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Rock Creek 2015 Water Quality Monitoring Results

Prepared for

Anne Arundel County Department of Public Works

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Introduction

Background

Rock Creek, a tributary of the Patapsco River, is a 270-acre tidal estuary in Anne Arundel County, Maryland (Figure 1). Rock Creek has experienced water quality problems over the past 35 years that are typical of many small, poorly flushed tidal waterways. Historic water quality problems were characterized by periodic summer fish and crab kills, noxious hydrogen sulfide odors, and depletion of water column dissolved oxygen. Numerous studies have been conducted to identify the major sources of pollution and determine the physical, chemical, and biological processes governing water quality in Rock Creek. In general, the studies attributed the poor water quality conditions to nutrient enrichment and organic sediments from a variety of sources, including primarily tidal exchange with the Patapsco River and watershed stormwater runoff (Gucinki and Bird, 1982; Steinfort and Beatty, 1987; Dames & Moore, 1988). Since more than half of the nutrients were found to have entered the estuary from the Patapsco River, it was hypothesized that not even a total cleanup of Rock Creek and its watershed would eliminate the most significant cause of the water quality problem (Schmidt, 1995; CH2M HILL, 2011a, 2011b).

It should be noted that other water quality issues may be present in Rock Creek, such as high bacteria contamination or sediment loads. These are not the focus of the current study.

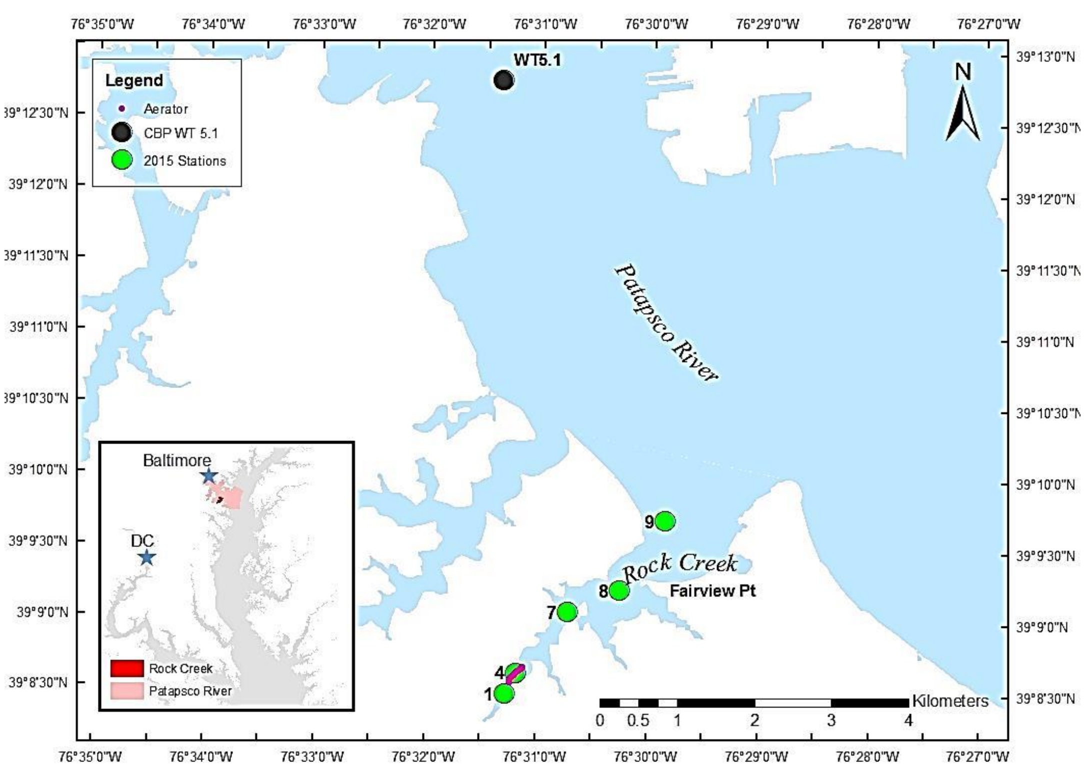


Figure 1. Rock Creek map and station locations for 2015 monitoring.

Water Quality Over Time

Water Quality Improvements Implemented by Anne Arundel County

Anne Arundel County has implemented a variety of water quality improvement measures, including (1) constructing an aeration system (1988–1989), (2) installing a series of check dams on the main tributary stream to prevent watershed sediments from entering the estuary (1990–1992) and (3) dredging organic-rich sediments from the head of the creek and Wall Cove (1991–1992) (Dames & Moore, 1988, 1990; Curtis, 1994).

Aeration System in Rock Creek

In October 1988 the Anne Arundel County Department of Public Works (DPW) installed an aeration system in Rock Creek to mitigate low dissolved oxygen (DO). The aeration system, installed above Whites Cove and Wall Cove, consists of 2,700 feet of diffuser pipe connected to two 30-horsepower (hp) blowers that put out 550 standard cubic feet per minute (scfm) of air (Figure 1). The aerators have suffered from significant operational difficulties, including sedimentation that disrupts air flow from diffusers, and boat anchors that pull up the aerator piping. The aeration system was refurbished in 1998 in response to damage to the air distribution laterals caused by boat anchors. Efforts are underway now for a re-design and new installation to repair the aeration system.

Post-aeration and dredging studies indicated that an improvement in water quality has occurred since the remediation projects were undertaken; however, performance data are relatively sparse, so a direct cause-and-effect relationship has been difficult to fully verify or quantify due to annual variations in rainfall and other variables (Dames & Moore, 1990; Curtis and Etzel, 1990; Curtis, 1993; Schmidt, 1995).

Water Quality Characterization in 2011 and 2012

In 2011, CH2M HILL conducted a water quality assessment study based on available data and evaluated the aeration system (CH2M HILL 2011a, 2011b). That study concluded that substantial improvements in the water quality and biological communities have occurred in the last 20 years; however, the overall health of Rock Creek can be characterized as partially degraded and water quality standards are not being met, particularly without the aeration system in operation. The nutrient and organic load, including inputs from the Patapsco, produce DO conditions below standards. The oxygen stress also prevents Rock Creek from meeting the designated use of suitable habitat for fish and other estuarine biota.

In addition, the 2011 study recommended that a monitoring study be conducted to determine whether conditions have improved to the point where continuous (both 24 hours a day and 7 days a week) aeration is still necessary. Anne Arundel County retained CH2M HILL and the University of Maryland's Center for Environmental Sciences (UMCES) at Chesapeake Biological Laboratory (CBL) to conduct an extensive monitoring study during the summer of 2012 to evaluate water quality conditions in Rock Creek and the effectiveness of the current aeration system. In 2012, twelve stations were established within and at the boundaries of the system, with periodic water column measurements taken at the surface and 0.5m depth intervals to the bottom. In addition a continuous recording device was located in the aeration zone and monitored dissolved oxygen throughout the study period. Nutrients (nitrogen and phosphorus) were also monitored on a less frequent basis because CH2M Hill (2011a) concluded that elevated nutrients were causing excessive algal growth which in-turn lowered dissolved oxygen concentrations. The 2012 Rock Creek aeration study was conducted in three phases: 1) base line monitoring with aerators on; 27 June to 10 July; 2) experimental period with aerators off; 10 July to 19 July; and 3) recovery period with aerators on again; 19 July to 2 August.

Baseline conditions with aerators on were associated with oxygenated bottom water that with concentrations above hypoxic or anoxic criteria (5 or 2 mg dissolved oxygen/L). By the end of the experimental period (9 days), the dissolved oxygen was less than 2 mg/L throughout the water column. Hydrogen sulfide was also indicated in the water column, increased as the experimental phase progressed, and by the end of the experimental period there was a noticeable hydrogen sulfide odor in portions of the creek. When the aeration system was restarted, there was rapid recovery of dissolved oxygen concentrations; the system was de-stratified as soon as the system was turned on. Hydrogen sulfide odors also dissipated rapidly. Within a day of restarting the aeration system conditions approached baseline conditions, with dissolved oxygen concentrations above 3 mg/l at all but one station. These results were reported to the public and published in the peer-review literature (Harris et al. 2014). Based on the results of the study, it was apparent that supplemental aeration could still be useful in the Rock Creek system to ameliorate poor water quality conditions.

Purpose of 2015 Monitoring Study

Ultimately, managers working in tributaries like Rock Creek need information that contributes to predicting restoration trajectories related to actions taken as part of the Total Maximum Daily Loads set for the Chesapeake Bay. Understanding the services provided by large scale aeration are of interest in these efforts because non-linear feedbacks affecting the biogeochemistry of these estuaries are affected by whether bottom waters are hypoxic (<2 mg dissolved oxygen/L) or normoxic (at concentrations expected for a given temperature and salinity). In 2015, we carried out a simple monitoring program directed towards quantifying the services provided by aeration while also adding information that may be used by collaborating engineers to optimize re-design of a new system. This monitoring will also inform our understanding of the impact of tidal waters entering from the Patapsco to Rock Creek. In addition to this limited monitoring, we also engaged in outreach to the Restore Rock Creek community and simple analytical efforts of long-term datasets that may be used to inform aerator design decision.

Methods

Overview

Hypoxic (low oxygen) or anoxic (no oxygen) conditions can develop as the result of eutrophication in estuarine systems, where excess carbon production from nutrient-induced phytoplankton blooms fall to the bottom of the water column to decompose. Microbial respiration produced during this decay process leads to consumption of dissolved oxygen, depleting bottom waters. During the summer months when temperatures are high, the decreased capacity of the water for dissolved oxygen can combine with stratification of the water column to reduce mixing and replenishment with the atmosphere, increasing the likelihood for hypoxic or anoxic conditions. Because microbes in these ecosystems have the capacity to use alternate electron receptors for respiration, microbial activity can continue under anoxic conditions, but may include consumption of sulfate and the production of hydrogen sulfide, a byproduct of sulfate reduction that can produce strong odors. Low dissolved oxygen availability to the sediments may also inhibit denitrification while leading to a release of ammonium and orthophosphate from the sediments to the overlying water column (Rozan et al. 2002). As described in the background information above, Anne Arundel County is engaging with an engineering firm to re-design the aeration system that has been in place since the 1980s. This simple monitoring program took place between June and November of 2015 to maintain some understanding of how the ecosystem functions before re-design is complete and a new system or alternative design is implemented. We also investigated historic water quality datasets from the adjacent Patapsco system to evaluate whether this region is generally nitrogen or phosphorus limited.

Sample Locations, Investigations, and Frequency

Locations

Figure 1 illustrates the locations of the monitoring stations in Rock Creek and the adjacent Patapsco estuary. Several of these stations were visited for a series of water quality studies carried out between 1990 and 1993 in Rock Creek, and all stations in Figure 1 (stations 1, 4, 7, 8, and 9) overlap with the stations sampled in 2012 . This area defines the boundaries of the monitoring program for 2015, and the five stations that were the focus for sample collection. It was important to keep some consistency in sampling among years when water quality monitoring has been carried out to enable comparisons. Including a station in the Patapsco (Station 9) helps to define the inputs and exports between Rock Creek and its adjacent estuary.

