2018 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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ICPRB Report

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Executive Summary

In the spring of 2018, WVDEP modified the scope of work of ICPRB's West Virginia Filamentous Algae Monitoring project to focus on identifying non-point sources of nutrient enrichment in the Upper Cacapon drainage. Specifically, ICPRB was to explore the likelihood of groundwater in the Upper Cacapon River drainage as a vector of nutrient enrichment. Due to historic levels of flooding in the summer of 2018, only one complete algal observation round was conducted with water chemistry and flow data. Seven of eight observation rounds were deemed not suitable for collection/observation due to significant flooding. Nearly 48% of the algae-producing season in the Cacapon River experienced flows greater than 1,000CFS, a value defined in the previous 5 years of algal observation as a scour threshold that prohibits algal growth.

ICPRB assembled a map of spring, cave, and karst locations from geospatial datasets provided by USGS, WVDEP, and VADEQ.There is a high degree of overlap between spring and cave locations with USGS defined karst seams in the eastern Appalachians. Interestingly, there appeared to be a lack of springs where one would expect in the Upper Cacapon valley. ICPRB focused field efforts on investigating regions likely to have springs in the Upper Cacapon. Despite the wet, high flow season that prohibited instream work, ICPRB was able to identify and confirm eleven (11) new spring locations between Wardensville, West Virginia and Capon Springs West Virginia. An additional ten (10) springs were flagged for investigation but were either halted by lack of land owner access or biologist's inability to locate the point source of the spring from anecdotal reports.

Aiding in the search for spring locations, ICPRB utilized a new tool, Forward Looking Infrared Imaging (FLIR E6), for locating temperature anomalies attributed to groundwater. Initial testing distinguished groundwater spring inputs from mainstem flow in a small creek, Trout Run, a tributary to the Cacapon River, in both summer and winter. We were not able to test the instrument in the mainstem Cacapon in 2018 due to the high flows, which were heavily influenced by surface runoff. Fortunately, ICPRB was able to identify a surrogate river, the Buffalo River, Arkansas, to assess the effectiveness of the tool in a system experiencing baseflow conditions. The FLIR E6 was able to identify several cold bank-fed springs and one deep upwelling due to cool water interacting with warmer mainstem flow. The use of FLIR imaging in future investigations will help with spring identification and presumably for source water tracking.

As a contribution to WVDEP and WV Department of Agriculture water chemistry monitoring in the Cacapon River, ICPRB developed a R-based program to rapidly analyze and visualize bi-weekly collection data. Through the use of R-Markdown, WV department of Agriculture data sets can be graphically displayed and easily updated as new data is entered. Currently the program is designed to display outputs for the duration of all water chemistry available. With the backbone of the code complete, future requests for data subsets, different displays, or new analyses can be easily added when requested.

Although much of the proposed fieldwork was not able to be completed in 2018 due to historic flooding, ICPRB was able to reinforce the case for groundwater dynamics influencing the biology of the Cacapon River. ICPRB was able to confirm novel methods and technology that will aide in future identification of springs in flowing waters as well as analyze hydrological, geological and spatial data which further support the case unique hydrogeological interactions in the Upper Cacapon River. If similar procedures and methods are followed in future projects, in years that do not coincide with high flows, it is expected that groundwater nutrient source tracking will yield positive results.

Introduction

Nuisance Filamentous Algae Research 2007-2016

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) has assisted the WVDEP in documenting algae blooms in the South Branch Potomac and Cacapon rivers since 2012. Descriptions are provided here:

ICPRB Filamentous Algae
(https://www.potomacriver.org/focus-areas/aquatic-life/)

WVDEP Filamentous Algae Program
(https://www.dep.wv.gov/WWE/Programs/wqs/Pages/FilamentousAlgaeinWestVirginia.aspx).

In the Greenbrier and Tygart rivers (located outside of the Potomac River basin), eutrophic environments and dense algal mats historically were found below nutrient point sources. WVDEP developed a source tracking approach capable of linking excess water column nutrients with nuisance levels of filamentous algae. Ultimately, this approach led to nutrient mitigation plans implemented at point sources and each river saw reduced levels of primary production within a relatively short period.

Laboratory analysis of water column chemistry was an important component of the nutrient mitigation plans. Water column grab samples were analyzed for nutrients known to cause algal blooms, such as nitrogen (nitrate, nitrite, TKN, and total nitrogen) and phosphorus (dissolved phosphorus, ortho-phosphorus, and total phosphorus). The results were used to track nutrients back to their point sources. Water column nutrient samples were also used to measure the efficacy of the management plans post-implementation.

Although WVDEP observed a positive correlation between increased water column nutrients and elevated algal biomass in the Tygart and Greenbrier rivers, some exceptions to the correlation have been observed elsewhere in the state. For example, water column chemistry samples collected in the Cacapon River between 2012 through 2017 have not shown excessive nutrient levels and no large point sources have been identified that could explain the hyper-productive reach found in each of those years between Yellow Springs, WV and Capon Springs, WV. An inability to detect an upper Cacapon River nutrient signal, or point source, has also been recorded in West Virginia Department of Agriculture data. Both data sources show phosphorus and nitrogen levels near detection limit for most of the year.

A New Approach: Non-Point Enrichment and Nutrient Transport Pathways (2017-2018)

In 2017, a high-intensity study was implemented by WVDEP and ICPRB between Yellow Springs, WV and the Capon Bridge, WV with a goal of source tracking nutrient enrichment to explain the hyper-productivity found within this reach. ICPRB ruled out any point sources for nutrient enrichment, as well as several small tributaries as vector pathways. Often instream water chemistry grab samples yielded phosphorus and nitrogen measurements at the detection limit of the screening methodologies.

In addition to nutrient levels at or near detection limit, small streams and tributaries proximal to the hyper-productive reach were perennial streams lacking the flow needed to transport adequate nutrients to support a bloom of the magnitude historically recorded within this reach.

One under-investigated nutrient transport pathway in the upper Cacapon River is nutrient enriched groundwater. To explore the feasibility of ground water transport as a nutrient vector, ICPRB analyzed multi-agency water chemistry and flow data around the high production reach. Results indicate that the underlying geology of the Upper Cacapon River is conducive to groundwater flow and potential nutrient transport. ICPRB analysis of flow and nutrient data suggests late winter and spring flows are dominated by surface runoff. During periods of high springtime surface water input, the upper Cacapon River lost mass, presumably to ground water seeps or seams (a losing segment). After spring rains and surface runoff decreased, the upper Cacapon river transitioned to a gaining segment condition which is likely explained by the input of ground water flow. The dynamic nature of the hydrology of the upper Cacapon combined with the underlying shale and limestone geology suggests this system is capable of transporting groundwater via non-surface flow paths where it can reemerge as springs or seeps.

ICPRB also investigated the hypothesis that non-nutrient ionic chemistry may be acting as a synergistic variable in nutrient adsorption and therefore effecting nutrient detectability. Ionic chemistry (calcium, magnesium, alkalinity, and hardness) within specific ranges may promote the release of nutrient species, in particular phosphorus, and make localized regions more favorable for primary production. Conversely, outside of these ranges these same ionic species may suppress the biological uptake of nutrients and promote a low primary production reach. Since this high-productivity reach has similar ionic chemistry to the rest of the Cacapon River, ICPRB ruled out the possibility that the increased production within the 6-mile reach was due to non-nutrient variables that favor primary production. Interestingly, the low levels of phosphorus that were detected in the system, appear to be depleted by excessive primary production in the summer months.

The influence of geology and groundwater connectivity in upper Cacapon was also observed by Evaldi and McCoy (2004) around Wardensville, West Virginia. These researchers identified the upper Cacapon and its tributaries, Trout Run and Waites Run, as losing/gaining stream segments due to a combination of karst and shale geological layers that interface with surface flow. They also found that groundwater held within the two seams were of different ages (20 year and 50-year-old residency times), which suggests they remain independent from one another and are influenced by their relative proximal synclines. Interestingly, where the Wardensville syncline ends just north of Wardensville township, the Meadows Brook syncline drains much of the southward ridge even extending into the Potomac River mainstem drainage. The Meadows Brook syncline runs parallel to and 0.5 miles south of the Cacapon river past the six-mile hyper productive reach. As both the river and the syncline may act as corridors for water transport, it is reasonable to predict that connectivity between these two channels will influence each.

