Filamentous Algae Monitoring Program:

Potomac River Basin

Report to the West Virginia Department of Environmental Protection,

Division of Water and Waste Management

by

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Commission on the Potomac River Basin

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Summary

West Virginia Department of Environmental Protection (WVDEP) has been observing and evaluating the breadth and causes of filamentous green algae (FGA) blooms in rivers across the state since 2007. Blooms of filamentous algae occur in rivers of the Potomac Basin, and the Interstate Commission on the Potomac River Basin (ICPRB) has assisted the WVDEP in documenting algae blooms in the South Branch Potomac and Cacapon Rivers. The 2015 sampling season focused on the Cacapon and South Branch Potomac rivers. A supplemental 2015 Cacapon River microcosm study was conducted concurrently with the standard WVDEP algal observation and water chemistry procedures in an attempt to better understand the ecological impacts of large algal blooms. 2015 was an abnormal year for the Cacapon and South Branch Potomac Rivers as it did not produce dense filamentous green algae in the quantity it has in previous years. Sites that often held a dense abundance of algae instead supported dense beds of submerged aquatic vegetation, or SAV. Sites such as Rim Rock (CA_RMRCK) that historically produced algae cover as high as 90% had SAV coverage of up to 95% in 2015. Interestingly, epiphytic communities of FGA did not form on the dense SAV beds as was observed in previous years. The South Branch Potomac produced very little FGA. Longitudinal surveys targeted to observe FGA bloom sites in 2014 yielded no significant algae manifestations in 2015. A longitudinal survey on the Cacapon yielded dense SAV blooms in reaches not surveyed regularly due to inaccessibility.

Field methods

In 2015, ICPRB biologists implemented the WVDEP Filamentous Algae Monitoring Protocol (WVDEP 2013) at 14 fixed locations over 10 rounds between June and October (**Table 1**). The protocol consists of routine water chemistry sampling, a rapid site characterization for each location, semi-quantitative algae coverage estimates, and longitudinal surveys to document the extent of bloom events. A total of two longitudinal surveys were performed. The ICPRB field crew consisted of at least two biologists for all sampling rounds and longitudinal surveys. ICPRB personnel included Gordon Selckmann (GMS, Aquatic Ecologist), Jim Cummins (JC, Director of Living Resources), and Charles A. Dean (CAD, Natural Resources Intern).

Table 1. 2015 sample rounds and dates.

Sampling Round	Sampling Dates
JUN-1	Jun 3-4
JUN-2	Jun 17-18
JUL-1	Jul 8-9
JUL-2	Jul 20-21
JUL-3	Jul 29-30
AUG-1	Aug 12-13
AUG-2	Aug 26-27
SEP-1	Sep 9-10
SEP-2	Sep 23-24
OCT-1	Oct 15-16

Station locations

Fourteen sampling stations were selected by the WVDEP based upon past observations, targeted inquiries, and best professional judgment. Eight stations were located in the Cacapon River basin, including seven on the Cacapon River mainstem between the towns of Largent and Wardensville, and one on North River, the Cacapon's largest tributary. Six stations were located on the South Branch Potomac, three above and three below the town of Moorefield, WV (**Table 2** and **Figure 1**). Nine of the Cacapon plus South Branch stations were located at or near bridge crossings, while the other five were accessed from parallel roadways. Seven stations had public assess put-ins, and the remainder were accessed from bridge right-of-ways or through private landowner permission. Stations were always sampled downstream to upstream and effort was made to sample each site at roughly the same time of day during each sampling round in order to limit diurnal variability of water chemistry samples.

Table 2. Sampling station names and locations.

Site Name	Site Location Description	Latitude/Longitude	
NO_FRKS	North River at Gaston Rd. / Forks of Cacapon	39.40194	-78.42448
CA_LRGNT	Cacapon River at Rt. 9 in the town of Largent	39.48112	-78.38448
CA_FRKS	Cacapon River at Rt. 127 / Forks of Cacapon	39.40387	-78.41842
CA_D_CPBRG	Cacapon River at farm off Cold Stream Road	39.32716	-78.42336
CA_CPBRG	Cacapon River at Rt. 50 in Capon Bridge	39.29754	-78.43517
CA_RMRCK	Cacapon River along Capon River Rd.	39.21969	-78.47605
CA_YLWSPR	Cacapon River at Rt. 259 below Wardensville	39.18281	-78.50597
CA_WRDS	Cacapon River at farm ford in Wardensville	39.07861	-78.61134
SB_L_TRGH	South Branch at Harmison's Landing	39.22810	-78.85251
SB_U_TRGH	South Branch at South Branch WMA	39.14630	-78.92519
SB_L_MRFLD	South Branch at Rt. 220/28 in Moorefield	39.10424	- 78.95801
SB_U_MRFLD	South Branch at Fisher Rd above Moorefield.	39.05006	-78.99316
SB_L_PBRG	South Branch at Weldon Park	38.98815	-79.12126
SB_U_PBRG	South Branch at Rt. 200 bridge	38.99955	-79.08596

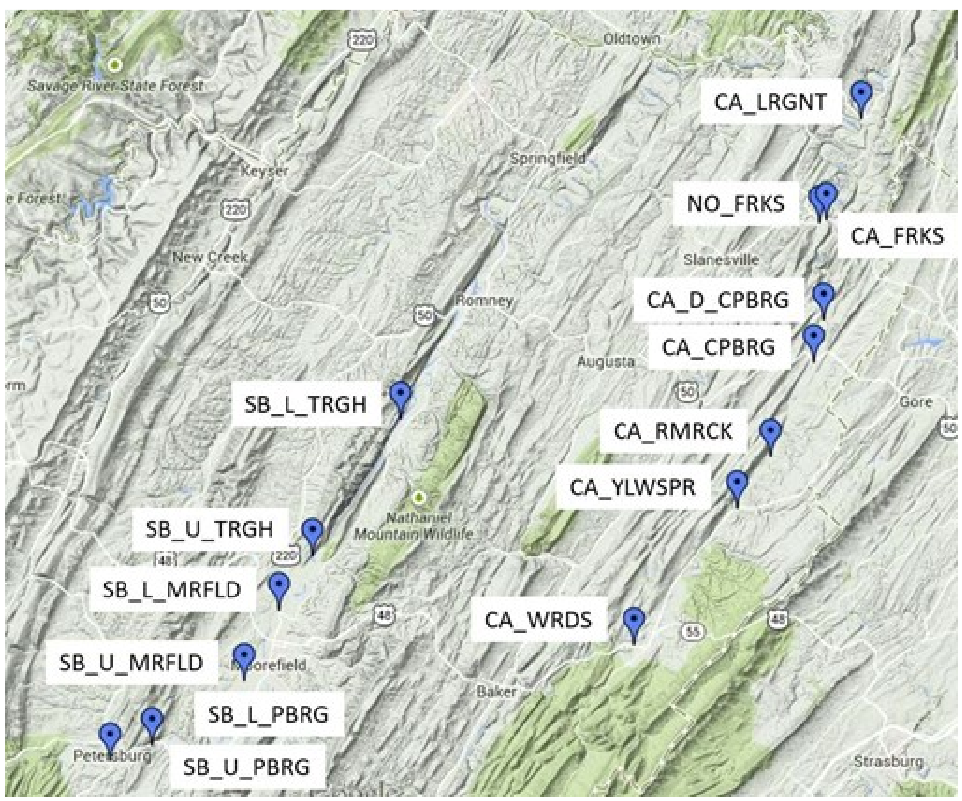


Figure 1. A map of 2015 algae monitoring stations on the Cacapon and South Branch Potomac rivers.

Site characterization

The WVDEP Filamentous Algae Monitoring Form was generally completed in the field by G. M. Selckmann. All sampling locations remained the same as for the 2014 sampling season. Global Positioning System (GPS) coordinates were taken using a Garmin Etrex20 on the first field visit to verify WVDEP provided coordinates. WVDEP coordinates and AN-codes were used with ICPRB site identifications on all datasheets to establish continuity of location information across years. GPS coordinates were recorded whenever transect measurements of algae were performed. Relevant USGS gage hydrographs for the study period are included in **Appendix I**. Qualitative observations of periphyton, aquatic moss, aquatic vascular plants, filamentous green algae (FGA) and cyanobacteria/blue-green algae (BGA) abundance were made on each site visit. The only change pertaining to site locations was a new entry point to the Largent site. New land owners allowed ICPRB access to the river from the general store's private property. Although the access point changed, the water chemistry sample location and algal observation area remained the same as for prior years.

Photo documentation

Pictures were taken on each site visit, arranged in folders according to site and sampling round, and stored on a DVD hard copy that was shared with WVDEP staff. Generally, photos were taken at the x- site, one picture each looking upstream, downstream, and across the channel. Photos were also taken of any algae observed or measured, including underwater photos, or anything else of note, including sample collection or processing, in-situ probe placement, etc. Photos were documented on page 4 of the field sheet. A Nikon AW100 was the primary camera used and is capable of attaching GPS coordinates of pictures as they are taken. This information is in the details of the image's file properties. GPS coordinates did not, however, always accompany pictures and are generally missing from underwater shots and videos. A digital SLR (Nikon D-40) was used during round 9 to test with the ability of a more powerful camera to detect algae in digital images. This camera did not have the ability to store GPS metadata with the image file.

Filamentous algae abundance measurements

Percent algae coverage measurements were performed according to WVDEP Standard Operating Procedures (SOP). Measurements were recorded in meters. Single visual estimates of the entire transect are sufficient if algae is estimated to be below 10% or above 80%. Moderate amounts of algae require transect-segment based estimate measures. If algae is measured between 20% and 40%, three separate transect measures are required spanning a length of 3X the average channel width. Lengths and depths of the lateral transects were reported in meters using a Nikon Aculon laser range finder and surveying rod. All values were entered on the field form and later entered into the percent algae calculation spreadsheet file. The file was modified from that provided by WVDEP to receive the measurements as recorded, in order to calculate the percent coverage of the entire transect. The modified percent algae coverage calculation spreadsheets and associated data are provided separately as a Microsoft Excel© file with each measurement occupying one tab. Transect measurements were required downstream of Camp Rim Rock (CA-RMRCK) only for the June 17th

sample. A miscalculated excel cell within our field sheet resulted in an incorrectly calculated transect of 18%. Upon correction of the miscalculated cell after the sampling round, the site yielded a total algae coverage of the 24.12%. No other Cacapon or South Branch Potomac stations required transect measurements, although several stations routinely produced algal growth at or below 5% coverage.

In-situ water quality

In-situ water quality data were collected at every site with the same YSI-556 multi-parameter sonde throughout the season. Water temperature (WTEMP), dissolved oxygen (DO), pH, specific conductance (SPCOND) and total dissolved solids (TDS) were measured in-situ and recorded on the field data sheet. The YSI-556 was calibrated at the beginning of each 2-day sampling round using concentration standards. Specific conductance was calibrated using a 447.1 µS/cm standard solution and pH was calibrated using a 2-point (pH 7.01 and pH 10.01) calibration. Dissolved oxygen was calibrated using a saturated air calibration method, according to the user manual of the YSI-556.

Water chemistry

Water chemistry testing included analysis for the following parameters: total phosphorous (TP), dissolved phosphorous (DP), total Kjeldahl nitrogen (TKN), nitrate-nitrite-N (NO3- NO2-N), total alkalinity (TALK), calcium (Ca), magnesium (Mg), and total suspended solids (TSS). Water samples were collected at each site visit according to WVDEP Standard Operating Procedures, and the sampling location within the river was indicated on the monitoring form. Two collection containers were rinsed 3 times and water samples collected facing upstream. Water chemistry sample containers were provided by the contracted analysis laboratory Bio-Chem, and were pre-fixed with acid preservatives. Three of the sample containers were filled directly from the collection containers, later to be tested for the following parameters: TSS/TALK (bottle 1), NO_3-NO_2-N/TKN/TP (bottle 2), and Ca/Mg (bottle 3). The DP sample (bottle 4) was filtered after collection using a Nalgene© filter funnel cup, Nalgene© vacuum flask, 0.45µm/ 47mm cellulose-nitrate filter papers, and a hand-operated vacuum pump. The funnel and vacuum flask were rinsed 3 times mid-stream prior to filtering at each site. Sample duplicates were collected at two sites during each round and were analyzed alongside the 14 station samples.

Sample handling

Water chemistry samples were labeled with a permanent marker and immediately stored on ice following collection. All samples were collected on contiguous days and delivered directly to BioChem drivers, typically in Petersburg at the end of the two-day sampling round. Exchange of samples was documented on change-of-custody forms each sampling round. On occasion, when BioChem drivers could not meet staff at the end of sampling, ICPRB biologists left samples and chain-of-custody forms at the West Virginia Department of Agriculture Moorefield laboratory for later pick-up by BioChem.

Completeness

All 14 stations identified by WVDEP personnel were sampled throughout the study period. Nine sampling rounds were completed during the study period on a roughly bi-weekly schedule. All sites were monitored within a consecutive 2-day period. Complete sets of water chemistry samples were collected and analyzed on every round with the exception of Round 2, where a DP sample (SB_L_PTBRG) was lost during the sampling round and not delivered to Biochem, and Round 3, where a TSS/TALK sample (SB_L_PTBRG) was incorrectly preserved and unable to be analyzed. Algae transects were performed whenever algae were observed and estimated to be above 20% coverage. Occasionally, water clarity, or visual surface disturbance due to precipitation, prevented performing the qualitative visual assessments at certain sites.

Longitudinal surveys

Longitudinal surveys were employed to document the magnitude and extent of filamentous algae blooms in targeted areas over the last three years. In order to survey suspected bloom areas that are not visible from roadways, biologists used canoes to travel along a river reach and record observations and measurements in suspected algae occurrence areas. The longitudinal surveys are an informal assessment method, but consist primarily of documenting observations with written narrative accounts, photographs, videos, and associated GPS coordinates of important observation points. Two longitudinal surveys were performed during the 2015 season. One survey was performed on the South Branch Potomac between Moorefield and the trough take-out at the SB_L_TRGH site. The Moorefield longitudinal was selected based on WVDEP's interest in a FGA dense region observed in 2014. A second survey was performed on the Cacapon River between Capon Bridge (CA_D_CPBRG) and Cacapon Forks (CA_FRKS). The Capon Bridge- Forks section of river was of interest to ICPRB biologists due to a wastewater outflow below Capon Bridge as well as a 10km "wilderness area" that is difficult to get to via automobile and is only logistically possible via canoe. Reports presenting the findings of the longitudinal surveys are included as separate results sections of this report.

Data Processing and Laboratory Methods

Data processing

Data were entered into MS Excel and R-studio for exploratory analyses. Hard-copy datasheets were delivered to WVDEP. A copy of this electronic dataset is included in the MS Excel spreadsheet appendix accompanying this report. All analyses were performed using R and analysis scripts are provided, preceding the associated analysis or chart in the data file. Four parameters were calculated from the water chemistry data for analysis purposes. Total nitrogen (TN) was calculated by summing the NO3-NO2-N and TKN values for each independent sample. Total hardness (HARDNESS) is represented as molar equivalents of $CaCO_3$ in mg/L, calculated using the equation:

$$[CaCO_3] = 2.5[Ca^+] + 4.1[Mg^{2+}].$$

Two Calcium-Magnesium ratio indices were calculated, following the analysis performed in the 2008 WVDEP Report on filamentous algae assessment report (Summers 2008). A traditional Ca:Mg ratio index with both ratio and additive terms of Ca^{2+} and Mg^{2+} (CA_MG_INDEX):

$$\log[Ca^{2+}/Mg^{2+}] - 0.5 \log[Ca^{2+} + Mg^{2+}],$$

A modified index considering only an additive variable (MOD_CA_MG):

$$-\log[Ca^{2+} + Mg^{2+}].$$

Results from the 2015 season

Summary of algal observations and measurements by station

Cacapon River at Rt. 9 in the town of Largent (CA_LRGNT)

Early growth FGA was observed at the Largent site but never manifested into long-chain filaments. The early growth FGA was observed in shallow stone bars near shore. In interviews, local residents expressed concern on the level of “algae” growth upstream from our sampling site. Several driving transects, therefore, were conducted upstream on Kilgore Lane (WV 9/27). This site did produce large beds of SAV and therefore could be flagged as a potential region of concern in the future.

