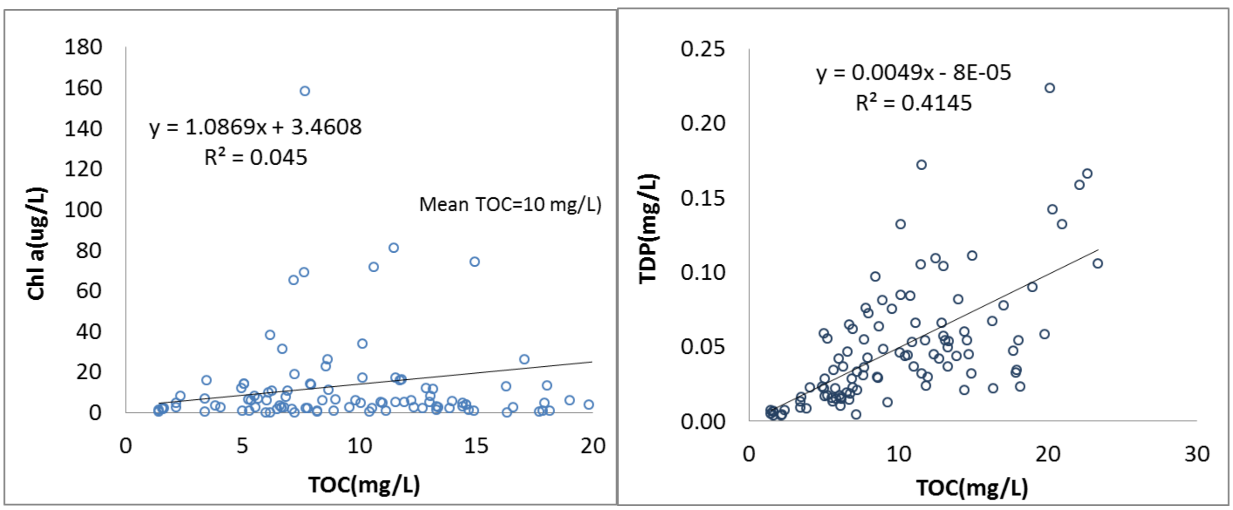

Figure A-27. Correlation between observed TOC and Chl a and TOC and TDP in the tributaries in the Upper Pocomoke River.

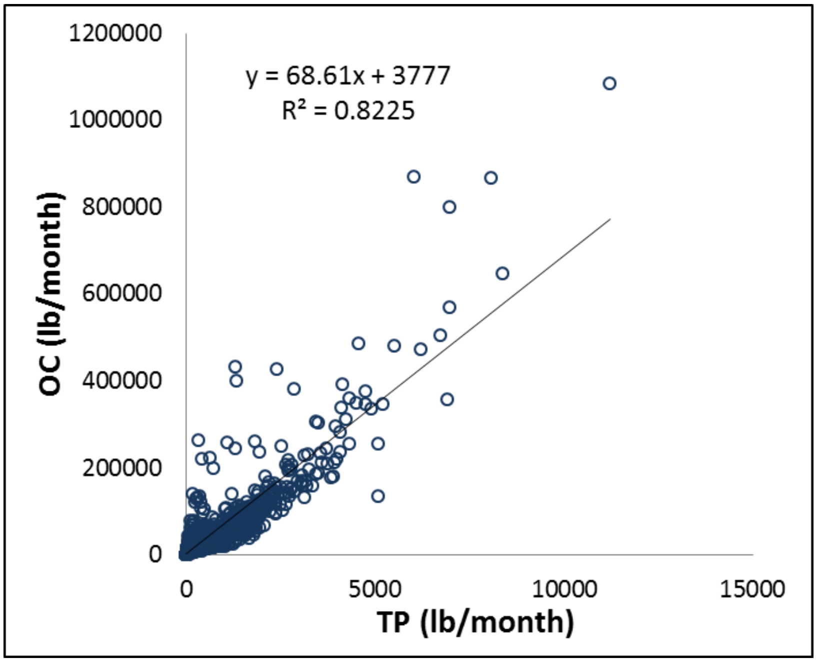

Figure A-28. Correlation between Monthly Loading of Organic Carbon and Total phosphorus.

Maryland's DO criterion for Use I waters requires a minimum DO concentration of 5.0 mg/l at any time (COMAR, 2012a). For this study, an allowance of up to 10% non-attainment for any 30-day period was applied to the current DO criterion. This is to account for environmental variability from extreme or unusual conditions. In addition, the models used to simulate water systems tend to have more uncertainties at extreme conditions. Therefore, a 30-day moving average of the percentage of non-attainment of 5mg/L is calculated for every cell of the model domain until no more than 10% of non-attainment for any 30-day period is achieved. The resulting load is considered the maximum allowable load that the waterbody can sustain without causing nutrient-related impacts to aquatic health. The model results are shown on Figures 29 to 42. The baseline loads chosen for this study is the 96-98 loading outputs from Chesapeake Bay Program P5.3.2 model 2010 progress scenario. P5.3.2 model 2010 progress scenario simulates 2010 land uses, BMP implementation, and point source loads over the hydrological period 1991-2000, which represents the current condition of the watershed. By reducing phosphorus loads, OC loadings decrease as a result of lower phosphorus levels in the watershed. Algal blooms in the tributaries will be reduced, which will result in a further reduction of OC output to the main channel in the Upper Pocomoke River where low DO persists during the summer season. Consequently, DO consumption in the water column and in the bottom sediment will decrease and DO conditions will be improved. The model simulation suggests that, by reducing phosphorus by 25%, DO attainment can be met for the entire model domain. Percentage reduction for each source and total reduction are listed in Tables A-3 and A-4.

Table A-3: MD 8-digit Upper Pocomoke River TMDL Phosphorus TMDL by Source

	Baseline Load Source Categories		Baseline Load (lbs/yr)	TMDL Components	TMDL (lbs/yr)	Reduction (%)
Upper Pocomoke River Contribution	Nonpoint Source	Forest	2,935	LA	2,935	0%
		AFOs	126		91	28%
		Pasture	2,231		1,607	28%
		Crop	35,247		25,378	28%
		Nursery	4,760		3,427	28%
		Septic	0		0	0%
		Non-Regulated Urban	2,766		1,991	28%
		Atmospheric Deposition	66		66	0%
		Sub-total	**48,130**		**35,494**	26%
	Point Source	CAFOs	6,027	WLA	4,339	28%
		Regulated Urban	15		11	28%
		WWT	991		1,552	-57**%
		CSO	0		0	0%
		Sub-total	**7,033**		**5,902**	16%
	Total MD 8-digit		**55,163**		**41,396**	25.0%
Upstream	**Delaware***		**20,105***	**Upstream**	**2,227***	**NA**

*DE's TMDL are based on Delaware existing phosphorus TMDL's daily load time 365 (DNREC, 2005) and baseline load is from CBP P5.3.2 model output. Therefore, the reduction is not applicable.

** The phosphorus WLA for process waters are larger than the baseline load because WLAs for the municipal facilities were calculated using their design flows, which are the maximum flow capacities these facilities could discharge. This is represented by the negative reduction.

Table A-4: Upper Pocomoke River Watershed TMDL for Phosphorus

	Baseline Load (lbs/Yr)	TMDL Scenario Load (lbs/yr)	Reduction (%)
DE*	20,105*	2,227*	NA
MD 8-digit	55,163	41,396	25%

*DE's TMDL are based on Delaware existing phosphorus TMDL's daily load time 365 (DNREC, 2005) and baseline load is from CBP P5.3.2 model output. Therefore, the reduction is not applicable.

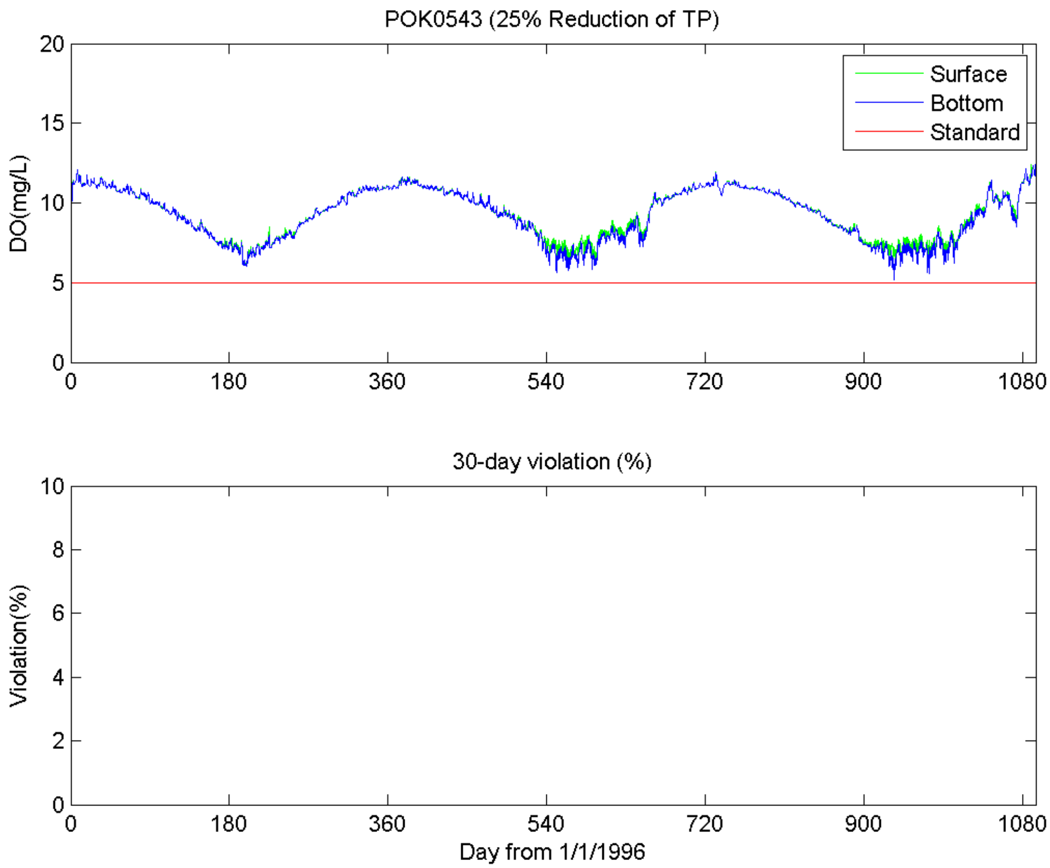

Figure A-28. Model results of DO distribution and percent of violation within a 30-day period at Stations POK0543.

