COMMONWEALTH of VIRGINIA

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Tidewater Regional Office

October 6, 2010

Mr. Greg Voigt
US EPA Region III TMDL Coordinator
USEPA REGION 3 – 3WP12
1650 Arch Street
Philadelphia, PA 19103-2029

RE: Submittal of Pocomoke Sound Natural Conditions DO Assessment

Dear Mr. Voigt,

This letter is to request approval of the Dissolved Oxygen natural conditions assessment for the Virginia portion of the Pocomoke Sound. This request is supported by the attached Assessment Report which concludes that the Pocomoke oligohaline segment's low dissolved oxygen conditions during the summer months are strongly influenced by natural conditions and the downstream estuarine condition. Virginia requests EPA's approval of the report and recategorization of the Pocomoke Sound dissolved oxygen impairment from "Category 5A – Impaired Needing a TMDL" to "Category 4C – Impaired Due to Natural Conditions".

You will find enclosed the Natural Conditions Assessment document. If you or your staff has any questions, please contact me at (804) 698-4299.

Sincerely,

David S. Lazarus
Watershed Program Manager
Office of Water Quality Programs

Enclosure

cc: Charlie Lunsford, VADCR
Darryl Glover, VADEQ
Alex Barron, VADEQ
Jennifer Howell, TRO TMDL coordinator
File CO

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Natural Conditions Assessment of Low Dissolved Oxygen in the Virginia Portion of CBP Segment POCOH (Pocomoke Sound)

Virginia Department of Environmental Quality
October 2010

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Description of the Watershed

The Pocomoke River originates in the Great Cypress Swamp along the Delaware-Maryland border and flows for approximately 95 km through Maryland into Pocomoke Sound of the Chesapeake Bay (LESHC 1994). Streams are mostly non-tidal, with tidal influence in the lowest reach of the Pocomoke mainstem at Pocomoke Sound to about 20 km upstream. The Pocomoke River drainage area is approximately 1,498.97 km^2 with approximately 85%, 9% and 6% of the area in Maryland, Virginia, and Delaware respectively. The boundary between Maryland (MD) and Virginia (VA) follows along the lower tidal river (CBP segment POCOH) on the eastern shores of these jurisdictions. The Pocomoke River watershed is located in portions of Worcester, Somerset, and Wicomico Counties in Maryland, as well as in portions of Sussex County, Delaware, and Accomack County, Virginia.

The Pocomoke River watershed is flat, with poorly drained soils underlain by unconsolidated Coastal Plain sediments. The shallow aquifer system is characterized by complex, heterogeneous hydrogeology with short, shallow groundwater flow paths (Hamilton et al. 1993). A relatively thin sandy surficial aquifer, which is overlain by poorly drained soils, contains the shallow water table (Hancock et al. 2007). The dominant tide in this region is the lunar semi-diurnal (M_2) tide, with a tidal range of 0.70 m in the Pocomoke Sound and a tidal period of 12.42 hours (National Oceanic and Atmospheric Administration (NOAA) 2006).

Table 1. Land use distribution by land use class

Land Use Class	Area (km^2)	Percentage
open water	6.08	0.41
low intensity developed	18.19	1.21
med intensity developed	8.52	0.57
high intensity developed	5.75	0.38
Transportation	22.58	1.51
urban/residential deciduous tree	24.00	1.60
urban/residential evergreen tree	5.57	0.37
urban/residential mixed trees	1.08	0.07
urban/residential/recreational grass	14.72	0.98
Extractive	0.23	0.02
Barren	21.33	1.42
deciduous forest	422.68	28.20
evergreen forest	242.09	16.15
mixed (deciduous-evergreen) forest	32.00	2.13
pasture/hay	235.17	15.69
Croplands	193.69	12.92
"natural" grass	11.65	0.78
deciduous wooded wetland	6.72	0.45
evergreen wooded wetland	87.99	5.87
emergent (sedge-herb) wetland	122.48	8.17
mixed wetland	16.46	1.10
Total	1498.97	100.00

The Pocomoke River watershed is primarily rural, based on land use/land cover data obtained from the Chesapeake Bay program, with nearly 44.35% of the area being forest, 14.04% being wetlands, and 28.61% being cropland (Fig. 1). The Great Cypress Swamp is the origin of the Pocomoke River and the source of much of the organic material that gives the river its characteristic dark color. The Pocomoke River meanders downstream through the non-tidal and tidal fringing wetlands located along its length, generating high rates of respiration (Fig. 2) and leading to a significant, natural reduction in dissolved oxygen (DO) concentrations.

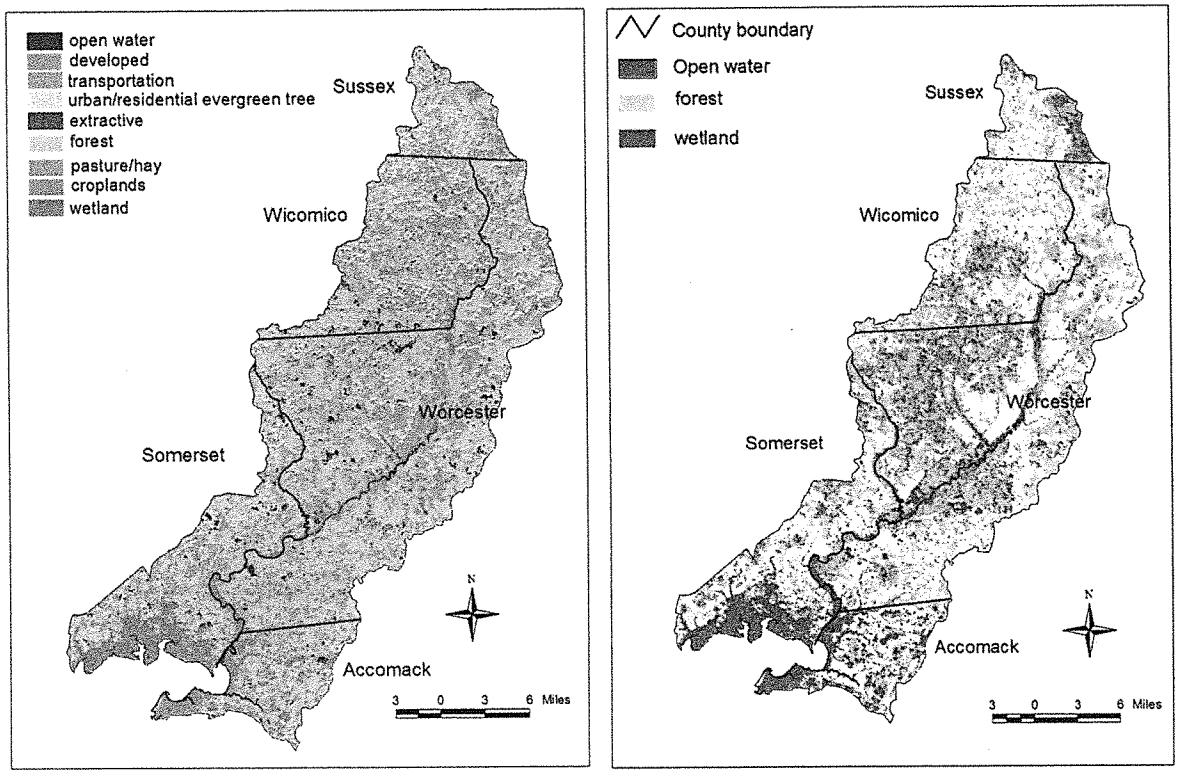


Figure 1. Land Use Distribution of Pocomoke River Watershed (Left: landuse distribution; Right: wetland and forest landuse distribution).

Description of the DO Problem

The tidal fresh Pocomoke River is designated use classified as "open water" that includes those waters beyond the shoreline and shallow waters of the Chesapeake Bay and tidal tributaries (U.S. EPA 2003). Based on requirements promulgated under the Clean Water Act, tidal waters designated as open waters of the State of Virginia are required to meet the dissolved oxygen criteria described in the Virginia Water Quality Standards (VAC 25-260-185) listed in Table 2. The Virginia portion of CBP segment POCOH has been assessed as failing to meet the open water designated use as assessed by the 30-day dissolved oxygen criteria during the summer assessment period (see *Virginia 305(B)/303(D) Water Quality Integrated Report To Congress And The EPA Administrator for the period January 1, 2001 To December 31, 2006 Richmond, Virginia, October 2008*). The following analyses show that much of this assessed impairment is due to natural causes and that this segment requires site-specific criteria to be developed.

