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Virginia Institute of Marine Science

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A Study of Dissolved Oxygen Impairment, North Branch of Onancock Creek, Accomack County, Virginia

Final Report for Contract # 10019
Submitted to the Department of Environmental Quality

By
Virginia Institute of Marine Science

September 14, 2005

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1.0 Introduction

1.1 Overview of the TMDL Process

TMDLs represent the total pollutant loading that a waterbody can receive without violating water quality standards. The TMDL process establishes the allowable loading of pollutants for a waterbody based on the relationship between pollution sources and in-stream water quality conditions. By following the TMDL process, states can establish water quality based controls to reduce pollution from both point and non-point sources to restore and maintain the quality of their water resources (EPA, 1991).

The first step in the TMDL development process is listing the water as impaired on the 303(d) list. This is done by a comparative analysis of existing water quality data to the relevant water quality standard. If known, the cause, source and extent of the impairment(s) are identified in this process. Listing of waters for TMDL development is an integrated process involving monitoring, water quality standards, and Virginia Pollution Discharge Elimination System (VPDES) permits.

The goal of the TMDL program is to establish a three-step path that will lead to attainment of water quality standards. The first step in the process is to develop TMDLs that will result in meeting water quality standards. The second step is to develop a TMDL implementation plan. The final step is to implement the TMDL implementation plan, and to monitor water quality to determine if water quality standards are being attained.

1.2 Listing of Water Bodies under the Clean Water Act

Water quality standards are regulations based on federal or state law that set numeric or narrative limits on pollutants. Water quality monitoring is performed to measure pollutants and determine if the measured levels are with the bounds of the limits set for the uses designated for the waterbody. Waterbodies with pollutant levels that exceed the designated standards are considered impaired for the corresponding designated use (e.g. swimming, drinking, shellfish harvest, etc.). Under the provisions of §303 (d) of the Clean Water Act, impaired waterways are placed on the list reported to the Environmental Protection Agency. The impaired water list is included in the biennial 305(b)/ 303(d) Water Quality Assessment Integrated Report. Those waters placed on the list require the development of a TMDL and corresponding implementation plan intended to eliminate the impairment and bring the water into compliance with the designated standards. A detailed description of Virginia's water quality assessment procedures can be found at http://www.deq.state.va.us/wqa/

1.3 Designated Uses and Applicable Criteria

According to Virginia Water quality Standards (9VAC25-260-10):

"*all state waters, including wetlands, are designated for the following uses: recreational uses, e.g., swimming and boating; the propagation and growth of a balanced, indigenous population of aquatic life, including game fish, which might reasonably be expected to inhabit* *them; wildlife; and the production of edible and marketable natural resources, e.g., fish and shellfish*".

The state promulgates standards to protect waters to ensure the uses designated for those waters are met. In Virginia's water quality standards, certain standards are assigned by water class, while other standards are assigned to specifically described water bodies/ waterways to protect designated uses of those waters. Virginia has seven waters classes (I through VII) with dissolved oxygen (DO), pH and temperature criteria for each class (9VAC25-260-50). The identification of waters by class is found in the river basins section tables. The tables delineate the class of waters to which the basin section belongs in accordance with the class descriptions given in 9VAC25-260-50. By finding the class of waters for a basin section in the classification column and referring to 9VAC25-260-50, the DO, pH and maximum temperature criteria can be found for each basin section. Onancock Creek is in the Chesapeake Bay, Atlantic Ocean and small coastal basins (9VAC25-260-520). Onancock Creek is classified as Section 2, Class II water.

Historically, the numerical criteria for dissolved oxygen for Class II waters have been a minimum of 4.0 mg/L and a daily average of 5.0 mg/L. On March 15, 2005, the State Water Control Board adopted changes in the dissolved oxygen criteria for the tidal waters in the Chesapeake Bay and its tributaries to protect designated uses from the impacts of nutrients and suspended sediment. The applicable sections in the Virginia Administrative Code are 9 VAC 25-260-5, 10, 50, 185, 186, and 350. Under these new criteria, Onancock Creek is considered part of Chesapeake Bay program segment CB7PH and designated as Open Water. The new criteria and the implementation procedures for the new criteria are shown below. The new criteria are expected to become effective in June 2005, pending EPA approval. Additional information on the new criteria can be found at http://www.deq.virginia.gov/wqs/rule.html

"9 VAC 25-260-185 Criteria to protect designated uses from the impacts of nutrients and suspended sediment in the Chesapeake Bay and its tidal tributaries.

A. Dissolved Oxygen

Designated Use	**Criteria Concentration/ Duration**	**Temporal Application**
Migratory fish spawning and nursery	7-day mean > 6 mg/l (tidal habitats with 0-0.5 ppt salinity)	February 1 - May 31
	Instantaneous minimum > 5 mg/l	
Open-water[1]	30 day mean > 5.5 mg/l (tidal habitats with 0-0.5 ppt salinity)	year-round
	30 day mean > 5 mg/l (tidal habitats with >0.5 ppt salinity)	
	7 day mean > 4 mg/l	

	Instantaneous minimum > 3.2 mg/l at temperatures <29^{o}C Instantaneous minimum > 4.3 mg/l at temperatures > 29^{o}C	
Deep-water	30 day mean > 3 mg/l	June 1 - September 30
	1 day mean > 2.3 mg/l	
	Instantaneous minimum > 1.7 mg/l	
Deep-channel	Instantaneous minimum > 1 mg/l	June 1 - September 30

1= In applying this open-water instantaneous criterion to the Chesapeake Bay and its tidal tributaries where the existing water quality for dissolved oxygen exceeds an instantaneous minimum of 3.2 mg/l, that higher water quality for dissolved oxygen shall be provided antidegradation protection in accordance with section 30 subsection A.2 of this chapter."

D. Implementation

1. Chesapeake Bay program segmentation scheme as described in Chesapeake Bay Program. 2004. *Chesapeake Bay Program Analytical Segmentation Scheme-Revisions, Decisions and Rationales: 1983 -2003,* CBP/TRS 268/04. Chesapeake Bay Program, Annapolis, Maryland is listed below and shall be used as the spatial assessment unit to determine attainment of the criteria in this section for each designated use.

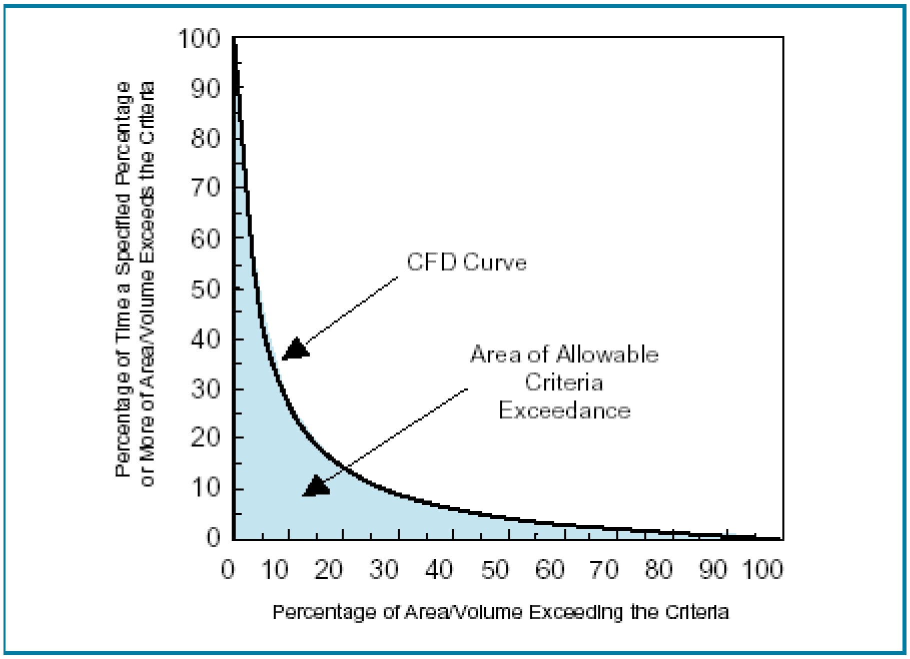
Chesapeake Bay Segment Description	**Segment Name**[1]	**Chesapeake Bay Segment Description**	**Segment Name**[1]
Lower Central Chesapeake Bay	CB5MH	Mobjack Bay	MOBPH
Western Lower Chesapeake Bay	CB6PH	Upper Tidal Fresh James River	JMSTF2
Eastern Lower Chesapeake Bay	CB7PH	Lower Tidal Fresh James River	JMSTF1
Mouth of the Chesapeake Bay	CB8PH	Appomattox River	APPTF
Upper Potomac River	POTTF	Middle James River	JMSOH
Middle Potomac River	POTOH	Chickahominy River	CHKOH
Lower Potomac River	POTMH	Lower James River	JMSMH
Upper Rappahannock River	RPPTF	Mouth of the James River	JMSPH
Middle Rapphannock River	RPPOH	Western Branch Elizabeth River	WBEMH
Lower Rapphannock River	RPPMH	Southern Branch Elizabeth River	SBEMH
Corrotoman River	CRRMH	Eastern Branch Elizabeth River	EBEMH
Piankatank River	PIAMH	Lafayette River	LAFMH
Upper Mattaponi River	MPNTF	Mouth of the Elizabeth River	ELIPH
Lower Mattaponi River	MPNOH	Lynnhaven River	LYNPH
Upper Pamunkey River	PMKTF	Middle Pocomoke River	POCOH
Lower Pamunkey River	PMKOH	Lower Pocomoke River	POCMH
Middle York River	YRKMH	Tangier Sound	TANMH
Lower York River	YRKPH		

1=First three letters of segment name represent Chesapeake Bay segment description, letters four and five represent the salinity regime of that segment (TF = Tidal Fresh, OH = Oligohaline, MH = Mesohaline and PH = Polyhaline) and a sixth space is reserved for subdivisions of that segment.

2. The assessment period shall be the most recent three consecutive years. When three consecutive years of data are not available, a minimum of three years within the most recent five years shall be used.

3. Attainment of these criteria shall be assessed through comparison of the generated cumulative frequency distribution of the monitoring data to the applicable criteria reference curve for each designated use. If the monitoring data cumulative frequency curve is completely contained inside the reference curve, then the segment is in attainment of the designated use. The reference curves and procedures to be followed are published in the USEPA, *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries*, EPA 903-R-03-002, April 2003. If no reference curve is published, the cumulative frequency distribution reference curve in Figure 1, which represents 10% allowable exceedance equally distributed between time and space, shall be the applicable reference curve. An exception to this requirement is in measuring attainment of the SAV acres, which are compared directly to the criteria.

Figure 1.”



“9 VAC 25-260-186 Virginia Pollutant Discharge Elimination System Permits and Schedules of Compliance

A As deemed necessary to meet the requirements of 9 VAC 25-260-185, the board shall issue or modify Virginia Pollutant Discharge Elimination System permits for point source dischargers located throughout the tidal and non-tidal sections of the following river basins:

Potomac (sections 390 and 400 of this chapter), James (sections 410, 415, 420 and 430 of this chapter), Rappahannock (section 440 of this chapter), York (section 530 of this chapter) and Chesapeake Bay/Small Coastal Basins (subsections 2 - 3g of section 520 of this chapter).

B National Pollutant Discharge Elimination System permits issued by permitting authorities within the Chesapeake Bay watershed may include a compliance schedule in accordance with implementing regulations requiring compliance as soon as possible with nutrient load limitations assigned to individual dischargers.”

Onancock Creek also has been designated as a nutrient enriched water as part of the Chesapeake Bay and its small coastal basins from the Virginia state line to the mouth of the Bay (a line from Cape Henry drawn through Buoys 3 and 8 to Fishermans Island), and its tidal tributaries, excluding the Potomac tributaries, those tributaries listed above, and the Mattaponi River upstream of Clifton, Virginia, and the Pamunkey River upstream of Sweet Hall Landing, Virginia (9VAC25-260-350). However, this provision was repealed as part of the rulemaking process described above. Under 9 VAC 25-40, a final draft “Regulation for nutrient enriched waters and dischargers within the Chesapeake Bay Watershed” has been developed to replace the previous “Policy for Nutrient Enriched Waters”. The final draft regulation will be presented to the State Water Control Board for adoption within the next few months. Additional information on the current status of this regulatory process can be found at http://www.deq.virginia.gov/bay/multi.html

1.4 Impairment Listing

DEQ’s Tidewater Regional Office maintains three water quality monitoring stations on North Branch Onancock Creek. Sufficient exceedances of Virginia's water quality standards for Dissolved Oxygen (DO) were recorded at these ambient water quality monitoring stations to assess this segment as not supporting of the Clean Water Act's Aquatic Life Use Support Goal.

Table xx: Exceedance Rates for Dissolved Oxygen determined for North Branch Onancock Creek in the 2002 and 2004 water quality assessments

Station ID	2002 Exceedance Rate	2004 Exceedance Rate
7-ONB000.20	4/29 (14%)	1/24 (4%)
7-ONB000.38	1/30 (3%)	2/24 (8%)
7-ONB000.56	7/30 (23%)	7/24 (29%)

North Branch Onancock Creek was included for a suspected dissolved oxygen impairment in Attachment B of the 1999 Federal Court Consent Decree as a “Water to be Identified to Virginia for Listing Consideration During Development of Next List”. Based on the data above, North Branch Onancock Creek was first included on Virginia’s impaired waters list in

2002. The impairment was listed again in the 2004 305(b)/303(d) Integrated Report. The segment begins at the end of tidal influence (upstream of Rt. 658) and extends downstream to the confluence with mainstem Onancock Creek.

Dissolved oxygen is a basic requirement for a healthy aquatic ecosystem. Most fish and beneficial aquatic insects "breathe" oxygen dissolved in the water column. Most desirable fish species suffer if dissolved oxygen concentrations fall below 3 to 4 mg/L (3 to 4 milligrams of oxygen dissolved in 1 liter of water, or 3 to 4 parts of oxygen per million parts of water). Many fish and other aquatic organisms can recover from short periods of low dissolved oxygen availability. When oxygen drops to about 4 mg/l, fish will begin to feel stressed and move away from the area. Below 3 mg/l, fish kills may be observed and shellfish begin to shut down. At about 2 mg/l or lower, animals living in the sediments will start to die. Exposure to less than 2 mg/l oxygen for prolonged episodes may kill most organisms, leaving only air-breathing insects and anaerobic. When a body of water experiences low levels of oxygen, the condition is known as hypoxia. When oxygen levels drop to virtually none, the condition is called anoxia.

Oxygen concentrations in the water column fluctuate under natural conditions. Severe oxygen depletion results from activities that introduce large quantities of nutrients into surface waters that promote the excessive growth of algae. When the algae die, the bacteria decomposition process uses large quantities of oxygen which can result in a net decline in oxygen concentrations in the water. Other factors (such as temperature and salinity) influence the amount of oxygen dissolved in water.

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

2.0 Watershed Characterization

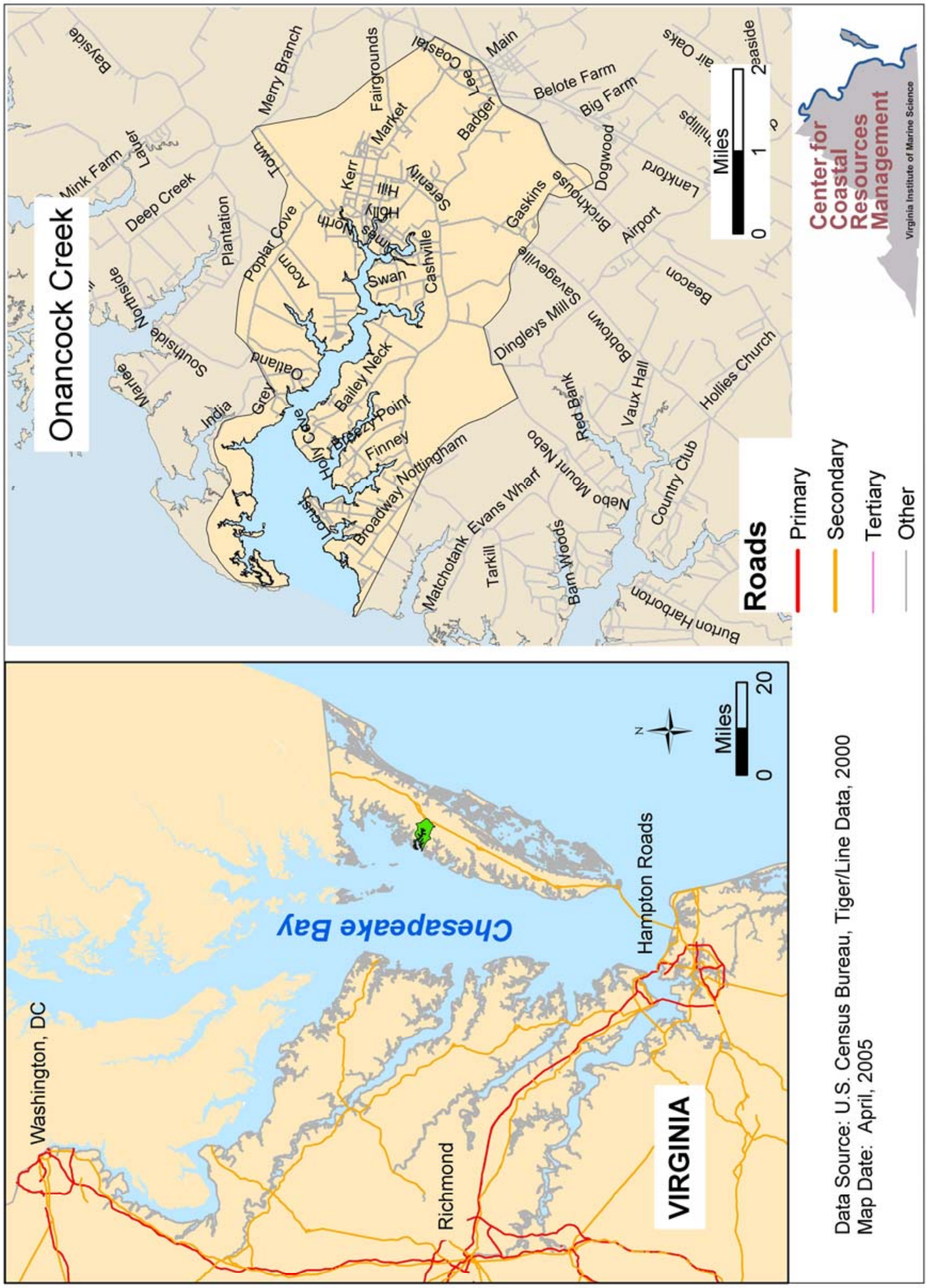
2.1 Land Use

The Onancock Creek watershed is located within Accomack County on the Eastern Shore of Virginia. The watershed occupies a landscape position along the eastern shore of the Chesapeake Bay (Figure 2.0). The watershed is roughly bounded on the north by Poplar Cove Road and India Creek, on the east by US Route 13 and Redwood Road, and on the south by a topographical high point extending from Gaskins Road toward Mt. Nebo / Dingleys Mill intersection then northwest to Cashville and Broadway Landing. The Town of Onancock and portions of the Town of Onley are located within the watershed. The drainage area of the watershed is approximately 9640 square acres or 15 square miles. The human population of the watershed estimated from the US Census 2000 is about 3250. The estimated population of the Town of Onancock is 1525 people.

A map displaying the landuse land cover in the Onancock study area is shown in Figure 2.1. The Onancock watershed is dominated by two landuse types; forest and agriculture (Figure 2.2). Some aggregation of landuse types were performed for this study to reflect the scientific understanding of role of landuse on water quality and thus parallel elements in the water quality models used in the study. The land class of uncultivated was created from a compilation of fallow agriculture fields, pasture and barren lands.

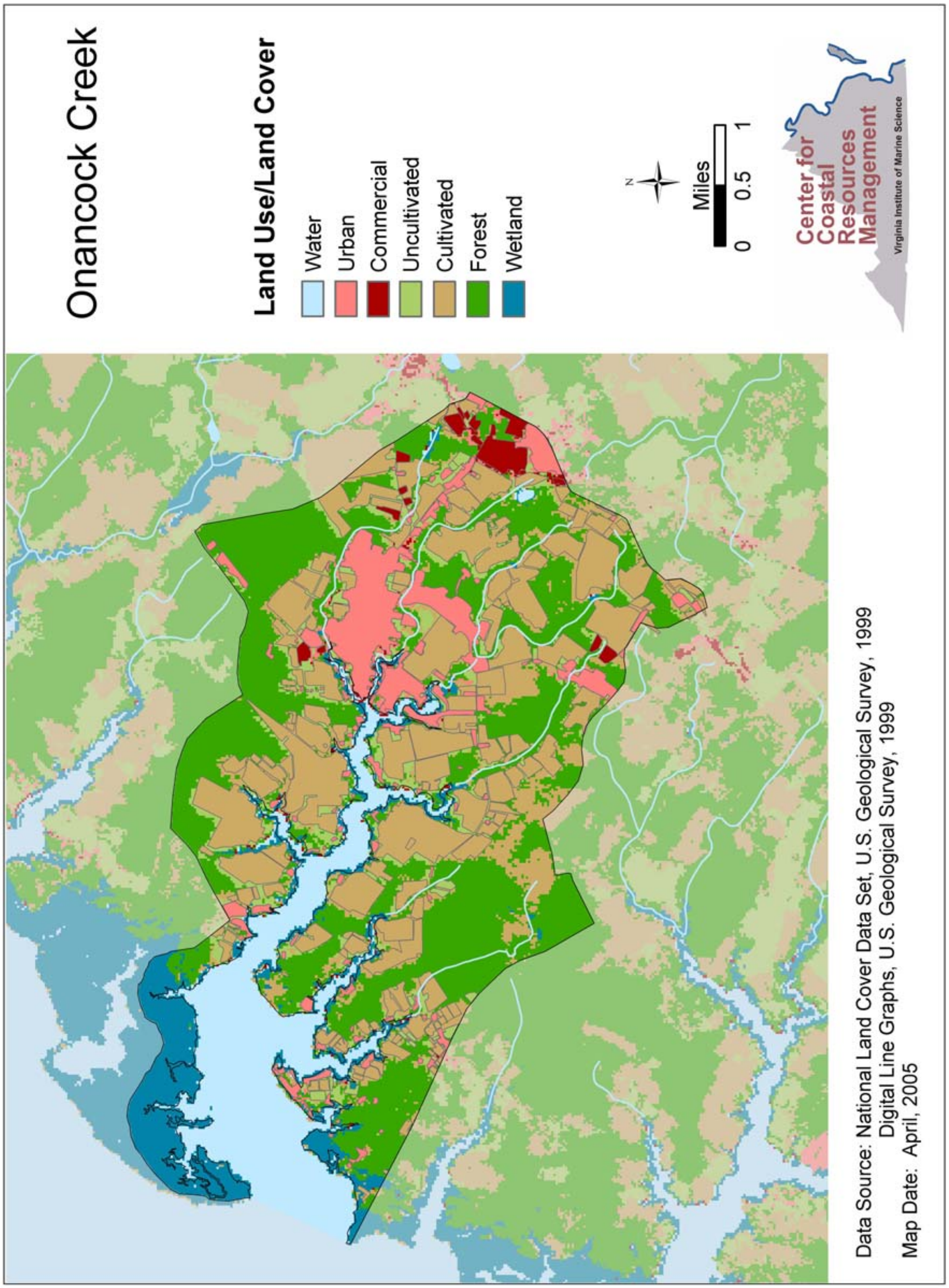
Land Use Categories for Onancock Creek TMDL Study			
Original Land Use Categories	**acres**	**Combined Land Use Categories**	**acres**
Low Intensity Residential	255	Urban	848
High Intensity Residential	593		
High Intensity Commercial/Industrial	142	Commercial	142
Deciduous Forest	536	Forest	3713
Evergreen Forest	2507		
Mixed Forest	670		
Pasture/Hay	1325	Uncultivated	1325
Row Crops	2855	Cultivated	2855
Woody Wetlands	4	Wetland	762
Emergent Herbaceous Wetlands	758		

Table 2.0 Land Use Categories: Original and Combined



Data Source: U.S. Census Bureau, Tiger/Line Data, 2000
Map Date: April, 2005

Figure 2.0 Location of Onancock Creek



Data Source: National Land Cover Data Set, U.S. Geological Survey, 1999
Digital Line Graphs, U.S. Geological Survey, 1999
Map Date: April, 2005

Figure 2.1 Land Use / Land Cover for Onancock Creek Watershed

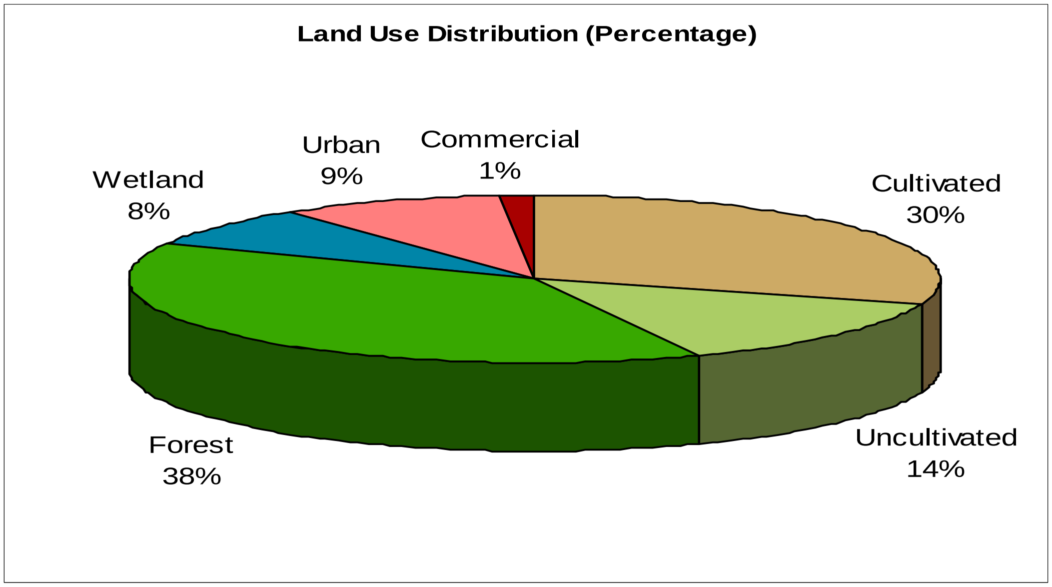


Figure 2.2 Land Use/ Land Cover Percentages Onancock Creek Watershed.

2.2 Geology and Soils

Onancock Creek watershed on Virginia's Eastern shore is in the Lowland subprovince of Coastal Plain province. The Virginia Coastal Plain is underlain by a thick wedge of sediments that increases in thickness from a featheredge near the Fall Zone to more than 4,000 meters under the continental shelf. These sediments rest on an eroded surface of Precambrian to early Mesozoic rock. Two-thirds of this wedge is comprised of late Jurassic and Cretaceous clay, sand, and gravel; they were stripped from the Appalachian mountains, carried eastward by rivers and deposited in deltas in the newly formed Atlantic Ocean basin. A sequence of thin, fossiliferous marine sands of Tertiary age overlie the older strata. They were deposited in warm, shallow seas during repeated marine transgressions across the Coastal Plain. This pattern of deposition was interrupted about 35 million years ago by a large meteorite that plummeted into a shallow sea, and created a crater more than 90 km in diameter, termed the Chesapeake Bay Impact Structure. It was subsequently buried under about 1.2 km of younger sediment. The Lowland subprovince is described as a flat, low-relief region along major rivers and near the Chesapeake Bay. Elevations of the subprovince range from 0-60 feet.

Latest Tertiary and Quaternary sand, silt, and clay, which cover much of the Coastal Plain, were deposited during interglacial highstands of the sea under conditions similar to those that exist in the modern Chesapeake Bay and its tidal tributaries.
http://www.wm.edu/geology/virginia/coastal_plain.html

2.3 Climate and Hydrology

As part of the Tidewater Climate Region, the Onancock Creek watershed experiences average January temperatures of 35-48 (F) and average July temperatures of 71-85 (F). Annual precipitation in shown in Figure 2.3 and monthly average precipitation is shown in Figure 2.4

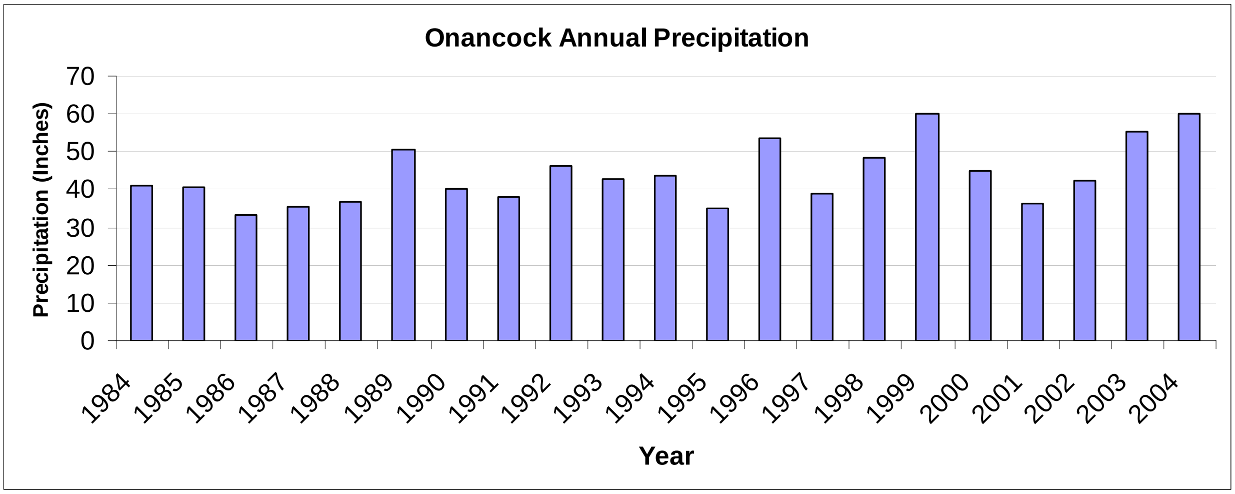


Figure 2.3 Annual precipitation 1984-2004

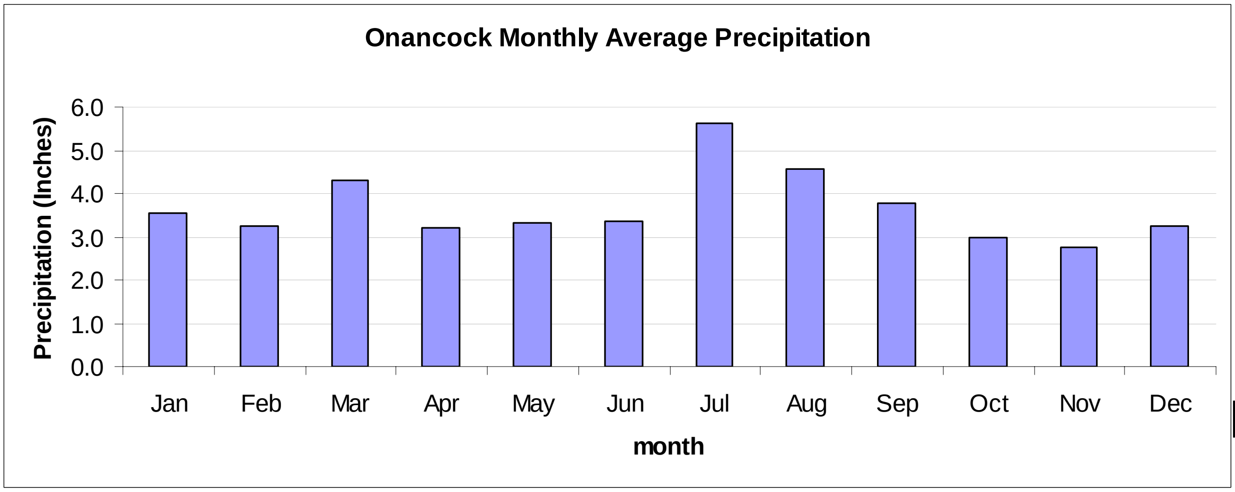


Figure 2.4 Monthly average precipitation (data from 1984-2004)

Onancock Creek is tidal in the main stem and all three branches. The tide is semi-diurnal and has a mean range of 1.8 feet. The average water depth of the creek is about 5 feet. The creek is also influenced by stream discharge, groundwater seepage and surface runoff.