Given the well documented dynamic hydrogeological nature of the upper Cacapon, and the inherent water chemistry of waters that interact with karst influenced streams, ICPRB and WVDEP decided to focus efforts on investigating the role of groundwater in the upper Cacapon drainage. The 2018 season was divided into three primary tasks: 1.) ICPRB was to locate ground water/surface interface locations (springs, seeps, and wells) throughout the upper Cacapon drainage. 2.) When conditions are not influenced by surface flow, water chemistry at ground water and instream sites should be collected and analyzed and, 3.) novel technologies such as Infrared imaging should bssessed for future work. Due to the persistent high flows that the Cacapon River experienced in 2018, objectives 1 and 3 were completed but objective 2 was not.

Field methods

ICPRB biologists implemented a modified version of the WVDEP Filamentous Algae Monitoring Protocol (WVDEP 2013) at 19 fixed locations between May and December 2018. The standard WVDEP filamentous algae protocols consist of routine water chemistry sampling, a rapid assessment style field form, semi-quantitative algae coverage estimates, and longitudinal surveys to document the extent of bloom events. To reduce effort required to survey all 19 fixed locations, a modified rapid assessment was used in 2018. Instead of a recording of algal composition at every site (usually taking 2 full days of work for 19 sites on the Cacapon and South Branch rivers) per round, a single ICPRB biologist made routine observations of the Cacapon and South Branch Potomac rivers, only recording visible algal bloom events. A total of eight driven longitudinal surveys were performed in 2018. Due to the severe flooding, streambed scouring, damage to roadways, and river bank erosion, no floated longitudinals were conducted in 2018. There were no field reports recorded in 2018 due to lack of algae observed.

Information on the WVDEP filamentous algae monitoring program for a standard non-flood year, including the Standard Operating Procedures for algae observation and water chemistry sampling, and the program's field data sheet can be found on-line at:

http://www.dep.wv.gov/WWE/Programs/wqs/Pages/FilamentousAlgaeinWestVirginia.aspx

2018: A Historically Wet Year

At the start of the 2018 season, ICPRB was to focus on identifying groundwater source locations, sample mainstem baseflow conditions, and compare them to groundwater sampling points (springs, wells, etc.). The timing of collection efforts was based on 2017 observations that groundwater seeps were more dominant in the mainstem ambient water chemistry as the river level approached base flows. This hypothesis is supported by seasonal shifts in ionic chemistry (specific conductance, hardness, and alkalinity) as surface water runoff becomes less of an influence. We propose that nutrient enriched groundwater introduced through the hyperhetic (benthic substrate) zone of the stream substrate allows for the rapid uptake of nutrients (nitrogen and phosphorus) by attached primary producers, such as filamentous algae and submerged aquatic vegetation (SAV).

From May Through October 2018, the Cacapon River experienced historical levels of flooding in both intensity and frequency (Table 1, 2.). Although the flooding was not continuous, the intervals between significant storm events rarely allowed discharge values at the Great Cacapon gage to fall to baseflow values or stabilize to a relative baseflow (Figures 1, 2). The lack of baseflow conditions prohibited water chemistry collections as well as flow measurements for all but a single time point on July 20th, 2018 (Figure 1, 2.)

ICPRB used two significant discharge values to assess the ability of biologists to survey the Cacapon River; 1.) 1,000 CFS threshold at the Great Cacapon Gage represents the minimum discharge value where significant river bed scouring occurs and no benthic attached algae remains and 2.) 8,000 CFS at the Great Cacapon Gage which represents historical flood stage. During 2018, The Cacapon River experienced the highest flow observed in the previous 5 years, hitting a maximum instantaneous discharge of 24,100 CFS. Analysis of just summer flow events when algae is most likely present revealed flows in the Cacapon River were nearly 48% of the time in exceedance of the 1000 CFS threshold and 5% of the time flooding at historical levels.

Full Water Year	Maximum Instantaneous Discharge (CFS)	Minimum Instantaneous Discharge (CFS)	Days with Discharge (CFS) >1000cfs	% Time >1000cfs	Days over >8000cfs
2014	19000	71.5	76.13	21.73%	2.08
2015	3990	61.1	38.35	11.03%	0
2016	5640	64	60.27	17.34%	0
2017	8070	57.3	42.58	11.74%	0.04
2018	24100	55.7	97.50	28.59%	5.15

Table 1. Annual flow analysis of water years 2014 through 2018. A water year is defined as October 1st through September 31st.

Primary Production Season (May-September)	Maximum Instantaneous Discharge (CFS)	Minimum Instantaneous Discharge (CFS)	Days with Discharge (CFS) >1000cfs	% Time >1000cfs	Days over >8000cfs
2014	19000	71.5	13.29	8.70%	0.94
2015	1930	61.1	4.10	2.70%	0
2016	3340	64	23.17	15.15%	0
2017	8070	57.3	21.29	13.93%	0.04
2018	24100	139	73	47.77%	5.15

Table 2. Flow analysis of summer season flows for water years 2014 through 2018. Primary Production season is defined as May 1st through September 31st.

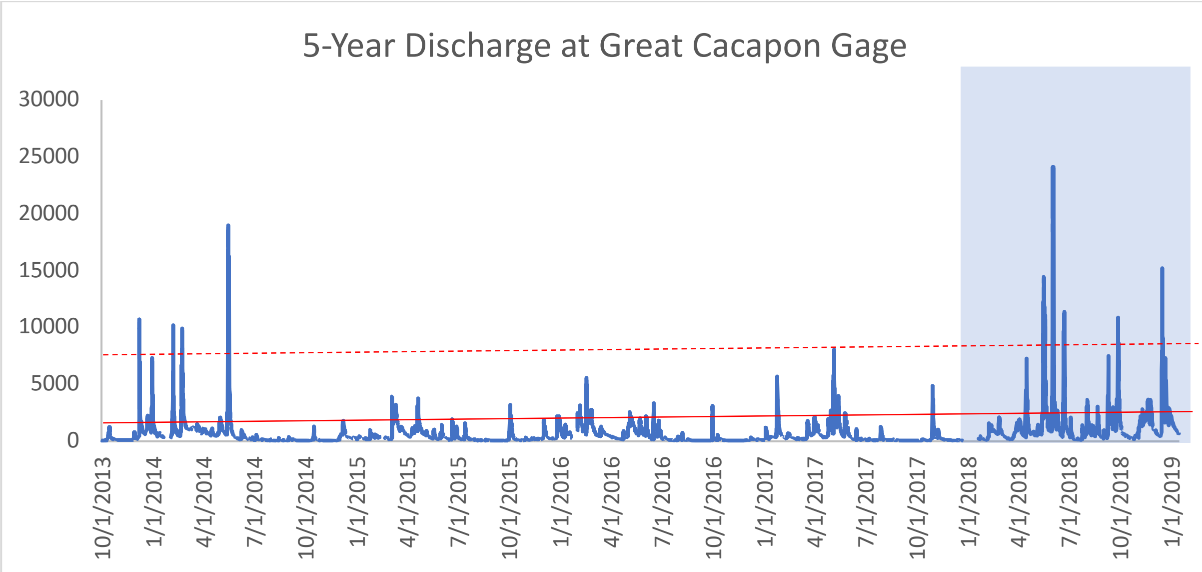


Figure 1. Discharge values at the Great Cacapon gage (USGS 01611500) for duration of previous 5 years. Red line represents Cacapon River scour threshold (1,000 CFS) and dotted red line represents flood stage (8,000 CFS). Area shaded in blue represents 2018.

