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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Interstate Commission on the Potomac River Basin

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Background

West Virginia Department of Environmental Protection (WVDEP) has been observing and evaluating the breadth and causes of filamentous green algae 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) assists the WVDEP in documenting algae blooms in the South Branch Potomac, Cacapon, and Shenandoah rivers.

Methods

In 2013, ICPRB biologists implemented the WVDEP Filamentous Algae Monitoring Protocol (WVDEP 2013) at 14 fixed locations over 10 rounds between June and October (Table 1). Information on the WVDEP filamentous algae monitoring program, including the Standard Operating Procedures for algae sampling and water chemistry, and the program's field data sheet can be found on-line at http://www.dep.wv.gov/WWE/Programs/wqs/Pages/FilamentousAlgaeinWestVirginia.aspx. The protocols consist of routine water chemistry sampling, a rapid assessment style field form, semi-quantitative algae coverage estimates, and longitudinal surveys to document extents of bloom events. A total of three longitudinal surveys were performed. The ICPRB field crew consisted of two biologists for all sampling rounds and longitudinal surveys. Personnel included ICPRB staff persons Adam Griggs (AG) and either Jim Cummins (JC), Claire Buchanan (CB) or summer intern Kylee Loss (KL).

Sampling Round	Sampling Dates
JUN-1	Jun 4-5
JUN-2	Jun 18-20
JUL-1	Jul 1-2
JUL-2	Jul 18-19
JUL-3	Jul 30-31
AUG-1	Aug 14-15
AUG-2	Aug 27-28
SEP-1	Sep 12-13
OCT-1	Oct 2-3
OCT-2	Oct 17-18

Table 1. Sample rounds and dates.

Station Locations

The fourteen sampling stations were targeted by the WVDEP, based upon past observations, targeted inquiries, and best professional judgment. Eight stations are located in the Cacapon basin, seven on the Cacapon River main-stem between the towns of Largent and Wardensville, and one near the mouth of the North River, the largest Cacapon tributary. Two stations monitored the short stretch of Shenandoah River in the state, one each near the upstream and downstream borders of the West Virginia state line. Four stations were located on the South Branch Potomac, one above and three below the town of Moorefield, WV (Table 2 and Figure 1). Ten out of fourteen stations were located at or near bridge crossings, while the other four were accessed along parallel roadways. Six stations had public assess put-ins, and the remainder were accessed from bridge right-aways or through private landowner permission. Stations were generally sampled one river at a time, traveling sequentially either upstream or downstream, depending upon the route. However, overnight accommodations or camping locations influenced sampling routes, if used.

Site Name	ID #	Site Location Description	Lat / Long Coordinates	
SHEN_LWR	1	Shenandoah at Rt. 340 near Harper's Ferry	39.32040	-77.74268
SHEN_UPR	2	Shenandoah at Ann Lewis Road near state line	39.18106	-77.85733
NO_FRKS	3	North River at Gaston Rd. / Forks of Cacapon	39.40194	-78.42448
CA_LRGNT	4	Cacapon River at Rt. 9 in the town of Largent	39.48112	-78.38448
CA_FRKS	5	Cacapon River at Rt. 127 / Forks of Cacapon	39.40387	-78.41842
CA_D_CPBRG	6	Cacapon River at farm off Cold Stream Road	39.32716	-78.42336
CA_CPBRG	7	Cacapon River at Rt. 50 in Capon Bridge	39.29754	-78.43517
CA_RMRCK*	8	Cacapon River along Capon River Rd.	39.21969	-78.47605
CA_YLWSPR**	9	Cacapon River at Rt. 259 below Wardensville	39.18281	-78.50597
CA_WRDS	10	Cacapon River at farm ford in Wardensville	39.07861	-78.61134
SBR_L_TRGH	11	South Branch at Harmison's Landing	39.22810	-78.85251
SBR_U_TRGH	12	South Branch at South Branch WMA	39.14630	-78.92519
SBR_L_MRFLD	13	South Branch at Rt. 220/28 in Moorefield	39.10424	-78.95801
SBR_U_MRFLD	14	South Branch at Fisher Rd above Moorefield.	39.05006	-78.99316

Table 2. Sampling station names and locations. * New site for 2013 **Station location changed from 2012 (Previously CA_LWR_WRDS).

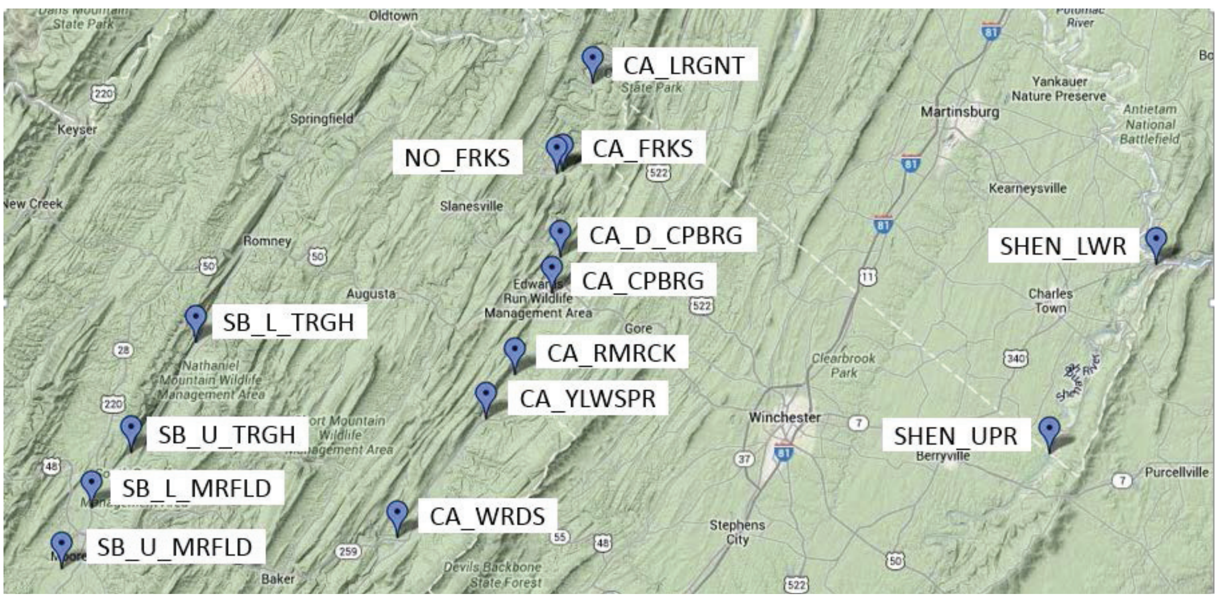


Figure 1 A map of algae monitoring stations on the Shenandoah, Cacapon, and South Branch Potomac Rivers.

Site characterization

The WVDEP Filamentous Algae Monitoring Form was completed in the field by the project leader (AG). Global Positioning System (GPS) coordinates were taken using a Garmin Etrex20 on the first, and most, subsequent field visits. If for any reason the sampling location was moved, the GPS coordinates recorded reflect that change. 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 by the project leader (AG). A site map was drawn on the first visit indicating the water quality sampling location (X-point) and the location of the algae transect, if performed.

Photo documentation

Pictures were taken on each site visit, arranged in folders according to site and sampling date, and uploaded to Dropbox to be 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. The camera used, a Nikon AW100, was capable of attaching GPS coordinates of the pictures as they were taken. This information is in the details of the file properties. GPS coordinates did not always accompany pictures, and were typically missing from underwater shots and videos. All pictures and videos were arranged by sample location and date and provided on a DVD hard copy to WVDEP.

Filamentous algae abundance measurements

Percent algae coverage measurements were performed according to Standard Operating Procedures (SOP) provided by WVDEP. Measurements were recorded in feet and tenths of a foot. Measurements were taken whenever filamentous green algae were observed in the channel in greater than trace amounts or ~ 5% by visual estimation. Lengths and depths of the cross-section being measured were reported in tenths of a foot using a field tape and surveying rod. All values were entered on the percent algae calculation spreadsheet file, which was modified from that provided by WVDEP to receive the measurements as recorded in order to calculate the percent coverage of the site. The modified percent algae coverage calculation spreadsheets and associated data are provided separately as a Microsoft Excel© file. Algal measurements were taken regularly at the station along Capon River Rd, downstream of Camp Rim ROCK (CA-RMRCK), where algae was present throughout most of the field season, and at the Cold Stream Road farm location (CA_D_CPBRG), when algae appeared there for several weeks. No other stations had manifestations of algae that required measurements during the sample season. Algal measurements were also performed on two of the three longitudinal surveys when filamentous algae were encountered. A total of 15 algal measurements were performed during the 2013 field season.

In-situ water quality

In-situ water quality was collected at every site using a YSI-556 multi-parameter sonde. 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. pH was calibrated using a 2-point method with 7.01 and 10.00 calibration standards. Dissolved Oxygen was calibrated using a saturated air calibration method, according to the user manual of the YSI-556.

Water chemistry

Four sample containers were filled at each sampling location 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-chemistry sample containers were provided pre-fixed with acid preservatives by the contracted analysis laboratory Bio-Chem. At each sampling location, a collection container was rinsed 3 times and samples were collected facing upstream. The sampling location within the river was indicated on the monitoring form. Filtering for the dissolved phosphorous sample was performed using a Nalgene© filter funnel cup, Nalgene© vacuum flask, 47 mm 0.45 µm cellulose-nitrate filter papers and a hand-operated vacuum pump. The vacuum flask and filter apparatus were also rinsed 3 times mid-stream prior to filtering. Samples were collected according to WVDEP Standard Operating Procedures for water chemistry sampling. Sample duplicates were collected 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. All samples were collected on contiguous days and delivered to the West Virginia Department of Agriculture Moorefield Complex. In most cases, ICPRB biologists met the Bio-Chem drivers there directly, though sometimes samples were left with the front office and picked up by Bio-Chem drivers. Chain-of-custody forms accompanied the samples.

Completeness

All 14 stations identified by WVDEP personnel were sampled throughout the study period. Ten sampling rounds were completed during the study period on a roughly bi-weekly schedule. With the exception of the second sampling round, which was interrupted by heavy rains, all sites were monitored within a consecutive 2-day period. Complete sets of water chemistry samples were collected at every visit without interruption. Algae transects were performed whenever algae were observed in the channel above trace amounts. Occasionally, water clarity, or visual surface disturbance due to precipitation, prevented performing the qualitative visual assessments at certain sites. Dissolved oxygen was not collected during the first sample round due to an incorrectly installed probe sensor in the sonde unit. A single In-situ water quality sample was missed at the Cacapon River farm ford location in Wardensville (CA_WARDS) during the last sample round, due to batteries failing in the field. Regrettably, the 5th round of pictures were mistakenly erased during photo processing. All other pictures and videos were completed and recorded.