On the Eastern Shore, high salt concentrations in water below a depth of 300 feet render the groundwater unpotable. Where saltwater interfaces fresh, brackish water may migrate inland as aquifers are pumped .(http://www.ext.vt.edu/pubs/farmasyst/442-901/442-901.html).

2.4 Water Quality Conditions

A. Historic Water Quality Monitoring/DEQ ambient data

The Virginia Department of Environmental Quality (DEQ) performs water quality monitoring throughout Virginia to determine if water quality standards are being met for the designated uses for the corresponding waters. DEQ has occupied a set of water quality monitoring stations in Onancock Creek covering the main stem and the three branches (North, Central and South) (Figure 2.5). Water quality samples have been taken bimonthly at the ambient water quality monitoring stations since the 1970s. Data reported here represent sampling from 1995 to 2004. A break in sampling occurred from July 2001 through March 2004. The most recent sampling measures 31 water quality parameters. The key parameters to this study are presented in this chapter.

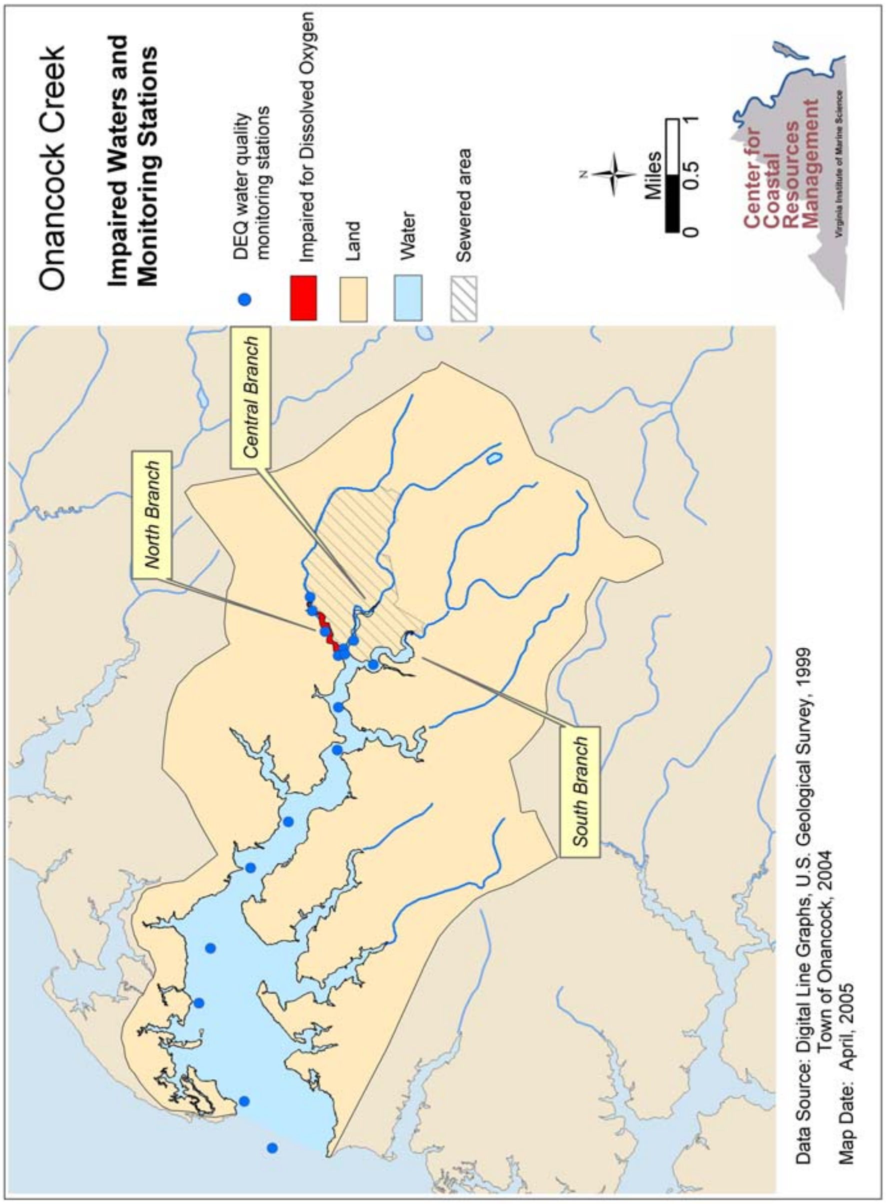


Figure 2.5 Impaired Waters and Monitoring Stations

A more detailed view of the DEQ monitoring stations and the locations of sampling locations specific to the Onancock TMDL study are shown in Figure 2.6.

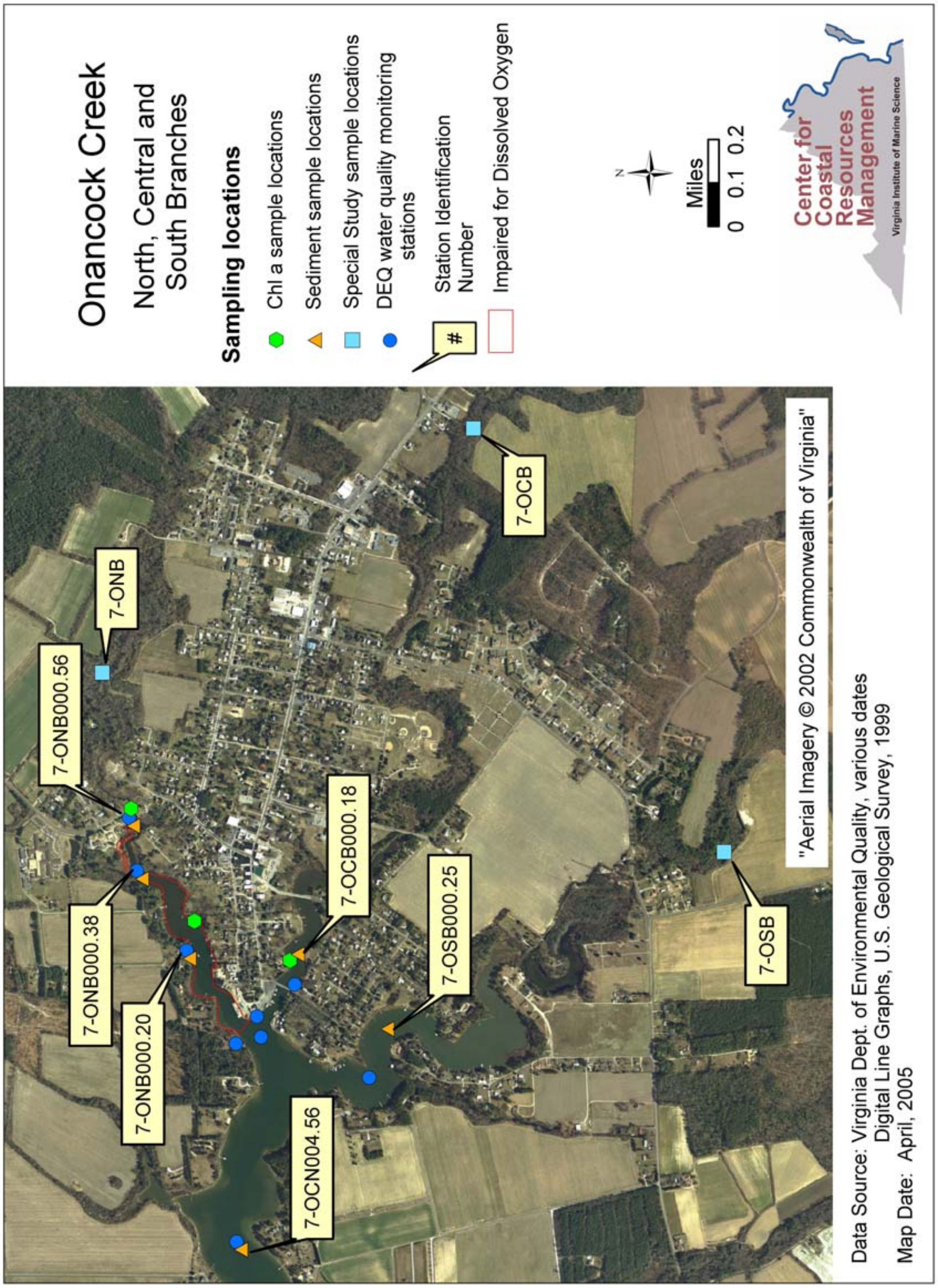


Figure 2.6 Sampling locations and monitoring stations

Table 2.1 details the station identification, location and type of samples collected for data used in the Onancock Creek TMDL study. These stations include those that are sampled as part of the ambient water quality sampling program at DEQ, and special study locations sampled by DEQ and VIMS.

Station ID	Station Location	Station Type	Data Type	Period of Record	Sampling Frequency
7-ONB000.56	North Branch Rt. 658	DEQ water quality monitoring	water quality	10/95 - 8/04	bimonthly
		Sediment samples	sediment	3/30/05	once
		Chl a samples	chlorophyll a	10/04	once
7-ONB000.56A		Special study samples	water quality	2/28/05	once
7-ONB000.38	North Branch Vicinity STP	DEQ water quality monitoring	water quality	10/95 - 8/04	monthly
		Sediment samples	sediment	2/26/04; 3/30/05	twice
7-ONB000.20	North Branch	DEQ water quality monitoring	water quality	10/95 - 8/04	bimonthly
		Sediment samples	sediment	2/26/04; 3/30/05	twice
7-ONB000.20A	North Branch	Chl a samples	chlorophyll a	7/04 - 11/04	
7-ONB	North Br. Nontidal	Special study samples	water quality	2/28/05; 4/19/05	twice
7-OCB000.18	Central Branch	Chl a samples	chlorophyll a	10/04 - 11/04	
		Sediment samples	sediment	2/26/04; 3/30/05	twice
7-OCB	Central Br. Nontidal	Special study samples	water quality	2/28/05; 4/19/05	twice
7-OSB000.25	South Branch	Sediment samples	sediment	2/26/04; 3/30/05	twice
7-OSB	South Br. Nontidal	Special study samples	water quality	2/28/05; 4/19/05	twice
7-OCN004.56	Mainstem Creek	DEQ water quality monitoring	water quality	2/73 - 8/04	bimonthly
		Sediment samples	sediment	3/30/05	once

Table 2.1 Onancock Creek stations by sample type and location

The North Branch of Onancock Creek shows DO levels below the water quality standard levels of 4 mg/L minimum and 5 mg/L average repeatedly throughout the sampling period of record (Figure2.7). There is a strong seasonal variation to the DO with the lowest values often occurring in the summer (Figure 2.8). The lowest levels of DO are recorded at station 7-ONB000.56 which is located at the head of the North Branch. (See Figure 2.6 for a detailed map of station locations.)

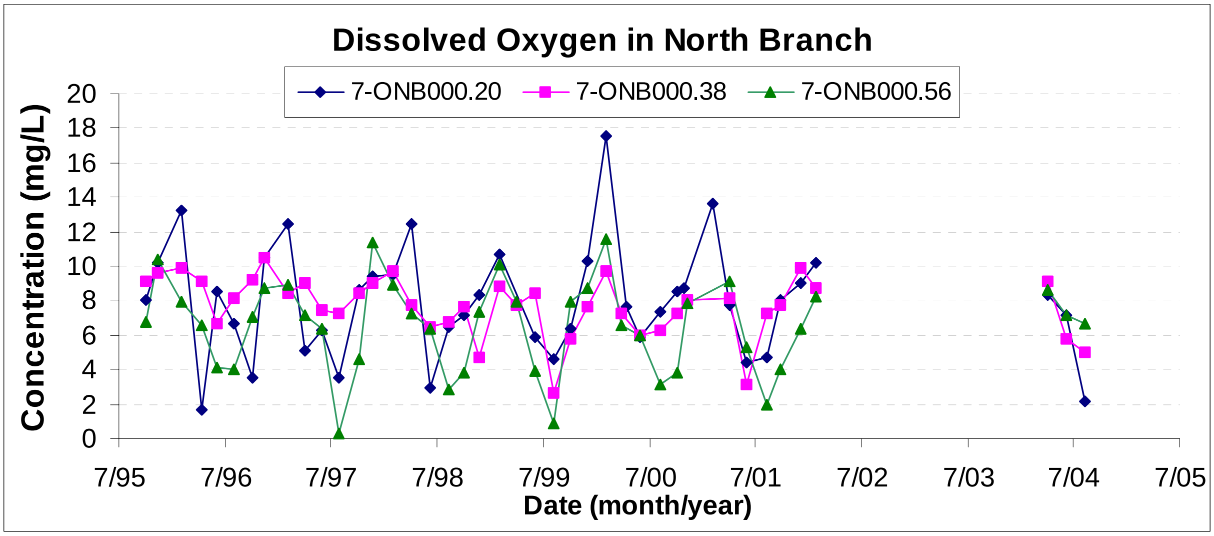


Figure 2.7 Dissolved Oxygen North Branch Onancock Creek

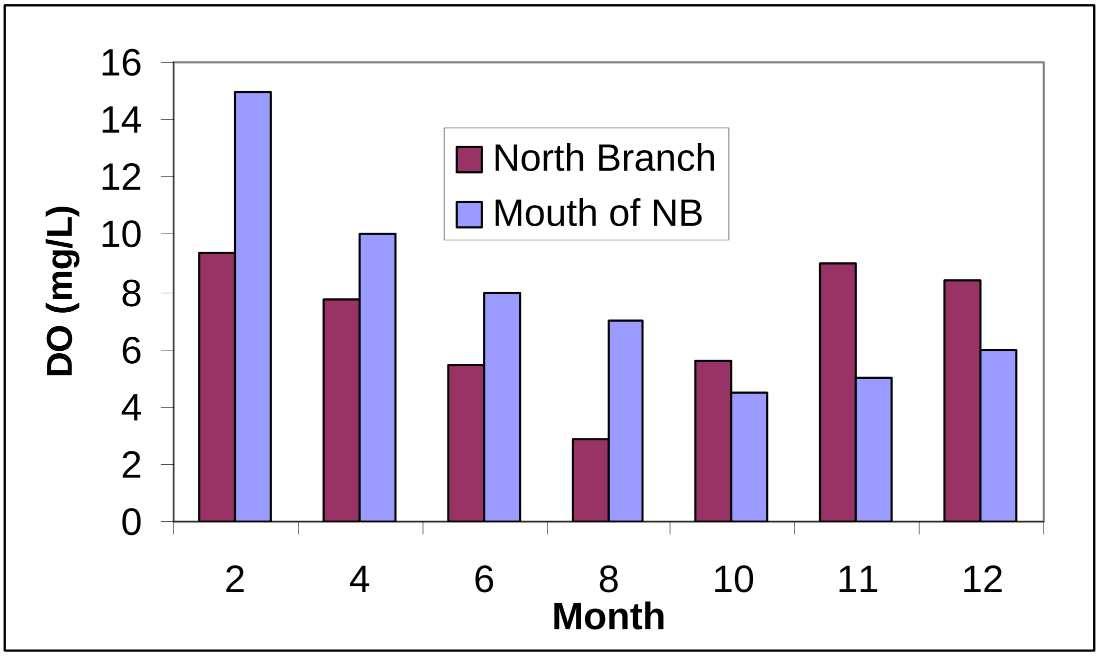


Figure 2.8 Average monthly DO North Branch Onancock Creek

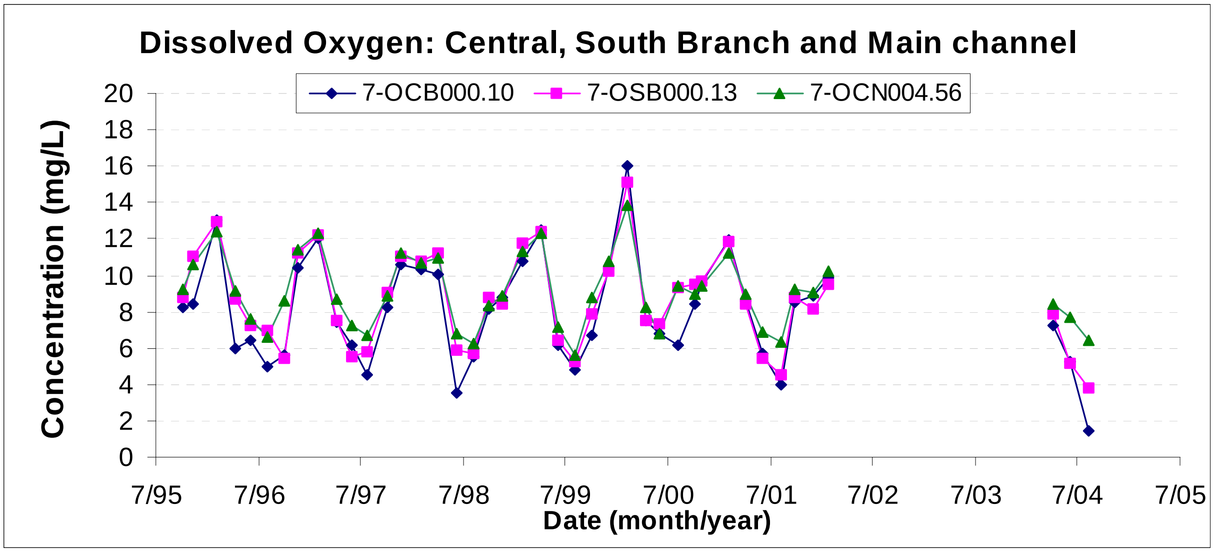


Figure 2.7 Dissolved Oxygen: Central, South and Main Stem Onancock Creek

Biochemical oxygen demand, BOD_5, is a measure of the amount of oxygen consumed in the biological processes that break down organic matter in water. BOD is used as an indirect measure of the concentration of biologically degradable material present. It usually reflects the amount of oxygen consumed in five days by biological processes breaking down organic matter. The test is considered to represent the amount of organic carbon available in the sample, but may include some nitrogenous and phosphorus based organic material unless the consumption of these materials are chemically inhibited. BOD can also be used as an indicator of pollutant level, where the greater the BOD, the greater the degree of pollution.

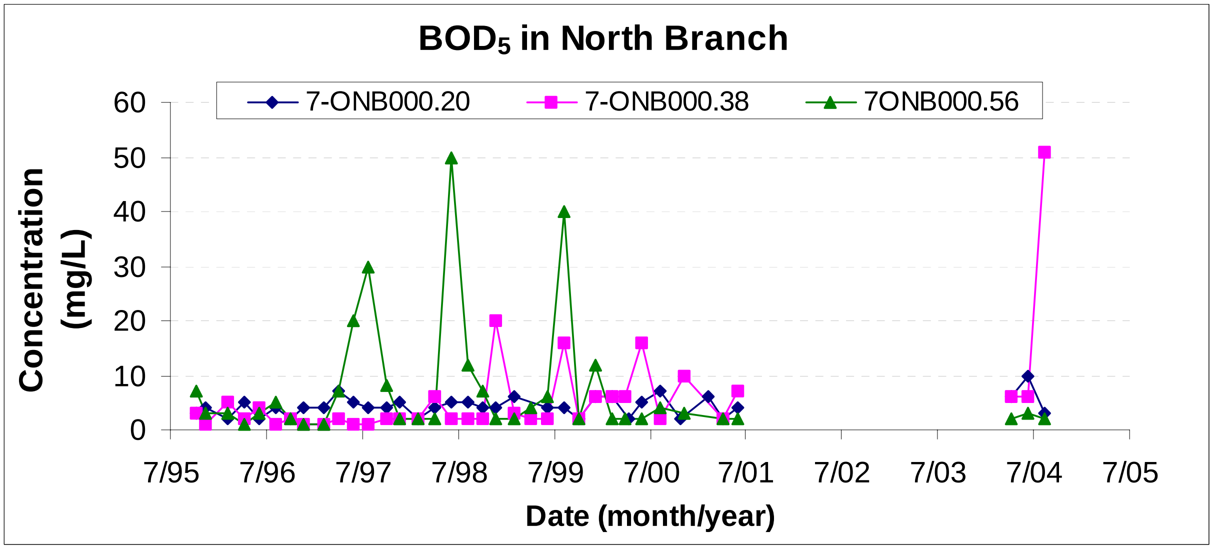


Figure 2.8 Biochemical Oxygen Demand: North Branch Onancock Creek

The nutrients nitrogen (N) and phosphorus (P) are elements, and are essential building blocks for plant and animal growth. Nitrogen is an integral component of organic compounds such as amino acids, proteins, DNA and RNA. Most of the earth's atmosphere (~78%) is made of di-nitrogen gas (N_2). Nitrogen exists in water both as inorganic and organic species, and in dissolved and particulate forms. Total nitrogen (abbreviated TN) is a measure of all forms of dissolved and particulate nitrogen present in a water sample.

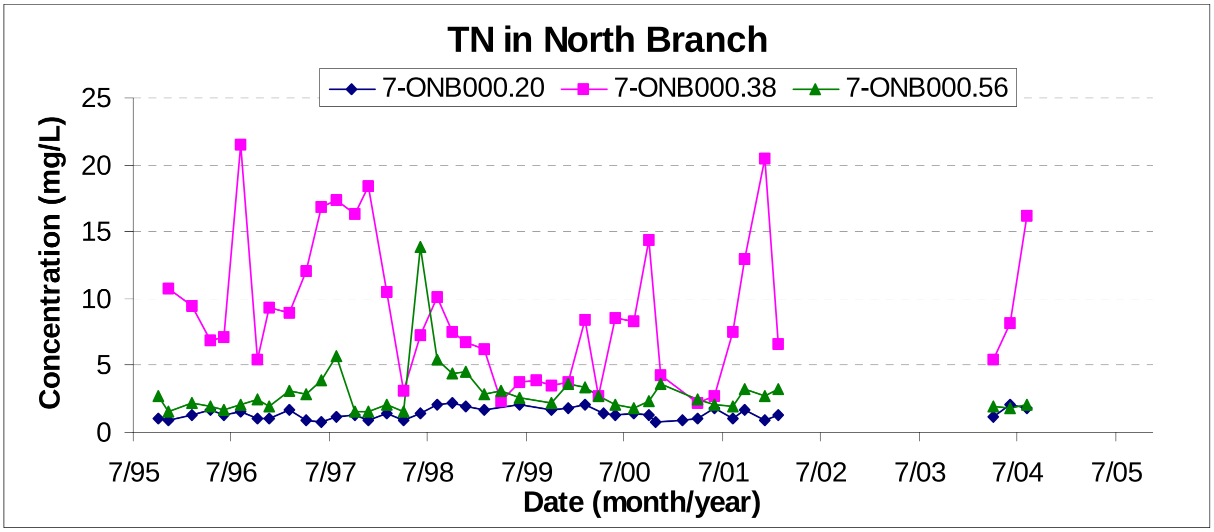


Figure 2.10 Total Nitrogen: North Branch Onancock Creek

Phosphorus is found in nucleic acids and certain fats (phospholipids). Phosphorus is a common element of igneous rocks. Phosphorus is found in waterbodies in dissolved and particulate forms. Total phosphorous (abbreviated TP) is a measure of all the various forms of phosphorus (dissolved and particulate) found in water.

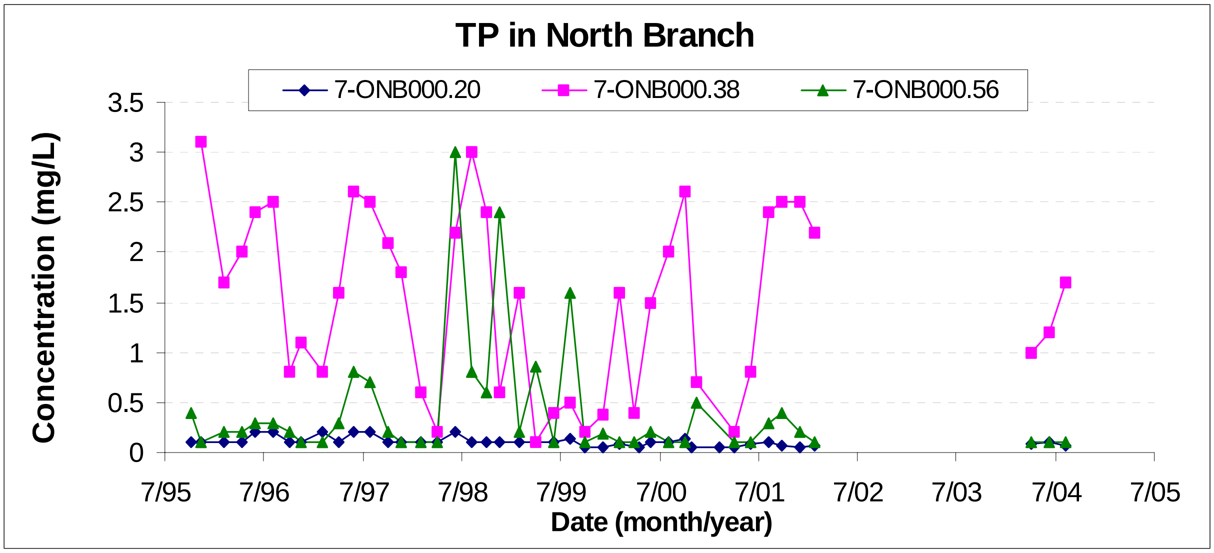


Figure 2.11 Total Phosphorus: North Branch Onancock Creek

Temperature and salinity for the North Brach of Onancock creek is shown in Figures 2.12 and 2.13, respectively.

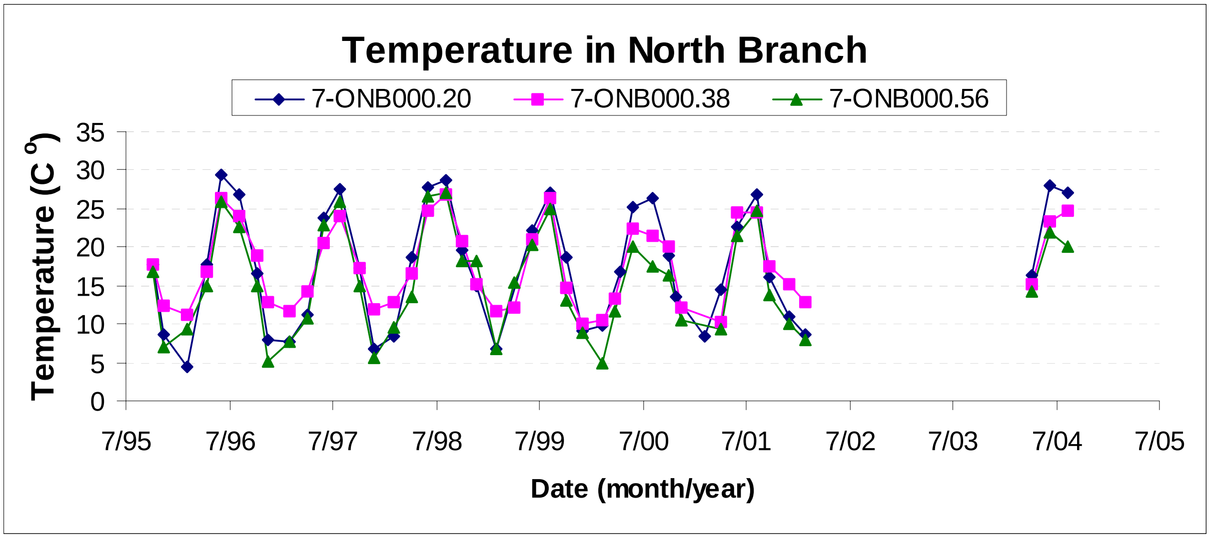


Figure 2.12 Temperature: North Branch Onancock Creek

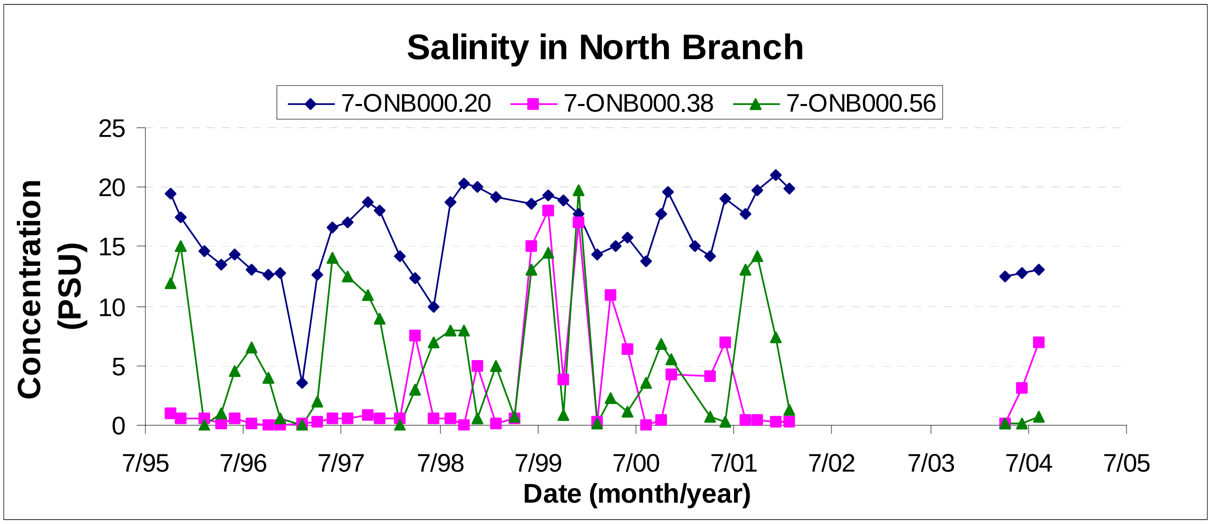


Figure 2.13 Salinity: North Branch Onancock Creek

B. Recent Data Collection Efforts

During the course of this study and the calibration and validation of the models, a determination was made for the need of additional data. The additional data was generated from samples collected by VIMS and the Tidewater Regional Office, DEQ. Sampling site locations are identified in Figure 2.6. To collect more DO data, an automatic Hydrolab^{TM} was deployed in the North Branch in the summer of 2004. Some results are shown in Figure 2.11. The continuous data show a strong diurnal DO variation. While the expectation is that the warmer daytime water temperatures would be associated with the lowest DO levels, the opposite is the case. Dissolved oxygen concentrations vary from nearly 0 mg l^{-1} at night to 12 mg l^{-1} during the daytime. The DO was supersaturated during the day but was quickly used up during the night. The supersaturated DO during the daytime is mainly caused by algal photosynthesis, while it is heavily consumed by both respiration and decomposition during the night. This type of diurnal DO phenomena suggested the water was in the "eutrophic" state during the sampling period.