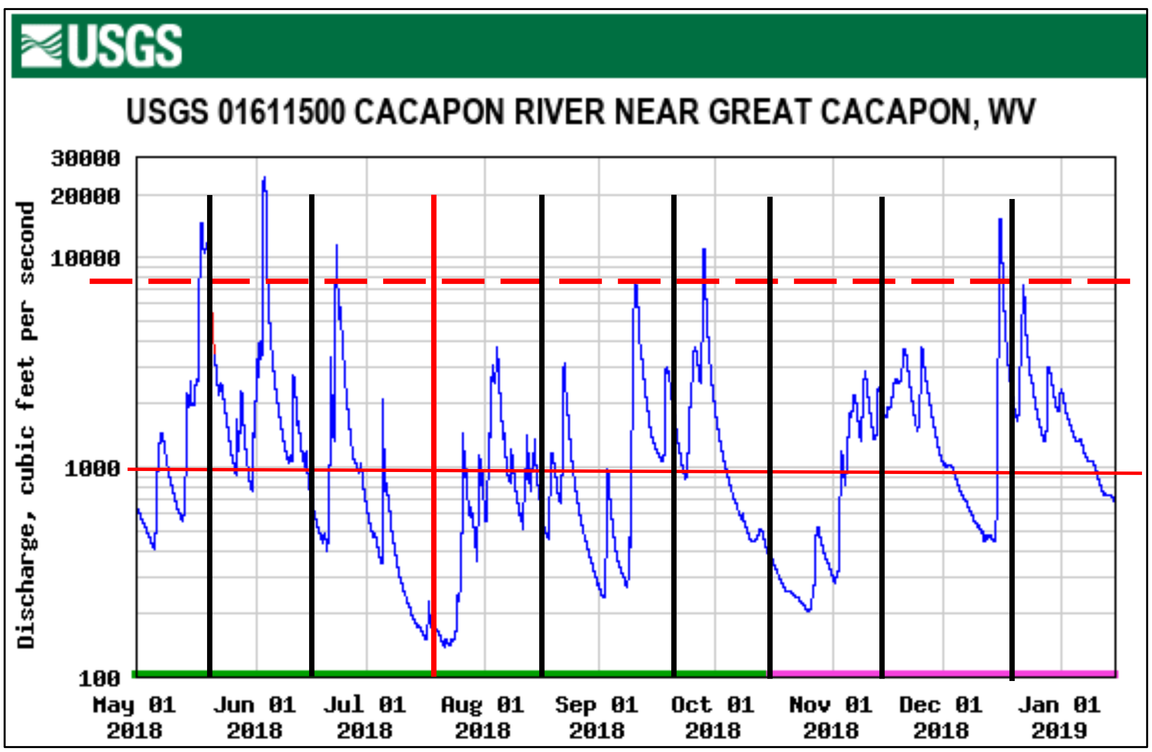


Figure 2. Great Cacapon Gage for duration of study period May 1, 2018 through January 15, 2019. Black lines represent driven longitudinals to assess condition of the Cacapon River. Solid red Line represents water chemistry samples and algal measurements taken. Dotted red line represents flood stage.

Groundwater Mapping and Investigation

Plotting available Groundwater Data and New Spring Locations

In 2018 ICPRB conducted a data call for available groundwater data for the Cacapon and South Branch Rivers. United States Geological Society (USGS), West Virginia Department of Environmental Protection (WVDEP), and Virginia Department of Environmental Protection (VADEP) provided data including known springs, caves, and karst formations. GIS was used to (Figure 3, 4, 5) visualize and quantify the co-occurrence of springs underlain by karst geology along the eastern Appalachian Ridge. Although a high percentage of springs do occur within the bounds of a karst layers, there are many springs not directly underlain by karst geology, suggesting that subsurface flow paths are not bound to karst geology alone and may also rely on the stratification of the synclines.

In addition to data provided to ICPRB by USGS, West Virginia, and Virginia agencies, 11 newly confirmed springs and 10 unconfirmed spring locations were found in the upper Cacapon Valley (Table 3.). Anecdotal reporting from residents suggest there are far more than the 21 groundwater spring locations identified in this report. Based on preliminary analysis of karst and groundwater spring distribution, we hypothesize subsurface connectivity between water bodies may be a significant component in understanding nutrient transport and enrichment in the Upper Cacapon River. Furthermore, we raise the question could land use practices of proximal drainages (Lost River, North River, North Shenandoah River) be affecting the upper Cacapon study area. Further research of ground water flow paths and groundwater transport times are needed to better understand this dynamic and highly interconnected hydrogeological region.

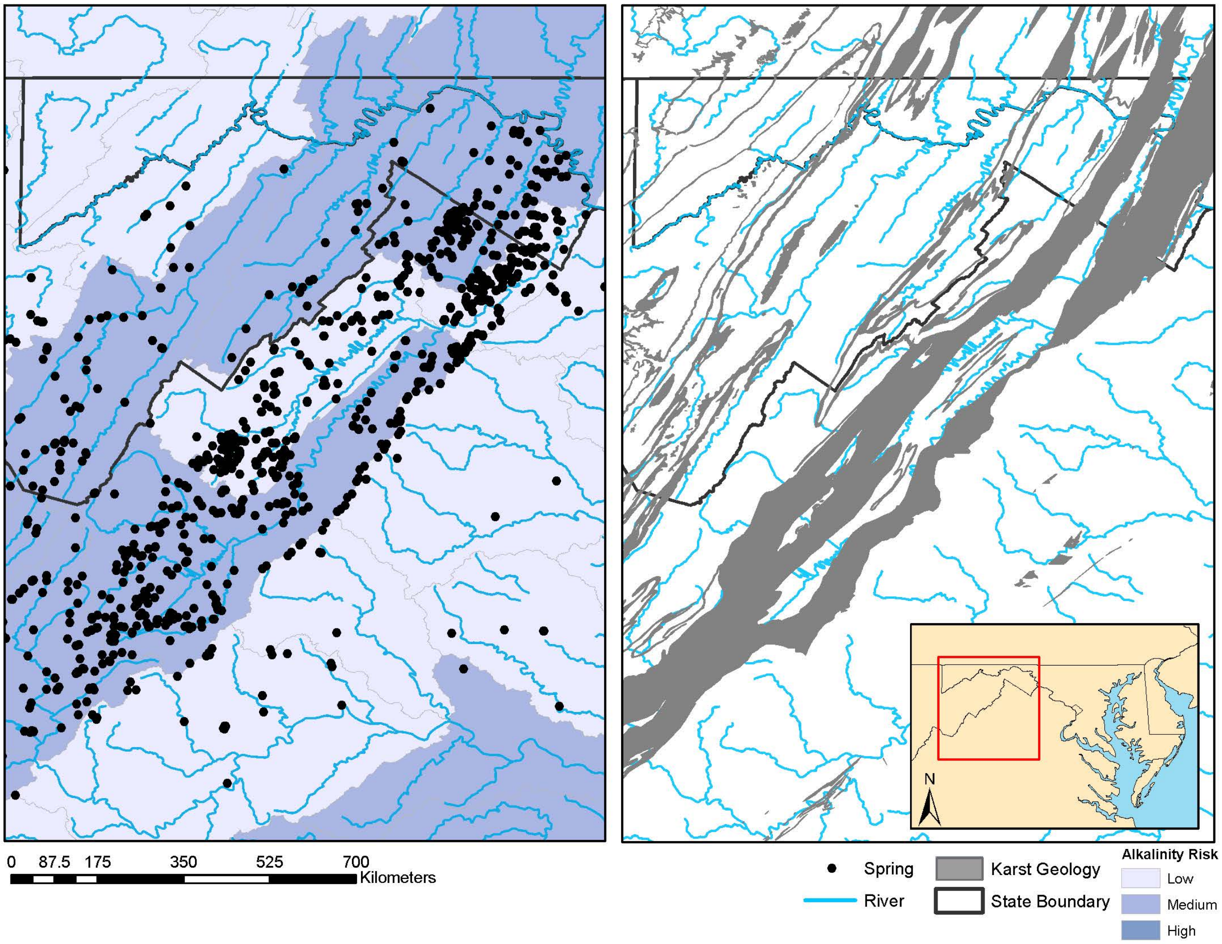


Figure 3. A map identifying known spring locations (left) and underlying karst geology (right) along the Blue Ridge range of the Appalachian Mountains.