Sampling

Field efforts were carried out monthly in June, July, August, September, and November of 2015 (5x). A list of sample site locations is provided in Table 1. At each of the five sampling stations, measurements of depth, dissolved oxygen, temperature, salinity, conductivity, and pH were executed along a vertical profile at 0.5 m intervals using an appropriately calibrated YSI 6600 sonde. Light attenuation at each station was evaluated using either an estuarine Secchi disk or determination of the light attenuation coefficient (kd) by measurement of surface and bottom irradiance using LiCOR PAR sensors. Station locations were logged with GPS and meteorological data were recorded from a nearby weather station to provide a record of weather conditions.

To document nutrient conditions, grab samples were collected at each station at surface and bottom for all stations sampled. Grab samples were processed and analyzed for concentrations of nitrate, nitrite, ammonium, total dissolved nitrogen, total phosphorus, orthophosphate, particulate nitrogen, particulate carbon and phosphorus, chlorophyll-a, and phaeophytin. These chemical and biological parameters are important for determining the potential for primary production, nutrient limitation, and standing stock phytoplankton biomass. All samples were collected and processed according to quality control protocols specified by the CBL Nutrient Analytical Services Laboratory (NASL).

Grab samples were collected in opaque, acid-washed, polypropylene containers. Field sampling and processing protocols were adapted for this project to reflect standard operating procedures (SOP) and provide quality control. These SOPs describe sample storage, holding times, sample processing, labeling procedures, sample custody, and datasheet use. Analytical quality control for nutrients, chlorophyll-a, and phaeophytin are available from NASL and follow currently approved protocols for the Chesapeake Bay Program. A detailed methods list is presented in Table 2 and SOPs are included in Appendix A.

Table 1. 2015 sampling station locations and site descriptions.

Station	latitude	longitude	Description	no. of sampling events in 2015
1	39.14150	-76.5208	Up-creek from active aeration zone	5
4	39.14379	-76.5193	Mid-channel & directly in the aeration zone	5
7	39.15101	-76.5117	Area where the creek widens, across from Long Cove & mid channel from a boat fueling station	5
8	39.15363	-76.5039	Mid-channel & outside Wall Cove, Woodland Beach & the Maryland Yacht Club	5
9	39.16204	-76.4968	Past the mouth of the creek in Patapsco River	4*

** not sampled in November due to small craft advisory conditions*

Due to inclement weather conditions, samples and measurements were not collected at Station 9 during the November 2015 ,monitoring cruise. We substitute data from the Chesapeake Bay Program's long term monitoring station at WT5.1 in the Patapsco (see Figure 1) for this date only.

Table 2. Grab sample parameters, method references, and method detection limits (MDL).

Analytical Parameter	Abbreviation of Analyte	Method Used	Method Detection Limit
Ammonium	NH4	EPA Method 350.2	0.001 mg NH4-N/L
Nitrate-Nitrite	NO3+NO2	EPA Method 353.2	0.0007 mg NO3+NO2-N/L
Nitrite	NO2	EPA Method 353.2	0.0007 mg NO2-N/L
Total dissolved Nitrogen	TDN	EPA Method 353.2	0.05 mg TDN as NO3-N/L
Particulate Nitrogen	PN	EPA Method 440.0	0.0105 mg N/L
ortho-Phosphate	DIP or PO4	EPA Method 365.1	0.0006 mg PO4-P/L
Total dissolved Phosphorus	TDP	EPA Method 365.1	0.0015 mg TDP as PO4-P/L
Particulate Phosphorus	PP	EPA Method 365.1	0.0021 mg P/L
Particulate Carbon	PC	EPA Method 440.0	0.0633 mg C/L
Chlorophyll-a	Chlor-a	EPA Method 445.0	0.21 µg/L total chlor-α
Active Chlorophyll (corrected)	active Chlor-a	EPA Method 445.0	0.18 µg/L active chlor-α
Phaeophytin	Phaeo	EPA Method 445.0	0.09 µg/L phaeophytin
Sources: http://nasl.cbl.umces.edu/methods/WCC.html			
http://nasl.cbl.umces.edu/methods/PS.html			

Investigations

In addition to collecting and analyzing the field samples, we provide graphs of the datasets over the course of this summer monitoring, comparisons with the 2012 study, and basic interpretations. We also performed a simple analysis of nitrogen (N) and phosphorus (P) concentrations at the long-term fixed monitoring station in the Patapsco (WT5.1) that is administered by the Chesapeake Bay Program. Interest was expressed in understanding whether and when Rock Creek is N or P limited. Nutrient limitation for N and P is evaluated by computing a ratio constrained by the stoichiometry of photosynthesis for phytoplankton, where ratios below 16:1 indicate N limitation, and those above indicate P limitation.

Results

Meteorological Conditions

Meteorological data collected at the Fairview weather station (KMDPASAD9) in Pasadena, MD are reported in Table 3 for the days when Rock Creek field cruises occurred. In general the summer temperatures were hot, and some rain events occurred on sampling days. Figure 2 puts the precipitation data in the context of longer term daily averages.

Table 3 Meteorological Data for Pasadena, MD using station KMDPASAD9.SOURCE: https://www.wunderground.com/personal-weather-station/dashboard?ID=KMDPASAD9#history/s20150622/e20150622/mdaily

Date	Time (EDT)	Air Temp.	Dew Point	Humidity	Wind Direction	Wind Speed	Pressure	Previous Day Total Precipitation	Daily Total Precipitation	Monthly Accumulated Precipitation	Conditions
6/22/2015	10:59 AM	85.5 °F	71.5 °F	63 %	WNW	0-6 mph	30.02 in Hg	0.04 in	0.00 in	7.15 in	Sunny. Clear skies.
7/6/2015	10:59 AM	79.5 °F	76 °F	89 %	SE	2-11 mph	30.10 in Hg	0.00 in	0.21 in	11.0 in	Overcast.
8/11/2015	10:59 AM	77.7 °F	75.2 °F	92 %	SW	9 mph	29.79 in Hg	0.22 in	0.37 in	2.42 in	Overcast. Rainy.
9/1/2015	10:59 AM	84 °F	75.2 °F	75 %	NNE	0-5 mph	30.06 in Hg	0.00 in	0.00 in	4.39 in	Sunny. Clear skies.
11/30/2015	11:10 AM	40.8 °F	35.1 °F	80 %	NE	2-8 mph	30.36 in Hg	0.37 in	0.08 in	3.05 in	Overcast. Choppy water.

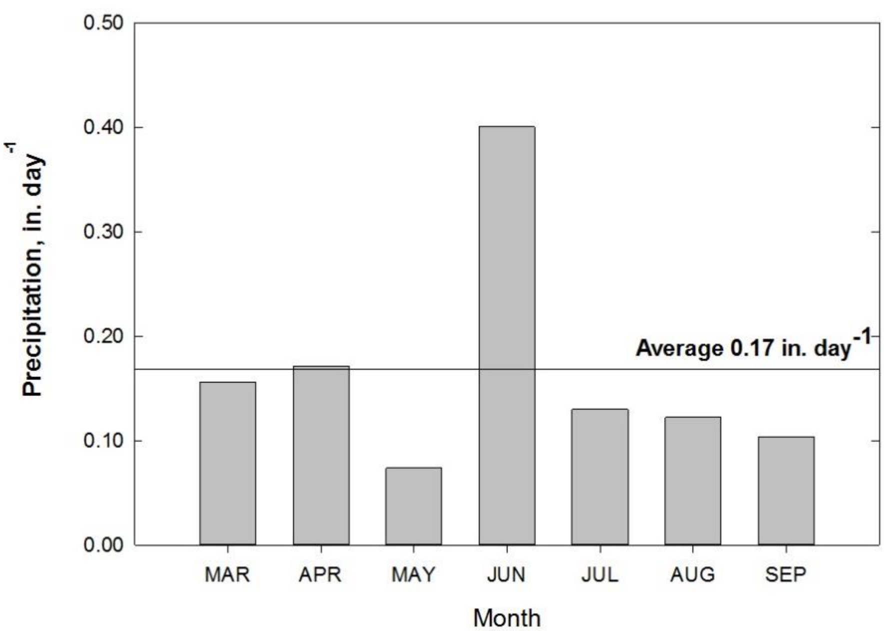


Figure 2. Monthly average precipitation compared to long term averages.

Dissolved Oxygen

Dissolved oxygen (DO) concentrations measured as part of the water column vertical profiles were interpolated to provide isopleths that estimate gradients of DO with distance from Station 1 out to Station 9 in the Patapsco. We provide these interpolations in Figures 3a and b. Generally speaking, low bottom water DO concentrations were documented from June through September. The field crew observed no visible signs of aeration near stations 1 and 4 during the August 2015 and November 2015 sampling cruise dates. The lack of aeration in combination with the summer conditions in August may have contributed to hypoxic conditions observed throughout much of the water column that day. These interpolations and the bottom water DO data suggest that the aerator system may not be operating as well as it did in 2012.

The isopleth interpolated from November of 2015, when the aerators were not operating, shows high oxygen concentrations throughout the water column at all stations (1,4,7, and 8). All of the stations experienced >10 mg/L dissolved oxygen, with the highest dissolved oxygen around 14 mg/L near the surface of the water column. This is not unusual, as meteorological conditions (cooler air temperatures, more wind) combine with lower nutrient availability to lower water column productivity and improve atmospheric aeration of the water column.