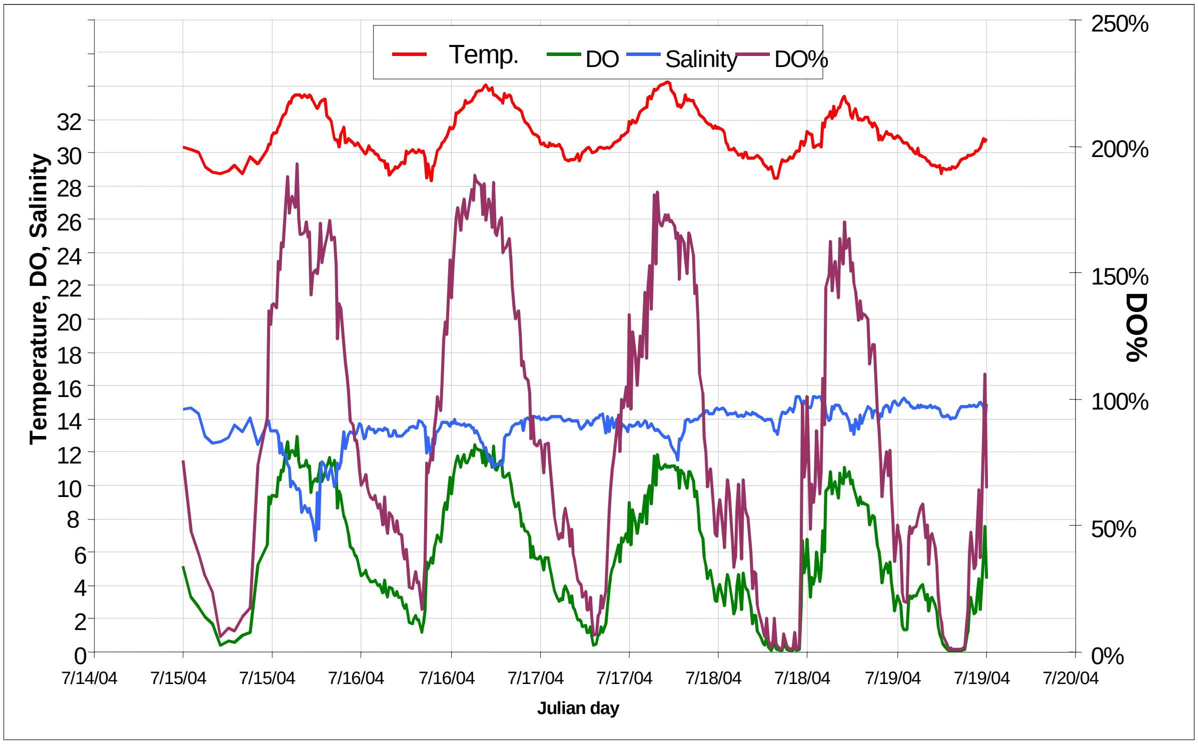


Figure 2.11 4-day continuous observation records of water temperature, DO, DO saturation, and salinity, July 15, 2005- July 19, 2005

Sediment samples were taken from the North, Central and South Branches in 2004 and are shown in Table 2.2. Sediment samples were collected from locations coincident with ambient water quality monitoring stations in the North, Central, South and Mainstem in 2005. These data are shown in Table 2.3.

Location	NITROGEN AMMONIA (mg/KG)	NITROGEN ORGANIC (mg/KG)	PHOSPHORUS ORGANIC (mg/L AS P)	PHOSPHORUS INORGANIC (mg/KG)	ORGANIC CARBON (g/KG)	CARBON SUSPENDED INORGANIC (mg/KG)
7-ONB000.38 North Branch	27.2	1374	115	95.1	39.1	210
7-ONB000.20 North Branch	38	1256	49	95	50.4	144
7-OCB000.18 Central Br.	8.2	372	26.2	30.6	4.9	56.8
7-OSB000.25 Southern Br.	5.4	1687	81.4	92.6	45.7	174

Table 2.2 Sediment data from samples collected February 2004

Location	NITROGEN AMMONIA (mg/KG-N)	NITROGEN ORGANIC (mg/KG-N)	NITRITE PLUS NITRATE (mgKG-N)	PHOS. TOTAL (mg/KG-P)	PHOS. INORGANIC (mg/KG-P)	PHOS. ORGANIC (mg/KG-P)	CARBON ORGANIC (g/KG-C)
7-ONB000.56 North Branch	14	1600	1.7	400	260	140	32.6
7-ONB000.38 North Branch	16	2300	2.5	510	340	170	23.0
7-ONB000.20 North Branch	38	4300	6.3	610	340	270	51.7
7-OCB000.18 Central Br.	44	3200	3.2	540	290	250	47.6
7-OSB000.25 Southern Br	17	3500	2.8	500	240	260	37.1
7-OCN004.56 Main stem	72	2500	2.6	410	190	220	28.3

Table 2.3 Sediment data from samples collected March 2005

Chlorophyll is the pigment that allows plants, including algae, to convert sunlight to organic compounds through the process of photosynthesis. Of several types of chlorophyll, chlorophyll a is the predominant type in algae. The measurement of chlorophyll a serves as a surrogate for the difficult process of measuring actual algal biomass. As such, high chlorophyll a values are indicative of dense algal blooms or high levels of algae production. Chlorophyll a samples were collected from the North and Central Branches in Fall 2004 (Table 2.3). Very high values were found in samples taken from the shallow waters of the North Branch indicating dense algal populations.

Station	Sample date	Chl a (ug/L)
7-ONB000.56A North Branch	10/13/2004	785.5
7-ONB000.20A North branch	7/7/2004	751.0
7-ONB000.20A North branch	10/12/2004	22.8
7-ONB000.20A North branch	10/12/2004	64.3
7-ONB000.20A North branch	10/13/2004	41.5
7-ONB000.20A North branch	11/1/2004	42.0
7-ONB000.20A North branch	11/5/2004	7.0
7-ONB000.20A North branch	11/10/2004	27.0
7-ONB000.20A North branch	11/15/2004	2.0
7-ONB000.20A North branch	11/22/2004	82.7
7-ONB000.20A North branch	11/29/2004	20.5
7-OCB000.18 Central branch	10/12/2004	15.9
7-OCB000.18 Central branch	10/12/2004	26.9
7-OCB000.18 Central branch	10/13/2004	40.3
7-OCB000.18 Central branch	11/1/2004	13.0
7-OCB000.18 Central branch	11/5/2004	4.7
7-OCB000.18 Central branch	11/10/2004	4.3
7-OCB000.18 Central branch	11/15/2004	32.7
7-OCB000.18 Central branch	11/22/2004	68.0
7-OCB000.18 Central branch	11/29/2004	5.5

Table 2.3 Chlorophyll a samples, Fall 2004

Water quality samples were taken at the headwaters of all three branches in Winter and Spring of 2005. Data from these collections provide information on the nutrient and organic contribution of stream flow from the headwaters of Onancock Creek. The samples taken in Winter 2005 (shown in Table 2.4) were collected at the end of a rain event and are possibly indicative of storm water contributions. Samples collection in April 2005 were specifically timed to avoid rain events in an effort to represent the typical base flow condition.

Sampling Location	NITROGEN AMMONIA (mg/L as N)	NITRITE NITROGEN (mg/L as N)	NITRATE NITROGEN (mg/L as N)	NITROGEN KJELDAHL (mg/L as N)	PHOSPHORUS (mg/L as P)	CARBON ORGANIC (mg/L as C)	PHOSPHORUS ORTHO (mg/L as P)
7-ONB North Branch	0.08	0.01	1.47	0.7	0.08	5.1	0.02
7-ONB000.56 North Branch	0.04	0.01	0.04	0.8	0.19	7	0.02
7-OCB Central Branch	0.1	0.01	0.72	0.8	0.15	11	0.02
7-OSB South Branch	0.04	0.01	1.67	0.2	0.02	3.6	0.02

Table 2.4 Water quality samples post rain event collected above head of tide North, Central and South Branches; February 28, 2005

Sampling Location	NITROGEN AMMONIA (mg/L as N)	NITRITE NITROGEN (mg/L as N)	NITRATE NITROGEN (mg/L as N)	NITROGEN KJELDAHL (mg/L as N)	PHOSPHORUS (mg/L as P)	CARBON ORGANIC (mg/L as C)	PHOSPHORUS ORTHO (mg/L as P)
7-ONB North Branch	0.05	0.01	1.52	0.6	0.06	4.9	0.02
7-OCB Central Branch	0.05	0.01	1.52	0.3	0.02	3.3	0.02
7-OSB South Branch	0.04	0.01	2.28	0.4	0.02	4.2	0.02

Table 2.4 Water quality samples dry weather event collected above head of tide North, Central and South Branches; April 19, 2005

3.0 Source Assessment

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

3.1 Permitted

A. Onancock STP Discharge Monitoring Reports Summary

The Onancock Wastewater Treatment Plant, which treats most of the domestic sewage from the Town of Onancock, is located at the head of North Branch with its final outfall coincident with the VA DEQ station 7-ONB000.38. Samples are collected regularly from the Onancock Sewage Treatment Plant (STP) to measure compliance with the Virginia National Pollution Discharge Elimination System (VPDES) permit. The permit effluent limits for DO, BOD_5, and TSS are 6.5 mg l^{-1}, 10.0 mg l^{-1}, and 10.0 mg l^{-1}, respectively. According to the historical Discharging Monitoring Report (DMR), the effluent water qualities in terms of DO, BOD_5 and TSS were very good and met the limits most of the time. However, the effluent nutrient concentrations were high (e.g., TN > 9 mg l^{-1} and TP > 3 mg l^{-1}). There are currently no specified limits for nutrients. Samples where collected during 2004 to determine the nutrient content of the STP effluent (Table 3.0).

Collection Date	AMMONIA Total (mg/L as N)	NITRITE Total (mg/L as N)	NITRATE Total (mg/L as N)	NITROGEN Total Kjeldahl (mg/L as N)	PHOSPHORUS Total (mg/L as P)	PHOSPHORUS ORTHO (mg/L as P)	Flow (MGD/Day)
3/29/2004	0.27	0.23	5.62	1.7	2.4	2.5	0.20
4/21/2004	1.44	0.15	2.85	2.4	1	0.9	0.28
5/25/2004	0.87	0.17	4.20	2.3	2.2	2.13	0.17
6/23/2004	0.54	0.21	16.1	1.9	3	2.6	0.20
7/27/2004	0.28	0.15	9.56	1.7	1.9	1.76	0.29
8/25/2004	0.17	0.13	3.66	0.9	1.2	1.07	0.32
9/22/2004	0.86	0.12	4.47	2.0	1	0.89	0.21
Mean	0.63	0.17	6.64	1.84	1.8	1.69	0.24

Table 3.0 Onancock STP Effluent Data: 2004

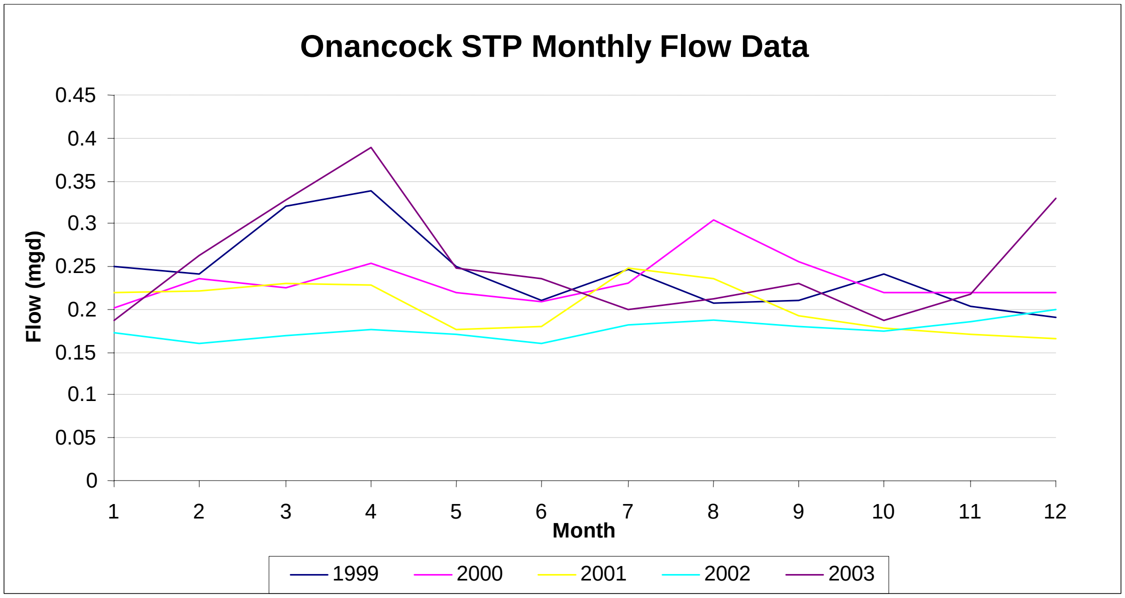


Figure 3.0 Flow data from the Onancock STP 1999-2003

3.2 Non-permitted

Non-permitted sources of nutrients do not have one discharge point but may occur over the entire length of the receiving water. Often referred to as non-point source pollution, these are pollution sources that are diffuse, without a single identifiable point of origin During rain events, surface runoff transports water and nutrients and discharges to the waterway. Nutrients delivered via runoff may originate from all land use /land cover categories. In the residential landscape (identified as urban and commercial in the land use description), nutrients may be introduced from residential land use practices, ie. fertilizer applications, failing septic systems and pet wastes. In the agricultural landscape, sources of nutrients can include crop applications, failing septic systems, livestock and pet waste. Contributions from wildlife, both mammalian and avian, are natural conditions associated primarily with undeveloped (forest and wetlands), but to some extent all land uses, and represent a background level of nutrient loading. There are some nutrient loads to the waterway from undeveloped lands considered to be background.

A. Population number summaries

Population numbers for livestock and wildlife are shown in Table 3.1. Human and dog populations estimates are shown in Table 3.2. Data sources for human and livestock numbers and an explanation of the pet and wildlife numbers is found in Appendix C. For purposes of this study it was necessary to estimate the populations for the North, Central, South Branches and those areas in the Onancock Creek watershed outside the three branches (Other). Figure 3.1 displays the watershed locations that correspond to the population data.

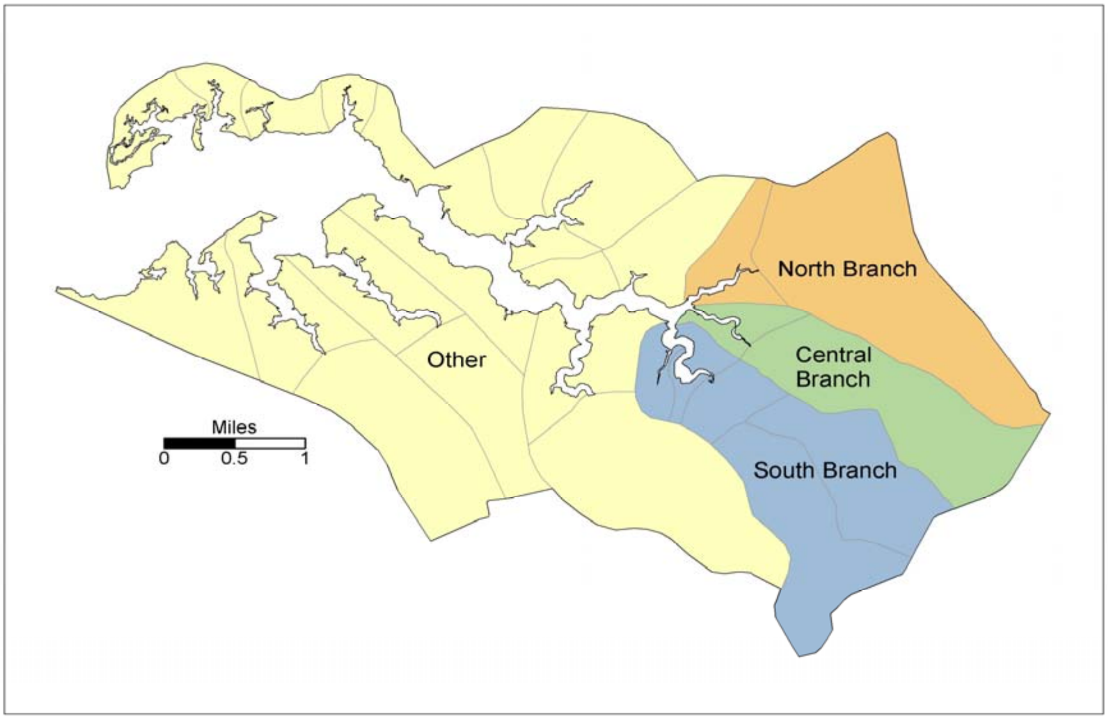


Figure 3.1 Watersheds for North, Central, South Branches and the remaining Onancock Creek area

Livestock						Wildlife			
Watershed Area	**Cattle**	**Swine**	**Horse**	**Sheep**	**Chicken**	**Duck**	**Geese**	**Deer**	**Raccoon**
North	<5	<5	<5	<5	0	50-75	25-50	50-75	50-75
Central	<5	<5	<5	<5	0	25-50	<25	<25	25-50
South	<5	10-15	<5	<5	168000*	50-75	25-50	50-75	50-75
Other	5-10	15-20	<5	<5	0	675-700	500-525	150-175	200-225
					* These are contained in a chicken house.				

Table 3.1 Livestock and Wildlife populations by watershed

Watershed Area	People	Dogs
North	960	190
Central	1150	220
South	530	100
Other	610	120

Table 3.2 Human and Dog populations by watershed

B. Septic system inputs

Septic tank systems normally consist of two main components: a treatment unit (septic tank) and a disposal unit (soil absorption system). A properly designed septic tank consists of a buried, watertight, multiple-compartment tank, equipped with inlet and outlet devices. The absorption system consists of one or more trenches containing crushed rock or gravel overlaid by a system of perforated pipes. The wastewater is then discharged through the perforated distribution piping and allowed to percolate into the soil. The soil provides secondary treatment by allowing micro-organism inhabitants to feed on the nutrients and bacteria in the waste water. Conventional septic tank systems are only effective where the soil is adequately porous to allow percolation of liquids, and the groundwater level is low enough to avoid contamination. Leaking pipes or treatment tanks (i.e., leakage losses) can allow wastewater to return to the groundwater, or discharge to the surface, without adequate treatment. Leaking septic systems are a source of nitrogen from human wastes and phosphorus from machine dishwashing detergents and some chemical water conditioners. Numbers of septic systems in the Onancock watershed, by subwatershed, are shown in Table 3.3. A location map is shown in Figure 3.2.

Septic Systems			
Subwatershed	**Total Septic System Numbers**	**Failing Ratio**	**Number of Failed Systems**
North Branch	98	12%	12
Central Branch	205	12%	25
South Branch	147	12%	18
Other	242	12%	29

Table 3.3 Number of total septic systems and failed systems for the Onancock watershed. Failure rate based on literature values.

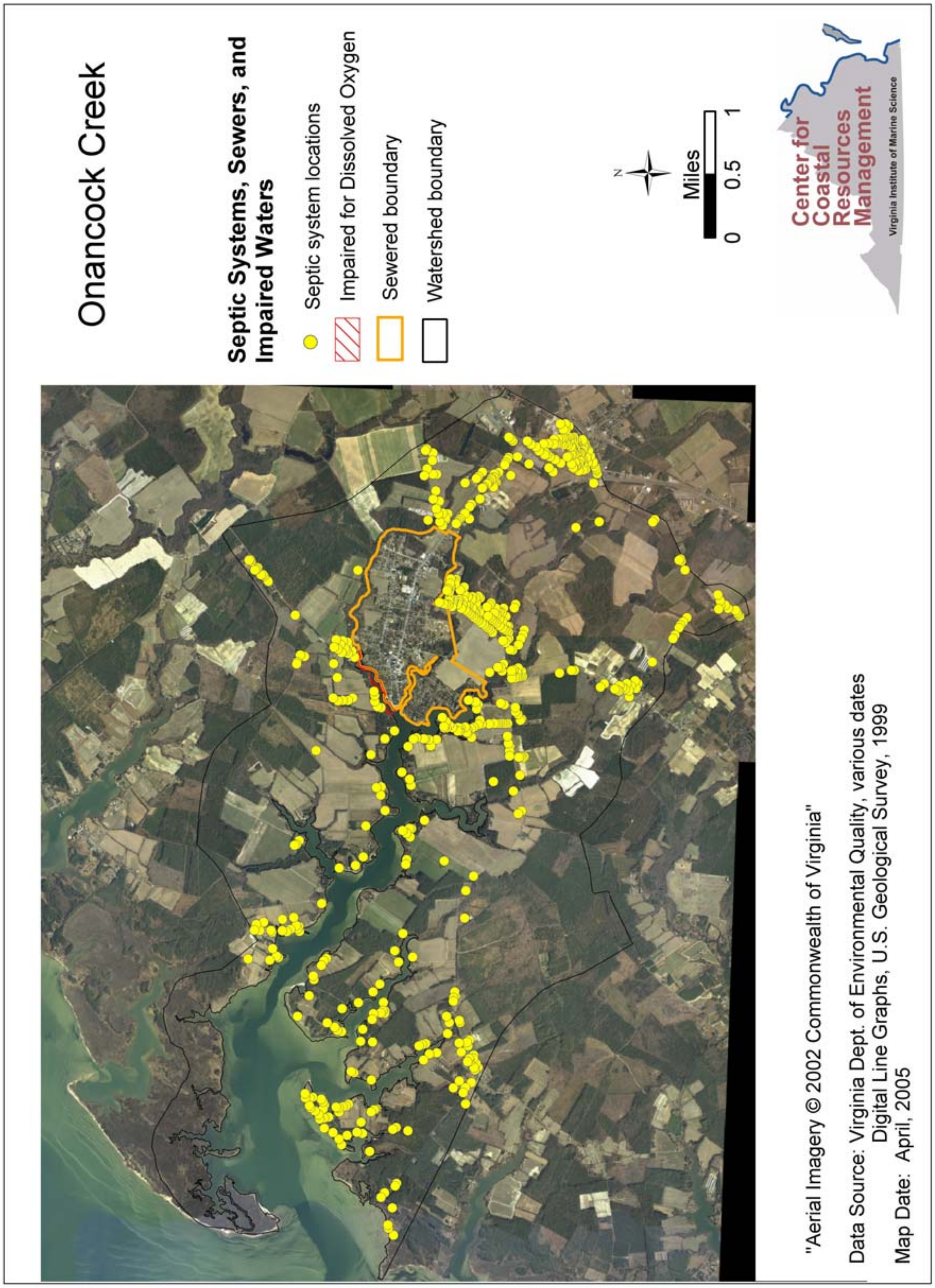


Figure 3.2 Septic system locations and area with sewer: Onancock Creek

C. Manure/litter/fertilizer applications

Farming practices are a source of nutrient contributions to the creek. Organic manure and litter and inorganic fertilizer are applied to croplands. When they are applied in excess of plant needs or just before a rain event, nutrients can wash into aquatic ecosystems. For purposes of developing a value for the potential source of nutrients from fertilizer application to croplands, we assumed one application rate for the watershed. Based on local information the estimated amount of N-fertilizer applied to the cropland is 125 lb/acre/year. From the same information, the rate of chicken manure application is 1-2 tons/acre. Lawn fertilizer loading is 44 lbs/acre using a literature value for the Chesapeake Bay region (with a ratio of nutrients of N:P = 70:30).

C. Other Sources

Inputs from groundwater are another source of nutrients to Onancock Creek. Specific values are not available for Onancock; however, a study in Cherrystone Inlet and other locations on the Eastern Shore provide a range of values for total Nitrogen of 2.0 - 7.0 mg/L and total Phosphorus of 0.02 - 0.03 mg/L

Atmospheric deposition of air-borne nutrients has been estimated using the value from the literature for the Chesapeake Bay region shown in Table 3.4.

Nutrient	Loading (lb/acre/year)
Total Nitrogen	11.48
Total Phosphorus	0.71

Table 3.4 Nutrient contribution from atmospheric deposition

D. Nutrient and BOD loads summary

As the building blocks for biotic production, nitrogen, phosphorus and carbon are used in the process of algal growth, and then become available again as the algae die and decay. The natural processes of biotic decay result in the consumption of oxygen. However, excessive levels of decaying material will result in unacceptability low levels if dissolved oxygen. Nitrogen and phosphorus background, or natural, levels can vary depending upon the location, hydrology and geology of the watershed. The critical determination in identifying the necessity and amount of nutrient reductions is defining the relationship between the nutrients and the target levels for dissolved oxygen. Quantifying the total loads for the nutrients is necessary to understanding the effects of various nutrient loads on dissolved oxygen. Total load numbers are also needed to develop scenarios to model reductions in nutrient inputs to analyze the effect of the reduction on dissolved oxygen. The goal is to identify the nutrient loads that result in ambient concentrations which support the target standard for dissolved oxygen. Total loads for the three braches on Onancock Creek, and the Sewage Treatment Plant, are shown in the following charts.

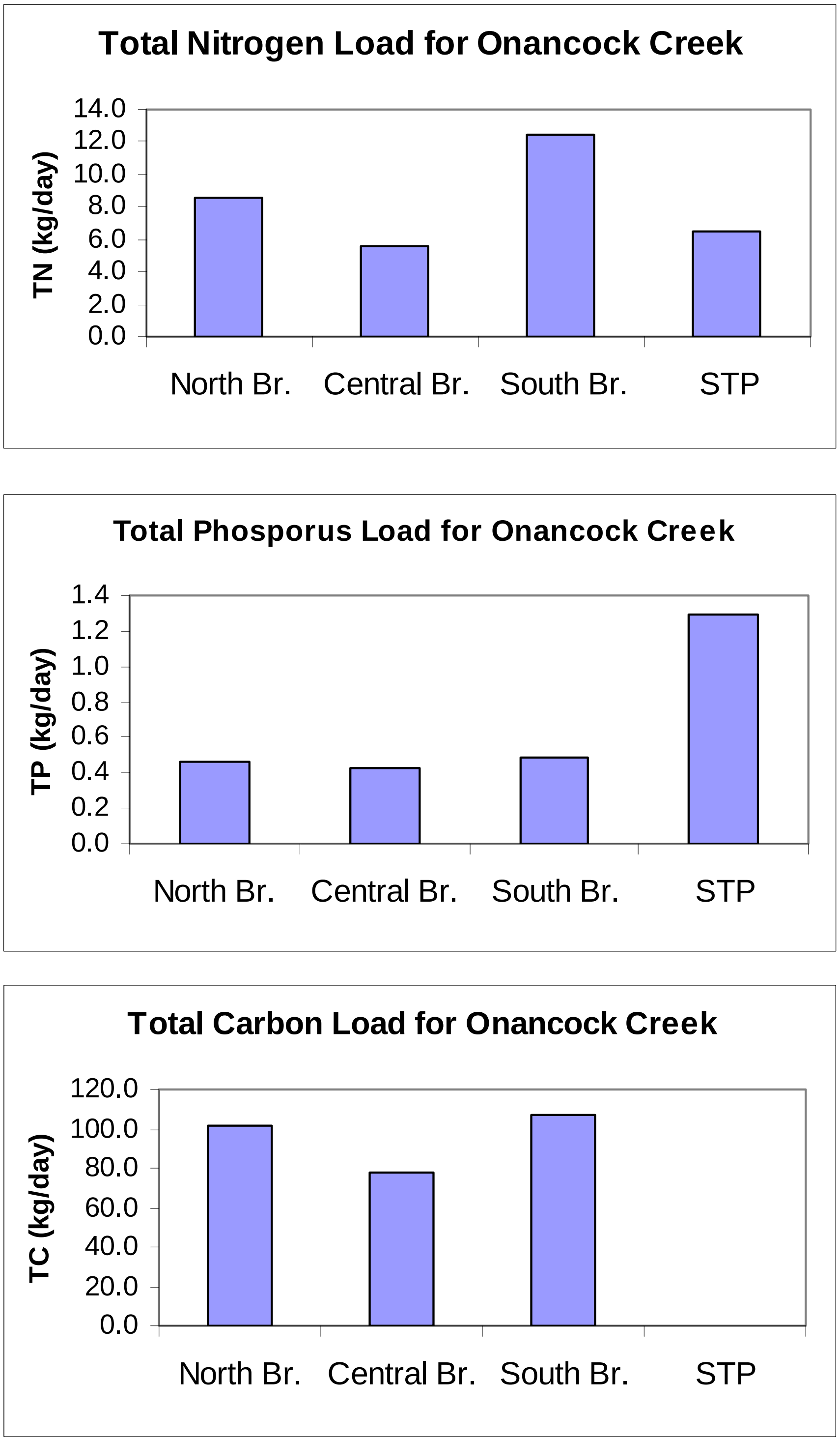


Figure 3.3 Total loadings for Nitrogen, Phosphorus and Carbon to Onancock Creek reported by branch and for the Sewage Treatment Plant

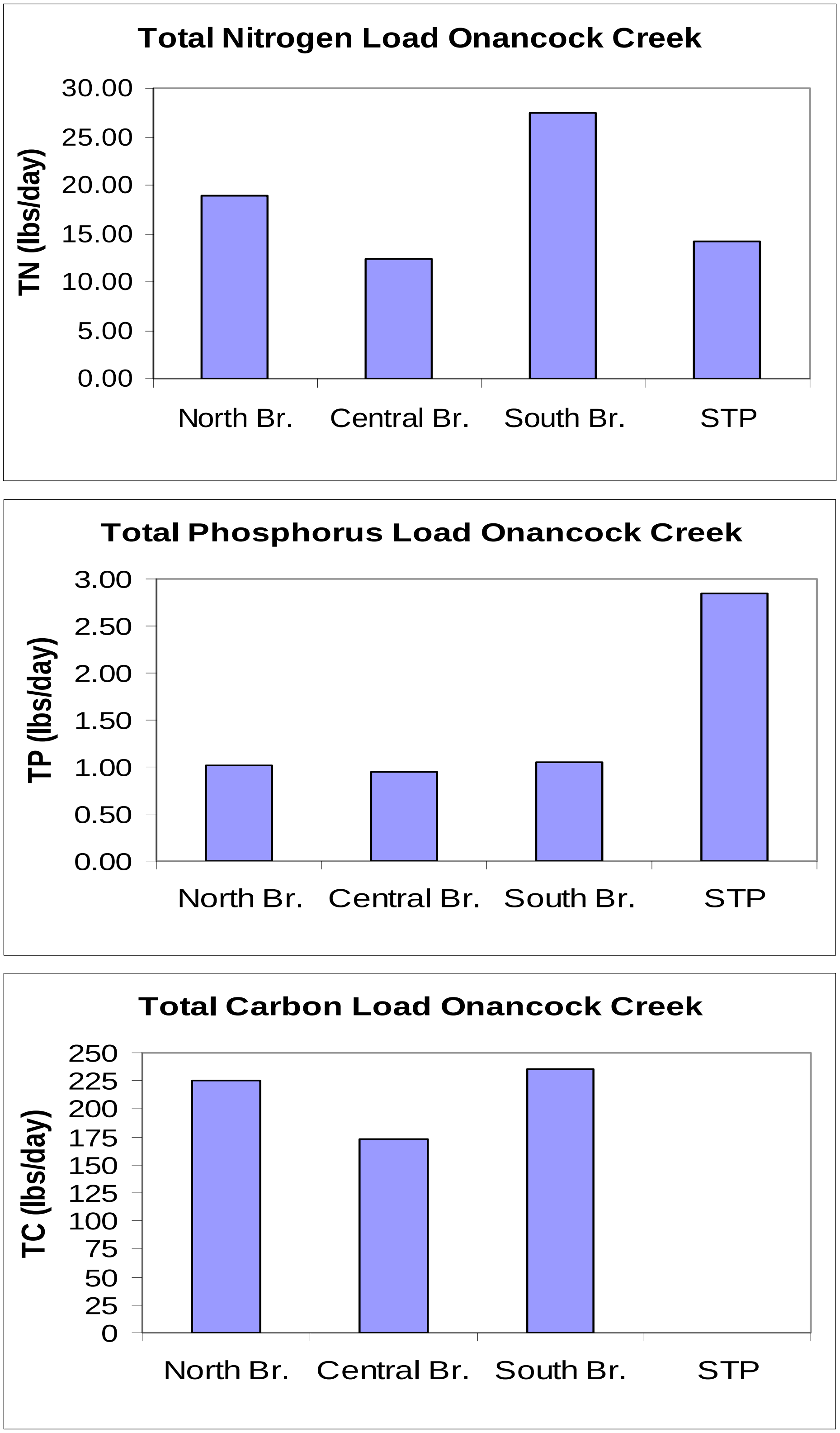


Figure 3.3 Total loadings for Nitrogen, Phosphorus and Carbon to Onancock Creek reported by branch and for the Sewage Treatment Plant

4.0 TMDL Model Development for Dissolved Oxygen

Numerical models are a widely used approach for TMDL studies. In this study, a system of numerical models was developed to simulate the loading of organic matter and nutrients from the watershed, and the resulting response of in-stream water quality variables such as DO, algae, and nutrients. The modeling system consists of two individual model components: the watershed model and the hydrodynamic-water quality model. The watershed model Loading Simulation Program in C^{++} (LSPC), developed by the US EPA, was selected to simulate the watershed hydrology and nutrient loads to the receiving water bodies of Onancock Creek. The EFDC, as modified by Park et al., 1995 was used to simulate the water quality of the receiving water. A short description of the model components and explanation of the model calibrations is presented in the following sections.