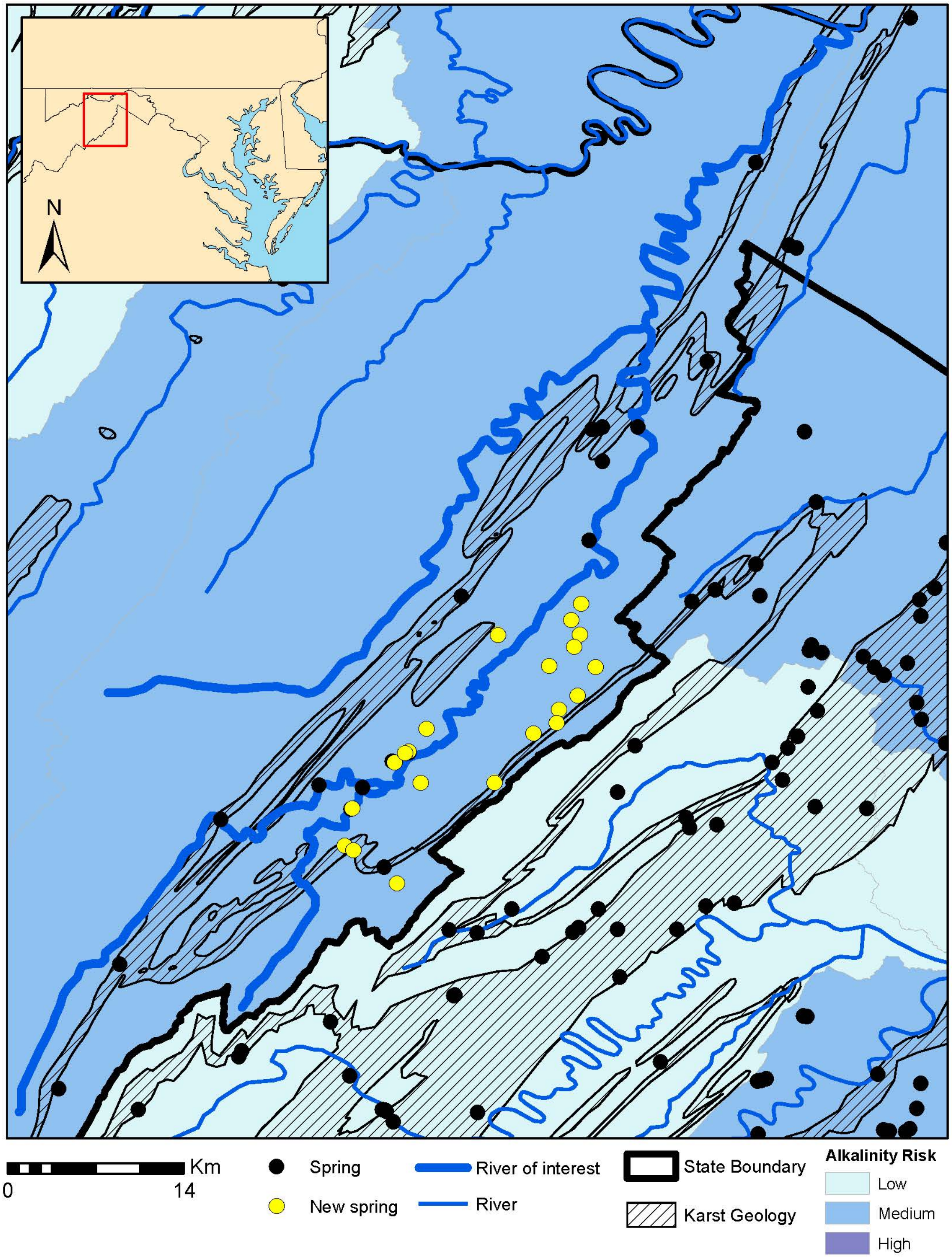


Figure 4. Map of Cacapon River drainage (including the Lost River, Trout Run, and North River) with spring locations (black markers) and karst layers (hatched lines). Regions with darker blue have a higher percentage of water chemistry conducive to algal blooms. New locations are represented by yellow markers and specific details can be found in Table 3.

Table 3. Table of new spring and well locations proximal to the Upper Cacapon River. The FLIR E6 was used to confirm temperature anomalies and identify springs. Locations that were not confirmed are locations where landowner access was not given, or general area of spring was provided but never identified.

Latitude	Longitude	Type	Name	Confirmed Location
39.133532	-78.480681	Spring	Capon Springs Resort	Yes-E6 confirmed
39.116474	-78.498903	Well	Well at Eagle Campground	Yes-E6 confirmed
39.081393	-78.526503	Spring	Highway 55 Spring	Yes-E6 confirmed
39.081114	-78.579320	Spring	Waites Run Bridge	Yes-E6 confirmed
39.095841	-78.598134	Spring	Spring House WVU	Yes-E6 confirmed
39.103590	-78.587913	Spring	WVU Field 1	Yes-E6 confirmed
39.102568	-78.590549	Spring	WVU Field 2	Yes-E6 confirmed
39.036494	-78.633770	Spring	Poison Spring	Yes-E6 confirmed
39.033178	-78.627518	Spring	Lower Trout Pen Pond	Yes-E6 confirmed
39.063096	-78.628090	Spring	Trout Run	Yes-E6 confirmed
39.009348	-78.596342	Spring	Trout Pen House	Yes-E6 confirmed
39.143415	-78.467440	Spring	Near Capon Springs	No
39.123984	-78.482480	Spring	Above Resort	No
39.163552	-78.454458	Spring	Bahavia Society (Loman Branch Headwater)	No
39.119930	-78.575048	Spring	Small business- "Healing waters"	No
39.208873	-78.464940	Spring Pond	Camp Tall Timbers/Sandy Cove	No
39.197306	-78.471986	Spring Pond	Concord Christian Retreat	No
39.186899	-78.465635	Spring Pond	Farm Pond 1	No
39.178264	-78.469743	Spring Pond	Farm Pond 2	No
39.164546	-78.487792	Spring Pond	Falling Water Creek (Headwater)	No
39.186677	-78.524293	Spring Pond	Informed by local	No