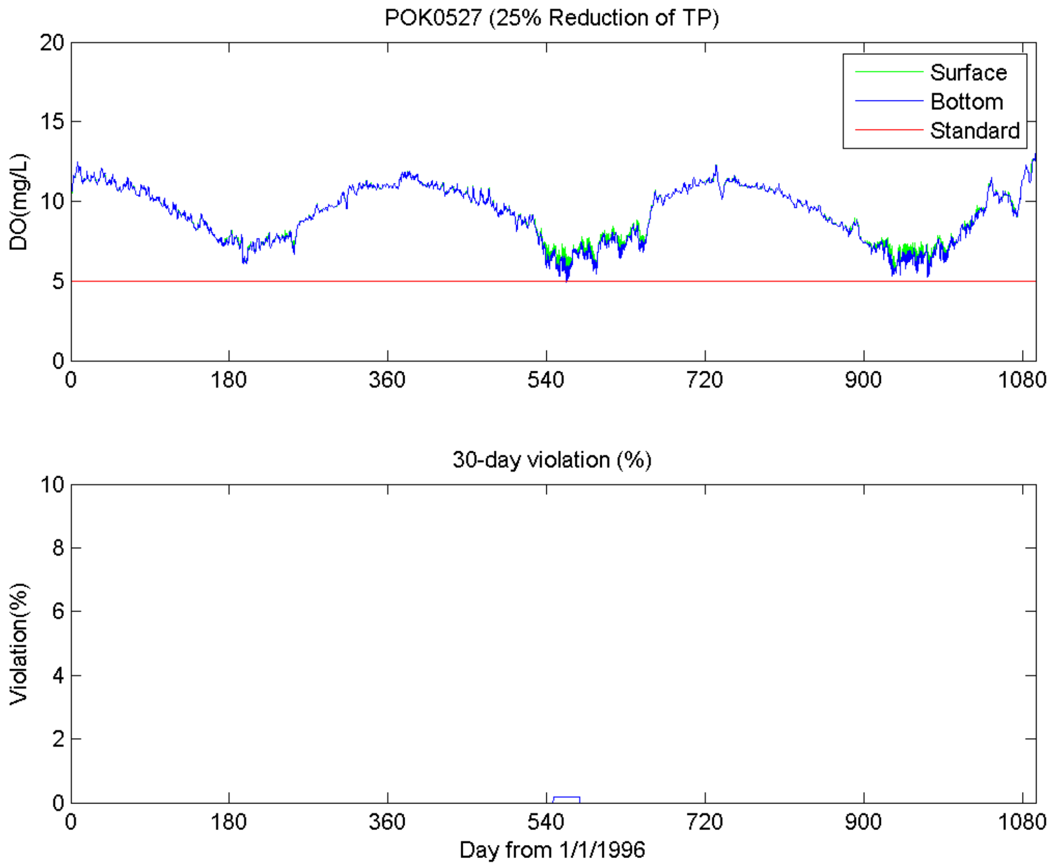

Figure A-29. Model results of DO distribution and percent of violation within a 30-day period at Stations POK0527.

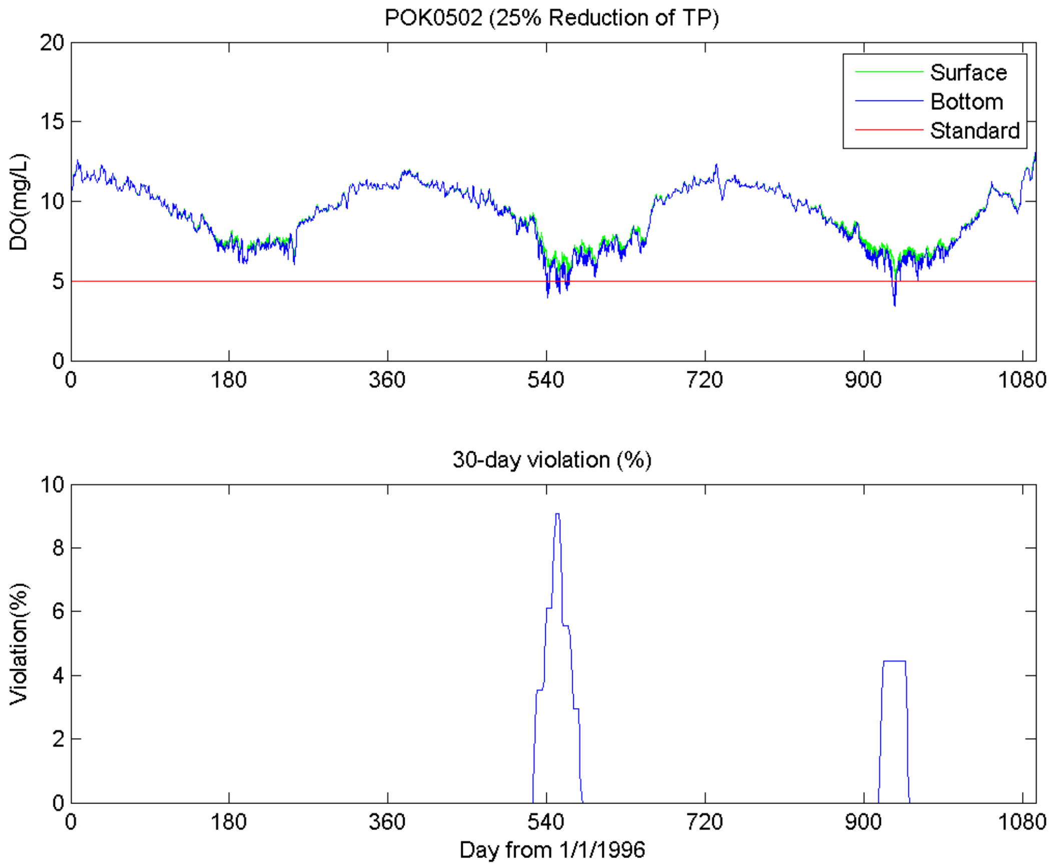

Figure A-30. Model results of DO distribution and percent of violation within a 30-day period at Stations POK0502.

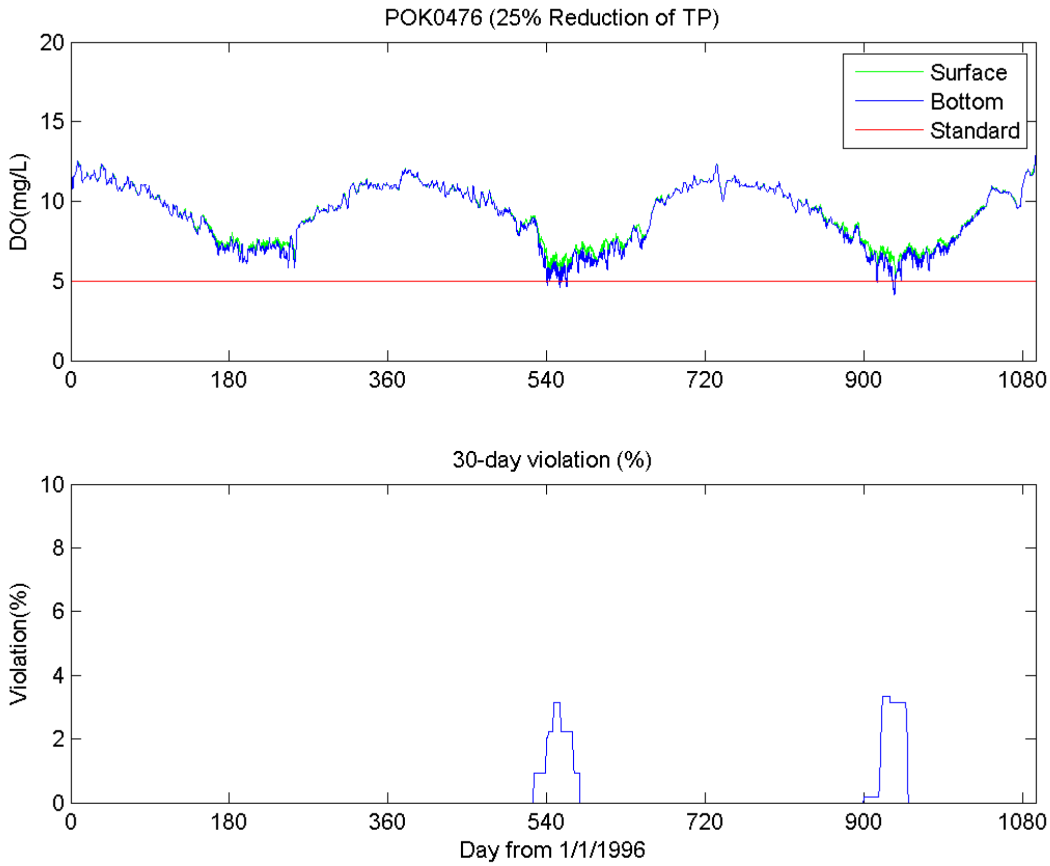

Figure A-31. Model results of DO distribution and percent of violation within a 30-day period at Stations POK0476.

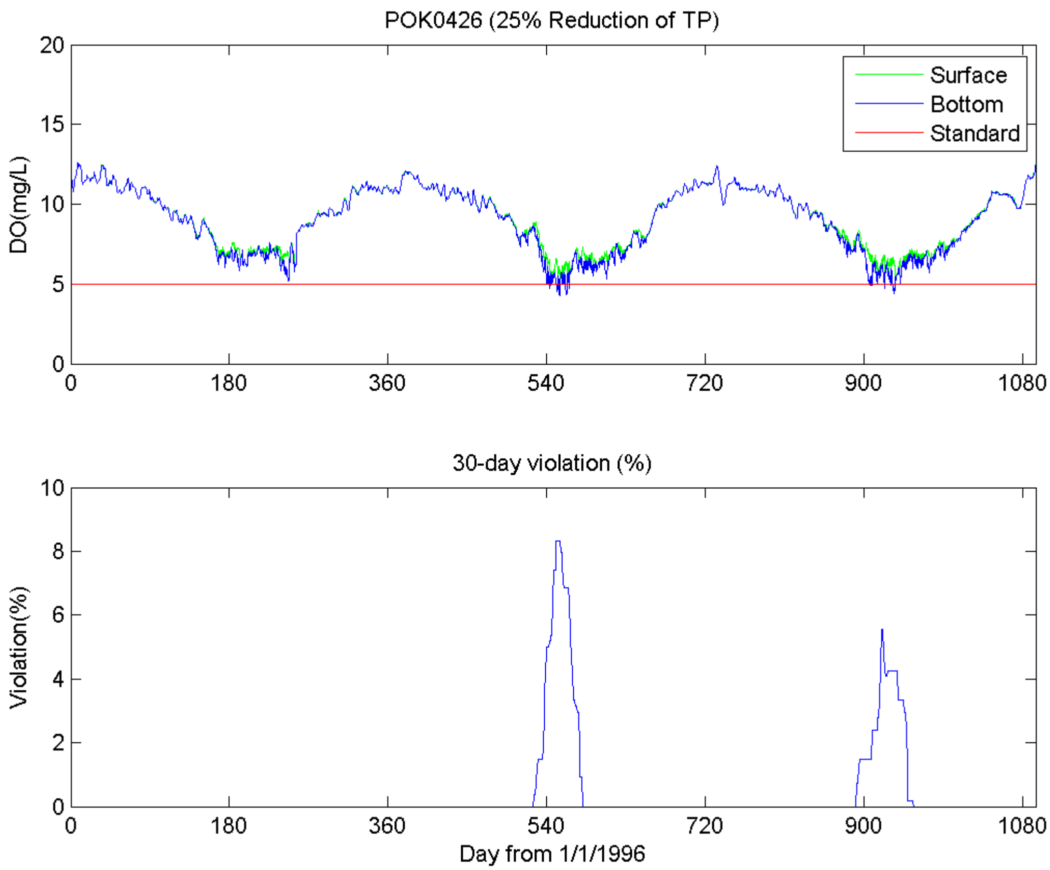

Figure A-32. Model results of DO distribution and percent of violation within a 30-day period at Stations POK0426.