4.1 Model Description

A. Watershed Model

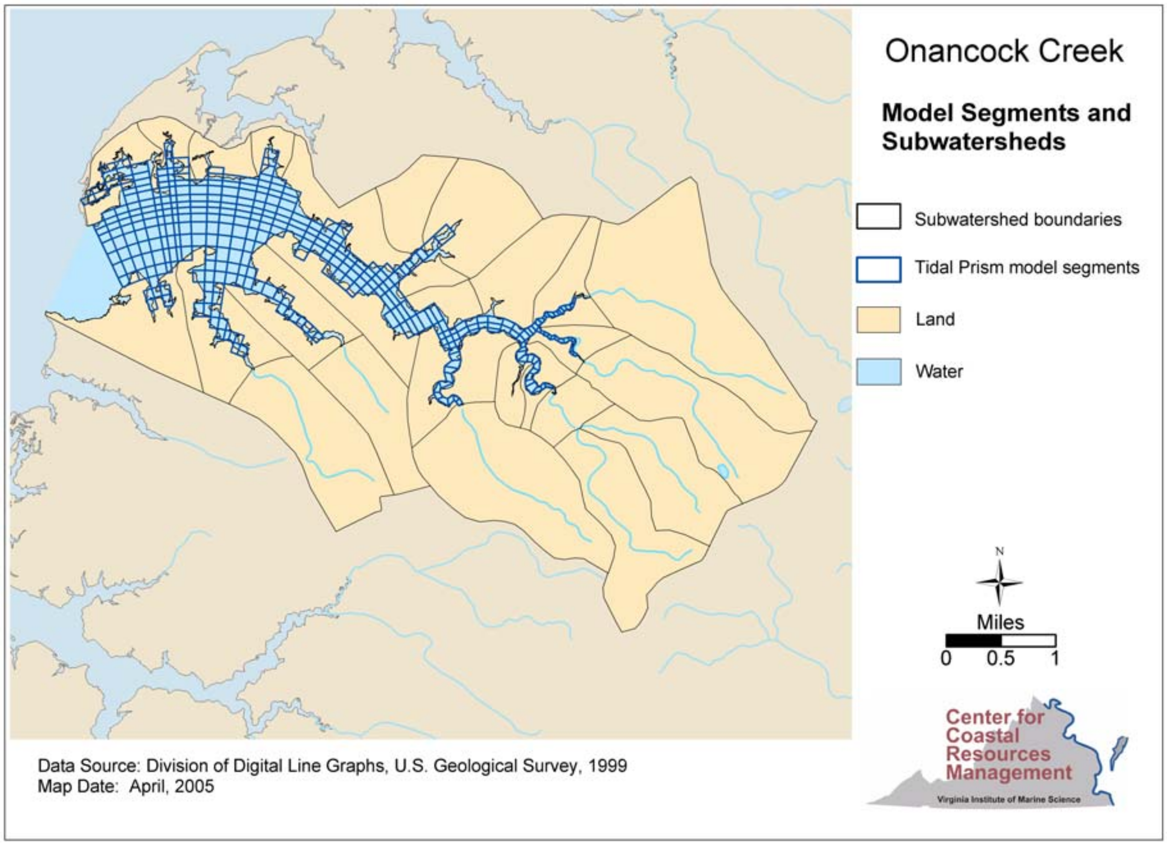
The LSPC model is a stand-alone, PC-based watershed modeling program developed in Microsoft C^{++} (Shen et al., 2005). It includes selected Hydrologic Simulation Program FORTRAN (HSPF) algorithms for simulating hydrology, sediment, and general water quality on land as well as a simplified stream transport model (US EPA, 2004). It is derived from the Mining Data Analysis System (MDAS) developed by EPA Region 3, and has been widely used for watershed modeling and TMDL development (Shen et al., 2002a,b; US EPA, 2001a,b). Like other watershed models, LSPC is a precipitation-driven model and requires necessary meteorological data as model input.

A unique key feature of LSPC is that it uses a Microsoft Access database to manage model related data and parameters. The user can easily modify the datasets, extract model parameters, prepare model inputs, and conduct comprehensive analyses of data and model results. The model also contains a module to assist in TMDL calculation and source allocations. The text-format output of LSPC can be easily processed and linked to receiving water quality models.

The LSPC was configured for Onancock Creek to simulate the watershed as a series of hydrologic connected subwatersheds. The model setup involved subdivision of the Onancock Creek watershed into 33 subwatersheds based on elevation data (e.g., USGS Digital Elevation Model (DEM) and topographic maps) and local survey information (Fig. 4.0). The subwatersheds are used as modeling units for the simulation of flow and nutrient loads based on meteorology, land use, and nutrient application.

The LSPC was used to simulate the freshwater flow and its associated nonpoint source pollutants. The simulated freshwater flow and pollutant (N, P, and Organic Carbon) loadings for each subwatershed are fed into the adjacent water quality model segments. In simulating nonpoint source pollutants from the watershed, LSPC uses a traditional buildup and washoff approach. Pollutants from various sources (fertilizer, atmospheric deposition, wild life, etc.) accumulate on the land surface and are available for runoff during rain events. Differing land uses are associated with various anthropogenic and natural processes that determine the potential pollutant load. The pollutants contributed by interflow and groundwater are also modeled in LSPC for each land use category. Pollutant loadings from surface runoff, interflow and groundwater outflow are combined to form the final loading output from LSPC. In summary, nonpoint sources from the watershed are represented in the model as land-based runoff from the land use categories to account for their contribution (US EPA, 2001a).

In this study, accumulation rates (ACQOP, unit in lbs/acre/day) can be calculated for each land use based on all sources contributing nutrients to the land surface. For example, croplands receive nutrients from fertilizer and manure application, atmospheric deposition and feces from wildlife. Summarizing all these sources together can derive the accumulation rates for croplands. The other two major parameters governing water quality simulation, the maximum storage limit (SQOLIM, unit in lbs/acre/day) and the washoff rate (WSQOP, unit in inches/hour), were specified based on soil characteristics and land use practices, and further adjusted during the model calibration. The washoff rate (WSQOP), is defined as the rate of surface runoff that results in 90% removal of pollutants in one hour. The lower the value, the more easily washoff occurs.



Data Source: Division of Digital Line Graphs, U.S. Geological Survey, 1999
Map Date: April, 2005

Figure 4.0 Subwatershed delineation and water body grid segments for Onancock Creek

B. Receiving Water Model

Hydrodynamic transport is the essential dynamic for driving the movement of dissolved and particulate substances in aquatic waters. Hydrodynamic models are used to represent transport patterns in complex aquatic systems. For the Onancock Creek study, the Environmental Fluid Dynamic Code (EFDC) model was selected to simulate hydrodynamics in the Creek. The EFDC is a general purpose modeling package for simulating 1, 2, and 3 dimensional flow and transport in surface water systems including: rivers, lakes, estuaries, reservoirs, wetlands and oceanic coastal regions. The EFDC model was originally developed at the Virginia Institute of Marine Science for estuarine and coastal applications and is considered public domain software (Hamrick, 1992). The EFDC 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, horizontal and vertical velocities. The model simulates density and gravitationally-induced circulation as well as tidal and wind-driven flows, and 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 (Hamrick et al., 1992b; Shen et al., 1999a; 1999b).

Inputs to the EFDC model for Onancock Creek include:

- Model grid and geometry
- Freshwater inputs (lateral and up-stream) from watersheds
- Tidal surface elevation at the mouth of Onancock Creek
- Salinity at the mouth of Onancock Creek
- 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 (Figure 4.0). 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. For Onancock Creek, the grid resolution is designed to be fine enough to represent each branch while maintaining efficiency for long term simulation. The model grid used for the Onancock Creek was developed based on the high-resolution shoreline digital files from US EPA and USGS Topographic Maps. The grid covers the entire Creek so that the mouth of the Creek can be used to set the boundary condition. Setting the model boundary well outside the model area of interest increases the model accuracy by reducing the influence of the boundary condition. The depth of model grid was obtained from NOAA 3-second (90 m) bathymetric survey data.

There are total of 363 cells in the horizontal, surface grid. According to depth, up to three layers were used to reflect the vertical stratification of the estuary.

A linkage between the watershed model and EFDC has been developed so that the daily freshwater discharges from the watershed can be directly input into the 3D model. All of the freshwater discharge or nonpoint source inputs are assigned to specific grid cells. For example, the output from the North Branch subwatershed is input into the last model grid cell in the North Branch.

The hydrodynamic model, EFDC, has been integrated with a water column eutrophication component and a sediment diagenesis component (Park et al., 1995). The integrated model simulates the spatial and temporal distributions of water quality parameters including dissolved oxygen, 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 dissolved oxygen. In order to predict primary production and dissolved oxygen, a large suite of model state variables representing nutrient dynamics are simulated in the model (See Table 4-1). The eutrophication model has the following water quality variable groups:

1. Algae (green, cyanobacteria, diatoms)
2. Macro-algae
3. Organic carbon (labile and refractory particulates, dissolved)
4. Organic phosphorus (labile and refractory particulates, and dissolved
5. Phosphate
6. Organic nitrogen (labile and refractory particulates and dissolved)
7. Inorganic nitrogen (ammonium and nitrate)
8. Silica (particulate and available silica)

The eutrophication processes included in the EFDC water quality model are those described by Park et al., 1995.

A diagram of model state variable and their relationship is demonstrated in Figure 4.1.

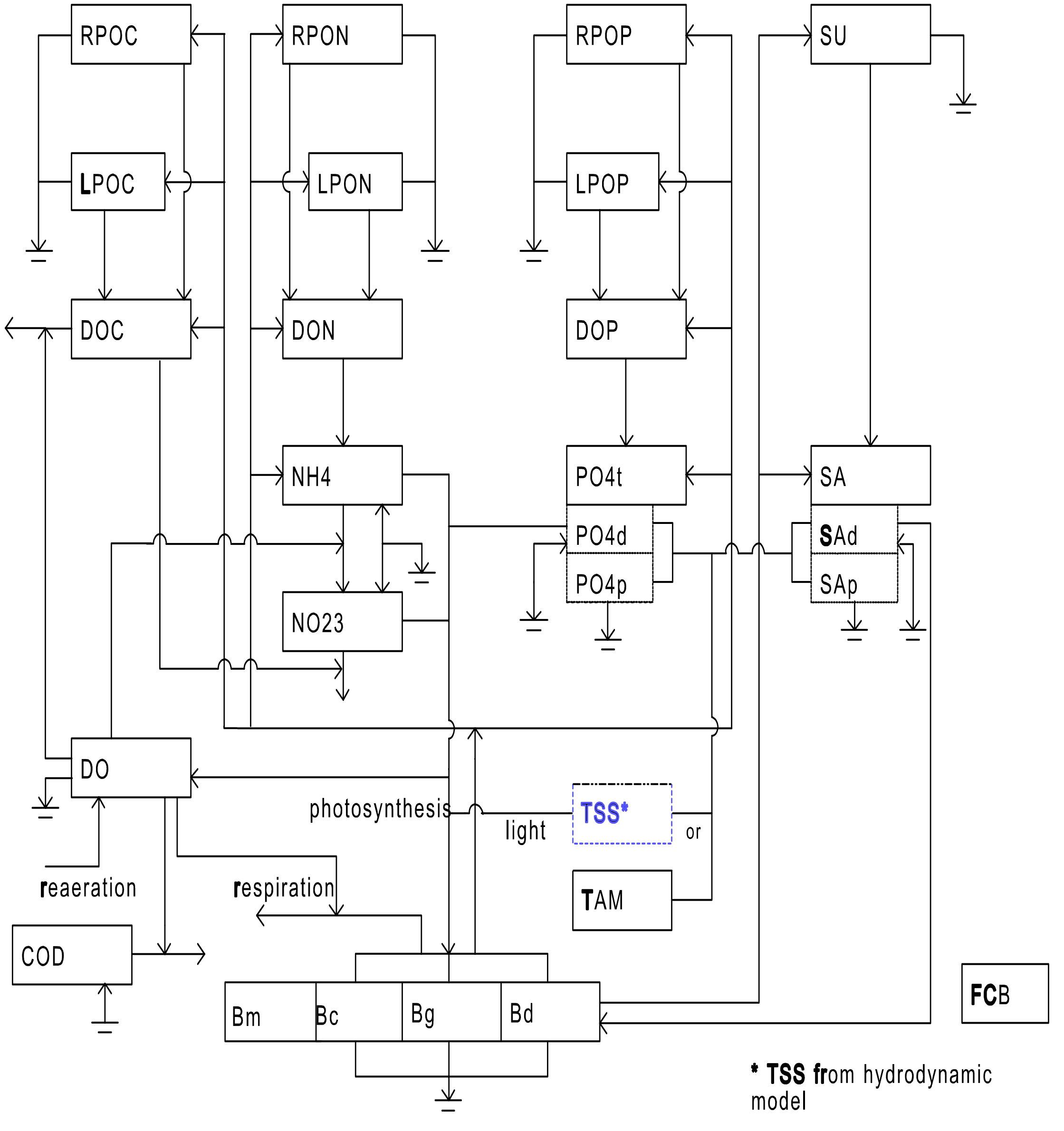


Figure 4.1 A diagram of water quality model in the water column

Sediment diagenesis is a group of chemical processes in sediment causing mineralization of organic matters after it has 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 sediment oxygen demand 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.

Table 4-1. EFDC model water quality state variables.

1) cyanobacteria (BC)
2) diatom algae (BD)
3) green algae (BG)
4) refractory particulate organic carbon (RPOC)
5) labile particulate organic carbon (LPOC)
6) dissolved organic carbon (DOC)
7) refractory particulate organic phosphorus (RPOP)
8) labile particulate organic phosphorus(LPOP)
9) dissolved organic phosphorus(DOP)
10) total phosphate(TPO4)
11) refractory particulate organic nitrogen(RPON)
12) labile particulate organic nitrogen(LPON)
13) dissolved organic nitrogen(DON)
14) ammonia nitrogen(NH4)
15) nitrate nitrogen(NO23)
16) particulate biogenic silica
17) dissolved available silica
18) chemical oxygen demand(COD)
19) dissolved oxygen (DO)
20) total active metal
21) fecal coliform bacteria (FC)
22) macroalgae (BM)

4.2 Model Calibration and Verification

A. Watershed Model

The calibration process involved adjustment of the model parameters used to represent the hydrologic processes until acceptable agreement between simulated flows and field measurements were achieved. Since there is no USGS gage or any other continuous flow data available in the Onancock Creek watershed, a reference watershed was used for calibration. The USGS Gage 01484800 in Guy Creek near Nassawadox, VA (Fig. 4.2), located 20 km south of Onancock Creek, was used to calibrate the model parameters for hydrology simulation. The derived parameters were further verified with local flow data collected by the VA DEQ in the Onancock Creek watershed. The calibration results are shown in Figs. 4.3 and 4.4. Figure 4.3 shows the time series comparison for the years 1993 and 1994. Figure 4.4 shows the 10-year daily stream flow frequency comparison between the model result and field data collected by the USGS gage. Based on the comparison, we can see that LSPC has reasonably reproduced the observed flow over a 10-year period.

Fig. 4.2. Locations of USGS Gage 01484800 and Onancock Creek on Eastern Shore, VA (map from USGS website

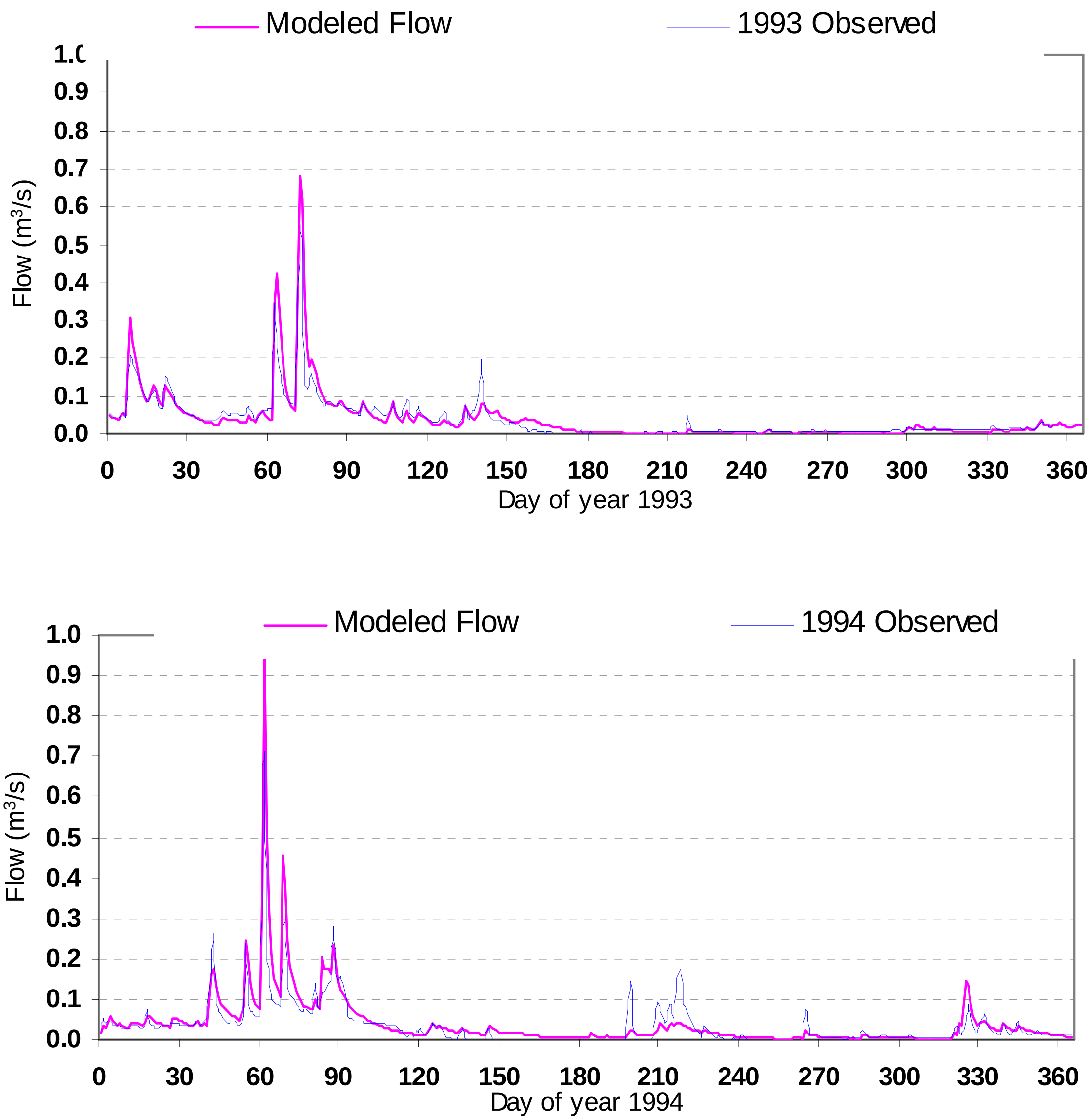


Figure 4.3. Time series comparison of daily stream flow between model simulation and observed data from USGS stream gage 01484800

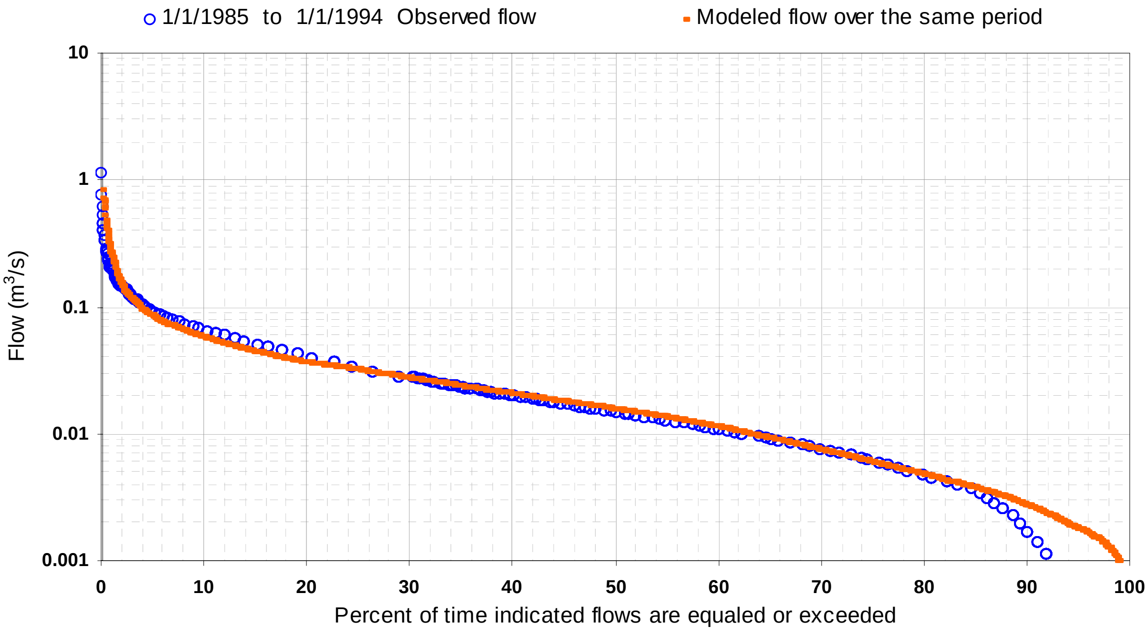


Figure 4.4. 10-year accumulated daily stream flow comparison between model simulation and the reference flow station USGS 01484800

The VA DEQ has collected some stream flow data in the freshwater portion of North Branch of Onancock Creek in 2003 and 2004. These data were used to verify the hydrology parameters of LSPC. The comparisons are shown in Figures 4.5 and 4.6.

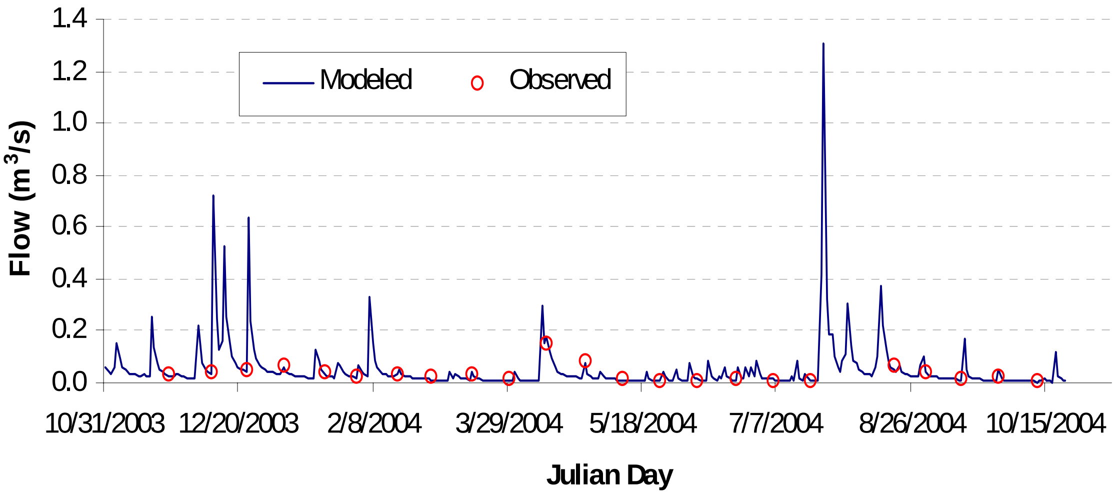


Figure 4.5. Time series comparison of daily stream flow between model simulation and observed data in North Branch of Onancock Creek

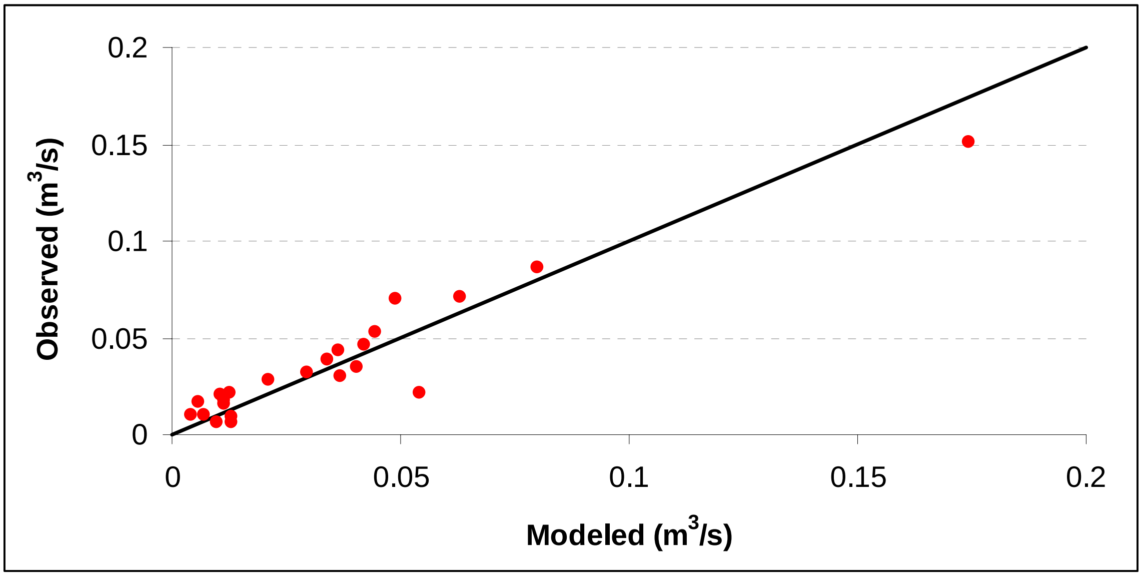


Figure 4.6. Comparison between model simulation and observed data in North Branch of Onancock Creek

Calibration of water quality simulations are typically performed using water quality measurements from the watershed. Absent the necessary data from Onancock Creek, the calibration was performed using an iterative approach between the watershed model and receiving water model. The watershed model parameters (accumulation and lost rates) for nitrogen and phosphate associated with surface runoff of each land use category were estimated on the basis of all available field survey data using US EPA recommended loading production rates (US EPA, "NutrientTool.xls" program, 1998). For the organic carbon, which is both naturally-produced on land and a potential pollutant in the waterway, accumulation rates were estimated based on empirical information (Cerco and Noel, 2004) and the ratio of carbon to nitrogen was obtained from storm water sampling monitoring instead of directly surveyed field data. Due to the absence of subsurface water quality measurements in Onancock Creek, pollutant concentrations for interflow and groundwater were derived from reference data from Cherrystone Inlet (Reay, 1996). The initial loading output from LSPC was fed into the receiving water quality model. A three-year model simulation was conducted. The model results of Central Branch and South Branch were used for the calibration of watershed loadings. The comparison of modeled state variables and observations provide a reference for calibration of the watershed model. In LSPC, the two major parameters SQOLIM and WSQOP with the greatest effect on loading simulation behavior were adjusted accordingly. Model simulation of loading by subwatershed is provided in Appendix D. Model input on nutrient sources for the Onancock Creek watershed based on field survey are summarized in of Appendix E.

B. Receiving Water Model

Calibration of the Receiving Water Model requires consideration of the hydrodynamic components; tides, current, salinity, and temperature and the water quality components.

Hydrodynamic Component: Tides

Variations in the surface elevation are caused by astronomical tides and wind induced surface fluctuation of the Chesapeake Bay. The tide is the dominant force on water surface variation in the Creek and the temporal tide variation at a particular location is well described by astronomical tides. Since there is no real-time tidal observation data available in the Creek, the model calibration for surface elevation is conducted by comparing the model output against the NOAA prediction of the surface elevation based on astronomic tide. NOAA publishes predictions hourly tidal elevation in many locations in the Chesapeake Bay including Onancock Creek (http://coops.nos.noaa.gov/tides04/tpred2.html#VA).