Longitudinal surveys

Longitudinal surveys were used to investigate and document algae blooms along a river's length. 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. The longitudinal surveys are an informal assessment method, but consist primarily of documenting observations with written accounts, photographs and videos, and associated GPS coordinates at observation points. Three longitudinal surveys were performed during the 2013 season. All three surveyed the Cacapon River, where algae was observed most commonly and abundantly.

Summary of algal observations and measurements by station

1. Shenandoah at Rt. 340 near Harper's Ferry (SHEN_LWR)

No significant algae was observed. Some periphytic algae at water's edge on exposed bedrock.

2. Shenandoah at Ann Lewis Road near state line (SHEN_UPR)

No algae was observed.

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

Algae observed briefly at the mouth of a small tributary that enters at the site. No FGA observed in the channel.

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

Small amounts of algae observed early and late in season.

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

BGA was common. FGA was observed late in season in small amounts. A larger amount of FGA was present upstream of site in bottom of large pool. No measurements taken.

6. Cacapon River at farm off Cold Stream Road (CA_D_CPBRG)

Algae bloomed late in the season to levels nearing 30%. Two measurements were taken, one each during rounds 8 and 9. The algae here formed long filaments. BGA was also observed. Algae extended through the downstream riffle area and continued upstream into a long pool section (confirmed by longitudinal survey). Above this site, algae coverage was significant and above criteria thresholds.

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

FGA observed once during season. BGA observed on most visits and was present to common.

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

This site continued to manifest bloom conditions, with frequencies and abundance greater that was observed in 2012. Ten FGA percent cover measurements were taken, seven during routine site visits, and three during a longitudinal survey. Algae was first observed on 7/19/2013 at 9.71% and continued to increase into early October, peaking at near 80% coverage (Table 3). Dominant algal filaments were very long, identified as *Oedogomium* sp. Diverse mixture of diatoms was in samples, including *Cymbella* and *Taballaria*. Blue greens included *Oscillatoria a*nd *Anabaena*. The linear extent of the bloom was rather short, reaching only about 650 meters, being constrained to a single north-south oriented "run-type" channel feature, beginning about 650 meters downstream from Camp Rim Rock.

9. Cacapon River at Rt. 259 below Wardensville (CA_YLW_SPR)

NO FGA observed. BGA was frequently observed in small amounts.

10. Cacapon River at farm ford in Wardensville (CA_WRDS)

Periphytic green algae were observed attached to large boulders at waterline. No FGA was observed in the channel, but was observed once in the 9th sample round in shallows along the river-left bank.

11. South Branch at Harmison's Landing (SB_L_TRGH)

FGA was observed sporadically in small amounts at the boatramp. NO FGA was observed in the channel.

12. South Branch at South Branch WMA (SB_U_TRGH)

No algae were observed at this site.

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

Trace amounts of FGA were observed during round 4.

14. South Branch at Fisher Rd above Moorefield (SB_U_MRFLD)

Occasional periphytic FGA was observed. Algae was sometimes observed in shallows along the shore. No FGA was observed in the channel.

Table 3 Summary of percent filamentous green algae cover measurements made during the 2013 season. Null values indicate when judgement was impaired by poor visibility, zero "0" values indicate non-detects or possibly trace amounts, values up to 5% were visually estimated, and values above 5% are physical algae measurements.

Site Name	JUN-1	JUN-1	JUL-1	JUL-2	AUG-1	AUG-2	AUG-3	SEP-1	OCT-1	OCT-2
CA-CPBRG	0		0	0	0	0	0	0	0	0
CA-D-CPBRG	0		0	1	0	1	0	17.32	28.38	0
CA-FRKS	0		0	0	0	0	0	1	2	0
CA-LRGNT	0		0	0	0	0	0	1	0	0
CA-RMRCK	0		0	9.71	22.31	40.05	33.15	57.5	77.67	2
CA-WARDS	0		0	0	0	0	0	0	2	0
CA-YLWSPR			0	0	0.5	0	0	0	0	0
NO-FRKS	2.5	0		0	0		0	0	5	0
SB-LWR-MRFLD	0	0	0	0.5	0	0	0	0	0	0
SB-LWR-TRGH	0	0		0	0	0	0	0	0	1
SB-UPR-MRFLD	0	0	0	0	0	0	0	0.5	0	1
SB-UPR-TRGH	0	0	0	0	0	0	0	0	0	0
SHEN-LWR	0	0	0	0	0	0	0	0	0	0
SHEN-UPR	0		0	0	0	0	0	0	0	0

Analysis of water chemistry

Analysis methods

Data were entered into MS Excel for exploratory analyses. A copy of this dataset was provided electronically on DVD to WVDEP along with 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 CaCO3 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):

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

Water chemistry data for the eight collected parameters (DP, TP, NO_3-NO_2-N, TKN, Ca^{2+}, Mg^{2+}, TSS,TALK), four calculated parameters (Total hardness(HARD), total nitrogen(TN), two calcium:magnesium indexes), and five in-situ parameters (DO, pH, SPCOND, WTEMP, TDS) were plotted across station, river system, and sample date using boxplots (Appendix II, file:2013_algae_potomac_icprb.xlsx). In each boxplot, the median, or 50th percentile, is the solid center line, and the box extends between the 25th and 75th percentiles. The "whiskers" were drawn to the highest (or lowest) datapoint within 1.5 of the inter-quartile range (IQR), where the IQR is between the first and third quartiles. Outliers were plotted as points. Basic numerical summaries were used to describe water quality attributes across river basins and a Kruskal-Wallis test was used to look for significant differences between them. Relationships between percent algal coverage and possible explanatory variables were investigated using scatter plots with loess regression curves and some exploratory classification and regression tree analysis, but analyses are limited by few overall algae measurements and the site-fidelity of those that were made.

Water chemistry across stations

Calcium, Magnesium, Total Alkalinity, and Hardness

Waterbody median values of the measured water quality parameters are provided in Table 4, and medians by station are provided in Appendix III. In general, levels of dissolved metals, carbonates, and other salts were lowest in the North River and Cacapon Rivers, higher in the South Branch, and highest in the Shenandoah. Within each river system, only the Cacapon demonstrated significant changes in concentration longitudinally. In general, dissolved constituents were at their highest at the most upstream site, where the Cacapon rises from Karst geology and springs from the ground, and decreased downstream. Small inputs fluctuate concentrations, and the effect of the North River, the Cacapon's largest tributary, is easily seen between the CA_FRKS and CA_LRGNT stations. Calcium concentrations were similar between the South Branch and Shenandoah Rivers, averaging around 40.4 and 39.4 mg/L, respectively. Concentrations of Ca^{2+} in the Cacapon system were lower, averaging 24.5 mg/L among the 7 Cacapon sites, and only 15.65 mg/L at the North River site. Magnesium ions (Mg2+) were much higher in the Shenandoah, as compared to the other systems which were calcitic, and had higher calcium:magnesium ratios. The Cacapon and North River therefore had overall lower calculated hardness values and would be considered soft, compared to the harder water of the South Branch and Shenandoah (Figure 2). Their median values were similar to the average hardness values reported for these rivers in the 2008 WVDEP assessment report (Summers 2008). Total alkalinity followed a similar pattern. The Cacapon and North River had significantly 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.

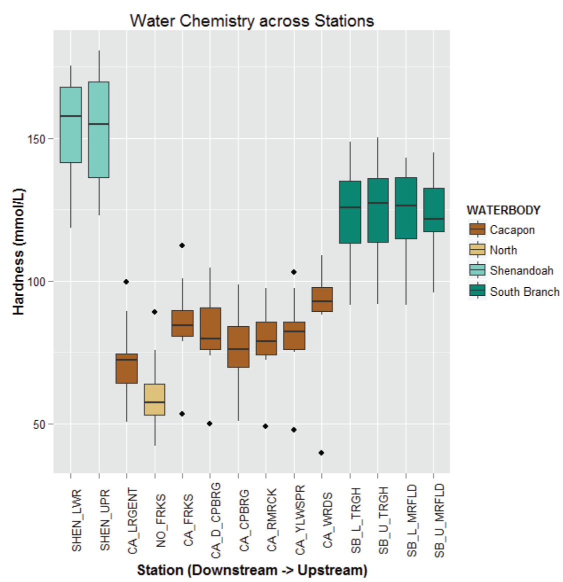


Figure 2 Total Hardness (mg/L CaCO3) among the 14 stations.

Table 4 Median values of the collected and calculated water chemistry variables across the four river systems.

Parameter	Cacapon	North	Shenandoah	So. Branch
CA (mg/L)	24.5	15.7	39.4	40.4
MG (mg/L)	4.6	4.6	12.7	6.0
ALK (mg/L)	67	47	130	96
HARD (mg/L)	80.3	57.3	157.5	125.0
CA_MG_INDEX	2.04	1.94	1.72	2.07
MOD_CA_MG	3.10	3.24	2.80	2.90
DP (mg/L)	0.025	0.0255	0.040	0.073
TP (mg/L)	0.028	0.0335	0.054	0.085
NO3_NO2_N (mg/L)	0.207	0.230	1.035	0.448
TKN (mg/L)	0.2	0.2	0.3	0.2
TN (mg/L)	0.40	0.46	1.31	0.62
SPCOND (uS/cm)	174.5	139.0	323.5	264.0
WTEMP (C)	22.40	21.85	24.89	23.50
DO (mg/L)	8.37	8.11	7.60	9.17
PH	8.06	7.64	8.21	8.34
TDS (mg/L)	116	91	224	175
TSS (mg/L)	2	4	6	2

Nitrogen and Phosphorous

The various nutrient species of N and P were of critical concern to this project, 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 and N measures were lowest overall in the Cacapon and North Rivers, with TP and TN having median values of 0.028 mg/L and 0.40 mg/L, respectively, across all Cacapon stations (Table 4). Phosphorous was highest in the South Branch Potomac, below the city of Moorefield, which incorporates several high inputs from industrial point sources, such as the Moorefield WWTP and the Pilgrim's Pride poultry processing facility, and the input of the South Fork of the South Branch. Specifically, TP increased from a median of 0.0245 mg/L at the SB_UPR_MRFLD station, to 0.119 mg/L at the SB_LWR_MRFLD station located just several miles downstream (Figure 3). Nitrate-nitrite and TN were highest in the Shenandoah, but increased only modestly between the upstream and downstream stations. On the Cacapon, TP was of nearly uniform concentration longitudinally, except for a small increase at the CA_D_CPBRG station, likely due to the input of the Capon Bridge WWTP, a small treatment facility serving less than 250 residents. Dissolved phosphorous ranged between 0.025 and 0.028 mg/L at all stations except the CA_RMRCK station, where the median concentration was 0.019 mg/L. Although not a significant difference, DP was the only chemistry parameter that seemed to differ at this location. It may be an indication that the abundant SAV and algae beds in this area were