Table 2. VA Water quality standards for open-water Dissolved Oxygen

Designated Use	Criteria Concentration/Duration	Temporal Application
Open-water	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°C Instantaneous minimum > 4.3 mg/l at temperatures > 29°C	

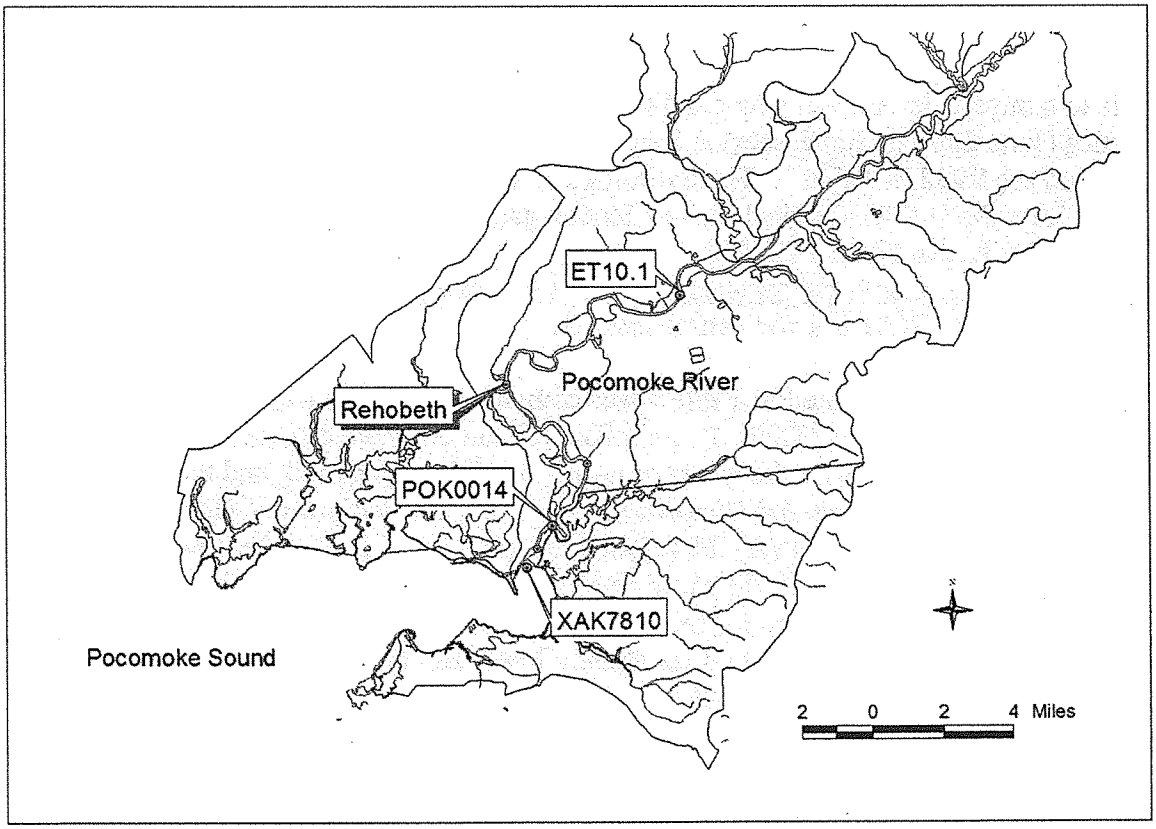


Figure 2. Locations of Observation Stations in the Pocomoke River

The data used in this report were obtained from the Chesapeake Bay Program (http://www.chesapeakebay.net), Virginia Department of Quality (DEQ), and the Maryland Department of Natural Resources (MDNR). There are four stations in the watershed (Table 3). The locations of these stations are shown in Figure 2. Among these four stations, Stations ET10.1 and XAK7810 are located in the Chesapeake Bay Program tidal fresh POCTF segment and the oligohaline POCOH segment, respectively. Both these stations have longer time series data, which are used for data analysis.

Between 1998 and 2002 MDNR deployed in-situ continuous monitoring devices at three locations on the tidal Pocomoke River at Rehobeth (Rehobeth), Cedar Hall Wharf (POK043), and Shelltown (POK0009). The location closest to POCTF was the Rehobeth station, which was in POCOH, approximately 1 mile downriver from POCTF. Station Rehobeth had data collection at 15-minute intervals. The data obtained from the dry year 2001 were selected for analysis.

Stations XAK7810 and ET10.0 data are available monthly. Therefore, monthly and instantaneous criteria for open water are used here to examine levels in relation to dissolved oxygen water quality standards. The instantaneous and monthly mean results are listed in Tables 4 and 5, respectively. In general, more violations occurred during the high temperature periods. Monthly and weekly mean DO concentrations are listed in Tables 5 and 6, respectively. Monthly mean DO ranged between 4.30 to 6.30 mg/L. Violation of monthly mean DO of 5 mg/L criterion ranges from 40.7% to 77.7% (Table 5). The highest violation occurs in July. However, the weekly mean DO concentrations at the continuous monitoring station met the 4.0 mg/L criterion (Table 6).

An analysis to compare dry vs. wet year conditions was also conducted. The mean summer characteristics (June through September) at 3 stations of the Pocomoke River during the 2007-to-2008 dry period are listed in Table 7. The hydrological dry period was determined based on flow data obtained from the U.S. Geological Survey Station gage number 01485500, which is located at Nassawango Creek near Snow Hill, MD (http://waterdata.usgs.gov/nwis/dv?referred_module=sw). The periods 2001 to 2002 and 2007-2008 are dry years. Year 2003 is a wet year (Figure 3).

The summary of statistics presented in Table 7 was compared to statistics computed for the Pamunkey and Mattaponi Rivers (Table 8), a similar wetland dominated system that is described as having "naturally lower ambient dissolved oxygen", for the same period, and the Table VI-2 of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake bay and its Tributaries-2004 Addendum* (U.S.EPA, 2004). Because measurements were not conducted in the same period, a dry year period of 2001 to 2002 was used to compute the summer statistics for the Pamunkey and Mattaponi Rivers. Both system have similar characteristics, except that DO is slightly lower and total nitrogen and organic carbon are relatively higher in the Pocomoke.

Table 3. Station Information and Statistics

CBP Segment	Station	Water Depth (m)	Vertical-mean DO Conc. (mg/L)	DO Standard deviation (mg/L)	Number of observations	Lat	Lon	Starting Observation date	Ending Observation date
POCTF	ET10.1	5.0	6.73	2.04	1732	38.076145	75.571250	1/7/1991	12/10/2009
POCTF	POK0014	3.0	10.96	1.10	12	37.981110	75.637500	1/13/2004	2/11/2009
POCOH	XAK7810	3.2	7.38	2.13	260	37.963955	75.650470	3/12/2003	12/23/2009
POCOH	Rehobeth	5.0	4.9	0.81	13485	38.038770	75.661780	5/16/2001	10/14/2001

Table 4. Summary of Instantaneous DO Violation

Bay segment	Station	Instantaneous minimum <= 3.2 mg/L at temp. <29°C			Instantaneous minimum <= 4.3 mg/L at temp. > 29°C			
		Total data	Violation counts	Violation (%)	Total data	Violation counts	Violations (%)	Total violations (%)
POCTF	XAK7810	245	0	0.00%	15	1	6.67%	0.38%
POCOH	ET10.1	1350	56	4.15%	21	4	19.05%	4.38%
POCOH	Rehobeth	8269	40	0.48%	463	271	58.53%	3.56%

Table 5. Monthly mean DO Values

STATION	Year	June	July	August	September
ET10.1 (POCTF)	1991	4.90	4.42	7.40	5.60
	1992	3.36	4.12	4.90	5.00
	1993	4.30	4.00	7.08	5.90
	1994	5.21	5.42	5.20	7.57
	1995	4.03	4.17	5.30	6.17
	1996	3.86	1.86	3.00	3.40
	1997	6.07	4.50	3.60	5.64
	1998	4.18	3.90	5.10	5.12
	1999	5.73	5.53	4.43	3.40
	2000	5.28	3.90	2.73	4.48
	2001	4.36	4.70	4.80	4.40
	2002	5.00	6.02	5.84	3.53
	2003	4.30	3.29	3.87	3.05
	2004	4.29	4.30	3.30	5.20
	2005	3.05	3.11	3.44	5.26
	2006	4.61	3.20	4.20	2.79
	2007	4.80	4.90	4.50	5.56
	2008	2.33		5.00	5.10
	2009	3.76	3.60	3.97	3.70
XAK7810 (POCOH)	2003	5.10	4.48	5.05	4.78
	2004	6.63	4.63	5.53	7.08
	2005	5.00	3.98	3.63	5.98
	2006	5.68	5.90	5.63	5.00
	2007	5.25	4.58	6.18	7.43
	2008	5.15	6.30	5.73	6.57
	2009	6.33	5.73	5.27	4.95
Rehobeth (POCOH)	2001	4.78	4.98	4.38	4.93
Violation (%)		**55.56%**	**77.78%**	**51.85%**	**40.74%**

Table 6. Weekly mean DO at Station Rehobeth (2001)

	Week	7-day mean (mg/L)
May	3	5.37
	4	5.16
June	1	5.30
	2	5.16
	3	5.00
	4	4.99
July	1	4.98
	2	4.89
	3	4.81
	4	4.70
August	1	4.38
	2	4.21
	3	4.12
	4	4.03
September	1	4.11
	2	4.71
	3	5.42
	4	5.07

Table 7. Summer Basic Characteristics of the Pocomoke River

CBP Segment	Station	Salinity (ppt)	Temp. (°C)	Total Suspended Solids (mg/L)	pH	Dissolved Oxygen (mg/L)	Chlorophyll a (µg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Dissolved inorganic Nitrogen (mg/L)	Dissolved organic Carbon (mg/L)	Particulate Carbon (mg/L)	Notes
POCTF	ET10.1	0.32	25.61	15.88	6.39	4.12	3.83	1.54	0.14	0.50	16.12	2.00	Dry-year (2007-2008)
POCTF	POK0087	2.20	26.17	38.63	6.57	4.52	10.05	1.55	0.16	0.32	15.36	3.69	
POCOH	XAK7810	7.96	26.03	24.72	7.19	5.35	16.28	1.23	0.11	0.13	11.70	2.61	
POCTF	ET10.1	0.85	25.98	18.93	6.58	4.69	8.62	1.68	0.12	0.63	14.16	2.17	Dry-year 2001-2002
POCTF	ET10.1	0.00	25.06	19.23	6.39	3.63	1.59	1.80	0.17	0.64	19.32	2.28	Wet-year (2003)
POCTF	POK0087	0.00	25.75	20.33	6.50	3.93	2.65	1.75	0.17	0.60	19.87	2.13	
POCOH	XAK7810	4.52	25.74	19.75	7.10	4.85	11.65	1.38	0.11	0.32	14.56	1.68	