The tidal component is comprised of 8 constituents (K_1, O_1, P_1, Q_1, M_2, S_2, K_2, and N_2). These tidal constituents, used to describe the open water boundary condition, are obtained from 3-D Chesapeake Bay model developed at the Virginia Institute of Marine Science. Adjustments to the model in the form of changes to the bottom friction parameter, were made in order to achieve agreement of model tidal predictions and the NOAA predictions.

The calibration and validation time period for the tidal simulation was from 9/1/04 to 10/31/04. In general, a minimum of 29 days is needed for tidal calibrations in order to capture one entire spring-neap tidal cycle. The second month of simulation serves as model verification. The model results are shown in Figure 4.7 at the NOAA station at the junction of South and Central branches (37° 43' 75° 45'). Comparison to NOAA tidal predictions indicates that the model does a good job simulating astronomical tides in Onancock Creek.

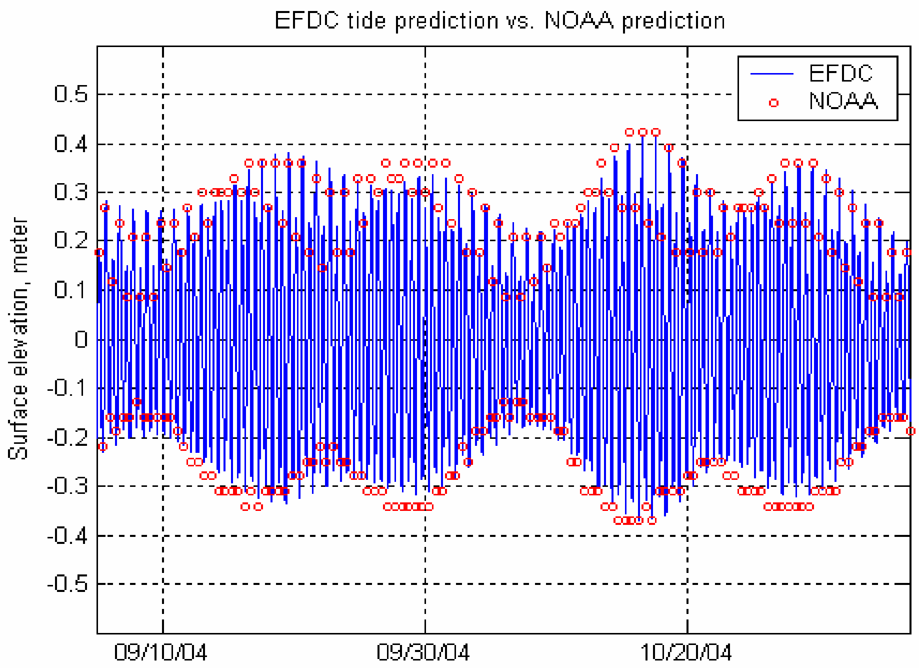


Figure 4.7. Results of tide calibration and verification

Hydrodynamic Component: Salinity

The DEQ monthly survey data from 1999 to 2001 were used for the 3-year calibration of salinity. The freshwater simulated by the LSPC was used as freshwater input to receiving water model. The salinity values near the mouth were used as the boundary condition. A linear interpolation was used to derive a continuous data series for salinity based on sampling data.

An example showing the comparison of model prediction (surface and bottom) and surface salinity observations in the middle of the North Branch is shown in Figure 4.8. It can be seen that the model reproduces the general trend of salinity variation for the three-year time period. Variations in salinity are very sensitive to the freshwater discharge; high salinity often corresponds to low freshwater discharge, while low salinity indicates a high runoff condition. The model results also indicate that stratification (i.e., lower salinity near the surface and high salinity near the bottom) can occur during the high runoff events. This stratification together with increased loading of organic matter and low light availability often cause low DO in the water column.

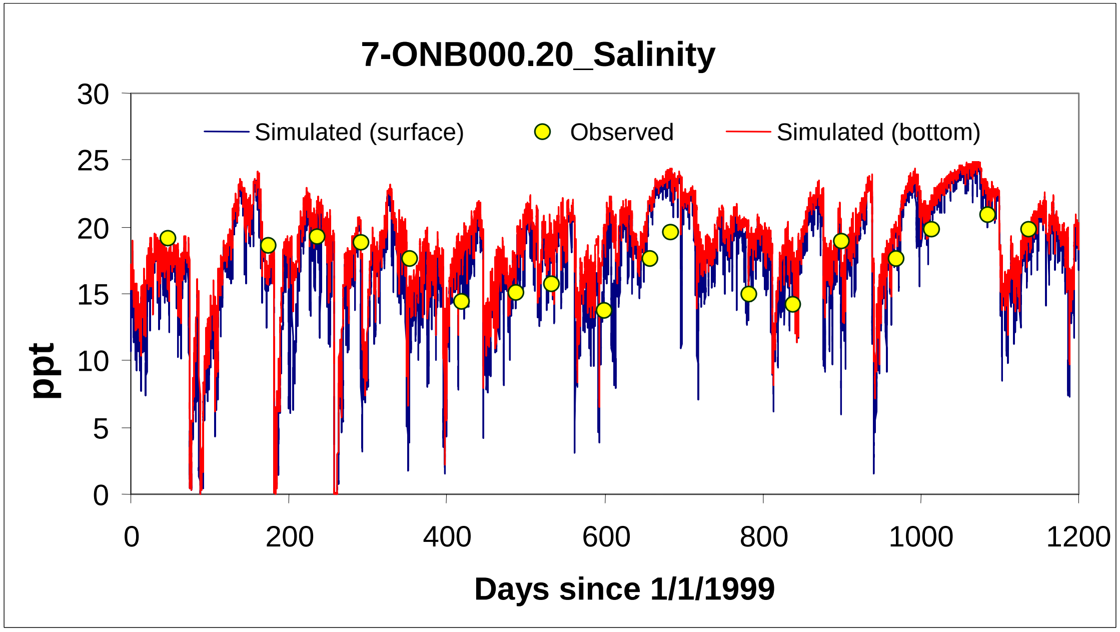


Figure 4.8. Comparison of simulated salinity and observed salinity

Hydrodynamic Component: Temperature

Water temperature represents one of the most important physical characteristics of surface water systems. To simulate temperature, the model was forced by the meteorological parameters, including wind, atmospheric pressure, solar radiation, dry and wet temperature, humidity, and cloud cover. For temperature calibration, the long-term DEQ monthly survey data from 1999 to 2001 were used. An example of comparison of model prediction and observations for temperature in the middle of the North Branch is shown in Figure 4.9. Comparison to observation data shows that the model simulated the temperature well.

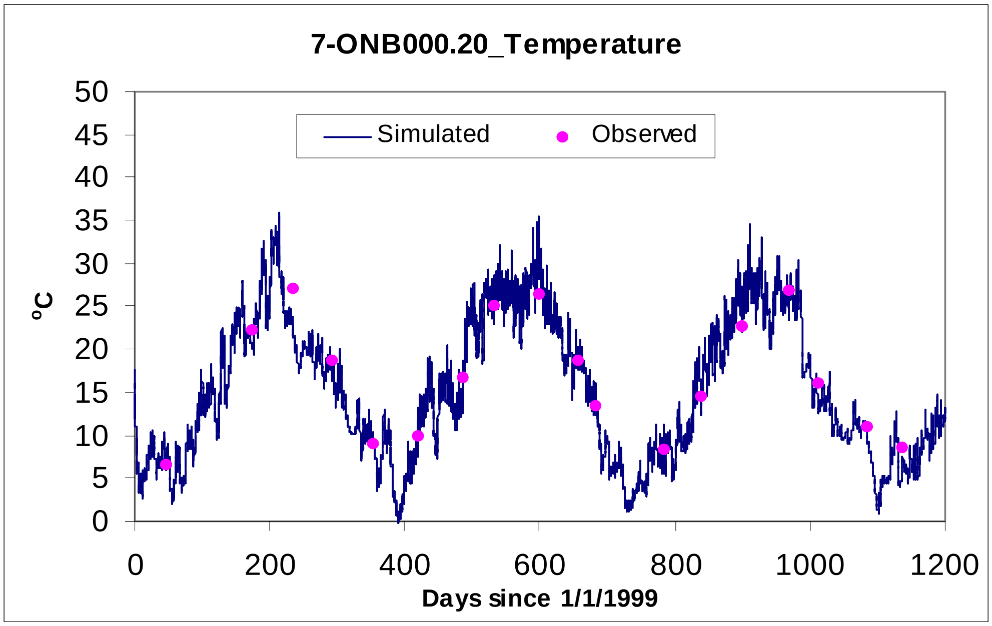


Figure 4.9. Comparison of simulated temperature against observed temperature

Water Quality Components: Eutrophication and Sediment Diagenesis

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, dissolved oxygen, nitrogen, phosphorus, and carbon in the water column. The water temperature from the hydrodynamic model is used in the calculation of kinetic processes of the eutrophication model.

Two data sets are available for water quality model calibration and verification. The first data set are monthly DEQ data, including DO, phosphorus and nitrogen. The second data set was obtained in 2004 as continuous DO observations in the North Branch of the Creek. The long-term data is used for model calibration. The model calibration period is from 1999 to 2001. The short term DO data set is used as model verification since DO is the primary concern of this study.

Concentrations of the state variables must be specified at the model boundaries. Because observation data at the open boundary is not available, the monthly concentration at the station near the mouth and the station in the main stem were compiled and used as open boundary conditions. Model sensitivity tests showed that the eutrophication model was more sensitive to nutrient loadings from upstream than at the open boundaries. Therefore, it is reasonable to use the monthly mean concentrations to force the model at the open boundaries.

The most important input data for simulation of eutrophication process and DO in the Creek are the nutrient and carbon loads from the watershed delivered via surface runoff or ground water. The watershed model simulated total phosphorus, total nitrogen, and total carbon. The loading discharge locations are identical to flow discharge locations along the bank of the Creek. The total phosphorus, nitrogen, and carbon simulated by the watershed model are split into individual state variables for the eutrophication model component. The total organic nitrogen, phosphorus, and carbon were split into refractory, labile, and dissolved nitrogen, phosphorus, and carbon. The ratios used to split the variables were based on Chesapeake Bay modeling and other eutrophication model applications in the Bay area. The final ratios were also adjusted during the model calibration processes.

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

The sediment diagenesis model (DiToro and Fitzpatrick 1993) was coupled to the water column eutrophication model component to simulate nutrient exchanges on the water-sediment interface. The model was run iteratively for 5 years with the use of 2004 nutrient loads. The model results at the end of the fifth year were used as the initial condition for model simulation. It was found that after 5 years of iterative simulation, the water quality concentrations in the sediment bed approached a dynamic equilibrium.

The water quality model was calibrated against the DO, nitrogen, phosphorus, BOD, and algae data from 1999 to 2001. Model results are show in Appendix A.

The 2004 continuous DO data was used as model verification. For model verification, all the calibrated model parameters were kept unchanged. The verification results for the North Branch are shown in Figure 4.10. It can be seen that model simulates the diurnal DO swing between high and low concentrations very well. The model also simulates the low DO event during high runoff period. These results indicate that the model is capable of simulating DO concentrations for TMDL studies.

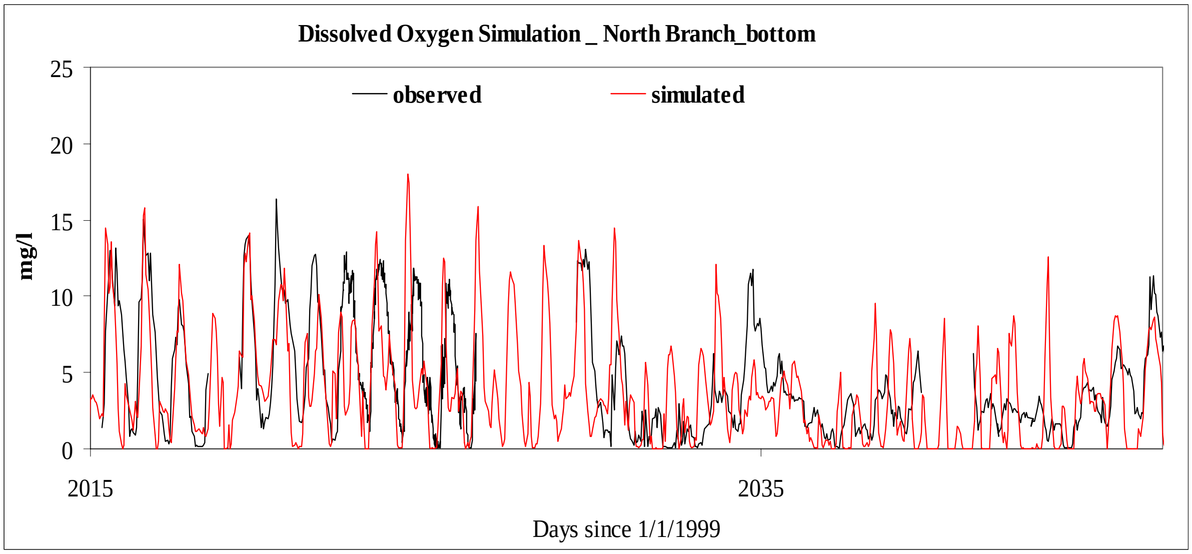


Figure 4.10. Comparison of simulated DO concentrations to observed concentrations

4.3 Capacity Assessment

A. Current Condition

A three-year model simulation from 1999 to 2001 was selected to represent the current condition, which is the same period used for the model calibration. The selection of these three years captures a wet, a mean, and a dry meteorologic condition. The loads of nitrogen, phosphorus, and organic carbon were generated by the LSPC with calibrated model parameters. The loading and flow output from the watershed model were input to the receiving water model to simulate hydrodynamic and water quality condition in the Creek. Since no measurements of point source discharge were available during these three years, the point source measurements in the year 2004 were used to represent existing point source loads. The model results including salinity, temperature, and water quality variables, at three selected stations at North, Central, and South branches are presented in Appendix A.

The averaged DO concentration (vertical and horizontal) in the North Branch is shown in Appendix B. The open water DO standard of 4.3 mg/L for temperature greater than 29° is used as the DO criteria. The model results show that DO violations occurred during the summer time. The corresponding daily loads of total nitrogen and phosphorus from both point and non-point sources are shown in Figure 4.11.

In a comparison of point and non-point source nutrient loads discharged into the North Branch, nitrogen loads are on the same order from both. The phosphorus discharged from the point source is about three times higher than the nonpoint source. In addition to the nitrogen and phosphorus nonpoint source inputs, a large amount of organic carbon is discharged to the North Branch from the watershed. The mean daily load of organic carbon is about 100 kg per day. According to the storm water sampling conducted in 2004 and 2005, the carbon concentration is about 3 times higher during a runoff event than the concentration during normal condition. More than 80% of organic carbon is in the dissolved form that is expected to undergo decay in the water column. Consequently, large amounts of DO are consumed during rainfall events.

B. Model Scenarios

In order to diagnose the cause of the hypoxia and estimate the loading capacity of the North Branch, eight sensitivity tests were conducted as model scenarios. The purpose of these sensitivity tests is to provide better understanding of the eutrophication processes and provide a basis for alternative management strategies for both point and nonpoint sources. The Chesapeake Bay Program has recommended a nutrient point source target. These new targets for nitrogen and phosphorus are 4mg/L and 0.3 mg/L, respectively. For the scenarios with a nonpoint source reduction, loads of total nitrogen, phosphorus, and organic carbon are reduced equally. The scenarios are listed as follows:

1. Reduce 64% of the nonpoint source loads and reduce point source loads to the new permitted level.

2. Reduce 64% of the nonpoint source loads, point source loads are unchanged.

3. Use existing point and nonpoint source loads and move point source discharge location to the mouth of North Branch.

4. Reduce 64% of nonpoint source loads, point source loads are unchanged, move point source discharge location to the mouth of North Branch.

5. Reduce 85% of nonpoint source loads, point source loads are unchanged.

6. Reduce 85% of nonpoint source loads, point source loads are unchanged, move point source discharge location to the mouth of North Branch.

7. Use existing nonpoint source loads and increase point source design flow three times with newly permitted concentrations.

8. Using existing nonpoint source loads and increase point source design flow three times with newly permitted concentrations. Move point source discharge location to the mouth of North Branch.

Two methods were used to assess the pollutant capacity and DO response of the North Branch. First, averaged hourly DO concentration (i.e., both vertically and horizontally for all the modeling cells) was plotted for each scenario test and the total violations of the three-year period was calculated. Second, the percent violation events for each model cell was computed based on hourly DO concentration and DO standard. The violations were plotted for each scenario. The results of these sensitivity tests are presented in Appendix B. A summary of percent violations of the 8 tests and the existing condition is listed in Table 4.2.

Model Scenarios	**Existing**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Mean DO concentration violation (%)	1.63	0.17	0.18	1.91	0.23	0.02	0.00	1.56	1.91
Highest violation (%) of any one segment	3.75	0.5	0.63	3.64	0.55	0.2	0.13	4.04	3.64

Table 4.2 Summary of Model Scenarios

5.0 Discussion/Recommendations for Water Quality Improvements

The North Branch of Onancock Creek shows DO levels below the water quality standard levels of 4 mg/L minimum and 5 mg/L average repeatedly throughout the sampling period of record. There is a strong seasonal variation to the DO with the lowest values often occurring in the summer. The lowest levels of DO are recorded at station 7-ONB000.56 which is located at the head of the North Branch. Low DO occurring in the North Branch can be attributed to excessive nutrient and organic carbon loads originating as non-point source from the watershed and from point source. Poor flushing of the Branch and stratification occurring during rainfall events further limits the assimilative capacity of the Branch.

As shown previously, low DO often occurs during the night under normal flow conditions in summer months, while low DO occurs during night and day under high (rain event) flow conditions. These characteristics have been also observed in many shallow water coastal embayments. Under normal flow conditions, a diurnal DO swing is typical of the shallow water environment. In shallow waters, light is available to the bottom benthic algae and macroalgae. With an excess supply of nutrients, algal blooms can occur. The large amounts of organic carbon and nutrients delivered to the creek from both point and nonpoint sources are deposited on the bottom and undergo mineralization. These nutrients are released to the water column and cause algal growth. Photosynthetic processes of the alga cause supersaturated DO levels during the daytime. However, the respiration processes of the algal community, in concert with decomposition of organic matter and SOD, leads to high rates of DO consumption and correspondingly low DO concentration. This type of diurnal DO phenomena suggests the water was in a “eutrophic” state.

Low DO was observed in during rainfall events in summer and fall of 2004. The storm water sampling conducted in 2005 indicates that high nutrients and dissolved organic carbon were discharged into the creek (Table 2.4). Several factors contribute to the low DO conditions associated with rainfall events. Because there are large marsh areas located in the upper streams of the Branch, low DO water accumulated in the marsh areas will be discharged into the Creek during rainfall events. High input of low DO water mixes with the receiving water causes a drop, or sag, in the ambient concentrations. In addition, the high concentration of dissolved organic matter increases DO consumption and the associated high turbidity reduces light availability that limits DO production in the water column. As freshwater input increases, the Branch becomes stratified as the low density freshwater flows downstream at the surface and the higher density salt water flows upstream at the bottom. Stratification acts to strengthen the physical separation of the top and bottom waters and vertical mixing is reduced. As such, DO in the bottom water will be consumed quickly. Consequently, low DO occurs during high runoff events.

The influences of both point and nonpoint source loads on low DO in North Branch have been investigated through a series of model scenario tests. Model runs were conducted to investigate each contribution alone, as well as in combination.

Two model runs were conducted to assess the response of DO levels to a reduction of 64% and 85% from nonpoint sources respectively (scenario 2 and 5). For these two scenarios, nitrogen, phosphorus, and organic carbon from the watershed were reduced equally and the existing point source loads unchanged based on 2004 monitoring data. The model results show that the DO condition in the Branch is very sensitive to the nonpoint source loading. DO conditions will improve with a reduction of 64% in the nonpoint source load. Mean DO violations will be less than 1%. With a reduction of 85% in nonpoint source load (scenario 5), the DO condition is further improved. Since large amount of nutrients and organic carbon are discharged into the stream during rainfall events, reductions in nonpoint source loads not only improves the low DO condition during these rainfall events, but also reduces the organic matter deposition in the bottom sediment. Consequently, nutrients released from the bottom will be reduced resulting in a decrease in algal growth under normal flow conditions.

Point source discharge also provides nutrients for both phytoplankton and macroalgae growth. Large amounts of phosphorus and smaller amounts of nitrogen were discharged into the North Branch under the existing condition. The excess phosphorus is one of the nutrient constituents that “feed” the algae bloom. As such, it is expected that the DO condition will improve if nutrient loads from the point source are reduced.

A reduction in point source loads, in conjunction with a nonpoint source reduction, was tested (scenario 1). For this experiment, the nonpoint source was reduced 64% and the point source loads were reduced to the new permitted level, i.e., 4mg/L nitrogen and 0.3mg/L phosphorus, respectively. Comparing the DO time series results with scenario 2 (Appendix B), it can be seen that the DO swing was reduced indicating algae concentration was reduced. The overall DO condition is improved.

Consideration was given to the possibility of minimizing the adverse effect on DO concentration by moving the discharge location downstream of the present outfall. As tidal flushing increases, the expectation is that the nutrient concentrations in the water column will decrease, thus reducing algal growth. A model experiment was conducted to test this hypothesis (scenario 3). The mean DO time series plot is shown in Appendix B. It can be seen that the diurnal DO swing and the magnitude of DO fluctuation in the Branch is reduced compared to the existing condition. However, the overall DO condition has not been improved as determined by percent violation of the DO standard in the North Branch (see table 4.2). Because the influence of the point source loads on water quality is an accumulated effect through interaction of the bottom sediment, it is expected that improvement in water quality through reduction of point source load (either through lower levels, or change in outfall location) will take a much longer time period. This scenario also suggests that reductions in point source loads without reductions in nonpoint source loads is not effective based on the estimation of 2004 data.

Model scenarios 4 and 6 were conducted to test the response of DO levels to a reduction in nonpoint source loads and downstream relocation point source discharge. Model run 4 had a reduction of 64% and model run6 had a reduction of 85% in nonpoint source loads.

The results of scenario 6, with 85% reduction, show that violations, based on mean DO percent violation, are eliminated.

Model scenarios 7 and 8 tested the potential modifications only to the point source and the effects on DO as determined by percent violations. Simulated DO levels produced by the modifications tested in these two scenarios are not different from the existing condition. Model run 7 produces a DO conditions with a diurnal swing (higher highs and lower lows) greater than existing conditions. Although the mean percent violation is comparable to the existing condition, the percent violation of any one segment increases. The potential for cumulative adverse effects from the increase in point source loads on the DO response is likely, but limits in the calibration of the short-term model simulation prevent determination of this effect. Model 8 results show that the mean percent violations are increased over the existing conditions, while violation percentage by segment is comparable to the existing condition. In addition, this scenario results in a reduced DO swing thereby producing the potential for a DO mean lower than the existing condition. Given the SOD, the lower mean DO concentration is likely to result in greater violations of the DO standard.

Model results indicate that both point and nonpoint source loads contribute to the low DO in the North Branch of Onancock Creek. The modeled DO in the Creek is more sensitive to changes to the nonpoint source loads. The primary source of phosphorus is the treatment plant, while the primary source of nitrogen and organic matter is nonpoint. Physical, chemical and biologic processes all interact to determine the fate of these constituents and the DO response. The results of the modeled scenarios highlight the necessity for reductions in nonpoint source loads, in conjunction with point source reductions, to achieve improvement in dissolved oxygen in the North Branch of Onancock Creek.

6.0 Public Participation

As part of this study of dissolved oxygen impairment in Onancock Creek, public meetings were held. Two meetings in the Town of Onancock on March 2, and April 6 2005 were conducted to garner input from the public with regard to the study process and local information on sources. Local and state agency personnel, and some Onancock residents and interested parties attended each meeting.

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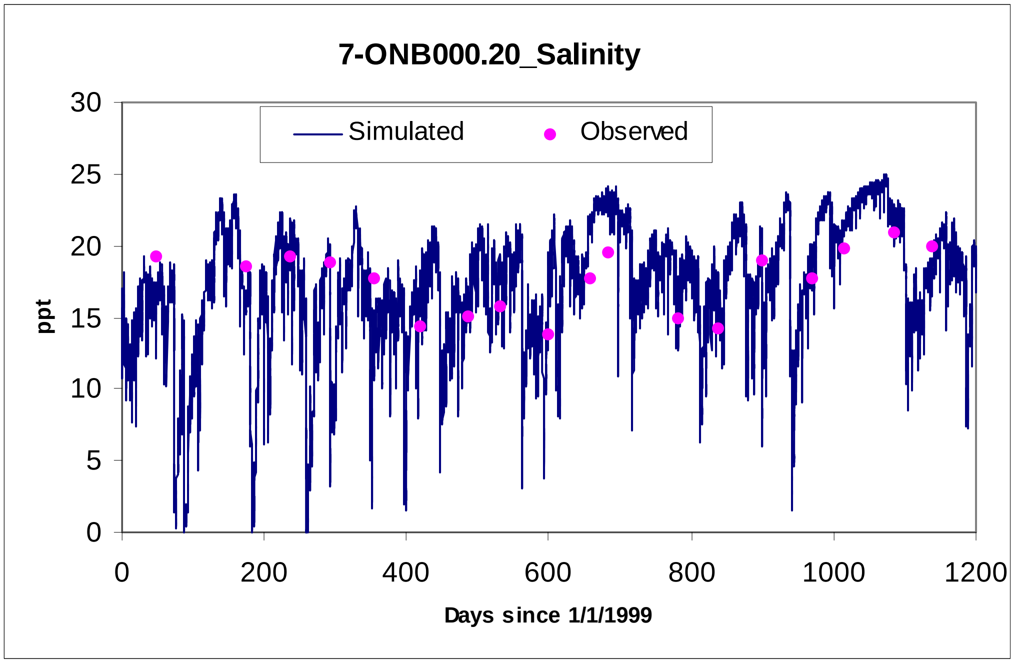
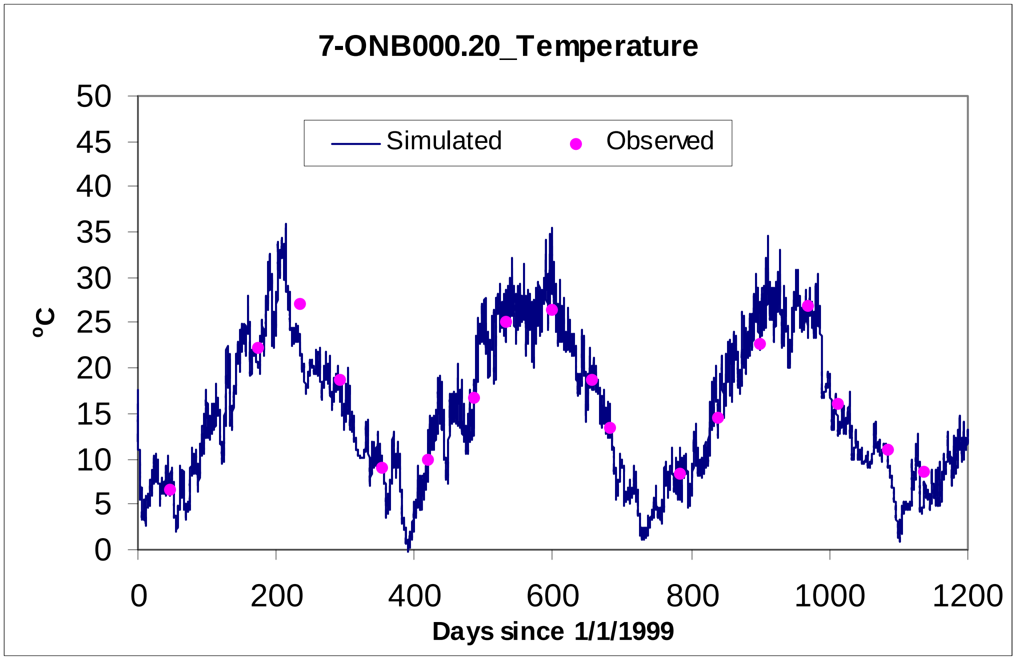
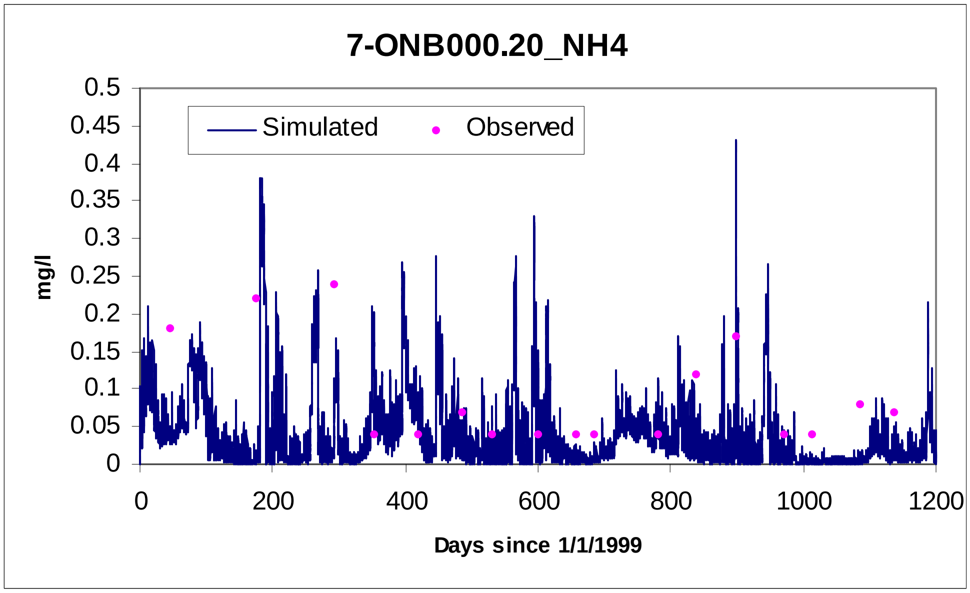
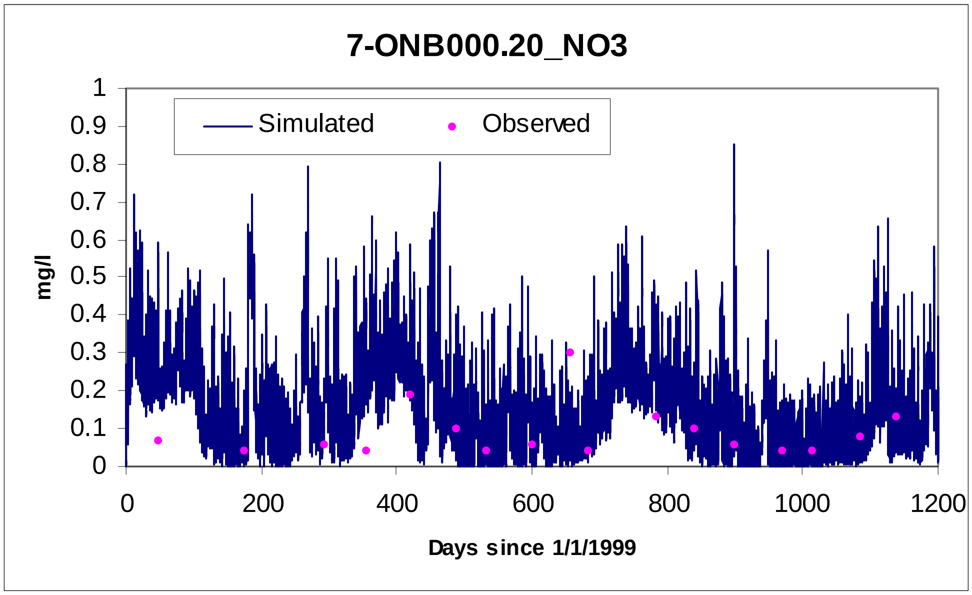
Appendix A. Model Calibration Results