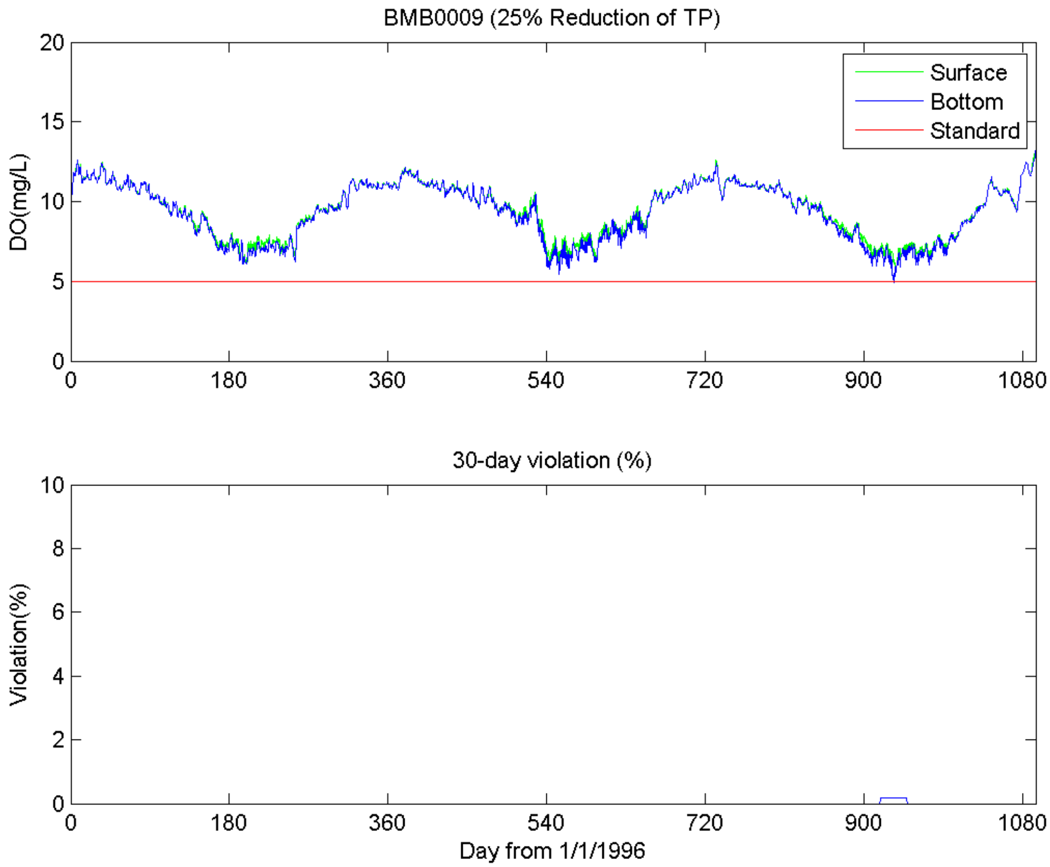

Figure A-33. Model results of DO distribution and percent of violation within a 30-day period at Stations BMB0009.

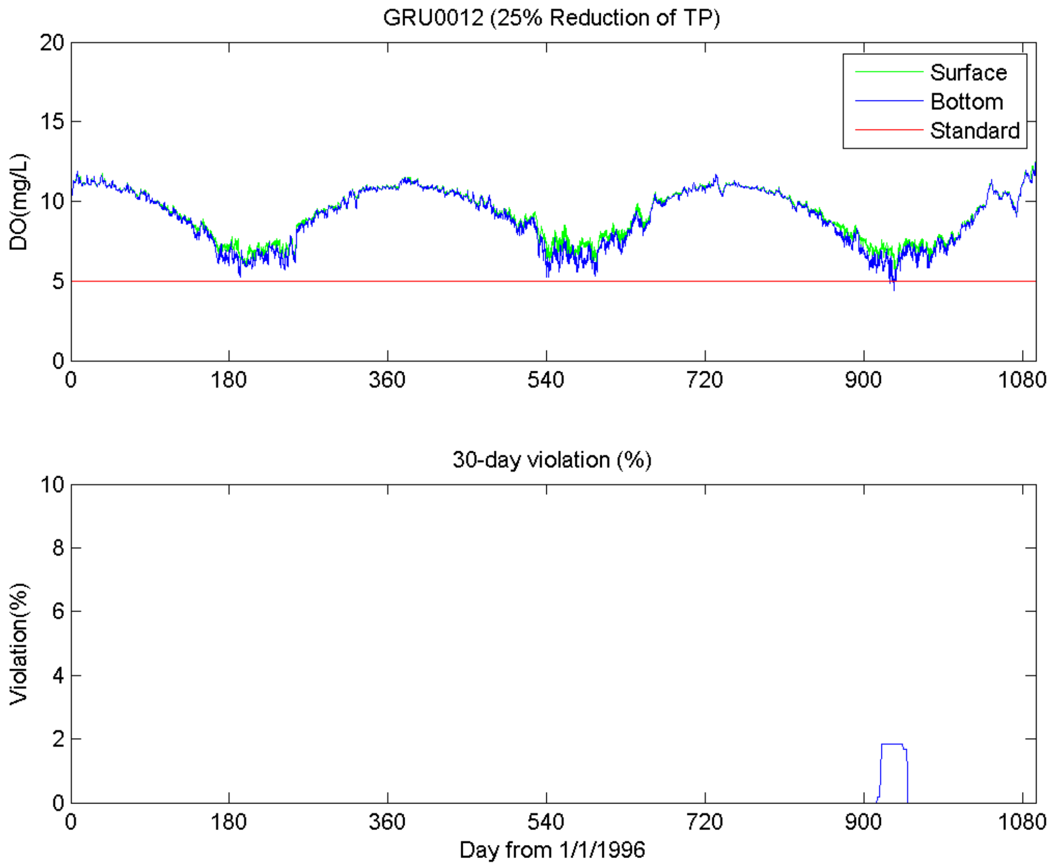

Figure A-34. Model results of DO distribution and percent of violation within a 30-day period at Stations GRU0012.

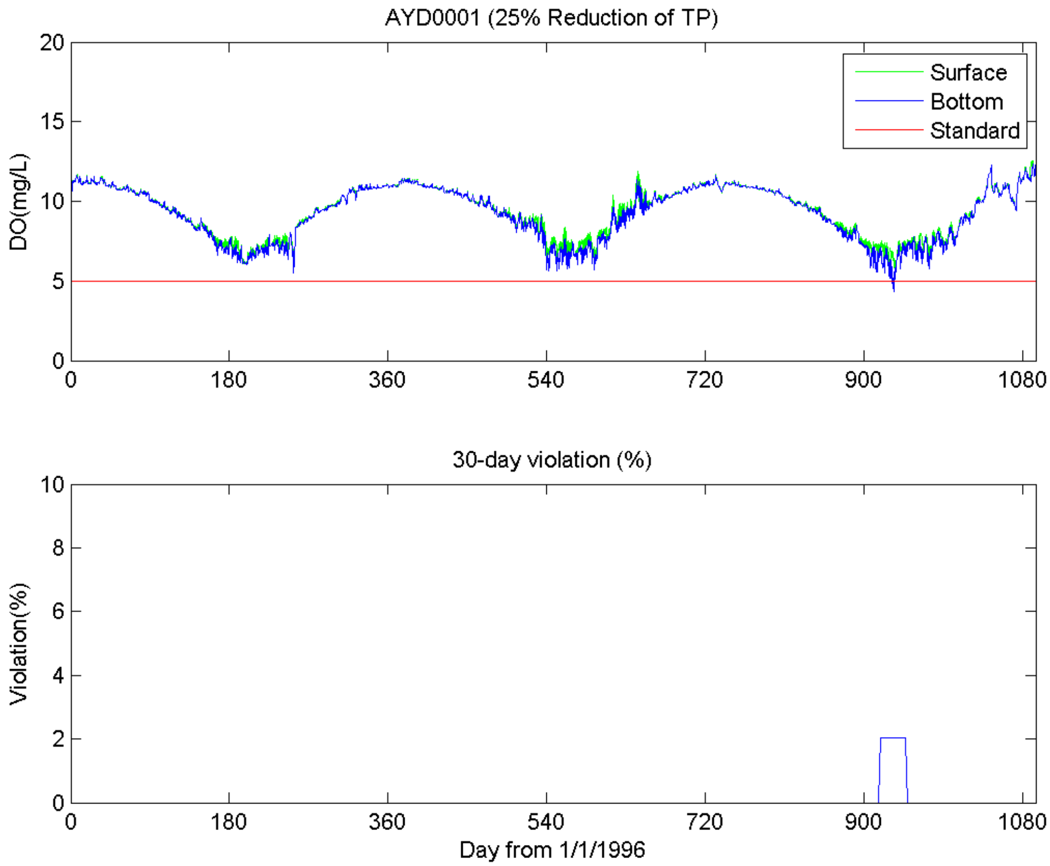

Figure A-35. Model results of DO distribution and percent of violation within a 30-day period at Stations AYD0001.

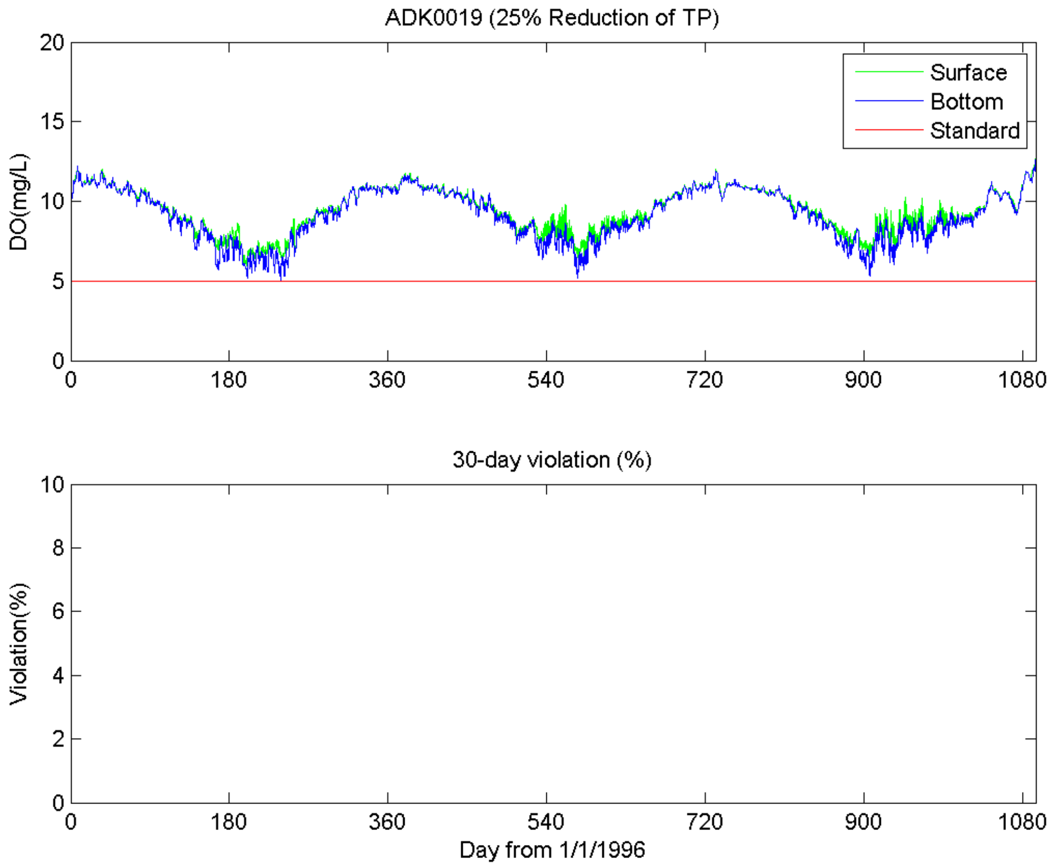

Figure A-36 Model results of DO distribution and percent of violation within a 30-day period at Stations ADK0019.