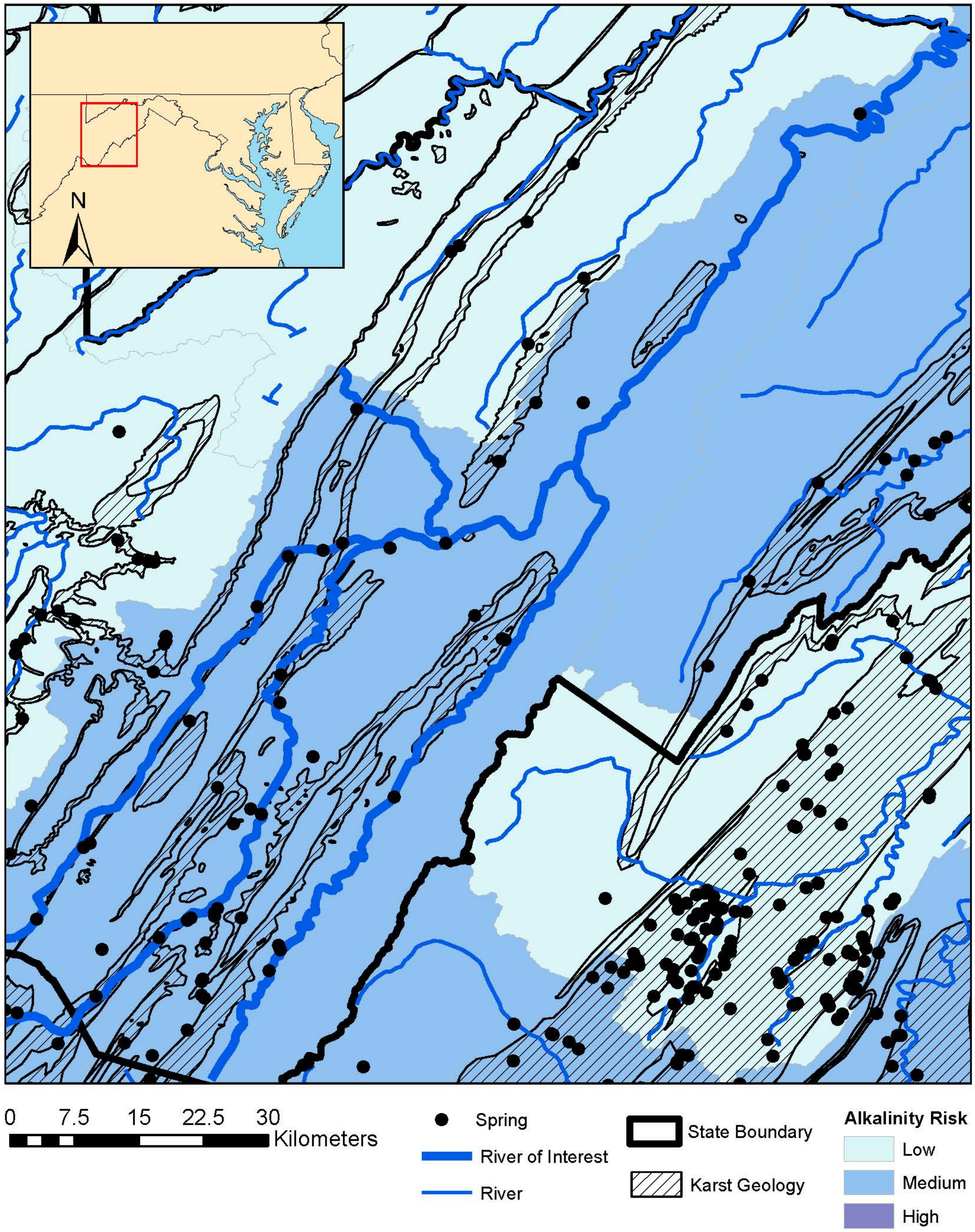
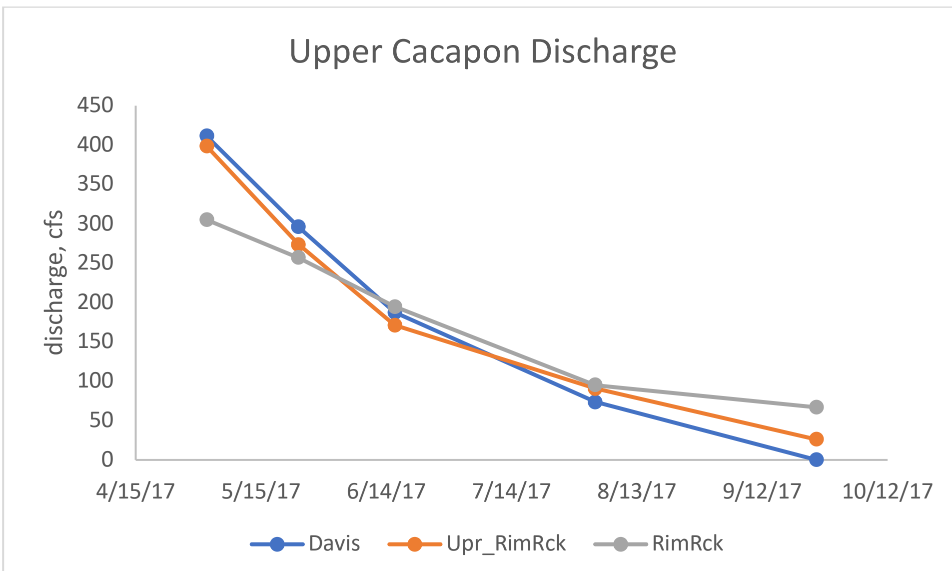


Figure 5. Map of South Branch Potomac River drainage with spring locations (black markers) and karst geology (hatched lines). Regions with darker blue have a higher percentage of water chemistry conducive to algal blooms.

Evidence of Dynamic Groundwater in Cacapon River Flow

From the record of flow measurements by ICPRB between 5/2/2017 and 9/25/2017, the five-mile segment of the Cacapon River between CA_YLWSPR and CA_RMRCK was a losing segment from May 2nd through the first half of June when it changed to a gaining segment. Possible bedding plane conduits/fractures/joints in the underlying Millboro shale – Needmore Formation may be providing an interchange of water between the stream and shallow un-confined aquifer. Figure 6 shows the reach losing flow from the upstream station, Davis Ford (Davis), to the downstream station, Camp Rim Rock (RimRck), at the first and second measurements but gaining flow between Upper Rim Rock (Upr_RimRck) and Rim Rock (RimRck) at the third measurement. At the fourth and last measurements the reach is gaining from Davis Ford to Rim Rock.

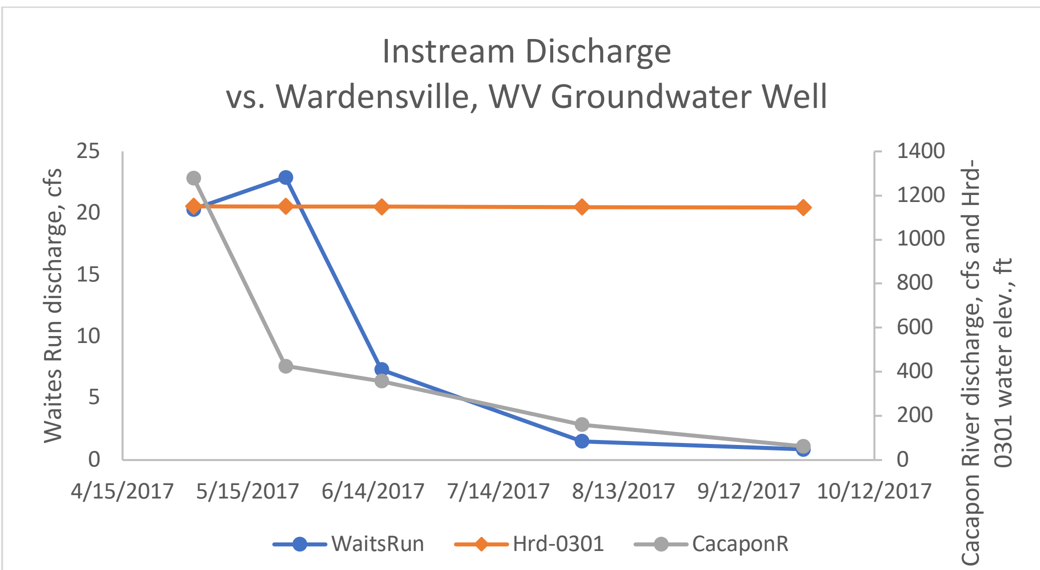
Figure 6. Total discharge (cubic feet/second) of three Cacapon River sites proximal to the Rim Rock bloom location. Within the surveyed 5-mile reach, there are seasonal differences in source water; early season is dominated by surface runoff while late season is dominated by groundwater.



ROUND	5/2/2017	5/24/2017	6/16/2017	8/3/2017	9/25/2017
DAVIS FORD	411.32	296.00	187.45	73.47	BTD
UP_RIM ROCK	398.49	273.41	171.13	90.64	25.94
RIM ROCK	304.99	256.74	194.59	94.89	66.80

Nearby upstream USGS gage stations on an upstream tributary to the mainstem Cacapon River showed similar results. Figure 7 shows the flow at USGS gages on Waites Run (0160400), a small tributary to Cacapon River upstream of the reach, and at Cacapon River near Great Cacapon, WV (01611500). Both these gages show a similar decline of flow during the same period as seen on the reach studied. The study reach flow declined by approximately 90% from May 2nd to September 25th, 2017; Waites Run and Cacapon River near Great Cacapon declined by 95% over the same period. A difference is that at the Waites Run and Cacapon River gages 70% and 64%, respectively, of this decline occurred between May 2nd and June 16th. This difference may be due to the connection between the streambed and the underlying aquifer. Over the period of these measurements, the water elevation in well Hrd-0301, approximately 10 miles upstream of the reach and completely in the same geologic formation, fell 5 feet (Figure 7). This decline in water level may or may not reflect the groundwater table change in the general area and adjacent to the stream. Local geologic conditions near the study reach could create different groundwater conditions adjacent to the reach and produce springs or seeps. Future investigation of nearby groundwater sources may provide additional details in defining source waters of the mainstem Cacapon River. The geology of this region appears to be conducive to groundwater flow which may also be influencing instream biology in the Cacapon River.

Figure 7. Waites Run (0160400) and the mainstem Cacapon River (01611500) both show very similar reductions in flow throughout the season. The groundwater level (well Hrd-0301) in this region changed very little.