North River at Gaston Rd. / Forks of Cacapon (NO_FRKS)

The site at the North River was dominated by a type of benthic riverweed (field id: *Podostemum sp.*). The river weed could occupy up to 80% of total benthic area and attach to the bedrock ledges. No FGA was observed growing in or around the river weed beds at this site.

Cacapon River at Rt. 127 / Forks of Cacapon (CA_FRKS)

Early growth FGA was observed at the Cacapon at Forks site but never manifested into long-chain filaments. The patchy, early growth, FGA was observed in shallows near shore. This site did rarely produce BGA columns/tufts (roughly 10cm – 50cm in height) over the year at a density of roughly one tuft per 1 meter radius.

Cacapon River at farm off Cold Stream Road (CA_D_CPBRG)

Filamentous green algae was present at low levels through most of the sampling season but never reached a qualitative estimate measurement greater than 5%. Algae density, frequency, and intensity were less than what was observed the previous year.

Cacapon River at Rt. 50 in Capon Bridge (CA_CPBRG)

Small periphytic communities of FGA and BGA were observed infrequently amongst a dense periphytic community. As has been observed in other years, this site is rich in freshwater snails, likely due to the abundance of periphyton.

Cacapon River along Capon River Rd. and downstream of Camp Rim Rock (CA_RMRCK)

This site produced an abundance of *Hydrilla sp.* in 2015. Early in the2015 sampling season small shoots of *Hydrilla* dominated the thalweg leaving the gravel and pebble bank opposite the entry point bare and exposed. The gravel bar was, as was also observed in 2014, the genesis of the problematic FGA early in the season. A transect was conducted in sampling round two measuring FGA abundance at 24% coverage. Due to high water velocity events that occurred early in the year, the gravel bar that generally produced the FGA remained scoured well into summer. It is the author's opinion that the more robust SAV was able to endure the high velocity events better than FGA early in the year and therefore could expand and colonize in the regions that, in previous years, had been dominated by FGA. Despite the lack of FGA in 2015 that this site is known for, Camp Rim Rock did produce a perceived overabundance of *Hydrilla*. *Hydrilla* beds in some regions (via driving transect and exploratory hiking) reached 100% coverage and column fill. Some regions even appeared as large grass fields/islands.

Cacapon River at Rt. 259 below Wardensville (CA_YLWSPR)

The Cacapon River at the Rt. 259 bridge did not produce any FGA, BGA, or abundant SAV in 2015. Some cold water upwelling was felt coming up from the substrate which raised questions of source water input to the Rim Rock Site downstream.

Cacapon River at farm ford in Wardensville (CA_WRDS)

Filamentous green algae (FGA) was not observed at this site in 2015. This site did produce a heavy periphyton load. Given the river morphology and substrate composition, it appears that this site is subject to flashy increases in water velocity and would not be ideal for FGA growth.

South Branch at Harmison's Landing (SB_L_TRGH)

There was no FGA or BGA observed at this site in 2015. Small isolated SAV was observed mid-stream, however. Much of this site is a shallow shoal of coarse sand, pebble and gravel sized substrate which was devoid of much primary production. Interestingly, this site frequently produced lower DO than was observed elsewhere on the South Branch Potomac. As this was our first sampling location (0700-0800) on the second day of our algae survey rounds, the low DO may suggest primary production located above this site. Road surveys with binoculars supported this suspicion as some aquatic macrophyte regions could be observed in the distance upstream. No longitudinal survey was conducted within the S. Branch Trough this year and therefore no measured estimated of plant growth upstream from this site are available.

South Branch at South Branch WMA (SB_U_TRGH)

There was no FGA or BGA observed at this site. This site narrows to a shallow channel characterized by cobble and boulder substrate. This site appears to be at too high a constant velocity to allow FGA or BGA growth.

South Branch at Rt. 220/28 in Moorefield (SB_L_MRFLD)

This site produced moderate to moderately-high amounts of SAV in the main flow leading to the riffle found at this site. There was little FGA observed. A large but short lived BGA bloom occurred in July. This short-lived bloom covered roughly 80% of the benthic substrate in dense diatomaceous mats with BGA tufts frequently growing from them. Matts of recently detached BGA were observed in eddies and in snags near shore.

South Branch at Fisher Rd above Moorefield (SB_U_MRFLD)

This site did not produce any algae at our standard sampling point, nor did it above the Fisher Rd Bridge. The main thalweg at this site is deep and channeled which appears to make it difficult for FGA to anchor and grow. This site, as was observed at many others, has a large eddy opposite to the thalweg. The eddy at this site produced a small amount of FGA in 2014 but not in 2015.

South Branch at Weldon Park off Rt.220/55 (SB_L_PBRG)

This site did not produce any significant FGA and the algae that was present was mostly periphytic growth. Interestingly, roughly 1km upstream there was a dense patch of fragile light green FGA in a back eddy next to the main thalweg. Frequency of algae growth increased as we approached the nearest upstream riffle from our observation site, only to diminish again upstream of the riffle.

South Branch at Rt.220 in Petersburg (SB_U_PBRG)

This site did not produce any significant FGA and the algae that was present was mostly periphytic growth. This site is particularly interesting due to the thalweg proximal to the entry site. This thalweg was always devoid of any FGA or BGA while only occasionally holding SAV. Once out of the main flow, small, sparse and fragile lightly colored FGA could be observed in low flow environments near shore and in the shallows.

Summary algae measurements also are included in **Table 3** below. This table includes actual measurements, and qualitative visual estimates of low abundance algae occurrences.

Table 3. Summary of percent filamentous algae cover measurements made during the 2015 season. Values up to 10% were visually estimated and recorded as "<1", "<5", or "<10", all other values are actual algae measurements using the wadeable transect method. *Measured by a single transect.

Site Name	Waterbody	JUN1	JUN2	JUL1	JUL2	JUL3	AUG1	AUG2	SEP1	SEP2	OCT1
CA_LRGNT	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
NO_FRKS	North River	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CA_FRKS	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CA_D_CPBRG	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CA_CPBRG	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CA_RMRCK	Cacapon	<1	24.12*	<1	<1	≤5	<1	<5	<5	<3	<1
CA_YLWSPR	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
CA_WRDS	Cacapon	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SB_L_TRGH	South Branch	<1	<1	<1	<1	<1	<1	<1	<3	<3	<1
SB_U_TRGH	South Branch	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SB_L_MRFLD	South Branch	<1	<1	<1	<1	<1	<1	<1	<1	<1	<3
SB_U_MRFLD	South Branch	<1	<1	<1	<1	<1	<1	<1	<1	<1	<1
SB_L_PTBRG	South Branch	<1	<1	<1	<1	<1	<1	<1	<5	<3	<3
SB_U_PTBRG	South Branch	<1	<1	<1	<1	<1	<1	<1	<3	<3	<3

Water chemistry across stations

(Boxplots of water chemistry data can be found in Appendix II, III)

Calcium, Magnesium, Total Alkalinity, and Hardness

Median and mean values of the measured water quality parameters for each site are provided in Table 5 and Table 6. In general, the South Branch Potomac River produced the highest concentrations of calcium (Ca+, Mg+, specific conductivity (SPCOND), total alkalinity (ALK) and hardness relative to the Cacapon and North rivers. The South Branch had similar water chemistry across all sampled sites and saw no longitudinal trends from upstream to downstream. The highest Ca, Mg, alkalinity and hardness concentrations in the Cacapon were observed at the most upstream site, CA_WRDS. Downstream from CA_WRDS water chemistry stabilized and did not change significantly between sites. The Cacapon and North River had lower alkalinity levels, yet were above the minimal threshold for algae that has been observed in previous work (Summers 2008). These two rivers have lower overall buffering capacity, and could be more susceptible to diel swings in pH resulting from increased primary productivity and carbonic acid from SAV and algae.

Nitrogen and Phosphorous

The various nutrient species of nitrogen and phosphorus are important to understanding algae abundance and frequency as they are known to be primary drivers of algal blooms. Phosphorous, particularly, is known to be a common limiting nutrient in freshwater systems. Both water column P measures were very similar in the Cacapon, North and South Branch Rivers, with TP having means of 0.046 mg/L, 0.044 mg/L, and 0.039 mg/L respectively, across all Cacapon stations (Table 4). Phosphorous was highest in the Cacapon River, below the city of Capon Bridge, which appeared to have grey water discharging into the river, possibly due to the input of the Capon Bridge WWTP, a small treatment facility serving less than 250 residents.

Nitrogen displayed a pattern that was consistent with previous years (2013, 2014); the highest nitrogen levels observed were at the upstream site, CA_WRDS, where the Cacapon rises from the ground. Nitrogen concentrations decreased moving downstream and stabilized around 0.4 mg/L. The mean concentration of total nitrogen all sites was 0.581 mg/l.

Table 4. Mean nutrient concentrations (mg/l) in the Cacapon, North, and South Branch rivers.

Parameter	Cacapon	North	South Branch
DP	0.026	0.022	0.026
TP	0.046	0.044	0.039
NO3_NO2	0.269	0.164	0.321
TKN	0.361	0.351	0.260
TN	0.630	0.515	0.581

Dissolved Oxygen, pH, Specific Conductance, Water Temperature, and Total Dissolved and Suspended Solids

Specific conductance and total dissolved solids are cumulative measures of all dissolved, reactive components in the water. As expected, they followed patterns across the 14 stations that were very similar to those of the dissolved ionic measurements discussed above (Tables 5, 6). Water temperature did not vary greatly between waterbodies, though the sites proximal to large SAV beds saw elevated temperatures. Total suspended solids were consistently below detection limits throughout the year. In previous years, phytoplankton production in the pools was suggested as a possible explanation for the elevated amounts of suspended material in baseflow over the riffle-run stations. Therefore, it is interesting that TSS was constantly below detection thresholds in a year where very little FGA was observed. Presumably factors promoting phytoplankton production may be also associated with FGA blooms as well. On the Cacapon, both DO and pH displayed strong swings and increases likely associated with excessive primary production. Similarly, pH at the CA_RMRCK station was increased overall and had a higher variance than nearby stations, as the SAV and algae took up or released CO_2. A more in depth analysis of diel variation of DO at highly productive sites can be found in the supplemental Cacapon Microcosm Study.

Table 5. Median values of the collected and calculated water chemistry variables across the samples sites.

Parameter	CA_LRGNT	NO_FRKS	CA_FRKS	CA_D_CPBRG	CA_U_CPBRG	CA_RMRCK	CA_YLWSPR	CA_WRDS	SB_L_TRGH	SB_U_TRGH	SB_L_MRFLD	SB_U_MRFLD	SB_L_PTBRG	SB_U_PTBRG
CA (mg/L)	23.10	21.20	27.40	24.80	23.65	24.20	25.35	28.60	39.35	38.80	39.35	40.60	41.25	41.00
MG (mg/L)	5.30	5.95	5.60	5.20	5.10	5.10	5.10	5.95	6.40	6.20	6.40	5.65	5.75	5.40
ALK (mg/L)	68	66	77	70	65	69	71	80	99	97	95	99	103	100
Hardness (mg/L)	79.15	77.40	91.46	83.12	79.83	81.41	83.88	95.90	124.62	122.42	124.62	124.26	126.70	124.89
SPCOND (uS/cm)	2.34	2.26	2.35	2.36	2.36	2.36	2.38	2.34	2.38	2.39	2.38	2.44	2.44	2.47
CA_MG Index	2.97	2.99	2.90	2.94	2.96	2.95	2.93	2.88	2.75	2.76	2.75	2.74	2.74	2.74
MOD_CA_MG	167.50	165.00	182.00	175.50	166.50	161.00	174.00	197.50	253.50	234.50	240.50	242.00	231.50	219.00
CA:MG Ratio	0.14	0.17	0.13	0.13	0.13	0.13	0.12	0.12	0.10	0.10	0.10	0.09	0.08	0.08
DP	0.016	0.022	0.022	0.025	0.019	0.020	0.022	0.027	0.036	0.026	0.017	0.017	0.019	0.015
TP	0.037	0.040	0.038	0.039	0.037	0.032	0.037	0.040	0.039	0.040	0.031	0.030	0.030	0.026
NO3_NO2	0.015	0.052	0.036	0.091	0.051	0.114	0.204	0.468	0.258	0.262	0.252	0.274	0.204	0.215
TKN	0.320	0.355	0.265	0.300	0.260	0.340	0.235	0.210	0.270	0.250	0.280	0.235	0.240	0.195
TN	0.410	0.419	0.358	0.490	0.382	0.497	0.489	0.725	0.508	0.555	0.505	0.504	0.532	0.389
WTEMP	25.50	22.99	23.81	23.15	25.54	24.90	24.60	22.32	23.23	22.79	22.55	22.06	22.06	22.45
DO	6.93	7.64	7.85	8.12	8.26	10.97	8.90	9.46	7.23	8.23	8.01	7.88	9.37	9.36
pH	8.00	8.00	7.89	7.94	8.11	8.72	8.31	8.22	8.12	8.16	8.08	8.24	8.27	8.39
TDS	110	108	118	114	109	105	113	129	165	162	157	153	146	142
TSS	3	1	1	1	1	1	1	1	1	1	1	1	1	1

Table 6. Mean values of the collected and calculated water chemistry variables across the samples sites.

Parameter	CA_LRGNT	NO_FRKS	CA_FRKS	CA_D_CPBRG	CA_U_CPBRG	CA_RMRCK	CA_YLWSPR	CA_WRDS	SB_L_TRGH	SB_U_TRGH	SB_L_MRFLD	SB_U_MRFLD	SB_L_PTBRG	SB_U_PTBRG
CA (mg/L)	24.22	21.76	27.62	25.28	23.78	23.82	27.03	28.24	39.42	39.21	39.21	40.41	40.44	39.11
MG (mg/L)	5.59	6.21	5.71	5.29	5.11	5.10	5.16	5.79	6.47	6.30	6.33	5.88	5.75	5.25
ALK (mg/L)	68.16	65.68	75.41	69.49	64.09	66.67	70.94	76.98	97.93	96.98	95.56	98.37	98.69	96.30
Hardness (mg/L)	83.47	79.86	92.46	84.89	80.40	80.46	88.73	94.34	125.08	123.86	123.98	125.13	124.68	119.30
SPCOND (uS/cm)	162.70	160.40	175.40	166.10	158.20	155.10	167.20	184.10	252.50	223.20	234.70	233.60	230.10	216.30
CA_MG Index	2.33	2.25	2.35	2.36	2.36	2.37	2.39	2.35	2.38	2.39	2.39	2.43	2.44	2.47
MOD_CA_MG	2.95	2.99	2.90	2.94	2.96	2.96	2.92	2.89	2.75	2.75	2.75	2.74	2.75	2.76
CA:MG Ratio	0.14	0.18	0.13	0.13	0.13	0.13	0.12	0.13	0.10	0.10	0.10	0.09	0.09	0.08
DP	0.016	0.022	0.025	0.030	0.027	0.027	0.027	0.030	0.043	0.039	0.017	0.020	0.018	0.016
TP	0.037	0.044	0.041	0.056	0.050	0.045	0.048	0.046	0.054	0.053	0.032	0.032	0.034	0.028
NO3_NO2	0.155	0.164	0.231	0.233	0.189	0.273	0.290	0.510	0.261	0.322	0.352	0.365	0.336	0.290
TKN	0.308	0.351	0.277	0.407	0.351	0.530	0.433	0.222	0.263	0.275	0.264	0.254	0.305	0.200
TN	0.463	0.515	0.508	0.640	0.539	0.803	0.723	0.732	0.524	0.597	0.616	0.619	0.641	0.490
WTEMP	23.59	21.62	22.14	21.91	23.28	23.06	22.85	21.55	22.11	21.78	21.57	21.79	20.95	21.67
DO	7.10	7.93	8.04	8.01	8.31	11.11	8.97	9.28	7.08	8.30	7.99	7.60	9.39	9.35
pH	8.01	8.02	7.93	7.95	8.09	8.58	8.19	8.18	8.13	8.12	8.10	8.27	8.26	8.40
TDS	105.80	104.50	114.10	108.00	103.40	100.90	108.60	119.70	164.30	162.90	152.60	150.10	148.50	140.50
TSS	4.80	3.20	3.40	7.80	5.40	3.90	3.20	2.30	1.70	1.60	1.80	2.50	3.60	3.10

Longitudinal surveys

Longitudinal surveys of the Cacapon River and South Branch of the Potomac River were conducted by boat in fall 2015. Observers taking part in the surveys were Gordon Selckmann (GMS, Aquatic Ecologist), Jim Cummins (JC, Director of Living Resources), and Charles A. Dean (CAD, Natural Resources Intern). The prominence of algae and SAV were recorded, along with any other observations relevant to growth of aquatic macrophytes or general stream health. Photos were taken of any observations using a Nikon CoolPix AW100 waterproof camera and GPS coordinates were marked using a Garmin handheld GPS.