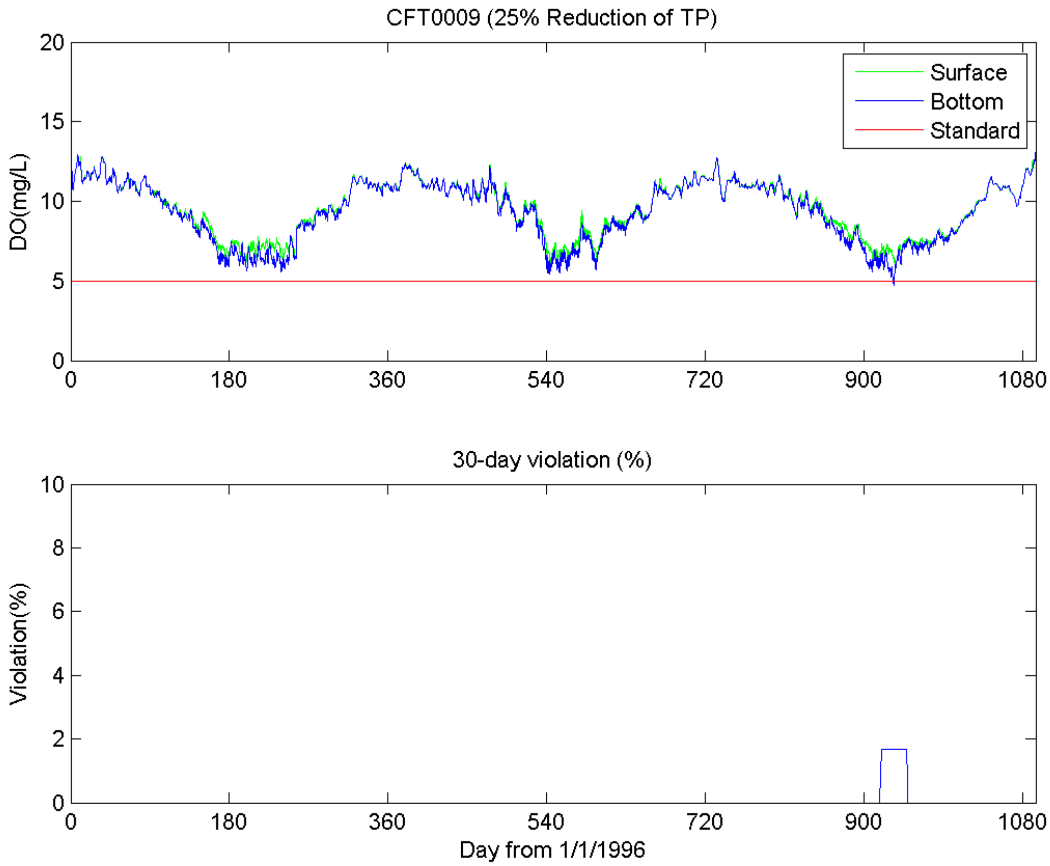

Figure A-37 Model results of DO distribution and percent of violation within a 30-day period at Stations CFT0009.

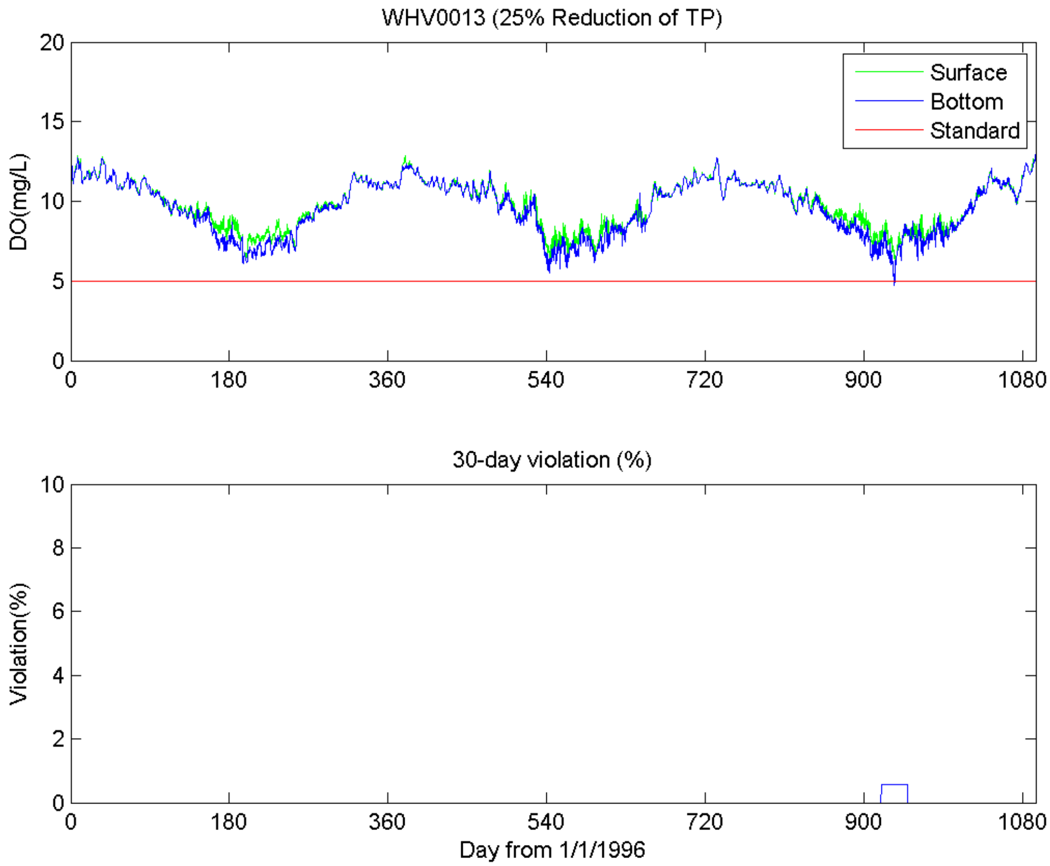

Figure A-38 Model results of DO distribution and percent of violation within a 30-day period at Stations WHV0013.

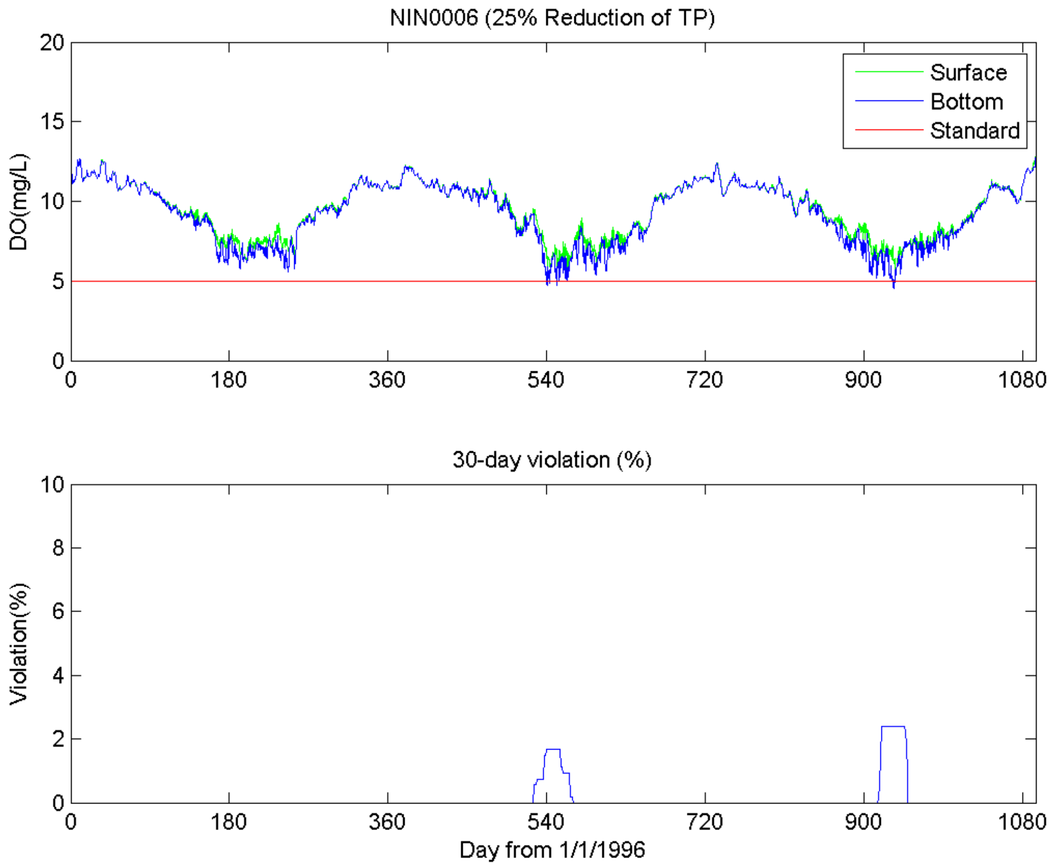

Figure A-39 Model results of DO distribution and percent of violation within a 30-day period at Stations NIN0006.

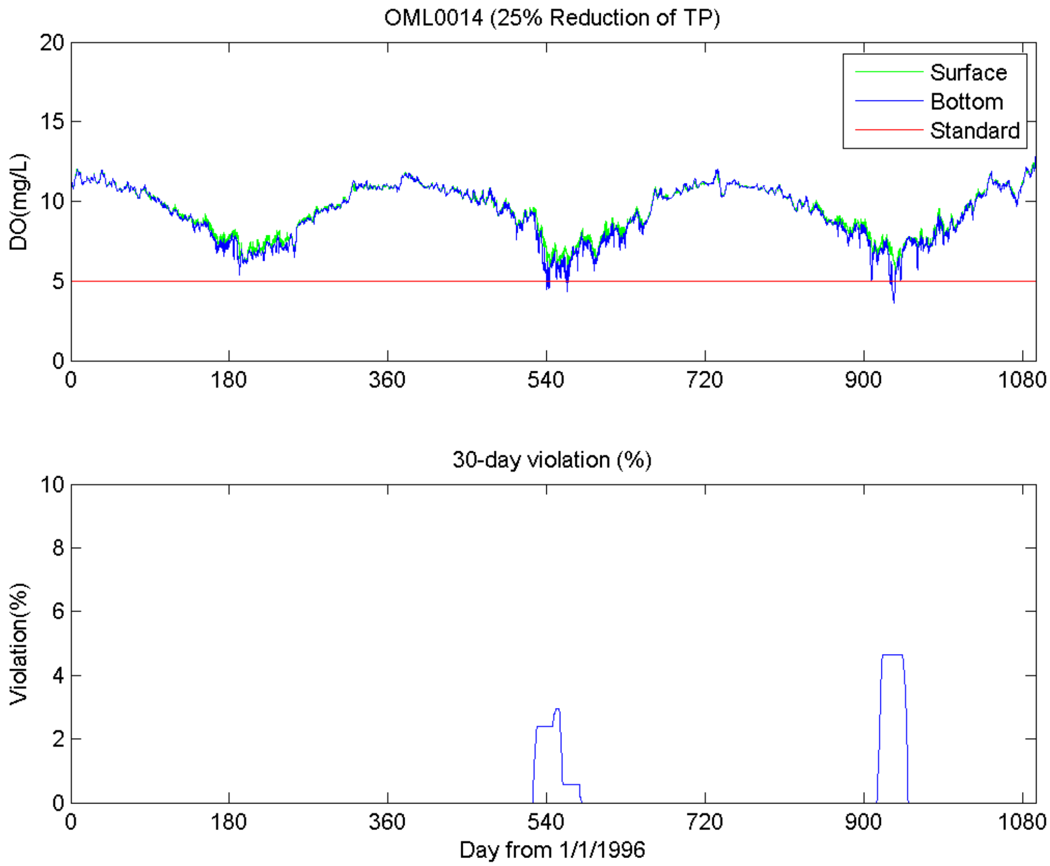

Figure A-40 Model results of DO distribution and percent of violation within a 30-day period at Stations OML0014.