Table 8. Summer Basic Characteristics of the Pamunkey and Mattaponi Rivers

CBP Segment	Station	Salinity (ppt)	Temp. (°C)	Total Suspended Solids (mg/L)	pH	Dissolved Oxygen (mg/L)	Chlorophyll a (µg/L)	Total Nitrogen (mg/L)	Total Phosphorous (mg/L)	Dissolved inorganic Nitrogen (mg/L)	Dissolved organic Carbon (mg/L)	Particulate Carbon (mg/L)	
MPNOH	RET4.1	8.40	26.28	77.72	7.13	5.14	14.80	0.86	0.14	0.12		3.06	Dry-year 2001-2002
PMKOH	RET4.2	9.86	27.18	67.56	6.95	5.37	11.76	0.82	0.14	0.12	5.84*	2.94	
MPNTF	TF4.2	0.49	27.28	25.42	6.73	5.56	7.18	0.62	0.10	0.13		1.69	
PMKTF	TF4.4	0.00	27.74	10.38	6.66	5.83	6.97	0.56	0.07	0.10	6.10*	1.02	
MPNOH	RET4.1	0.38	25.11	35.00	6.85	5.03	6.50	0.96	0.11	0.29		2.13	Wet-year 2003
PMKOH	RET4.2	2.98	25.64	70.88	6.53	4.65	8.77	1.05	0.12	0.24		3.00	
MPNTF	TF4.2	0.00	24.79	11.63	6.66	5.59	2.14	0.93	0.10	0.46		0.76	
PMKTF	TF4.4	0.00	24.84	7.94	6.40	5.64	1.64	0.80	0.08	0.28		0.66	

* measured in 1994.

Appearance and Flow/Slope

The DEQ procedure guidance for classification of 4c requires a characterization of the waters as having very low slopes and low velocity flows (Procedure For Natural Conditions Assessment Of Low pH And Low DO In Virginia Streams, prepared by Virginia Department of Environmental Quality, October 2004, Final revision 10/22/04). POCOH is an estuarine water segment and POCTF is a tidally fresh segment. Both segments are influenced by tide. NOAA tidal prediction ranges are listed in Table 9. The tidal range decreases from 0.70 m in the Pocomoke Sound to 0.48 m near the Snowhill City Park. For tidal rivers, the surface slope is determined by the mean sea level, which is influenced by freshwater discharge and tidal fluctuation, and so the conventional process of determining slope for stream waters is not applicable. Flow measurement from the U.S. Geological Survey Station gage 01485500 (Nassawango Creek near Snow Hill, MD) is shown in Figure 4. The total mean flow of the watershed can be estimated based on the area ration between mean flow (1995-2009) of the drainage area of the gauged watershed and the total watershed area, which is approximately 20.8 m^3/s. The model simulations showed that the residence time for these two segments is approximately 10.5 days under mean flow and tide range conditions. The relatively long residence time is somewhat analogous to low velocity flows in streams, suggesting that organic matter will be transported out of the estuary slowly and undergo decay inside the estuary.

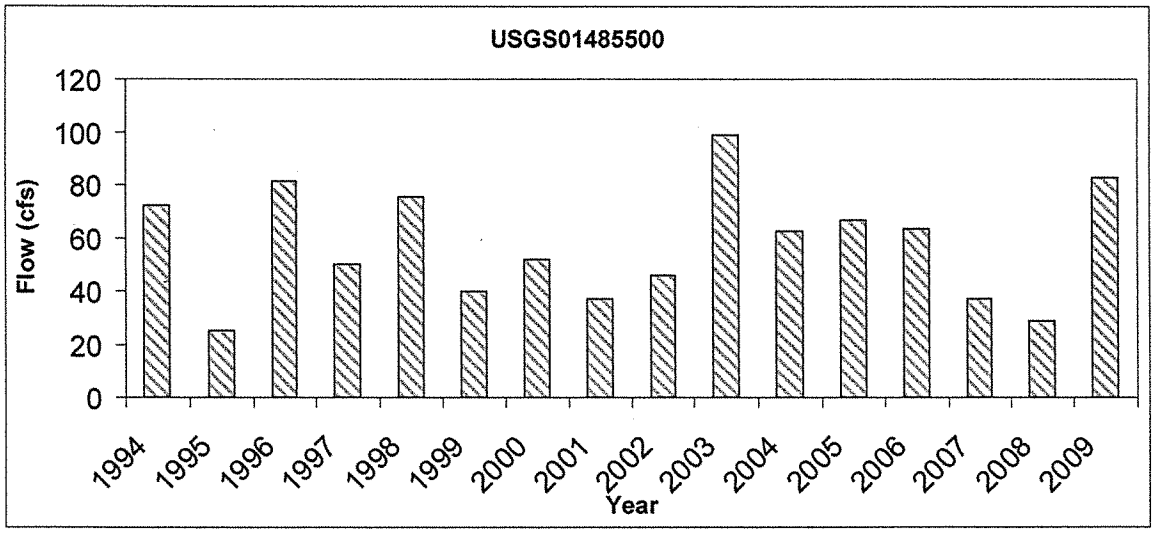


Figure 3. Annual Mean Flow Distribution at Station USGS01485500.

Table 9. NOAA Predicted Tide along the Pocomoke River

Station	NOAA Predicted Tidal Range (m)	Location
Ape Hole Creek, Pocomoke Sound	0.701	14.9 km downstream from Station XAK78
Shelltown	0.731	near XAK7810
Pocomoke City	0.487	near ET10.1
Snowhill, City Park	0.579	19.34 km upstream from Pocomoke City

Nutrient levels

The summary of statistics presented in Table 7 was compared to statistics computed for the Pamunkey and Mattaponi Rivers, a similar wetland-dominated system that is described as having "naturally lower ambient dissolved oxygen", for the dry-year period (Table 8), and the Table VI-2 of *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake bay and its Tributaries-2004 Addendum* (U.S.EPA, 2004). There are no available "national background concentrations" for a tidal river, but it can be seen that the POCOH Station (XAK7810) has similar characteristics to the Mattaponi/Pamunkey, except that DO is slightly lower and nitrogen (total nitrogen and dissolved inorganic nitrogen) and organic carbon are relatively higher at the POCOH station. Total nitrogen (TN) concentration in the Pocomoke River ranges from 1.2 to 1.5 mg/L, which is higher than TN concentration of 0.5-1.0 mg/L for the Pamunkey and Mattaponi Rivers. But, it is noted that higher nitrogen is present in the organic fraction, as would be expected in a wetland/marsh-dominated system. Total phosphorus concentrations are in the same range as those in the Pamunkey and Mattaponi Rivers.

Figure 4 shows the mean total nitrogen and phosphorus during the summer at POCTF (ET10.1) from 1994 to 2009. It shows that total nitrogen and phosphorus do not fluctuate very much. A correlation between monthly mean flows and total nitrogen exists with a correlation coefficient of 0.76. The flow is positively correlated with TN ($p= 0.0069$, $\alpha=0.05$). However, total phosphorus decreases slightly as flow increases. The flow is weakly negatively correlated with TP ($p=0.0197$, $\alpha= 0.05$).

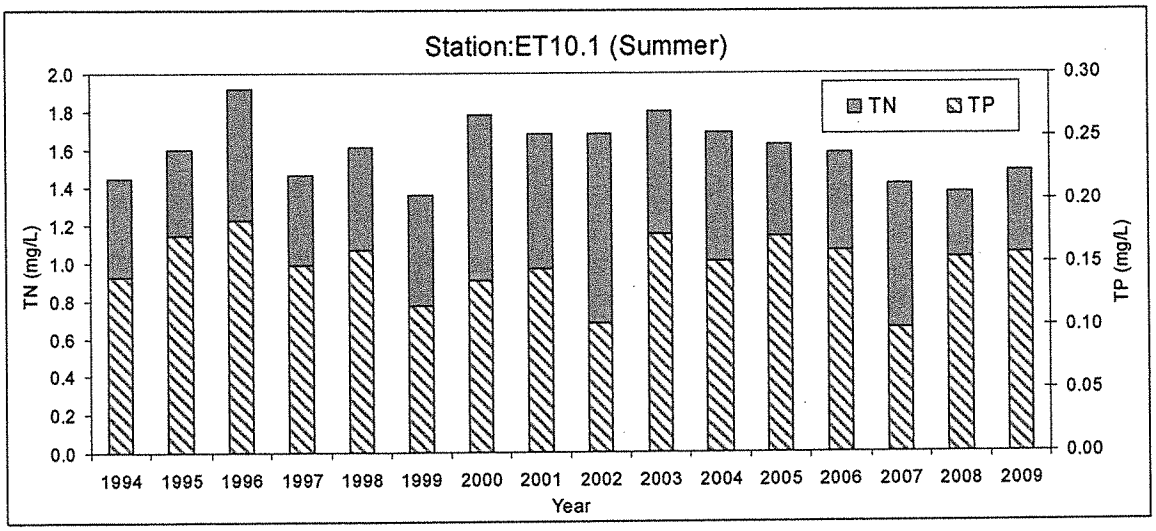


Figure 4. Summer Mean Total Nitrogen and Phosphorus

Degree of Seasonal Dissolved Oxygen Fluctuation

Mean DO concentrations during summer months are shown in Table 10. These mean DO values have minor variations. Monthly mean DO concentrations are approximately 4.1 and 5.9 mg/L at Stations ET10.1 and XAK7810, respectively. DO distributions are homogenous vertically at POCTF (ET10.1). Very minor variations between the surface and bottom occur at POCOH station (XAK7810). The monthly mean chlorophyll concentration from May to October is low at Station ET10.1 (less than 11 μg/L) with a peak in August. Chlorophyll concentrations are less than 20 μg/L in summer at Station XAK7810, but peak concentrations occurred in May and reached a monthly mean of 26 μg/L (Table 11).