South Branch of the Potomac River – Lower Moorefield to Upper Trough

The South Branch of the Potomac River, from Moorefield at Rt. 220/28 to the Upper Trough at Harmison's Landing (4.3 Km), was surveyed on September 17, 2015. In 2014 this reach produced a FGA bloom on a shoal large enough to merit a return visit at the request of WVDEP. Contrary to 2014 observations, 2015 macrophytes were very sparse in this reach of the river, and the river bed was largely free of FGA and BGA. Freshwater sponges were observed along the longitudinal.

Event Log for South Branch Longitudinal (Figure 2).

1. Start. Entry Point on South Branch. (39.10424 N, 78.95801 W)
2. Site #1 flagged for revisit (2014 bloom site). No FGA Bloom. (39.11027 N, 78.94833 W)
3. Site #2 flagged for revisit (2014 bloom site). No FGA Bloom. (39.12172 N, 78.93440 W)
4. End. Take out point from South Branch Potomac River. (39.22810 N, 78.43221 W)

Cacapon River - Capon Bridge to Forks of Cacapon

A survey of the Cacapon River, from Capon Bridge to Forks of Cacapon (20km), was conducted on September 18, 2015. The first quarter of this reach, from Capon Bridge to Cold Stream Road, had been surveyed in fall 2013. The survey in 2013 revealed multiple locations of heavy FGA blooms reaching up to 90% coverage, along with a concerning discharge of grey waste from a waste water treatment plant (WWTP) located just downstream of the Rt. 50 bridge at Capon Bridge. An extended longitudinal was conducted this year to document if problematic blooms were occurring in a low residential density, well forested area, and revisit the site of the outfall at the WWTP. A discharge of grey water was again observed to be flowing from the WWTP outfall in 2015 (Event # 2). The discharge came from a metal pipe (marked with permit # WV0103730), unlike in 2014 when it was observed to be flowing directly from of the adjacent field as subsurface flow. The appearance of the discharge was similar to that observed in 2014, however no prominent odor was detected. The plume of grey water from this outfall reached about 75m downstream and terminated at Event #3. Multiple pictures were taken to document the discharge and resultant plume. Dense *Hydrilla* SAV patches were first observed downstream from the WWTP outfall at Event #4 (20% cover) and appeared regularly to Event #6. *Hydrilla* patches reached up to 95% coverage. *Vallisneria* occurred within *Hydrilla* beds at the confluence of Farms River. We spoke with a citizen of Capon Bridge who expressed that the excessive growth of macrophytes along Farms River is a nuisance to himself and other nearby landowners. Filamentous green algae became prominent at Event #7, where it appeared to be senescing yet still completely covering benthic structures. A prominence of blue green algae was also first observed here. This BGA growth led into a full bloom just downstream where combined FGA, BGA, and diatomaceous mats covered roughly 90% of the river bottom in a deep pool below a rock outcrop. At Event #8, *Hydrilla* and *Vallisneria* were again prominent, with small amounts of FGA and *Podostemum* observed. Long chains of FGA occurred at Event #8 but were confined to the riffle, covering 10% of that area. As water velocity became less contained within the thalweg and slowed, there was an immediate large bloom covering 70% of the total stream bottom and ending at Event #10. A more wild area began at Event #11, where dense *Vallisneria* was observed, and continued for most of the remaining longitudinal transect. This reach of the Cacapon River is surrounded by forest and is generally inaccessible from the adjacent land. A large FGA bloom occurred within the first half of this forested area, from Event #12 to Event #13, where coverage reached 70%. Presence of FGA in this stretch of river was scattered and appeared in clustered distributions, suspended on SAV growth. Weeping rocks (Event #14) were recorded as a point of reference as well as marked as a potentially new water chemistry input. Event points #15 and #16 marked the reappearance of SAV (~40% coverage) and FGA (~60% coverage) on the last leg of our Cacapon longitudinal. The longitudinal concluded at the Rt. 127 bridge boat ramp.

Event Log for Cacapon River Longitudinal (Figure3).

1. Start. Entry Point on Cacapon. (39.29759 N, 78.43522 W)
2. Start of Grey Water Discharge. (39.29980 N, 78.43221 W)
3. End of grey water discharge. (39.30011 N, 78.43176 W)
4. Begin SAV: Dense *Hydrilla* patch, with 20% stream-bed cover. (39.30274 N, 78.42996 W)
5. SAV: *Hydrilla* and *Vallisneria* patches reach 95% stream-bed cover and continue to *Event #6*. (39.30537 N, 78.42959 W)
6. End SAV: Dense SAV patches stop. (39.32042 N, 78.41152 W)
7. FGA and BGA observed in abundance. Due to depth of pool accurate measure of FGA/BGA abundance was not feasible, however a visual estimate of greater than 90% benthic cover was recorded. The bloom a continued for 100m. (39.32313 N, 78.41203 W)
8. Hydrilla, Vallisneria, Potostemum sp., and FGA observed in high densities. (39.33437 N, 78.42447 W)
9. FGA bloom observed at greater than 70% benthic coverage. Bloom continues to Event #10. (39.33706 N, 78.42716 W)
10. End of FGA bloom. (39.33758 N, 78.42804 W)
11. Dense *Vallisneria* coverage. Start of river access only area. (39.34214 N, 78.43376 W)
12. Start of high primary production reach. FGA and SAV Alternated dominance with coverage between 50-80%. (39.34396 N, 78.42779 W)
13. End of high primary productivity reach. (39.37507 N, 78.42283 W)
14. Weeping rocks. (39.37762 N, 78.42573 W)
15. SAV coverage ~40%. (39.39452 N, 78.41248 W)
16. FGA coverage ~60%. (39.39452 N, 78.41237 W)
17. Take out at Rt. 127 bridge. (39.40089 N, 78.41550 W)

Figure 1. Map of logitudinal observation of the South Branch Potomac River between Rt. 220/28 Bridge and Harmison's Landing. Numeric points are associated with the longitudinal event log found on page 17.

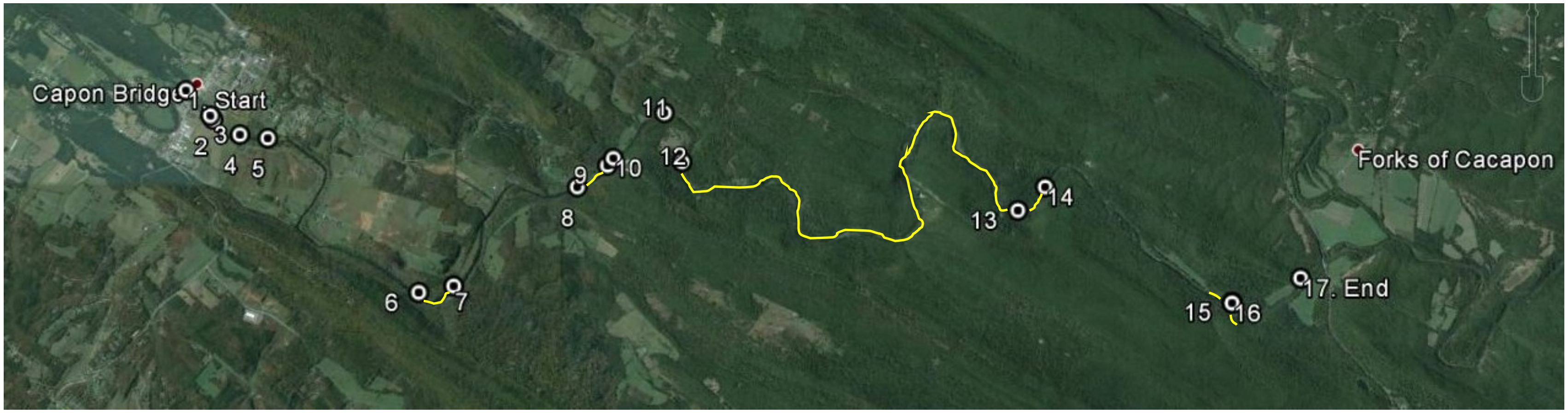


Figure 2. Map of longitudinal observation of the Cacapon River between Cacapon Bridge, WV and Forks of Cacapon, WV. Numeric points are associated with the longitudinal event list found on page 18. Regions with excessive primary production (SAV, BGA and FGA) are defined in yellow.

Conclusion and suggestions for the future

Results of the 2015 survey were unlike those from the previous three years. Sites that had regularly and predictably produce high density filamentous algae blooms did not hold significant amounts of FGA. Instead, large FGA blooms appear to have been replaced by large, dense SAV beds that dominated the river throughout the sampling season. It is difficult to identify specifically what factors contributed to the shift in floral composition at the regularly sampled sites, however, based on available evidence, it appears that physical factors such as flow rate and rainfall early in the summer (Appendix 1 and 2), not a change in nutrient input, played a large role in settlement and eventual dominance of SAV.

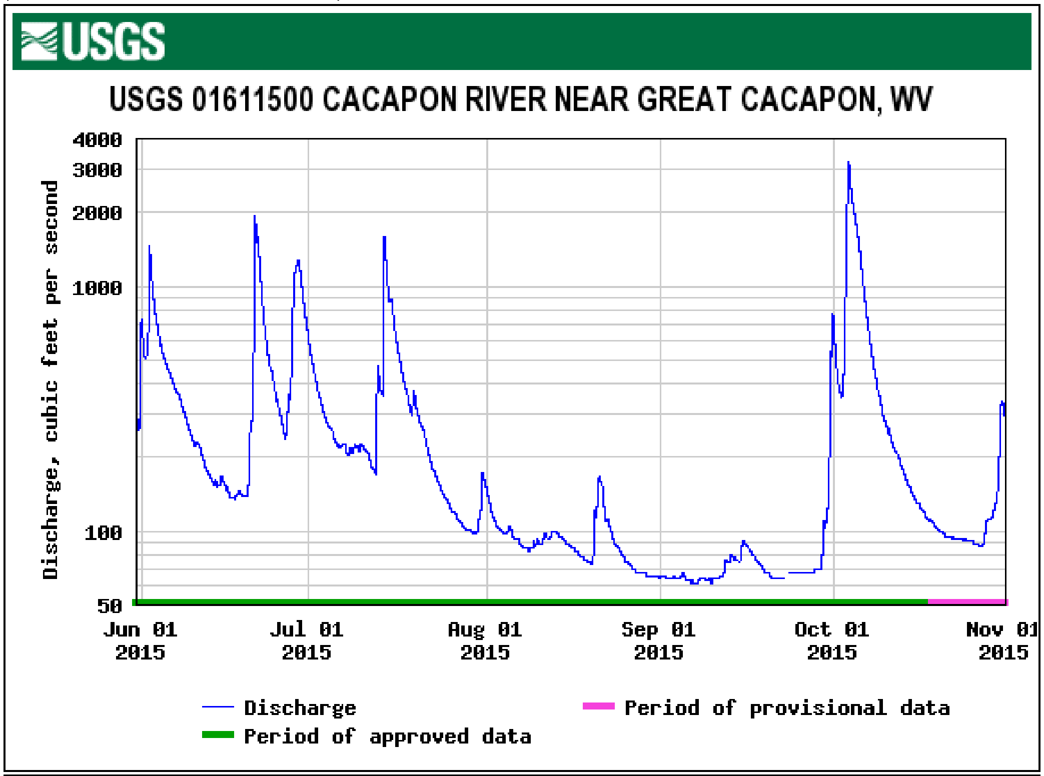
Considerations for future work should include earlier nutrient sampling, additional sites in the Lost, North Fork and South Fork rivers and source water tracking. Spring water chemistry samples may elucidate water column nutrients loads better than the summer months when biologic activity, and specifically the increase in macrophyte and/or algae biomass, are not cofounding variables. The inclusion of additional sites will increase our sample size as well as aid in the tracking of source nutrients in each of the study systems.

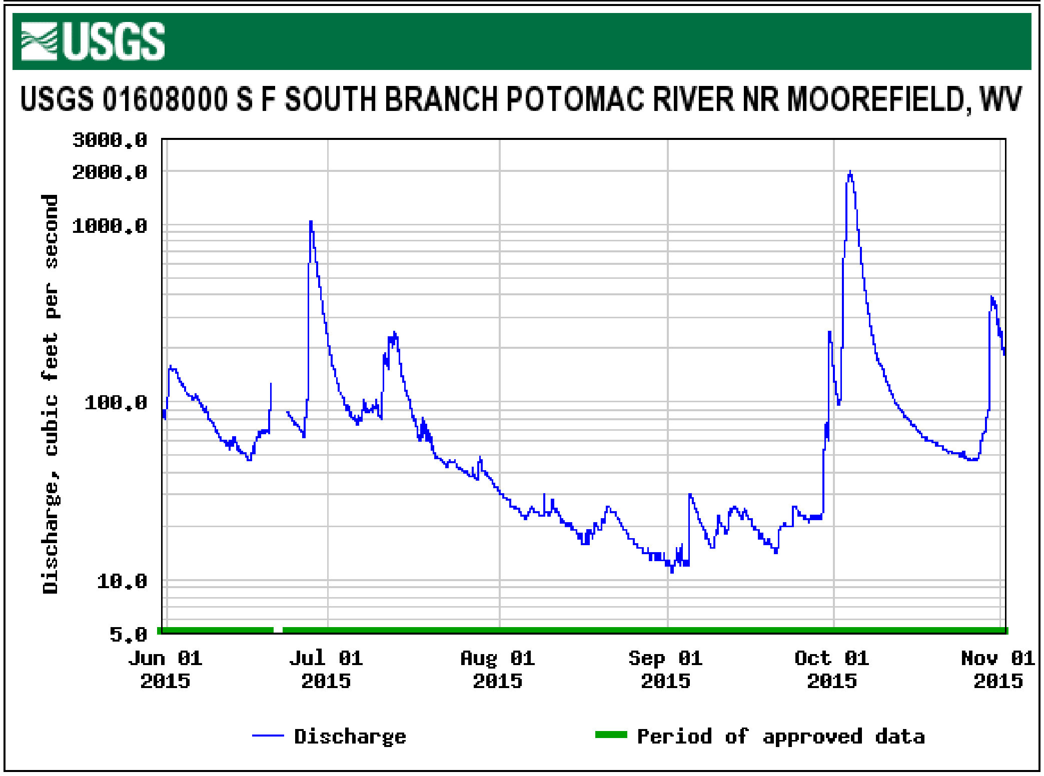
Results of the 2015 supplemental study, “The Cacapon River Microcosm Study 2015” offer a closer look at the effects of excessive macrophyte production. Small scale, rigorous targeted studies with continuous DO loggers give a more complete picture of possible causes and effects related to nutrient pollution.

References

WVDEP (West Virginia Department of Environmental Protection). 2015. Watershed Assessment Branch 2015 Field Sampling Standard Operating Procedures. Division of Water and Waste Management, Watershed Assessment Branch, Charleston, WV.