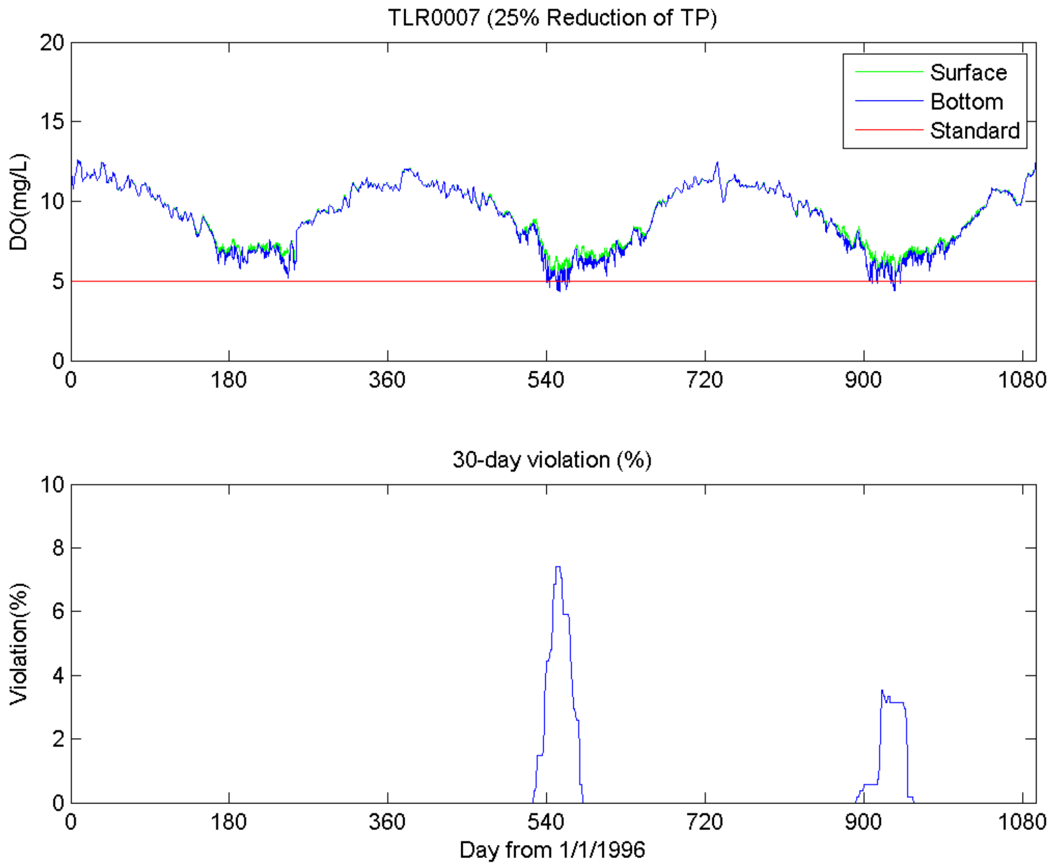

Figure A-41 Model results of DO distribution and percent of violation within a 30-day period at Stations TLR0007.

Appendix B. MDE Water Quality Monitoring Data in Upper Pocomoke River

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
ADK0017	7/26/2001	25.7	5.2	.	.	.	62.7984
ADK0017	7/26/2001	25.7	5.2	.	.	.	68.7792
ADK0017	7/30/2001	19.2	5.1	1.383	0.1441	15.15	70.2744
ADK0017	7/30/2001	19.2	5.1	.	.	.	70.2744
ADK0017	8/6/2001	22.2	3.3	1.986	0.1395	20.78	89.712
ADK0017	8/6/2001	22.2	3.3	.	.	.	164.472
ADK0019	6/16/1997	22.2	8	1.871	0.192	16.78	20.63376
ADK0019	6/30/1997	24.8	6.3	1.592	0.251	15.86	14.5782
ADK0019	7/23/1997	25.2	4.8	1.984	0.342	18.17	34.3896
ADK0019	8/6/1997	23	7.1	2.489	0.33	11.72	32.8944
ADK0019	8/20/1997	22.7	5.4	1.481	0.165	13.25	69.5268
ADK0019	9/16/1997	21.5	5.6	1.217	0.139	9.29	7.476
ADK0019	10/22/1997	12.5	8.3	1.759	0.189	10.78	12.9584
ADK0019	2/5/1998	5.5	10.2	1.7	0.542	11.72	0.4984
ADK0019	3/3/1998	8.5	9.4	3.527	0.074	14.93	1.1214
ADK0019	3/18/1998	7.2	10.5	2.984	0.06	12.16	1.1214
ADK0019	7/9/1998	23.4	6.7	1.647	0.192	19.2	5.9808
ADK0019	10/31/2000	9.5	8.4	1.466	0.1361	18.12	17.9424
ADK0019	11/28/2000	7.8	7	1.481	0.1527	25.49	
ADK0019	12/19/2000	4.2	10.4	2.757	0.1063	18.37	9.7188
ADK0019	1/23/2001	0.8	12	5.34	0.101	16.356	0.9968
ADK0019	2/21/2001	7.7	10.8	4.1029	0.0425	12.478	1.9936
ADK0019	3/28/2001	4.7	11.1	4.0138	0.0475	14.326	0.59808
ADK0019	4/11/2001	14.8	8.6	2.991	0.0884	18.01	4.4856
ADK0019	5/2/2001	17.2	8.7	2.281	0.1053	18.72	4.4856
ADK0019	6/5/2001	18.5	7.4	3.112	0.1268	18.88	0.7476
ADK0019	11/9/2004	8.9	7.3	1.871	0.153	25.15	
ADK0019	12/9/2004	9.3	9.2	2.395	0.0966	18.69	
ADK0019	1/12/2005	7.2	11.1	2.4859	0.1128	14.3	0.7476
ADK0019	2/8/2005	3.4	11.4	2.9011	0.0654	12.77	0.9968
ADK0019	4/12/2005	12.2	9.6	2.071	0.126	18.81	2.2428
ADK0019	5/4/2005	13.8	6.3	1.719	0.1657	22.43	4.4856
ADK0019	5/18/2005	17.7	7	1.851	0.2393	21.83	19.936
ADK0019	6/7/2005	21	5.7	3.435	0.56	23.17	1.4952
ADK0019	6/22/2005	23.1	8.2	1.992	0.2809	23.54	50.8368
ADK0019	7/7/2005	23.7	2.3	1.882	0.2224	21.3	8.2236
ADK0019	7/21/2005	26.6	5.7	2.33	0.2173	33.78	
ADK0019	8/3/2005	24.2	5.9	1.487	0.1915	18.22	0.7476
ADK0019	8/17/2005	25.6	5.3	1.792	0.2124	23.48	7.476
ADK0019	9/8/2005	22.4	4.3	1.065	0.162	14.81	5.9808

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
ADK0019	9/28/2005	21	6.6	0.852	0.1892	15.14	23.1756
ADK0019	10/6/2005	21.4	6.1	1.15	0.2245	14.36	23.9232
ADK0019	10/26/2005	11.3	8.4	2.952	0.1508	16.36	
ADK0019	1/25/2010	9.3	9.8	2.2124	0.0691	14.69	1.068
ADK0019	2/16/2010	1.4	9.5	2.1776	0.0581	12.366	1.7088
ADK0019	3/22/2010	15	7.8	1.659	0.1631	19	4.272
ADK0019	4/19/2010	14.5	6.7	1.634	0.2332	23.35	5.34
ADK0019	5/17/2010	17.6	6.7	1.782	0.2933	22.16	33.108
ADK0019	6/21/2010	28.7	9.1	1.375	0.2557	20.34	88.11
ADK0019	7/19/2010	28.8	5.1	1.669	0.364	22.69	92.382
ADK0019	8/16/2010	.	.	.	.	.	
ADK0019	9/20/2010	21.4	6.3	1.342	0.2874	14.96	48.06
ADK0019	10/18/2010	14.1	7.1	0.986	0.1222	10.65	51.798
ADK0019	11/15/2010	10.4	7.6	0.885	0.106	10.46	
ADK0019	12/13/2010	5.9	5.4	0.925	0.1897	12.49	
ADK0020	7/26/2001	25	4.3	.	.	.	
ADK0020	7/26/2001	20.2	1	.	.	.	
ADK0020	7/30/2001	18.9	6.1	.	.	.	
ADK0020	8/6/2001	21.5	1.6	.	.	.	
ADK0021	7/26/2001	24.3	2.3	.	.	.	62.7984
ADK0021	7/26/2001	24.3	2.3	.	.	.	65.0412
ADK0021	7/26/2001	22.6	1.2	.	.	.	
ADK0021	7/30/2001	18.8	5.1	1.477	0.1343	16.13	
ADK0021	7/30/2001	18.8	5.1	.	.	.	1.34568
ADK0021	7/30/2001	18.8	5.2	.	.	.	
ADK0021	8/6/2001	21.9	1.8	2.97	0.2121	26.31	280.35
ADK0021	8/6/2001	21.9	1.8	.	.	.	349.503
ADK0021	8/6/2001	19.4	1	.	.	.	
ADK0023	7/26/2001	25.5	3.7	.	.	.	
ADK0023	7/30/2001	18.9	5.2	.	.	.	
ADK0023	8/6/2001	22	3.7	.	.	.	
ADK0023	8/6/2001	21.5	2.5	.	.	.	
AYD0001	1/25/2010	12	9.1	3.386	0.1358	13.88	1.424
AYD0001	2/16/2010	3.3	11.6	3.059	0.1363	13.38	1.2816
AYD0001	3/22/2010	13.1	9.1	2.325	0.1251	13.02	3.204
AYD0001	4/19/2010	10.9	8.7	1.973	0.1665	11.77	10.68
AYD0001	5/17/2010	15.2	6.9	1.86	0.1737	7.97	8.544
AYD0001	6/21/2010	19.8	6.6	5.1041	0.1286	6.28	6.052
AYD0001	7/19/2010	22.2	4.5	5.3866	0.0366	6.514	1.246
AYD0001	8/16/2010	20.7	3.6	4.9902	0.022	6.186	
AYD0001	9/20/2010	16.6	3.1	5.2838	0.0244	5.804	
AYD0001	10/18/2010	12.7	2.8	4.5138	0.0161	9.28	
AYD0001	11/15/2010	10.4	7.4	2.6547	0.1597	9.58	1.9224
AYD0001	12/13/2010	7.9	8	2.906	0.281	13.16	6.764