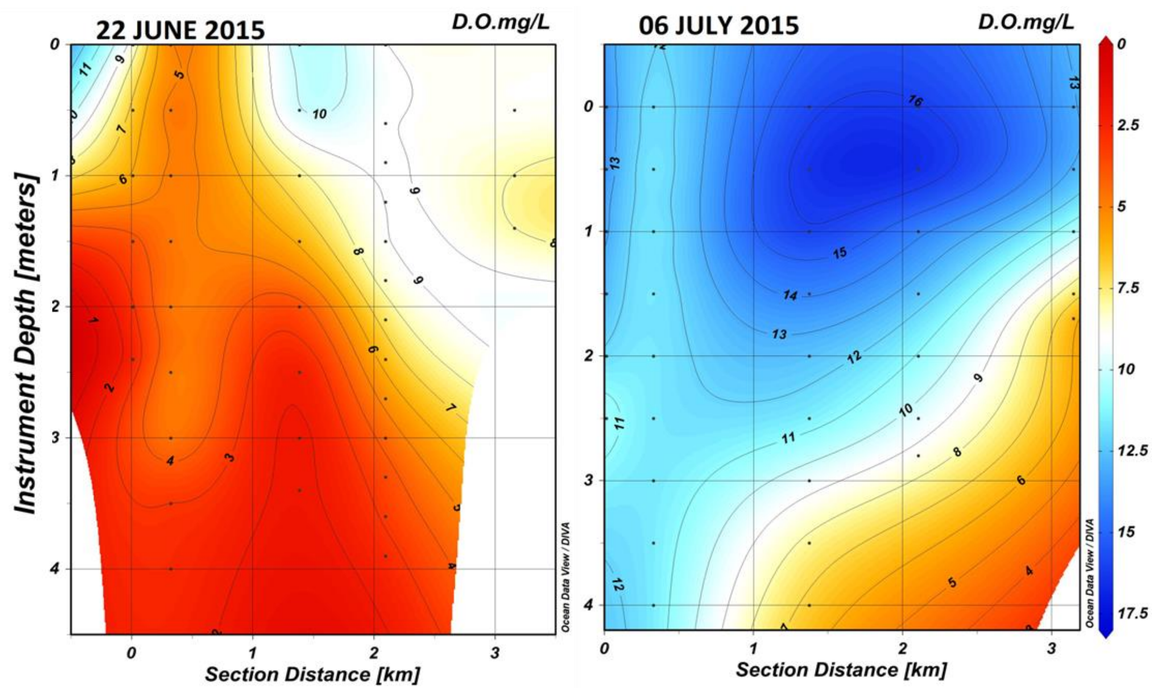
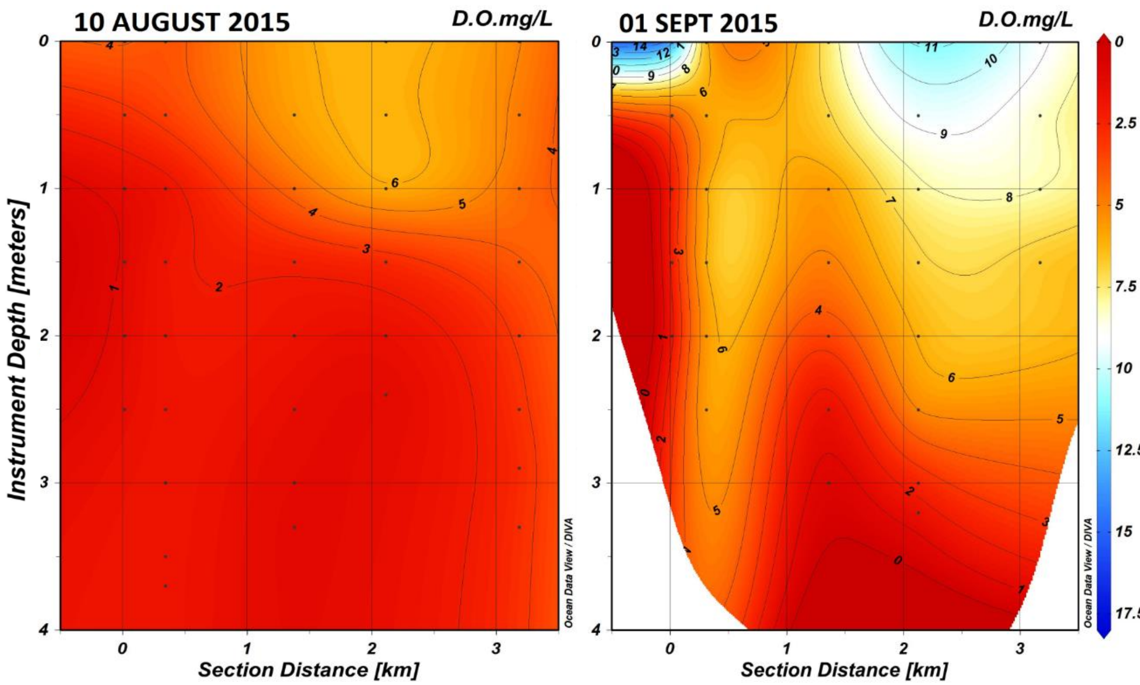


Figure 3a. Interpolated water column isopleths of dissolved oxygen from sampling dates. Isopleths are oriented from station 1 (left side of graph) out to the Patapsco River (right side



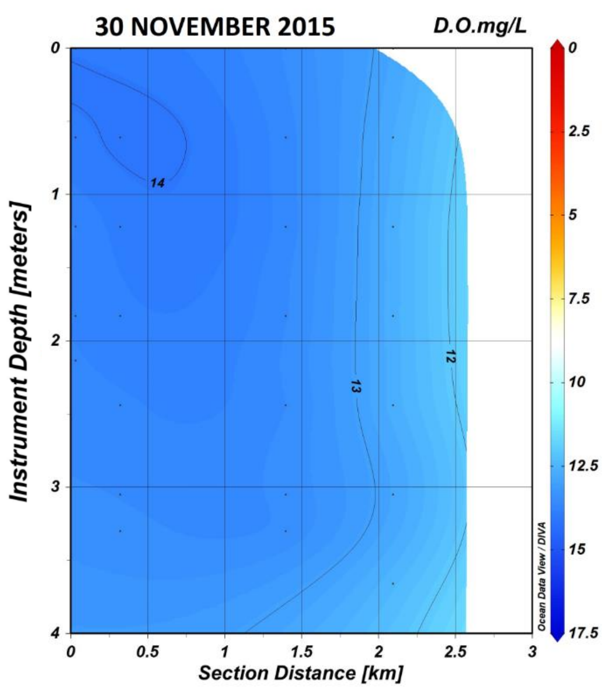


Figure 3b. Interpolated water column isopleths of dissolved oxygen from sampling dates. Isopleths are oriented from station 1 (left side of graph) out to the Patapsco River (right side). Note the 30 November plot does not extend to station 9 since conditions did not allow for us to sample that station.

Water Temperature and Salinity

Bottom water temperature over the course of the June through September sampling dates was consistent, ranging from 24-27° C. November temperatures ranged from 9.1-10.3°C. Salinity values were more variable, with fresher conditions present during the summer than the fall. Graphs of bottom water conditions are presented in Figures 4a and 4b. It is possible that the lower salinity values recorded in July were associated with rain events during that time period. Isopleths were computed for temperature (Figure 5) and salinity (Figure 6) to provide a better s visual of the water column during 2015. Note that the water temperatures are much more homogenous with depth than salinity values.