Appendix I. Hydrographs from related USGS gages for the period of June 1, 2015 – October 31, 2015



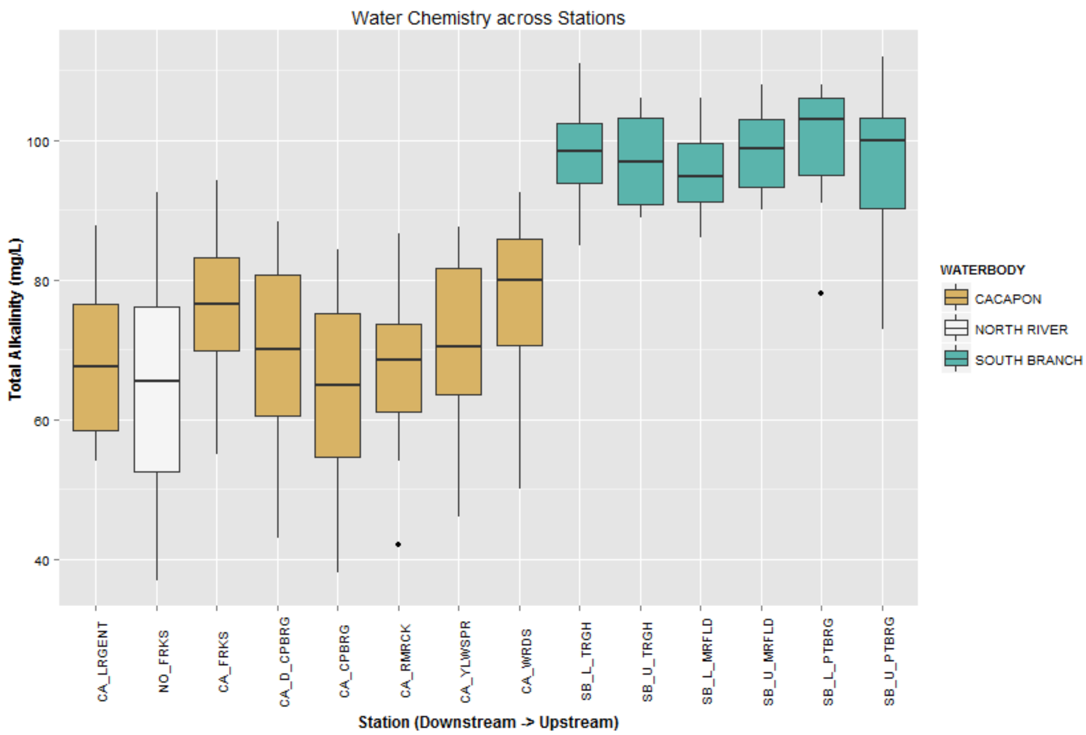


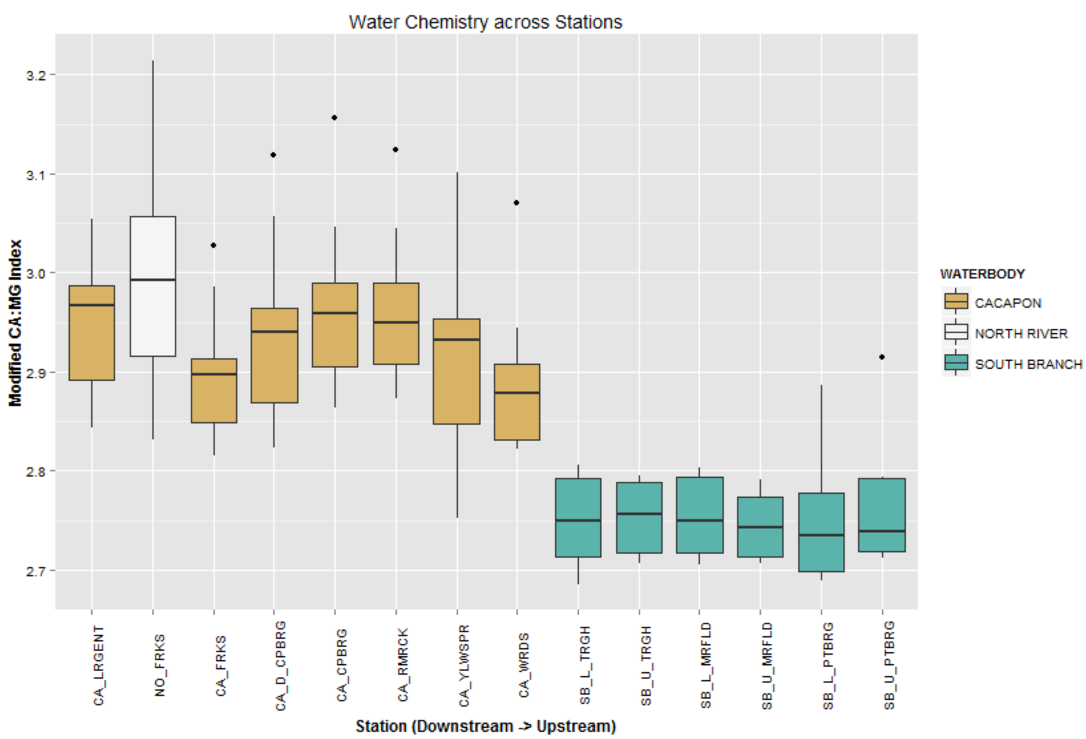
Appendix II.
Accumulative monthly rainfall (cm) for Winchester, Virginia. (Winchester Va is the nearest weather station 30Km west of Yellow Springs, WV).

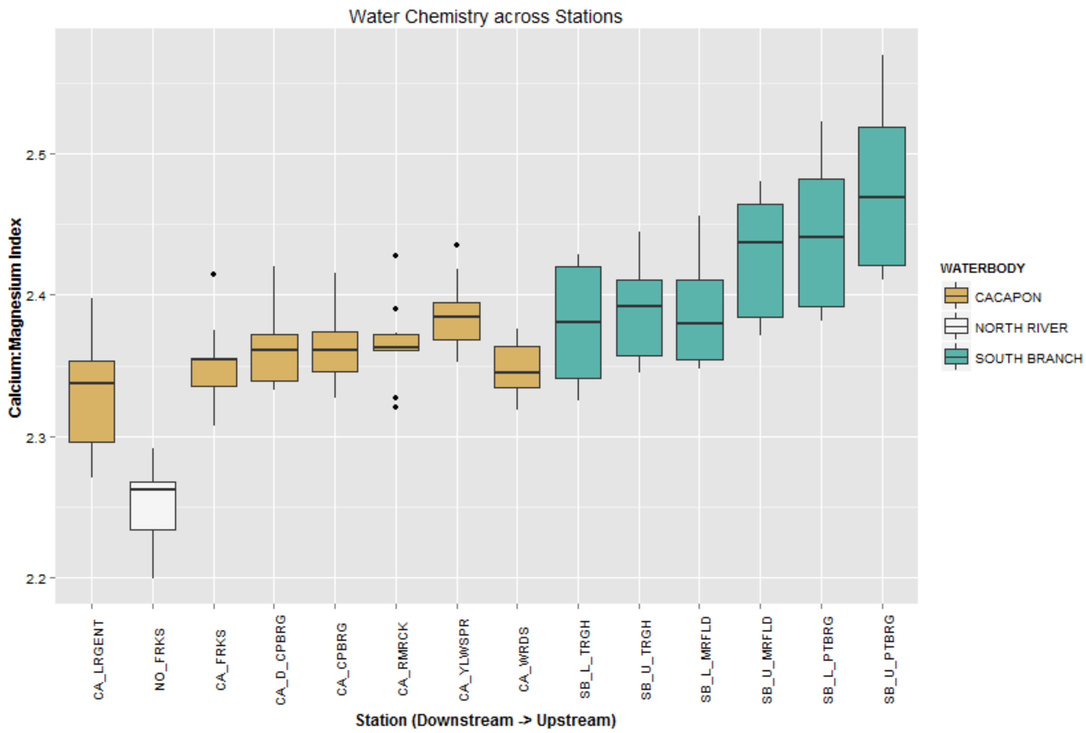
	2015 Precipitation (cm)	Historical Average Precipitation (cm)
May	8.66	9.70
June	15.57	9.30
July	6.93	9.09
August	2.34	8.20
September	11.89	9.91
October	7.77	7.49

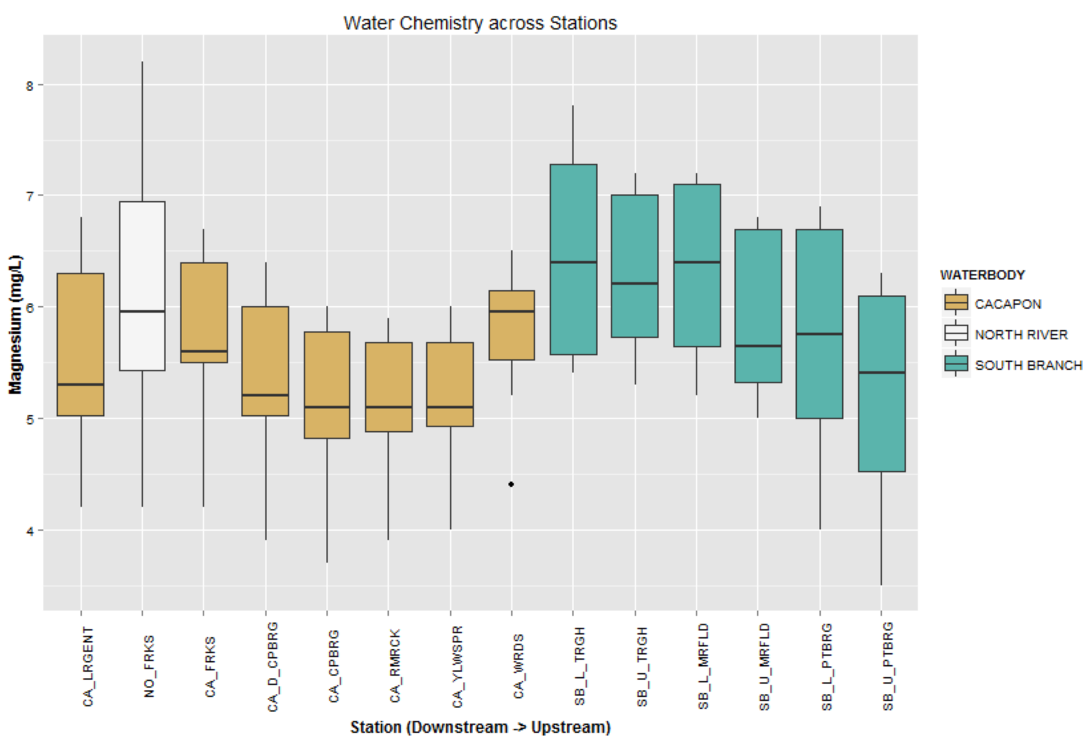
Appendix III.

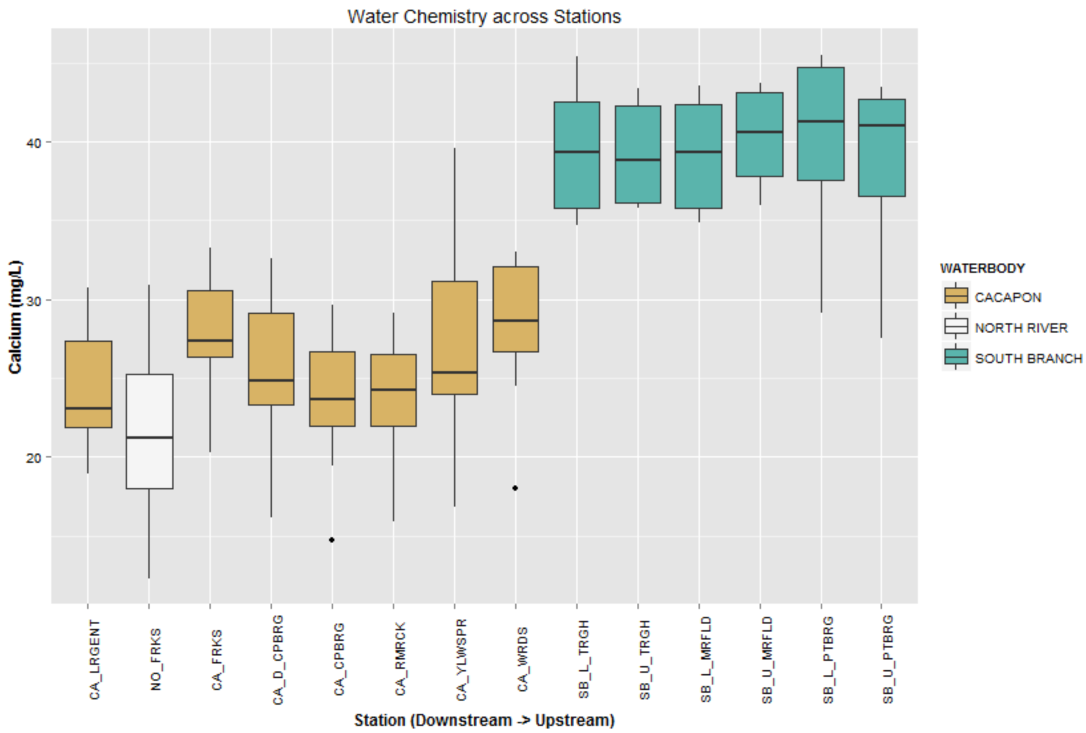
Site specific trends in water chemistry across all sites in 2015.