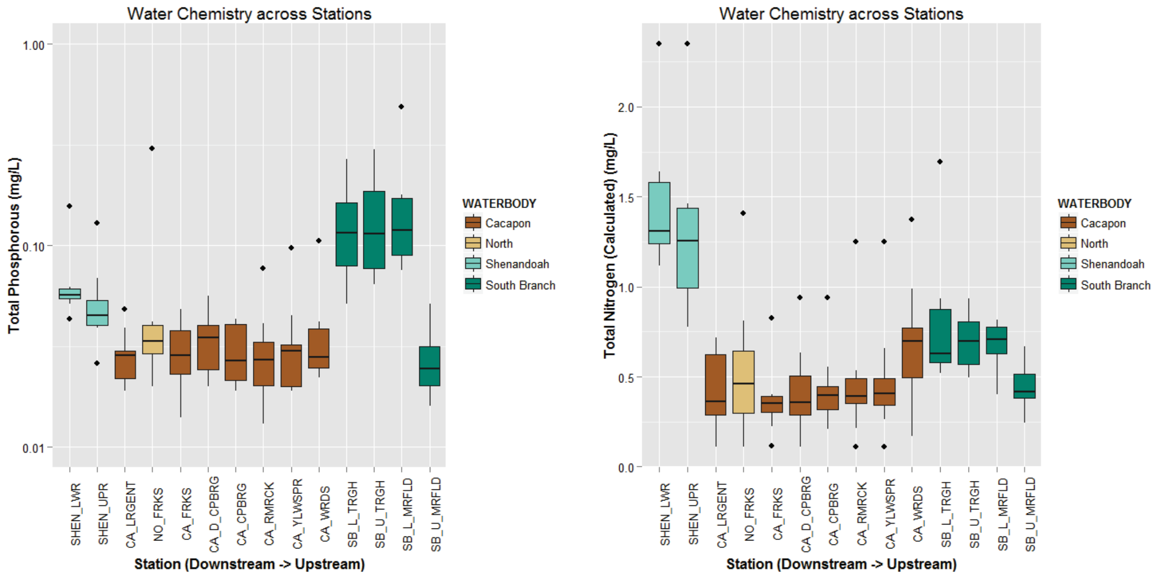


Figure 3 Total phosphorous and total nitrogen across all stations

stripping orthophosphate from the water column. Nitrogen displayed an interesting pattern that was consistent with the previous year; like the dissolved metals and salts discussed above, the highest nitrogen levels observed were at the upstream site, CA_WRDS, where the Cacapon rises from the ground, and decreased moving downstream.

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 (Appendix II and III). Water temperature did not vary greatly between waterbodies, though the Cacapon and North Rivers were slightly cooler than the Shenandoah and South Branch rivers. Total suspended solids were highest in the Shenandoah River, with a median of 6 mg/L, followed by the North River at 4 mg/L, and the South Branch and Shenandoah were most often reported at the detection limit of 2 mg/L (Figure 4). In the Cacapon,

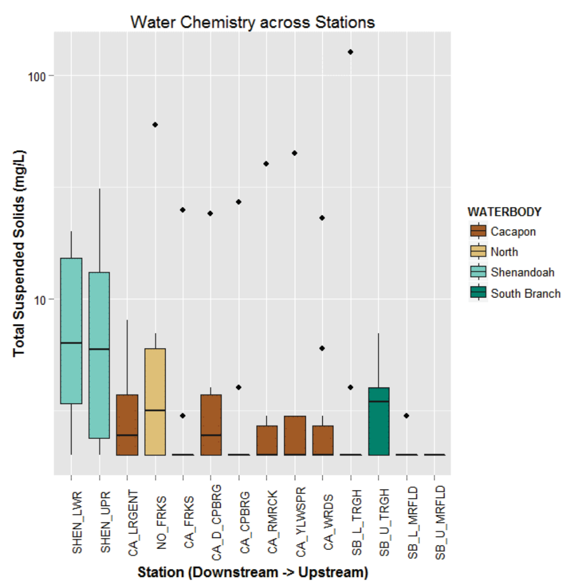


Figure 4 Total suspended solids (mg/L) across sample stations.

the two stations with TSS medians above the detection limit were located immediately downstream of large pools. Phytoplankton production in the pools could be a possible explanation for the slight amounts of suspended material in baseflow over the riffle-run stations. In the South Branch, the small uptick in median TSS at the SB_U_TRGH station could possibly be attributed to an upstream tributary named Mudlick Run entering on the river-left bank. During Round 3 on July 1, 2013, there was strong discoloration of the water along the river-left shore. On the Cacapon, both DO and pH displayed strong swings and increases likely associated with algae blooms. At the CA_RMRCK station, where filamentous algae coverage has been the most abundant and persistent, DO had a median of 10.57 mg/L, compared to the upstream and downstream stations with medians of 8.37 and 8.24 mg/L, and peaked at 12.15 mg/L in our measurements (Figure 5). The DO saturation for that peak sample, given a water temperature of 21.79 °C, was over 130%. It is worth mentioning that DO swing was not measured in this study and would possibly record significant shifts as the SAV and algae productivity waxed and waned between day and night. 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.

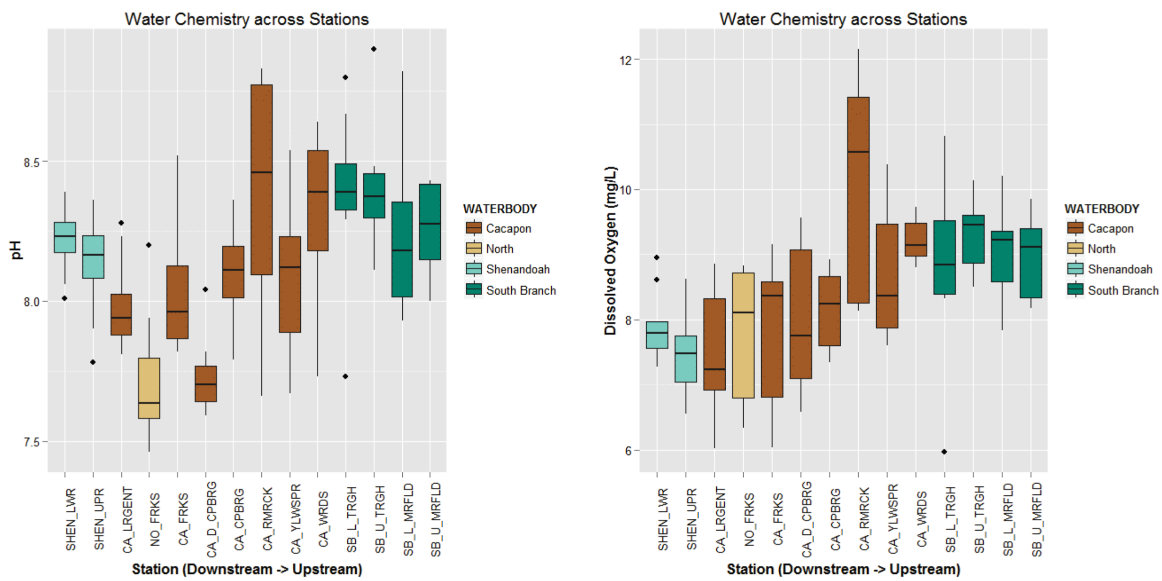


Figure 5 Dissolved oxygen (mg/L) and pH across sample stations.

Longitudinal survey reports

Cacapon River – Yellow Springs to Capon Bridge

Figure 6 Map of longitudinal survey area on the Cacapon River between Yellow Springs and Capon Bridge, WV. The area of filamentous algae blooms are indicated in red.

Table 5 Coordinates and percent algae coverage measurements from the September 4th longitudinal survey of the Cacapon River.

Left bank coordinates	Right bank coordinates	% filamentous algae
39.21879 -78.47770	39.21852 -78.47753	46.96%
39.21841 -78.47831	39.21825 -78.47799	41.56%
39.21946 -78.47665	39.21922 -78.47649	41.32%

The first longitudinal survey focused on documenting the extent of a bloom occurring along Capon River Road, between Yellow Springs and Capon Bridge, WV (Figure 6). The survey occurred on September 4, 2013. It was performed both from a vehicle and boat, where necessary. At the time of the previous routine sample round (SEP-1), algae coverage was just less than 40% at the CA_RMRCK location, and a new decision rule for the violation of recreational use required additional measurements if coverage was between 20% and 40%. The longitudinal survey began by vehicle, at the beginning of Capon River Road near Yellow Springs, and traveled south along the river, making observations of FGA and SAV coverage along the roadway. No significant algae was observed in the upstream portions of the reach from Yellow Springs to Camp Rim Rock, a youth-horse camp, though beds of *Hydrilla sp*. were common (Photos: DSCN1564-1572). At the routine sampling location, CA_RMRCK, the extent and severity of the persistent bloom was investigated by canoe, paddling upstream to find the beginning of the bloom event, and recording percent coverage along the length of the bloom. Below a braided channel, a section of fairly uniform “run-type”channel was filled bank to bank with *Hydrilla sp*., predominantly, and other SAV species (Photos: DSCN1573-1595). At a certain point, filamentous green and blue algae colonized the Hydrilla beds (Photos: DSCN1596-1597). The amount of algae increased downstream through the “run” section. Three cross-sectional measurements were taken, one at the beginning of the FGA bloom, one near the center of the bloom, and another at the typical measurement location for the CA_RMRCK station (See Table 5). The average width in this section, as measured by the three cross-sections, was 142 feet. The three measurements were taken over a longitudinal distance of approximately 635 feet, exceeding a length of three times the average channel width, per the new criteria decision rule (Figure 7) (Photos: DSCN1598-1601). Other SAV species in this section included: Curly Pondweed (*Potamogeton crispus*) most commonly, with lesser amounts of Water Stargrass (*Heteranthera dubia)*, Wild Celery (*Vallisneria americana*) and Sago Pondweed (*Potamogeton pusillus)*. Much of the FGA in this section was attached to *Hydrilla*. Below the CA_RMRCK station, a riffle section ends the run-type section and algae persists in lower levels for roughly the next 100 meters before subsiding and giving way to clean SAV beds again.

Figure 7 Cross-sectional algae measurement during the Yellow Springs to Capon Bridge longitudinal survey.