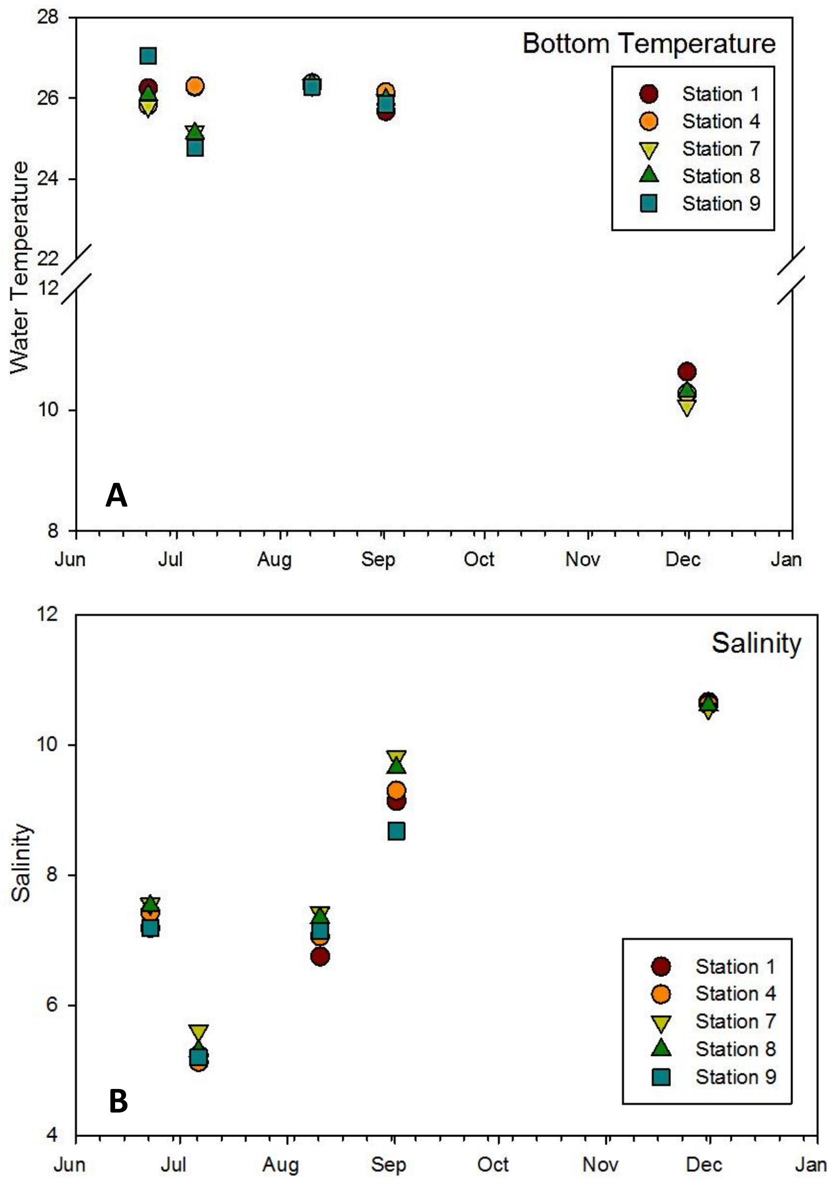
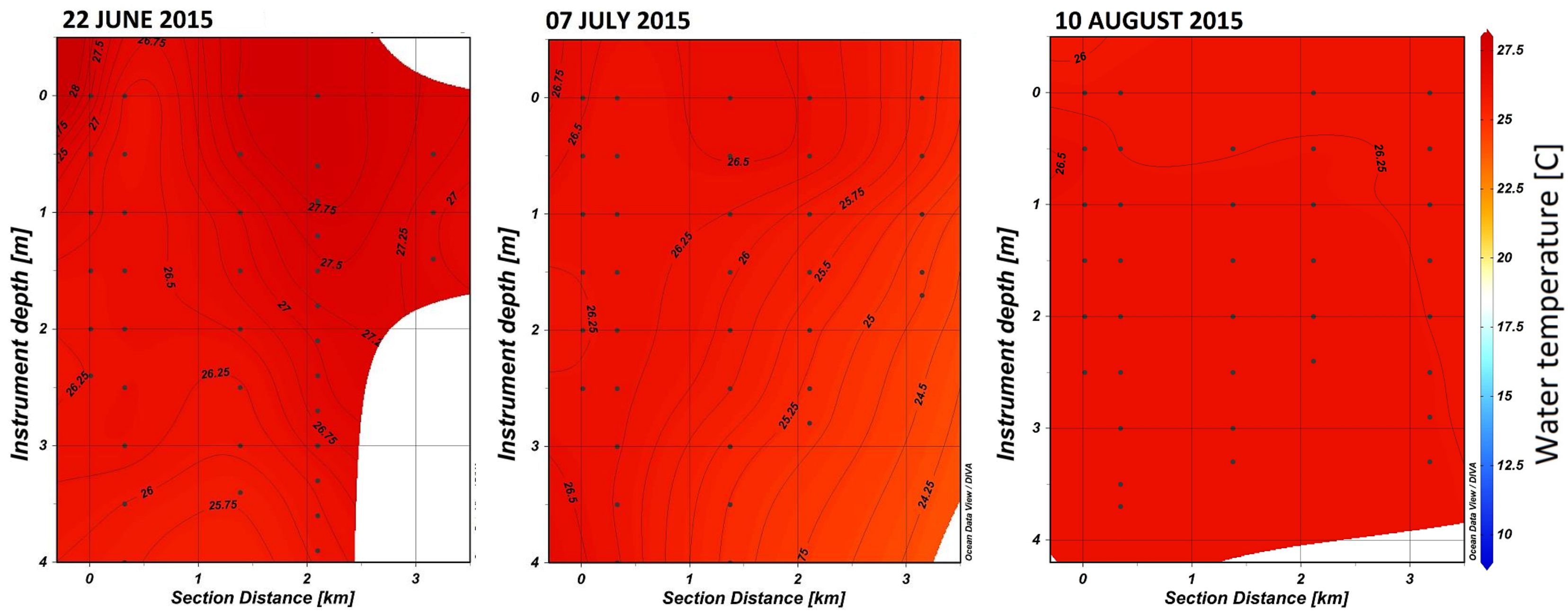
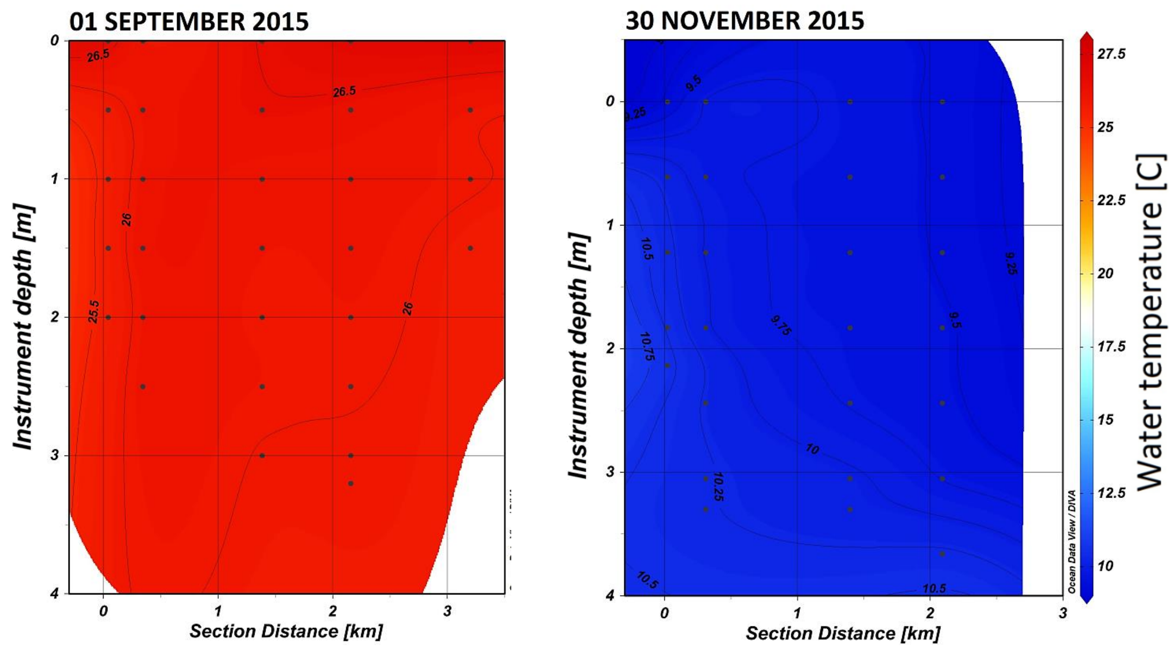
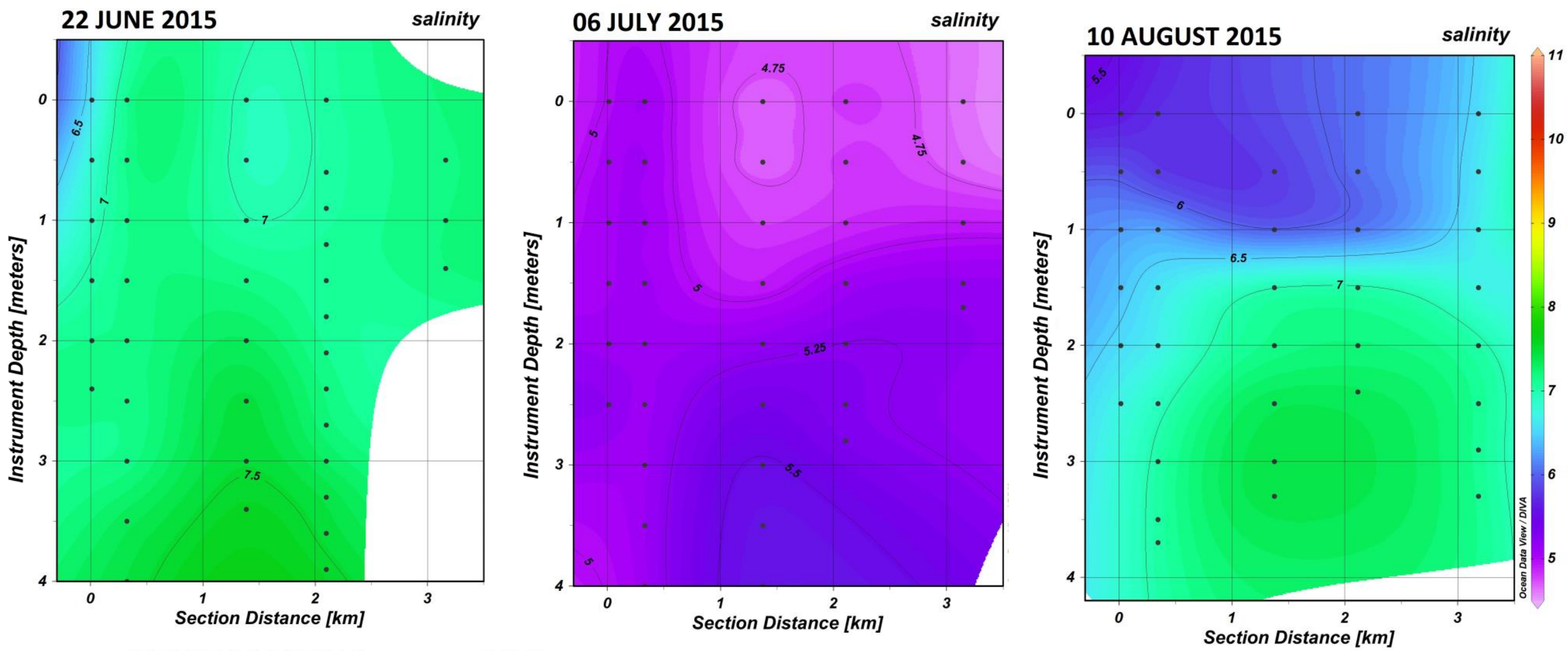


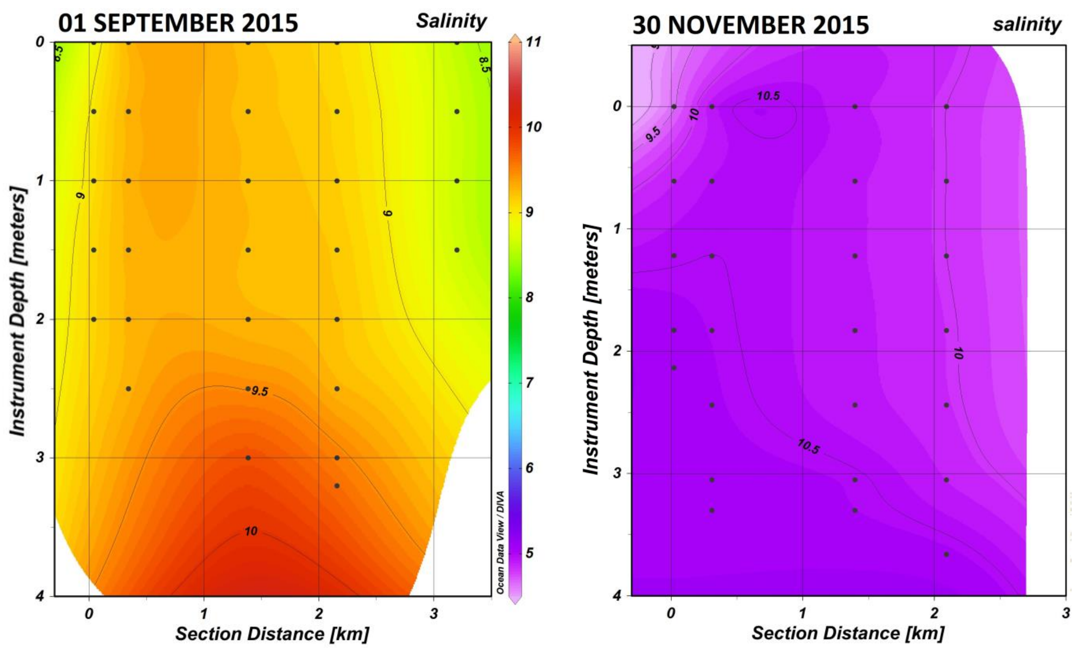
***Figure 4a & 4b**. Bottom water temperature, Celcius, and bottom salinity conditions during 2015 sampling.*





Figures 5. Interpolated water Column isopleths of water temperature for sampling dates. Isopleths are oriented from station 1 (left side of graph) out to the Patapsco River (right side). Note the 30 November plot does not extend to station 9 since conditions did not allow for us to sample that station.





Figures 6. Interpolated water column isopleths of salinity profiles for sampling dates. Isopleths are oriented from station 1 (left side of graph) out to the Patapsco River (right side). Note the 30 November plot does not extend to station 9 since conditions did not allow for us to sample that station.