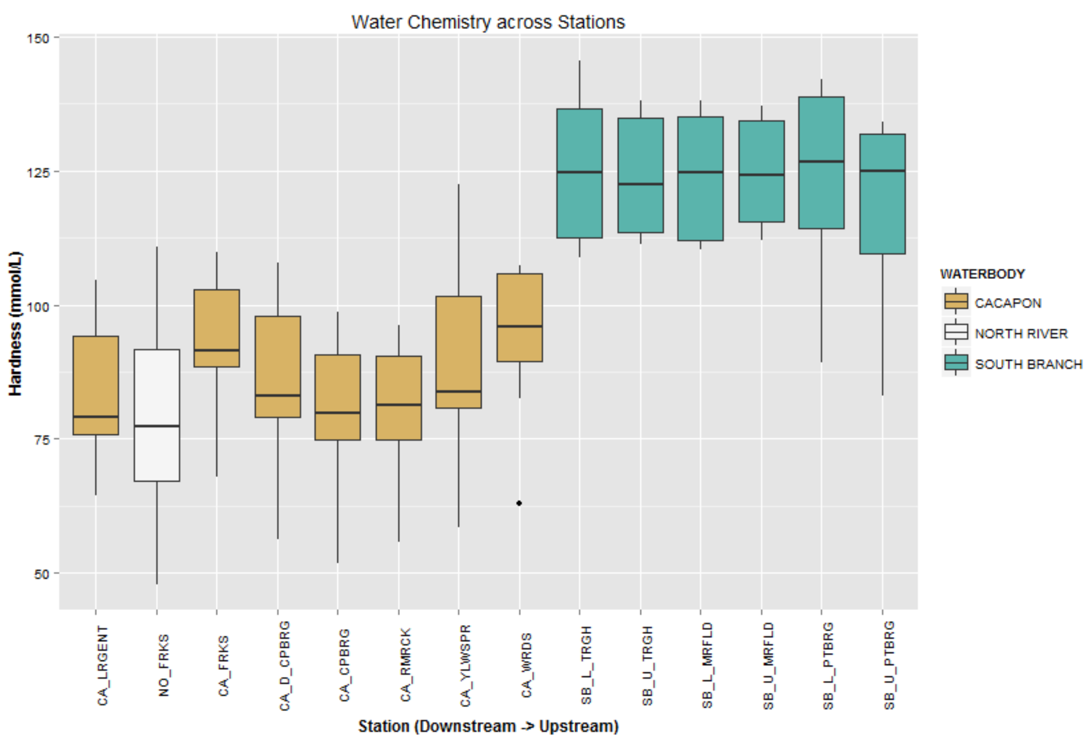


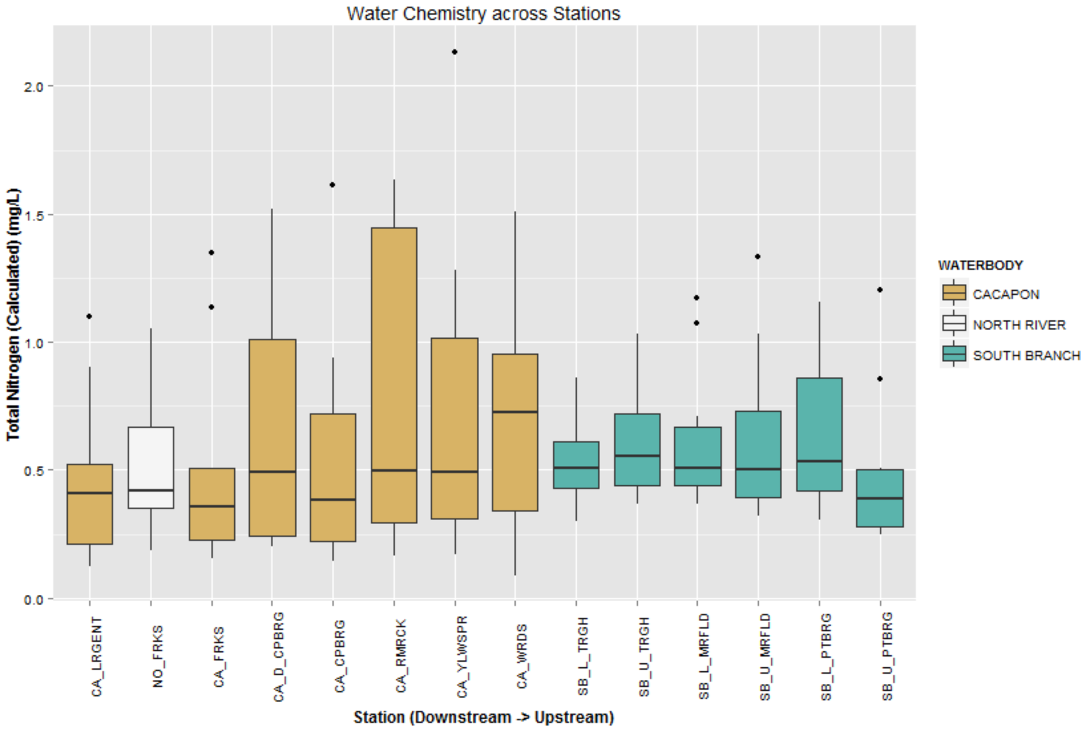


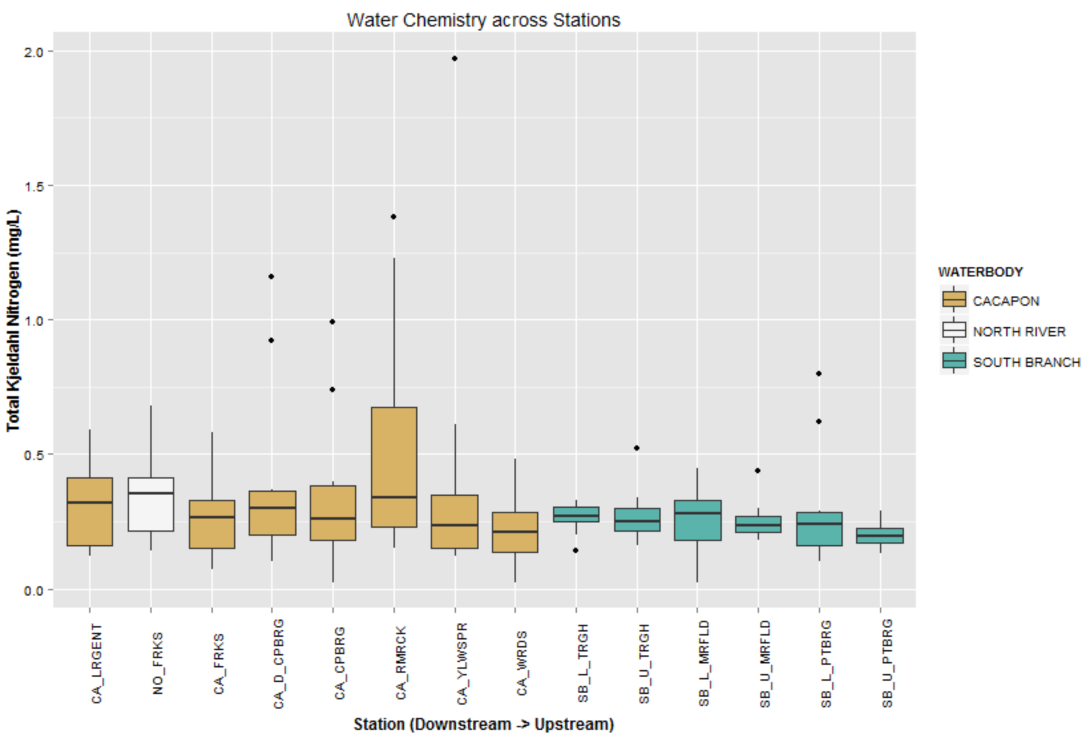

Water Chemistry across Stations
Calcium:Magnesium Index
2.5
2.4
2.3
2.2
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

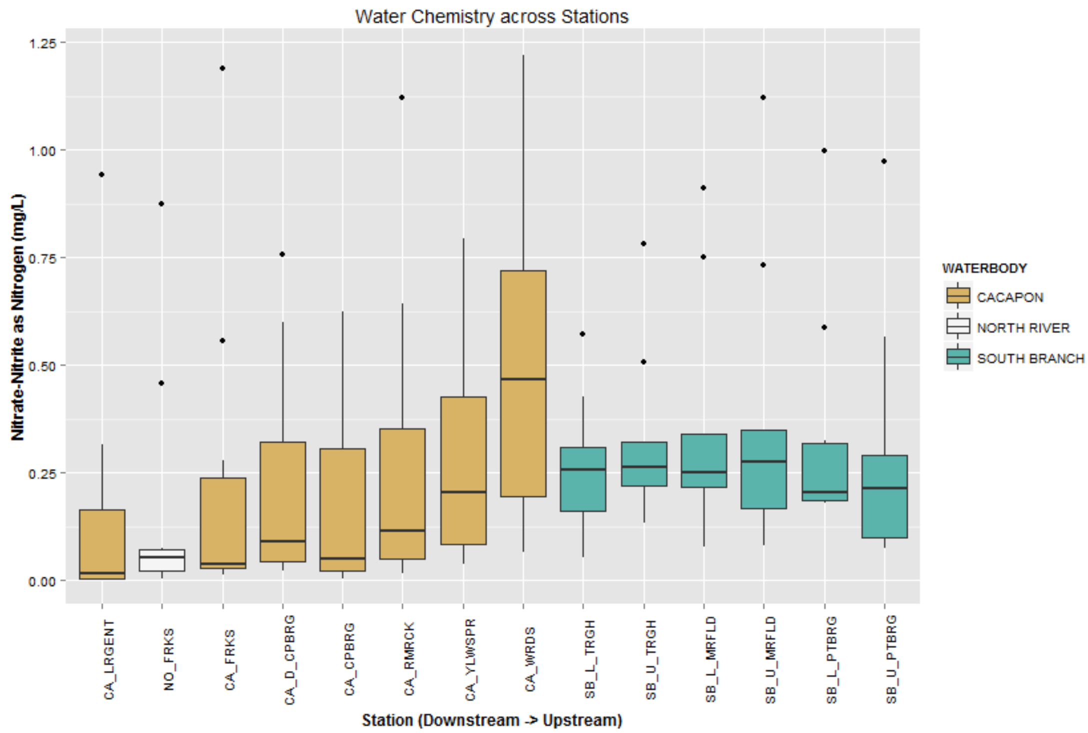

Water Chemistry across Stations
Magnesium (mg/L)
8
7
6
5
4
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

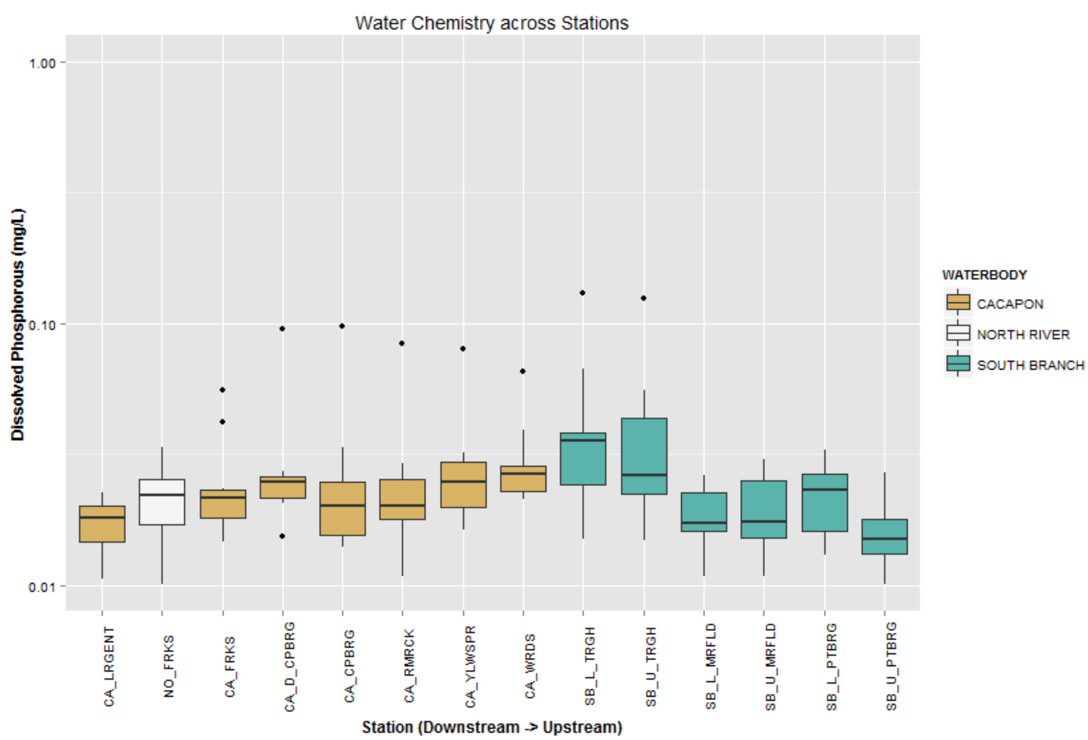

Water Chemistry across Stations
Calcium (mg/L)
40
30
20
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

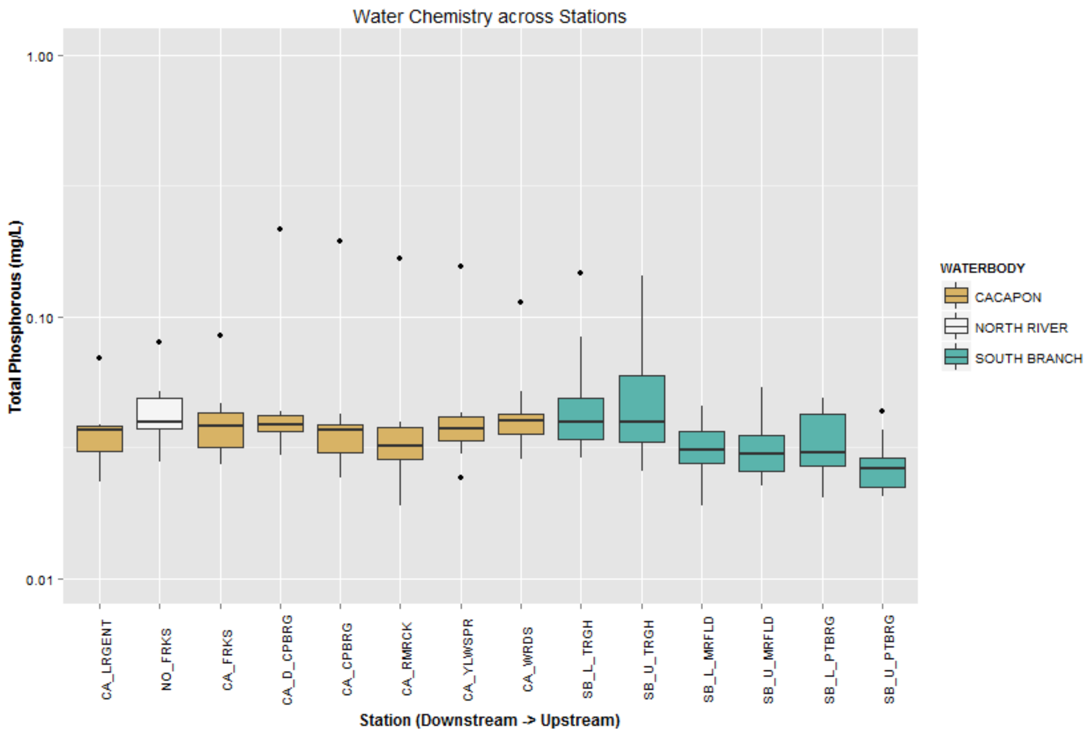

Water Chemistry across Stations
Hardness (mmol/L)
150
125
100
75
50
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH


Water Chemistry across Stations
Total Nitrogen (Calculated) (mg/L)
0.0
0.5
1.0
1.5
2.0
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

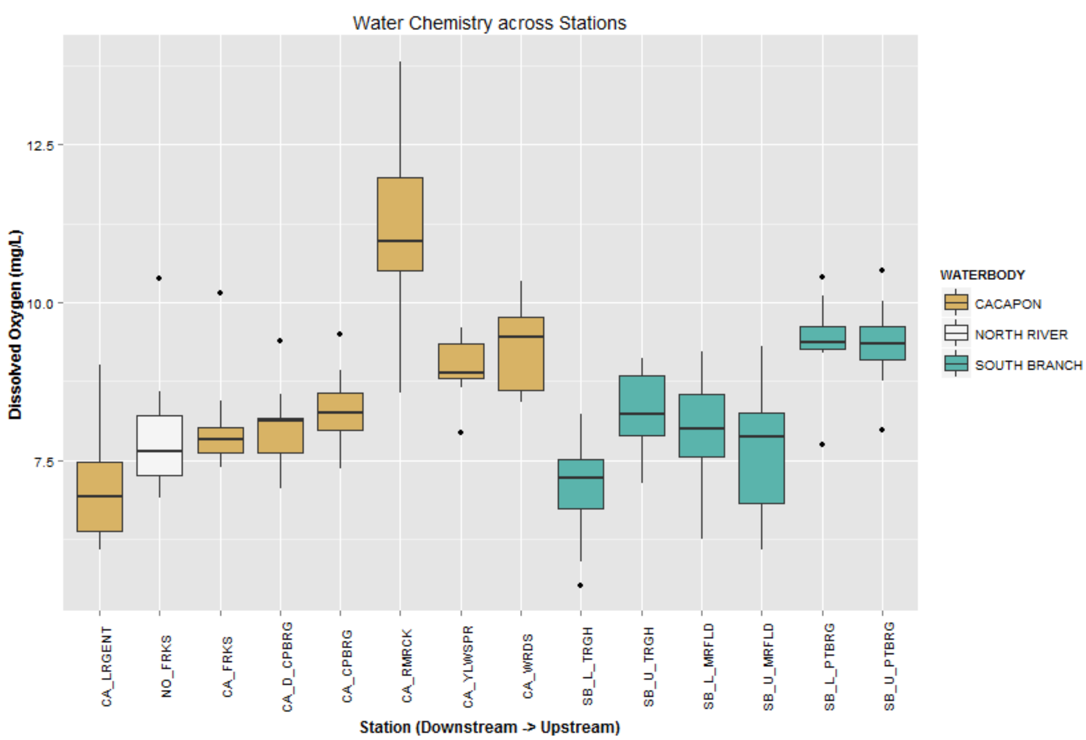

Water Chemistry across Stations
Total Kjeldahl Nitrogen (mg/L)
0.0
0.5
1.0
1.5
2.0
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH


Water Chemistry across Stations
Nitrate-Nitrite as Nitrogen (mg/L)
1.25
1.00
0.75
0.50
0.25
0.00
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