Forward Looking InfraRed (FLIR) Imaging

Cacapon River, West Virginia

In 2018 ICPRB procured a Forward Looking InfraRed (FLIR) camera (FLIR® E6) to identify Cacapon River mainstem river spring site locations using temperature anomalies as markers. The use of thermal imaging for nutrient source tracking and groundwater detection is a novel adaptation of Martin Briggs work with USGS. Although ICPRB was unable to use this tool within the mainstem Cacapon River in 2018 due to elevated flows, nearby Trout Run was used to assess the tool's ability to detect groundwater influences in flowing waters. In summer, when Trout Run was nearest baseflow, ICPRB took a picture of a previously documented spring that enters the descending left bank of Trout Run (Figure 8A.). The cool groundwater water makes an obvious blue glow in contrast to adjacent warm (orange, yellow and red) instream flow. This observation is flipped in the winter, when images taken in December revealed warm (red and yellow) spring water relative to the cold flow of the channel (Figure 8B). Interestingly, the temperature signal was discernable far downstream showing the tendency of the spring water to stay stratified and detectable in Trout Run. The FLIR E6 was also used in field testing of spring locations throughout the summer. Cool groundwater could be observed in cow pastures, forests, and residential lots due to the solar radiation and warm summer air temps. ICPRB did not attempt to detect springs outside of the mainstem Cacapon River in the winter. It seems feasible, however, that the E6 would be equally as useful in detecting springs in the winter as well.

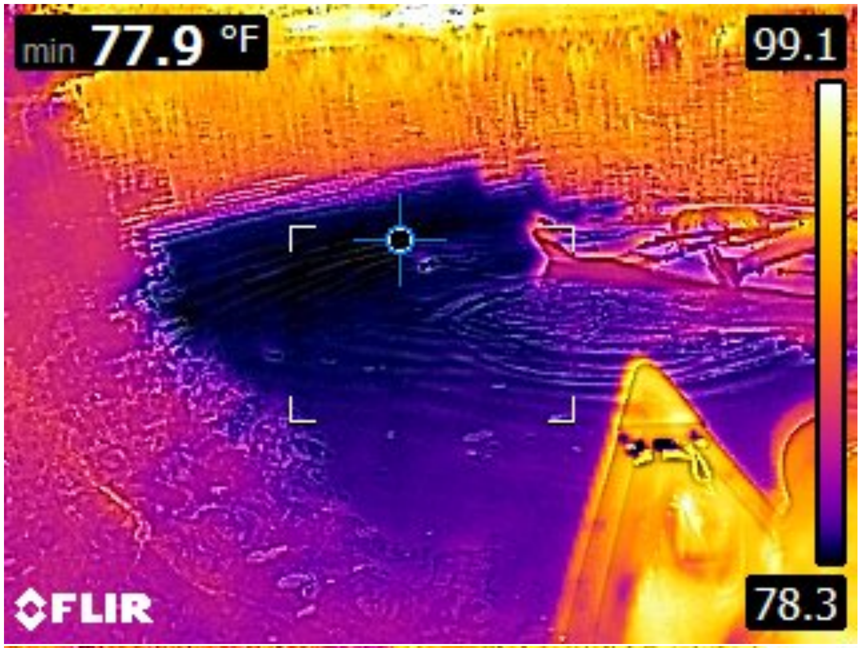
Buffalo River, Arkansas

ICPRB had the opportunity to test the FLIR E6 tool in the Buffalo River, Arkansas, which is a large, karst influenced, river. Although work in Arkansas was not a project task of WVDEP contract, ICPRB used this opportunity (which was funded by USEPA) to ground test the FLIR's ability to identify mainstem springs in larger bodies of water. Unlike the Cacapon River that was experiencing historic high flows, the Buffalo River was running below baseflow due to a 3-year drought in the region. As baseflow conditions are critical to spring detection due to the negated impact of surface runoff, the Buffalo River was a prime candidate for methodology testing. ICPRB implemented the WVDEP canoeing longitudinal method to cover roughly 20 miles of the Buffalo River in 3 days. During the three-day float, one significant instream spring (9A) and several bank influenced (9B) springs were located. These results proved thermal imaging very successful in the Buffalo River. Since the Buffalo and Cacapon Rivers are similar in morphology and base geology, we expect FLIR imaging for instream spring detection to work equally as well in the Cacapon River during a year where baseflow conditions (or a drought year) are experienced.

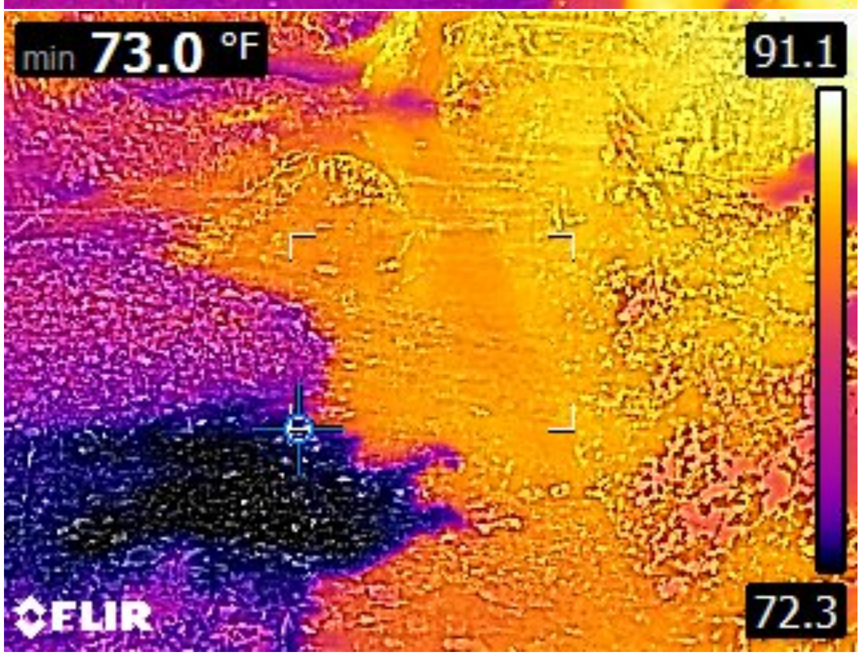
A.

B.

Figure 8. FLIR E6 thermal images of Trout run in summer (A) and winter (B). A large tree and bridge landmark were used to create duplicate images in the two seasons. The influence of the groundwater spring flowing on the far bank of Trout Run can be observed in both seasons.



A.



B.

Figure 9. Examples of mainstem springs located by the FLIR E6 in the Buffalo River, Arkansas. The thermal influence of instream springs, (A.) mid channel roughly 3ft deep and (B.) shore influenced, were detected as blue regions when the E6 photographed the mainstem river.

West Virginia Department of Agriculture Water Chemistry

ICPRB has started developing R-based analytical tools to rapidly analyze and visualize large water quality datasets. As a first iteration of a rapid assessment tool for WVDEP and WV Department of Agriculture, ICPRB developed a R code language (R-markdown package) capable of rapidly visualizing bi-weekly water quality samples and exporting the report as PDF, HTML, or word documents (.docx). The code and output provided in this report (Appendix 1.) will allow for datasets within the WV Department of Agriculture database to rapidly summarize and visualize long term datasets. The rapid processing of data can quickly help identify long term trends as well as anomalies in the dataset such as equipment drift and or methodology change impacts. One such example of the advantage of rapid analysis observed in 2018 is the effect of high flows on instream water chemistry. High variability of nitrogen species, ortho-phosphate, and fecal coliform bacteria (FCB) all point to large amounts of surface nutrient inputs in 2018. The variability observed in 2018 is unlike anything observed prior to 2018 and shows that, despite the typical difficulty of identifying nutrient sources in the Cacapon, nutrient enriched surface water runoff is an issue throughout the Cacapon river basin.

Conclusion

Although much of the proposed fieldwork was not able to be completed in 2018 due to historic flooding, ICPRB was able to begin investigating the influence of spring and groundwater inflows on the habitat and biology of the Cacapon River. Hydrological, geological and spatial analysis conducted in 2018 suggest that the Cacapon River is a unique hydrogeological location. The addition of the FLIR E6 thermal imaging technology to existing protocols, such as continuous monitoring tools and YSI field instruments, will aide in future identification of springs in flowing waters and will further elucidate dynamic interactions of ground water on the Upper Cacapon River. If similar procedures and methods are followed in future efforts, and appropriate baseflow conditions are available, it can be expected that groundwater nutrient source tracking will yield positive results.