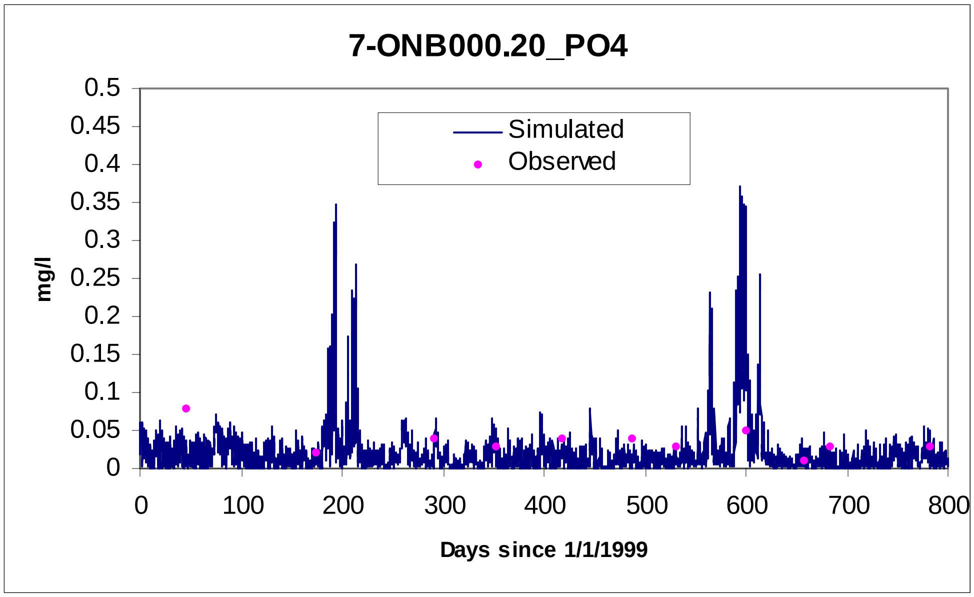
Water quality calibration results for North Branch (Station 7-OCB0000.20)

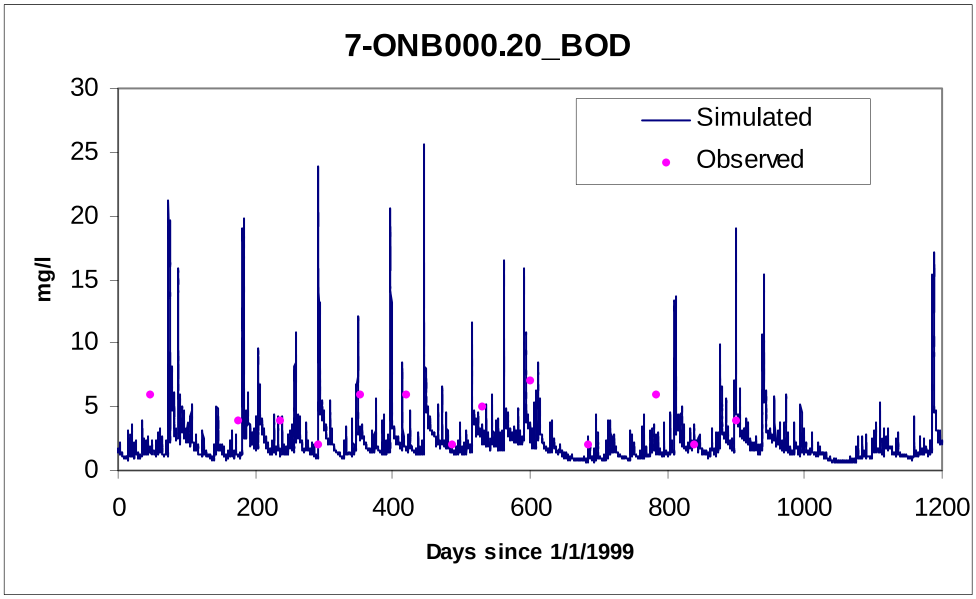





7-ONB000.20_NH4
Simulated
Observed
mg/l
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-ONB000.20_NO3
Simulated
Observed
mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-ONB000.20_PO4
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
mg/l
Simulated
Observed
0
100
200
300
400
500
600
700
800
Days since 1/1/1999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mg/l
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Observed
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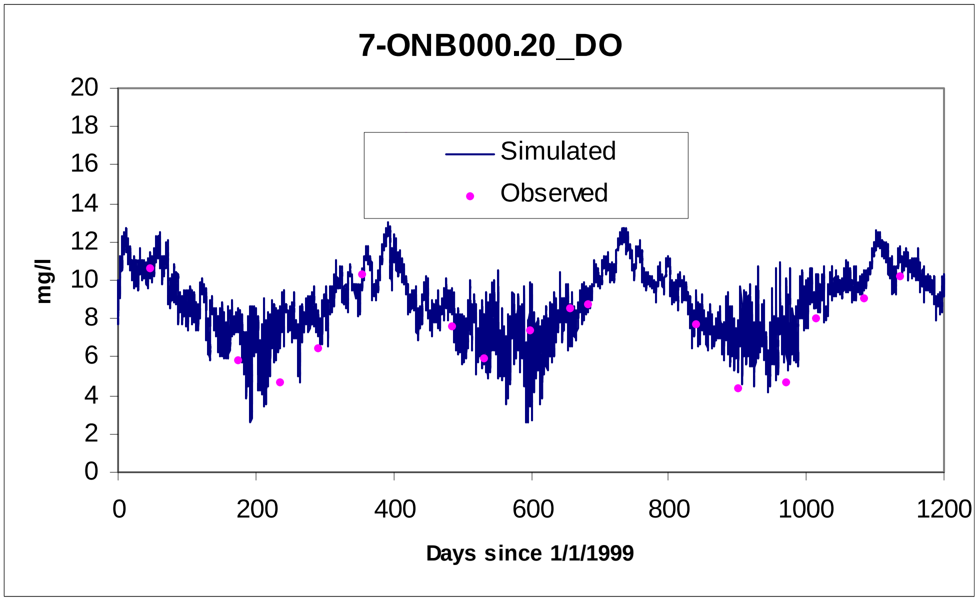
1200
Days since 1/1/1999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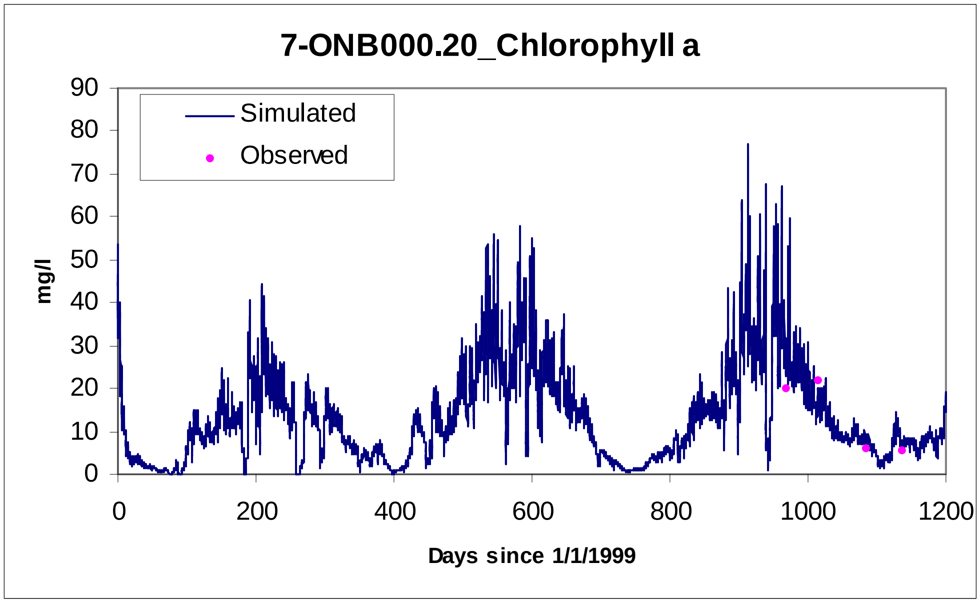
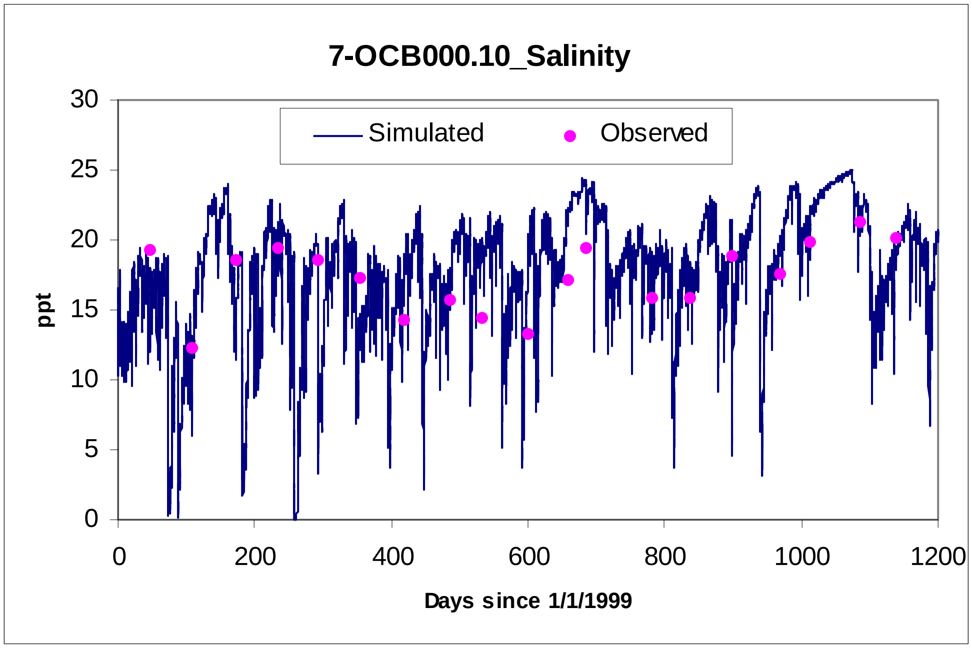
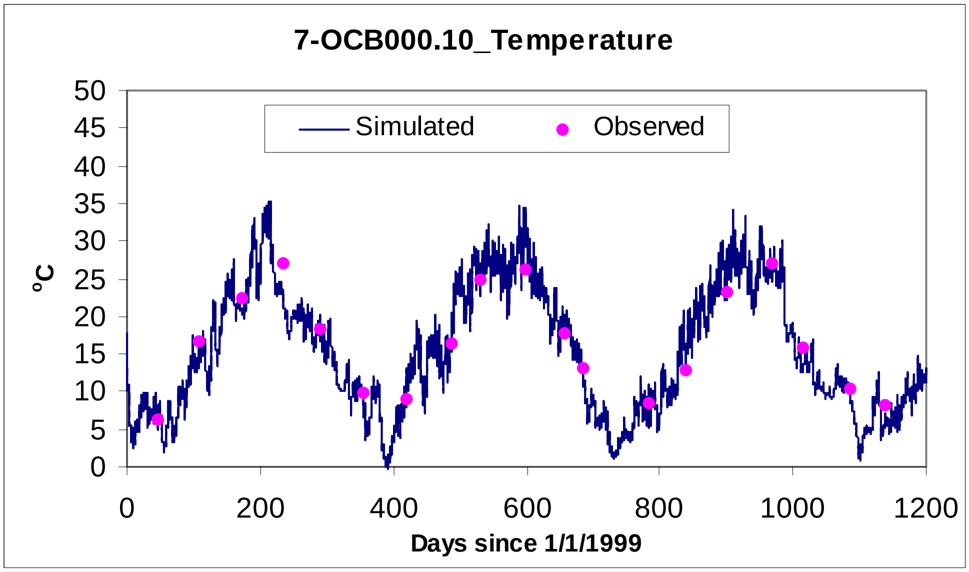
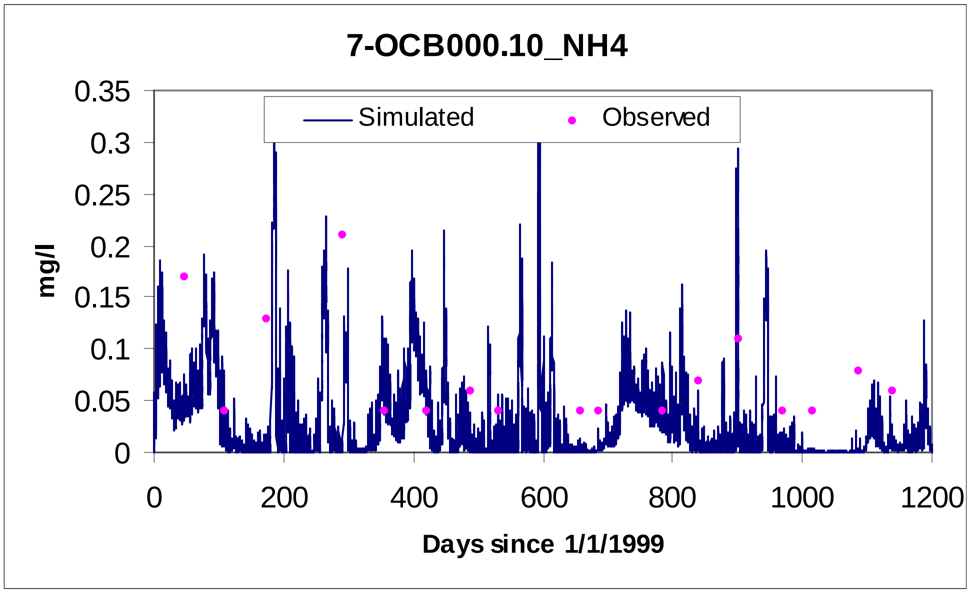
Simulated
Observed
mg/l
20
18
16
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

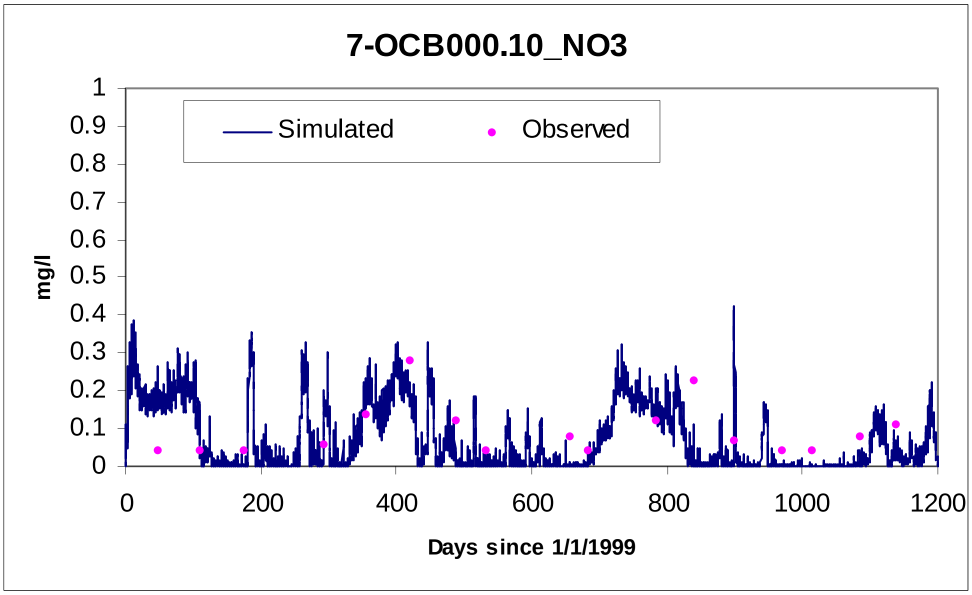

7-ONB000.20_Chlorophyll a
Simulated
Observed
mg/l
90
80
70
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

Water quality calibration results for Central Branch (Station 7-OCB0000.10)






7-OCB000.10_NH4
Simulated
Observed
mg/l
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-OCB000.10_NO3
Simulated
Observed
mg/l
1
0.9
0.8
0.7
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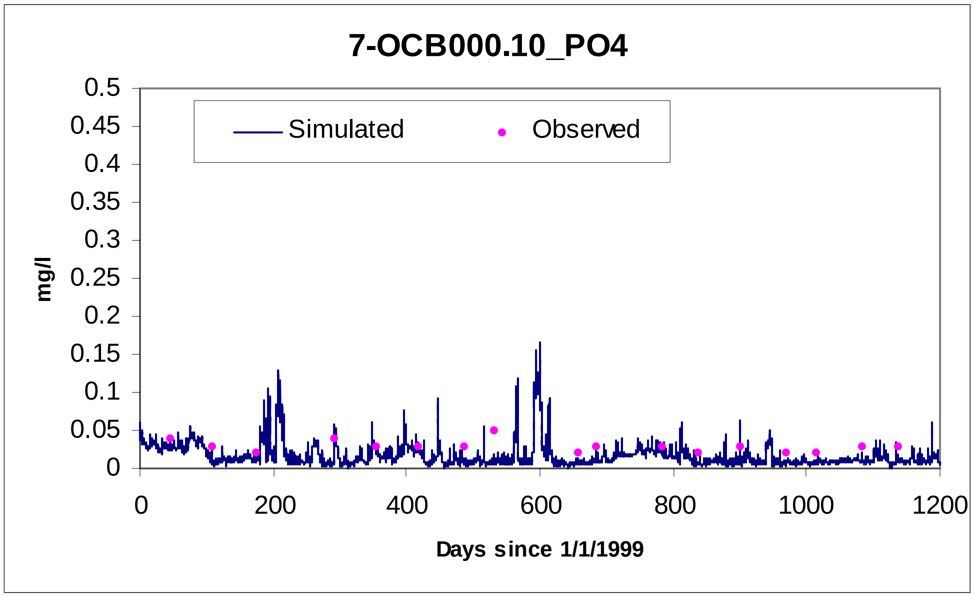
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-OCB000.10_PO4
Simulated
Observed
mg/l
0.5
0.45
0.4
0.35
0.3
0.25
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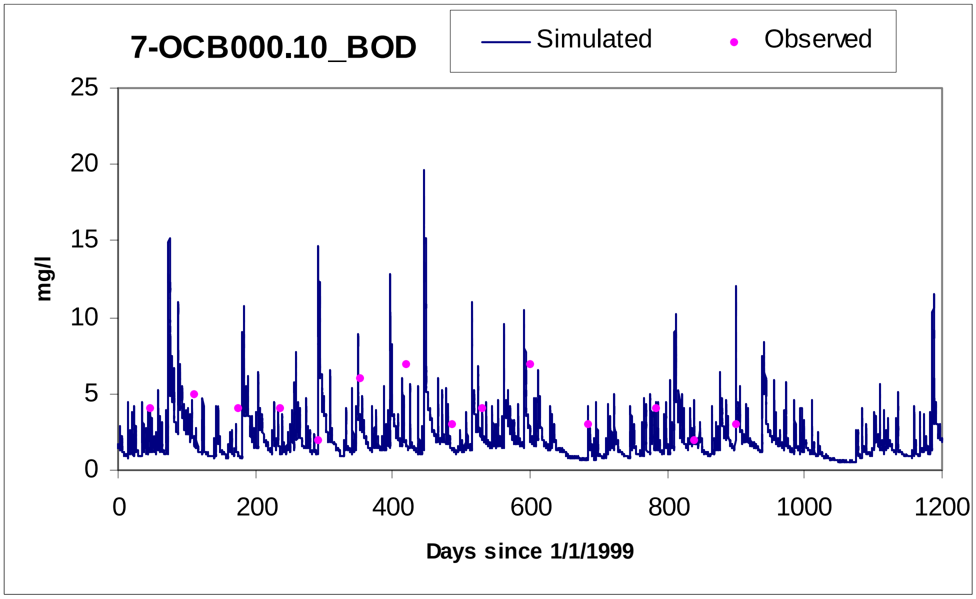
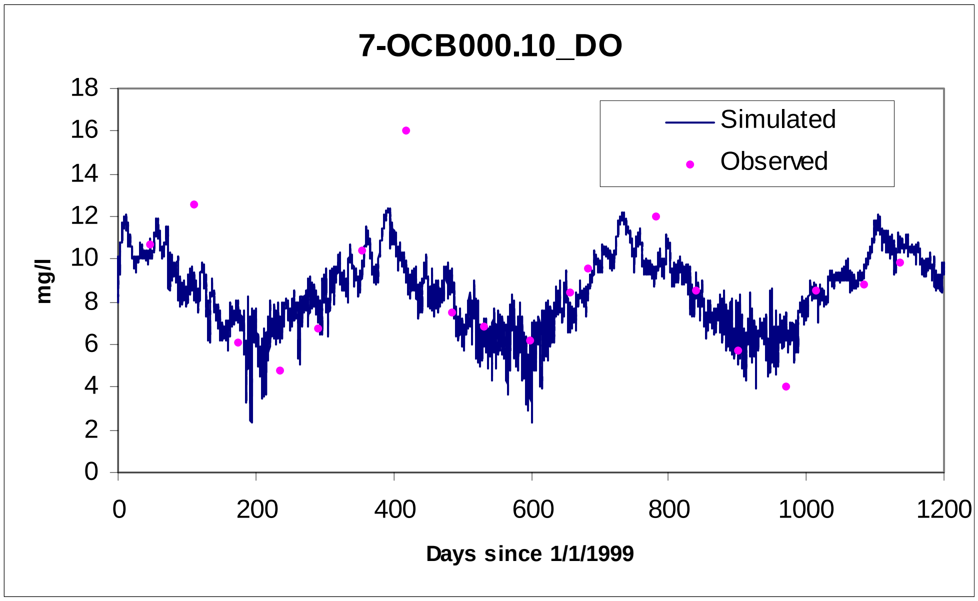
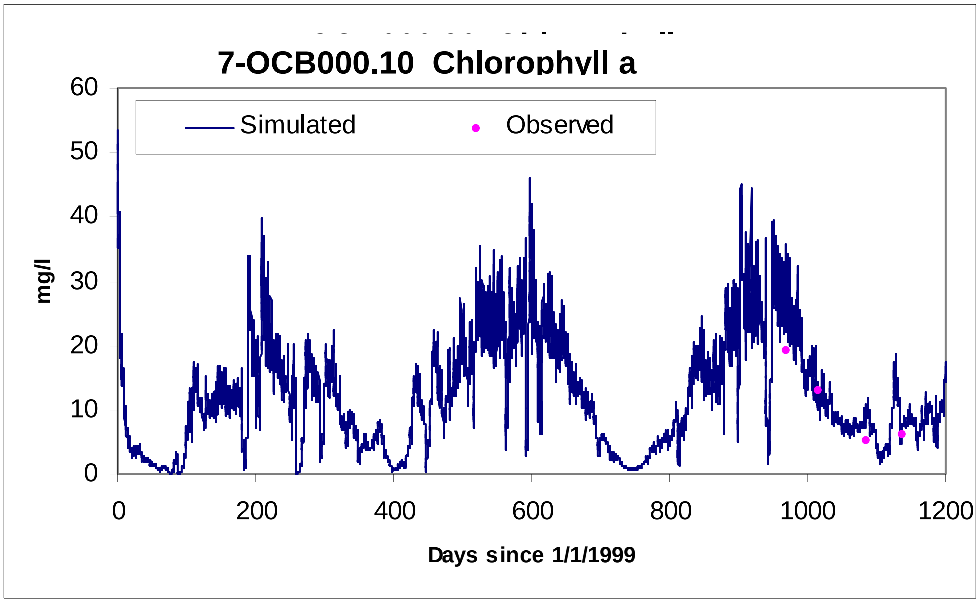
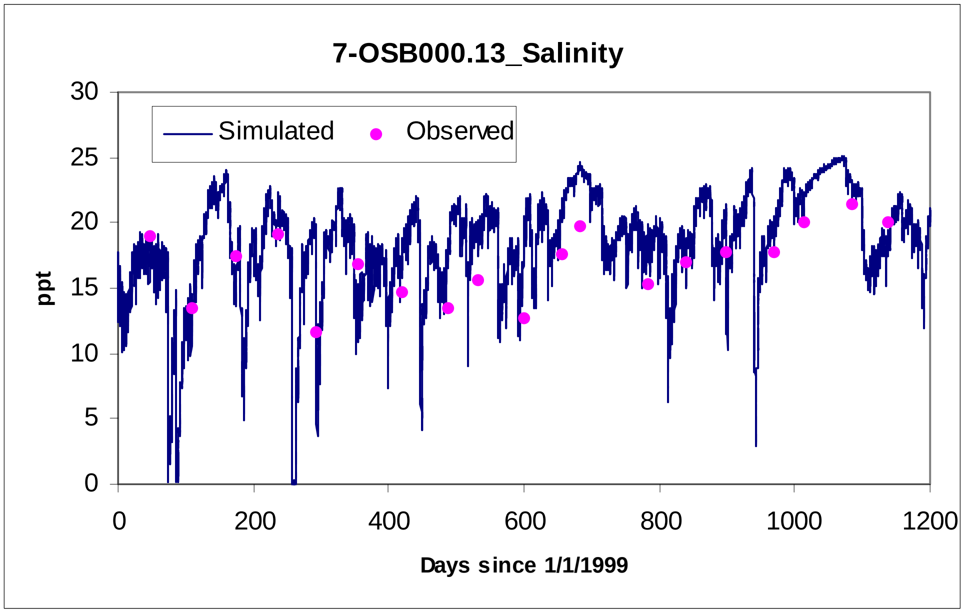
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

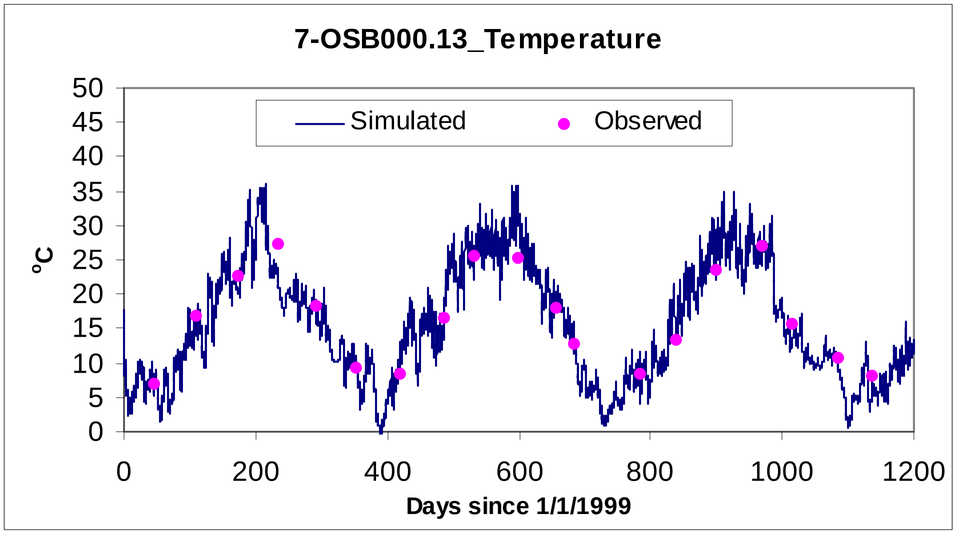

7-OCB000.10_BOD
Simulated
Observed
mg/l
25
20
15
10
5
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

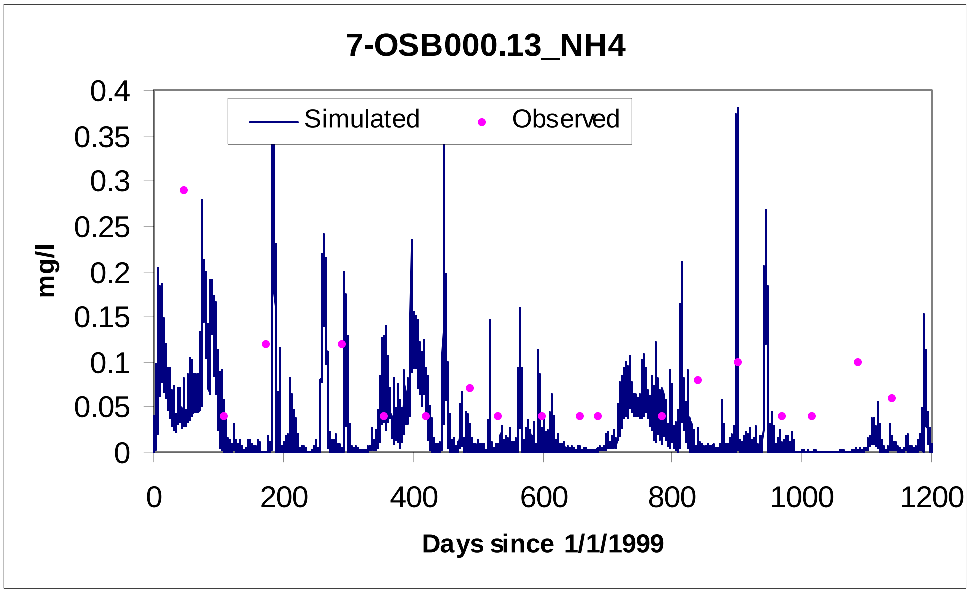

7-OCB000.10_DO
Simulated
Observed
mg/l
18
16
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

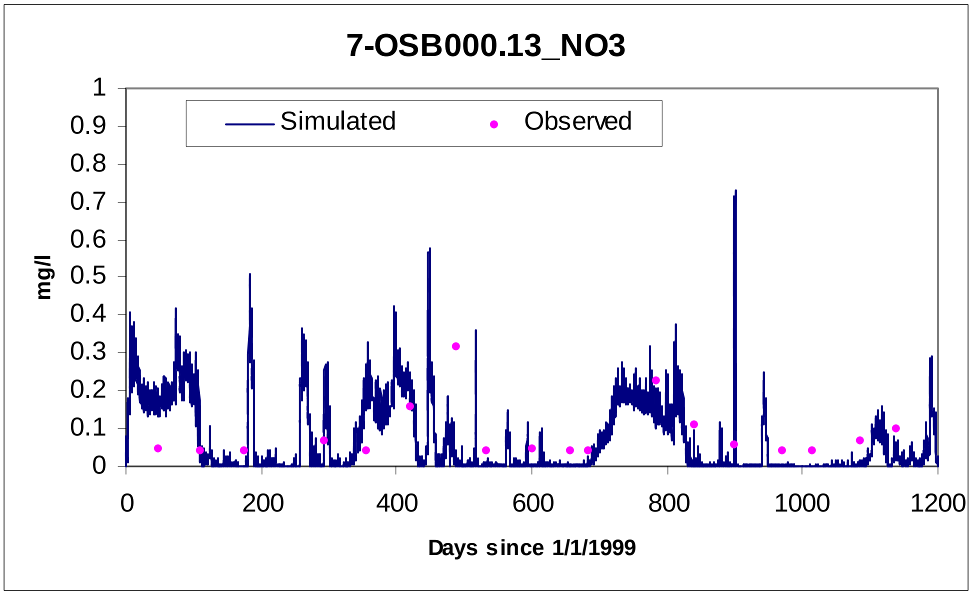

7-OCB000.10 Chlorophyll a
Simulated
Observed
mg/l
60
50
40
30
20
10
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