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
BMB0009	1/25/2010	12.2	8.6	3.47	0.1353	13.3	2.136
BMB0009	2/16/2010	3.7	10.5	3.357	0.1004	12.72	1.2816
BMB0009	3/22/2010	13.6	8.1	2.102	0.099	11.58	2.67
BMB0009	4/19/2010	10.8	8.9	1.623	0.0905	8.58	14.952
BMB0009	5/17/2010	15	8.5	1.4507	0.0824	5.67	4.272
BMB0009	6/21/2010	25.3	8.1	1.0418	0.0343	5.526	4.272
BMB0009	7/19/2010	27.1	9.1	0.4755	0.0225	6.12	6.052
BMB0009	8/16/2010	26	7.8	0.2998	0.0281	5.253	3.916
BMB0009	9/20/2010	19	8.1	0.3773	0.0203	5.57	1.78
BMB0009	10/18/2010	13.1	7.7	1.277	0.0081	7.146	1.424
BMB0009	11/15/2010	11.3	8.9	2.1886	0.0565	6.79	
BMB0009	12/13/2010	8.8	7.4	2.438	0.2687	11.84	8.9
CFT0009	1/25/2010	11.2	8.6	2.908	0.2029	18.05	5.874
CFT0009	2/16/2010	3.9	10	2.513	0.0909	10.08	2.3496
CFT0009	3/22/2010	14	8.1	3.12	0.0717	8.66	18.69
CFT0009	4/19/2010	13.3	8.4	2.9096	0.0293	3.401	4.806
CFT0009	5/17/2010	14.7	8.3	2.2578	0.0201	2.379	5.696
CFT0009	6/21/2010	23.2	10.6	2.0982	0.0117	2.181	3.204
CFT0009	7/19/2010	20.9	9	1.9459	0.0097	2.169	1.78
CFT0009	8/16/2010	20.6	8.3	1.8053	0.0097	1.645	1.78
CFT0009	9/20/2010	17.9	8.2	1.9633	0.0146	1.605	1.602
CFT0009	10/18/2010	12.8	6	2.3312	0.0135	1.598	1.424
CFT0009	11/15/2010	10.3	7.5	2.61	0.0203	1.432	
CFT0009	12/13/2010	9.3	6.8	2.5345	0.0095	1.4288	
CMP0016	10/31/2000	7.9	2.9	1.625	0.127	18.27	
CMP0016	11/28/2000	6.1	7.1	1.174	0.1073	23.43	
CMP0016	12/19/2000	2.8	10.6	1.89	0.064	16.726	2.492
CMP0016	1/23/2001	0.6	10.6	3.651	0.0693	16.881	2.7412
CMP0016	2/21/2001	7.8	10.2	2.092	0.0312	13.34	4.4856
CMP0016	3/28/2001	3.5	10.6	2.3967	0.0355	15.025	0.9968
CMP0016	4/11/2001	11.9	7.7	1.64	0.0666	16.88	3.3642
CMP0016	5/2/2001	14.2	7.3	1.397	0.0863	18.98	1.4952
CMP0016	6/5/2001	16.4	7.2	1.552	0.1151	21.02	0.7476
GIV0012	10/31/2000	9.3	5.6	2.569	0.0958	5.858	3.4888
GIV0012	11/28/2000	7.5	5.6	2.672	0.1142	9.68	2.492
GIV0012	12/19/2000	4	10.1	6.277	0.0946	12.655	2.2428
GIV0012	1/23/2001	1.3	11.7	9.3104	0.1739	14.243	1.19616
GIV0012	2/21/2001	7.9	10.2	6.8164	0.0424	9.074	4.7348
GIV0012	3/28/2001	5.2	10.9	7.1365	0.0454	10.04	0.7476
GIV0012	4/11/2001	11.9	7.3	4.945	0.0922	11.629	9.4696
GIV0012	5/2/2001	14.2	6.5	3.7759	0.1025	8.632	2.492
GIV0012	6/5/2001	17.2	6	5.805	0.6764	16.98	3.738
GRU0012	1/25/2010	12.2	8.9	4.556	0.1141	11.01	2.136
GRU0012	2/16/2010	2.5	10.7	4.822	0.1396	10.92	2.136

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
GRU0012	3/22/2010	13.8	7.5	3.931	0.1267	9.01	3.204
GRU0012	4/19/2010	11.3	8.7	2.211	0.1189	7.91	9.078
GRU0012	5/17/2010	16.1	6.6	1.006	0.1788	8.69	5.34
GRU0012	6/21/2010	22.4	6.4	0.639	0.1085	6.87	4.984
GRU0012	7/19/2010	23.9	4.1	0.52	0.1357	6.94	7.476
GRU0012	8/16/2010	23.3	5.2	0.425	0.1056	5.09	10.68
GRU0012	9/20/2010	17.1	4.6	0.304	0.0679	3.85	2.492
GRU0012	10/18/2010	13	6.3	1.117	0.0332	6.683	1.78
GRU0012	11/15/2010	10.4	5.8	1.7439	0.0627	6.04	4.628
GRU0012	12/13/2010	8.6	7.1	1.854	0.0965	7.23	13.172
NIN0006	1/25/2010	7.9	9.1	1.102	0.0729	13.33	0.712
NIN0006	2/16/2010	2.4	10.6	1.1129	0.0842	11.142	0.712
NIN0006	3/22/2010	14.2	6.1	1.042	0.153	13.99	2.67
NIN0006	4/19/2010	14.2	3.1	1.2	0.2495	10.17	12.816
NIN0006	5/17/2010	16.4	4.9	0.957	0.181	7.64	48.06
NIN0006	6/21/2010	24.3	3	0.728	0.1166	4.99	7.476
NIN0006	7/19/2010	25.4	4.9	0.577	0.0903	6.2	24.564
NIN0006	8/16/2010	23.6	3.9	0.717	0.1206	7.22	46.992
NIN0006	9/20/2010	18.2	4.8	0.563	0.0917	5.07	9.434
NIN0006	10/18/2010	12.2	3.7	0.9	0.2041	6.72	16.554
NIN0006	11/15/2010	8.2	1.8	1.166	0.3547	10.15	24.03
NIN0006	12/13/2010	6.8	3.8	0.74	0.1753	5.01	
OML0014	1/25/2010	11.5	8.3	1.906	0.0552	17.92	2.848
OML0014	2/16/2010	0.6	12	1.419	0.0347	14.42	1.602
OML0014	3/22/2010	14.1	6.9	2.54	0.0806	19.82	1.78
OML0014	4/19/2010	11.5	6.4	3.962	0.0802	14.59	1.068
OML0014	5/17/2010	14.4	4.4	5.78	0.0846	7.72	0.712
OML0014	6/21/2010	18.7	3.2	6.367	0.0635	4.09	1.424
OML0014	7/19/2010	21.3	6.5	6.543	0.0545	3.48	11.5344
OML0014	8/16/2010	19.8	3.9	4.685	0.0933	7.7	115.344
OML0014	9/20/2010	.	.	.	.	.	
OML0014	10/18/2010	.	.	.	.	.	
OML0014	11/15/2010	8.5	1.8	1.473	0.1209	8.92	
OML0014	12/13/2010	5.6	0.8	1.325	0.3741	20.14	
POK0373	8/20/1997	20.8	6.2	1.293	0.121	6.98	
POK0373	9/16/1997	18.7	6.4	1.278	0.118	5.64	0.59808
POK0373	10/22/1997	12.1	7.2	1.474	0.121	8.97	0.9968
POK0373	3/3/1998	8.6	8.9	2.786	0.061	13.21	0.7476
POK0373	3/18/1998	7.5	9.9	2.522	0.068	11.8	0.7476
POK0373	7/9/1998	21.2	6.4	1.64	0.202	11.78	0.7476
POK0373	1/25/2010	8.8	9.3	2.212	0.0752	14.73	
POK0373	2/16/2010	1.4	11.9	2.1809	0.0634	11.915	0.534
POK0373	3/22/2010	14.3	8.1	1.74	0.1092	15.23	2.67
POK0373	4/19/2010	13	7.1	1.93	0.1612	15.71	1.602

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0373	5/17/2010	16.4	6.4	1.6444	0.1841	10.005	
POK0373	6/21/2010	23.1	4.8	1.3795	0.1761	8.268	
POK0373	7/19/2010	24.6	4.4	1.3086	0.1597	7.451	0.2136
POK0373	8/16/2010	22.5	4.3	1.2776	0.1559	6.257	0.356
POK0373	9/20/2010	18.4	6.3	1.1375	0.115	4.559	
POK0373	10/18/2010	13.5	7.7	1.4232	0.0875	6.947	
POK0373	11/15/2010	9.2	7.8	1.499	0.0906	8.661	
POK0373	12/13/2010	6	8.4	1.1712	0.1198	8.675	
POK0426	8/20/1997	20.9	4.4	0.887	0.165	7.98	2.6166
POK0426	9/16/1997	19.5	5.1	0.77	0.155	6.18	4.4856
POK0426	10/22/1997	12.1	6.2	1.522	0.166	9.44	
POK0426	2/5/1998	5.7	9.91	2.095	0.46	11.55	0.4984
POK0426	3/3/1998	9.2	7.9	3.342	0.062	13.31	0.7476
POK0426	3/18/1998	7.9	9.8	2.99	0.066	11.26	0.7476
POK0426	7/9/1998	21	5.4	1.292	0.167	10.78	0.59808
POK0426	11/9/2004	10.1	5.2	1.514	0.1396	16.51	
POK0426	12/9/2004	10.7	8.3	2.913	0.1029	15.04	0.3738
POK0426	1/12/2005	8.1	10.7	2.574	0.0892	11.83	
POK0426	2/8/2005	5.3	10.1	3.17	0.0716	12.86	1.246
POK0426	4/12/2005	12.2	7.7	2.47	0.0993	16.62	1.4952
POK0426	5/4/2005	13.1	8.2	1.79	0.1218	15.18	2.9904
POK0426	5/18/2005	16.8	5.1	1.709	0.1879	14.65	2.492
POK0426	6/7/2005	20	4.4	2.564	0.2373	19.55	1.4952
POK0426	6/22/2005	19.2	5.5	1.714	0.1656	13.5	
POK0426	7/7/2005	22.6	2.6	1.749	0.1907	15.7	
POK0426	7/21/2005	24.5	4.4	2.037	0.199	21.65	
POK0426	8/3/2005	23.4	5	1.616	0.2084	16.93	0.7476
POK0426	8/17/2005	23.9	4.2	1.479	0.1728	14.67	Not Detected
POK0426	9/8/2005	20.1	4.9	0.9656	0.0958	7.994	Not Detected
POK0426	9/28/2005	19.4	3.2	0.8445	0.1315	8.628	
POK0426	10/6/2005	17.9	5.1	0.778	0.1322	6.77	
POK0426	10/26/2005	12.2	7.4	4.06	0.1897	16.53	0.4984
POK0426	1/25/2010	8.4	8.9	2.3014	0.0697	13.37	0.4272
POK0426	2/16/2010	1.6	12.1	2.2683	0.066	13.091	0.89
POK0426	3/22/2010	13.8	6.8	1.732	0.1084	15.76	3.204
POK0426	4/19/2010	13.4	7	1.613	0.1288	15.42	2.136
POK0426	5/17/2010	17.3	5.2	1.2215	0.1933	10.44	3.738
POK0426	6/21/2010	23.7	3.1	0.8273	0.2547	9.7	
POK0426	7/19/2010	25.7	1.7	0.9479	0.1911	9.23	0.6408
POK0426	8/16/2010	23.2	1.4	0.7687	0.2122	8.25	
POK0426	9/20/2010	18.7	3.6	0.6427	0.1502	6.01	
POK0426	10/18/2010	13	6.4	0.9967	0.1496	8.505	
POK0426	11/15/2010	8.8	8	1.4129	0.0915	8.704	
POK0426	12/13/2010	6.8	7.4	1.1035	0.1189	8.67	