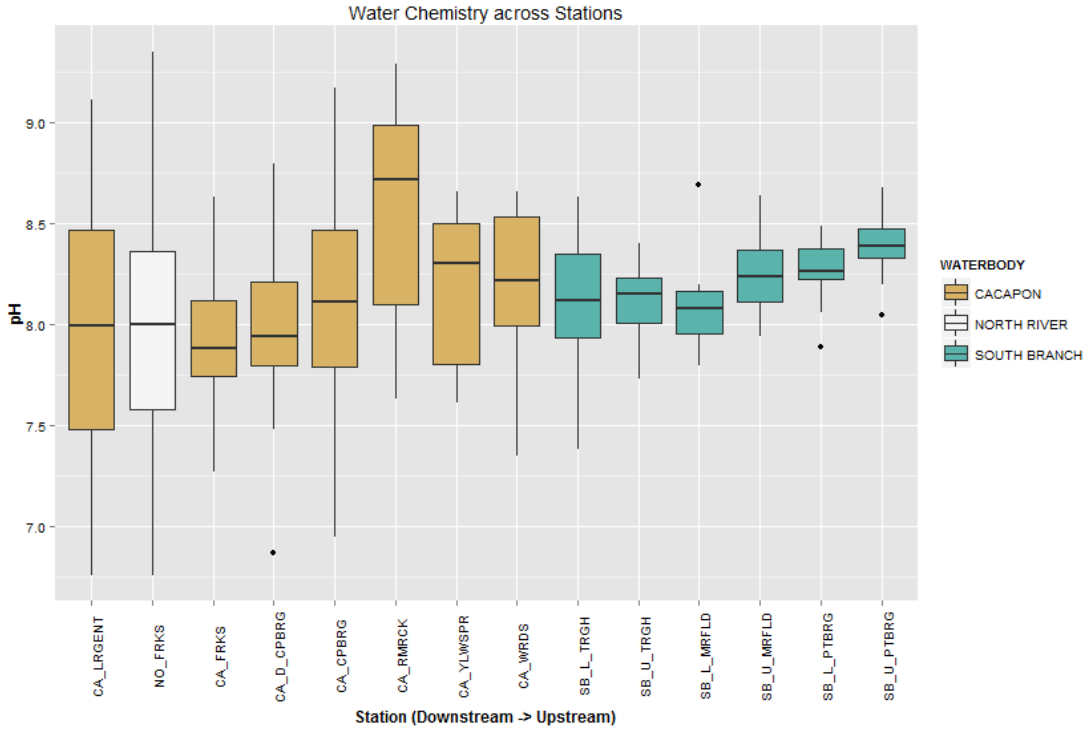

Water Chemistry across Stations
Dissolved Phosphorous (mg/L)
1.00
0.10
0.01
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

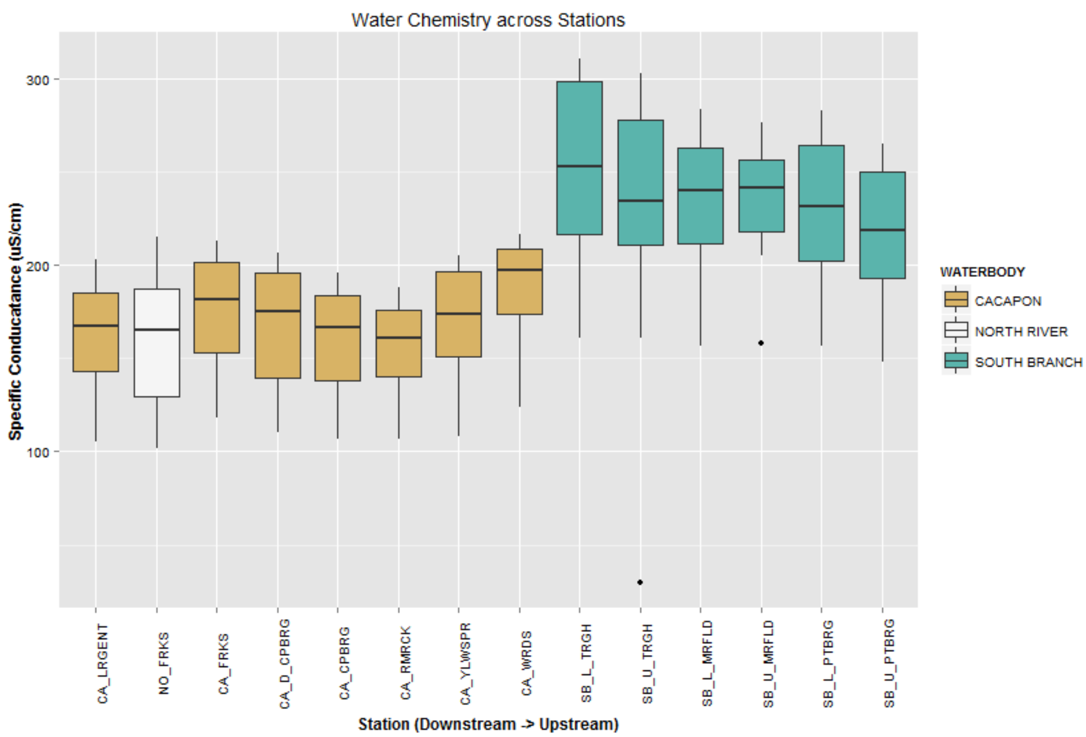


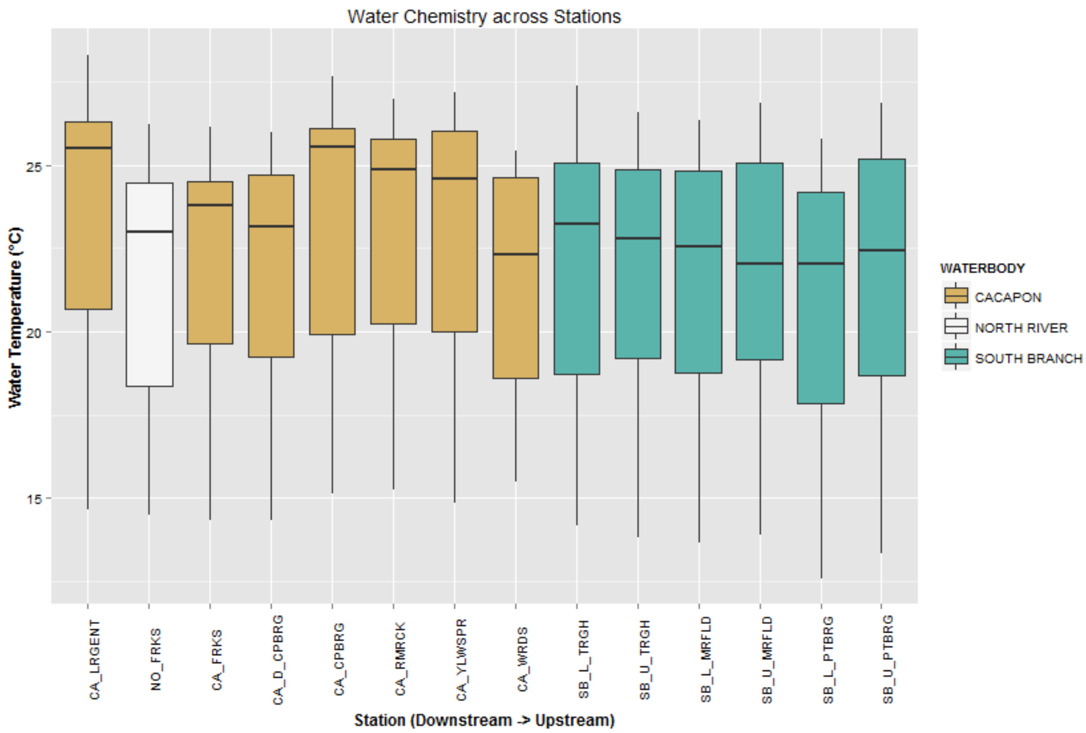
Water Chemistry across Stations
Total Phosphorous (mg/L)
1.00
0.10
0.01
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

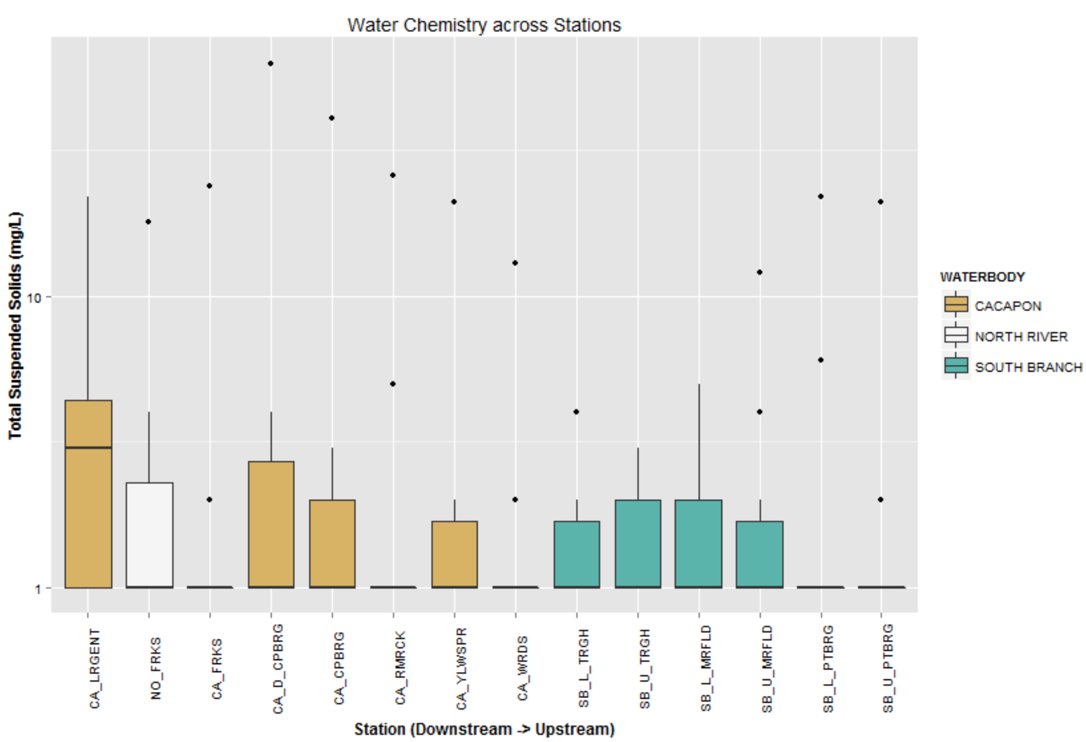


Water Chemistry across Stations
Dissolved Oxygen (mg/L)
12.5
10.0
7.5
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH


Water Chemistry across Stations
pH
9.0
8.5
8.0
7.5
7.0
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

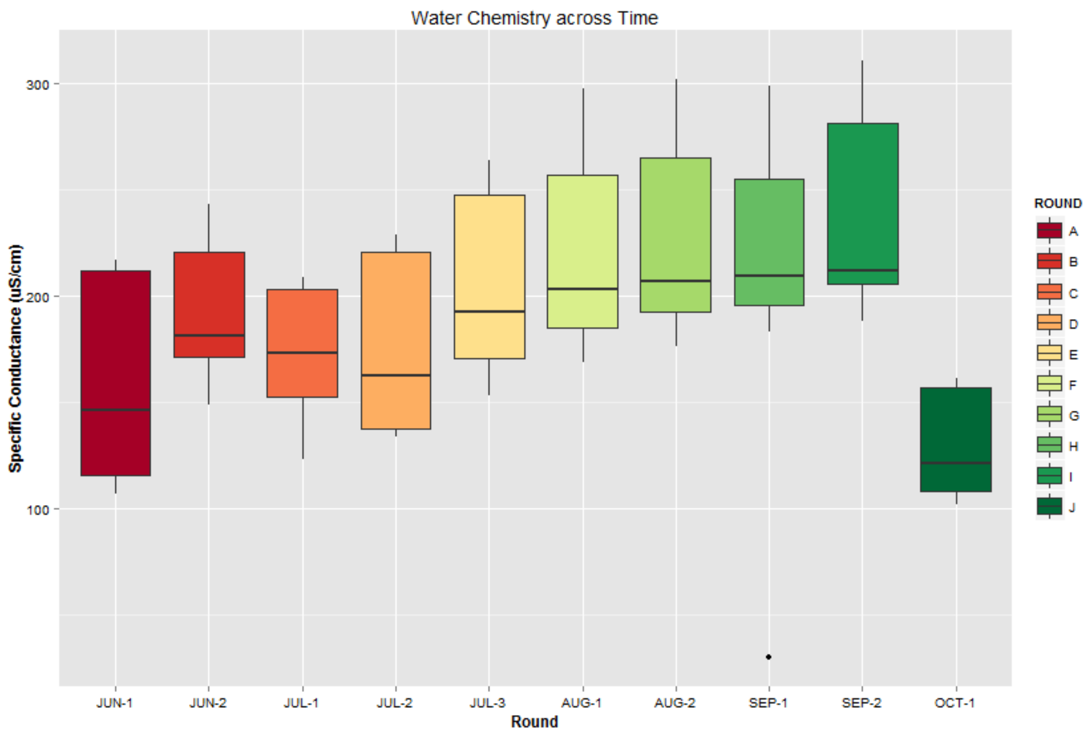

Water Chemistry across Stations
Specific Conducatance (uS/cm)
300
200
100
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH

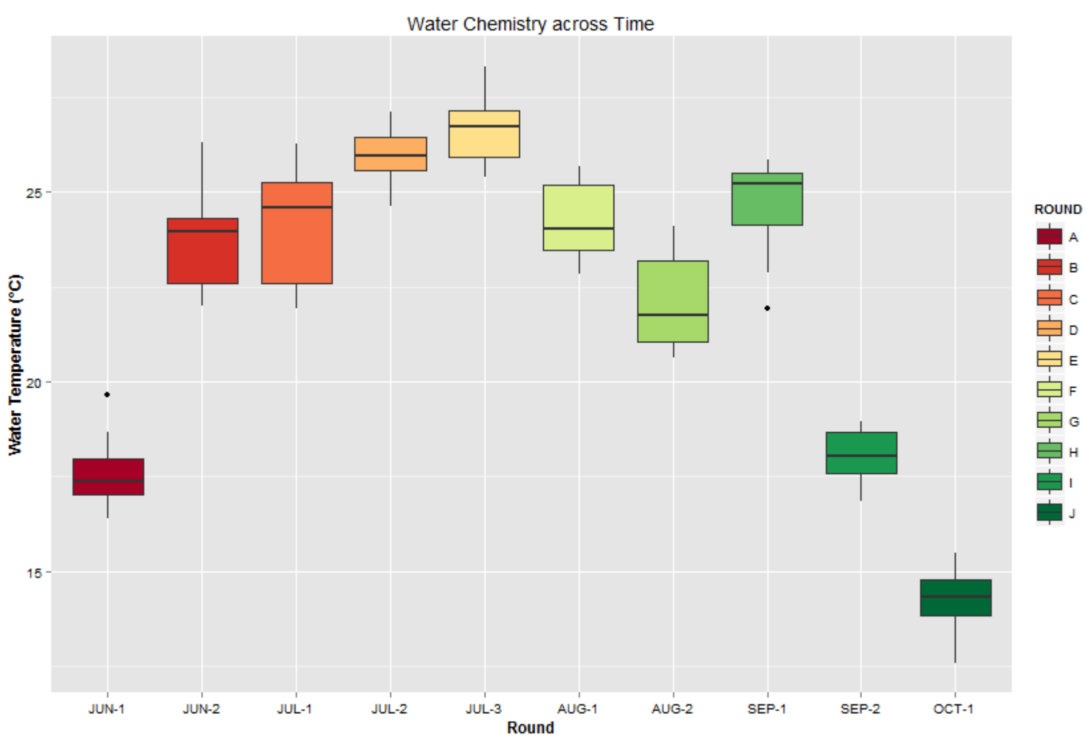

Water Chemistry across Stations
Water Temperature (°C)
25
20
15
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)

