MARYLAND
DEPARTMENT OF
NATURAL RESOURCES

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2009 Bush River Shallow Water Monitoring Data Report

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2009 Bush River
Shallow Water Monitoring Data Report

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Martin O'Malley, Governor

Anthony G. Brown, Lt. Governor

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EXECUTIVE SUMMARY

The Bush River watershed drains 117 square miles of land in Harford County, Maryland. This watershed is becoming increasingly urbanized as approximately 35% of the land has been developed and impervious surface area (roads, rooftops, parking lots) has increased to around 11%. All three major subwatersheds of the Bush River have been listed by the State of Maryland as impaired waterways, and the watershed as a whole is considered a high priority for restoration. Causes of impairment include elevated levels of nutrients, suspended sediments, and toxic substances that are harmful to aquatic organisms and degrade the ecosystem. The Maryland Department of Natural Resources (DNR), in partnership with the Harford County Government and the National Oceanic and Atmospheric Administration (NOAA), therefore, began a water quality criteria assessment of the Bush River in 2003 as part of its Shallow Water Monitoring Program. Two fixed Continuous Monitoring stations, configured to record measurements every fifteen minutes, were set up in the Bush River watershed to quantify the effects of nutrient and sediment pollution and associated algal blooms on water clarity and the living resources within the waterways. The stations were located at Church Point (39.4582°, -76.2323°) and Otter Point Creek (39.4508°, -76.2746°).

This report contains the results of Continuous Monitoring for the Bush River during 2009. (Results from previous years may be found in the 2003-2008 Bush River Shallow Water Monitoring Data Reports, available online at http://mddnr.chesapeakebay.net/eyesonthebay/publications.cfm).

A summary of the 2009 Bush River report is as follows:

- Salinity levels remained low during the wetter than average year peaking at 3.7 parts per thousand (ppt) at Church Point and 2.0 ppt at Otter Point Creek.
- Dissolved oxygen levels generally remained at healthy levels during 2009, particularly at Otter Point Creek where the dissolved oxygen criteria failure rate (3.96%) was the lowest since 2003.
- Algal blooms were infrequent and short in duration as only ~1% of chlorophyll readings measured levels indicative of significant blooms.
- Water clarity continued a declining trend as nearly 100% of all measurements were beyond thresholds considered optimal for underwater grass growth.
- Submerged aquatic vegetation (SAV) total area (381 acres) was 9% higher than the restoration goal, but total area has decreased by 41% since 2007.

Introduction

Temporally Intensive Monitoring

In 2009, Maryland DNR was contracted by Harford County, Maryland to conduct temporally intensive water quality monitoring on the Bush River. The Continuous Monitoring component of the Shallow Water Monitoring Program is designed to acquire temporal records of water quality data at shallow water stations throughout the Chesapeake and Maryland Coastal Bays. The purpose of the program is to characterize water quality and habitat conditions for assessing compliance with the Environmental Protection Agency's (EPA) Chesapeake Bay ambient water quality criteria for dissolved oxygen, water clarity, and chlorophyll (US EPA, 2003). Maryland DNR deployed and maintained YSI 6600™ datasondes (multi-parameter logging instruments), at 40 Continuous Monitoring sites in 2009 spread across 17 segments of the Chesapeake Bay watershed. Four Coastal Bay sites were also monitored during 2009. The following water quality data parameters were collected at 15-minute intervals during deployment: water temperature, salinity, dissolved oxygen, fluorescence (used to estimate chlorophyll concentration), pH, and turbidity, which is a measure of water clarity. Data from salinity, chlorophyll, and turbidity readings were also used to calculate an additional measure of water clarity called the coefficient of light attenuation (K_d; US EPA, 2007), which estimates how far light travels through the water column.

Pigment, Nutrient, Suspended Solids, and Secchi Samples

Data concerning pigments, nutrients, and suspended solids were obtained by DNR staff during deployment of Continuous Monitoring datasondes. Discrete whole water samples were collected to measure chlorophyll *a*, pheophytin, total suspended solids, volatile suspended solids, ammonium, nitrite, nitrate, total dissolved nitrogen, particulate nitrogen, phosphate, particulate phosphate, total dissolved nitrogen, and particulate carbon. Datasondes were removed and replaced with freshly calibrated instruments on a biweekly basis. At the time of each instrument replacement, Secchi disk depth and photosynthetically active radiation (PAR) measurements were recorded for use in additional calculations of K_d.

Bush River Continuous Monitoring

In 2009, Continuous Monitoring data were collected at two sites in the Bush River: Church Point (XJG7461) and Otter Point Creek (XJG7035) (Figure 1). The Church Point Continuous Monitor was deployed from March 31st to October 28th (Table 1), and was suspended from a float, 1m below the water's surface. The Continuous Monitor at Otter Point Creek was fixed 0.3m above the bottom sediments and was deployed from March 31st to December 14th (Table 1).

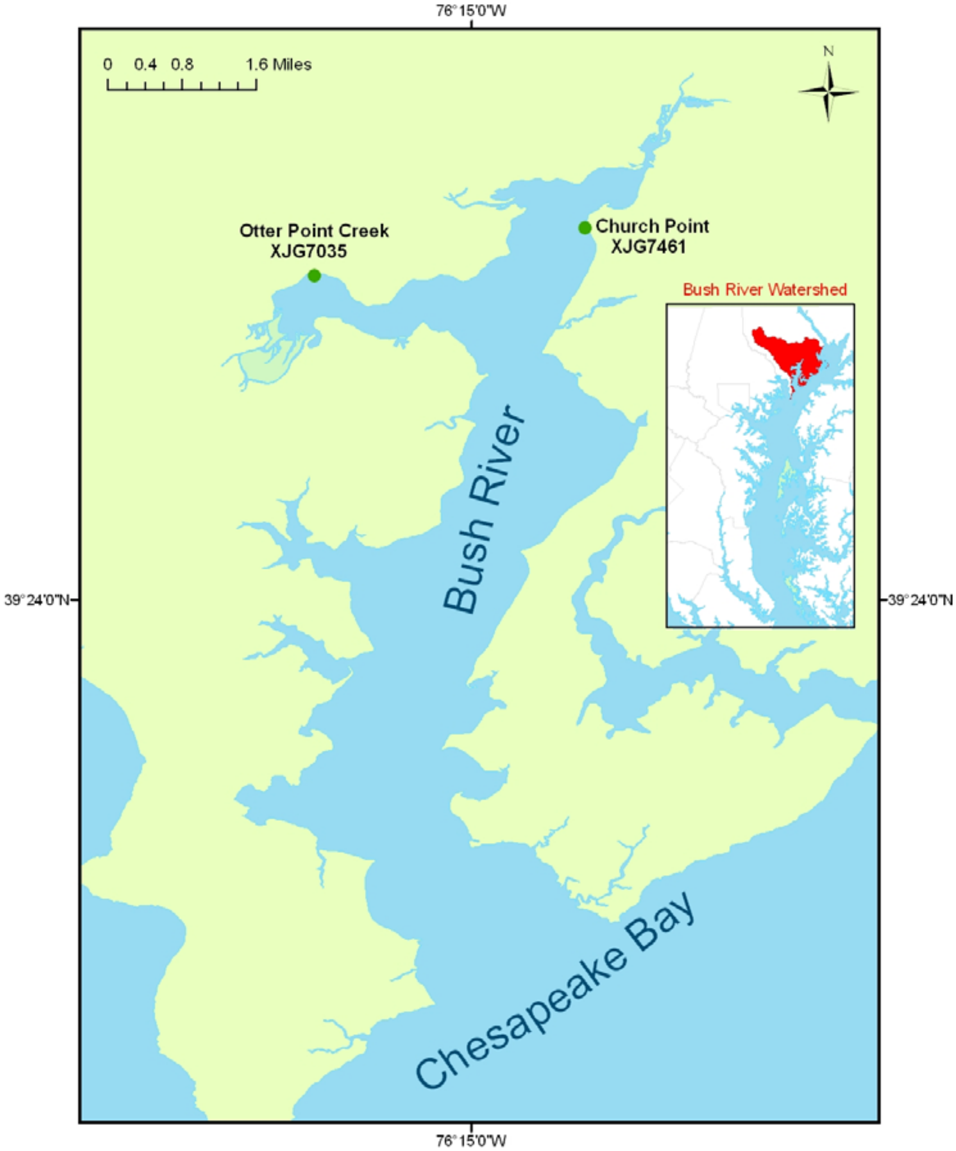


Figure 1. Map of Bush River Continuous Monitoring sites for 2009.

Several gaps in collected data occurred during 2009 due to mechanical problems. Dates and causes of data gaps at both Bush River Continuous Monitoring sites are found in Table 2.

The Harford County Government provided funding for the Continuous Monitoring equipment, nutrient analyses, and maintenance of the Church Point site. The Otter Point Creek site was funded through a cooperative agreement with NOAA's National Estuarine Research Reserve System (NERRS) Program.

Bush River Continuous Monitoring data are archived on DNR's "Eyes on the Bay" website, www.eyesonthebay.net. The interface allows users to view and download data and graphs of current and archived water quality measurements. Table 1 displays a 2009 timeline for the Bush River Continuous Monitoring sites, including related weather events and sanitary sewer overflows in the watershed that were reported to the Maryland Department of the Environment (http://www.mde.state.md.us/Programs/WaterPrograms/overflow/index.asp).

	Dates	Events and Details
2009	2-Feb	Sanitary sewer overflow due to mechanical failure; 500 gallons; Fallston; Winters Run drainage area
	31-Mar	Continuous Monitoring begins at Church Point and Otter Point Creek
	20-Jun	Heavy rain across northeast Maryland and tornado touch down near Pleasant Hills
	22-Jun	Sanitary sewer overflow due to rainfall; 300 gallons; Aberdeen Proving Ground; Bush River
	22-Jun	Sanitary sewer overflow due to filled holding tank; 300 gallons; APG, Edgewood Area; Bush River
	28-Aug	Heavy rain and flooding across northeast Maryland
	10-Sep	Sanitary sewer overflow due to structural failure; Bel Air; Plumtree Run drainage area
	11-Sep	Heavy rain and flooding across northeast Maryland
	28-Oct	Continuous Monitoring stopped at Church Point
	9-Dec	Sanitary sewer overflow due to precipitation; 7,500 gallons; Bel Air; Bynum Run drainage area
	14-Dec	Continuous Monitoring stopped at Otter Point Creek due to threat of icing

Table 1. Timeline of 2009 Continuous Monitoring related events.

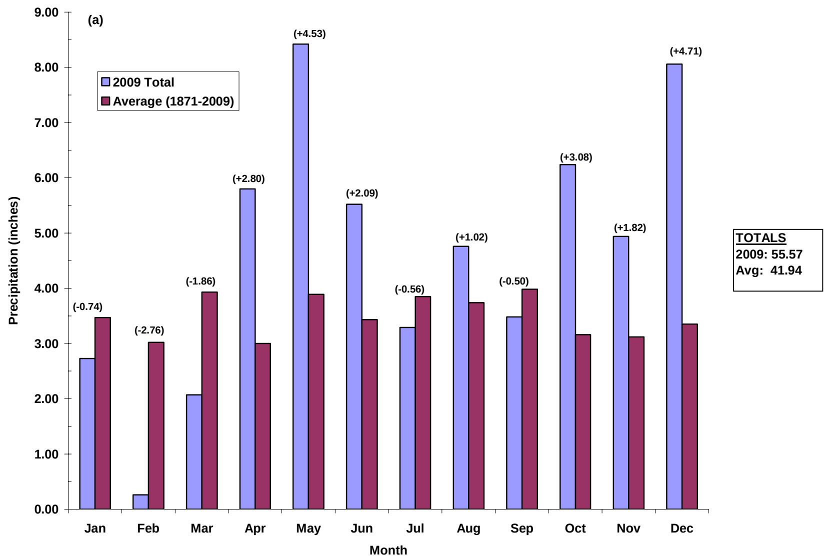
	Dates	Details
Church Point	11-21 Apr	Datasonde power failure
	13-19 May	Datasonde power failure
	11-16 Jul	Datasonde power failure
	7-18 Aug	Salinity and Dissolved Oxygen data failed quality control checks
	24-31 Aug	Turbidity probe wiper malfunction
	26-31 Aug	Chlorphyll probe wiper malfunction
	25-29 Sep	Chlorphyll probe wiper malfunction
	11-13 Oct	Dissolved Oxygen data failed quality control checks
Otter Point Creek	12-21 Apr	Datasonde power failure
	14-19 May	Datasonde power failure
	6-16 Jul	Blocked Chlorophyll probe
	9-16 Jul	Dissolved Oxygen data did not meet post-claibration thresholds
	14-18 Aug	Chlorophyll probe wiper malfunction
	28-30 Jul	Datasonde power failure
	13-14 Sep	Chlorophyll probe wiper malfunction
	24-29 Sep	Turbidity data did not meet post-calibration thresholds
	25-29 Sep	pH data did not meet post-calibration thresholds
	9-13 Oct	Turbidity data failed quality control checks
	11-15 Nov	pH data did not meet post-calibration thresholds
	12-15 Nov	Turbidity probe wiper malfunction
	15 Nov - 1 Dec	Datasonde power failure

Table 2. Data gaps at Bush River Continuous Monitoring sites during 2009.

(There were also several occasions during which the datasonde at Otter Point Creek was not submerged due to low tidal conditions and did not collect valid data.)

Yearly Precipitation and Discharge Events

Precipitation increases run off into waterways, which can lead to a higher discharge of nutrients that fuels algal blooms, decreases water clarity, and suppresses SAV growth. In 2009, precipitation at Baltimore Washington International (BWI) Thurgood Marshall Airport was above normal, totaling 13.6-inches above the 138-year average (Figure 2a). A USGS Rain Gage in the Winters Run Basin (part of the Bush River watershed) at Fallston also recorded high levels of precipitation with seven months each totaling more than 5-inches (Figure 2b). Mean flow of discharge at the USGS Gaging Station on Otter Point Creek (Figure 3) was also higher in 2009 (85.6 cubic feet per second – cfs) as compared to the previous two years (2007: 65.0 cfs; 2008: 53.4 cfs). Average discharge was also high (81.0 cfs) during the growing season of April through October, a time when discharge events can have the greatest effect on SAV growth.