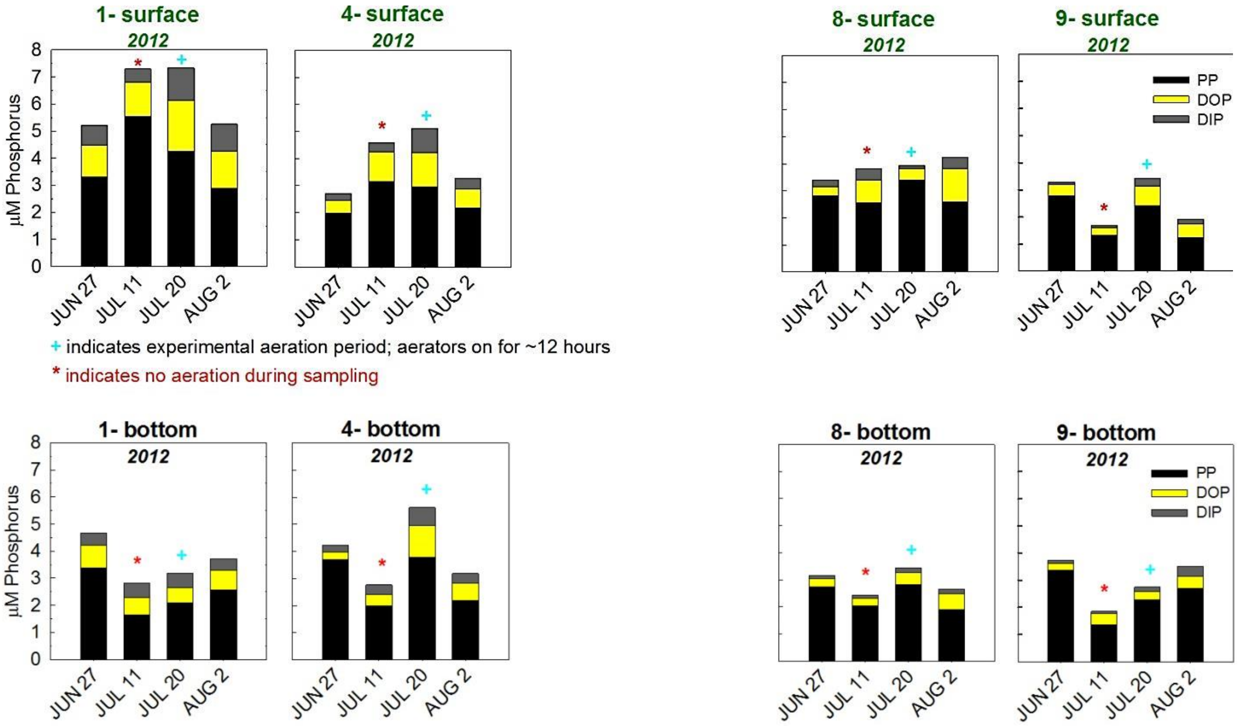
Nutrient Grab Samples

Phosphorus

Nitrogen and phosphorus concentrations were analyzed for both the dissolved forms (nitrate, nitrite, ammonium, orthophosphate, organics) as well as particulate components. These data are compared to the data collected during the 2012 Rock Creek estuary study (Figures 5 and 6).

We first discuss the phosphorus (P) data presented in Harris et al. (2015) and collected over the course of the 2012 aeration system experimental shutoffs. Concentrations in the 2012 mid-summer time period for P were consistently below 6 µM. This contrasts with the generally higher values measured in 2015 for phosphorus that are presented in the second two rows of Figure 5. Please note the difference in scale bars between the surface values at station 1 in 2015 and the rest of the plots. Clearly, station 1 had particularly high P concentrations. Across the stations, phosphorus was dominated by the particulate form, with notable high dissolved organic P measured during the September cruise. There appears to be a pattern of declining concentrations with distance from the aerators.

2012 Experimental Monitoring Data



2015 Monitoring Data

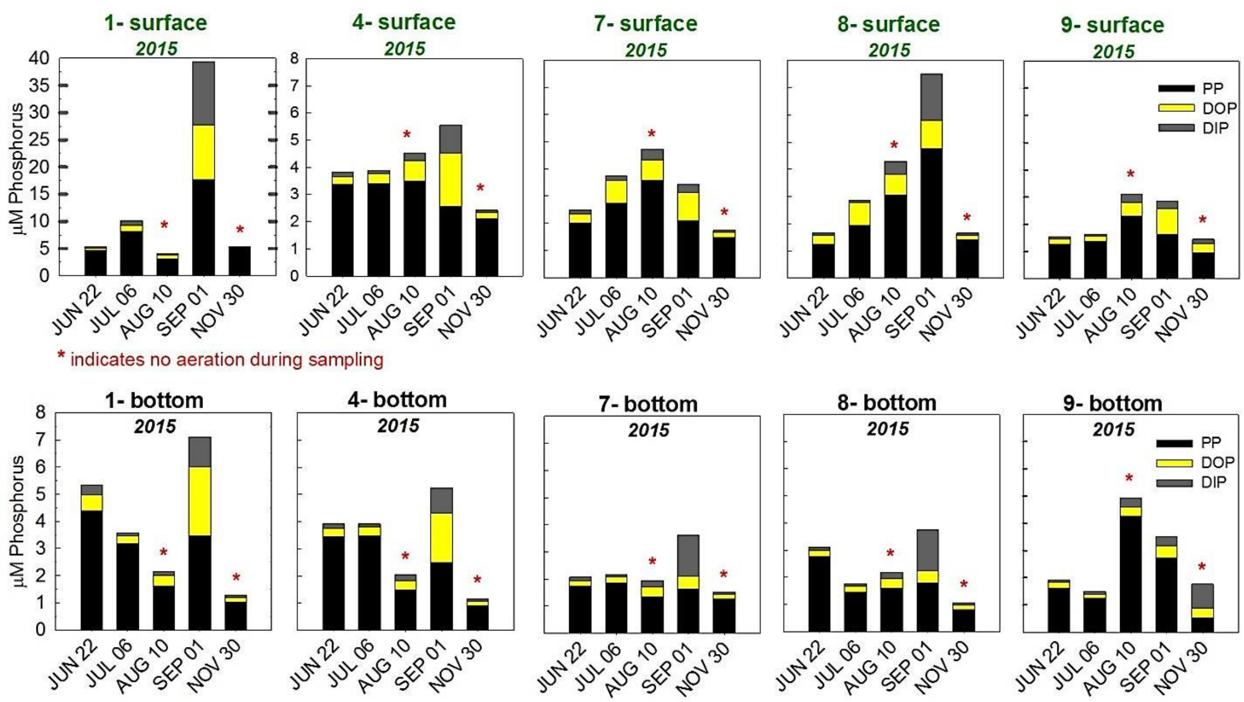


Figure 5. Phosphorus concentrations from 2015 (lower two rows) in comparison to 2012 bottom water concentrations. Note difference in scale for station 1 surface water in 2015.

Nitrogen

Our data are presented similarly for nitrogen in Figure 6. Compared with the bottom water measurements taken in mid-summer of 2012, bottom water nitrogen concentrations were lower in 2015 apart from samples collected at station 1 in September. However, the gradient of high values near the aerators and lower concentrations in the Patapsco was preserved. Dissolved organic N and particulate N form a large portion of the nitrogen pool, indicative of a biologically active system. A greater proportion of N is inorganic in November at the stations closer to the Patapsco.

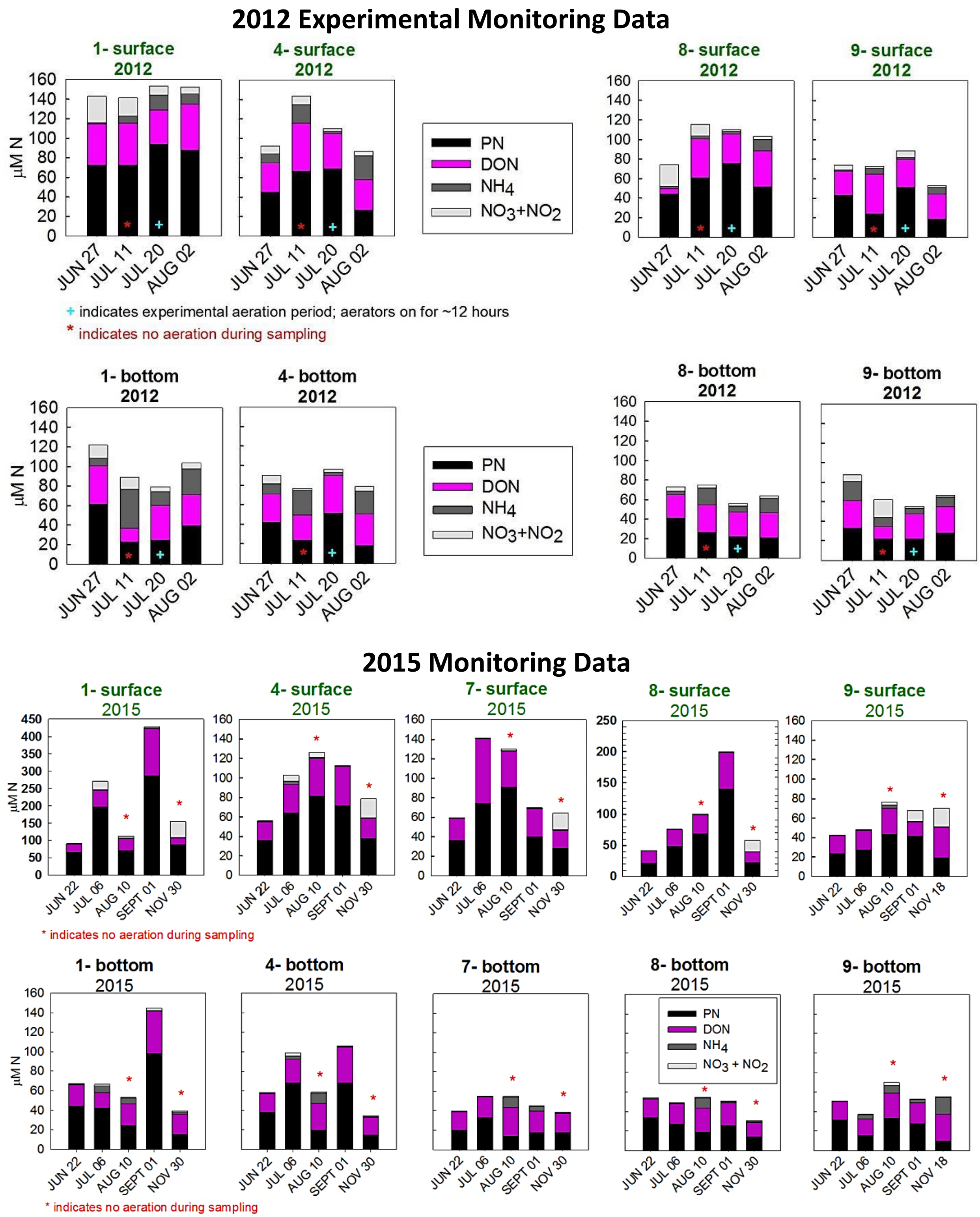
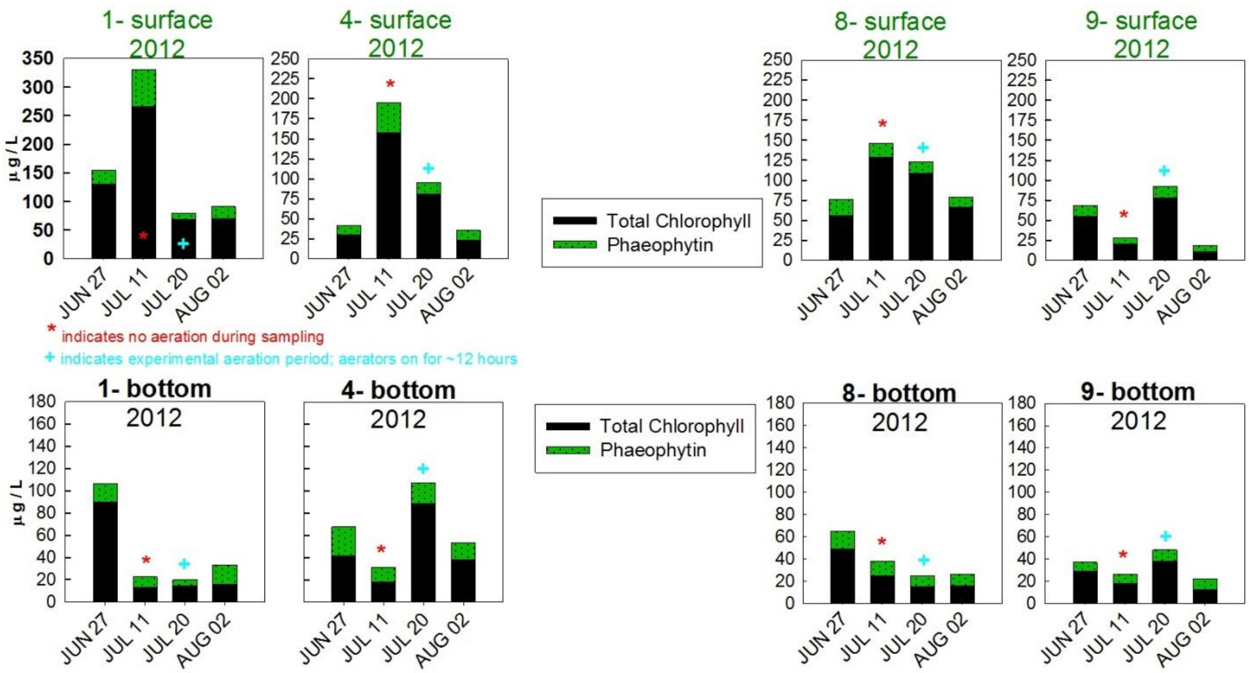