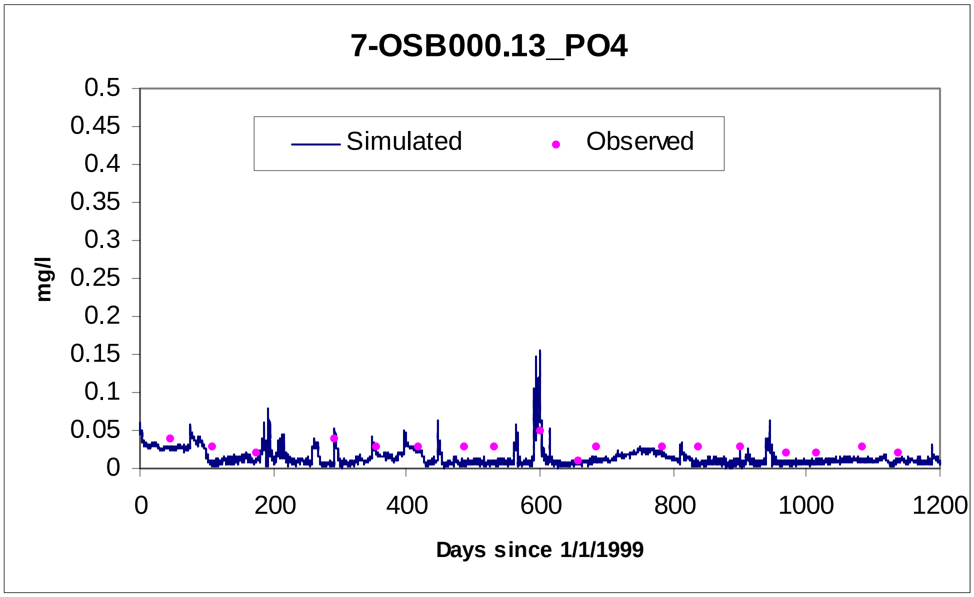
Water quality calibration results for South Branch (Station 7-0SB0000.13)

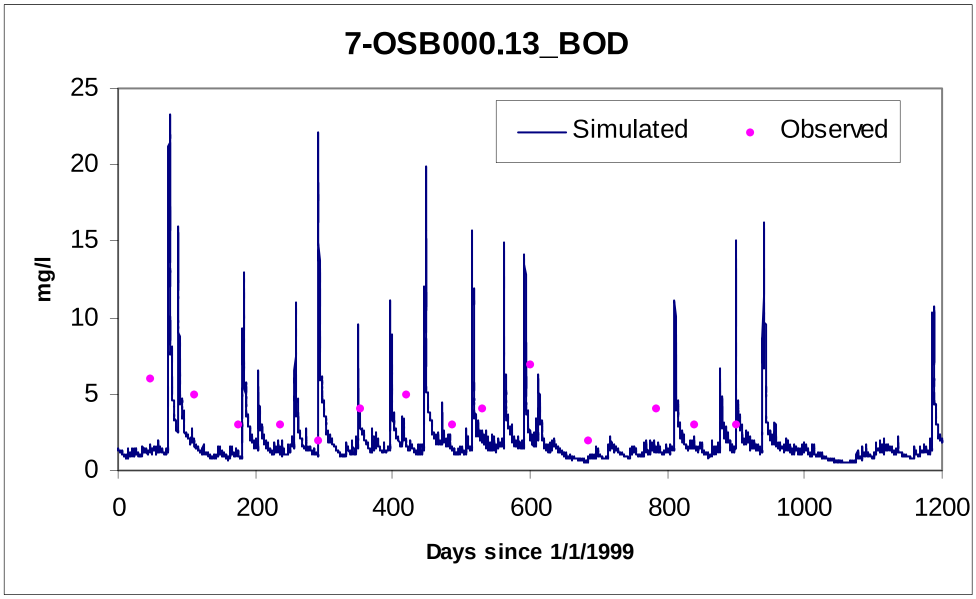


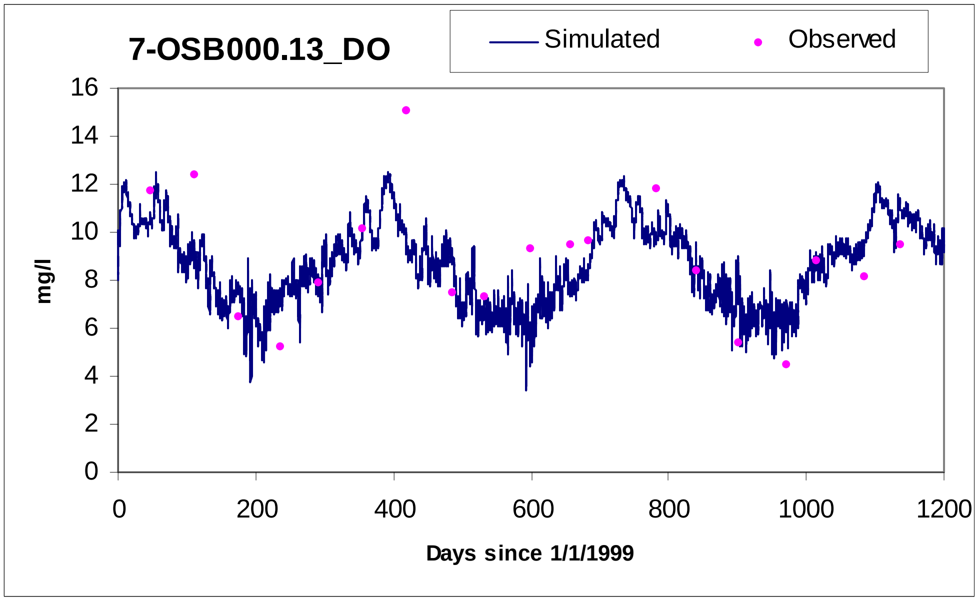


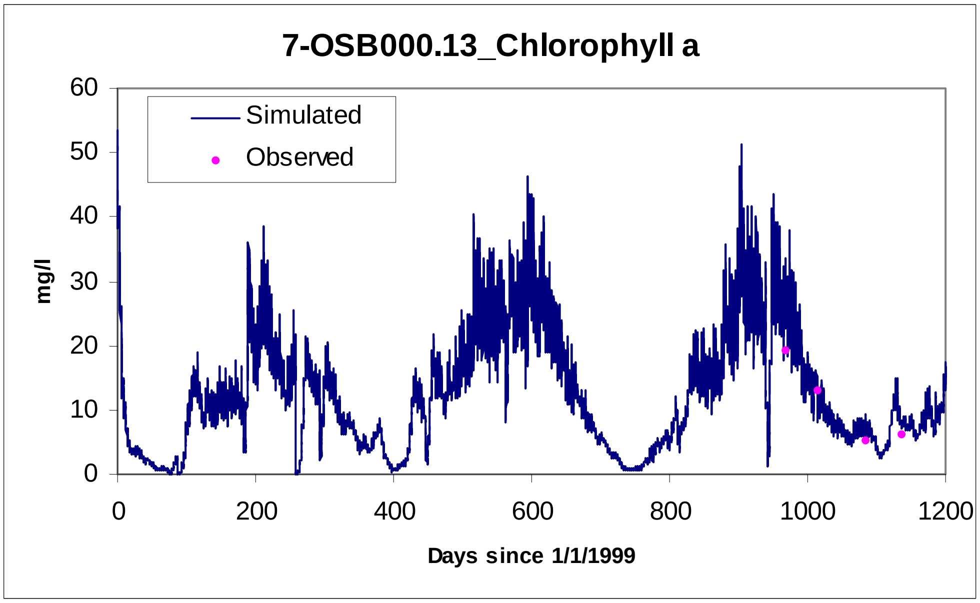

7-OSB000.13_NH4
Simulated
Observed
mg/l
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-OSB000.13_NO3
Simulated
Observed
mg/l
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-OSB000.13_PO4
Simulated
Observed
mg/l
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

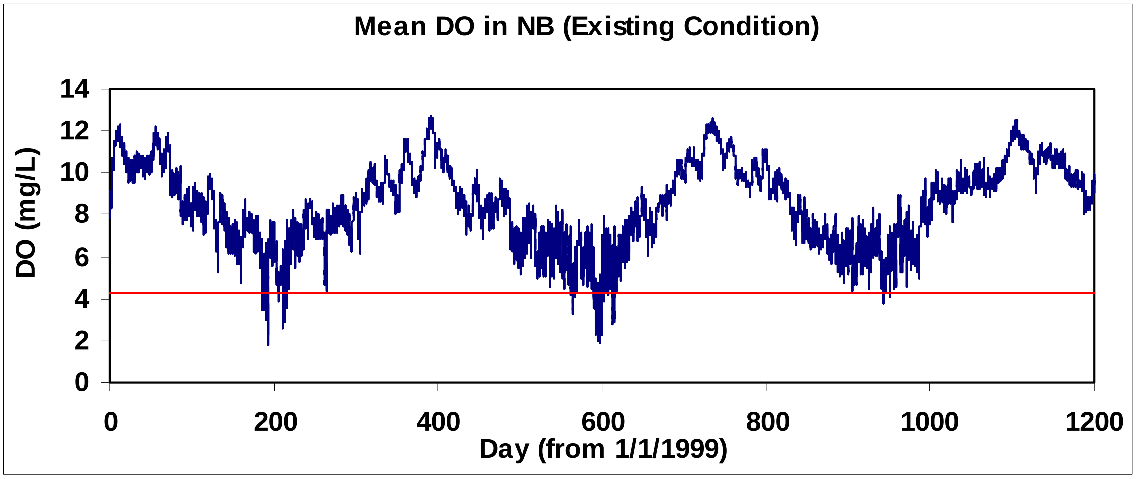

7-OSB000.13_BOD
Simulated
Observed
mg/l
25
20
15
10
5
0
0
200
400
600
800
1000
1200
Days since 1/1/1999

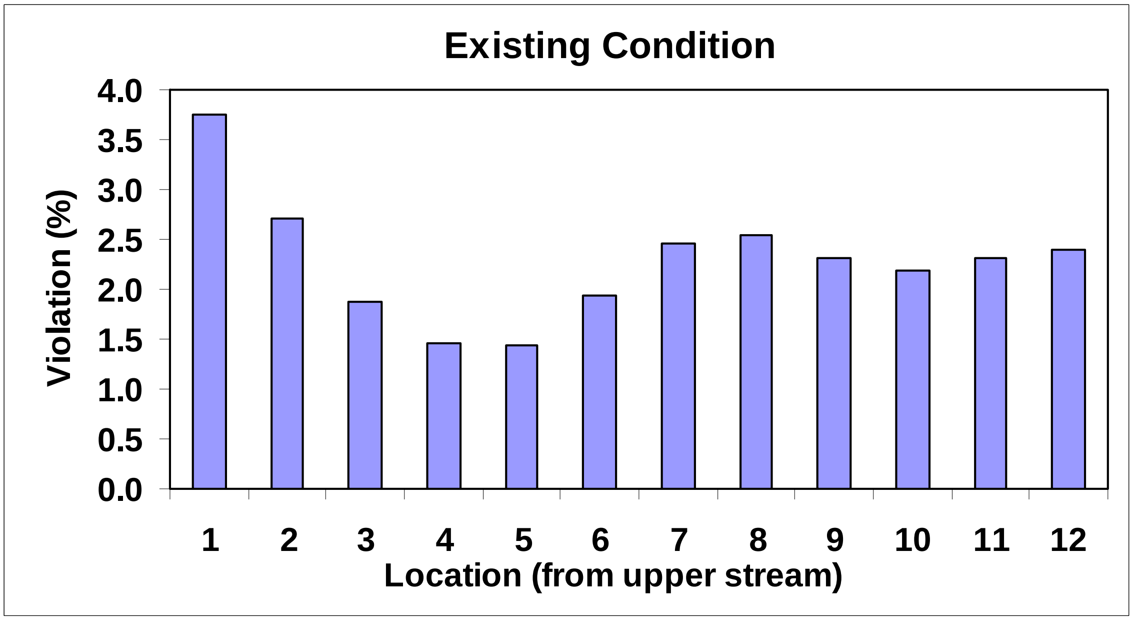

7-OSB000.13_DO
Simulated
Observed
mg/l
0
2
4
6
8
10
12
14
16
0
200
400
600
800
1000
1200
Days since 1/1/1999


7-OSB000.13_Chlorophyll a
Simulated
Observed
mg/l
0
10
20
30
40
50
60
0
200
400
600
800
1000
1200
Days since 1/1/1999

Appendix B. Model Scenario Results

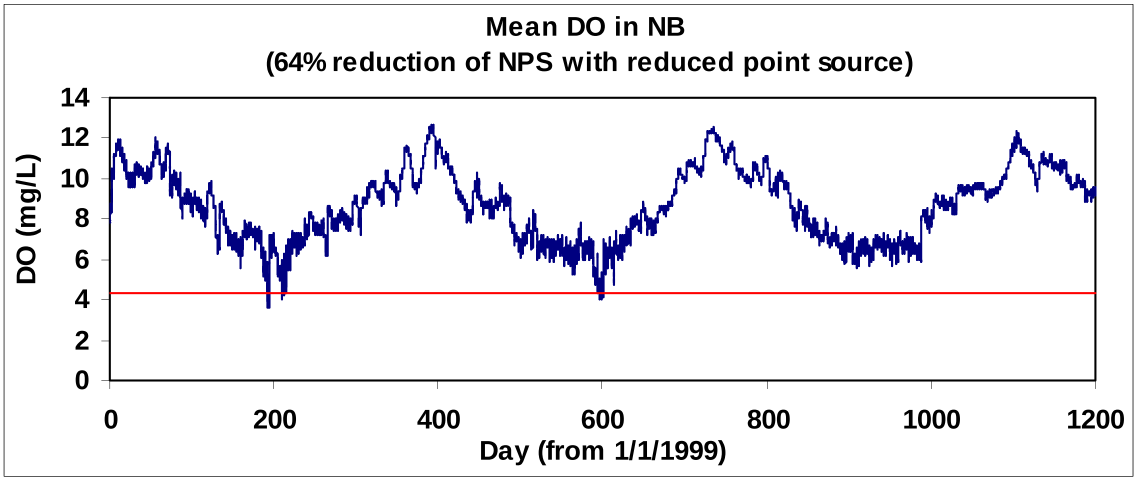
1. Existing Condition

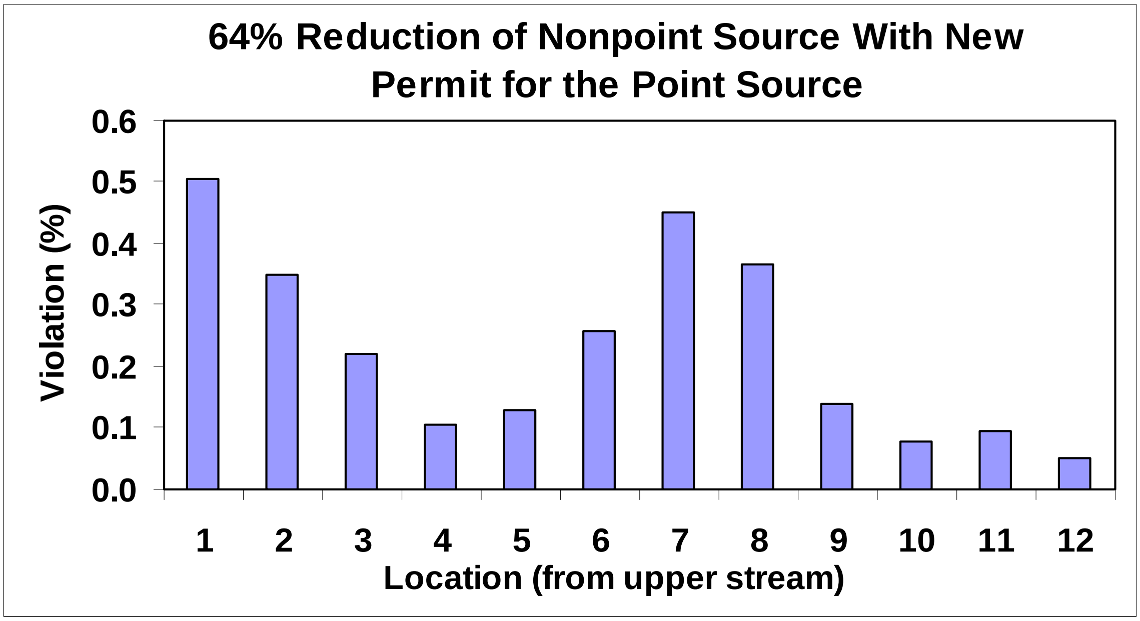




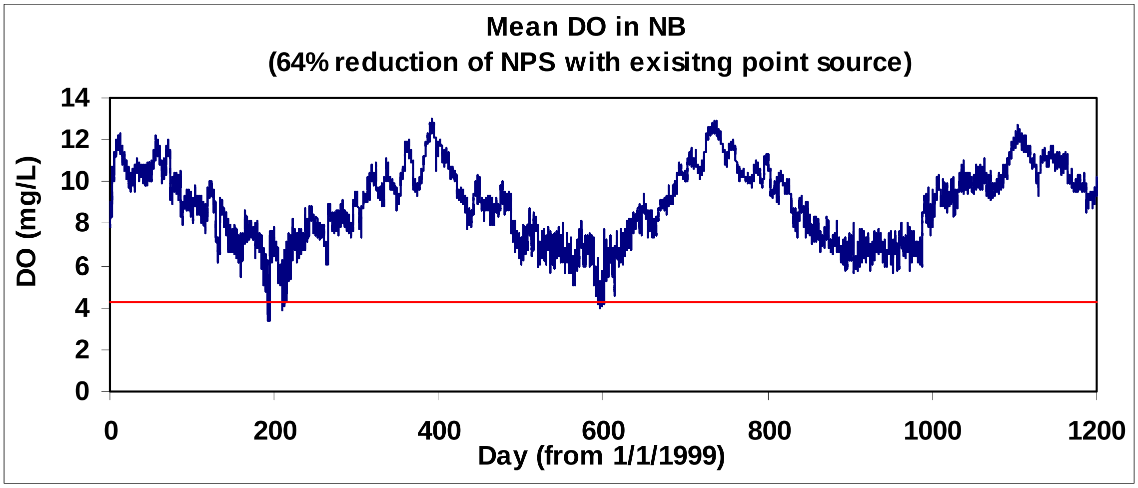
2. Scenarios

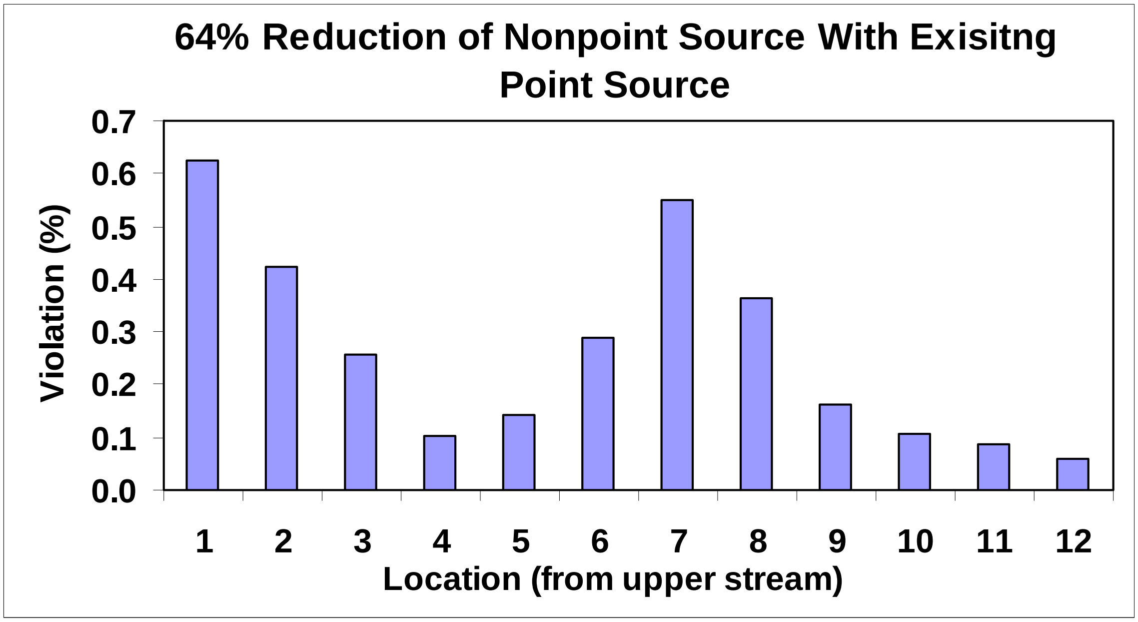
(1) 64% reduction of nonpoint source and reduction of point source using new permitted point source of 4 mg/l for TN and 0.3 mg/l for TP



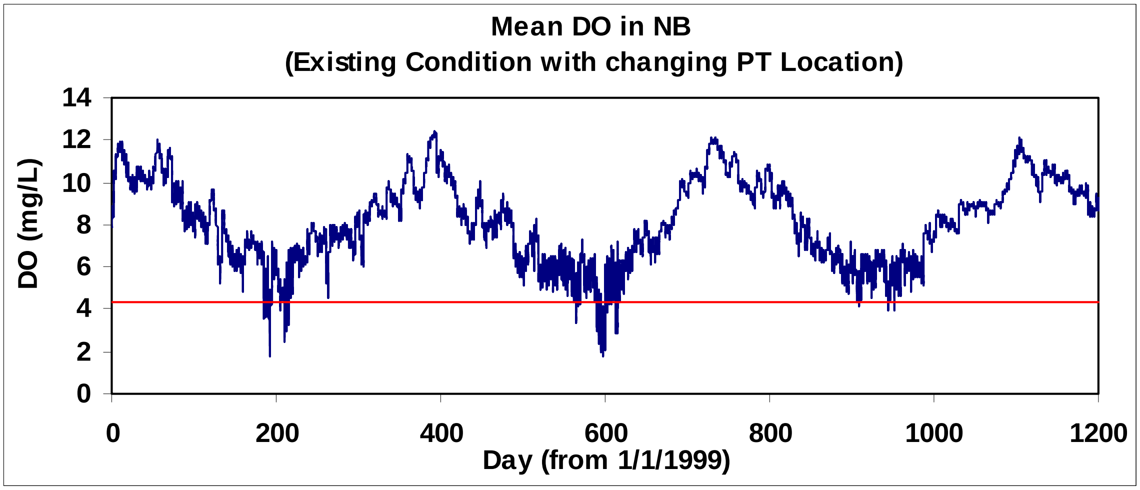


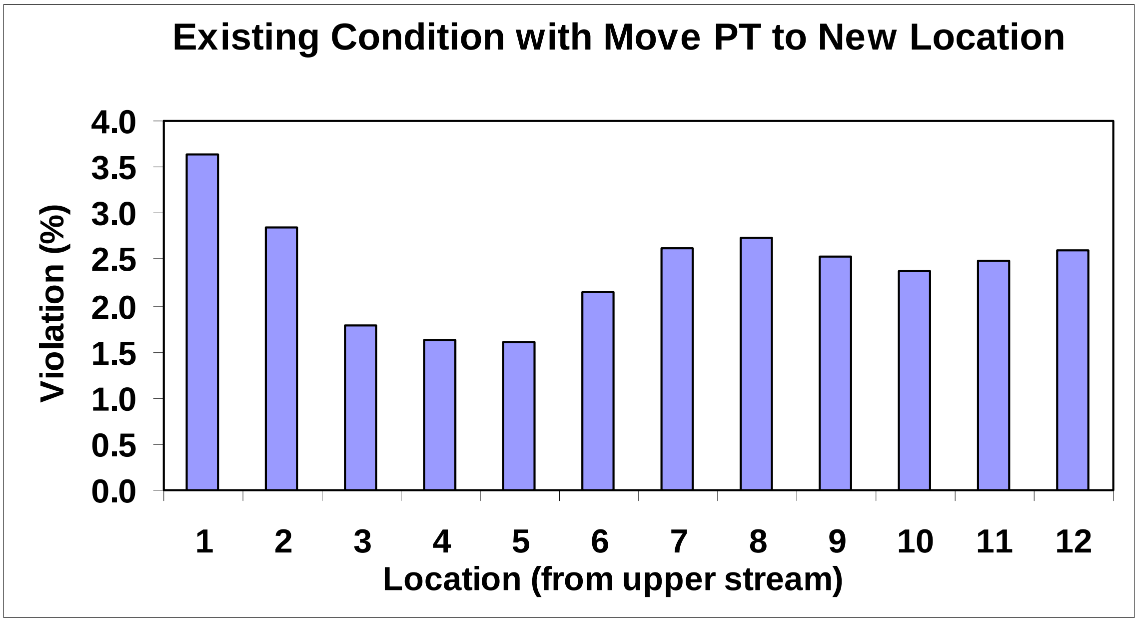
(2) 64% reduction of nonpoint source with existing point sources



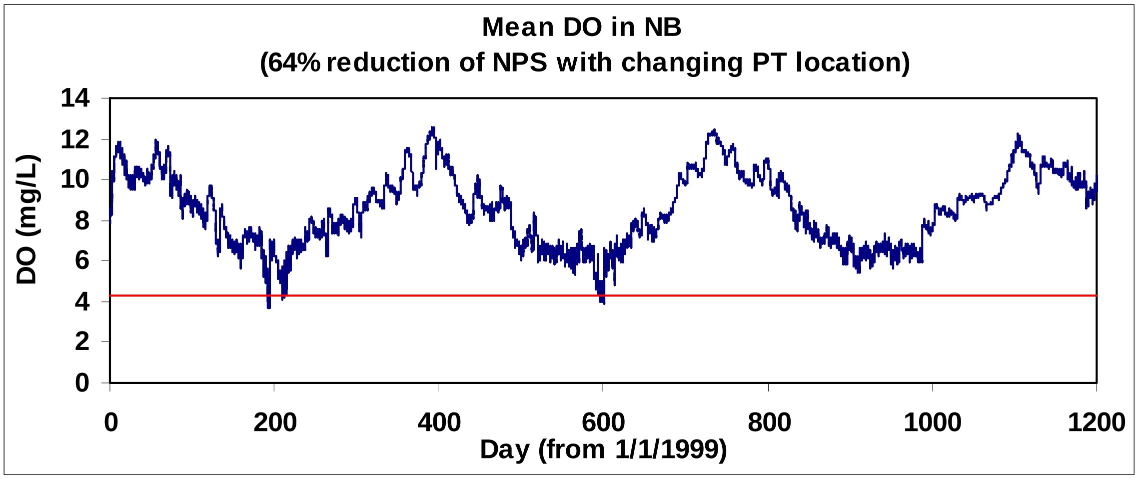


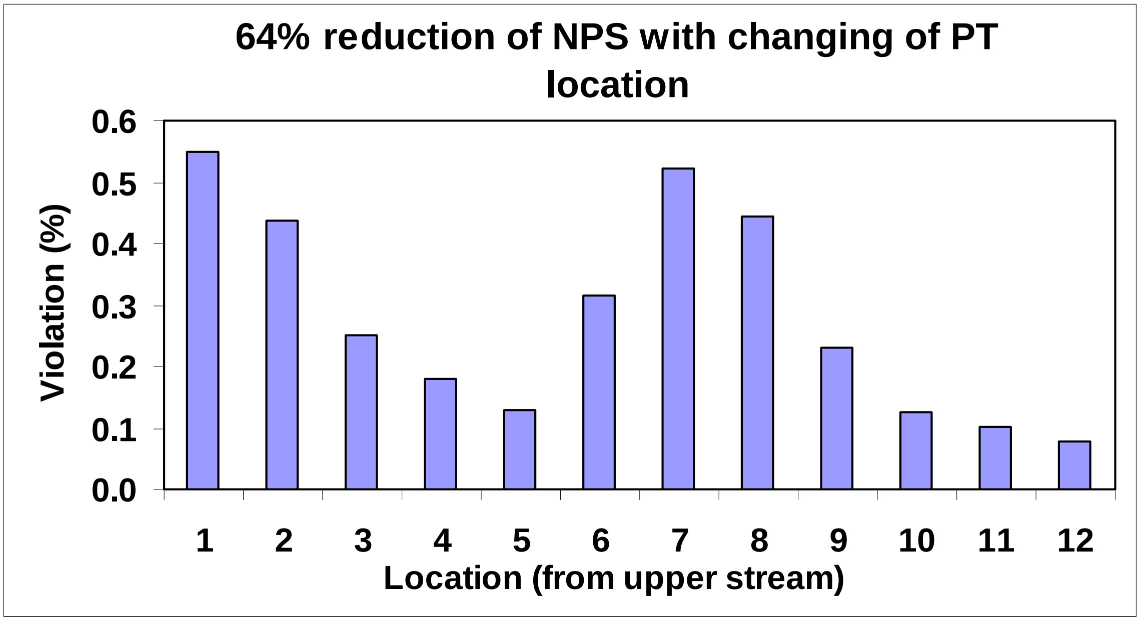
(3) Existing condition with the change of the location of point source. The new point source is located at the downstream outside of the North Branch