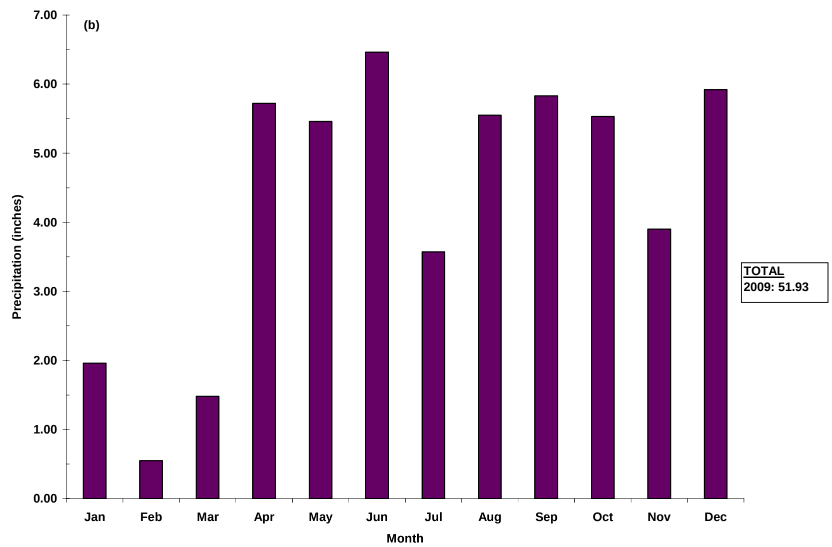


Figure 2. Total 2009 monthly precipitation at (a) BWI Marshall Airport (compared to 138-year averages) and (b) USGS 393126076244301 Rain Gage in the Winters Run Basin at Fallston, MD. (Values in parentheses indicate departures from average.)

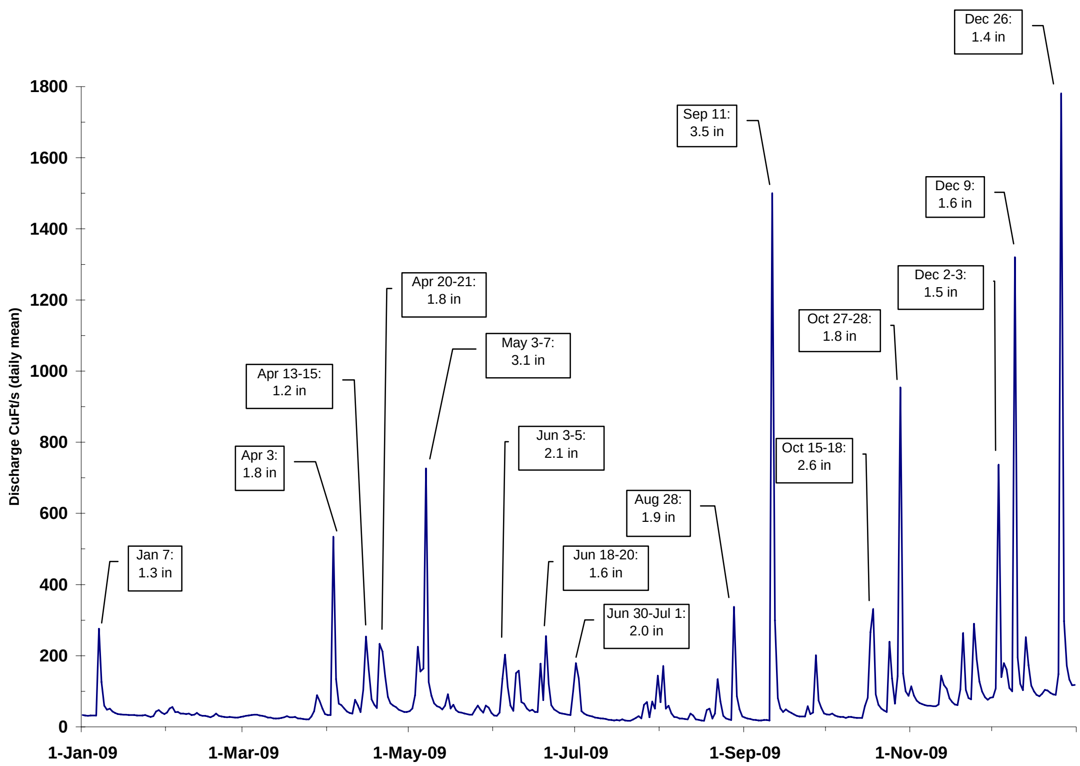
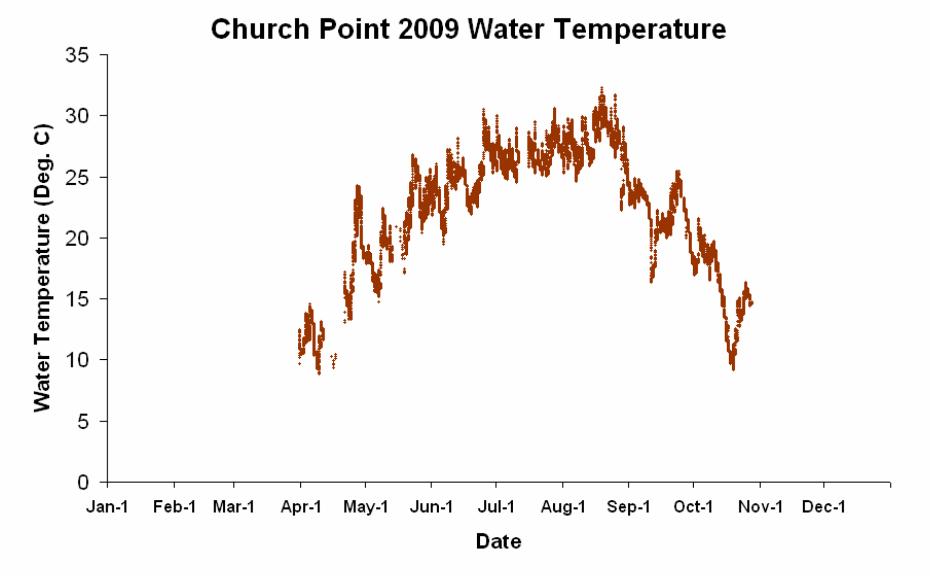


Figure 3. Daily discharge in cubic feet per second measured at USGS Gaging Station 01581757 on Otter Point Creek near Edgewood, MD in 2009. (Boxes indicate precipitation events at BWI Marshall Airport that coincided with spikes in discharge.)

Continuous Monitoring Data

Water Temperature

Water temperature at both Bush River Continuous Monitoring sites rose predictably as air temperatures increased during the summer months and peaked in August (Figure 4). Church Point reached a peak of approximately 32°C, while Otter Point Creek peaked at 34°C.



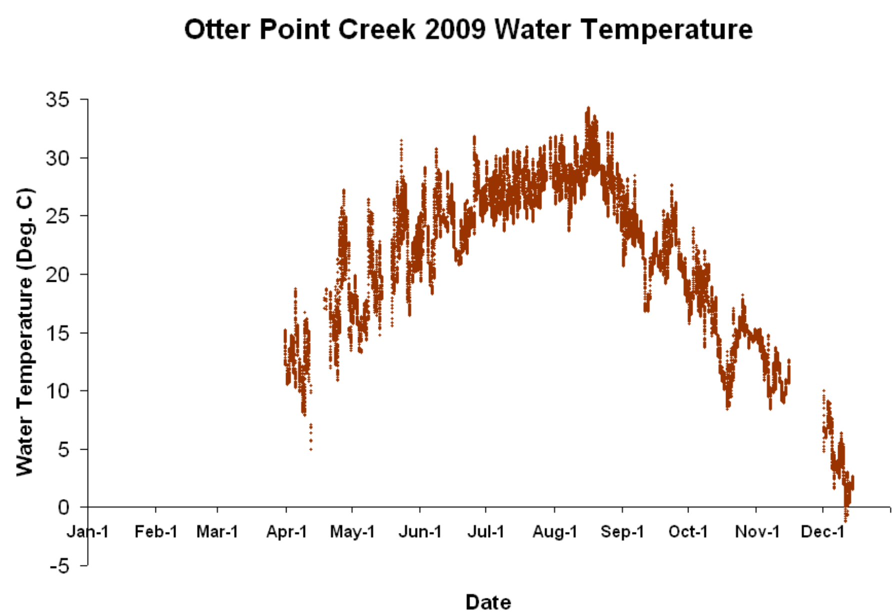
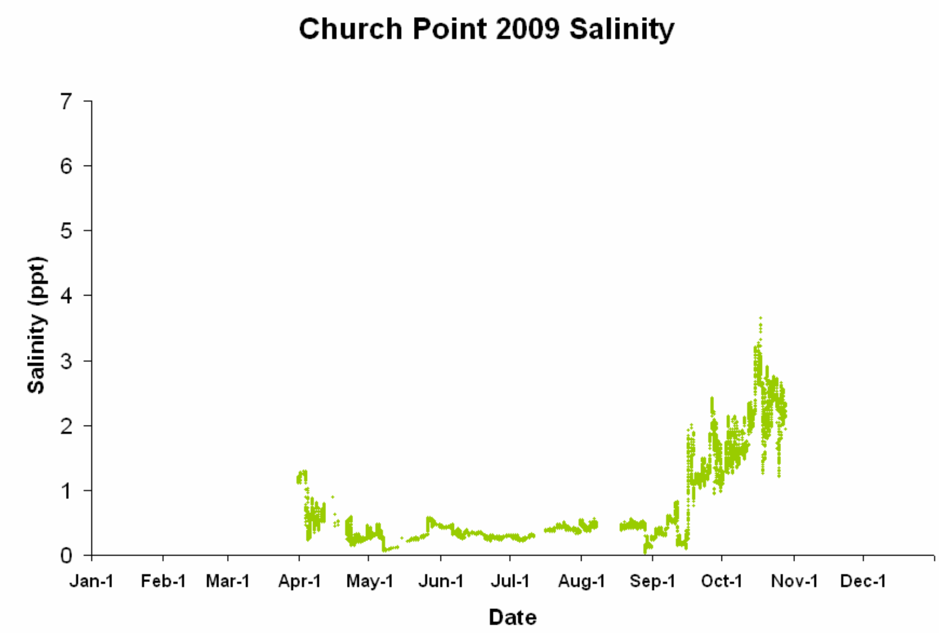


Figure 4. Water temperature at Bush River Continuous Monitoring sites during 2009.

Salinity

Salinity levels for both the Church Point and Otter Point Creek Continuous Monitoring sites remained low for most of the spring and summer (Figure 5). Levels then increased during the late summer and early fall, but not to the extent that was seen during the drier years of 2007 and 2008. Church Point salinity levels peaked at 3.7 parts per thousand (ppt) on October 17th and Otter Point Creek levels peaked at 2.0ppt on October 24th.



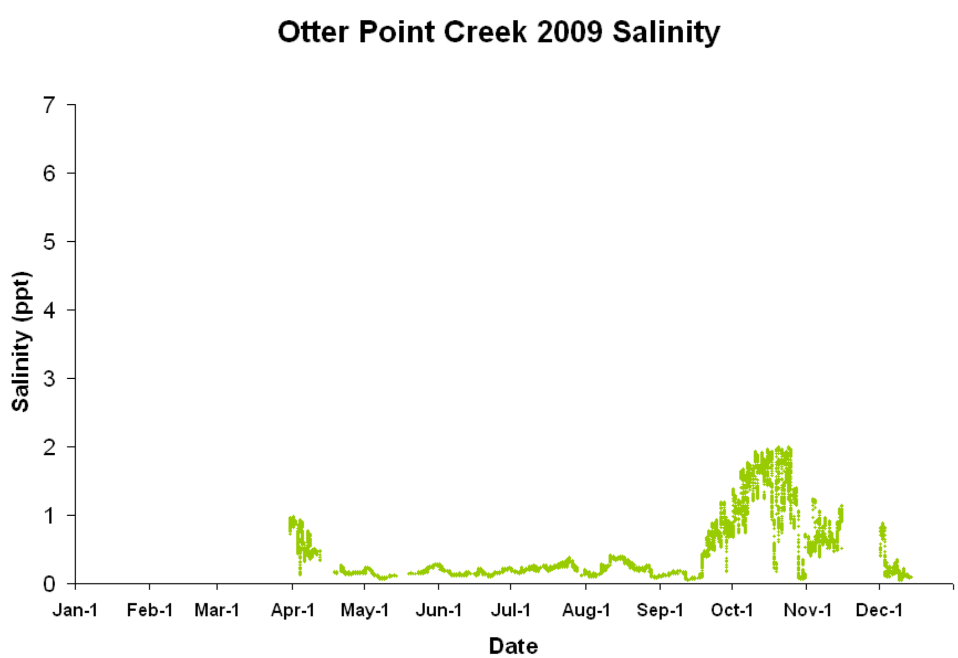


Figure 5. Salinity levels at Bush River Continuous Monitoring sites during 2009.

Dissolved Oxygen

In 2009, both Continuous Monitoring sites were located closer to the head waters than the mouth of the Bush River (Figure 1) and exhibited similar variability in dissolved oxygen levels (Figure 6). Both sites also experienced relatively few days of dissolved oxygen concentrations below 5 milligrams per liter (mg/l) (Table 2). This threshold as been set by the US Environmental Protection Agency (EPA) because dissolved oxygen levels below 5mg/l can be detrimental to the survival of juvenile fish (US EPA, 2003).

The highest dissolved oxygen concentration measured at Church Point was 14.98mg/l on September 20th, and the lowest was 1.88mg/l on August 29th. In general, dissolved oxygen levels were concentrated around 6-9mg/l during the summer months and 5.8% of 7,347 valid readings between July and September were below 5mg/l (Table 2). At Otter Point Creek, dissolved oxygen concentrations reached a high of 17.14mg/l on August 25th and a low of 2.34mg/l on August 19th. Levels during the summer varied more widely than at Church Point, but they generally remained above 5mg/l. Less than 4% of 7,985 valid readings between July and September were below 5mg/l (Table 2). This represents an over 60% decrease in criteria failure rate in the last two years and is the lowest failure rate at Otter Point Creek since 2003 (Table 2).