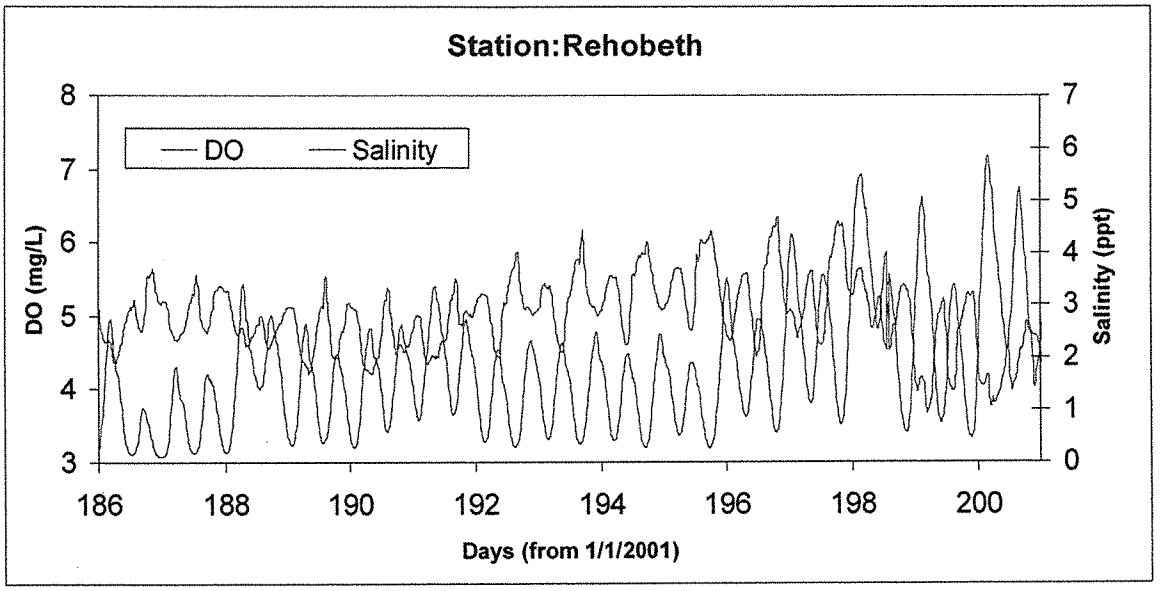
For a phytoplankton-dominated system in shallow water region, the diurnal oxygen variation is often observed with high DO during the day and lower DO during the night. However, the high-frequency monitoring data present no significant diurnal oxygen variation. Hourly moving-average DO and chl-a concentrations (with correction of measurement errors) show that both DO and chl-a concentrations are highly correlated with salinity (Figure 5). Low DO and high chlorophyll concentrations occur during flood tide, indicating that the POCOH and POCTF segments are influenced by the tide significantly and that the downstream condition can affect this region. These results suggest that phytoplankton does not directly control daily DO variations.

Table 10. Monthly Mean DO Values at Surface, Bottom, and Middle Layers

Station	Month	Mean (mg/L)	Min. (mg/L)	Max (mg/L)	Std. Dev. (mg/L)	Count	Layer*
POCTF (ET10.1)	June	4.52	2.30	6.10	0.97	23	B
		4.52	2.30	6.10	0.91	104	M
		4.49	2.40	6.00	0.95	25	S
	July	4.12	1.80	6.00	1.08	21	B
		3.97	1.80	6.00	1.08	99	M
		4.17	1.90	6.10	1.07	23	S
	August	4.45	2.70	7.40	1.21	24	B
		4.29	2.70	7.40	1.19	94	M
		4.46	2.90	7.40	1.23	24	S
	September	4.74	2.80	7.30	1.15	24	B
		4.59	2.70	7.90	1.19	101	M
		4.67	2.80	8.20	1.24	25	S
POCOH (XAK7810)	June	5.51	4.90	6.80	0.58	19	B
		5.76	5.20	6.90	0.73	7	S
	July	4.88	3.90	6.30	0.77	18	B
		5.13	4.00	6.30	0.84	7	S
	August	5.38	3.60	6.30	0.73	18	B
		5.24	3.60	6.40	0.86	7	S
	September	5.88	4.40	7.50	1.01	19	B
		5.90	4.30	7.60	1.26	7	S

Table 11. Monthly Chlorophyll Concentrations

Station	Month	Mean (µg/L)	Min. (µg/L)	Max (µg/L)	Std. Dev. (µg/L)	Count
POCTF (ET10.1)	5	2.57	0.00	5.38	1.19	56
	6	5.46	1.00	17.57	4.43	55
	7	7.51	0.37	25.42	7.01	49
	8	11.29	0.90	55.82	12.66	52
	9	7.48	0.37	29.48	7.35	44
	10	7.23	0.27	29.90	6.92	44
POCOH (XAK7810)	5	26.48	1.50	44.86	16.88	11
	6	18.96	10.09	28.84	5.82	9
	7	13.49	6.73	21.72	5.47	8
	8	17.45	8.22	29.90	8.11	9
	9	13.94	3.20	26.54	9.28	9
	10	9.71	1.42	17.94	5.63	11