Cacapon River – Wardensville to Yellow Springs

A longitudinal survey of the Cacapon River between Wardensville and Yellow Springs was made on September 11, 2013 (Figure 8). ICPRB biologists Adam Griggs and Jim Cummins surveyed the Cacapon River between the Rt. 259 bridge, just below the Wardensville Waste Water Treatment Plant (WWTP), and the Yellow Springs public access ramp along Rt. 259 downstream. This section of the river is not frequently paddled due to low flows, and there were several occasions that required exiting the boat to walk it through riffles and other shallow areas. In general, this section of the Cacapon looked very different from downstream areas. It was highly variable in channel width, shape, and slope. It was also variable in dominant substrate, habitat structure, and observed aquatic vegetation and algae. Table 5 lists coordinate points and descriptions of observations made along the survey route. From nearly the start of the surveyed area, blue-green algae (BGA) or cyanobacteria was observed attached to cobble substrate in the stream channel (Photos: DSCN1602-1642). The amounts and frequency of BGA were higher than any that had been observed at

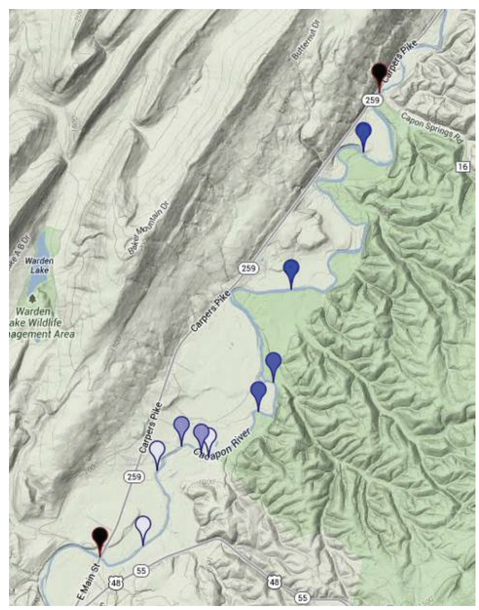


Figure 8 Cacapon River – Wardensville to Yellow Springs longitudinal survey route. Pins are locations where observations were recorded.

any location in either the 2012 or 2013 season. Most of the BGA observed appeared to be attached benthic *Oscillatoria sp*., based upon laboratory identification of several samples collected during the survey (Figure 9). FGA was present at multiple locations throughout the longitudinal survey area, but not in an abundance that would violate the recreational use criteria, and was generally benthic with short filaments. Attached BGA occurred at levels of up to ~50% estimated coverage where present. Most of the reach, however, did not manifest significant levels of algae of either type. Instead, freestone cobble bottoms with periphyton or SAV were typical, or, there were numerous sections with very deep channels, where either benthic algae would not likely occur, or visibility was obscured by the depth (Photos: DSCN1643-1697. It can be assumed that either of these situations occurred in between the sample observation coordinates. Generally, coordinates were taken at the bottom of a feature described by the observations. Additionally, an interesting observation of very large colonies of freshwater sponges was made near the end of the longitudinal survey. These colonies were up to and greater than one meter in length and were the largest ever personally (AG) observed on any river (Photos: DSCN1698-1707).

Table 6 Coordinate locations and observations made during the Wardensville to Yellow Springs longitudinal survey.

Coordinates	Observations made
39.09399 -78.57859	BGA common - *Oscillatoria*? From this point and ~100 m upstream.
39.10462 -78.57590	Bed of *Oscillatoria*? Many pictures taken. Thickest patch observed anywhere to date.
39.10803 -78.57144	Sago Pondweed, Stargrass, and *Hydrilla* present. BGA continues. Video taken.
39.10703 -78.56791	First observance of FGA in riffle.
39.11305 -78.55747	Unusual bend of river with great diversity and abundance of SAV. FGA in cobble at shore.
39.11713 -78.55457	Bottom of large system pool extending from previous point.
39.13036 -78.55132	Another pool section. Shallows had ~20% FGA/BGA coverage. *Vallisneria sp.* dominant.
39.14978 -78.53822	~ 50 % BGA coverage of bottom, stream-wide for ~ 100 yards.

Figure 9 Blue-green algae (*Oscillatoria sp*.).

Cacapon River – Capon Bridge to Cold Stream Road

Algae observations at the CA_D_CPBRG site on the September 17 and October 2 routine visits prompted the need for a longitudinal survey of algae blooms below the town of Capon Bridge. Planning a longitudinal survey in this area was problematic due to a lack of public access, or access of any kind, between Capon Bridge (Rt. 50) and the Forks of Cacapon (Rt. 127). This section is popular with whitewater paddlers and has several Class I-II rapids. If only paddling, the distance between access points is not problematic (12.6 miles), however, the longitudinal surveys require written and photo

Figure 10 Section of river floated to monitor for algae below the town of Capon Bridge. Sites of two algae measurements appear as white dashes. Sections of river with filamentous algae appear in red.

documentation, and potential algae measurements if encountered, slowing the pace and making 12.5 miles too long of a trip for a single day. A shorter section of the river (3.4 miles) was floated between the CA_CPBRG and CA_D_CPBRG stations on October 4th 2013 to look for signs of algae (Figure 10).

Immediately below the Rt. 50 bridge, BGA (*Oscillatoria sp*.) was present in the river channel, holding close to the left downstream bank. A thick *Hydrilla* sp. bed was observed alongside an island at 0.15 miles. At 0.2 miles, the outfall of the Capon Bridge waste water treatment plant (WWTP) was observed. The outfall was noted for several reasons. First, the discharge was not exiting from a pipe or trough of any kind, but rather directly out of the bank, just above water level, and was located underneath a large fallen tree. There was a ditch perpendicular to the river several meters upstream, that could be the intended outfall, but it was dry. Second, the discharge had both a foul appearance and odor. The discharge water was very grey, and clouded the river for some area where it mixed. Several pictures and video of the outfall area were taken, and these are included on the photo documentation DVD (Figure 11). The outfall was reported to WVDEP staff for investigation (Photos: DSCN1956-1963).

Figure 11 Outfall of Capon Bridge waste water treatment plant.

Below the WWTP outfall, BGA and light, fluffy FGA tufts were observed, occurring mostly in the center, deep channel. The length of filaments were ~ 3 inches. Where present, coverage was roughly 40% of the bottom, but as it was constrained only to the thalweg, overall coverage was less than 20% by visual estimation (Photos: DSCN1964-1971). Around mile 0.35, BGA replaced FGA as being dominant and covered roughly 15% by visual estimation (Photos: DSCN1973-1975). Below the slight bend, light fluffy

FGA again occurred with coverage around 20%. At mile 0.55, FGA increased just upstream of a central island-bar. An algae measurement, pictures, and video were taken (Figure 12) (Photos: DSCN1976-1978). The coordinates for the algae measurement are provided in the percent cover calculation excel file. Filamentous green algal coverage was measured at 38%, near the 40% criteria for a single bloom site. Below the island was a large Hydrilla bed with attached FGA and BGA – samples were taken for ID at coordinates 39.30839 -78.42953. Another large patch of BGA covered the bottom ahead of the next right-hand bend in the river, and below the island.

Figure 12 Taking a cross-sectional measurement of algae below Capon Bridge,

Between mile 0.75 and 2.25, the river was mostly free of algae. Several wood turtles were observed. BGA and FGA were patchy and light (Photos: DSCN1979-1991). At mile 2.25, there was a substantial increase in algae abundance ahead of a left-hand bend in the river. *Hydrilla* and other SAV species, and the bottom itself, had heavy loads of attached FGA and BGA. A second algae cover measurement was taken (Figure 12). Much of this algae was already beginning to senesce, however, and it is likely that we did not catch the highest extent of the bloom (Photos: DSCN1992-2003). Algal coverage was measured at 37%, however, the center of the channel had upwards of 90% coverage, while the shallow, shaded shores had only light coverage. It is likely that both light availability and channel morphology were constraining algal growth. Heavy algae coverage continued until the following left-hand bend at mile 2.5. Following the bend, the river deepened considerably to depths ranging from 6 – 10+ feet. This section continued from river mile 2.5-3.1). Large boulders and bedrock filled the bottom of the channel, yet these were covered in short (up to one foot) lengths of algae. The depth made taking measurements in this area impossible, but two videos were taken (Photos: DSCN2004 and MVI_0607). From mile 3.1-3.4, algae persisted in low to moderate abundance until the take-out at the CA_D_CPBRG station (Photos: DSCN2005-2006).

Algal Identification

On several occasions, algae samples were collected for lab identification. Samples were preserved in formaldehyde and Lugol's iodine solution and stored on ice in 50 mL graduated sample tubes. Samples were taken back to the ICPRB lab and identified using a microscope by Associate Director of Aquatic Habitats, Claire Buchanan.

At the CA_RMRCK site, a diverse algal assemblage was present in the collected samples. Blue-green algae were dominated by *Oscillatoria sp*. but also included *Anabaena sp*. and numerous diatoms suspended in a mutilaginous matrix. Diatoms included *Tabellaria*, *Cymbella* among others. Green algae included *Cladophora* which colonized the shores and shallows, and *Oedogonium* sp. which formed very long filaments and was the dominant green algae in the river channel.

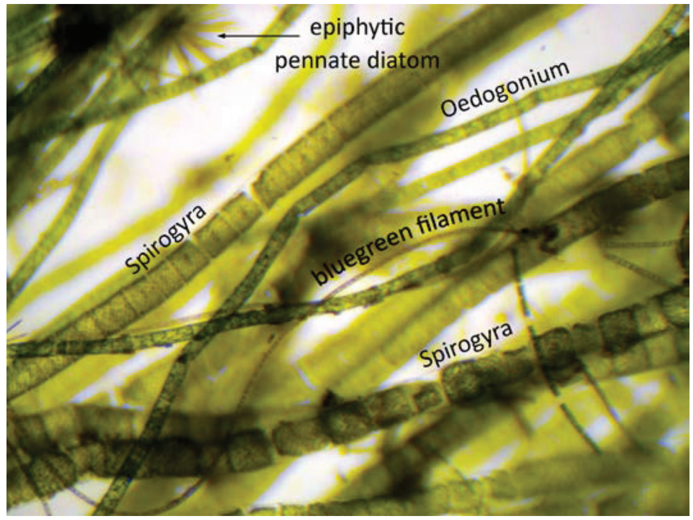


Figure 13 A photograph taken during microscopic identification of algal samples and annotated with identifications from the Capon Bridge longitudinal survey.

At the SB_U_MRFLD site, an interesting benthic algae was observed on one visit and collected for identification. The algae was identified as *Tetraspora gelatinosa*. Also present at the site were some blue-green algae identified as *Oscillatoria sp*.

Algal samples were also collected during a longitudinal survey that began at Capon Bridge, WV and continued downstream. In this sample, *Cladophora sp*. was identified as the dominant filamentous green algae in a riffle section, attached to cobble substrate, while *Spirogyra sp. and Oedogonium sp.*, also filamentous green algae, formed long filaments in much of the affected run-type section of river. Blue green algae collected at the site was identified as *Oscillatoria sp*.