Algal blooms in waterways are identified by measuring chlorophyll concentrations and dissolved oxygen levels often drop following the death and decomposition of algal blooms and associated decreases in chlorophyll levels. The decomposition process can consume significant amounts of dissolved oxygen in the water and can lead to conditions harmful to aquatic organisms. For example, decreases in dissolved oxygen levels at Church Point to 3.94mg/l on June 6th, 4.82mg/l on June 17th, and 3.24mg/l on October 11th coincided with drops in chlorophyll levels (Figure 7). Decreases in dissolved oxygen levels at Otter Point Creek to 4.13mg/l on May 9th, 2.34mg/l on August 19th, 2.40mg/l on August 29th, and 4.47mg/l on September 15th also coincided with drops in chlorophyll levels (Figure 7). Furthermore, heavy rain and flooding across northeast Maryland on August 28th (Table 1) coincided with dissolved oxygen levels dropping to below 3mg/l at both sites on August 29th (Figure 6).

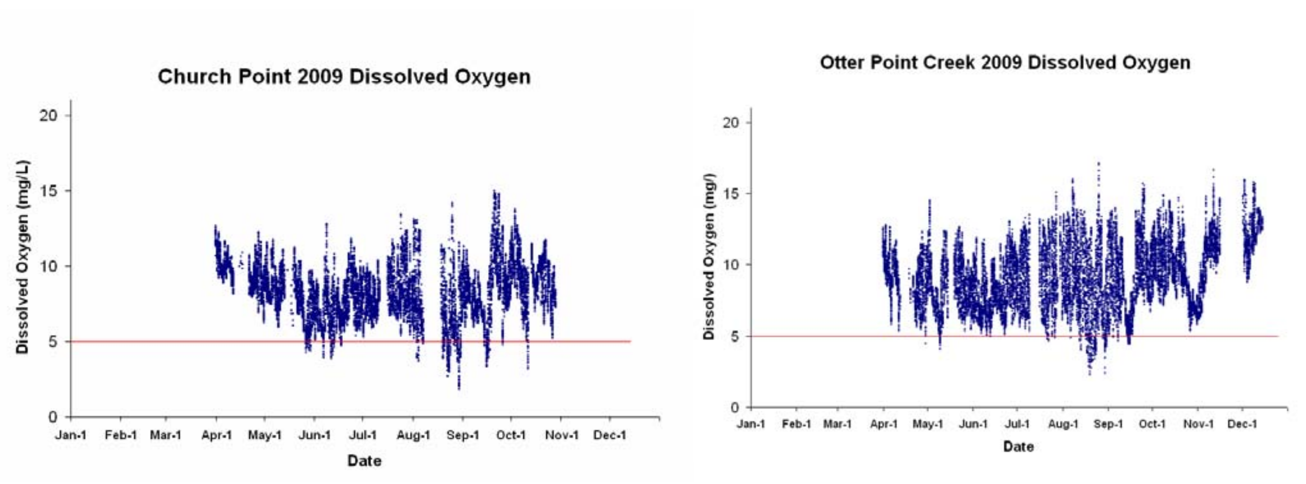


Figure 6. Dissolved oxygen levels at Bush River Continuous Monitoring sites during 2009.

(Red line indicates threshold below which levels can lead to ecosystem stress.)

Continuous Monitoring Site	2003	2004	2005	2006	2007	2008	2009
Church Point							
Dissolved Oxygen less than 5 mg/l	N/A	N/A	N/A	N/A	N/A	5.46%	5.81%
Dissolved Oxygen less than 3.2 mg/l	N/A	N/A	N/A	N/A	N/A	0.37%	0.52%
Otter Point Creek							
Dissolved Oxygen less than 5 mg/l	3.78%	31.82%	23.17%	5.04%	10.33%	10.01%	3.96%
Dissolved Oxygen less than 3.2 mg/l	0.43%	9.70%	8.40%	0.10%	1.62%	1.17%	0.15%

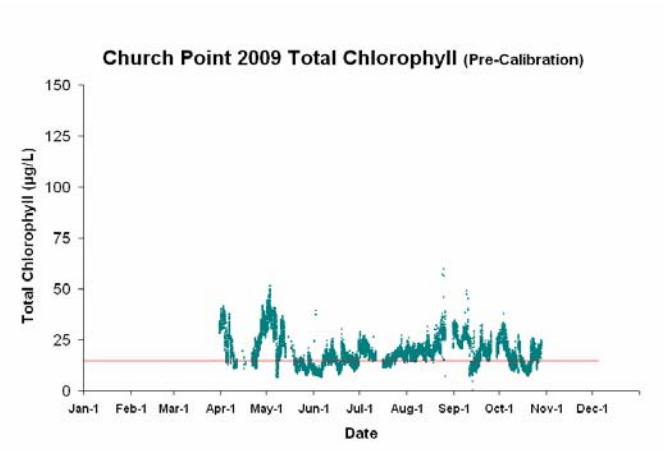
Table 3. Dissolved Oxygen criteria failure at Church Point and Otter Point Creek during July through September, 2003 to 2009. *(5mg/l is the 30-day mean and 3.2mg/l is the instantaneous EPA threshold for shallow-water habitat; US EPA, 2003.)*

Chlorophyll

At both Continuous Monitoring sites in 2009, there were very few chlorophyll readings greater than 50 micrograms per liter (µg/l), which are indicative of significant algal blooms, or 100µg/l, which indicates severe blooms (Figure 7 and Table 3). A substantial proportion of chlorophyll readings during the wet spring and summer, however, were greater than 15µg/l (Table 3), a threshold above which detrimental effects on aquatic ecosystems may occur.

At Church Point, chlorophyll levels briefly spiked above 50µg/l in early May. During the remainder of the year only three additional readings above 50 µg/l were recorded. Of 2,935 valid readings between March and May and 6,480 valid readings between July and September, 66.1% and 85.7% respectively were greater than 15µg/l.

At Otter Point Creek, chlorophyll levels spiked above 50µg/l in early May and early September, and above 100µg/l following the SAV growing season in mid-November and early December. Of 3,225 valid readings between March and May and 3,402 valid readings between July and September, 70.9% and 47.2%, respectively, were greater than 15µg/l.



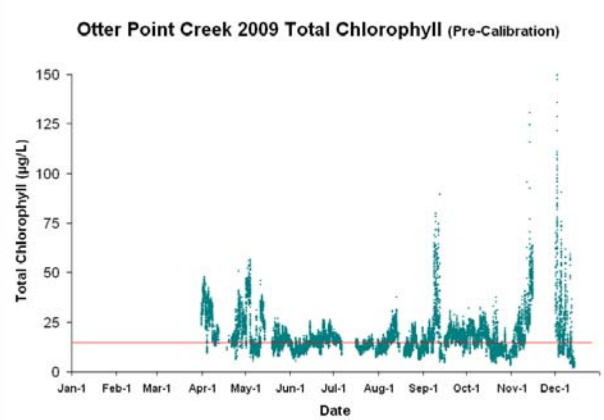


Figure 7. Total chlorophyll levels at Bush River Continuous Monitoring sites during 2009.

(Red line indicates threshold above which levels may have harmful effects on aquatic ecosystems.)

Continuous Monitoring Site	Months	2009
Church Point		
Readings greater than 15µg/l	Mar - May	66.06%
	July - Sept	85.70%
Readings greater than 50µg/l	Mar - May	0.05%
	July - Sept	0.04%
Readings greater than 100µg/l	Mar - May	0%
	July - Sept	0%
Otter Point Creek		
Readings greater than 15µg/l	Mar - May	70.88%
	July - Sept	47.23%
Readings greater than 50µg/l	Mar - May	0.40%
	July - Sept	1.31%
Readings greater than 100µg/l	Mar - May	0%
	July - Sept	0%

Table 4. Chlorophyll criteria failure at Church Point and Otter Point Creek in 2009.

pH

Church Point and Otter Point Creek displayed similar variability in pH levels (Figure 8). Both sites displayed a dip in pH in early to mid-May, which coincided with the wettest month at BWI Marshall Airport in 2009 (Figure 2), and a spike in pH levels in July and August. Of note, pH at both sites dropped dramatically in mid-September following an influx of fresh water into the system from a heavy rain event across northeast Maryland (Table 1) and associated discharge event (Figure 3). pH at Church Point dropped from 8.2 on September 10th to 6.3 on September 13th, and then rebounded to 9.5 on September 21st. At Otter Point Creek, pH dropped from 9.1 on September 10th to 6.4 on September 13th, and rebounded to 9.0 on September 19th.

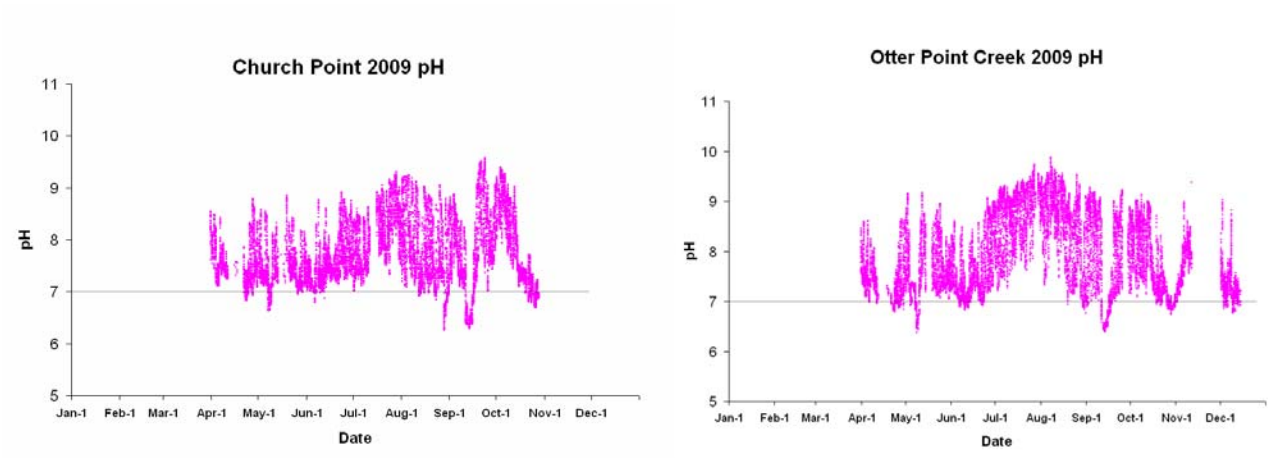


Figure 8. pH levels at Bush River Continuous Monitoring sites during 2009.

(Line indicates neutral pH.)

Turbidity and Coefficient of Light Attenuation (K_d)

Turbidity is one measure of water clarity and is quantified by measuring how much light is reflected from suspended particles in the water. Lower turbidity values indicate less reflection and, therefore, clearer water, while values over 15 nephelometric turbidity units (NTUs) are considered to be detrimental to bay grass growth.

2009 was a wetter than average year (Figure 2), which led to frequent spikes in discharge (Figure 3), and to the vast majority of turbidity values reading above 15 NTU at both Continuous Monitoring sites on the Bush River (Figure 9). Both sites also experienced spikes and declines in turbidity levels following weather patterns and chlorophyll levels. Turbidity levels at Church Point spiked above 200 NTU in early April, which coincided with chlorophyll levels greater than 40µg/l (Figure 7), above 300 NTU in late May during the wettest month of the year at BWI Marshall Airport, and above 100 NTU in mid-September following a sanitary sewer overflow and heavy rain (Table 1) and discharge event (Figure 3) in the watershed. At Otter Point Creek, elevated chlorophyll levels above 40µg/l (Figure 7) also coincided with turbidity levels above 300 NTU. Turbidity levels also spiked to 186 NTU in mid-September following a sanitary sewer overflow and heavy rain (Table 1) and discharge event (Figure 3) in the watershed, and above 300 NTU on December 9th, which coincided with a high volume sanitary sewer overflow in Bel Air (Table 1).

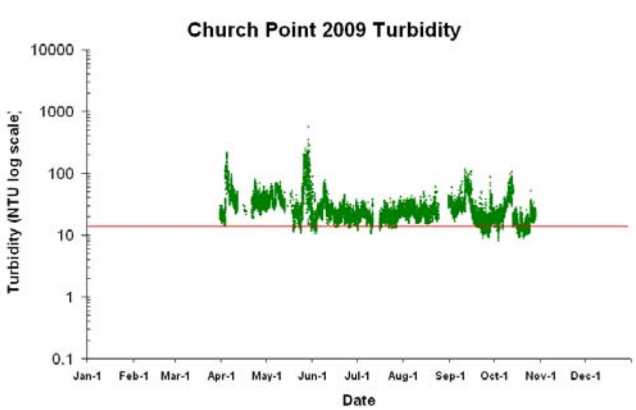


Figure 9. Turbidity levels at Bush River Continuous Monitoring sites during 2009.

(Red line indicates threshold above which levels are considered detrimental to bay grass growth.)

Another measure of water clarity is the coefficient of light attenuation (K_d). This coefficient quantifies how far light can travel down the water column and is calculated using salinity, chlorophyll, and turbidity data (US EPA, 2007). Clearer water has lower K_d values while murky or cloudy water has higher values. For the Continuous Monitoring sites on the Bush River, K_d values less than or equal to 2.1 are considered optimal for SAV growth. During the SAV growing season (April through October) in 2009, water clarity continued a declining trend as the vast majority of K_d values were greater than 2.1 (Table 4). Almost 100% of 15,978 valid readings at Church Point and over 97% of 16,634 valid readings at Otter Point Creek resulted in K_d values greater than 2.1.

Continuous Monitoring Site	2009
Church Point	
K_d greater than 2.1	99.97%
Otter Point Creek	
K_d greater than 2.1	97.21%

Table 5. Coefficient of light attenuation failure (K_d) at Church Point and Otter Point Creek during April through October, 2009.

Submerged Aquatic Vegetation (SAV) in the Bush River

SAV, or underwater grasses, are an important component of estuarine ecosystems. They provide habitat for juvenile fish and shellfish, supply food for waterfowl, oxygenate the water, and help stabilize bottom sediments. Since 1984, SAV total area and density within the Bush River has been quantified annually (with the exception of 1988) by the Virginia Institute of Marine Science (VIMS).