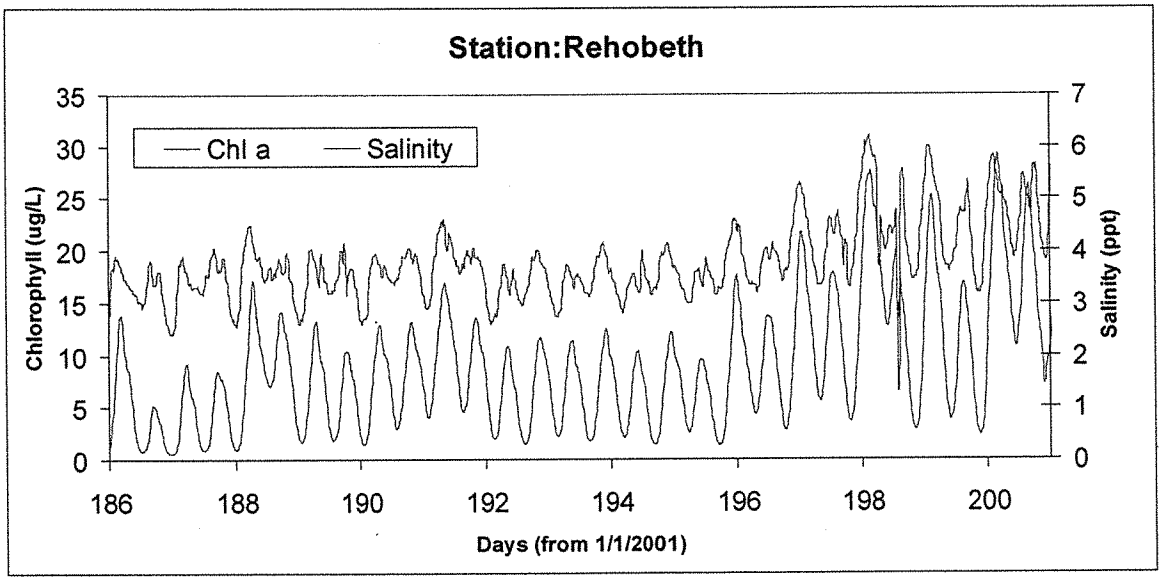


Figure 5. Hourly Moving-average DO, Chl a, and Salinity Distributions

Determination of Anthropogenic Impacts

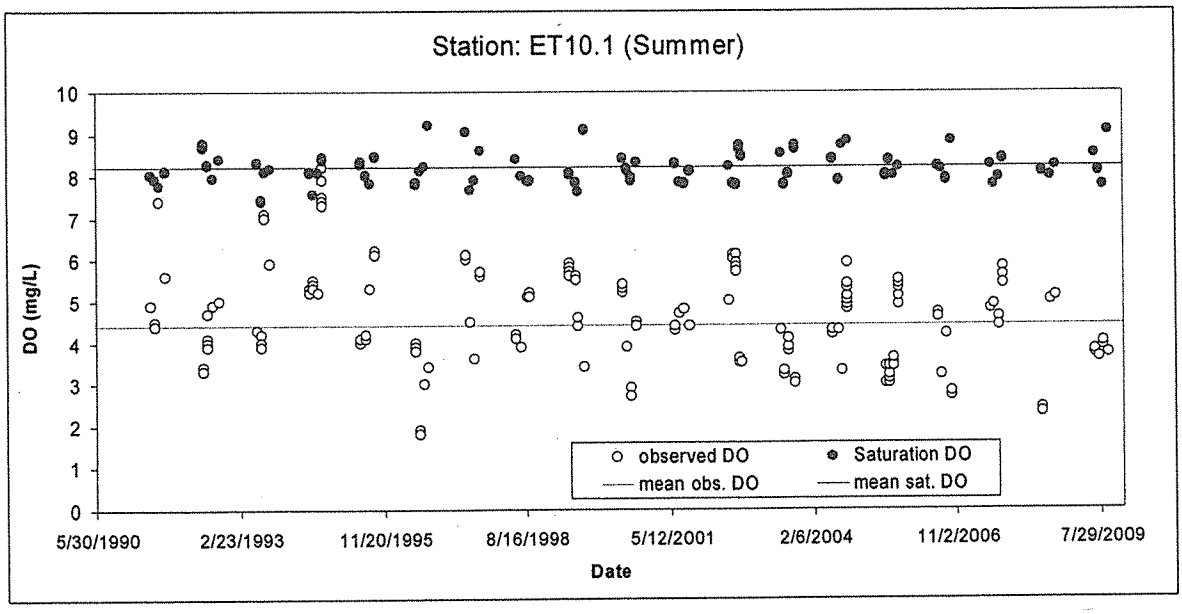
The Pocomoke River watershed is primarily rural with nearly 44.35% of the area being forest, 14.04% being wetlands, and 28.61% being cropland. There are 4 major waste water treatment plants in Maryland with a combined total design flow of 2.99 MGD. There are no waster water treatment plants in the Virginia portion of the watershed that discharge to the Pocomoke River. There are two small facilities with a total design flow of 0.03 MGD. Estimated major point and nonpoint source loadings to the POCOH segment based on the watershed model V5.3 of the Chesapeake Bay program are listed in Table 12. The estimated total point source nutrient loading to the POCOH segments is approximately 628.3 lb/year for TN and 80.4 lb/year for TP. Nonpoint sources in the POCOH segment are runoffs from agriculture land and forest land, and septic system on the watershed. Nonpoint source are dominant nutrient loadings in the region. It should be noted that large amounts of DOC are transported from upstream to the POCOH segment which can not be totally accounted for by the runoff from the local watershed (Jian Shen, VIMS, personal comm.).

Table 12. Estimated Nutrient Loadings from Point and Nonpoint Sources in the POCOH watershed (from EPA CBPO Watershed Model P5.3_Loads-Acres_06142010 ftp://ftp.chesapeakebay.net/Modeling/phase5/Phase53_Loads-Acres-BMPs/)

Bay segment	Source	TN(lbs/yr)	TP(lbs/yr)
POCOH	Agriculture	233,745.4	28,675.4
POCOH	Forest	59,518.5	4,686.9
POCOH	Septic	14,618.9	0
POCOH	Extractive	1,902.0	1,045.0
POCOH	Urban	6,704.3	1,274.7
POCOH	Wastewater	628.3	80.4

Dissolved Oxygen Deficit

The dissolved oxygen deficit can be used to measure the oxygen that is consumed due to community respiration. It indicates the amount of oxygen being consumed, which includes chemical and biological oxygen demands, as well as sediment oxygen demand (SOD). The oxygen deficit was computed as the difference between DO saturation and observed DO. Oxygen saturation was computed based on the temperature and salinity (Chapra 1997). DO and DO saturation and DO deficit are shown in Figures 6 and 7, respectively. The results show that the system is persistently under-saturated indicating that high respiration rates occur in the system. Mean summer (June-September) dissolved oxygen deficits that were calculated for Station ET10.0 and XAK7810 are 3.77 and 2.71 mg/L with standard deviations of 1.23 and 0.77, respectively. These values are within 1 mg/L of the surface and bottom DO deficits reported for the wetland dominated tidal fresh segments of the Mattaponi (MPNTF) and Pamunkey (PMKTF) Rivers (U.S. EPA 2004).



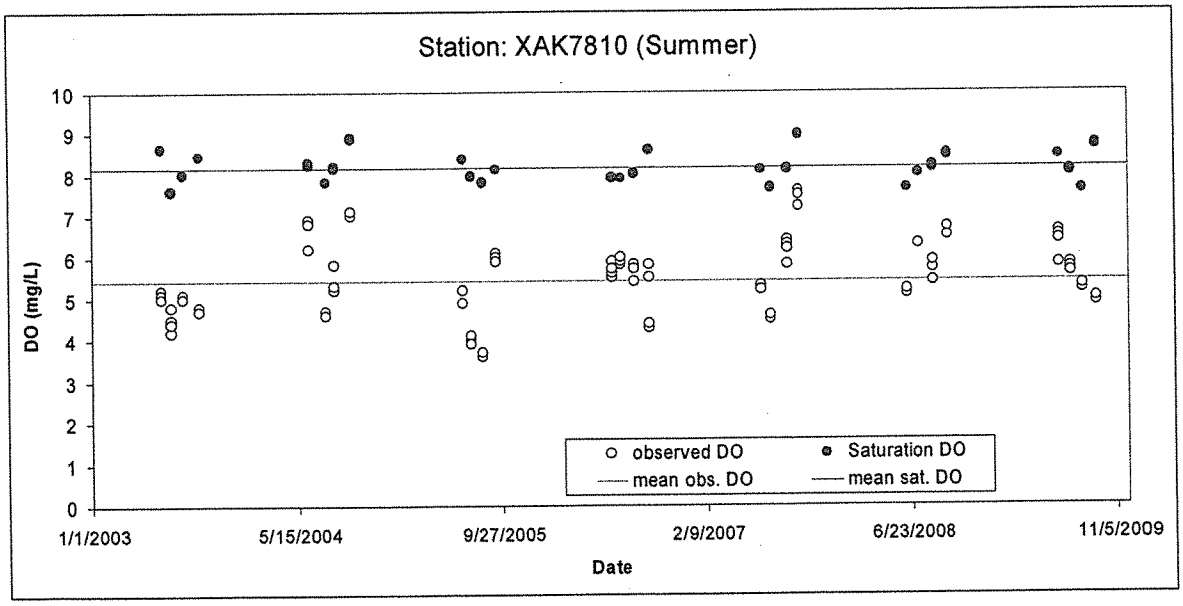


Figure 6. Observed DO and Saturation DO Distributions during Summer (June-September) at Stations ET10.1 and XAK7810.