Figure 6. Nitrogen concentrations from 2015 (lower two rows) in comparison to 2012 (upper row) bottom water concentrations

Chlorophyll-a and Phaeophytin

We measured chlorophyll-a concentrations along with phaeophytin as indicators of phytoplankton biomass. Phaeophytin is linked with dead phytoplankton cells. Concentrations of these pigments were astonishingly high at station 1, especially in September. With organic N and P, as well as particulate nutrients quite high at this station in September, it is likelyr that the cruise on that date captured a significant phytoplankton bloom event. The aerators were on during sampling, and so this finding is a bit surprising. However, phytoplankton biomass was also high at station 8, and it is possible that hydrodynamic forces impacted the bloom dynamics. As we might expect, pigment concentrations were low in late November, coinciding with cooler temperatures and less daylight hours. Concentrations of greater than 20 $\mu g\ L^{-1}$ indicate the presence of an algal bloom, so an important takeaway from 2015 monitoring was the consistent presence of phytoplankton blooms, punctuated by extreme events that are truly remarkable concentrations (near 1000 µg / L in September). These values were typically higher than those measured in 2012, where surface water total chlorophyll-a ranged from 11 to 470 $\mu g\ L^{-1}$ and bottom water total chlorophyll-a ranged from 12 to 89 $\mu g\ L^{-1}$..

2012 Experimental Monitoring Data



2015 Monitoring Data

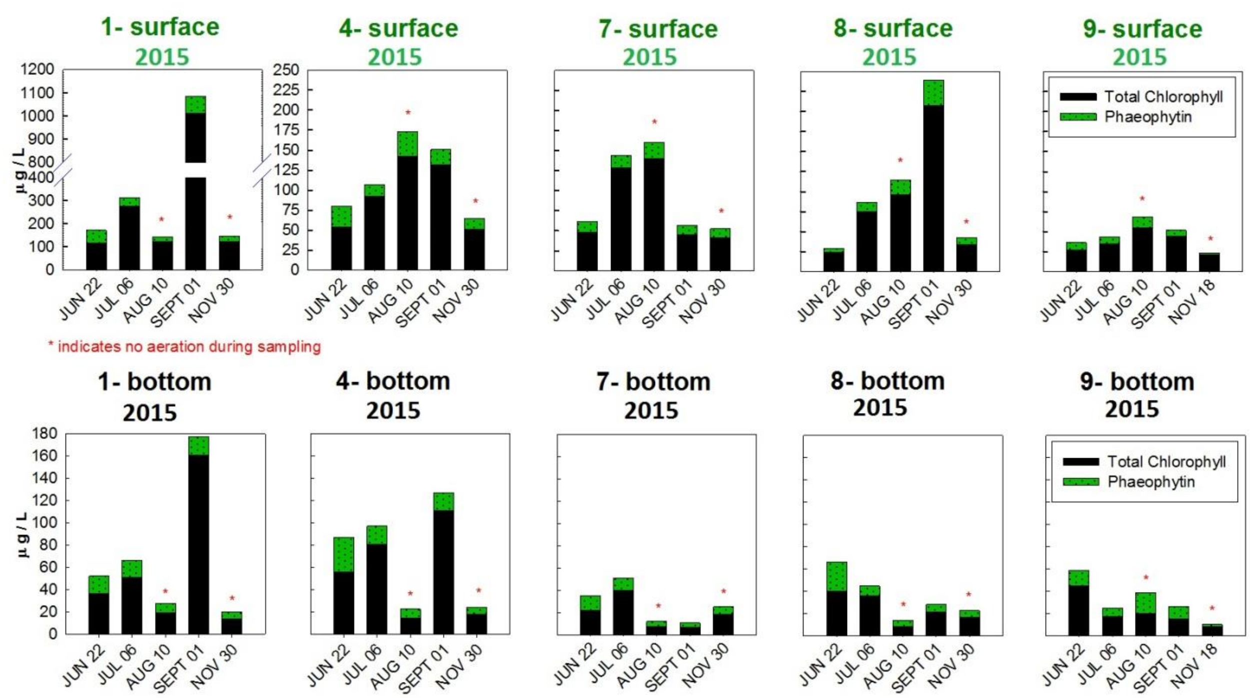


Figure 7 Chlorophyll-a and phaeophytin concentrations from 2015 (lower two rows) in comparison to 2012 (upper row) bottom water concentrations

Nutrient Limitation

Questions regarding which nutrient is generally limiting in Rock Creek have been raised in order to better inform management strategies. We pulled data from the long term monitoring station in the Patapsco (WT 5.1), where measurements of dissolved inorganic nutrients have been taken since the 1980s. Measurements were converted to molar units and stoichiometric ratios of dissolved N and P were computed over the course of the time series. Redfield (1934) used the stoichiometric relationships of photosynthesis to provide thresholds for phytoplankton N and P demand in a ratio of 16:1. Values below 16 indicate N-limitation, and those above are P-limited. The exception to this is in estuaries where nutrients are in such abundant supply that dissolved inorganic N and P concentrations exceed phytoplankton half saturation constants describing uptake rates. In other words, when nutrients are present in concentrations higher than what can be used by phytoplankton given limits on uptake kinetics. In the Chesapeake Bay these half saturation constants are typically set at ~0.5 µM L^{-1} for N and 0.1 µM L^{-1} for P as representative of common phytoplankton species (Malone et al. 1996).

Several management actions took place during the period when measurements were collected from the 1980s through 2015. In particular, regulations required upgrades at wastewater treatment plants the required removal of P (1985), implementation of secondary treatment, caps on point source inputs, and advanced wastewater treatment that includes biological nitrogen reduction (BNR). We present the entire dataset first (Figure 8a), and then provide a series of plots showing changes in ratios associated with these upgrades (8b-8f). Generally speaking, the system is P limited, except in the late summer and early fall months (July, August, September). Overall, 32% of the concentrations measured at station WT5.1 represent DIN:DIP ratios less than 16. A histogram pictured in Figure 9 shows the distribution of values, where DIN-DIP ratios are binned into ranges indicated on the x-axis and frequency of those measured values is on the y-axis. When examining the concentrations associated with these ratios, it is clear that actual nutrient limitation by either N or P is extremely rare in the Patapsco. Only 19 measured values for dissolved inorganic nitrogen were less than the ~0.5 µM L^{-1} threshold that would limit phytoplankton uptake rates (less than 3%). Just 12% of the measured orthophosphate values indicated true P limitation where values were less than 0.1 µM L^{-1} P.

We also show ratios of DIN-DIP for values available from 2012 and 2015 in Figure 9. N limitation was more commonly measured in 2015 than in 2012 and there may be some indication that ratios decrease closer to the Patapsco. Nitrogen was always available in abundant supply in Rock Creek (concentrations above the half saturation threshold). However, phosphorus values were occasionally slightly below 0.1 µM L^{-1} P (30% of samples).