SAV acreage continued a two year decline in the Bush River in 2009. Total area of SAV in 2009 was 381 acres, which is approximately 9% higher than the restoration goal for the Bush River (Figure 10). Total area, however, has decreased by 41% in the Bush River since 2007 and the amount of high density beds has decreased from 66% of total acreage in 2007 to 28% of total acreage in 2009. VIMS did not conduct ground survey observations on the Bush River in 2009 so SAV species diversity could not be determined.

The decrease in SAV acreage in the Bush River follows the patterns seen in precipitation and discharge events and water clarity. 2009 was a wetter than average year (Figure 2) which led to numerous spikes in daily discharge and runoff events into waterways (Figure 3). Water clarity was also poor in 2009 (Figure 9) and K_d values (Table 4) indicate that light conditions within the water column were not optimal to facilitate SAV growth.

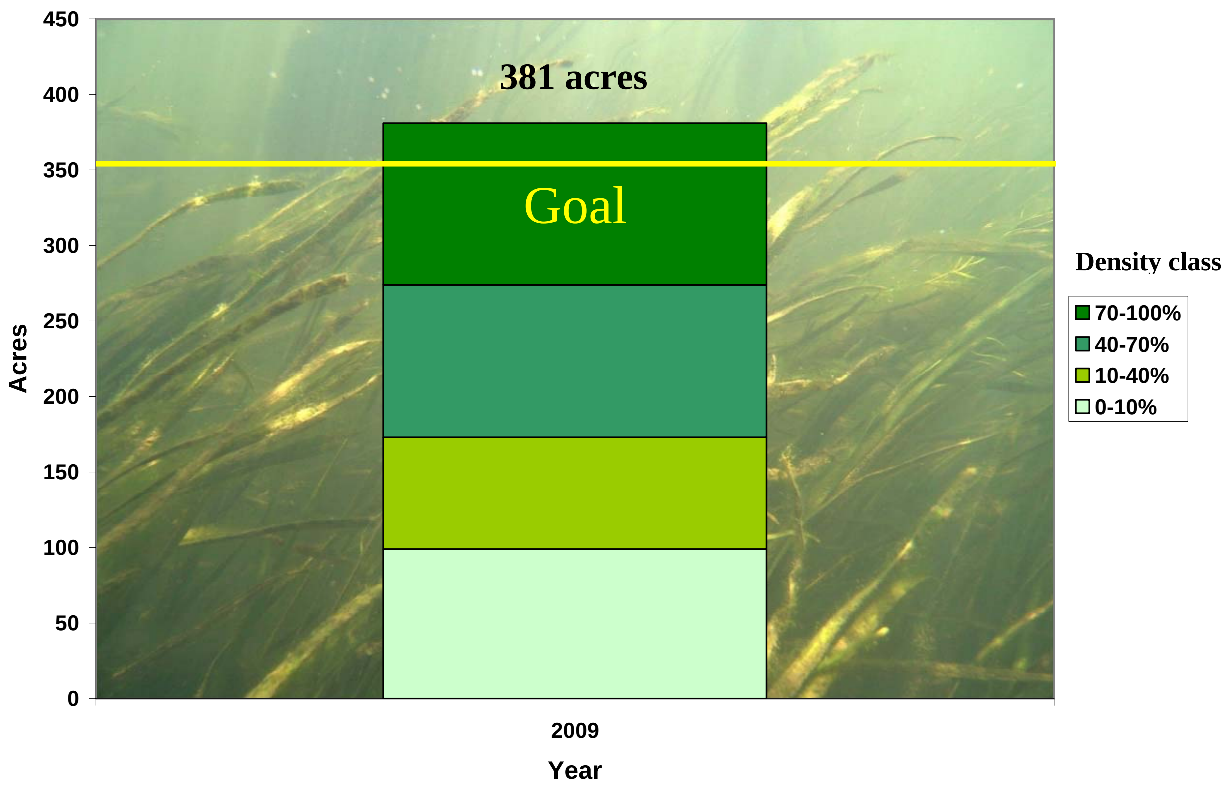


Figure 10. Total area and density of SAV in the Bush River in 2009.

Pigments, Nutrients, Suspended Solids, and Secchi Data

Bi-weekly grab samples of water were taken at each of the two Continuous Monitoring stations on the Bush River when the YSI meters were exchanged. Secchi depth, a measure of water clarity, was also recorded at the time of the grab sample.

For the grab samples, the water was processed in the field using vacuum filtration, and the resulting particulate and filtrate samples were delivered to the laboratory for analysis of pigments, nutrients, and suspended solids. All analyses were performed by the University of Maryland's Chesapeake Biological Laboratory (CBL) Nutrient Analytical Services Laboratory (NASL). For details on methods, procedures, analysis and detection limits, refer to the Quality Assurance Project Plan (QAPP) for the Shallow Water Monitoring Program. This document can be found at http://mddnr.chesapeakebay.net/eyesonthebay/documents/SWM_QAPP_2009_2010_Draft1.pdf. Results of the nutrient analyses, suspended sediments, and pigments are presented graphically in Appendix A (Figures A-1a through A-16b). If replicate grab samples were taken at a single depth, the graph depicts the average of these samples.

Ambient water quality data (dissolved oxygen, pH, salinity, and water temperature) were collected concurrently with the grab samples. These values are presented in Figures A-17a to A-21b in Appendix A. These water quality parameters are measured at multiple depths at each station. In the graphs, the data range for each parameter is represented by a vertical bar for each sample date. The connecting line intersects each bar at the average value for the station on that date.

One trend of note observed across several graphs is a spike in values (nitrite, nitrate, ammonium, total dissolved nitrogen, phosphate, total dissolved phosphorus, total suspended solids, volatile suspended solids) that occurred in early to mid-September along with a drop in dissolved oxygen concentrations. These patterns coincide with a sanitary sewer overflow and heavy rain event that took place in the watershed on September 10th-11th (Table 1). Such events can carry large concentrations of sediment and nutrients into the waterways and may have led to the observed spikes in measurements.

Conclusion

Shallow water monitoring, consisting of temporally intensive Continuous Monitoring, provides a critical function for assessing the health of Maryland's tidal waters in areas historically lacking water quality information. Not only is this information used for characterizing the health of shallow water habitats, but it is also useful for: 1) assessing newly developed Chesapeake Bay water quality criteria for dissolved oxygen, water clarity and chlorophyll in shallow water habitats; 2) determining attainment or non-attainment of shallow water habitats for their designated uses; 3) assessing SAV habitats and identifying potential SAV restoration sites, 4) providing information to better understand ecosystem processes and the impact of extreme events (e.g. hurricanes, high flows, sanitary sewer overflows) in shallow water and open water environments; 5) providing data for calibrating the Bay Eutrophication and Watershed Model.

References

U. S. Environmental Protection Agency. 2003. *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. Region III Chesapeake Bay Program Office, Annapolis, Maryland.

U. S. Environmental Protection Agency. 2007. *Ambient Water Quality Criteria for Dissolved Oxygen, Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tidal Tributaries – 2007 Addendum.* EPA 903-R-07-003. CBP/TRS 285/07. Ambient Water Quality Criteria for Dissolved Oxygen Water Clarity and Chlorophyll a for the Chesapeake Bay and Its Tributaries Region III Chesapeake Bay Program Office, Annapolis, Maryland.

Appendix A

Results of laboratory and ambient water quality analyses for:
Church Point (Station XJG7461)
Otter Point Creek (Station XJG7035)

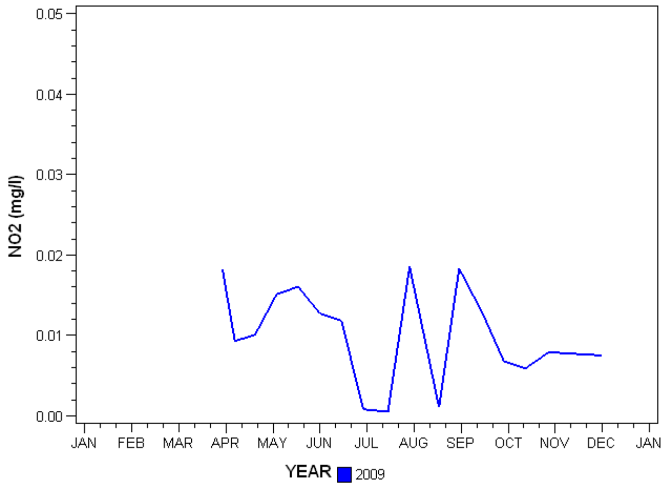


Figure A-1a. Nitrite concentrations at Otter Point Creek.

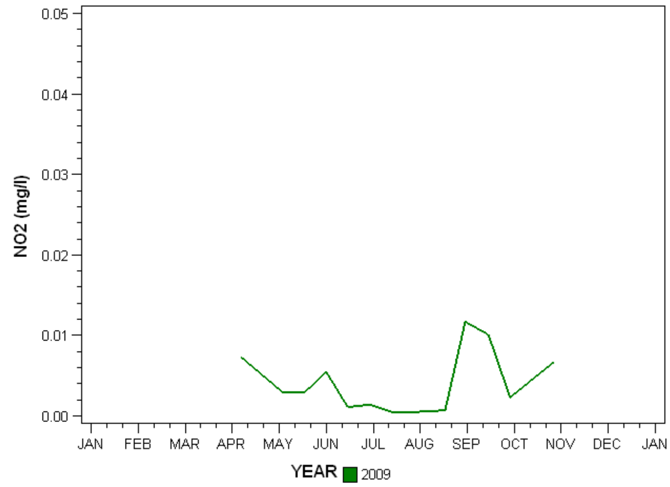


Figure A-1b. Nitrite concentrations at Church Point.

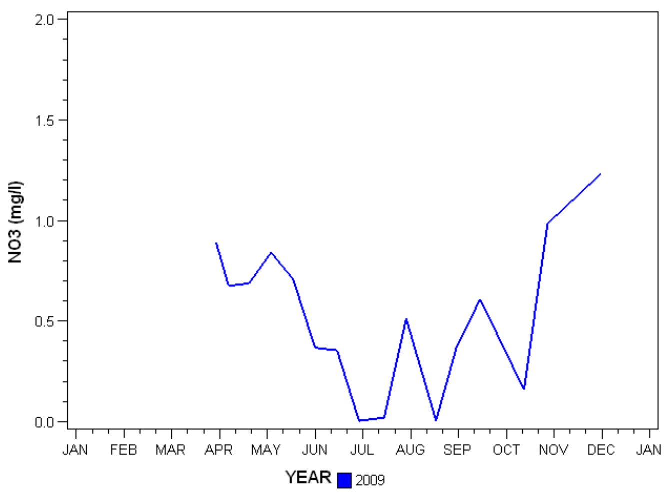


Figure A-2a. Nitrate concentrations at Otter Point Creek.

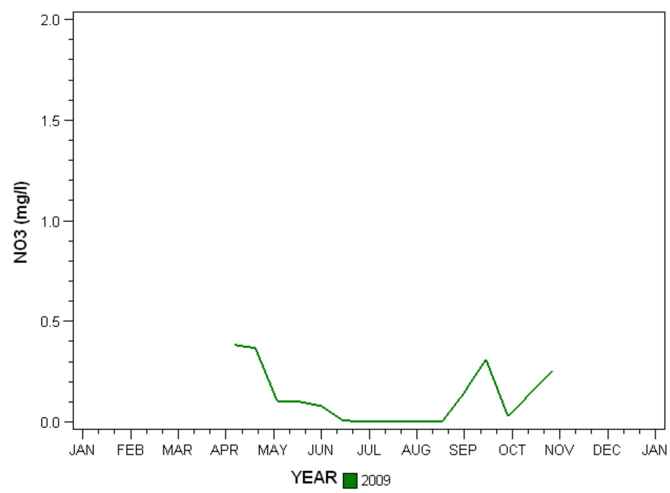


Figure A-2b. Nitrate concentrations at Church Point.

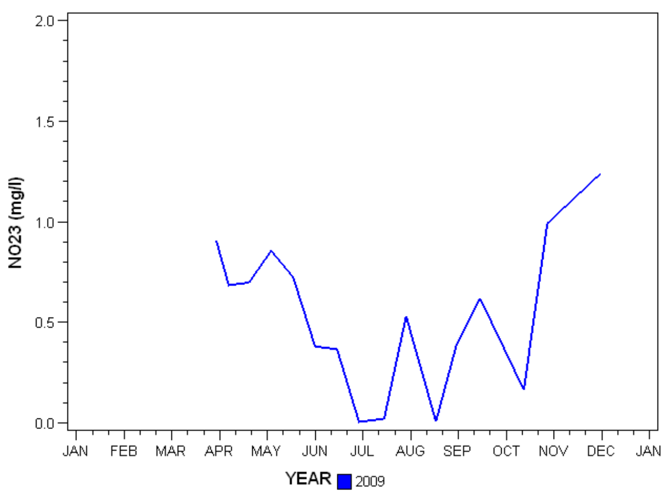


Figure A-3a. Nitrite + Nitrate concentrations at Otter Point Creek.

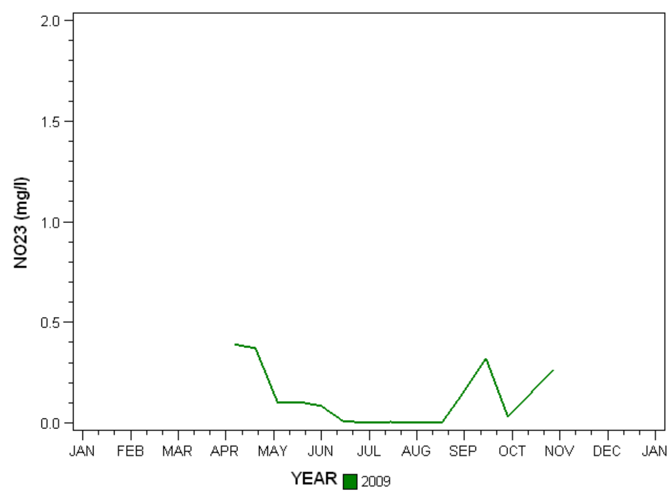


Figure A-3b. Nitrite + Nitrate concentrations at Church Point.