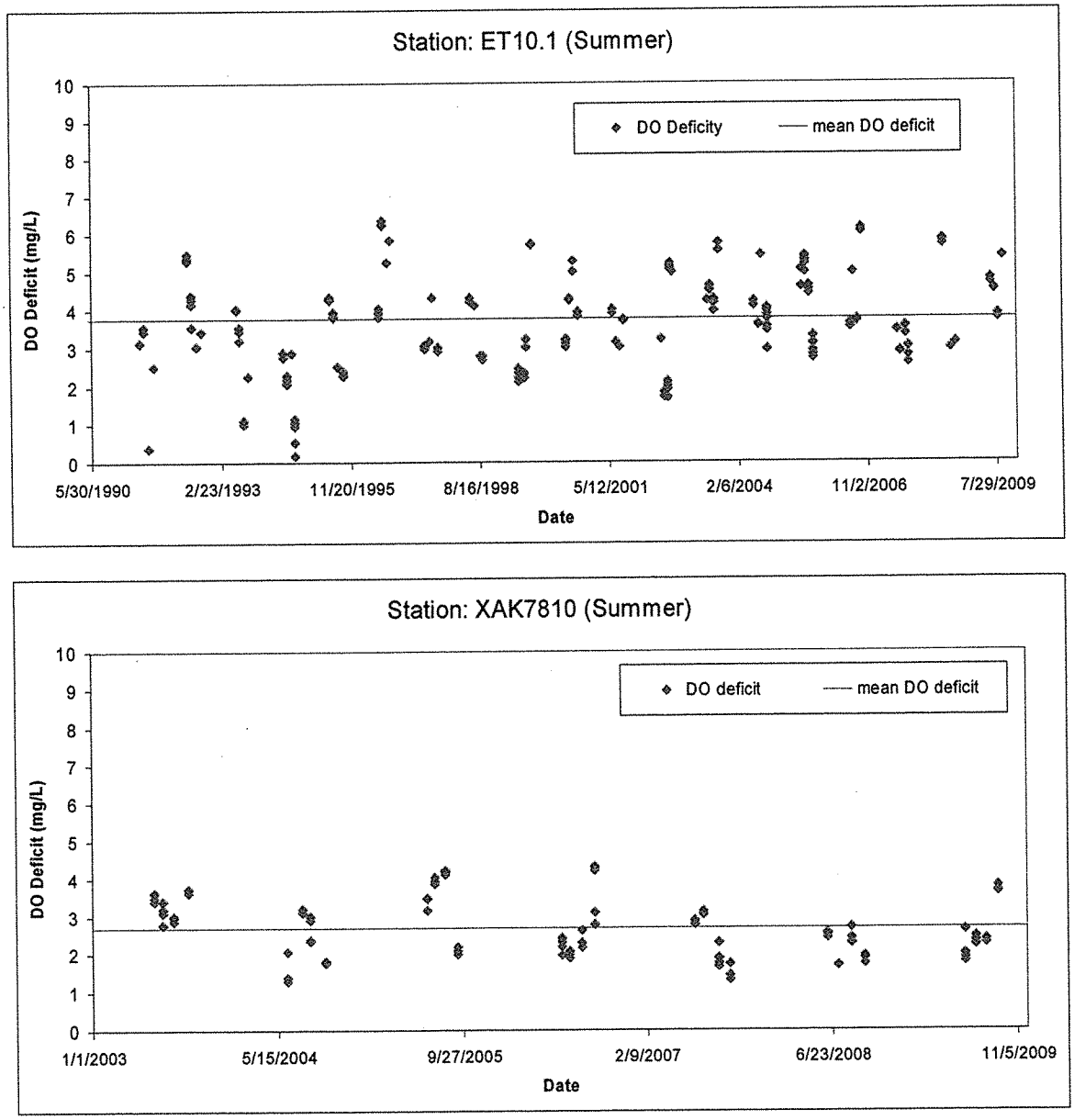
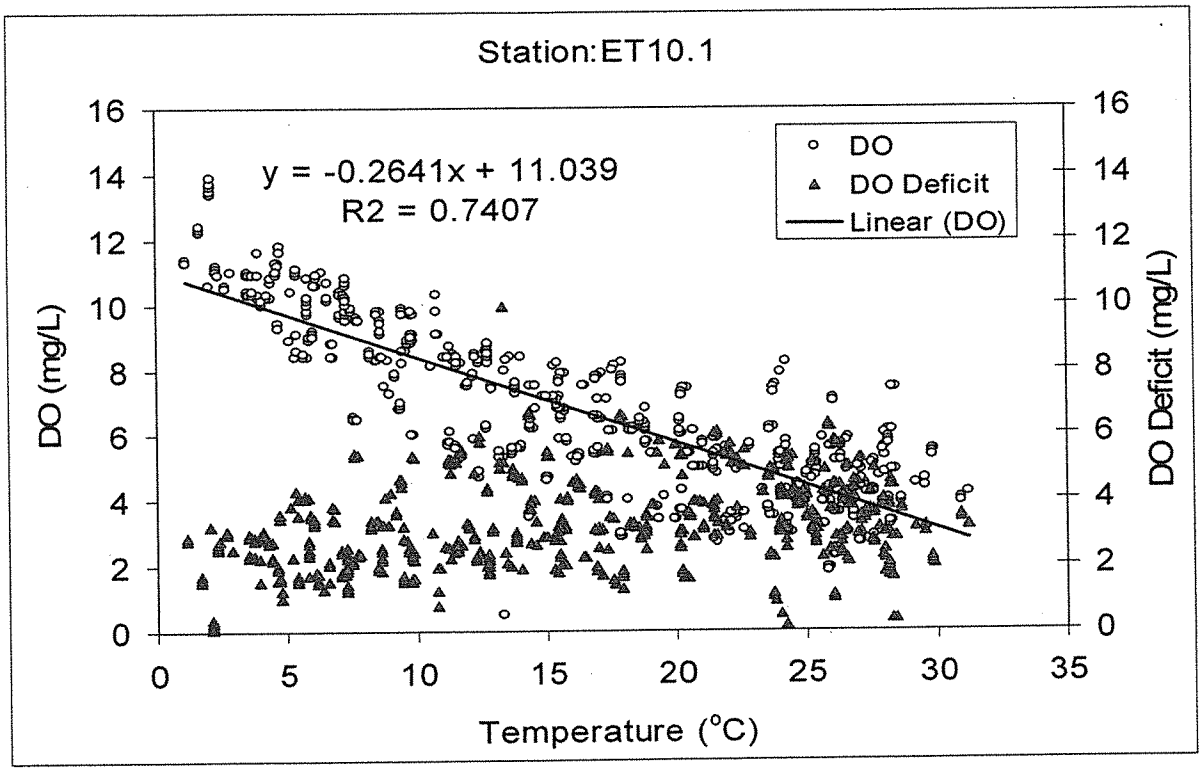


Figure 7. Summer (June-September) DO Deficit at Stations ET10.1 and XAK7810.

Dissolved Oxygen and Temperature

Dissolved oxygen and temperature are highly correlated. When temperature increases, DO decreases as a function of increasing respiration and the decay of organic materials. Another feature of black-water systems where respiration is dominated by internal chemical processes is a strong relationship between dissolved oxygen concentration and dissolved oxygen deficit, and water temperature. Figure 8 shows the dissolved oxygen and oxygen deficit plotted against water temperature using mean concentration from the period of record. A high correlation exists between temperature and DO. DO deficit increases slightly as temperature increases.



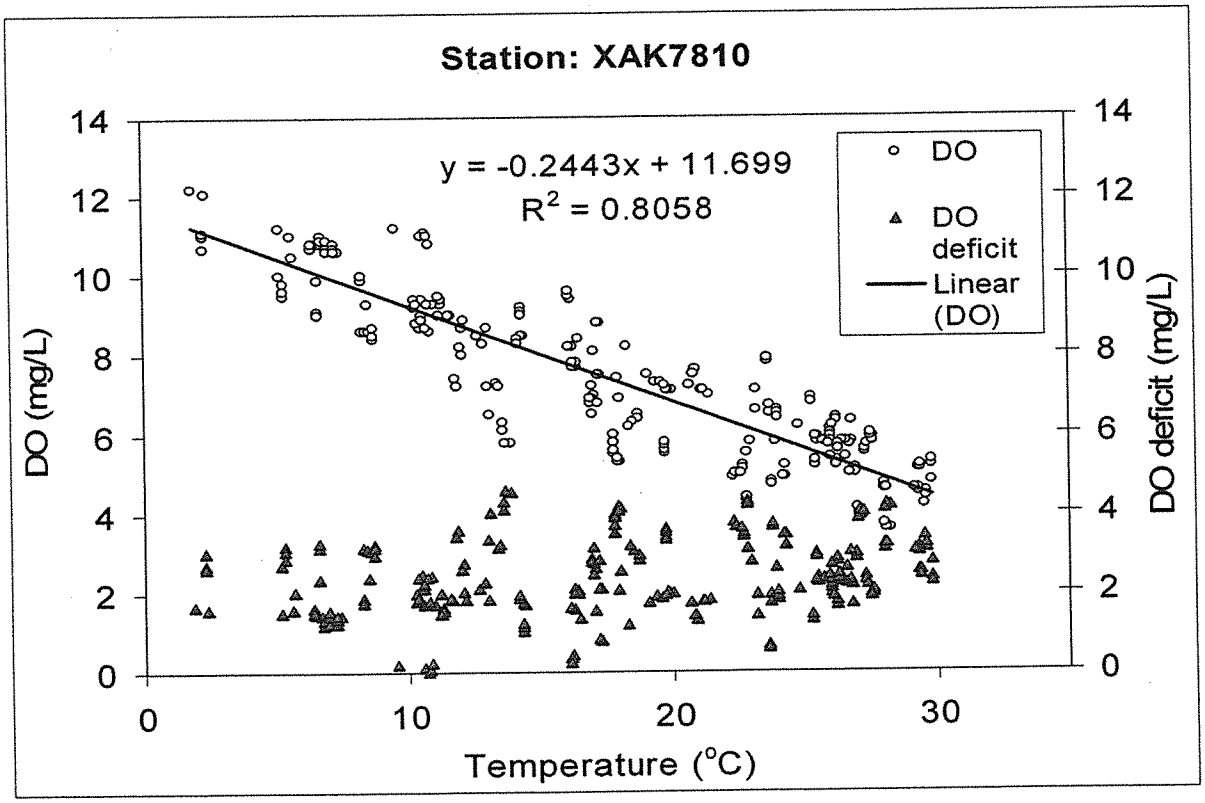


Figure 8. Correlations between Temperature and DO and DO Deficit at Stations ET10.1 and XAK7810.

Dissolved Oxygen and Organic Carbon

It is noted that dissolved carbon concentrations are very high in the Pocomoke River, with mean concentrations ranging between 12 to 16 mg/L during the summer period.
The distribution of monthly DOC data is shown in Figure 9. It can be seen that relatively low DOC concentrations are observed in spring, but with persistently high concentrations in each month. An analysis of DOC and DO data shows that they are highly correlated, which suggests that monthly DO variations are controlled by temperature and DOC (Figure 10).

For a system that is not dominated by phytoplankton and for which organic carbon and DO are highly correlated, Equation 1 can be simplified as follows (Chapra 1997; Shen et al., 2009):

$$\frac{dO}{dt} = 2.67(P - R) + k_s(O_s - O) - k_c C - \frac{SOD}{H} + \frac{O_m}{V} - \frac{Q_{in}}{V} O \qquad (1)$$

$$\frac{dA}{dt} = (P - R - M) - \frac{v}{H} A - \frac{Q_{in}}{V} A \qquad (2)$$

where O, A, and C are dissolved oxygen, algae, and organic carbon (mg l^{-1}), respectively, P = algae production (mg l^{-1} d^{-1}), and R = algae respiration (mg l^{-1} d^{-1}). Additionally, v = settling velocity of phytoplankton ($m \cdot d^{-1}$), v_c = settling velocity of organic carbon ($m \cdot d^{-1}$), Q_{in} = river discharge ($m^3 s^{-1}$), and O_m and C_m are mass input of DO and carbon, respectively (g d^{-1}), k_c = carbon decay rate (d^{-1}), k_s = reaeration rate (d^{-1}), O_s is the saturated DO concentration (mg l^{-1}), SOD stands for the sediment oxygen demand ($gO_2\ m^{-2}\ d^{-1}$), which is a parameter representing the total amount of oxygen consumed by decomposition of organic matter accumulated in the sediment, H = water depth, V = volume of the creek (m^{-3}).