Discussion

Factors affecting algae growth

A complex set of factors combine and interact to form environmental conditions that promote blooms of filamentous algae. The 2008 WVDEP assessment report on filamentous algae in the Greenbriar and other rivers provides an excellent synopsis of the pertinent literature. Much of what follows is a re-cap of those ideas regarding the chemical parameters being monitored in this study, and their effects on the growth of algae. More details can be found in that document (Summers 2008). Briefly, physical factors such as channel substrate and morphology, current, depth, or hours and intensity of sunlight, control growth. Water temperature can influence respiration rates and other cellular activity, while pH can change the distribution of nutrient and carbon dioxide species, or alter the availability of trace metals and other essential nutrients. The Ca^{2+} and Mg^{2+} measured in this study are known to influence phosphorous availability by having the ability to bind PO_4^- and form solid salts that fall to the stream bottom. Furthermore, the ratio of calcium to magnesium will also determine which forms of CA-P and Mg-P salts will form, which may be more or less soluble. Finally, every stream has its own individually fluctuating ion matrix that presents a complex stoichiometric equation, complicating the role of any one measured constituent.

Nutrients, specifically N and P, may be present in a number of forms, which are more or less available to primary producers such as algae. Algae can utilize reactive orthophosphate (PO_4-) most efficiently, while other P may be attached to suspended particles in the TP sample. The TP and DP measured in this study represent concentrations in the water column; P is also present and available in sediments, or already stored in the algal biomass, available for future use. Nitrogen also exists as a number of species, including but not limited to: nitrite (NO_2), nitrate (NO_3), ammonia (NH_3), or ammonium (NH_4). Algae use these types with varying efficiencies, preferring NH_4 and NO_3. Nitrate is highly soluble and mobile, quickly dissolving into surface runoff or entering groundwater, and thus is generally available in streams and rivers for plants and algae. Phosphate is typically considered limiting, due to the ready availability of nitrates, and its tendency to bind to soil particles or form solid salts.

Building on observed trends in WV algae

Calcium, Magnesium, and Alkalinity

In the 2008 WVDEP algae assessment report (Summers 2008), several water chemistry conditions were highlighted as reasons rivers appear to be vulnerable to nutrient-driven FGA growth. Hardness, alkalinity, CA-Mg concentrations and ratios, and the availability of phosphorous all were identified as potential controls on FGA growth. In general, algae was not observed above hardness levels around 145 mg/L or below alkalinities of 35 mg/L.

Table 7 Comparison table of 2008 and 2013 hardness, alkalinity, and Ca:Mg index data.

	Ca:Mg Index		Hardness		Alkalinity	
Waterbody	**2008**	**2013**	**2008**	**2013**	**2008**	**2013**
Cacapon	1.92	2.05	96	81	56	67
So. Branch	2.08	2.07	130	123	85	95
Shenandoah	1.54	1.69	174	153	117	127
North	-	1.95	-	61	-	51

Water chemistry and filamentous algae results in the Potomac rivers of West Virginia were generally consistent with the findings of the 2008 report. Extensive algal blooms were not observed above hardness levels of 145 mg/L $CaCO_3$. This year, the average hardness of the North River samples was 61 mg/L (Table 7). The Cacapon had an average hardness measure of 81 mg/L, lower than either the 2008 assessment or data collected in 2012. The South Branch and the Shenandoah had average values of 123 and 153 mg/L hardness, respectively, both somewhat lower than the 2008 values of 130 and 174 mg/L, but near or above the hardness threshold where filamentous algae blooms have been observed occurring (Table 7). The Ca:Mg Index was similar to 2008 data for the South Branch, but higher in 2013 for the Cacapon and Shenandoah Rivers (Table 7). Overall, waters were more alkaline and less hard than they were when sampled five years previously. It is not known if this is an actual pattern of increase, or simple annual variability, however, the increase in total alkalinity is within rates published regarding wide-scale alkalinity increases in eastern streams and rivers (Kaushal et al. 2013).

Nutrients

The CA_RMRCK site had the lowest median levels of dissolved phosphorous of all monitored sites at 0.019 mg/L though it was the site of highest algal coverage. The Greenbriar River was reported to have algae blooms manifesting at DP levels between 0.01 and 0.014 mg/L (Summers 2008). These P levels are generally lower than rivers not producing FGA blooms. It is possible that water column nutrient measurements are not valuable predictors of algae blooms, but instead represent an end result of nutrient assimilation by abundant growing algae and SAV. Figure 14 seems to indicate that DP was actively being removed from the water column at the CA_RMRCK site. In the plot, each Cacapon

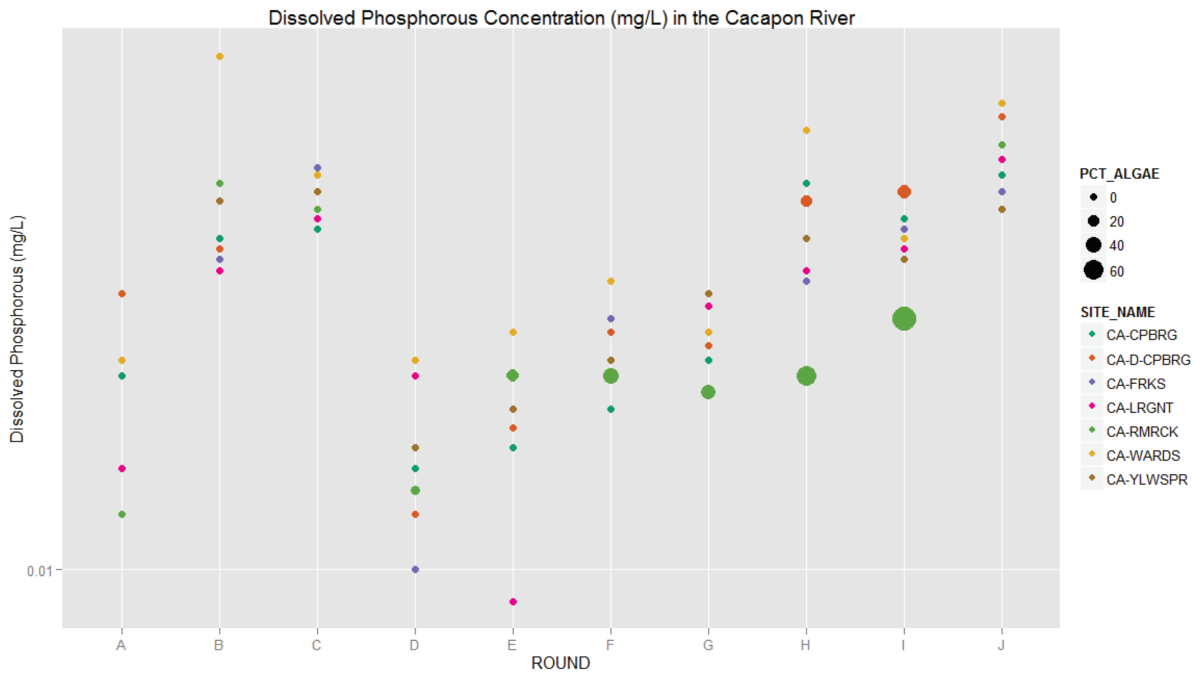


Figure 14 Dissolved phosphorous concentrations and percent algae in the Cacapon River

station's DP value is plotted along the 10 sample rounds. The size of the point is expressed by the percent FGA at the site at the time of the sample. CA_RMRCK is plotted in green and as the percent of FGA increases, the DP values separate from the remainder of the Cacapon station values, only to return when the algae died and was transported downstream before the final round. This would also seem to indicate that P may be limiting algae growth due to its active uptake, and a similar uptake in nitrate-nitrate or TN not being observed. Also, the addition of nutrients from the Capon Bridge WWTP site seemed to be a direct cause for algae to manifest downstream of that location as observed during the longitudinal survey. In general, nutrients were of higher concentrations in the other three river systems than they were in the Cacapon (Table 6) and should not be considered limiting. Likely, other variables such as hardness, flow, shade, or other as-of-yet unknown mechanisms are controlling the growth of algae.

Recommendations for listing

Neither the Shenandoah nor the South Branch Potomac had significant growths of algae at the WVDEP monitored stations, or violated the percent algae cover criteria for recreational use in 2013. The North River station also did not violate the percent cover criteria, though algae were observed on more than one occasion in small amounts. The Cacapon River, however, had multiple sections that violated the recreational use criteria for percent algae cover. The immediate area of the CA_RMRCK station, and the section between the CA_CPBRG and CA_D_CPBRG stations, had levels of algae above the longitudinal or single-site filamentous algae criteria (Figure 15). It is not known how far filamentous green and blue-green algae continues downstream, though FGA was observed at the downstream CA_FRKS station in low amounts, and immediately above it in a moderate amount on one occasion. Above this section, filamentous blue-green algae, or cyanobacteria, was observed in large amounts, some that would have exceeded the 40% criteria, based on visual estimation at the site. There do not seem to be any distinguishing characteristics among the algae-prone stations' measured physical and chemical attributes, which could be identified as causing the seasonal and excessive algal blooms. The length of river that exhibits these conditions is not great, extending between 200 and 250 meters seasonally, and water chemistry is not significantly different at nearby stations. Both upstream and downstream however have thick beds of *Hydrilla sp.* with other SAV species mixed in. It is possible that if the SAV were to disappear, that algae could colonize a larger section of the river. Therefore, it is suggested that the section between Wardensville and Forks of Cacapon be considered as vulnerable or prone to algae blooms that would violate the current recreational use criteria.

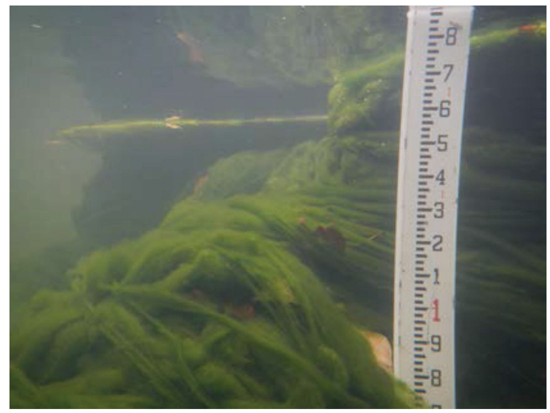


Figure 15 Underwater shot of algae mats at the CA_RMRCK site.

Suggestions for the filamentous algae monitoring program

Potential additions to monitoring protocols

It is suggested that WVDEP formalize the longitudinal method, with a reporting form, and protocol for documenting blooms. Suggestions for formal assessment could include the collection of GPS coordinates at edges of bloom area, guidance for photo documentation, algal sample collection and ID, and possibly upstream and downstream water chemistry sample collections.

WVDEP could consider adding sediment nutrients, and algal nutrient content to better calculate total system N & P.

WVDEP could consider recording additional site attributes in the rapid site characterization. Parameters could include channel shape, slope, and width, substrate, bank height, riparian vegetation, percent shading, stream channel orientation, and flow and velocity measures. These attributes would expand the number of possible explanatory variables to be considered alongside the water chemistry currently being collected.