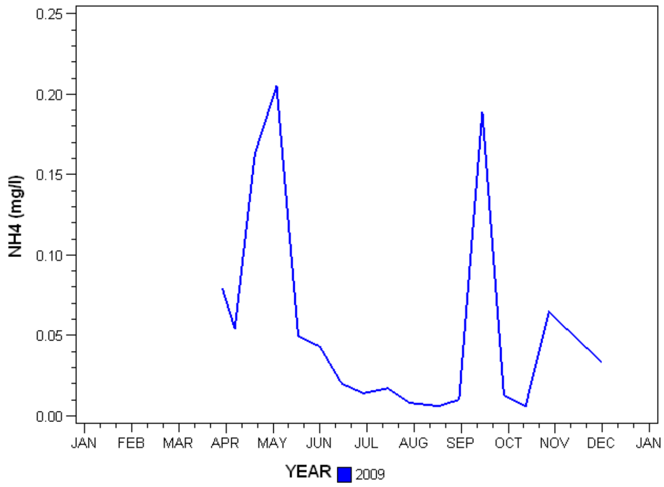


Figure A-4a. Ammonium concentrations at Otter Point Creek.

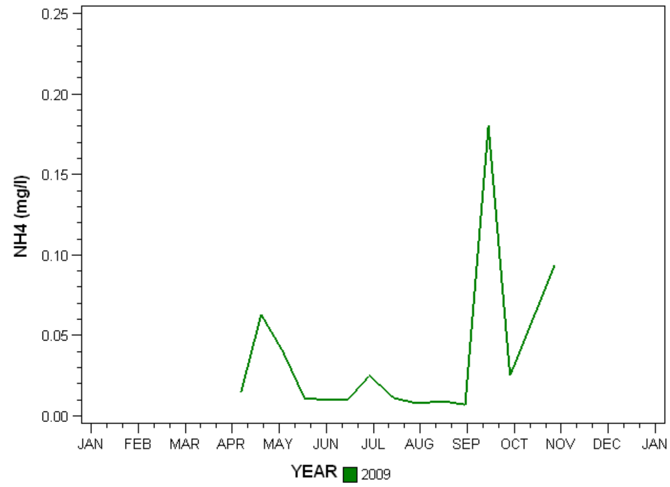


Figure A-4b. Ammonium concentrations at Church Point.

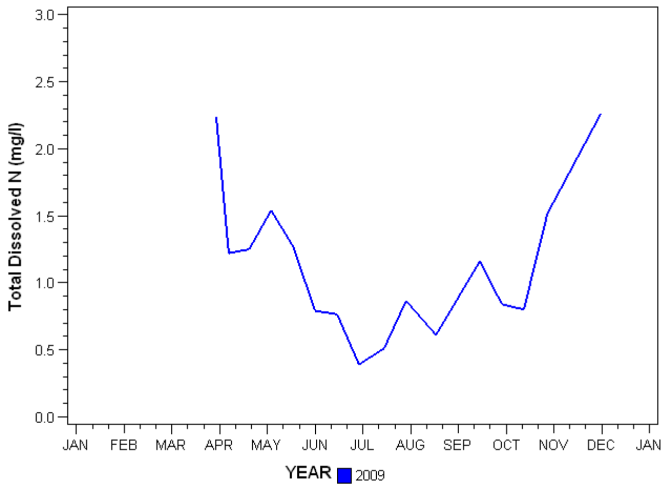


Figure A-5a. Total dissolved nitrogen concentrations at Otter Point Creek.

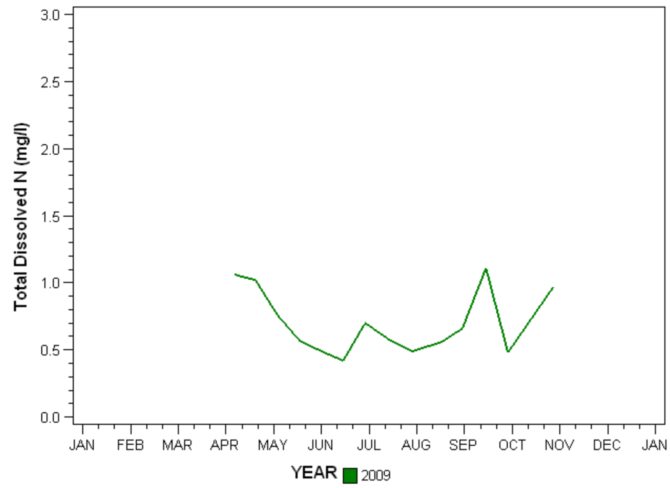


Figure A-5b. Total dissolved nitrogen concentrations at Church Point.

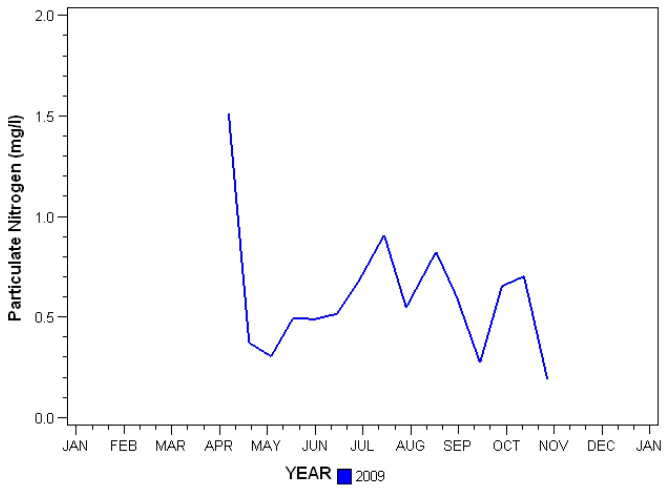


Figure A-6a. Particulate nitrogen concentrations at Otter Point Creek.

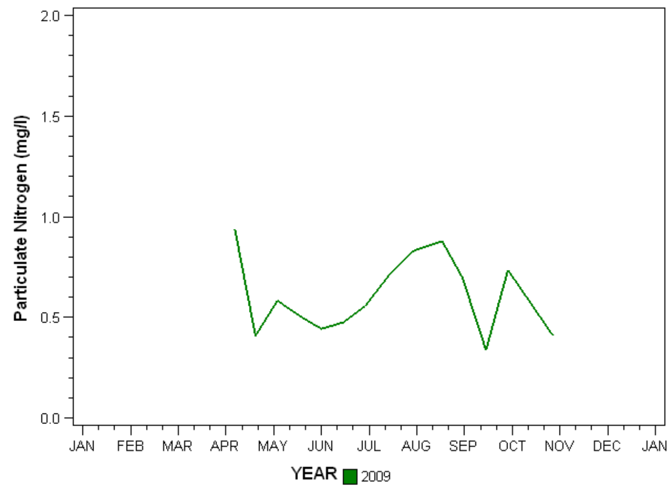


Figure A-6b. Particulate nitrogen concentrations at Church Point.

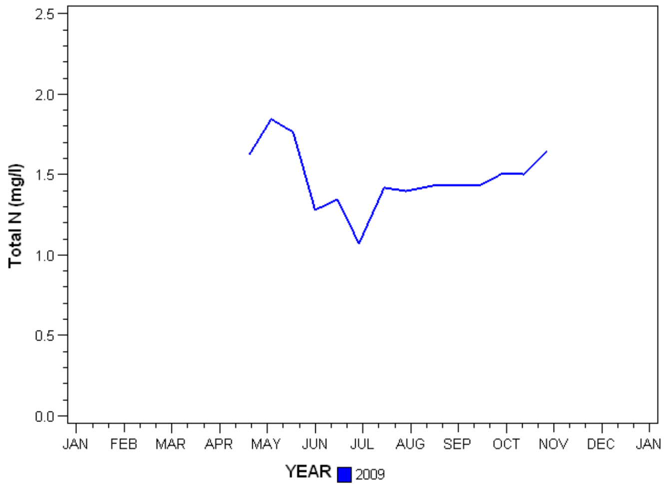


Figure A-7a. Total nitrogen concentrations at Otter Point Creek.

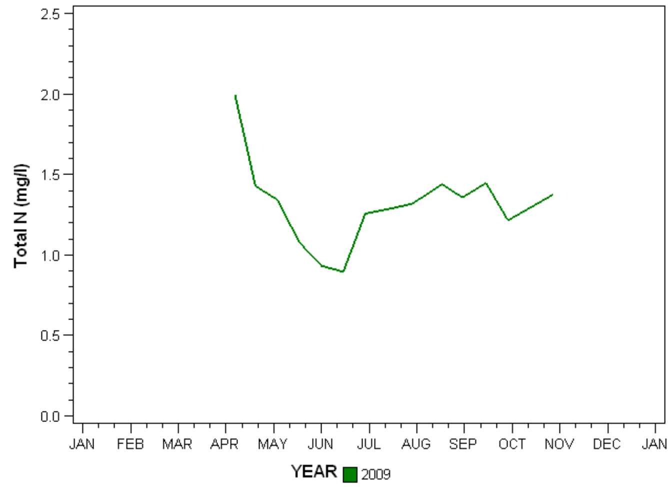


Figure A-7b. Total nitrogen concentrations at Church Point.

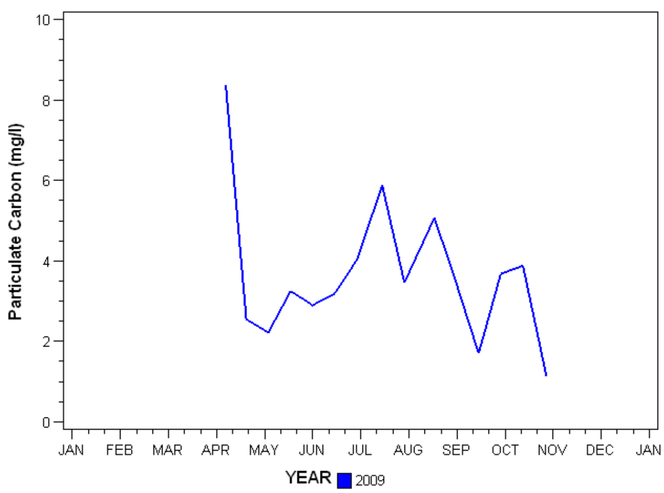


Figure A-8a. Particulate carbon concentrations at Otter Point Creek.

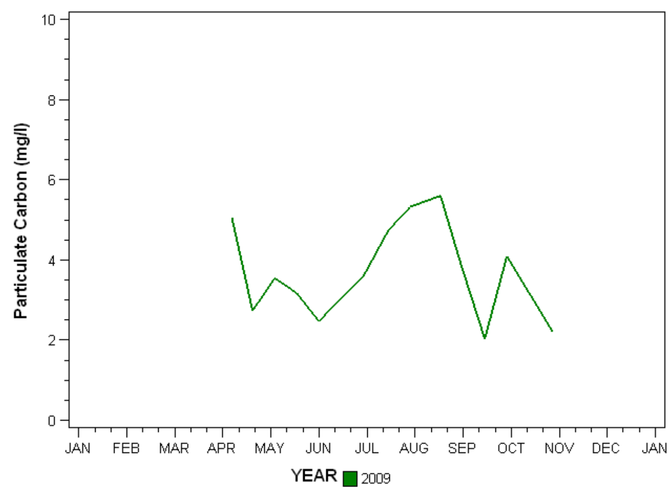


Figure A-8b. Particulate carbon concentrations at Church Point.

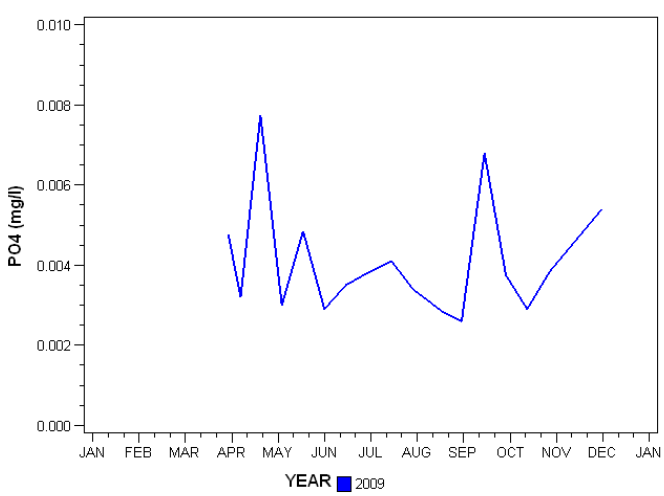


Figure A-9a. Phosphate concentrations at Otter Point Creek.

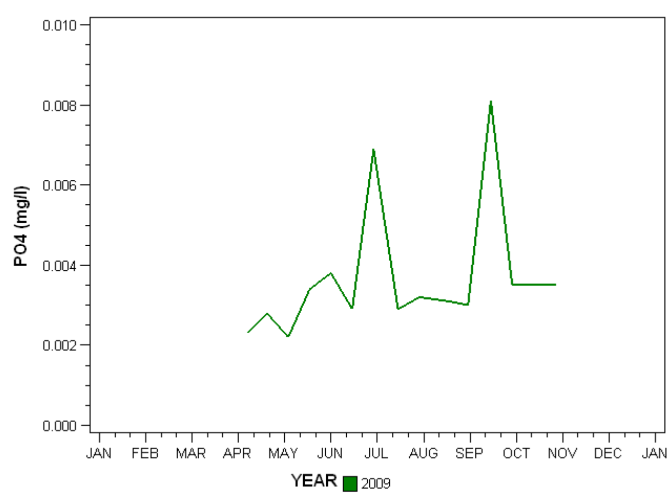


Figure A-9b. Phosphate concentrations at Church Point.