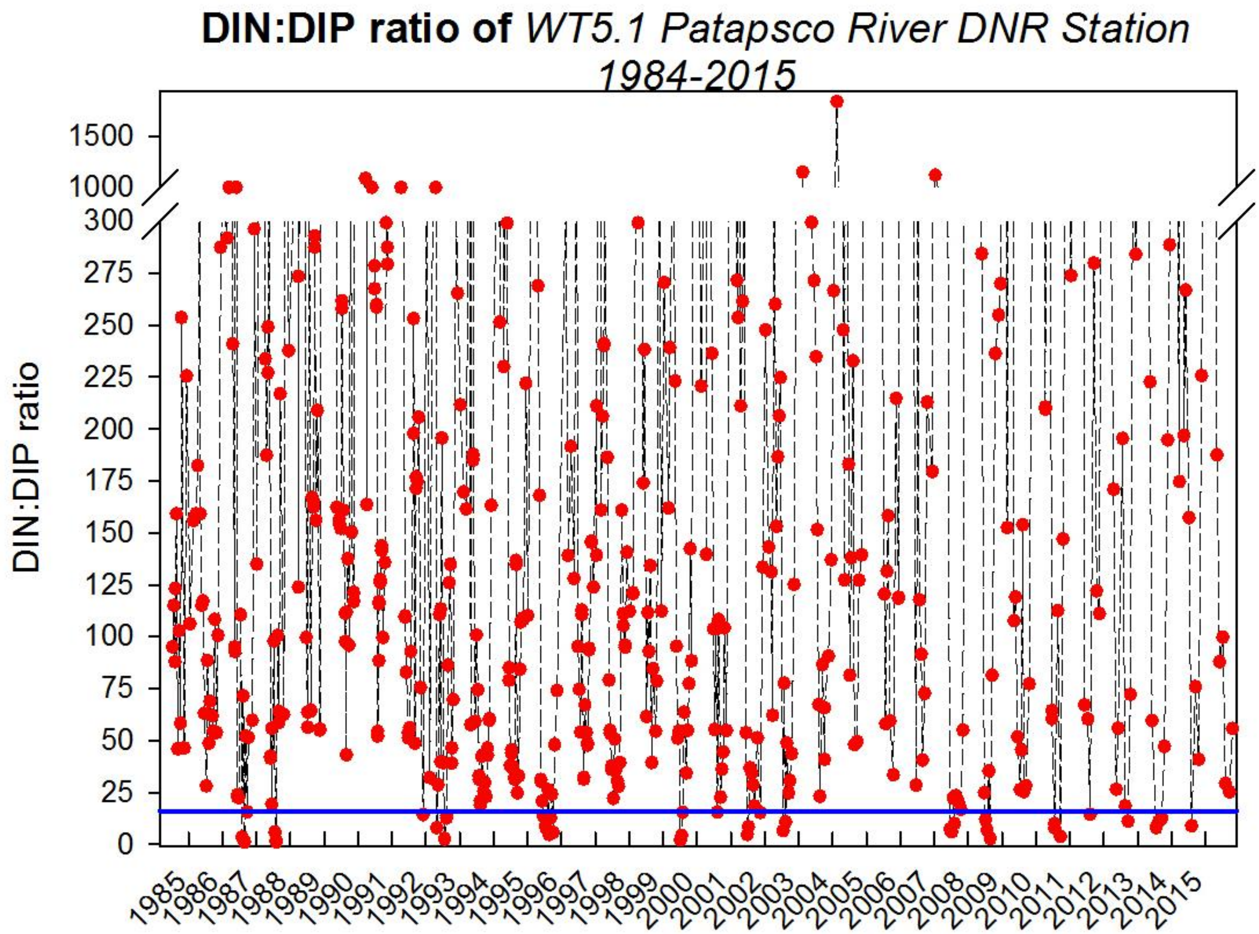


Figure 8a. Computed N:P ratios for the long term monitoring station adjacent to Rock Creek. The blue line indicates the 16:1 Redfield ratio threshold. Few months were DIN limited. Most months are DIP limited. From 1984-1990 June through August samplings experienced the most N-limitation with the lowest mean ratio during August samples for all years at 87:1.In the 1991-2005 time range, the N limited months were July through September with the lowest mean ratios for those years 52:1 in September and62:1 in July of those years. The most recent time period, 2006-2015, revealed N-limitations occurring more frequently and overall lower mean ratios for all months. The most N-limited months for the 2006-2015 months were July through September with the summer months mean ratio for all years ranging from 41:1 to 78:1. The overall trend from 1984-2015 is decrease in ratio, and especially over summer months.

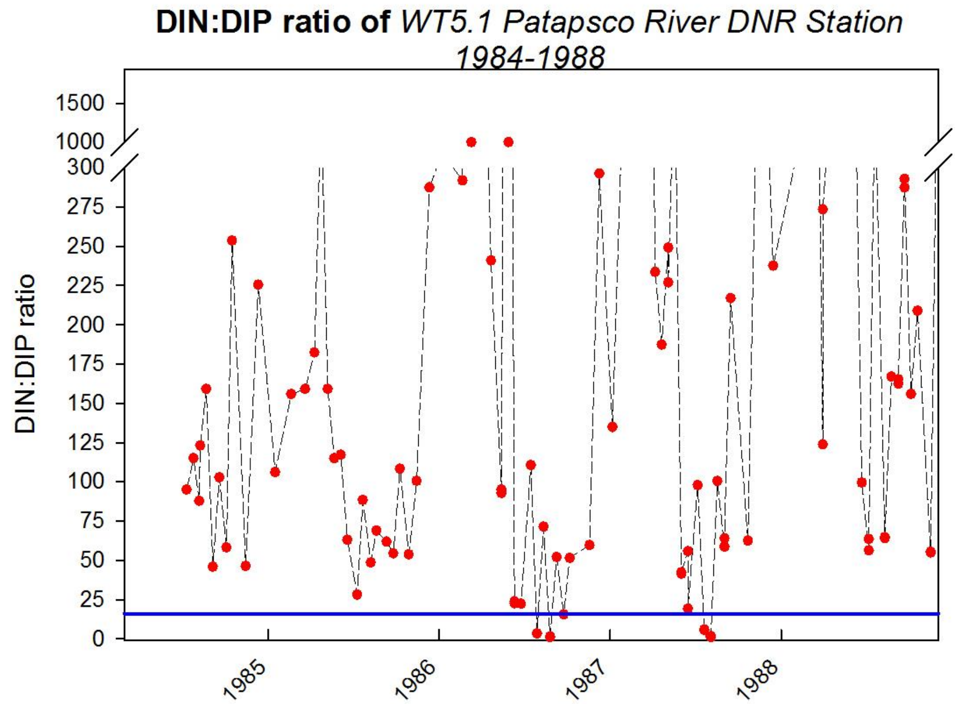


Figure 8b. Computed N:P ratios for the 1984 through 1988 of the long term monitoring station adjacent to Rock Creek. The blue line indicates the 16:1 Redfield ratio threshold.In 1985, the Patapsco WWTP opened to start meeting more stringent waste water requirements- including phosphorus removal.

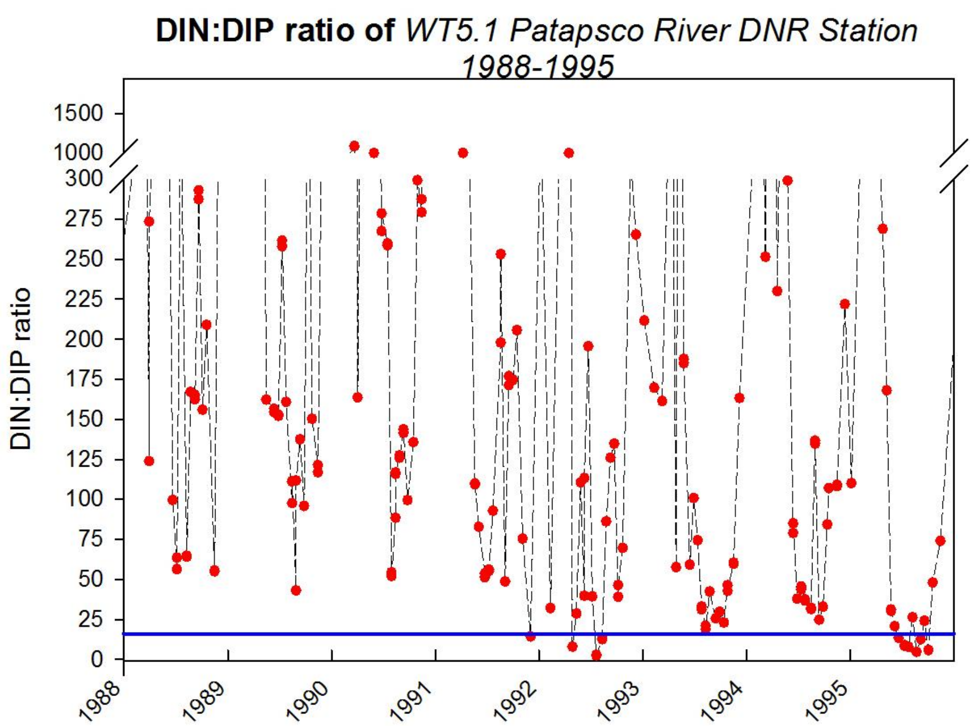


Figure 8c. Computed N:P ratios for the 1988 through 1995 of the long term monitoring station adjacent to Rock Creek. The blue line indicates the 16:1 Redfield ratio threshold. These years represent when some WWTP started secondary treatment.

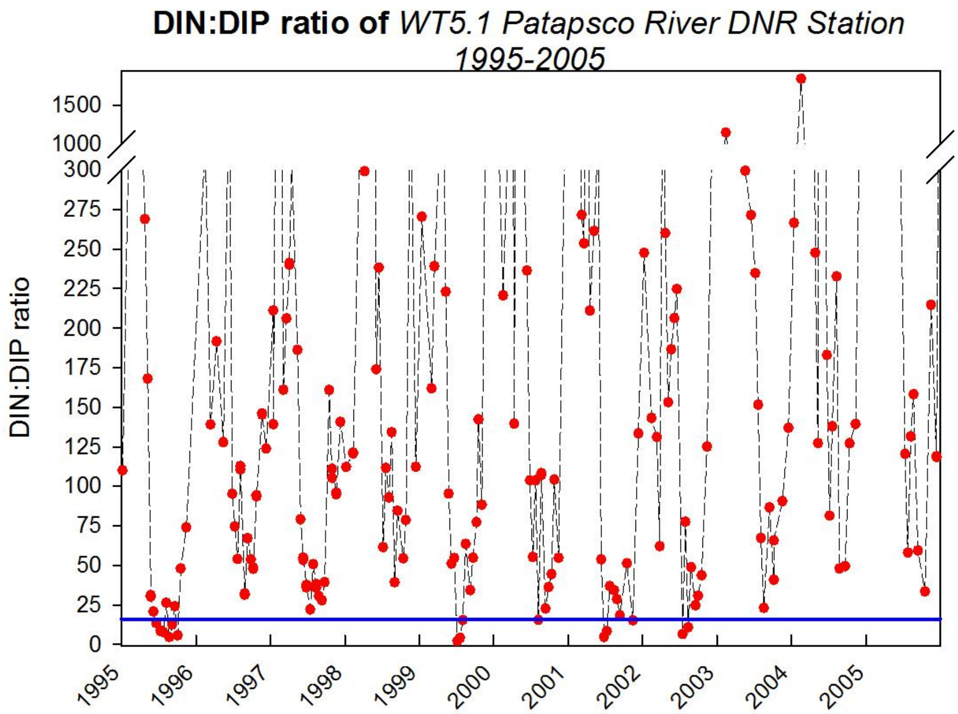


Figure 8d. Computed N:P ratios for the 1995 through 2005 of the long term monitoring station adjacent to Rock Creek. The blue line indicates the 16:1 Redfield ratio threshold.In 2004 the Chesapeake Bay Tributary Strategy established point source caps limiting TN to 3.0 mg/L and TP to 0.3 mg/L.