Sampling locations

In order to investigate the drivers of algal blooms in the Potomac drainage of WV, where underlying geology and ecoregions are different from elsewhere in the state, additional algae bloom sites are required. Currently, algae growth is restricted to a section of the Cacapon River, and auto-correlation of explanatory variables with characteristics of the positive-algal sites is problematic. Exploratory windshield surveys of the remainder of the basin, during peak bloom times, could yield new algae sites. These surveys could explore the lower South Branch Potomac the Lost River, the South Fork of the South Branch, and Opequon Creek.

Priorities for longitudinal surveys for 2014 should include the Cacapon between Coldstream Road south of Capon Bridge and the Forks of Cacapon, between Forks of Cacapon and Largent, and the South Branch through the Trough in order to explore as-of-yet unsurveyed reaches.

Potential future work

Investigate groundwater upwellings, which could be carrying dissolved nutrients as possible explanatory variables of patchy blooms occurrences. These can be found in cold or hot weather while checking for changes in water temperature along a river's length. Infrared scanning is another alternative for detection.

Investigate land uses, geology, soils, and potential point-sources as variables for algae growth.

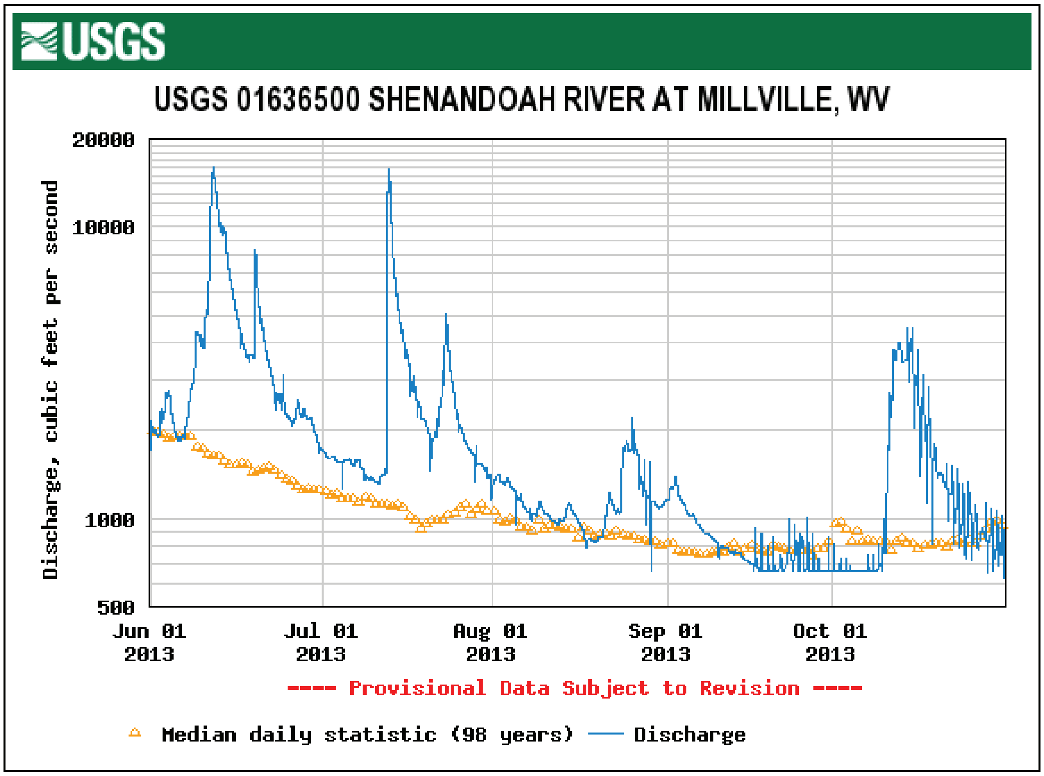
Further investigate the impacts of algal blooms on aquatic life. Consider the addition of continuous monitor probes at bloom sites to measure DO and pH swing. Investigate potential harmful algal bloom toxins such as Microcystin using passive Solid Phase Adsorption Toxin Tracking (SPATT) samplers or other methods.

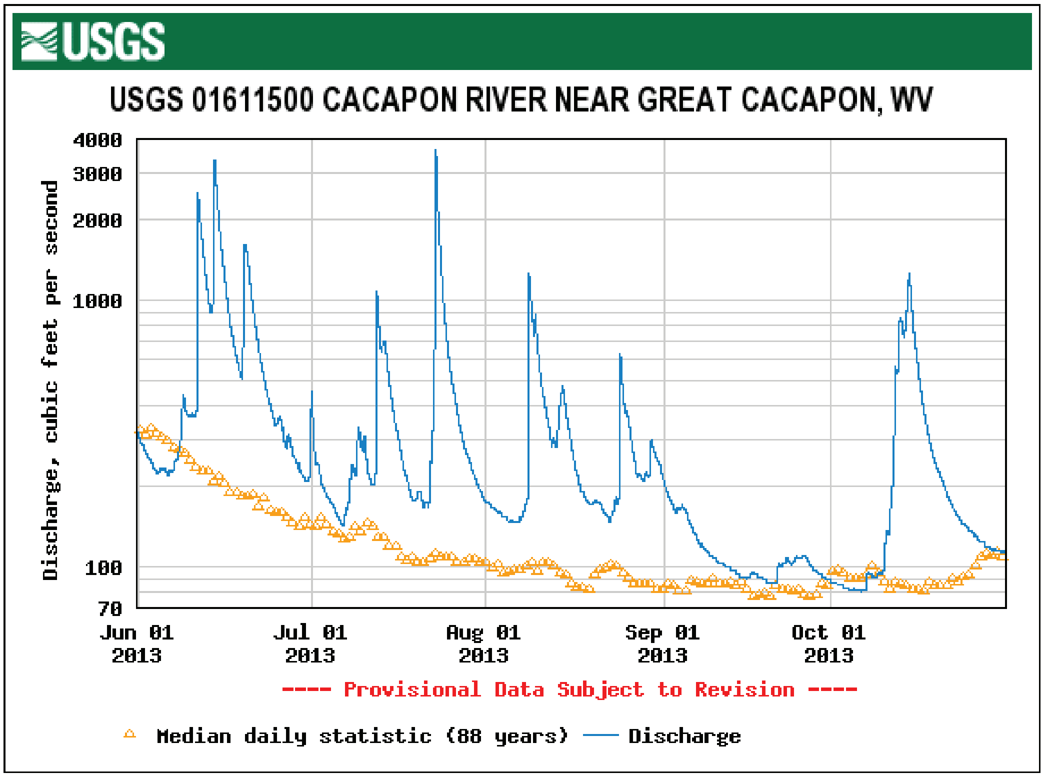
Literature Cited

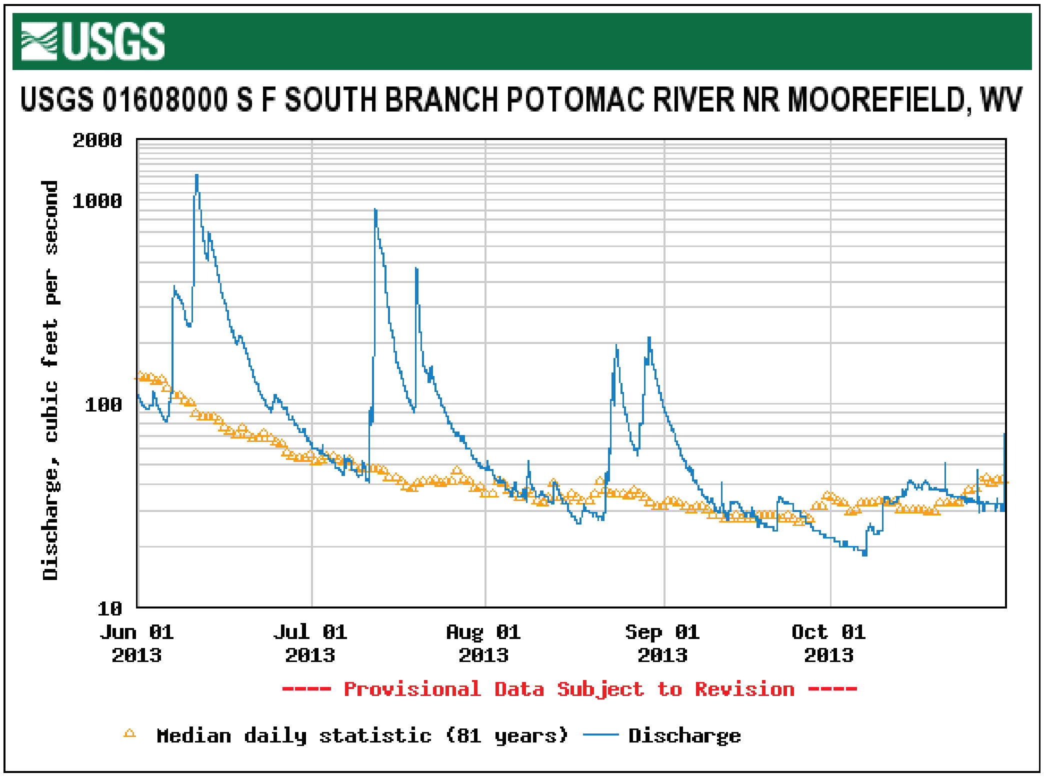
Kaushal, S, G Likens, R Utz, R, Pace, M, Grese, M, and Yepsen, M. 2013. Increased River Alkalinization in the Eastern U.S. Environmental Science and Technology 47: 10302-10311.

Summers, JS. 2008. Assessment of Filamentous Algae in the Greenbrier River and Other West Virginia Streams. West Virginia Department of Environmental Protection. Technical Report.

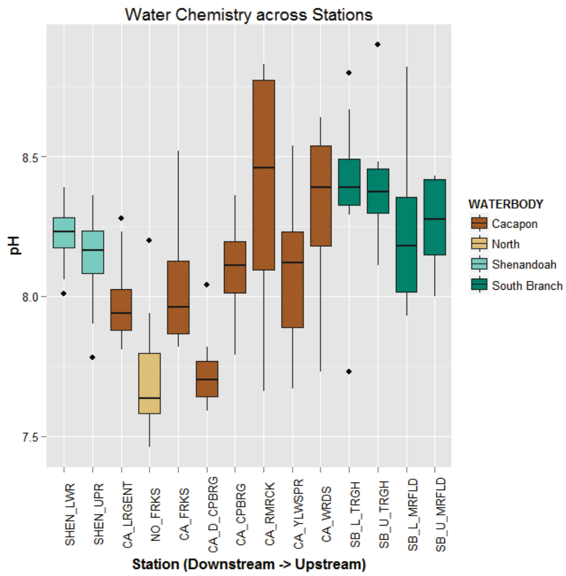
Appendix I – Hydrographs from related USGS gages for the period of June 1, 2013 – Octtober 31, 2013.