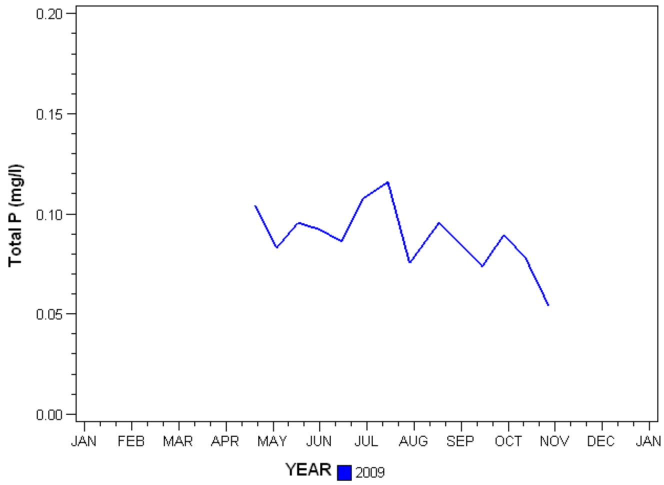


Figure A-10a. Total phosphorus concentrations at Otter Point Creek.

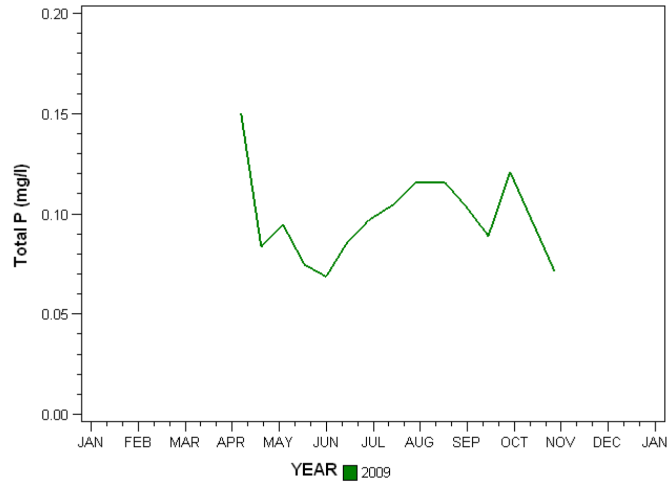


Figure A-10b. Total phosphorus concentrations at Church Point.

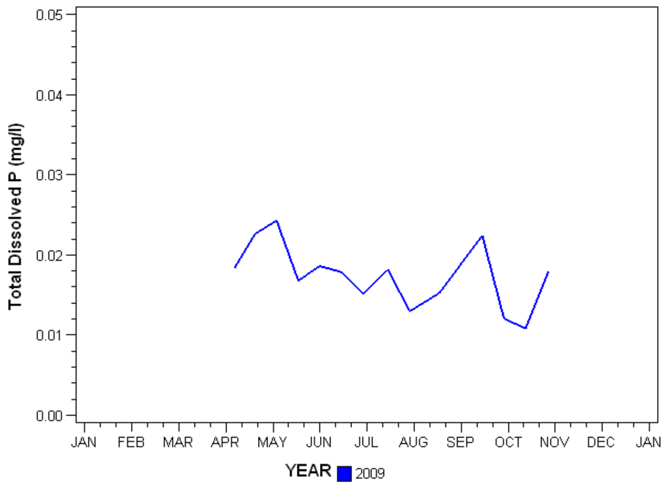


Figure A-11a. Total dissolved phosphorus concentrations at Otter Point Creek.

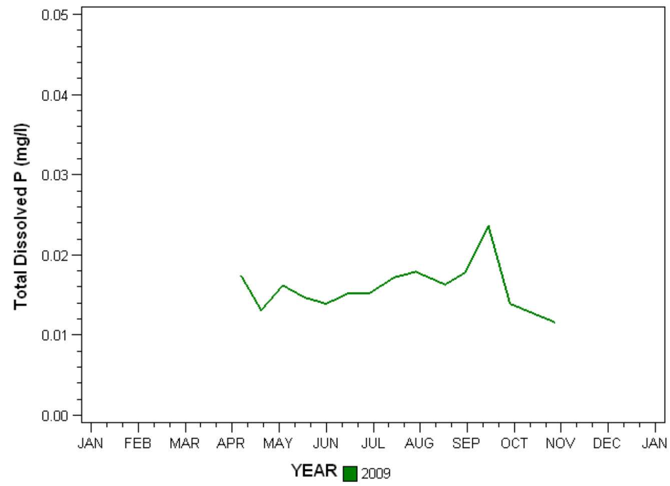


Figure A-11b. Total dissolved phosphorus concentrations at Church Point.

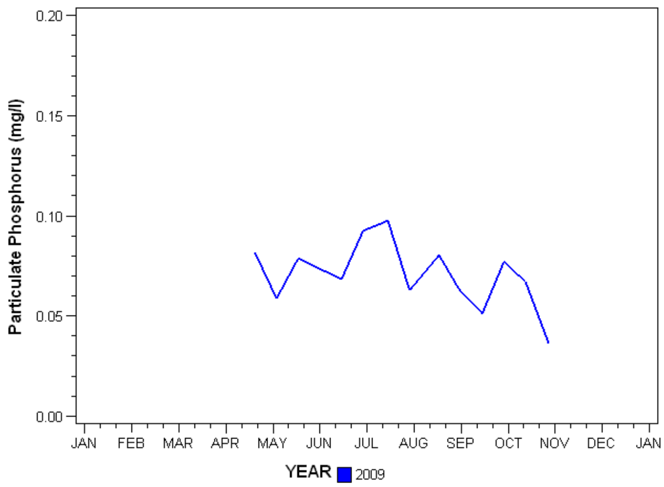


Figure A-12a. Particulate phosphorus concentrations at Otter Point Creek.

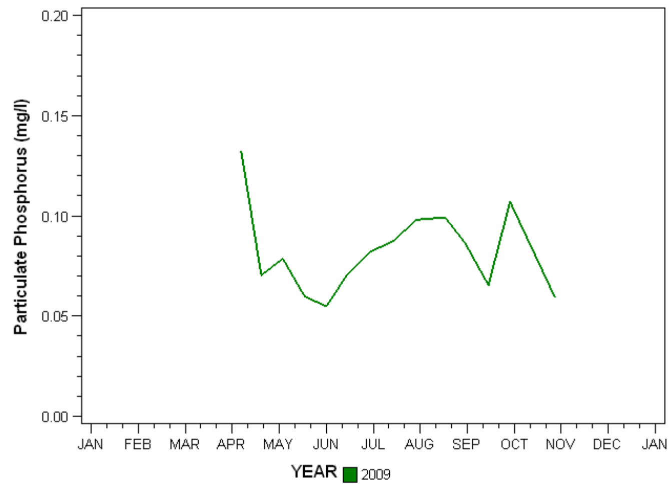


Figure A-12b. Particulate phosphorus concentrations at Church Point.

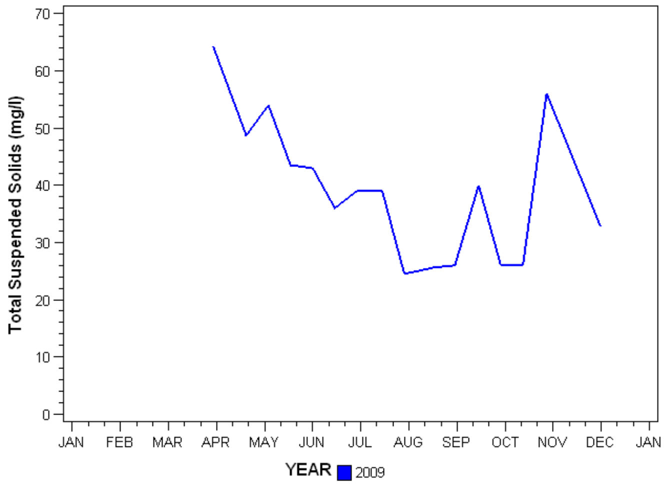


Figure A-13a. Total suspended solids concentrations at Otter Point Creek.

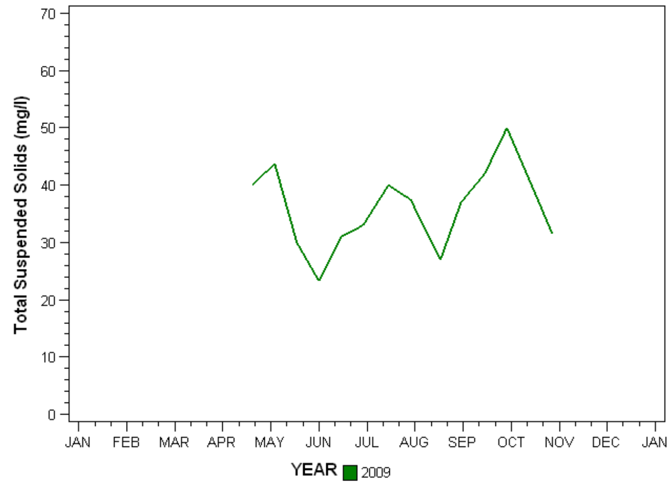


Figure A-13b. Total suspended solids concentrations at Church Point.

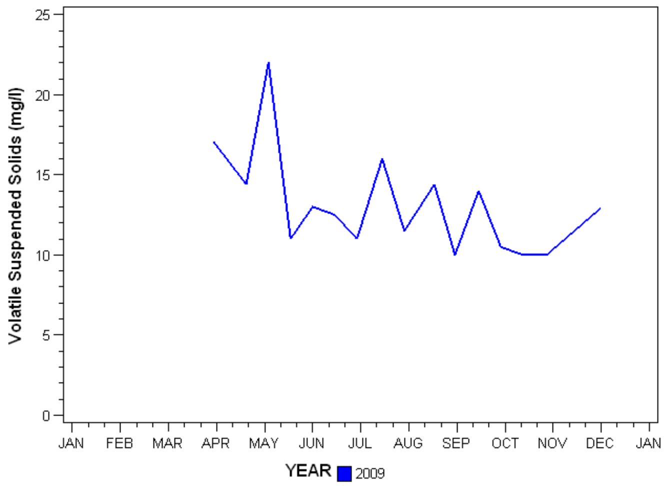


Figure A-14a. Volatile suspended solids concentrations at Otter Point Creek.

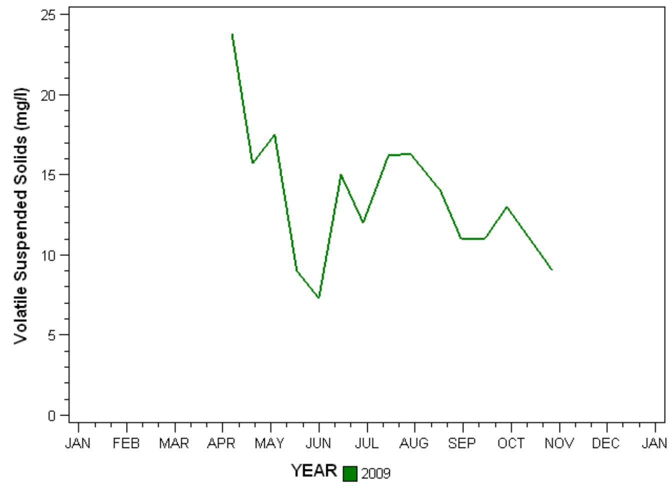


Figure A-14b. Volatile suspended solids concentrations at Church Point.

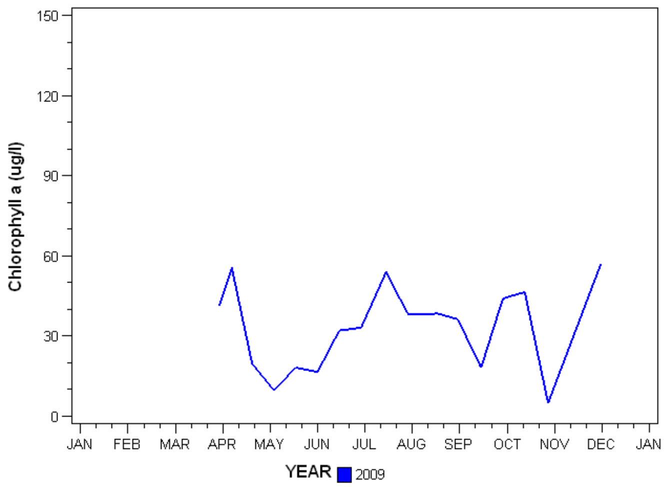


Figure A-15a. Chlorophyll *a* concentrations at Otter Point Creek.

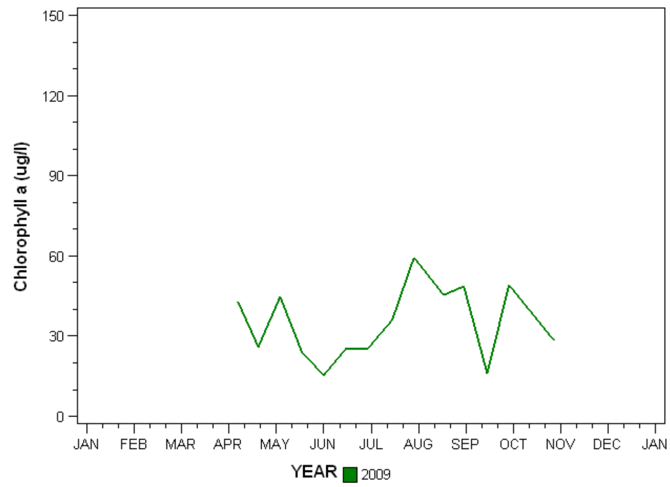


Figure A-15b. Chlorophyll *a* concentrations at Church Point.

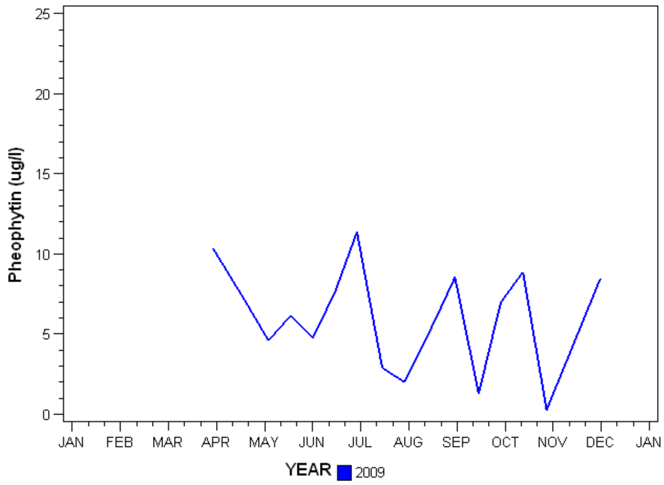


Figure A-16a. Pheophytin concentrations at Otter Point Creek.