For a system that is not a phytoplankton-dominated system with a high correlation between organic carbon and DO, it can be simplified as follows:

$$\frac{dO}{dt} = k_s(O_s - O) - k_c C - \frac{SOD}{H}$$

where the water column is balanced by surface reaeration, organic carbon decay, and SOD. Under a steady state condition (i.e., not considering tidal variation), DO can be predicted based on temperature, surface reaeration, and organic carbon. As k_c and SOD are functions of temperature, the temperature correction can be applied to the above equation, which gives (Thomann and Mueller 1987; Chapra 1997):

$$k_c = k_{c20}\theta^{T-20}$$
$$SOD = DOS_{20}\theta^{T-20}$$
$$O = O_s - (k_c C + \frac{SOD}{H})\theta^{T-20} k_s^{-1}$$

Where T is temperature and θ^{T-20} is a temperature-dependent function. θ is about 1.047 and K_s is on the order of 1. Using a typical SOD value of 2.0 g/m^2 (EPA 2004), k_{c20}=0.08 per day, θ is about 1.047 (Chapra 1997), and k_s = 1.0/day and 1.3/day for Stations ET10.1 and XAK7810, respectively. The predicted DO, based on observed temperature and DOC, are shown in Figure 11. The linear interpolation method was used to model the DOC values. Good predictions can be obtained at two stations with R^2 values larger than 0.80 (Figure 12). The results suggest that the low DO of the system can be attributed to organic carbon that persists in the system.

A comparison of the water quality statistics for the Pocomoke River with those of the Pamunkey and Mattaponi Rivers (US EPA 2004) indicates that DO variation and DO deficit are in the same range. In general, the mean concentration of organic carbon in the Pamunkey and Mattaponi Rivers ranges from 1.0 – 8 mg/L, which is lower than the Pocomoke River, which ranges from 3 – 27 mg/L with a mean summer concentration of 14 mg/L. The organic carbon concentrations in the Dragon Swamp system, another naturally carbon-rich environment in Virginia, has organic carbon concentrations that range from 3 to 13 mg/L. Assuming an SOD value of 2 g/m^2, which is typical of the region (U.S. EPA 2004) and mean DOC concentration of 10 mg/L, a typical natural condition environment representative of a naturally carbon-rich system, the model can be used to compute the DO distribution in the Pocomoke River. The results, which are plotted in Figure 13, shows DO will not meet the 5 mg/L criteria during the summer months. The results are consistent with the Chesapeake Bay Program modeling scenarios as demonstrated in Table 13 which shows that even under an "all forest watershed" loading scenario, the segment would still be impaired by current water quality standards.

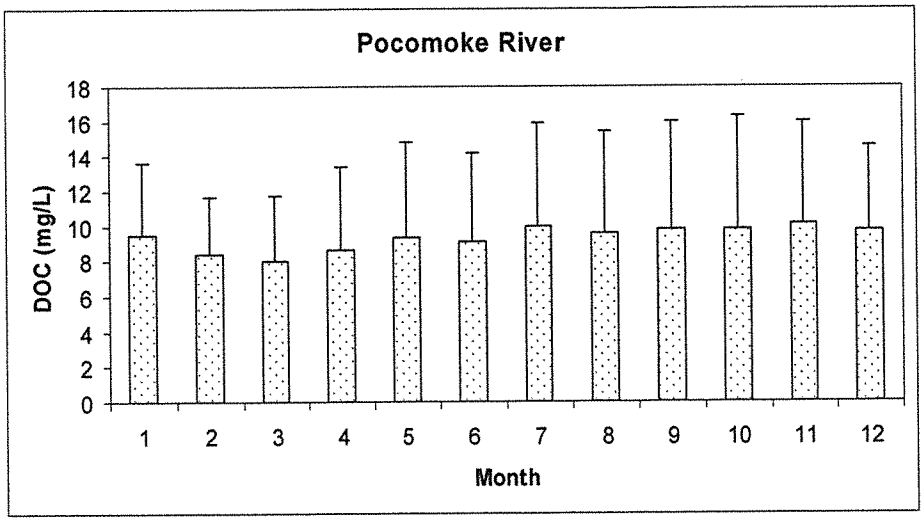


Figure 9. Monthly Distribution of Organic Dissolved Carbon in the Pocomoke River. All available data for Stations ET10.1 and XAK7810, 1991 though 2009.

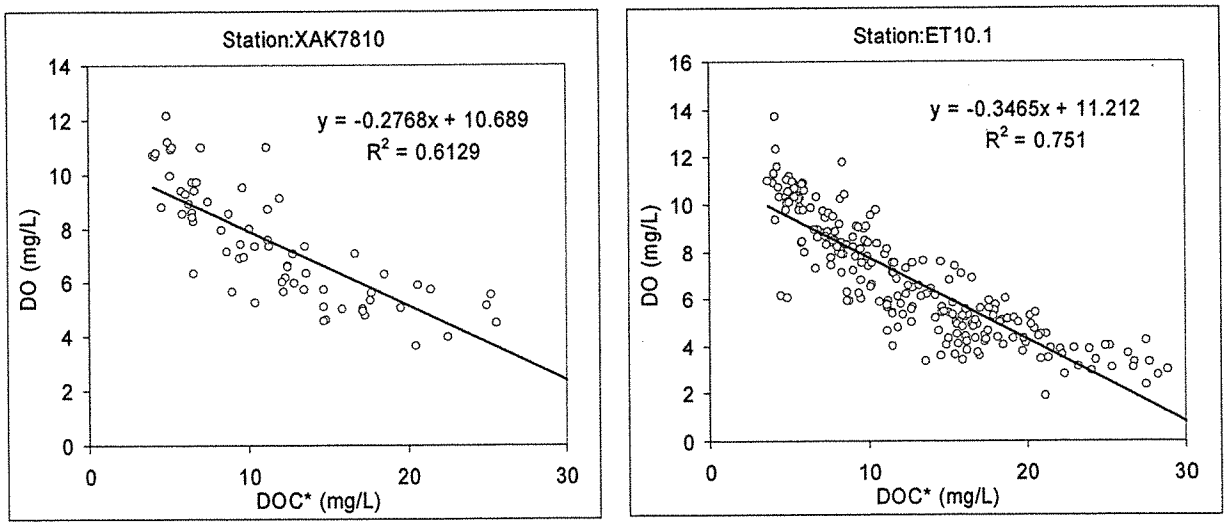


Figure 10. Correlation Analysis of Temperature and Organic Dissolved Carbon Organic Carbon ($DOC \times \theta^{T-20}$) at Stations XAK7810 and ET10.1

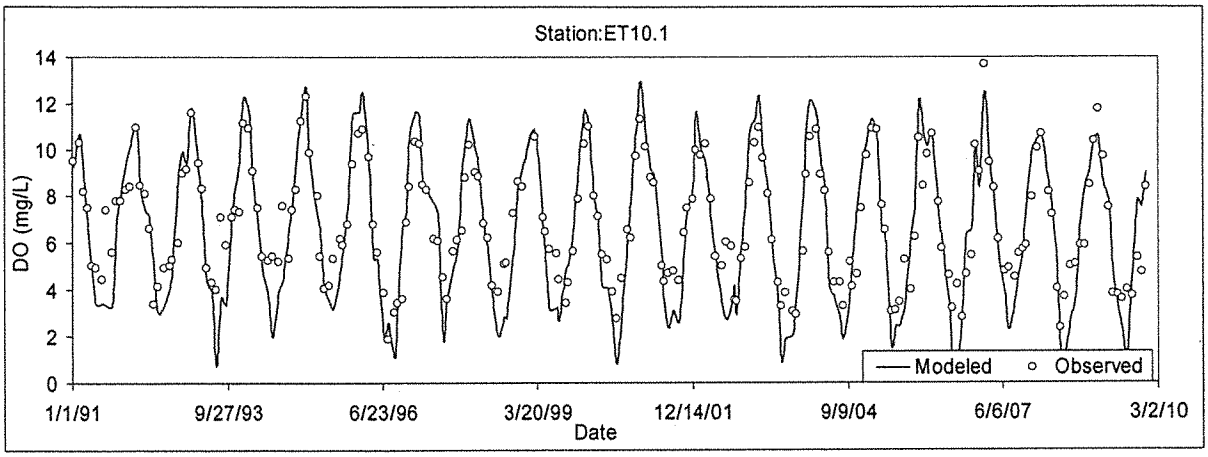


Figure 11. Comparisons of Observed and Modeled DO.