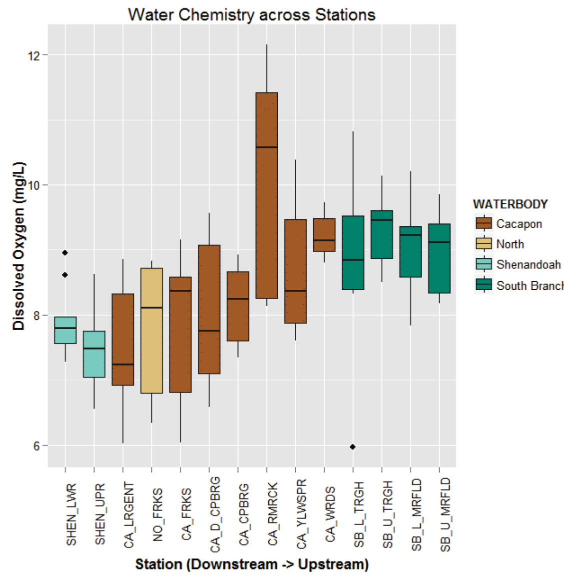


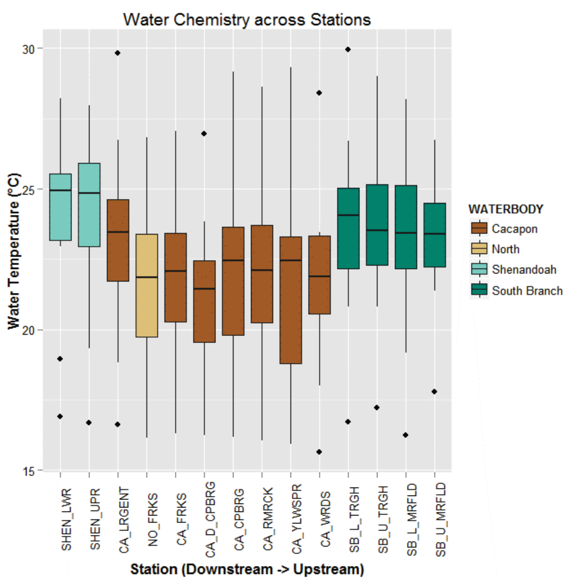

USGS
USGS 01611500 CACAPON RIVER NEAR GREAT CACAPON, WV
Discharge, cubic feet per second
4000
3000
2000
1000
100
70
Jun 01 2013
Jul 01 2013
Aug 01 2013
Sep 01 2013
Oct 01 2013
---- Provisional Data Subject to Revision ----
Median daily statistic (88 years)
Discharge

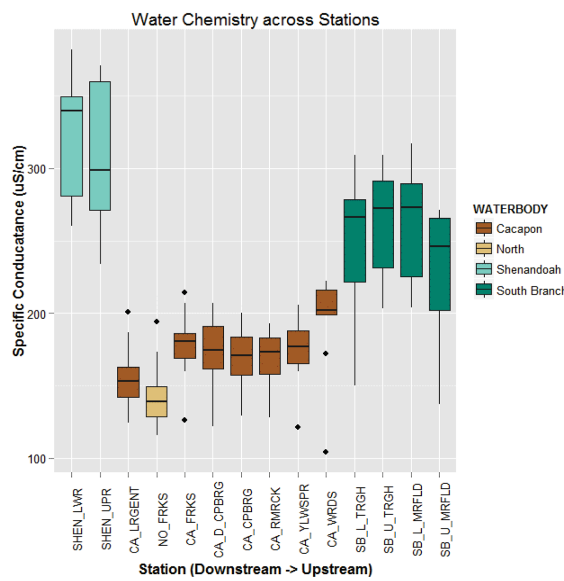

USGS
USGS 01608000 S F SOUTH BRANCH POTOMAC RIVER NR MOOREFIELD, WV
Discharge, cubic feet per second
2000
1000
100
10
Jun 01 2013
Jul 01 2013
Aug 01 2013
Sep 01 2013
Oct 01 2013
---- Provisional Data Subject to Revision ----
Median daily statistic (81 years)
Discharge

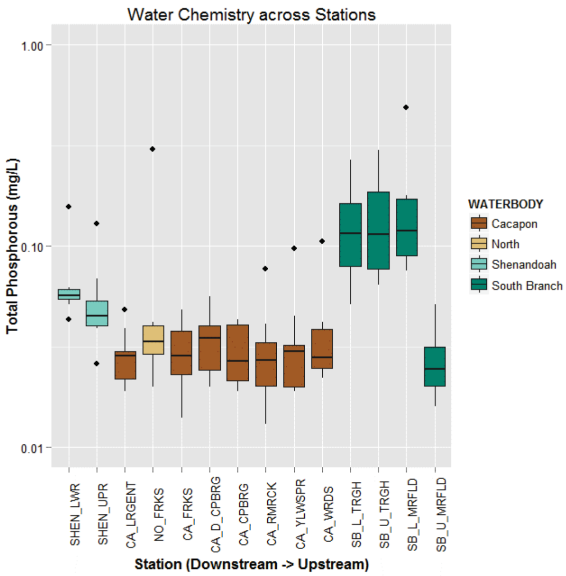
Appendix II – Water chemistry plots across station

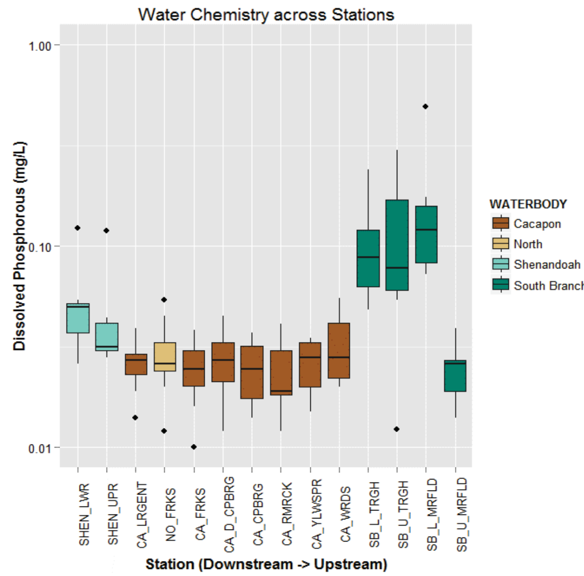


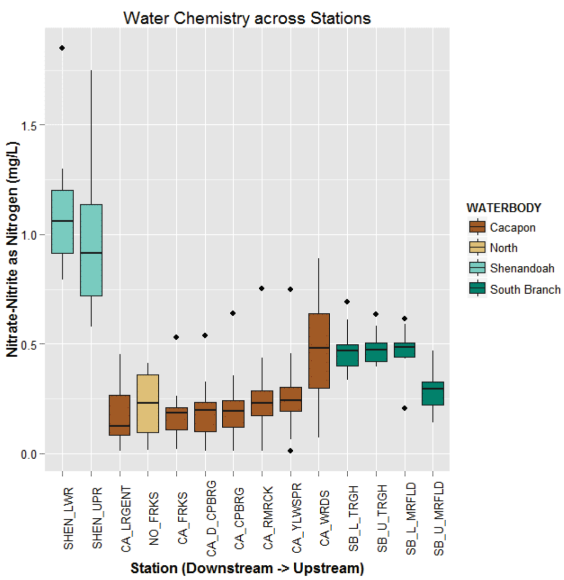


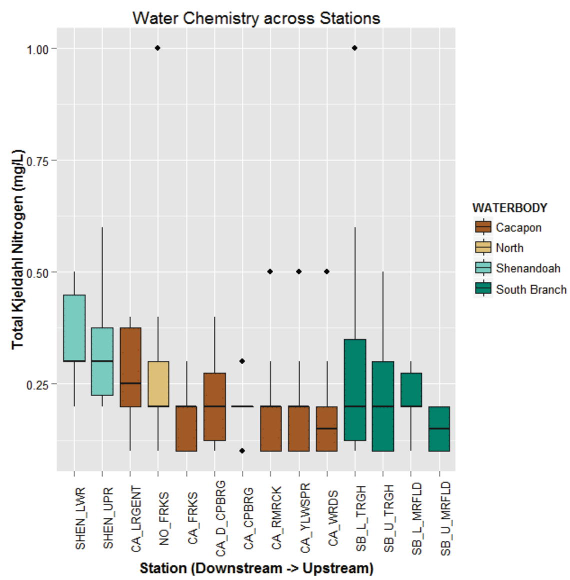


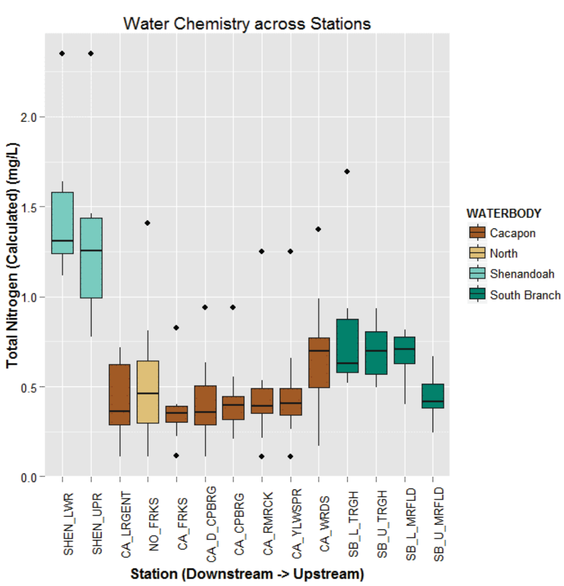


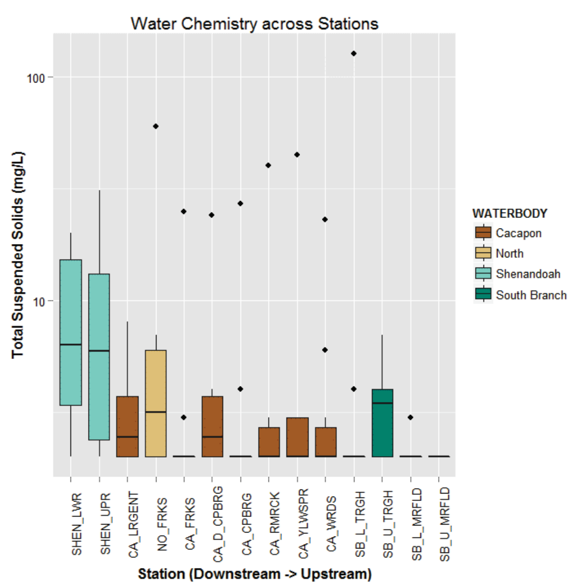

Water Chemistry across Stations
Total Phosphorous (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