Appendix I. Cacapon and Lost River WV Dept of Agriculture Data 2016-Current (R-Markdown Program)

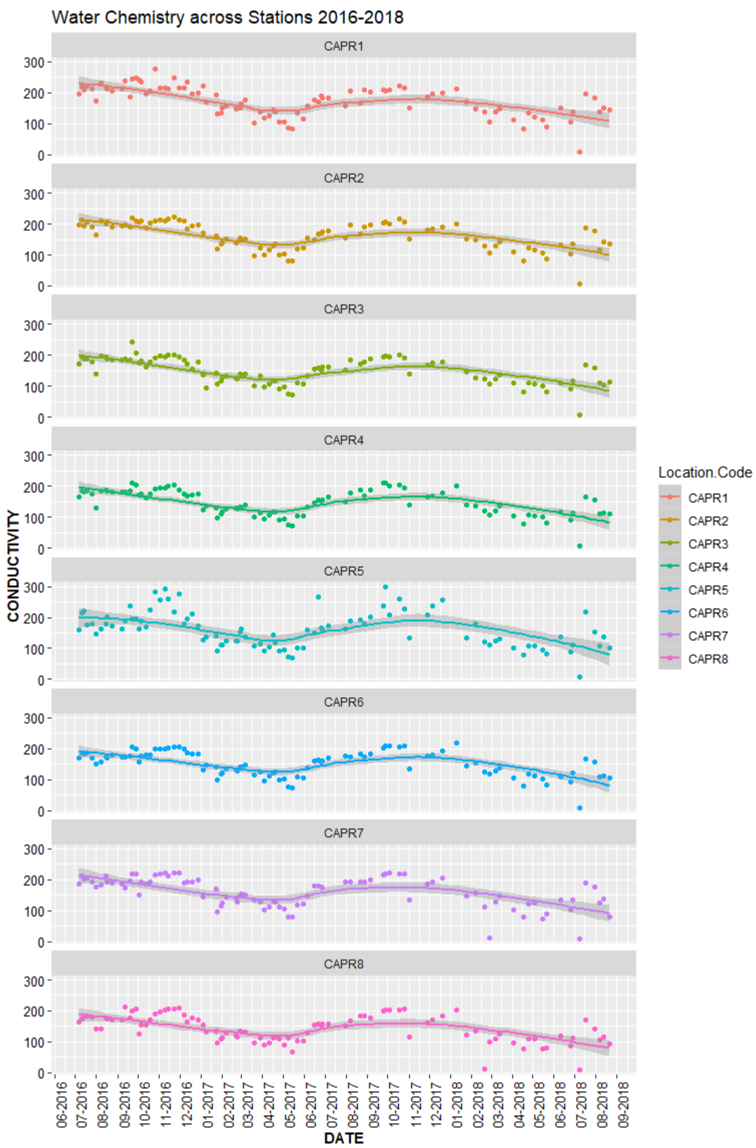
This R-notebook/R-Code is intended for the West Virginia Department of Agriculture and West Virginia Department of Environmental Protection. The purpose of this document is to expedite water chemistry data analysis, collected by the West Virginia Department of Agriculture. Analysis outputs are found under their corresponding code as well as in the text document.

Load in Package for Analysis and Graphics + Clean Data

```
library(tidyverse)

## -- Attaching packages ------------------------------------------------------------
-------- tidyverse 1.2.1 --

## v ggplot2 3.1.0     v purrr   0.2.5
## v tibble  1.4.2     v dplyr   0.7.8
## v tidyr   0.8.2     v stringr 1.3.1
## v readr   1.3.1     v forcats 0.3.0

## -- Conflicts ---------------------------------------------------------------------
-- tidyverse_conflicts() --
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()

library(ggplot2)
#Import dataset as you best see fit. User can set a working directory or isolate a
set of data and import as a CSV (as in the case below).

Cacapon2018<- read.csv("C:/Users/gmselckmann/Documents/CacaponRscripts/Data/CAPON RIV
ER 82018.csv",
                                   stringsAsFactors = FALSE)

Ag_Data.df <- Cacapon2018 %>%
  mutate(date=as.Date(Collection.Date, format="%m/%d/%Y"),
         ORTHOPHOSPHATE_W=as.numeric(ORTHOPHOSPHATE_W))
```

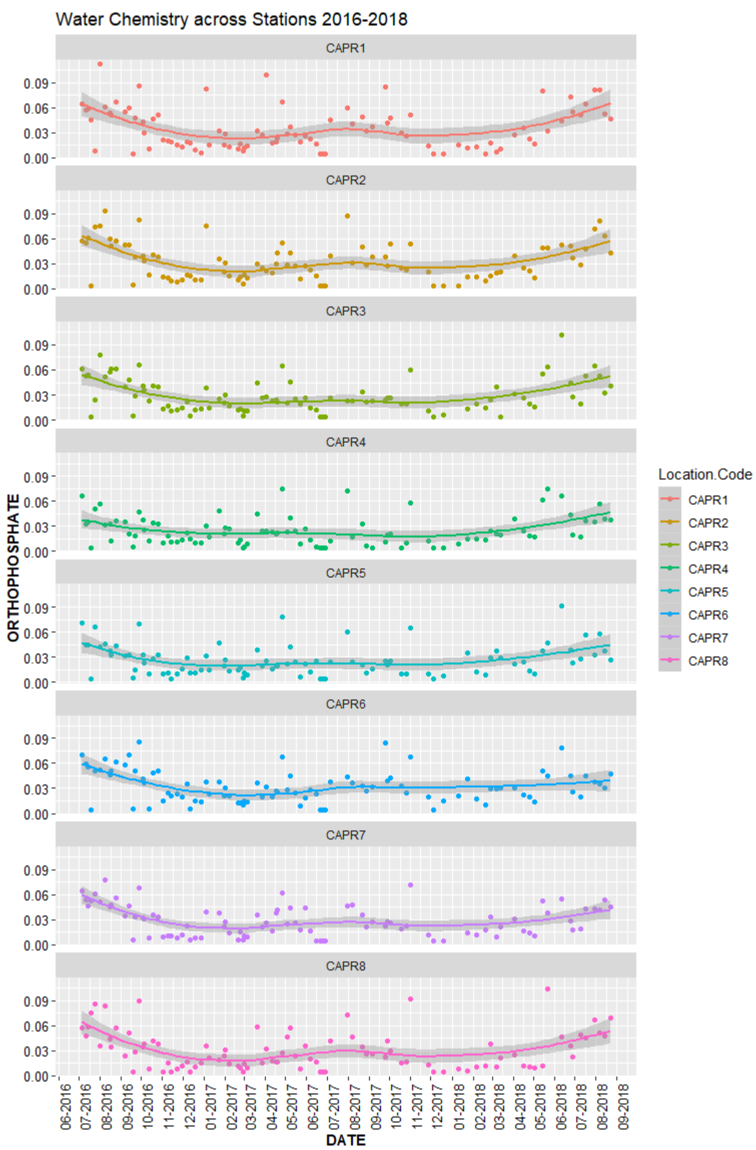
Cacapon Data Conductivity

```
p <- ggplot(`Ag_Data.df`, aes(date, CONDUCTIVITY_W, group = Location.Code, color = Lo
cation.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("CONDUCTIVITY") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") + geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



OrthoPhosphate_W

```
p <- ggplot(`Ag_Data.df`, aes(date, ORTHOPHOSPHATE_W, group = Location.Code, color = Location.
Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("ORTHOPHOSPHATE") + scale_fill_brewer(palette="BrBG")     +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text.y=elemen
t_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y", date_brea
ks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```