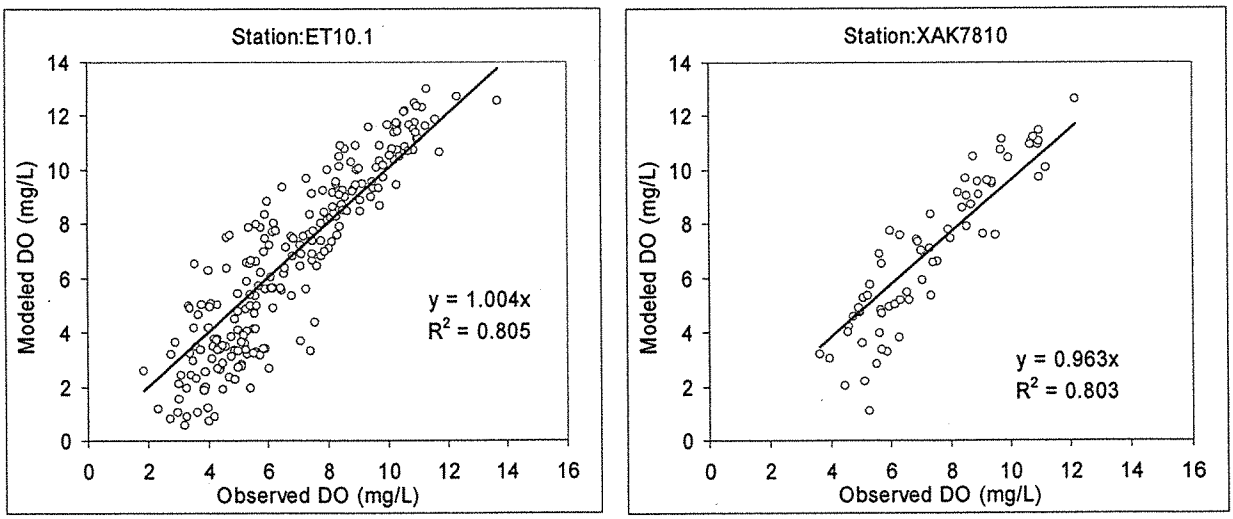


Figure 12. Scatter Plots of Observed and Modeled DO at Stations ET10.1 and XAK7810.

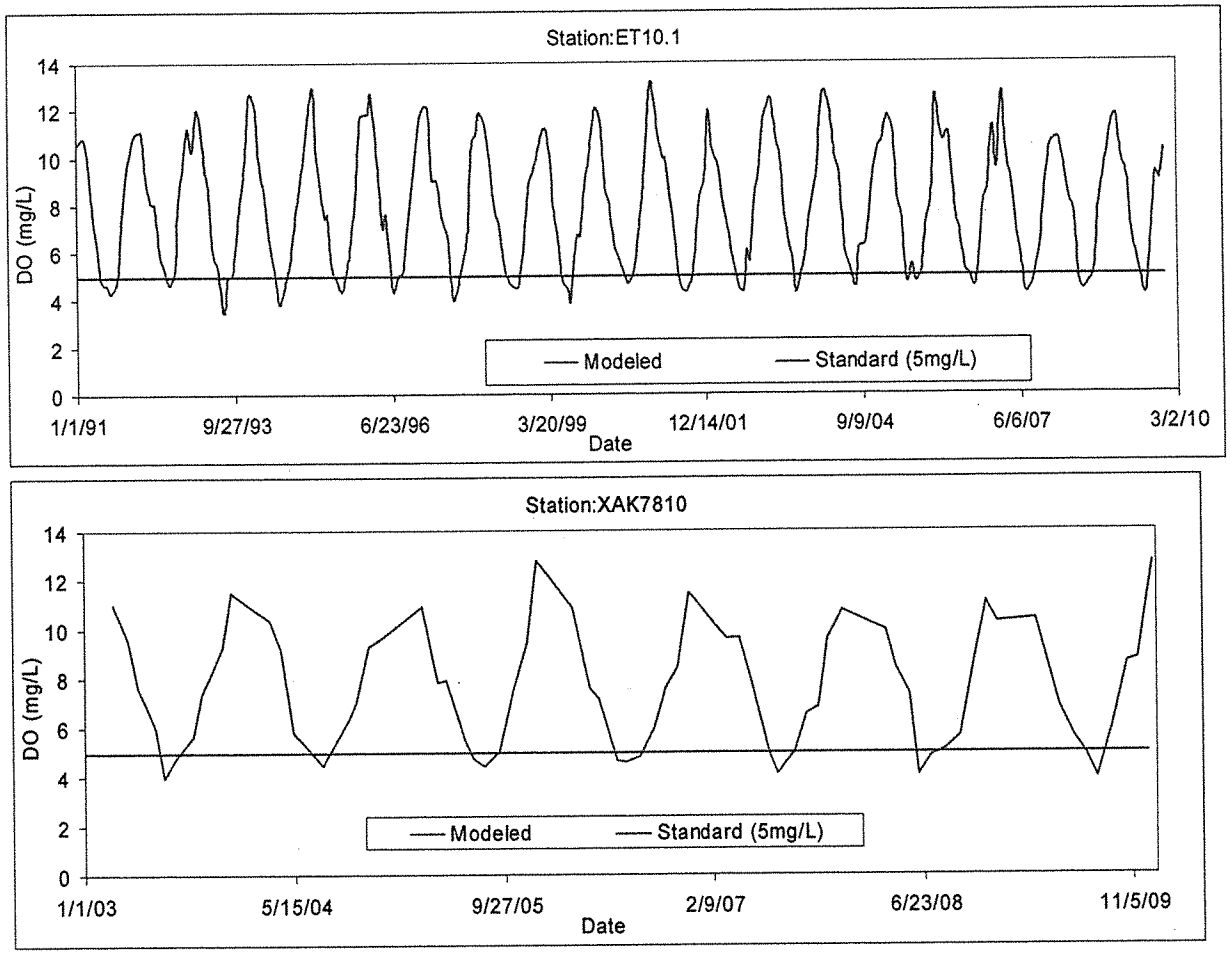


Figure 13. Comparison of Model Results Using a Constant DOC of 10 mg/L.
As indicated in table 13, the CBP modeling of the current dissolved oxygen criteria indicates that it is attained (i.e. 0% non attainment) only with an unachievable "All Forest" level of nutrient reductions.

Table 13) Level of dissolved oxygen percent non-attainment under various CBP model nutrient loading scenarios. Results are for the 1993-1995 critical period used for Bay TMDL development. Excerpted from materials distributed for Water Quality Goal Implementation Team Conference Call, Monday June 07, 2010 (http://archive.chesapeakebay.net/calendar.cfm?EventDetails=10852&DefaultView=all&RequestDate=06/08/2010); file 47043_06-07-10_Handout_3_10852.xls; Available at http://archive.chesapeakebay.net/pubs/calendar/47043_06-07-10_Handout_3_10852.xls; POCOH = Complete Pocomoke Oligohaline, VPOCOH = Virginia portion of Pocomoke Oligohaline, MPOCOH = Maryland portion of Pocomoke Oligohaline.

Model Scenario	1985 Scenario 342TN, 24.1TP, 9790TSS	"91 -'00 Base Scenario 309TN, 19.5TP, 8950TSS	2009 Scenario 248TN, 16.6TP, 8110TSS	Target Load Option A 200TN, 15TP, 6390TSS	Tributary Stategy 191TN 14.4TP, 6462 TSS	190 Loading Scenario 190TN 12.6TP, 6030TSS	179 Loading Scenario 179TN 12.0TP, 5510TSS	170 Loading Scenario 170TN 11.3TP, 5650TSS	E3 2010 Scenario 141TN 8.5TP, 5060TSS	1/3 Between E3 & Forest 113TN 7.1TP 4450TSS	2/3 Between E3 & Forest 85TN 5.7TP 3840TSS	All Forest Scenario
Years	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95	'93-'95
Cbseg	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly	DO Open Water Summer Monthly
POCOH	33%	42%	29%	25%	25%	18%	5%	5%	5%	5%	5%	0%
VPCOH	32%	41%	28%	25%	25%	18%	5%	5%	5%	5%	5%	0%
MPCOH	33%	42%	31%	25%	25%	18%	5%	5%	5%	5%	5%	0%

Conclusions

The Pocomoke oligohaline segment (POCOH) in Virginia has low dissolved oxygen conditions during summer period that are strongly influenced by natural conditions and downstream estuarine condition. The watershed is dominated by natural wetlands and forest. Analysis of dissolved oxygen conditions is indicative of impact from these wetlands with high levels of organic matter (e.g. DOC). The system is not a phytoplankton-dominant system and phytoplankton has a weak influence on dissolved oxygen directly. The oxygen concentration persists under saturation level with constant oxygen deficit as opposed to the boom-bust characteristics of an anthropogenically eutrophic-dominated system. The system shows a strong correlation between dissolved organic carbon and dissolved oxygen. The empirical model based on observed DOC and temperature shows that the DO will not meet their current 5 mg/L criterion with reduced organic carbon input under a typically natural condition due to high community respiration and ambient high DOC concentration.

These analyses and results are similar to those performed for the tidal Mattaponi and Pamunkey rivers which found that it was inappropriate to apply the general open water D.O. criteria (Chapter VI of U.S. EPA 2004). The Maryland DNR has also performed their own analysis on the Pocomoke Tidal fresh segment (POCTF) and proposed alternative dissolved oxygen criteria (Romano, 2010). The Virginia DEQ concludes that the waters of CBP segment Pocomoke oligohaline (POCOH) should be classified as 4c water (water is impaired or threatened for one or more designated uses but does not require a TMDL because the impairment is not caused by a pollutant and/or is determined to be caused by natural conditions).

Based on calculations using background levels of organic carbon, the site specific DO concentration for the Virginia portion of the Pocomoke River is recommended at 4 mg/L. This recommendation is based on the concentration of DO that is a result of natural conditions at the site.

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