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0476	6/16/1997	18.2	7.1	1.662	0.147	14.64	0.29904
POK0476	6/30/1997	21.7	6.8	1.433	0.156	11.17	
POK0476	7/23/1997	22.6	6.3	0.914	0.128	8.1	0.7476
POK0476	8/6/1997	21	6.2	1.98	0.375	8.03	2.9904
POK0476	8/20/1997	20.4	7	0.805	0.111	7.19	
POK0476	9/16/1997	18	7.5	0.596	0.103	6.17	0.7476
POK0476	10/22/1997	11.4	8.6	1.123	0.095	7.29	
POK0476	2/5/1998	5.6	10.2	1.932	0.444	11.46	0.9968
POK0476	3/3/1998	9.1	7.6	3.552	0.074	12.9	0.7476
POK0476	3/18/1998	8.3	9	3.18	0.064	11.27	0.3738
POK0476	7/9/1998	20.6	6.8	1.256	0.122	9.65	0.89712
POK0476	1/25/2010	9.2	7.2	2.7	0.0805	14.13	0.6408
POK0476	2/16/2010	3	9.5	2.8068	0.0697	13.502	1.068
POK0476	3/22/2010	13.3	6.9	2.073	0.092	14.57	1.602
POK0476	4/19/2010	12.7	8.1	1.682	0.1229	14.29	2.136
POK0476	5/17/2010	17	6.3	1.2726	0.1624	9.765	1.068
POK0476	6/21/2010	23.4	5.8	0.9914	0.1811	9.127	
POK0476	7/19/2010	25.8	5.2	0.8618	0.194	9.97	0.89
POK0476	8/16/2010	23.8	4.5	0.6467	0.1568	7.35	
POK0476	9/20/2010	18.2	6.9	0.5925	0.1048	5.938	
POK0476	10/18/2010	12.7	8.8	1.1132	0.0506	8.074	0.178
POK0476	11/15/2010	10.2	8.5	1.5585	0.0528	7.902	
POK0476	12/13/2010	8	8.8	1.344	0.0933	7.43	5.5536
POK0502	1/25/2010	9.7	8.3	3.174	0.0714	14.2	0.8544
POK0502	2/16/2010	3.2	9.4	3.2888	0.0669	14.45	0.8544
POK0502	3/22/2010	13.4	7	2.275	0.0826	15.66	1.602
POK0502	4/19/2010	12	8	1.799	0.1093	13.79	4.272
POK0502	5/17/2010	17	6.5	1.2989	0.1646	10.315	0.712
POK0502	6/21/2010	24.3	5.1	0.9645	0.1437	9.259	0.356
POK0502	7/19/2010	27.2	5	0.7226	0.1544	9.266	0.4272
POK0502	8/16/2010	24.4	5.3	0.5373	0.1109	7.317	0.712
POK0502	9/20/2010	18.7	6.5	0.5232	0.0862	6.3	
POK0502	10/18/2010	13	8	1.0497	0.0372	7.961	
POK0502	11/15/2010	9.9	8.1	1.6172	0.0484	7.623	
POK0502	12/13/2010	8.1	8	1.408	0.0665	7.184	3.6312
POK0527	6/16/1997	17.5	7.4	1.973	0.116	14.11	0.2136
POK0527	6/30/1997	21.4	7	1.73	0.153	11.44	
POK0527	7/23/1997	22.7	6.6	1.4	0.14	8.49	0.29904
POK0527	7/23/1997	22.7	6.6	1.311	0.132	8.43	
POK0527	8/6/1997	21.3	7.9	1.241	0.09	6.92	0.59808
POK0527	8/6/1997	21.3	7.9	1.215	0.092	6.85	
POK0527	8/20/1997	20.5	7.7	1.18	0.111	7.79	
POK0527	8/20/1997	20.5	7.7	1.127	0.096	7.39	
POK0527	9/16/1997	18.1	7.8	0.791	0.107	6.52	0.89712

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0527	10/22/1997	11	9.3	0.801	0.068	6.54	
POK0527	2/5/1998	5.6	10.1	1.56	0.172	12.6	0.9968
POK0527	3/3/1998	8.5	8.1	4.301	0.053	14.52	1.1214
POK0527	3/18/1998	8.3	9	3.764	0.061	12.41	0.3738
POK0527	7/9/1998	20.1	7	1.345	0.119	8.64	0.59808
POK0527	12/7/1998	14.9	7.4	0.437	0.1	8.31	15.6996
POK0527	12/7/1998	14.9	7.4	0.469	0.102	8.41	17.5686
POK0527	12/14/1998	6.9	8.4	1.196	0.084	10.8	10.16736
POK0527	12/14/1998	6.9	8.4	1.078	0.082	11.4	10.76544
POK0527	1/4/1999	5.5	9.5	3.016	0.138	14.3	23.25866667
POK0527	1/16/1999	5.4	8.9	48.911	23.0394	29.49	3.9872
POK0527	1/26/1999	8.7	8.3	8.767	0.15	17.7	2.69136
POK0527	1/26/1999	8.7	8.3	8.756	0.15	17.5	2.9904
POK0527	2/8/1999	7	8.9	6.51	0.081	13.1	3.3642
POK0527	2/8/1999	7	8.9	7.06	0.092	13.1	3.738
POK0527	2/22/1999	4.1	10.4	5.765	0.05	12.6	
POK0527	2/22/1999	4.1	10.4	5.758	0.052	11.9	
POK0527	3/22/1999	8.8	8.5	5.817	0.374	18.4	7.476
POK0527	3/22/1999	8.8	8.5	5.803	0.361	18.5	
POK0527	4/22/1999	14	8.7	2.678	0.04	13.9	2.9904
POK0527	4/22/1999	14	8.7	2.803	0.033	14.3	4.984
POK0527	2/8/2000	4.4	10.4	7.173	0.068	10.7	1.4952
POK0527	2/8/2000	4.4	10.4	7.025	0.06	11	1.79424
POK0527	3/22/2000	7.3	9.4	4.728	1.038	15.1	2.9904
POK0527	3/22/2000	7.3	9.4	4.709	1.116	15	2.9904
POK0527	4/18/2000	12	7.5	4.35	0.107	15.7	4.4856
POK0527	4/18/2000	12	7.5	6.939	0.359	15.5	2.2428
POK0527	1/31/2001	9.1	0.85	5.093	0.052	9.68	1.4952
POK0527	1/31/2001	9.1	0.85	4.841	0.046	9.61	1.79424
POK0527	3/5/2001	6.4	9.5	4.595	0.062	10.6	7.476
POK0527	3/5/2001	6.4	9.5	.	.	.	7.476
POK0527	3/22/2001	8.8	7.3	5.138	0.482	15.6	5.2332
POK0527	3/22/2001	8.8	7.3	4.963	0.47	15.7	4.4856
POK0527	1/7/2002	6	.	2.24	0.124	5.6	12.7092
POK0527	1/7/2002	6	.	2.24	0.13	5.59	
POK0527	1/16/2003	2.5	12.8	.	.	.	
POK0527	1/29/2003	4.2	11.7	.	.	.	
POK0527	2/6/2003	3.7	11.5	.	.	.	
POK0527	2/24/2003	5.3	10.4	.	.	.	
POK0527	2/24/2003	5.3	10.4	.	.	.	
POK0527	3/6/2003	10.1	9.2	.	.	.	
POK0527	3/20/2003	8.6	7.9	.	.	.	
POK0527	4/29/2003	16.1	8.4	.	.	.	
POK0527	5/8/2003	18	7.8	.	.	.	

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0527	5/22/2003	14.1	8.8	.	.	.	
POK0527	6/5/2003	18.1	8.2	.	.	.	
POK0527	6/19/2003	18.9	7.9	.	.	.	
POK0527	7/10/2003	22.7	7.1	.	.	.	
POK0527	7/24/2003	22.6	7.3	.	.	.	
POK0527	8/7/2003	22.7	6.8	.	.	.	
POK0527	8/21/2003	21.9	6.4	.	.	.	
POK0527	9/11/2003	18.6	7.9	.	.	.	
POK0527	9/25/2003	20	6.5	.	.	.	
POK0527	10/9/2003	16.3	7	.	.	.	
POK0527	10/23/2003	12.1	8.8	.	.	.	
POK0527	11/9/2004	8.4	8.3	1.4221	0.0446	11.788	0.2492
POK0527	12/9/2004	10.1	8.2	3.4568	0.0672	14.37	0.2492
POK0527	1/12/2005	9	10.3	2.987	0.0713	12.14	1.4952
POK0527	2/8/2005	6	9.8	3.943	0.0656	14.05	1.7444
POK0527	4/12/2005	11	7.8	2.942	0.0644	18.18	1.1214
POK0527	5/4/2005	13.2	8.1	1.94	0.0913	13.84	2.2428
POK0527	5/18/2005	15.4	7.5	1.874	0.1128	13.45	0.9968
POK0527	6/7/2005	20	5.3	4.498	0.7615	25.36	5.2332
POK0527	6/22/2005	20	7.4	2.046	0.1182	12.46	0.4984
POK0527	7/7/2005	22.6	2.8	1.9176	0.1164	13.43	Not Detected
POK0527	7/21/2005	23.5	5.5	2.373	0.1338	18.47	0.7476
POK0527	8/3/2005	23.7	6.2	2.045	0.1266	13.59	0.7476
POK0527	8/17/2005	22.8	6.5	1.683	0.0996	13.01	0.2492
POK0527	9/8/2005	19.1	7.7	0.9917	0.0739	6.938	
POK0527	9/28/2005	17.4	7.1	0.7868	0.1062	8.382	
POK0527	10/6/2005	19	7.1	0.7486	0.0848	6.008	
POK0527	10/26/2005	11.8	7.4	4.583	0.2053	16.32	0.7476
POK0527	1/25/2010	9.7	8.3	3.4937	0.0595	15.28	0.6408
POK0527	2/16/2010	3.1	9.3	3.1842	0.0634	15.213	0.8544
POK0527	3/22/2010	13.4	7.1	2.489	0.0737	15.63	1.602
POK0527	4/19/2010	12	8.2	1.88	0.1069	14.68	2.136
POK0527	5/17/2010	16.6	6.7	1.2517	0.1687	9.981	
POK0527	6/21/2010	23.5	5.6	0.9873	0.1807	9.801	
POK0527	7/19/2010	26.1	5.5	0.8619	0.1678	10.284	0.534
POK0527	8/16/2010	24.2	6.1	0.626	0.1694	7.839	0.178
POK0527	9/20/2010	18.5	7.3	0.847	0.1075	6.808	1.246
POK0527	10/18/2010	12.4	8.6	1.3464	0.0382	7.762	
POK0527	11/15/2010	9.3	8.6	1.5614	0.0405	8.204	
POK0527	12/13/2010	7.5	7.9	1.2275	0.0585	7.184	6.1944
POK0543	6/16/1997	17.5	6.8	1.909	0.108	13.63	2.9904
POK0543	6/30/1997	21.7	6.3	1.196	0.105	8.32	2.9904
POK0543	7/23/1997	22.8	6.1	1.494	0.117	8.31	2.9904
POK0543	8/6/1997	21.1	6.9	1.475	0.101	6.4	2.2428