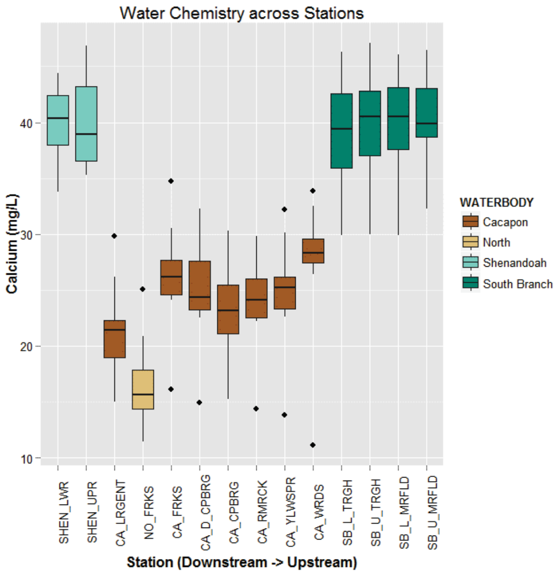

Water Chemistry across Stations
Dissolved Phosphorous (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

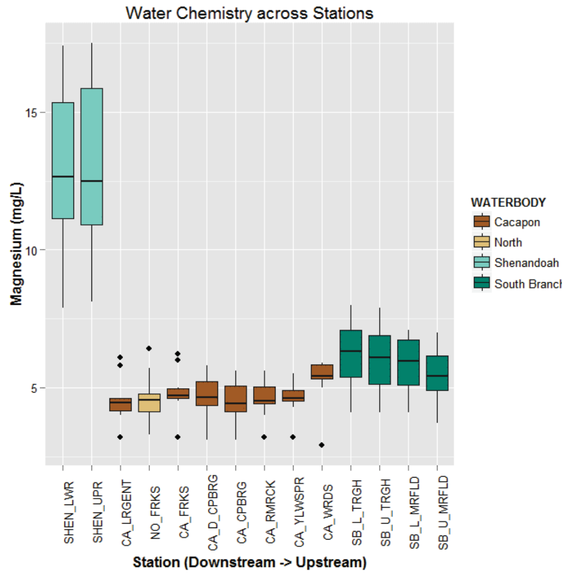

Water Chemistry across Stations
Nitrate-Nitrite as Nitrogen (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

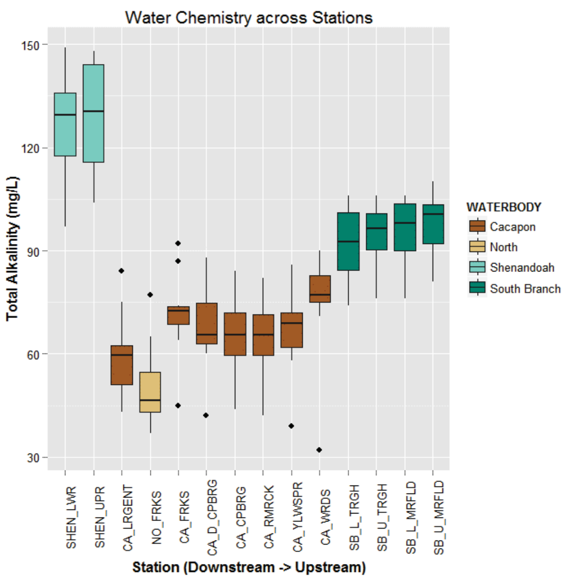

Water Chemistry across Stations
Total Kjeldahl Nitrogen (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

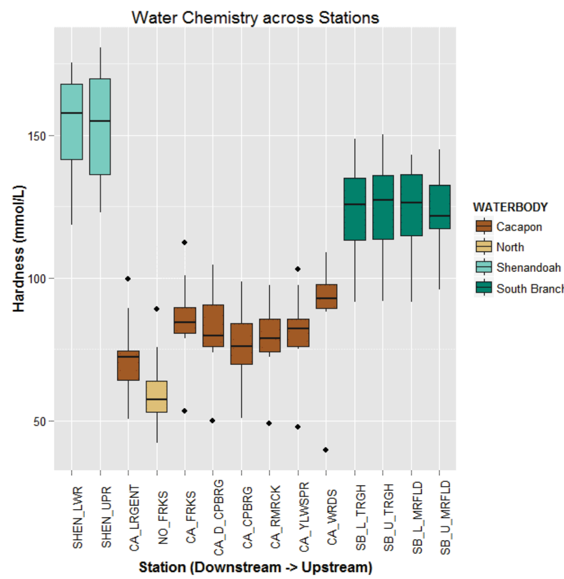

Water Chemistry across Stations
Total Nitrogen (Calculated) (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

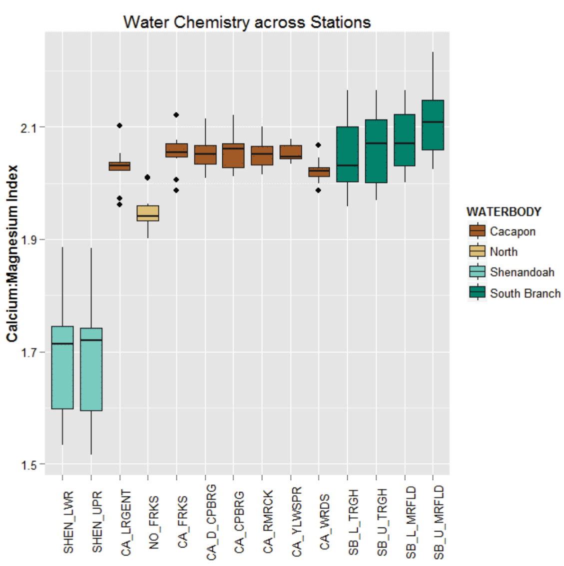

Water Chemistry across Stations
Total Suspended Solids (mg/L)
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

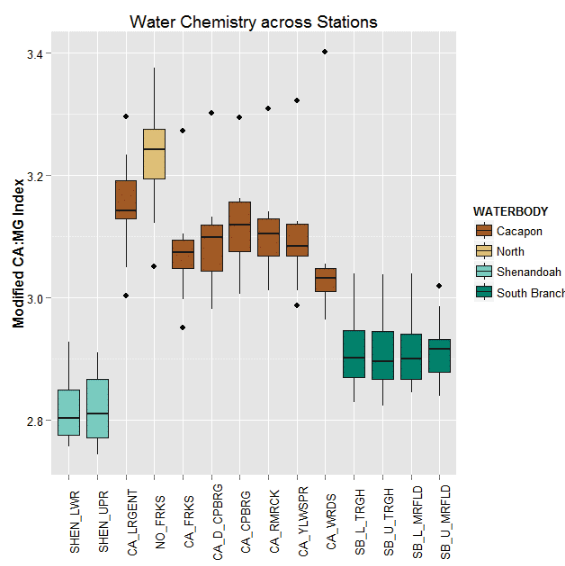

Water Chemistry across Stations
Calcium (mg/L)
10
20
30
40
SHEN_LWR
SHEN_UPR
CA_LRGENT
NO_FRKS
CA_FRKS
CA_D_CPBRG
CA_CPBRG
CA_RMRCK
CA_YLWSPR
CA_WRDS
SB_L_TRGH
SB_U_TRGH
SB_L_MRFLD
SB_U_MRFLD
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch


Water Chemistry across Stations
Magnesium (mg/L)
5
10
15
SHEN_LWR
SHEN_UPR
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
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch


Water Chemistry across Stations
Total Alkalinity (mg/L)
30
60
90
120
150
SHEN_LWR
SHEN_UPR
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
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch


Water Chemistry across Stations
Hardness (mmol/L)
50
100
150
SHEN_LWR
SHEN_UPR
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
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch


Water Chemistry across Stations
Calcium:Magnesium Index
1.5
1.7
1.9
2.1
SHEN_LWR
SHEN_UPR
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
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch


Water Chemistry across Stations
Modified CA:MG Index
2.8
3.0
3.2
3.4
SHEN_LWR
SHEN_UPR
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
Station (Downstream -> Upstream)
WATERBODY
Cacapon
North
Shenandoah
South Branch

Appendix III – Median water chemistry values by station

Parameter	**CA-LRGNT**	**NO-FRKS**	**CA-FRKS**	**CA-D-CPBRG**	**CA-CPBRG**	**CA-RMRCK**	**CA-YLWSPR**	**CA-WARDS**	**SB-LWR-TRGH**	**SB-UPR-TRGH**	**SB-LWR-MRFLD**	**SB-UPR-MRFLD**	**SHEN-LWR**	**SHEN-UPR**
CA (mg/L)	21.4	15.7	26.2	24.4	23.2	24.1	25.2	28.4	39.5	40.5	40.6	39.9	40.4	38.9
MG (mg/L)	4.5	4.6	4.7	4.7	4.4	4.5	4.6	5.4	6.3	6.1	6.0	5.4	12.7	12.5
ALK (mg/L)	60	47	73	66	66	66	69	77	93	97	98	101	130	131
HARDNESS (mg/L	72.2	57.3	84.2	79.7	76.1	78.7	82.4	92.8	125.7	127.3	126.2	121.6	157.5	154.7
CA_MG_INDEX	2.03	1.94	2.05	2.05	2.06	2.05	2.05	2.02	2.03	2.07	2.07	2.11	1.71	1.72
MOD_CA_MG	3.14	3.24	3.07	3.10	3.12	3.10	3.08	3.03	2.90	2.90	2.90	2.92	2.80	2.81
DP (mg/L)	0.026	0.026	0.025	0.027	0.025	0.019	0.028	0.028	0.089	0.078	0.121	0.025	0.050	0.032
TP (mg/L)	0.029	0.034	0.029	0.035	0.027	0.027	0.030	0.028	0.116	0.116	0.119	0.025	0.057	0.045
NO_3_NO_2 (mg/L)	0.12	0.23	0.19	0.20	0.19	0.23	0.24	0.48	0.47	0.47	0.48	0.29	1.06	0.91
TKN (mg/L)	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3
TN (mg/L)	0.36	0.46	0.35	0.36	0.39	0.39	0.41	0.70	0.63	0.70	0.71	0.41	1.31	1.25
SPCOND (uS/cm)	153	139	181	175	171	174	177	202	267	273	273	246	340	299
WTEMP (C)	23.5	21.8	22.1	21.4	22.5	22.1	22.5	21.9	24.1	23.5	23.4	23.4	24.9	24.9
DO (mg/L)	7.24	8.11	8.37	7.75	8.24	10.57	8.37	9.15	8.85	9.45	9.23	9.11	7.79	7.48
PH	7.94	7.64	7.96	7.70	8.11	8.46	8.12	8.39	8.39	8.38	8.18	8.28	8.23	8.17
TDS (mg/L)	103	91	119	115	113	114	116	133	178	184	182	167	226	222
TSS (mg/L)	2.5	3.5	2.0	2.5	2.0	2.0	2.0	2.0	2.0	3.5	2.0	2.0	6.5	6.0