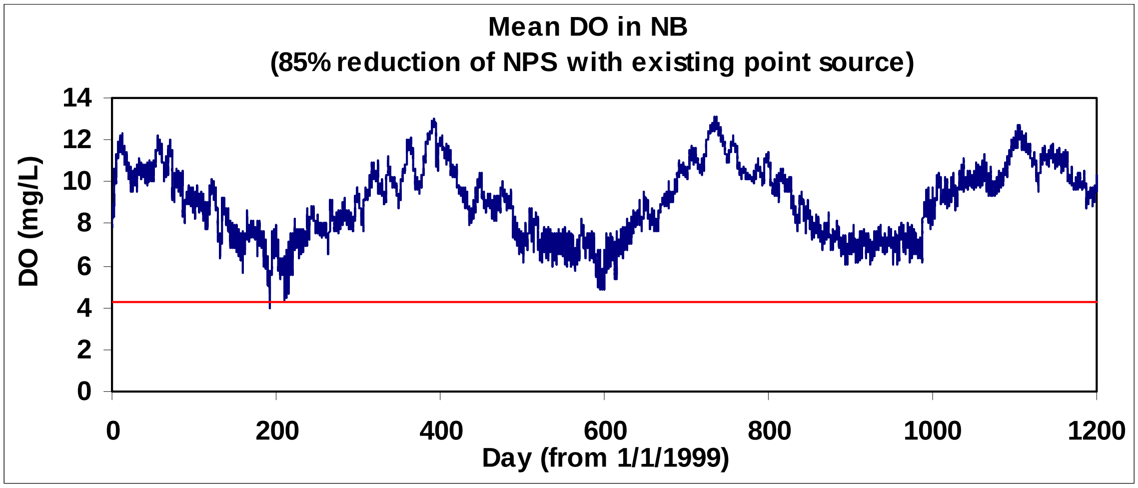


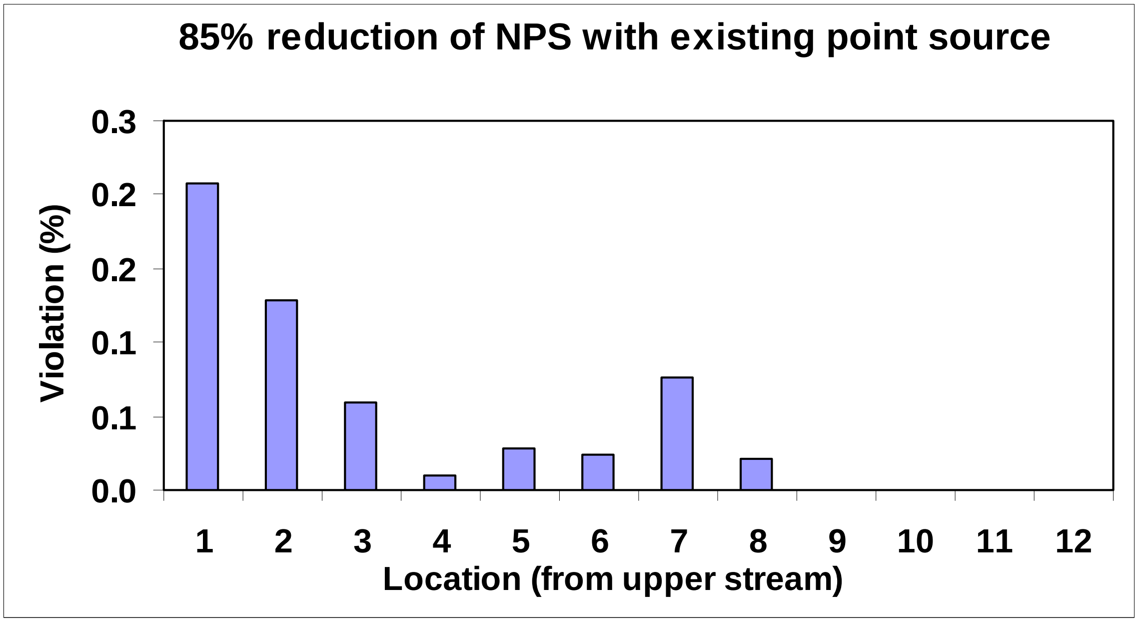
(4) 64% reduction of nonpoint source with the change of the point source location



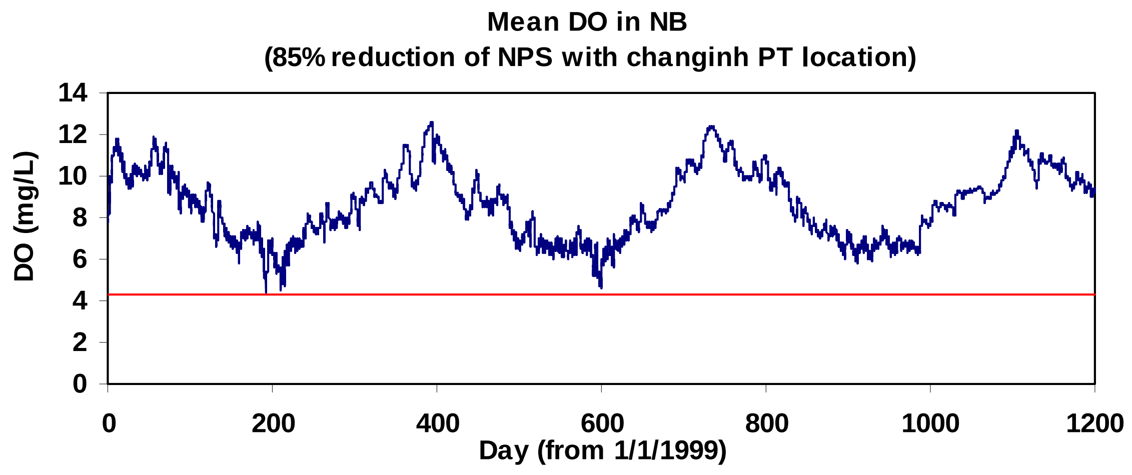


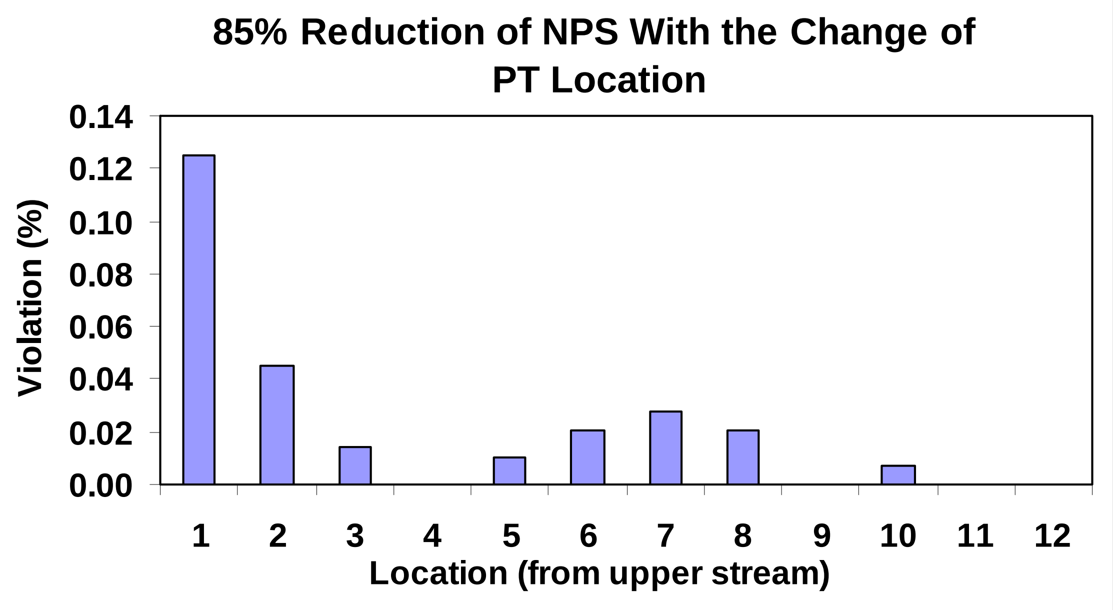
(5) 85% reduction of nonpoint source with existing point source



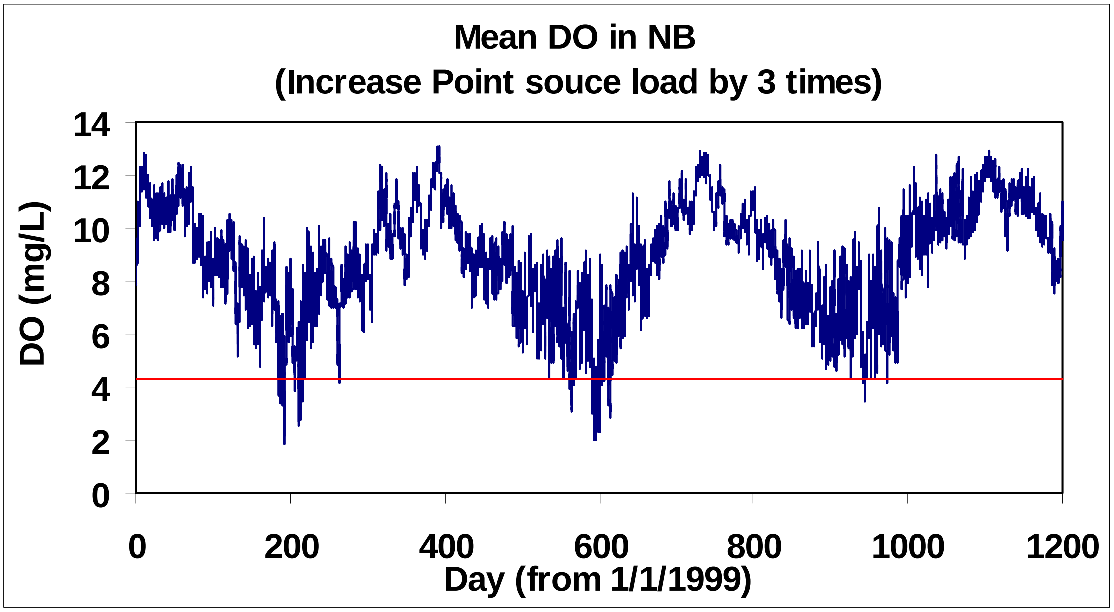


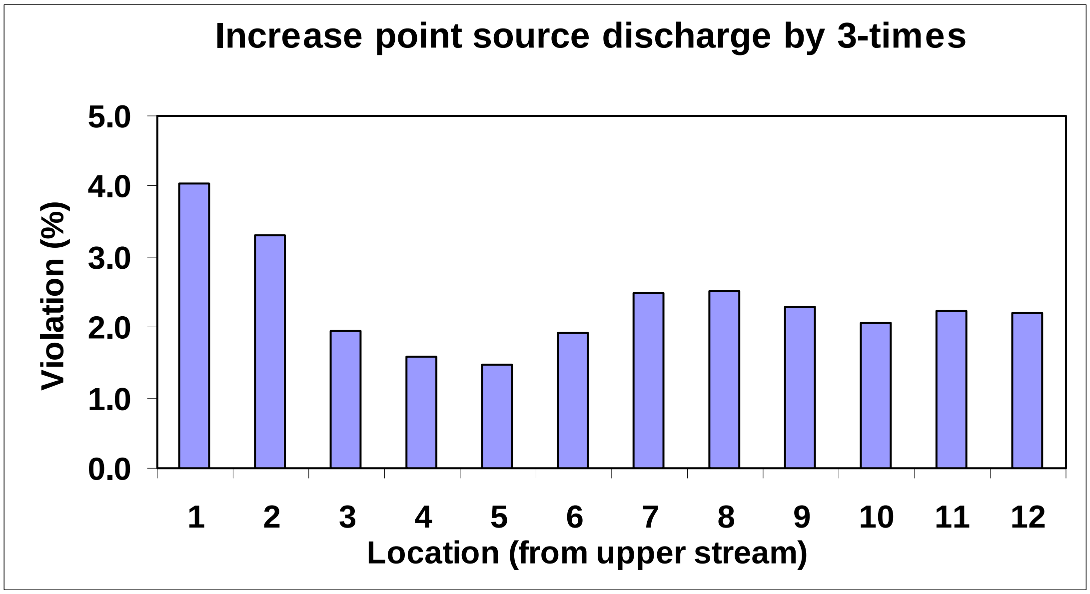
(6) 85% reduction of nonpoint source with the change of the point source location



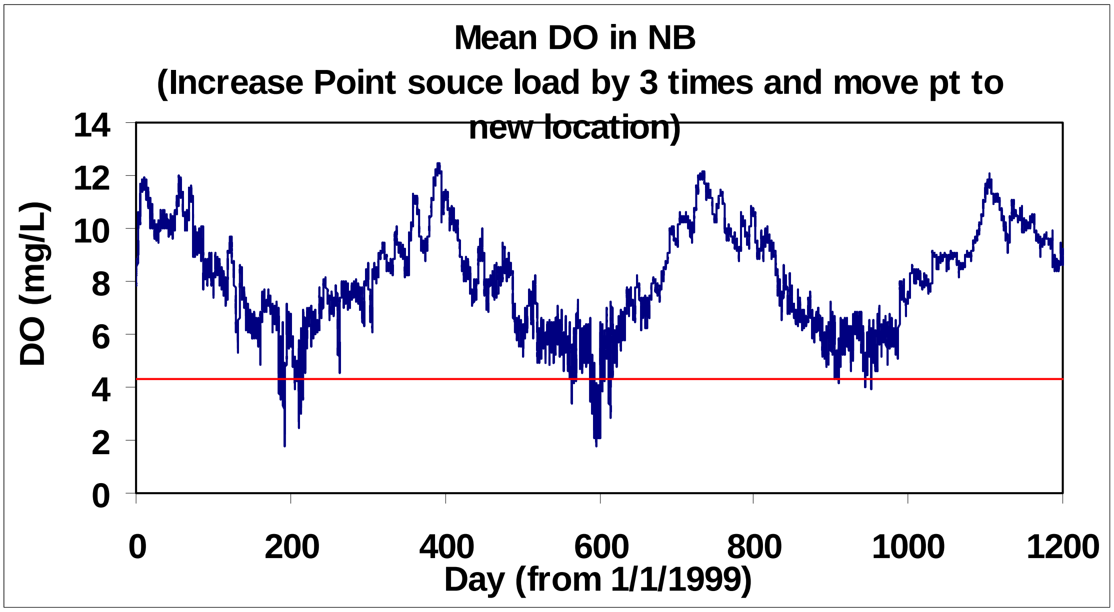


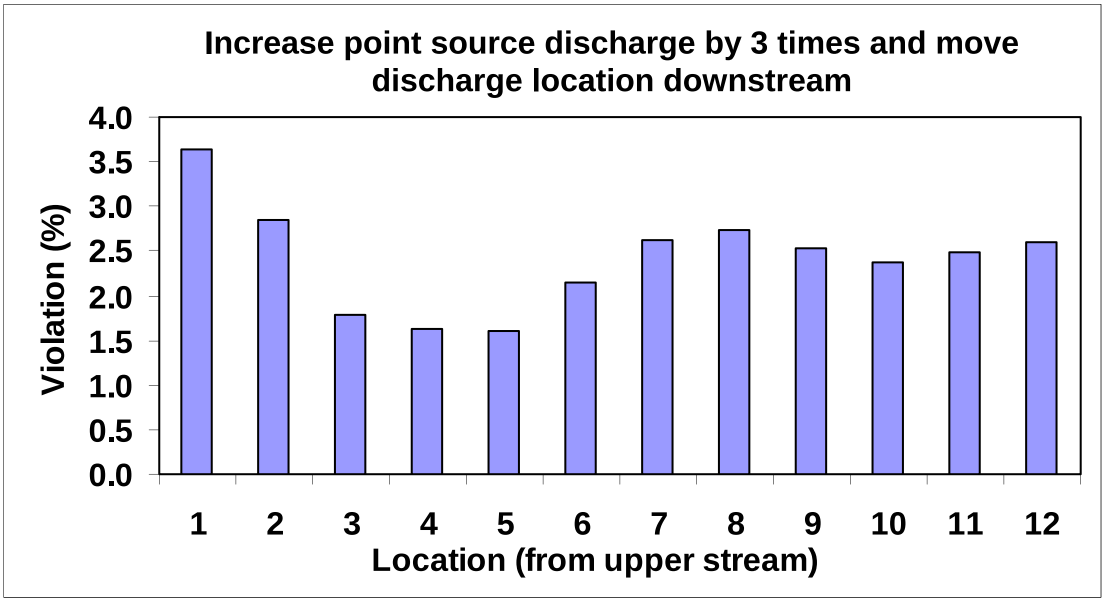
(7) Use existing nonpoint source loads and increase point source design flow three times with newly permitted concentrations





(8) Using existing nonpoint source loads and increase point source design flow three times with newly permitted concentrations. Move point source discharge location to the mouth of North Branch





Appendix C. Supporting Data Document

Below is a table that lists the data layers that were developed for the watershed and hydrodynamic models.

Table C-1 Data Elements and Sources

Data Element	Source	Date
Watershed boundary and shoreline	Division of Shellfish Sanitation, VA Department of Health	1998
Land use	Virginia Baseline Mapping Program (VBMP), Commonwealth of Virginia National Land Cover Data (NLCD) set, USGS	2002 1999
Elevation	Digital Elevation Models (DEM) and topographic maps, USGS	Various dates
Soils	SSURGO and STATSGO, National Resource Conservation Service	Various dates
Stream network	National Hydrography Dataset, USGS	1999
Meteorological data	Chesapeake Bay Program, Phase V Chesapeake Bay National Estuarine Research Reserve Onancock WWTP National Climatic Data Center, NOAA	1984-1999 2002-2004 1990-2004 1990-2004
Stream flow data	Gauging stations, USGS VA DEQ	1984-1994 2003-3004
Sewered area coverage	Town of Onancock	2004
Dog population	US Census Bureau American Veterinary Association	2000 2002
Agricultural and urban nutrient data	Field survey and literature values	2004
Domestic livestock	National Agricultural Statistics Service, US Department of Agriculture	1997/2001
Wildlife	Virginia Department of Game and Inland Fisheries US Fish and Wildlife Service	2004 2004
Septic tanks	Virginia Baseline Mapping Program (VBMP), Commonwealth of Virginia	2002
Atmospheric deposition of nutrients	Literature values	Various dates
Lawn fertilizer application	Literature values	2004
Groundwater monitoring data	Field data and literature values	Various dates
Bathymetric data	Field survey by VIMS NOAA	2004 1950s
Tidal data	NOAA tide tables	2004

Data Description and Process

Subwatershed boundaries were delineated based on elevation, using digital 7.5 minute USGS topographic maps.

Sewer data layer was digitized from Shoreline Sanitary Survey by CCRM and verified by Onancock STP.

Population Numbers

The process used to generate population numbers for the nonpoint source contribution analysis part of the watershed model is described for each below.

Human:
The number of failing septic tanks was digitized from the total number of septic systems using an average septic failure rate of 12%.

Livestock:
National Agriculture Statistics Survey data was used to calculate the livestock values. Numbers for each type of livestock (cattle, pigs, sheep, chickens, and horses) were reported by county. Each type of livestock was assigned to the land use(s) it lives on, or contributes to by the application of manure, as follows:

Cattle	cropland and pastureland
Pigs	cropland
Sheep	pastureland
Chickens	cropland
Horses	pastureland

Using MS Access, for each type of livestock, the animal density for Accomack County was multiplied by the area of each land use in each subwatershed of Onancock Creek to get the number of animals in each subwatershed. The number of animals in each subwatershed was summed to get the total number of animals in the watershed.

Pets:
The dog population was calculated using a formula for estimating the number of pets using national percentages, reported by the American Veterinary Association:
dogs = # of households * 0.58.
US Census Bureau data provided the number of households.

Wildlife:
Deer—
The number of deer were calculated using information supplied by DGIF, consisting of an average deer index by county and the formula:
#deer/mi^2 of deer habitat = (-0.64 + (7.74 * average deer index)).
Deer habitat consists of forests, wetlands, and agricultural lands (crop and pasture). GIS was used to overlay data layers for the following steps:

1) The subwatershed boundaries to get the area of each.
2) The subwatershed boundaries and the deer habitat to get the area of deer habitat in each subwatershed.

Using MS Access, number of deer in each subwatershed were calculated by multiplying the #deer/mi^2 of deer habitat times the area of deer habitat. The number of deer in each subwatershed was summed to get the total number of deer in the watershed.

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

Summer

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

Winter

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

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

Raccoons—

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

Appendix D. Nutrient Load by Subwatershed

Below are tables that list simulated watershed loads by watershed and land uses.

Table C-1. Watershed nutrients load summary by area and land use

Area	Variable	Land use	Load (Kg/day)
CB	OC	Cropland	15.80
CB	OC	Forest	9.55
CB	OC	Pasture	6.16
CB	OC	Urban impervious	29.53
CB	OC	Urban pervious	12.30
CB	OC	Wetlands	1.00
CB	TP	Cropland	0.06
CB	TP	Forest	0.04
CB	TP	Pasture	0.02
CB	TP	Urban impervious	0.15
CB	TP	Urban pervious	0.11
CB	TP	Wetlands	0.00
CB	TN	Cropland	2.82
CB	TN	Forest	0.29
CB	TN	Pasture	0.44
CB	TN	Urban impervious	0.89
CB	TN	Urban pervious	1.04
CB	TN	Wetlands	0.06
NB	OC	Cropland	30.94
NB	OC	Forest	25.03
NB	OC	Pasture	8.07
NB	OC	Urban impervious	22.91
NB	OC	Urban pervious	10.19
NB	OC	Wetlands	1.44
NB	TP	Cropland	0.13
NB	TP	Forest	0.11
NB	TP	Pasture	0.03
NB	TP	Urban impervious	0.12
NB	TP	Urban pervious	0.07
NB	TP	Wetlands	0.01
NB	TN	Cropland	5.51
NB	TN	Forest	0.75
NB	TN	Pasture	0.58
NB	TN	Urban impervious	0.69
NB	TN	Urban pervious	0.83
NB	TN	Wetlands	0.09
SB	OC	Cropland	55.54
SB	OC	Forest	17.25
SB	OC	Pasture	12.57

SB	OC	Urban impervious	11.28
SB	OC	Urban pervious	5.84
SB	OC	Wetlands	1.52
SB	TP	Cropland	0.23
SB	TP	Forest	0.07
SB	TP	Pasture	0.05
SB	TP	Urban impervious	0.06
SB	TP	Urban pervious	0.06
SB	TP	Wetlands	0.01
SB	TN	Cropland	9.89
SB	TN	Forest	0.52
SB	TN	Pasture	0.90
SB	TN	Urban impervious	0.34
SB	TN	Urban pervious	0.50
SB	TN	Wetlands	0.09

Table C-2. Watershed nutrient loads distribution by area

Area	**Variable**	**Load (kg/day)**
CB	OC	74.3
CB	TP	0.4
CB	TN	5.5
NB	OC	98.6
NB	TP	0.5
NB	TN	8.4
SB	OC	353.0
SB	TP	1.5
SB	TN	33.8

Appendix E. Model Parameters

Table E-1. Monthly accumulation rate

Land use	Parm.	SWS	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Barren	OC	8001-8003	0.616	0.616	0.616	0.770	0.924	0.924	0.924	0.924	0.924	0.770	0.616	0.616
	OP	8001-8003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8001-8003	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Cropland	OC	8001-8003	2.772	2.772	2.772	3.080	3.850	4.620	4.620	4.620	4.620	3.850	3.080	3.080
	OP	8001-8003	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8001-8003	0.158	0.189	0.173	0.130	0.142	0.448	0.019	0.019	0.225	0.019	0.162	0.019
Forest	OC	8001-8003	2.156	2.156	2.156	2.464	2.772	3.080	3.080	3.080	3.080	2.464	2.156	2.156
	OP	8001-8003	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8001-8003	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Pasture	OC	8001-8003	1.848	1.848	1.848	2.156	2.464	2.772	2.772	2.772	2.464	2.156	1.848	1.848
	OP	8001-8003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8001-8003	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Pervious	OC	8001-8003	2.464	2.464	2.464	2.464	2.464	2.772	2.772	2.772	2.772	2.464	2.464	2.464
	OP	8001-8003	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017	0.017
	TN	8001-8003	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028	0.028
Wetlands	OC	8001-8003	2.772	2.772	2.772	3.850	3.850	4.312	4.312	4.312	3.850	2.772	2.772	2.772
	OP	8001-8003	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	TN	8001-8003	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Other	OC	8001-8003	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
	OP	8001-8003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8001-8003	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Impervious	OC	8001-8003	0.616	0.616	0.616	0.616	0.924	0.924	0.924	0.924	0.616	0.616	0.616	0.616
	OP	8001-8003	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8001-8003	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Barren	OC	8004-8006	0.616	0.616	0.616	0.770	0.924	0.924	0.924	0.924	0.924	0.770	0.616	0.616
	OP	8004-8006	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8004-8006	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Cropland	OC	8004-8006	2.772	2.772	2.772	3.080	3.850	4.620	4.620	4.620	4.620	3.850	3.080	3.080
	OP	8004-8006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
	TN	8004-8006	0.158	0.190	0.173	0.131	0.143	0.448	0.020	0.020	0.227	0.020	0.163	0.020
Forest	OC	8004-8006	2.156	2.156	2.156	2.464	2.772	3.080	3.080	3.080	3.080	2.464	2.156	2.156
	OP	8004-8006	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8004-8006	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Pasture	OC	8004-8006	1.848	1.848	1.848	2.156	2.464	2.772	2.772	2.772	2.464	2.156	1.848	1.848
	OP	8004-8006	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8004-8006	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Pervious	OC	8004-8006	2.464	2.464	2.464	2.464	2.464	2.772	2.772	2.772	2.772	2.464	2.464	2.464
	OP	8004-8006	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030	0.030
	TN	8004-8006	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
Wetlands	OC	8004-8006	2.772	2.772	2.772	3.850	3.850	4.312	4.312	4.312	3.850	2.772	2.772	2.772
	OP	8004-8006	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011	0.011
	TN	8004-8006	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
Other	OC	8004-8006	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
	OP	8004-8006	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8004-8006	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Impervious	OC	8004-8006	0.616	0.616	0.616	0.616	0.924	0.924	0.924	0.924	0.616	0.616	0.616	0.616
	OP	8004-8006	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8004-8012	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019

Barren	OC	8013-8037	0.616	0.616	0.616	0.770	0.924	0.924	0.924	0.924	0.924	0.770	0.616	0.616
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Cropland	OC	8013-8037	2.772	2.772	2.772	3.080	3.850	4.620	4.620	4.620	4.620	3.850	3.080	3.080
	OP	8013-8037	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8013-8037	0.158	0.189	0.173	0.130	0.142	0.448	0.019	0.019	0.225	0.019	0.162	0.019
Forest	OC	8013-8037	2.156	2.156	2.156	2.464	2.772	3.080	3.080	3.080	3.080	2.464	2.156	2.156
	OP	8013-8037	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Pasture	OC	8013-8037	1.848	1.848	1.848	2.156	2.464	2.772	2.772	2.772	2.464	2.156	1.848	1.848
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Pervious	OC	8013-8037	2.464	2.464	2.464	2.464	2.464	2.772	2.772	2.772	2.772	2.464	2.464	2.464
	OP	8013-8037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037	0.037
	TN	8013-8037	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
Wetlands	OC	8013-8037	2.772	2.772	2.772	3.850	3.850	4.312	4.312	4.312	3.850	2.772	2.772	2.772
	OP	8013-8037	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007	0.007
	TN	8013-8037	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021	0.021
Other	OC	8013-8037	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Impervious	OC	8013-8037	0.616	0.616	0.616	0.616	0.924	0.924	0.924	0.924	0.616	0.616	0.616	0.616
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Barren	OC	8013-8037	0.616	0.616	0.616	0.770	0.924	0.924	0.924	0.924	0.924	0.770	0.616	0.616
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Cropland	OC	8013-8037	2.772	2.772	2.772	3.080	3.850	4.620	4.620	4.620	4.620	3.850	3.080	3.080
	OP	8013-8037	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8013-8037	0.158	0.189	0.173	0.130	0.142	0.447	0.019	0.019	0.225	0.019	0.162	0.019
Forest	OC	8013-8037	2.156	2.156	2.156	2.464	2.772	3.080	3.080	3.080	3.080	2.464	2.156	2.156
	OP	8013-8037	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Pasture	OC	8013-8037	1.848	1.848	1.848	2.156	2.464	2.772	2.772	2.772	2.464	2.156	1.848	1.848
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Pervious	OC	8013-8037	2.464	2.464	2.464	2.464	2.464	2.772	2.772	2.772	2.772	2.464	2.464	2.464
	OP	8013-8037	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046	0.046
	TN	8013-8037	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049	0.049
Wetlands	OC	8013-8037	2.772	2.772	2.772	3.850	3.850	4.312	4.312	4.312	3.850	2.772	2.772	2.772
	OP	8013-8037	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006	0.006
	TN	8013-8037	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020	0.020
Other	OC	8013-8037	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019
Urban Impervious	OC	8013-8037	0.616	0.616	0.616	0.616	0.924	0.924	0.924	0.924	0.616	0.616	0.616	0.616
	OP	8013-8037	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004	0.004
	TN	8013-8037	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019	0.019

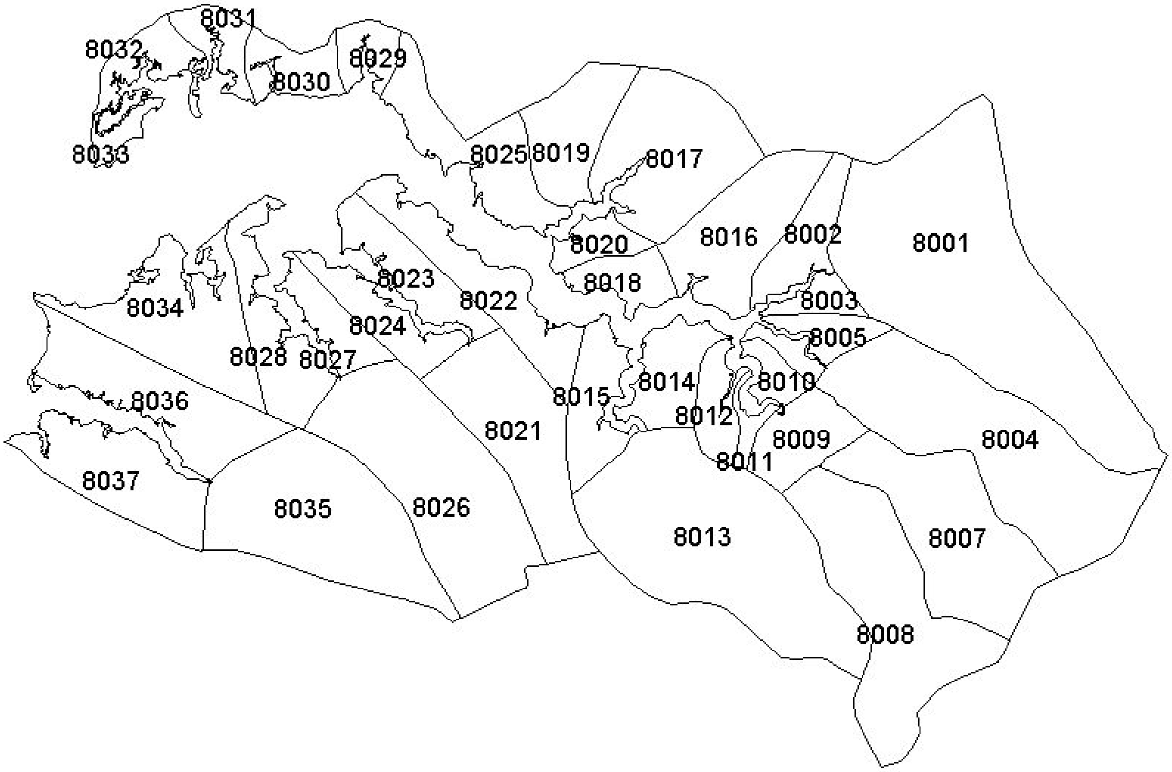


Figure E-1. Subwatershed identification numbers.