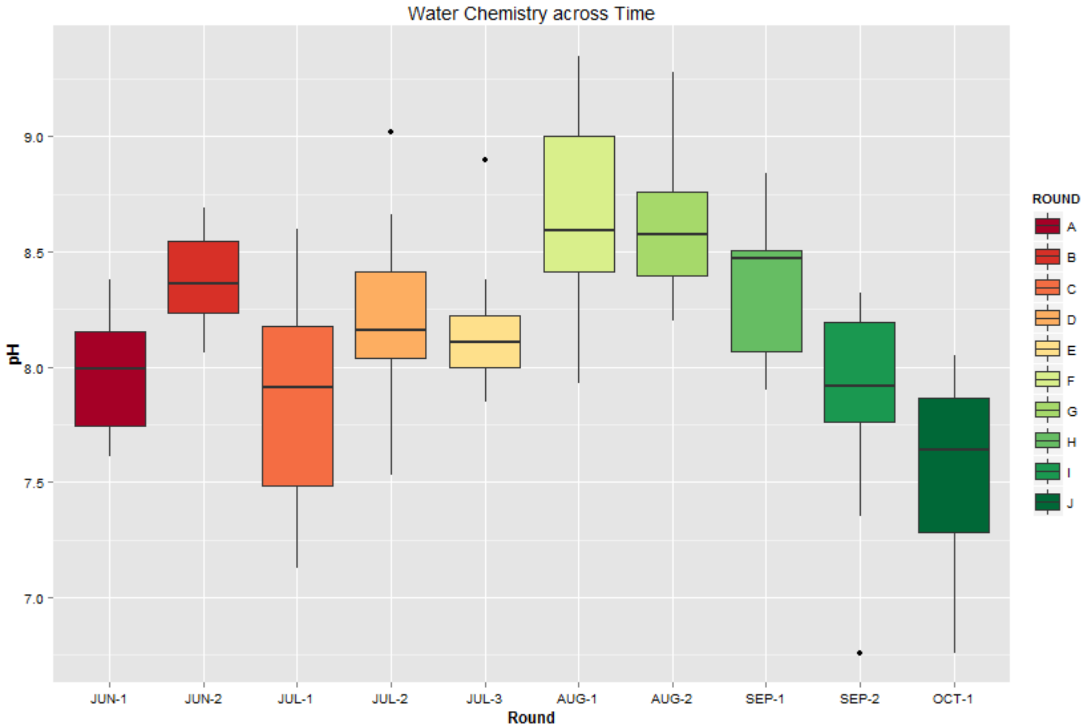

Water Chemistry across Stations
Total Suspended Solids (mg/L)
10
1
WATERBODY
CACAPON
NORTH RIVER
SOUTH BRANCH
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
SB_L_PTBRG
SB_U_PTBRG
Station (Downstream -> Upstream)

Appendix IV

Temporal trends in water chemistry across all sites in (2015).







Water Chemistry across Time
pH
9.0
8.5
8.0
7.5
7.0
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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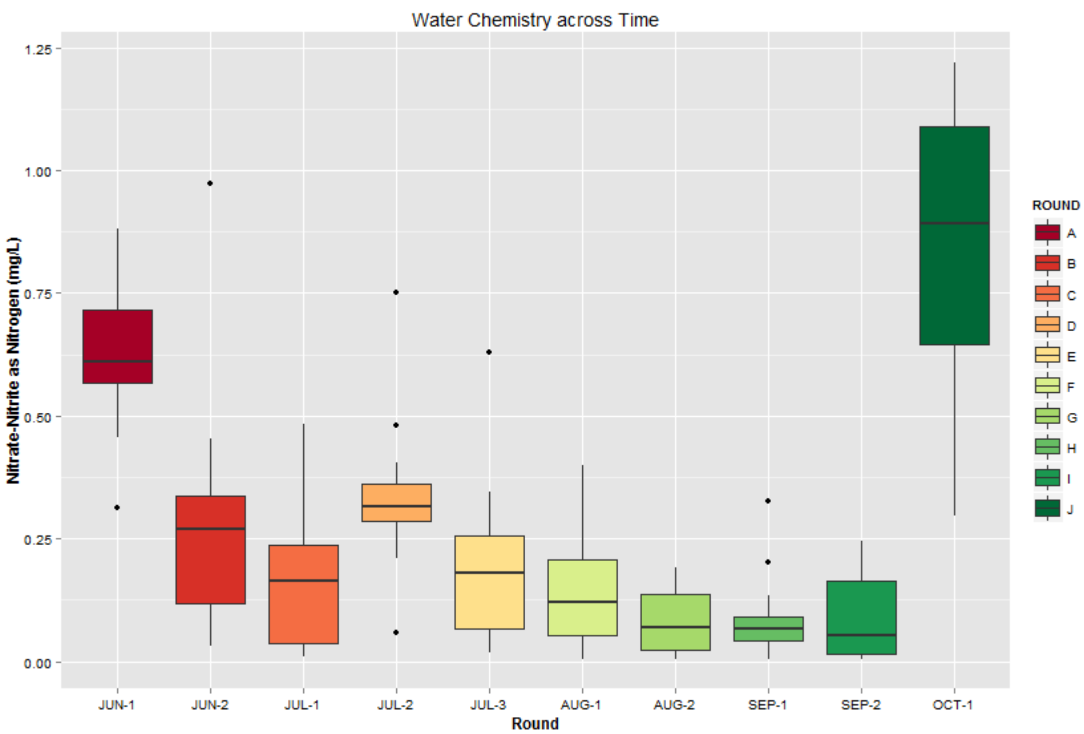

Water Chemistry across Time
Nitrate-Nitrite as Nitrogen (mg/L)
1.25
1.00
0.75
0.50
0.25
0.00
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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C
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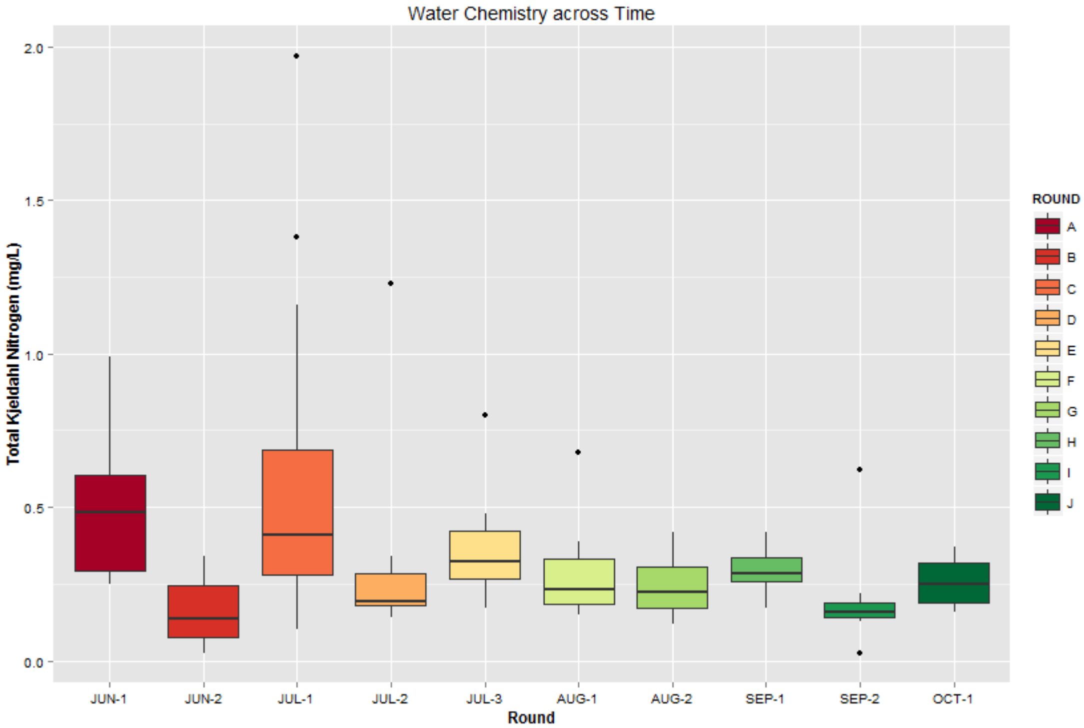

Water Chemistry across Time
Total Kjeldahl Nitrogen (mg/L)
2.0
1.5
1.0
0.5
0.0
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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C
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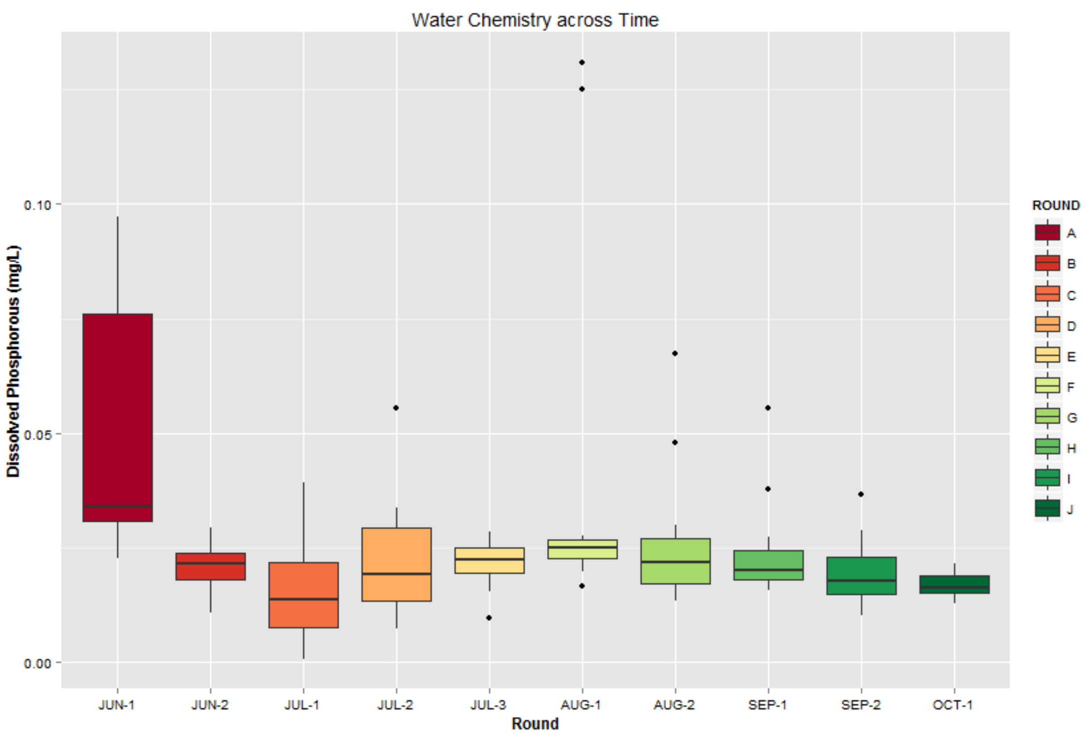
J



Water Chemistry across Time
Dissolved Phosphorous (mg/L)
0.10
0.05
0.00
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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C
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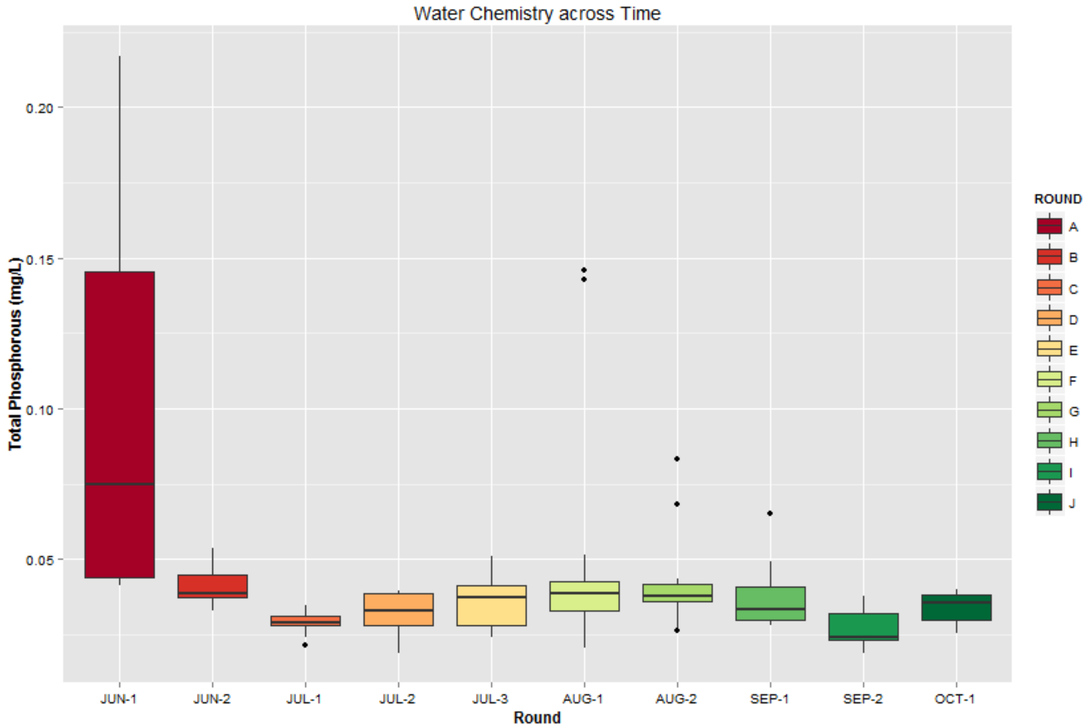
I
J


Water Chemistry across Time
Total Phosphorous (mg/L)
0.20
0.15
0.10
0.05
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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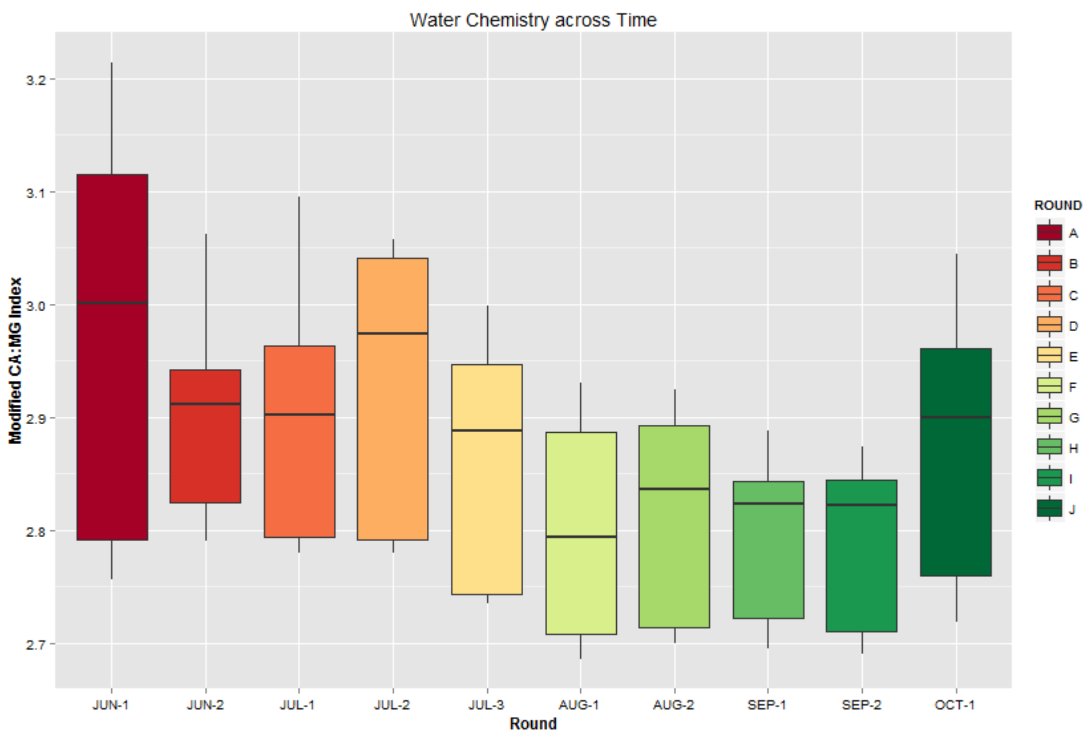
I
J