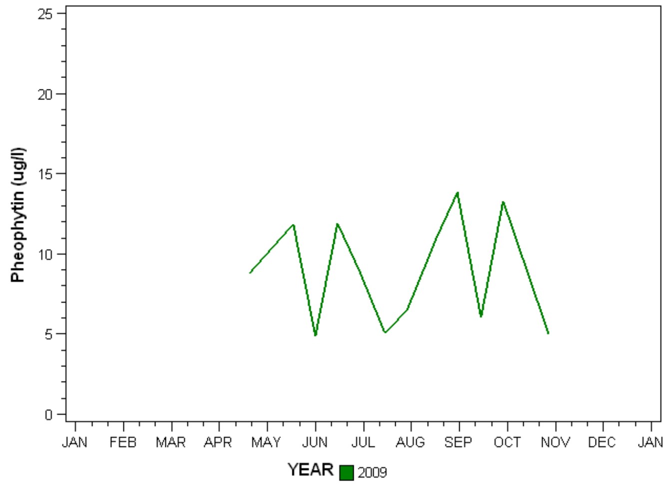


Figure A-16b. Pheophytin concentrations at Church Point.

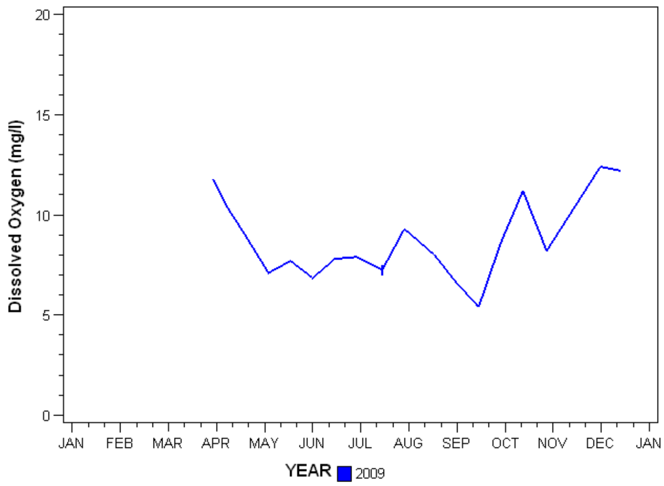


Figure A-17a. . Dissolved oxygen concentrations at Otter Point Creek.

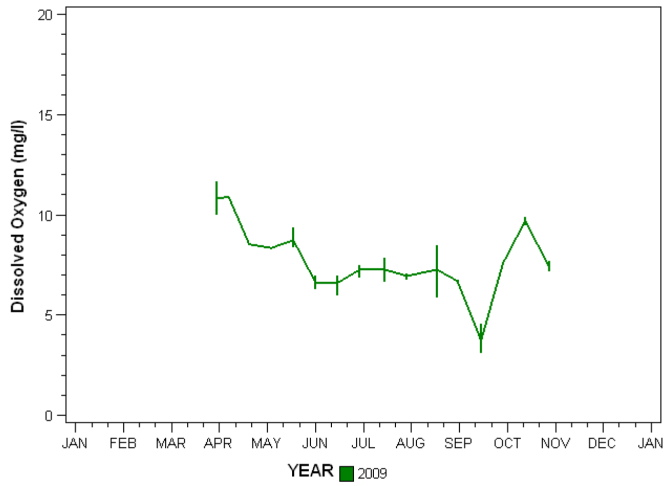


Figure A-17b. Dissolved oxygen concentrations at Church Point.

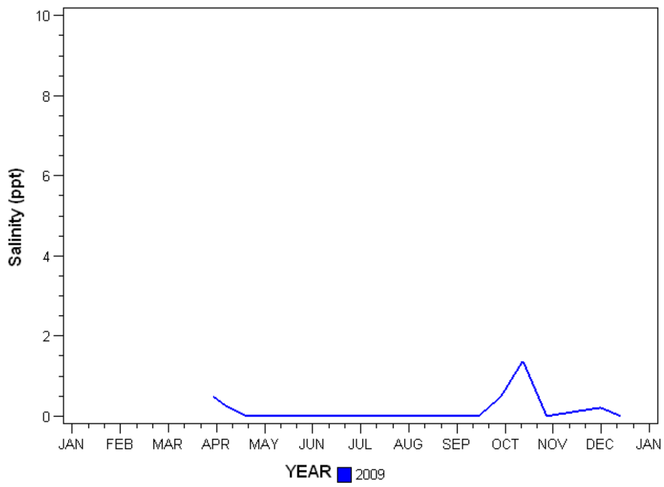


Figure A-18a. Salinity values at Otter Point Creek.

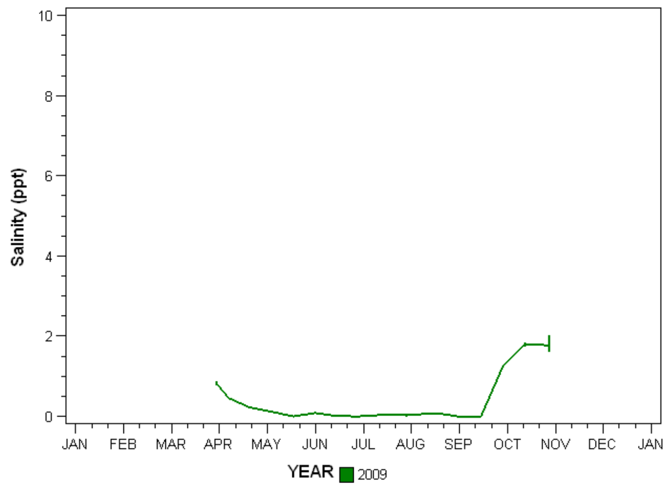


Figure A-18b. Salinity values at Church Point.

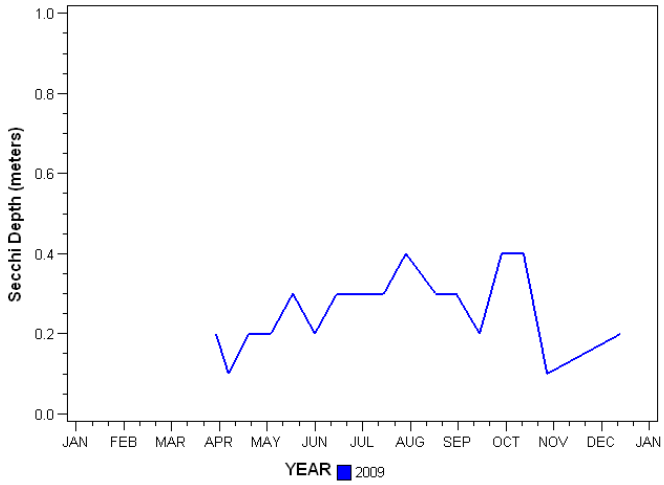


Figure A-19a. Secchi depth at Otter Point Creek.

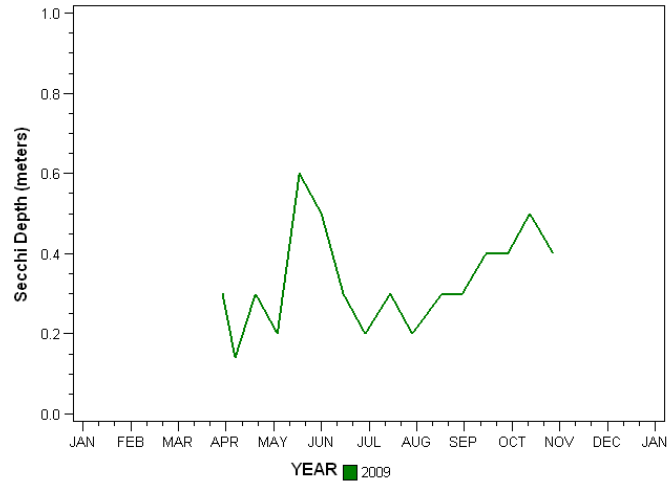


Figure A-19b. Secchi depth at Church Point.

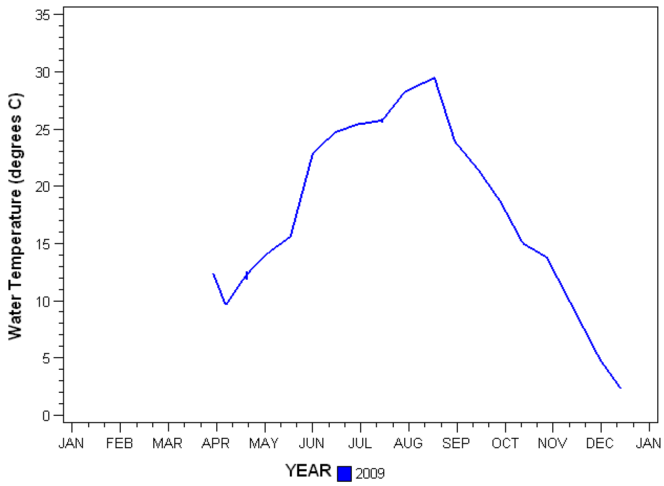


Figure A-20a. Water temperatures at Otter Point Creek

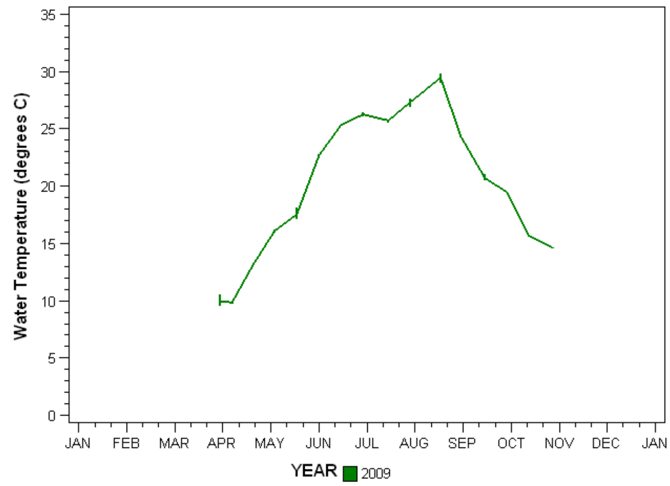


Figure A-20b. Water temperatures at Church Point.

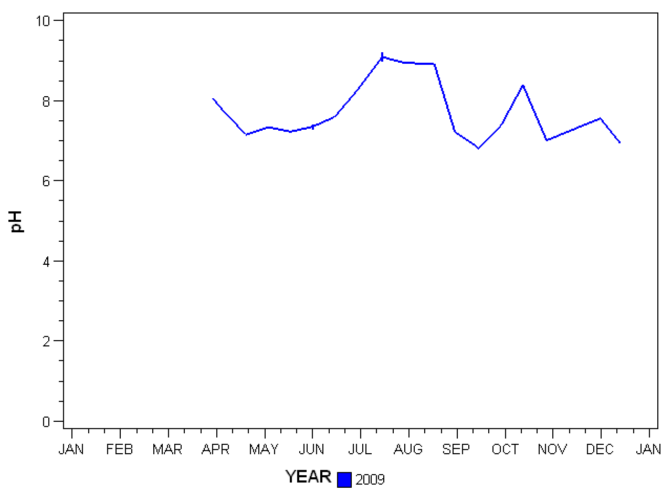


Figure A-21a. Values of pH at Otter Point Creek.

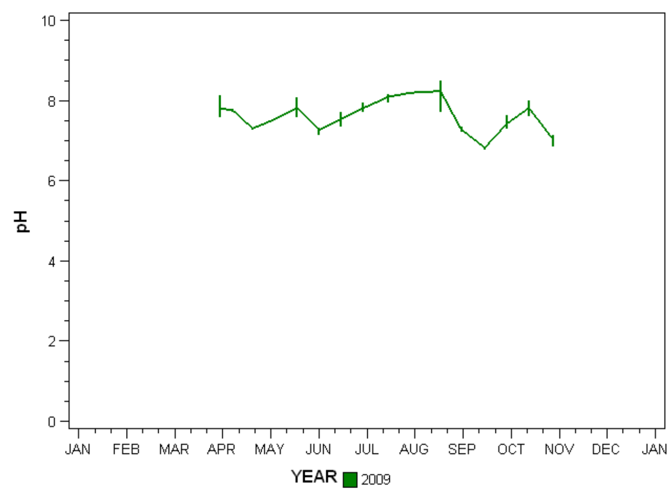


Figure A-21b. Values of pH at Church Point.

Table A1. Discrete Continuous Monitoring Data for Otter Point Creek (XJG7035) in 2009; ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), nitrite + nitrate (NO23), total dissolved nitrogen (TDN), particulate nitrogen (PN), total nitrogen (TN), phosphate (PO_4), total dissolved phosphorus (TDP), particulate phosphorus (PP), total phosphorus (TP), and particulate carbon (PC).