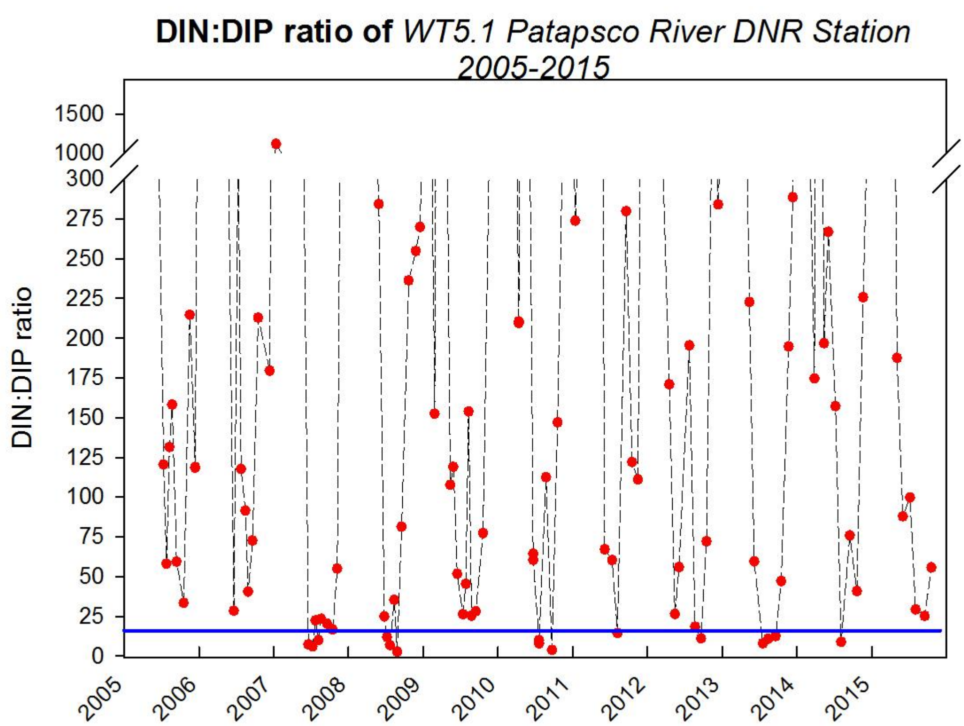


Figure 8e. Computed N:P ratios for the 2005 through 2015 of the long term monitoring station adjacent to Rock Creek. The blue line indicates the 16:1 Redfield ratio threshold.

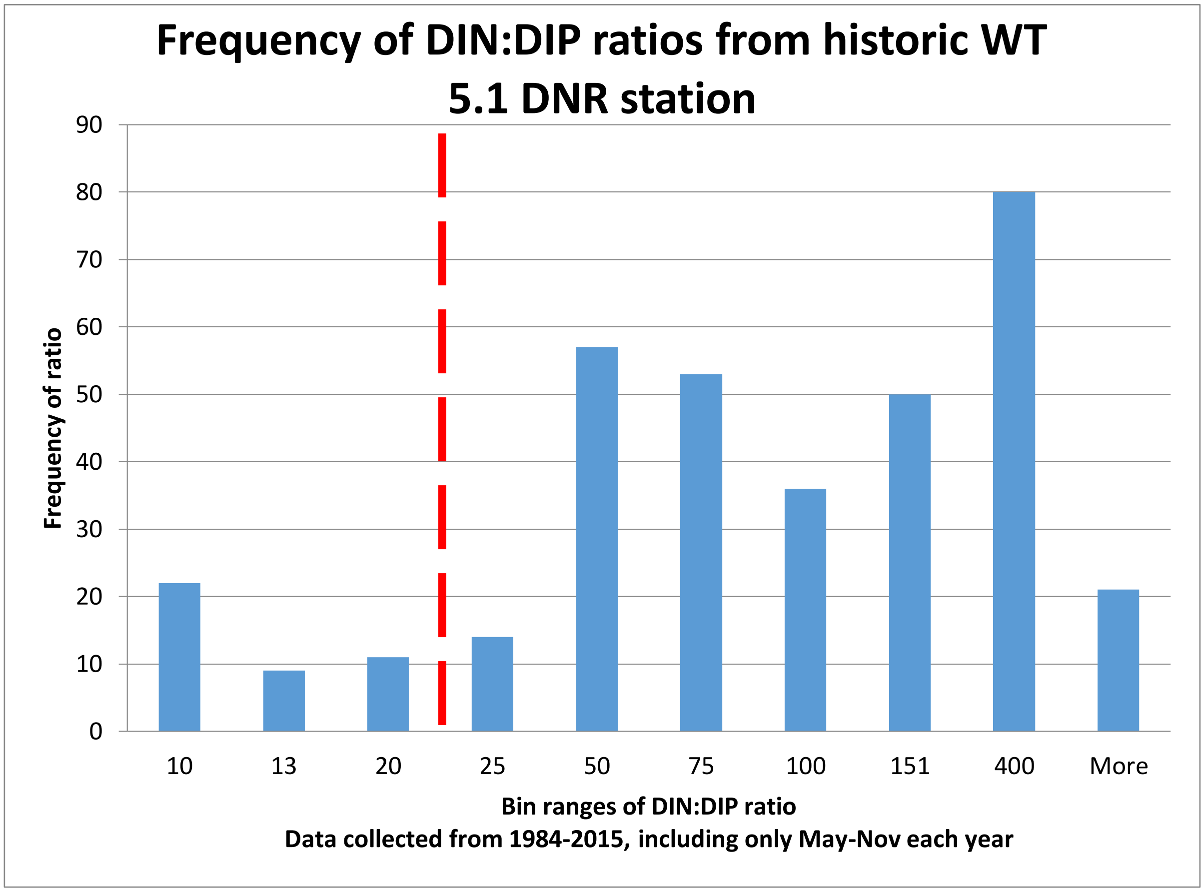


Figure 9. Histogram of DIN:DIP ratios from historic WT5.1 DNR site from 1984-2015, sampled monthly. The histogram shows that a majority of the DIN:DIP ratio values are higher than 16:1.The red line represents the lower ratio or P dominated on the left and higher ratio N dominated on the right (with a buffer for error).

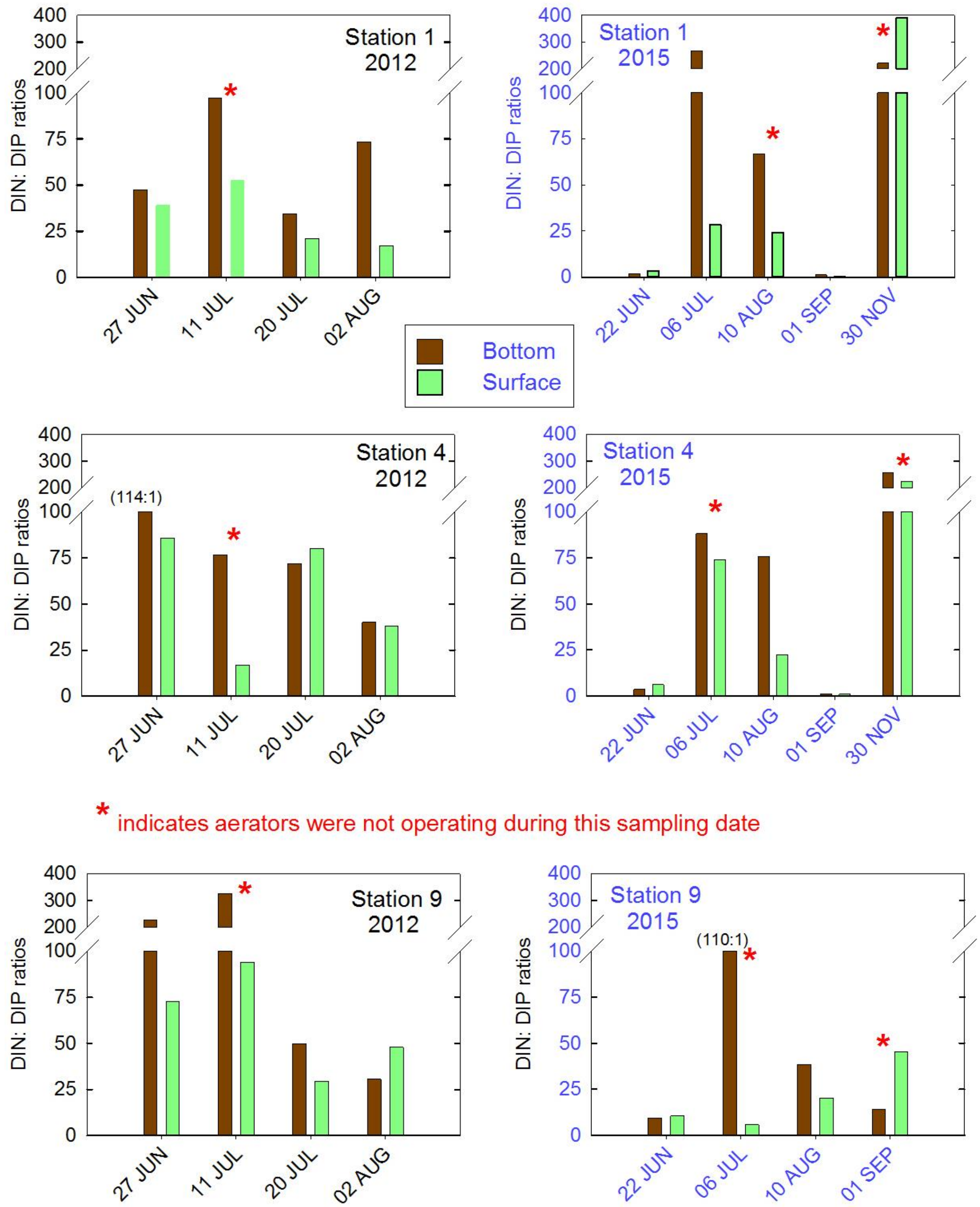


Figure 9. DIN:DIP ratios from selected sample stations in Rock Creek from the area before the aerators, over aerators and the Patapsco River station to show the spatial difference in ratios on the same dates during different years, 2012 and 2015. All scales are the same for easy comparison, with 2 ratios typed above the bar marking the value within the break in scale. The red asterisk represents when aerators were not operating during sampling.

Conclusions

Water quality conditions in Rock Creek continue to be representative of an extremely eutrophic system. With high nutrient concentrations and chlorophyll-a concentrations at a level consistently indicative of phytoplankton blooms, many of which are extreme compared with comparable regional conditions (Hodgkins et al. 2016), it is unlikely that dissolved oxygen will rebound without either declines in nutrient loading, or continued efforts at engineered de-stratification.

Nutrient limitation varies between nitrogen and phosphorus on a seasonal basis, but few incidences are apparent in the long term record where values fall below concentrations that would inhibit phytoplankton uptake rates in the Patapsco. In this regard, phytoplankton blooms there are easily maintained regardless of N:P ratio as more of each relevant nutrient is available than can be used according to uptake kinetics. On the dates we sampled Rock Creek (a much smaller sample size than is available from the long term record), P limitation was evident in 30% of the samples.

The influence of Patapsco inputs on Rock Creek water quality is still uncertain, although our efforts associated with new research funding from Maryland Sea Grant will shed a great deal of light on this question. We anticipate having a fully enumerated mass balance box model for N and P within a year and a half.

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