Water Chemistry across Time
Modified CA:MG Index
3.2
3.1
3.0
2.9
2.8
2.7
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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C
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E
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G
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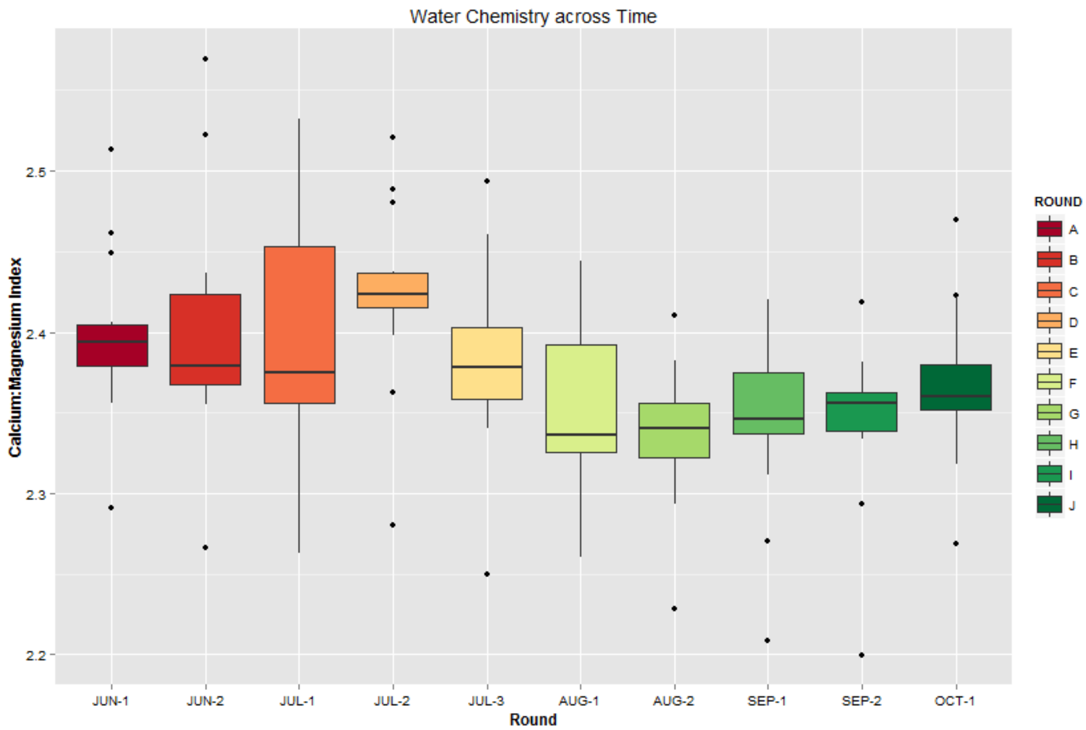
I
J



Water Chemistry across Time
Calcium:Magnesium Index
2.5
2.4
2.3
2.2
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
B
C
D
E
F
G
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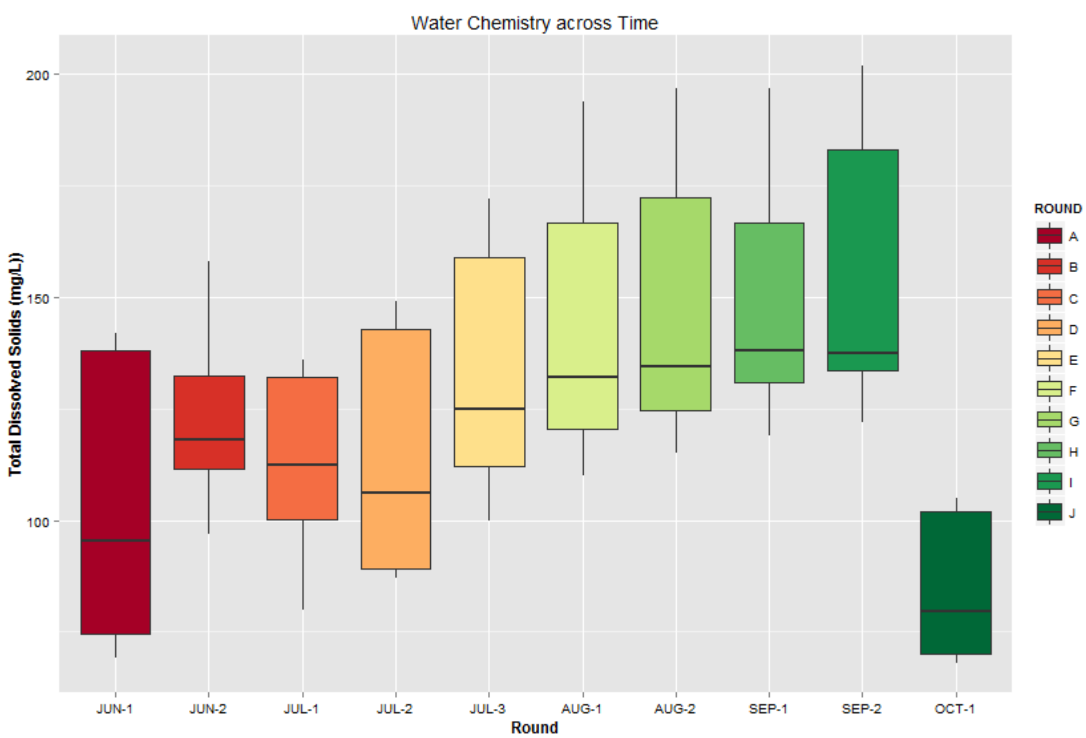
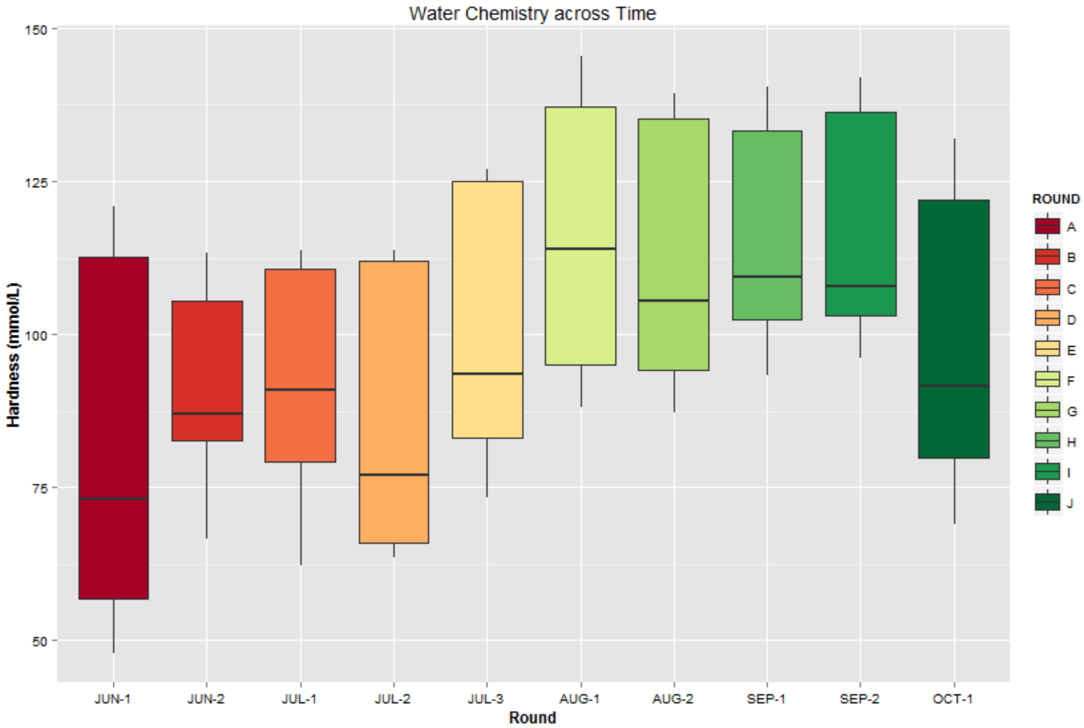
I
J



Water Chemistry across Time
Total Dissolved Solids (mg/L))
200
150
100
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
B
C
D
E
F
G
H
I
J


Water Chemistry across Time
Hardness (mmol/L)
150
125
100
75
50
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
A
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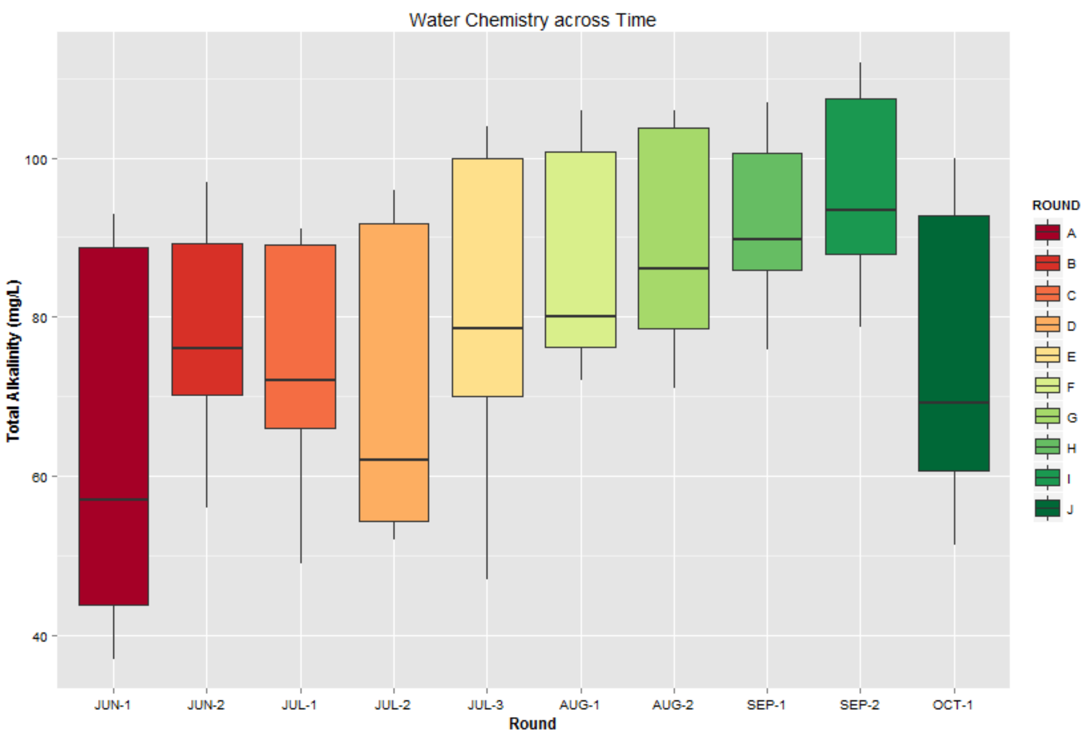
Water Chemistry across Time
Total Alkalinity (mg/L)
100
80
60
40
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
ROUND
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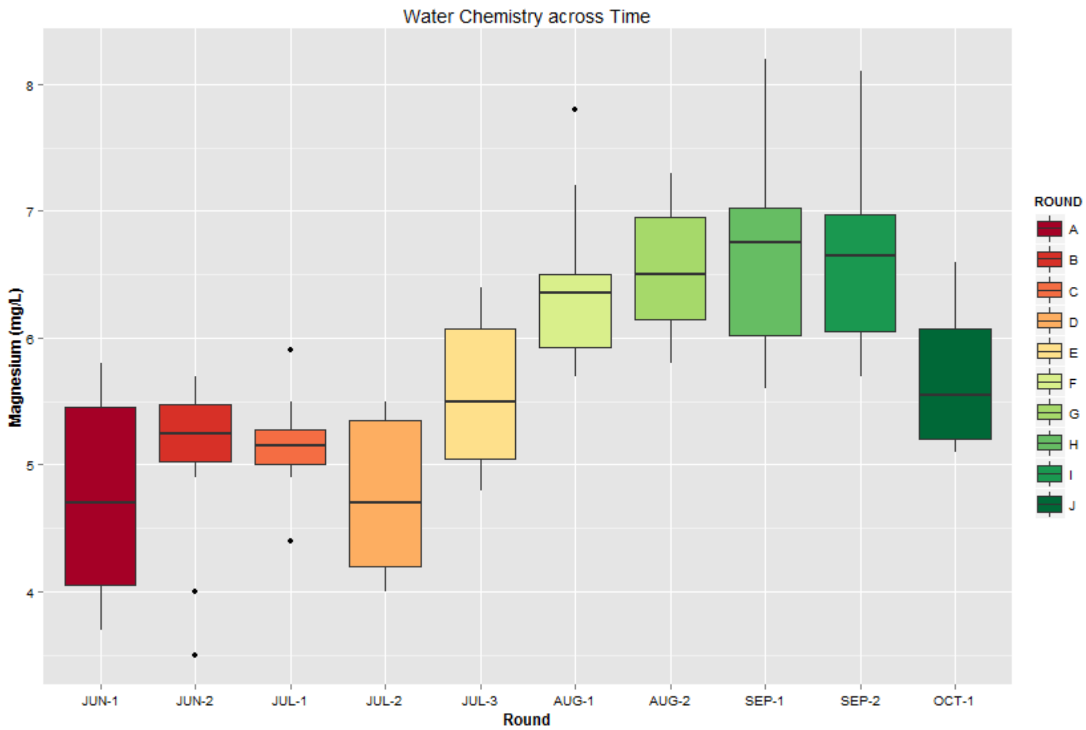
Water Chemistry across Time
Magnesium (mg/L)
8
7
6
5
4
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
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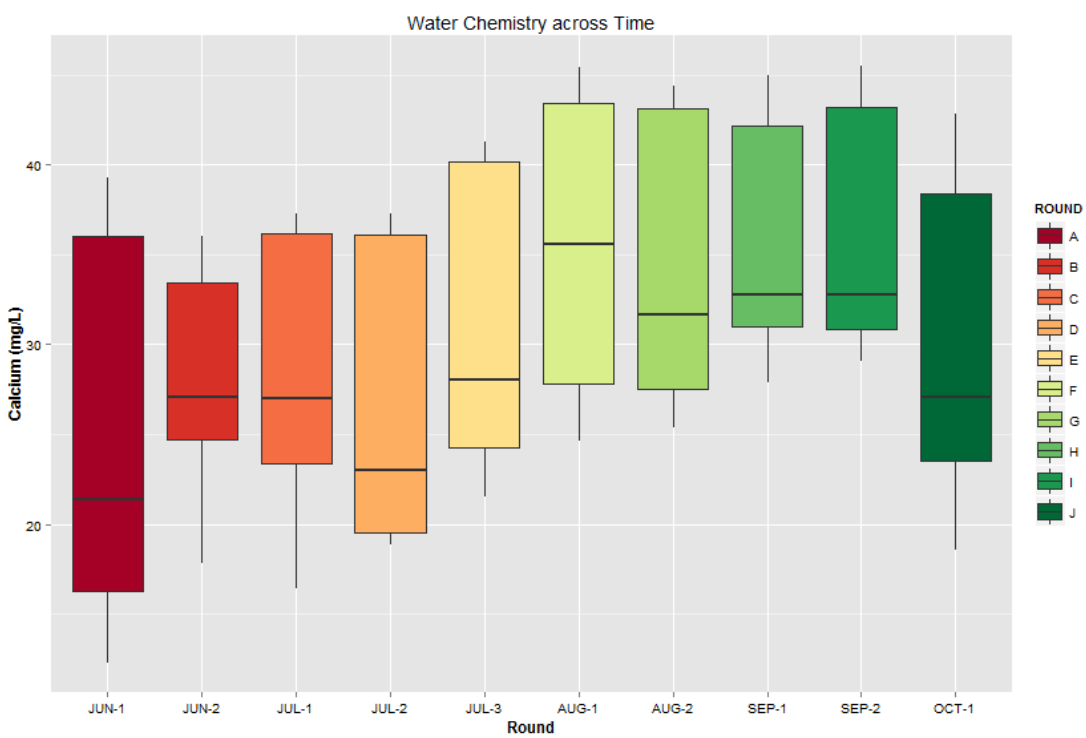
Water Chemistry across Time
Calcium (mg/L)
40
30
20
JUN-1
JUN-2
JUL-1
JUL-2
JUL-3
AUG-1
AUG-2
SEP-1
SEP-2
OCT-1
Round
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