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0543	8/20/1997	20.8	6.4	1.212	0.159	7.99	3.738
POK0543	9/16/1997	18.3	7	0.823	0.151	5.89	1.79424
POK0543	10/22/1997	11.2	8.4	1.038	0.089	7.23	1.4952
POK0543	2/5/1998	5.5	11.2	2.136	0.9	10.74	0.4984
POK0543	3/3/1998	8.5	7.7	4.144	0.053	20.26	1.1214
POK0543	3/18/1998	8.2	8.9	3.445	0.049	12.9	0.3738
POK0543	7/9/1998	19.6	7.4	1.661	0.132	8.97	0.59808
POK0543	12/7/1998	14.9	6.7	0.526	0.118	7.04	16.198
POK0543	12/14/1998	7.2	7.6	2.378	0.111	13.7	34.888
POK0543	1/5/1999	0.7	10.7	2.607	0.127	14.2	8.5974
POK0543	1/26/1999	8.5	8.8	6.537	0.119	14.4	3.3642
POK0543	2/8/1999	6.9	8.9	6.21	0.072	14.2	5.2332
POK0543	2/22/1999	4	10.8	6.145	0.059	14.3	
POK0543	3/22/1999	9.2	8.2	5.527	0.388	19	11.06448
POK0543	4/22/1999	14.7	10.2	2.439	0.05	14.7	4.4856
POK0543	2/8/2000	4.8	10.6	6.439	0.047	9.96	2.9904
POK0543	3/22/2000	7	9.5	4.083	0.884	15.7	2.2428
POK0543	4/18/2000	11.8	7.2	3.666	0.098	14.2	3.738
POK0543	7/16/2000	.	.	52.449	23.067	.	
POK0543	1/31/2001	8.9	0.83	4.346	0.048	9.99	1.9936
POK0543	3/5/2001	6.5	9.1	4.004	0.048	12.9	9.4696
POK0543	3/22/2001	8.9	7.3	4.37	0.441	14.8	6.4792
POK0543	1/7/2002	6	.	2.67	0.13	6.52	17.9424
POK0543	11/9/2004	8	7.4	1.437	0.0705	12.47	
POK0543	12/9/2004	9.6	8.1	3.98	0.0545	19.65	0.2492
POK0543	1/12/2005	8.9	9.3	3.103	0.0591	16.25	1.4952
POK0543	2/8/2005	5.8	9.2	3.258	0.0535	13.82	2.492
POK0543	4/12/2005	10.5	6	2.807	0.0599	17.22	1.1214
POK0543	5/4/2005	11.8	7.6	1.966	0.0864	14.93	2.2428
POK0543	5/18/2005	14.3	7.3	1.955	0.1159	13.86	1.9936
POK0543	6/7/2005	19.6	3.9	4.002	0.6674	25.58	5.9808
POK0543	6/22/2005	18.4	7.9	1.901	0.1104	11.13	0.9968
POK0543	7/7/2005	21	3.1	1.7995	0.1184	11.75	0.3738
POK0543	7/21/2005	22.7	5.3	2.246	0.1134	16.46	0.7476
POK0543	8/3/2005	21.7	5.7	1.953	0.1408	13.72	0.7476
POK0543	8/17/2005	21.4	5.6	1.809	0.1132	13.85	Not Detected
POK0543	9/8/2005	18.1	7	1.186	0.0696	6.513	
POK0543	9/28/2005	17.2	6.2	1.0417	0.1014	8.47	
POK0543	10/6/2005	18.8	6.7	1.0393	0.0833	6.605	0.2492
POK0543	10/26/2005	12.1	5.8	4.509	0.1623	17.08	0.4984
POK0543	1/25/2010	9.6	7.6	3.487	0.0574	26.02	0.6408
POK0543	2/16/2010	3.5	9.2	3.0795	0.0574	13.54	1.2816
POK0543	3/22/2010	13.3	6.8	2.513	0.0759	15.34	1.068
POK0543	4/19/2010	11.3	7.6	1.961	0.1088	17.26	

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
POK0543	5/17/2010	16.4	5.9	1.3907	0.1598	10.12	1.602
POK0543	6/21/2010	23.2	4.1	1.1736	0.1719	8.3	0.712
POK0543	7/19/2010	25.7	4.2	1.0965	0.159	9.65	0.356
POK0543	8/16/2010	24.1	5.1	0.802	0.1489	7.293	0.534
POK0543	9/20/2010	18.1	6.5	0.6888	0.1182	5.9	0.534
POK0543	10/18/2010	12.2	8	1.0664	0.0529	6.625	
POK0543	11/15/2010	9.2	7.4	1.5491	0.0722	7.5	
POK0543	12/13/2010	8.5	7	1.584	0.077	8.58	4.9128
SAA0005	10/31/2000	7	4	1.598	0.1447	28.02	
SAA0005	11/28/2000	5.1	6.1	1.6	0.1197	28.82	2.9904
SAA0005	12/19/2000	2.7	10.1	2.471	0.1156	22.19	23.9232
SAA0005	1/23/2001	0.4	8.4	5.409	0.1142	16.61	1.9936
SAA0005	2/21/2001	8.7	9.2	4.618	0.0601	15.33	5.4824
SAA0005	3/28/2001	4.5	10.3	5.115	0.0572	14.633	2.492
SAA0005	4/11/2001	12.5	7	3.168	0.0947	19.77	6.7284
SAA0005	5/2/2001	15	7	3.463	0.1252	20.33	5.9808
SAA0005	6/5/2001	17.5	5.7	2.915	0.1621	23.36	
TLR0007	1/25/2010	9.4	8.4	0.824	0.0493	18.17	0.6408
TLR0007	2/16/2010	1.6	11.9	0.6191	0.0243	16.338	Not Detected
TLR0007	3/22/2010	13	7.3	0.7186	0.0365	17.864	0.8544
TLR0007	4/19/2010	11.3	7.6	0.8495	0.0599	17.725	
TLR0007	5/17/2010	13.5	5.8	1.19	0.144	10.81	
TLR0007	6/21/2010	19.1	4.4	1.217	0.1779	6.91	
TLR0007	7/19/2010	20.5	4.1	1.135	0.1383	5.77	
TLR0007	8/16/2010	19.5	2	0.944	0.2545	7.8	
TLR0007	9/20/2010	17	5.5	0.896	0.105	3.41	
TLR0007	10/18/2010	13.4	3.2	0.971	0.1286	4.9	
TLR0007	11/15/2010	10.5	3.8	0.7656	0.132	5.26	
TLR0007	12/13/2010	8.2	6.6	0.6533	0.0597	6.006	
TUI0006	10/31/2000	7.1	6.1	0.8992	0.0418	8.3	
TUI0006	11/28/2000	7.3	4.9	2.97	0.0484	15.93	
TUI0006	12/19/2000	3.5	10.3	10.624	0.0447	16.637	
TUI0006	1/23/2001	1	12.1	12.466	0.055	17.158	3.9872
TUI0006	2/21/2001	8.1	10.5	10.097	0.0276	14.285	3.2396
TUI0006	3/28/2001	4	10.2	8.912	0.0526	17.61	1.7444
TUI0006	4/11/2001	12.4	5.8	5.952	0.0939	18.25	11.214
TUI0006	5/2/2001	17.7	5.3	3.53	0.1254	17.33	4.361
TUI0006	6/5/2001	18.2	6	7.001	0.1853	18.82	2.9904
WHV0013	1/25/2010	11.6	8.2	3.758	0.4193	20.98	3.738
WHV0013	2/16/2010	2.7	9.8	4.354	0.1544	14.43	1.7088
WHV0013	3/22/2010	13.8	7.5	2.848	0.1422	16.3	7.476
WHV0013	4/19/2010	10.9	7.2	1.864	0.1896	17.08	13.73142857
WHV0013	5/17/2010	15.7	4.7	1.74	0.2668	13.04	3.204
WHV0013	6/21/2010	25.4	3.2	1.0982	0.1589	8.44	2.67

Sampling Station Identifier	Sampling Date	Water Temperature °C	Dissolved Oxygen Field Value mg/l	Total Nitrogen mg/l	Total Phosphorus as P mg/l	Total Organic Carbon mg/l	Chlorophyll A µg/l
WHV0013	7/19/2010	27.4	6.4	1.083	0.2639	11.51	58.206
WHV0013	8/16/2010	27.7	4.4	0.845	0.2415	11.58	10.68
WHV0013	9/20/2010	19.6	5.1	0.639	0.1034	6.61	2.136
WHV0013	10/18/2010	13	4.8	1.424	0.0526	14.91	1.068
WHV0013	11/15/2010	9.8	5	2.5665	0.0519	11.956	3.8448
WHV0013	12/13/2010	8.2	6	2.117	0.1307	12.89	8.9

Appendix C. Technical Approach Used to Generate Maximum Daily Loads

All TMDLs have some probability of being exceeded, with the probability being either explicitly specified or implicitly assumed. This level of probability reflects, directly or indirectly, two separate phenomena:

1. Water quality criteria consist of components describing acceptable magnitude, duration, and frequency. The frequency component addresses how often conditions can allowably surpass the combined magnitude and duration components.
2. Pollutant loads, especially from wet weather sources, typically exhibit a large degree of variability over time. It is rarely practical to specify a "never to be exceeded value" for a daily load, as essentially any loading value has some finite probability of being exceeded.

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 95^{th} 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 95^{th} percentile was selected as the pre-defined probability and the MDL is computed as follows (USEPA 2007)

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

Where Zp is p^{th} percentage point of the standard normal distribution. 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 standard deviation divided by the mean.

Using method described above, the maximum daily load of phosphorus in MD's Upper Pocomoke River Watershed was calculated based on the average annual TP TMDL shown in Table C1. The result of maximum daily load was shown in Table C2.

Table C1: MD 8-digit Upper Pocomoke River Average Annual TMDL of Phosphorus (lbs/yr)

		LA						WLA						
TMDL (lbs/yr)	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**	+	**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**	+	**MOS**
43,592	=	2,227		35,494	+	0	+	4,339	+	11	+	1,520	+	Implicit
		Upstream Load Allocation[2]		MD 8-digit Upper Pocomoke River Watershed TMDL Contribution										

[1] The LA_{DE} was determined based on a DE TMDL that is expressed in lbs/day and converted herein to an annual loading by multiplying by 365 (DNREC 2005). The LA_{DE} meets Maryland water quality standards within the MD 8-digit Upper Pocomoke River watershed. It accounts for the upstream load from DE entering MD waters.

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.

Table C2: MD 8-digit Upper Pocomoke River Maximum Daily Loads of Phosphorus (lbs/day)

		LA						WLA						
TMDL (lbs/day)	+	**LA_{DE}**[1,2]	+	**LA_{UPR}**	+	**$Septic_{UPR}$**	+	**CAFO WLA_{UPR}**	+	**NPDES Stormwater WLA_{UPR}**	+	**Process Water WLA_{UPR}**	+	**MOS**
392.2	=	6.1		370.02	+	0	+	11.9	+	0.03	+	4.2	+	Implicit
		Upstream Load Allocation[2]		MD 8-digit Upper Pocomoke River Watershed TMDL Contribution										

[1] LA_{PA} was based on the DE TMDL (DNREC, 2005).

[2] Although for the purpose of this analysis the upstream load is referred to as an LA, it could include loads from point and nonpoint sources.