Date	Depth (m)	Replicate	NH_4 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	NO23 (mg/L)	TDN (mg/L)	PN (mg/L)	TN (mg/L)	PO_4 (mg/L)	TDP (mg/L)	PP (mg/L)	TP (mg/L)	PC (mg/L)
03/31/09	0.5	1	0.091	0.0212	0.8918	0.9130	2.24			0.0059	0.1188			
03/31/09	0.5	2	0.067	0.0153	0.8867	0.9020				0.0036				
04/08/09	0.5	1	0.054	0.0093	0.6747	0.6840	1.22	1.510	2.730	0.0032	0.0184	0.2013	0.2197	8.38
04/21/09	0.8	1	0.165	0.0103	0.6920	0.7023	1.25	0.372	1.622	0.0077	0.0226	0.0816	0.1042	2.55
04/21/09	0.8	2	0.161	0.0098	0.6837	0.6935				0.0078				
05/05/09	0.4	1	0.205	0.0151	0.8407	0.8558	1.54	0.304	1.844	0.0030	0.0243	0.0587	0.0830	2.22
05/19/09	0.5	1	0.068	0.0170	0.6943	0.7113	1.27	0.494	1.764	0.0058	0.0168	0.0788	0.0956	3.25
05/19/09	0.5	2	0.031	0.0151	0.7225	0.7376				0.0039				
06/02/09	0.8	1	0.043	0.0127	0.3669	0.3796	0.79	0.489	1.279	0.0029	0.0186	0.0735	0.0921	2.90
06/16/09	0.6	1	0.021	0.0117	0.3725	0.3842	0.83	0.516	1.346	0.0038	0.0178	0.0684	0.0862	3.19
06/16/09	0.6	2	0.019	0.0119	0.3350	0.3469	0.70			0.0032	0.0179			
06/30/09	0.7	1	0.014	0.0008	0.0035	0.0043	0.39	0.681	1.071	0.0038	0.0151	0.0926	0.1077	4.03
07/16/09	0.9	1	0.017	0.0005	0.0191	0.0196	0.51	0.908	1.418	0.0041	0.0182	0.0976	0.1158	5.88
07/30/09	0.1	1	0.008	0.0189	0.5191	0.5380	0.85	0.547	1.397	0.0033	0.0125	0.0628	0.0753	3.46
07/30/09	0.1	2	0.008	0.0182	0.5048	0.5230	0.88			0.0035	0.0134			
08/18/09	0.5	1	0.006	0.0011	0.0022	0.0033	0.61	0.824	1.434	0.0027	0.0152	0.0804	0.0956	5.07
08/18/09	0.5	2	0.006	0.0010	0.0075	0.0085				0.0030				
08/31/09	0.3	1	0.010	0.0183	0.3667	0.3850		0.603		0.0026		0.0633		3.55
09/15/09	0.5	1	0.189	0.0128	0.6072	0.6200	1.16	0.273	1.433	0.0068	0.0224	0.0513	0.0737	1.70
09/29/09	0.4	1	0.015	0.0068	0.3352	0.3420	0.85	0.654	1.504	0.0039	0.0125	0.0771	0.0896	3.68
09/29/09	0.4	2	0.010	0.0067	0.4363	0.4430	0.83			0.0036	0.0116			
10/13/09	0.6	1	0.006	0.0059	0.1571	0.1630	0.80	0.702	1.502	0.0029	0.0108	0.0670	0.0778	3.88
10/28/09	0.7	1	0.066	0.0075	0.9785	0.9860	1.46	0.187	1.647	0.0032	0.0178	0.0361	0.0539	1.11
10/28/09	0.7	2	0.063	0.0083	0.9897	0.9980	1.57			0.0045	0.0183			
12/01/09	0.1	1	0.033	0.0073	1.2127	1.2200	2.26			0.0049	0.0825			
12/01/09	0.1	2	0.034	0.0077	1.2523	1.2600				0.0059				

Table A2. Discrete Continuous Monitoring Data for Church Point (XJG7461) in 2009; ammonium (NH_4), nitrite (NO_2), nitrate (NO_3), nitrite + nitrate (NO23), total dissolved nitrogen (TDN), particulate nitrogen (PN), total nitrogen (TN), phosphate (PO_4), total dissolved phosphorus (TDP), particulate phosphorus (PP), total phosphorus (TP), and particulate carbon (PC).

Date	Depth (m)	Replicate	NH_4 (mg/L)	NO_2 (mg/L)	NO_3 (mg/L)	NO23 (mg/L)	TDN (mg/L)	PN (mg/L)	TN (mg/L)	PO_4 (mg/L)	TDP (mg/L)	PP (mg/L)	TP (mg/L)	PC (mg/L)
04/08/09	1.0	1	0.015	0.0073	0.3825	0.3898	1.06	0.934	1.994	0.0023	0.0174	0.1324	0.1498	5.04
04/21/09	1.0	1	0.063	0.0052	0.3666	0.3718	1.02	0.408	1.428	0.0028	0.0131	0.0704	0.0835	2.73
05/05/09	0.9	1	0.040	0.0029	0.1012	0.1041	0.76	0.583	1.343	0.0022	0.0162	0.0786	0.0948	3.55
05/19/09	1.0	1	0.011	0.0029	0.1010	0.1039	0.57	0.508	1.078	0.0034	0.0147	0.0599	0.0746	3.17
06/02/09	1.0	1	0.010	0.0055	0.0790	0.0845	0.49	0.443	0.933	0.0038	0.0139	0.0548	0.0687	2.47
06/16/09	1.0	1	0.010	0.0011	0.0072	0.0083	0.42	0.475	0.895	0.0029	0.0152	0.0710	0.0862	3.04
06/30/09	1.0	1	0.025	0.0014	0.0012	0.0026	0.70	0.556	1.256	0.0069	0.0152	0.0819	0.0971	3.58
07/16/09	1.0	1	0.011	0.0004	0.0051	0.0055	0.57	0.718	1.288	0.0029	0.0172	0.0876	0.1048	4.74
07/30/09	0.8	1	0.008	0.0005	0.0010	0.0015	0.49	0.828	1.318	0.0032	0.0179	0.0980	0.1159	5.33
08/18/09	1.0	1	0.009	0.0007	0.0015	0.0022	0.56	0.879	1.439	0.0031	0.0163	0.0992	0.1155	5.60
08/31/09	1.0	1	0.007	0.0117	0.1333	0.1450	0.66	0.697	1.357	0.0030	0.0178	0.0863	0.1041	3.88
09/15/09	1.0	1	0.180	0.0101	0.3109	0.3210	1.11	0.337	1.447	0.0081	0.0236	0.0654	0.0890	2.03
09/29/09	1.0	1	0.025	0.0023	0.0283	0.0306	0.48	0.735	1.215	0.0035	0.0139	0.1070	0.1209	4.09
10/28/09	1.0	1	0.094	0.0068	0.2582	0.2650	0.97	0.406	1.376	0.0035	0.0116	0.0594	0.0710	2.21

Table A3. Discrete Continuous Monitoring Data for Chlorophyll-a, Pheophytin, Total Suspended Solids, Volatile Suspended Solids, and Secchi Disk Depth for Otter Point Creek (XJG7035) in 2009.

Date	Sample Depth (m)	Replicate	Chlorophyll-a (ug/L)	Pheophytin (ug/L)	Total Suspended Solids (mg/L)	Volatile Suspended Solids (mg/L)	Secchi Depth (m)
03/31/09	0.5	1	42.720	11.748	64.3	17.1	0.2
03/31/09	0.5	2	39.669	8.925			
04/08/09	0.5	1	55.536	31.933	164.0	28.0	0.1
04/21/09	0.8	1	20.025	6.608	51.2	12.5	0.2
04/21/09	0.8	2	19.357	7.276	46.2	16.3	
05/05/09	0.4	1	9.612	4.592	54.0	22.0	0.2
05/19/09	0.5	1	18.690	8.224	57.0	11.0	0.3
05/19/09	0.5	2	17.622	4.058	30.0	11.0	
06/02/09	0.8	1	16.554	4.753	43.0	13.0	0.2
06/16/09	0.6	1	31.506	7.743	39.0	13.0	0.3
06/16/09	0.6	2	32.574	7.423	33.0	12.0	
06/30/09	0.7	1	33.108	11.374	39.0	11.0	0.3
07/16/09	0.9	1	53.934	2.884	39.0	16.0	0.3
07/30/09	0.1	1	38.982	2.884	29.0	12.0	0.4
07/30/09	0.1	2	37.380	1.121	20.0	11.0	
08/18/09	0.5	1	38.715	6.608	26.3	11.3	0.3
08/18/09	0.5	2	38.048	4.939	25.0	17.5	
08/31/09	0.3	1	36.312	8.544	26.0	10.0	0.3
09/15/09	0.5	1	18.156	1.282	40.0	14.0	0.2
09/29/09	0.4	1	49.128	7.316	29.0	11.0	0.4
09/29/09	0.4	2	38.982	6.622	23.0	10.0	
10/13/09	0.6	1	46.458	8.864	26.0	10.0	0.4
10/28/09	0.7	1	4.450	0.534	59.3	10.0	0.1
10/28/09	0.7	2	5.340	0.000	52.8	10.0	
12/01/09	0.1	1	55.689	7.323	32.9	12.9	
12/01/09	0.1	2	58.740	9.612			
12/14/09	0.2	1					0.2

Table A4. Discrete Continuous Monitoring Data for Chlorophyll-a, Pheophytin, Total Suspended Solids, Volatile Suspended Solids, and Secchi Disk Depth for Church Point (XJG7461) in 2009.

Date	Sample Depth (m)	Replicate	Chlorophyll-a (ug/L)	Pheophytin (ug/L)	Total Suspended Solids (mg/L)	Volatile Suspended Solids (mg/L)	Secchi Depth (m)
03/31/09	1.0	1					0.3
04/08/09	1.0	1	42.720	29.237	81.3	23.8	0.1
04/21/09	1.0	1	25.937	8.773	40.0	15.7	0.3
05/05/09	0.9	1	44.723	25.365	43.8	17.5	0.2
05/19/09	1.0	1	24.030	11.855	30.0	9.0	0.6
06/02/09	1.0	1	15.308	4.877	23.3	7.3	0.5
06/16/09	1.0	1	25.098	11.908	31.0	15.0	0.3
06/30/09	1.0	1	25.632	8.384	33.0	12.0	0.2
06/30/09	1.0	2	24.564				
07/16/09	1.0	1	36.045	5.073	40.0	16.2	0.3
07/30/09	0.8	1	59.408	6.475	37.5	16.3	0.2
08/18/09	1.0	1	45.390	11.054	27.0	14.0	0.3
08/31/09	1.0	1	48.594	13.831	37.0	11.0	0.3
09/15/09	1.0	1	16.020	6.034	42.0	11.0	0.4
09/29/09	1.0	1	49.128	13.297	50.0	13.0	0.4
10/13/09	1.0	1					0.5
10/28/09	1.0	1	28.302	4.966	31.4	9.0	0.4

Table A5. Ambient Water Quality Data for Dissolved Oxygen (D.O.), pH, Salinity, and Water Temperature for Otter Point Creek (XJG7035) in 2009.

Date	Sample Depth (m)	D.O. (mg/L)	pH	Salinity (ppt)	Water Temperature (^oC)
03/31/09	0.5	11.8	8.05	0.49	12.4
04/08/09	0.5	10.5	7.67	0.26	9.6
04/21/09	0.5	8.9	7.15	0.00	12.6
04/21/09	0.8	8.9	7.16	0.00	11.9
05/05/09	0.4	7.1	7.34	0.00	14.2
05/19/09	0.5	7.7	7.23	0.00	15.6
06/02/09	0.5	6.8	7.28	0.00	22.9
06/02/09	0.8	6.9	7.42	0.00	22.8
06/16/09	0.6	7.8	7.60	0.00	24.7
06/30/09	0.7	7.9	8.25	0.00	25.4
07/16/09	0.5	7.0	8.98	0.00	25.9
07/16/09	0.9	7.5	9.20	0.00	25.6
07/30/09	0.1	9.3	8.95	0.00	28.2
08/18/09	0.5	8.0	8.91	0.00	29.5
08/31/09	0.3	6.7	7.22	0.00	23.9
09/15/09	0.5	5.4	6.82	0.00	21.4
09/29/09	0.4	8.6	7.37	0.48	18.6
10/13/09	0.6	11.2	8.39	1.38	15.0
10/28/09	0.7	8.2	7.01	0.00	13.8
12/01/09	0.1	12.4	7.56	0.21	4.8
12/14/09	0.2	12.2	6.92	0.00	2.3

Table A6. Ambient Water Quality Data for Dissolved Oxygen (D.O.), pH, Salinity, and Water Temperature for Church Point (XJG7461) in 2009.

Date	Sample Depth (m)	D.O. (mg/L)	pH	Salinity (ppt)	Water Temperature (^oC)
03/31/09	0.5	11.7	8.15	0.78	10.6
03/31/09	1.0	10.7	7.61	0.84	9.7
03/31/09	1.3	10.0	7.61	0.89	9.6
04/08/09	0.5	10.9	7.81	0.45	9.8
04/08/09	1.0	10.9	7.74	0.46	9.9
04/21/09	0.5	8.5	7.33	0.20	13.0
04/21/09	1.0	8.6	7.27	0.23	13.1
04/21/09	1.4	8.5	7.32	0.25	13.1
05/05/09	0.5	8.3	7.52	0.11	16.2
05/05/09	0.9	8.4	7.54	0.12	16.0
05/19/09	0.5	9.4	8.10	0.00	18.2
05/19/09	1.0	8.4	7.60	0.00	17.2
05/19/09	1.3	8.4	7.75	0.00	17.2
06/02/09	0.5	6.6	7.33	0.08	22.8
06/02/09	1.0	7.0	7.14	0.09	22.5
06/02/09	1.5	6.3	7.33	0.08	22.7
06/16/09	0.5	6.8	7.53	0.00	25.4
06/16/09	1.0	7.0	7.73	0.01	25.3
06/16/09	1.3	6.0	7.37	0.00	25.3
06/30/09	0.5	7.4	7.97	0.00	26.5
06/30/09	1.0	7.5	7.72	0.00	26.1
06/30/09	1.3	6.9	7.74	0.00	26.2
07/16/09	0.5	7.2	8.13	0.02	25.9
07/16/09	1.0	7.9	8.18	0.08	25.6
07/16/09	1.4	6.7	7.97	0.02	25.7
07/30/09	0.5	6.8	8.20	0.01	27.7
07/30/09	0.8	7.1	8.19	0.05	27.0
08/18/09	0.5	7.4	8.50	0.08	29.6
08/18/09	1.0	8.5	8.50	0.09	29.8
08/18/09	1.4	5.9	7.71	0.07	29.0
08/31/09	0.5	6.6	7.35	0.00	24.3
08/31/09	1.0	6.8	7.22	0.00	24.3
09/15/09	0.5	4.6	6.87	0.00	21.1
09/15/09	1.0	3.5	6.78	0.00	20.6
09/15/09	1.3	3.1	6.82	0.00	20.5
09/29/09	0.5	7.6	7.32	1.26	19.5
09/29/09	1.0	7.6	7.65	1.26	19.5
09/29/09	1.3	7.6	7.30	1.26	19.4
10/13/09	0.5	9.9	8.02	1.75	15.6
10/13/09	1.0	9.5	7.61	1.85	15.7
10/28/09	0.5	7.4	7.11	1.62	14.6
10/28/09	1.0	7.2	6.87	1.67	14.6
10/28/09	1.3	7.7	7.15	2.02	14.7