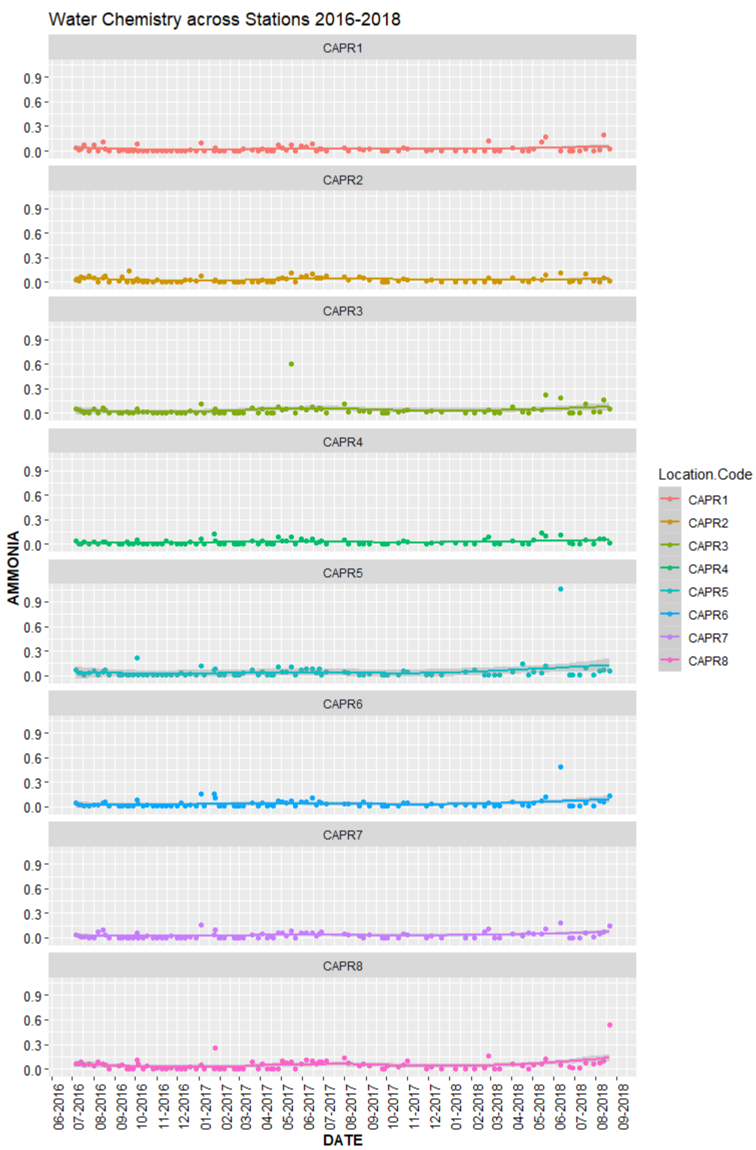


Total Phosphorus

```
p <- ggplot(`Ag_Data.df`, aes(date, PHOSPHOROUS_W, group = Location.Code, color = Loc
ation.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("TOTAL PHOSPHORUS") + scale_fill_brewer(palette="BrBG")   +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```

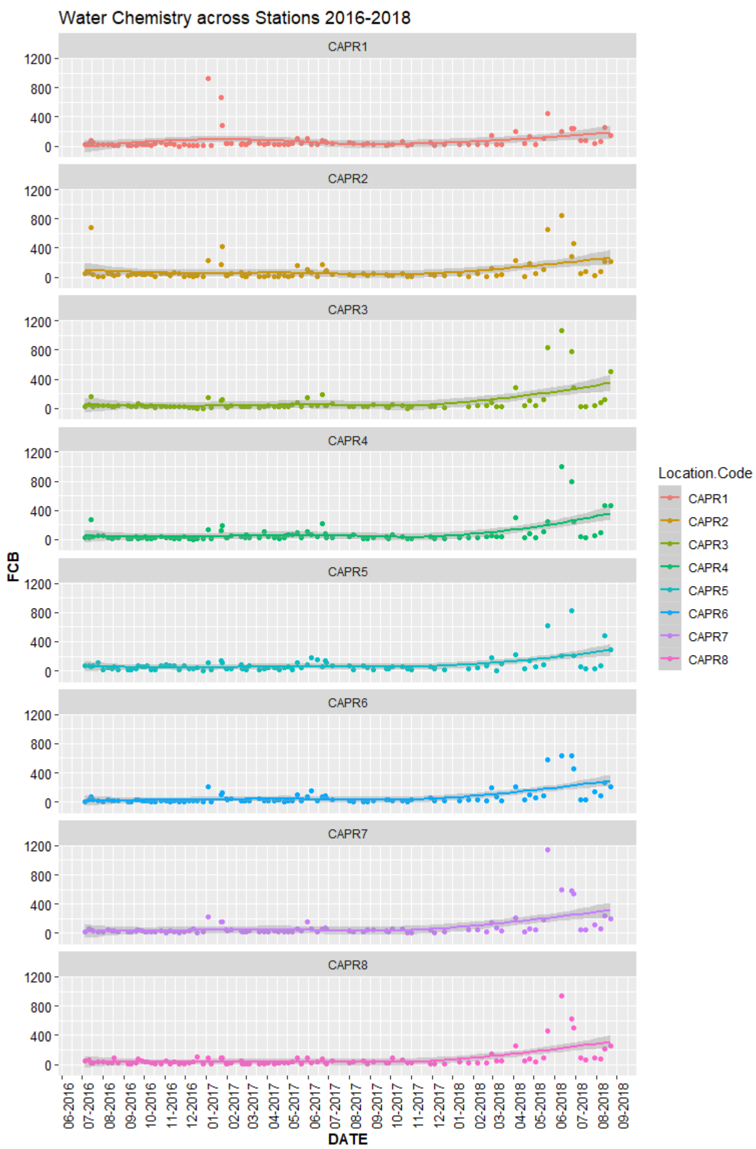
AMMONIA

```
p <- ggplot(`Ag_Data.df`, aes(date, AMMONIA_W, group = Location.Code, color = Locatio
n.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("AMMONIA") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



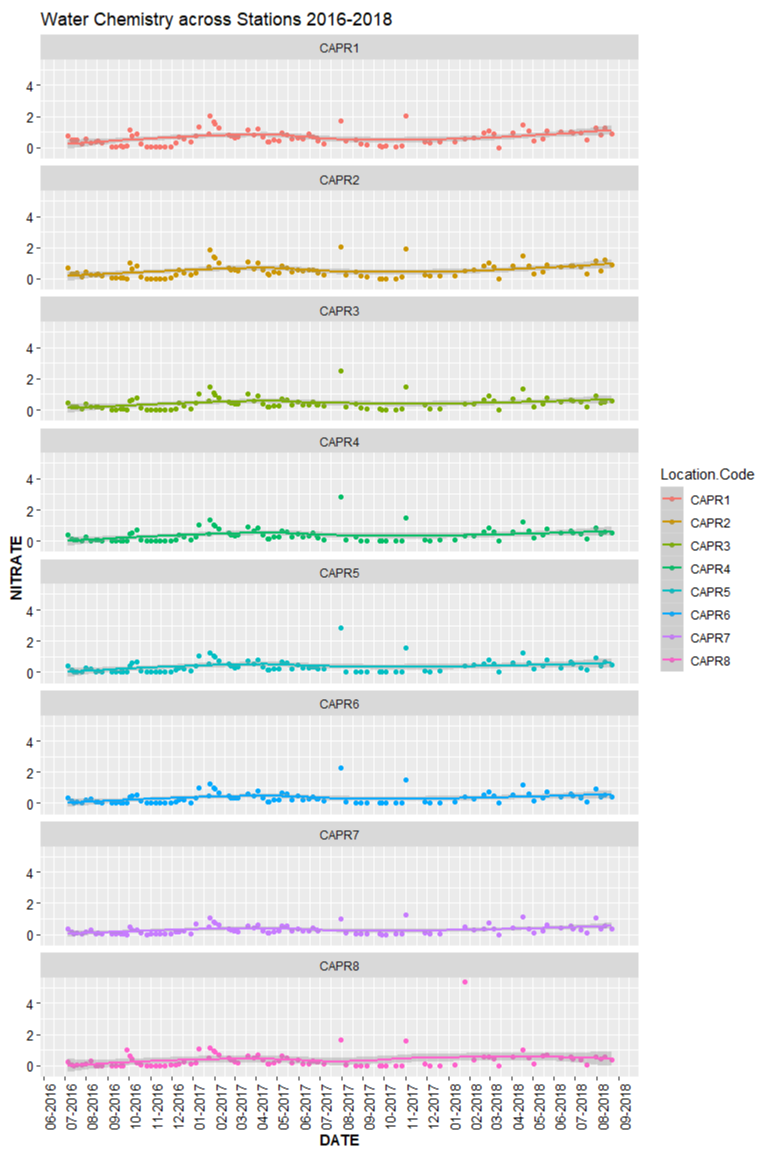
#FECAL COLIFORM BACTERIA

```
p <- ggplot(`Ag_Data.df`, aes(date, FCB_W, group = Location.Code, color = Location.Co
de))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("FCB") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



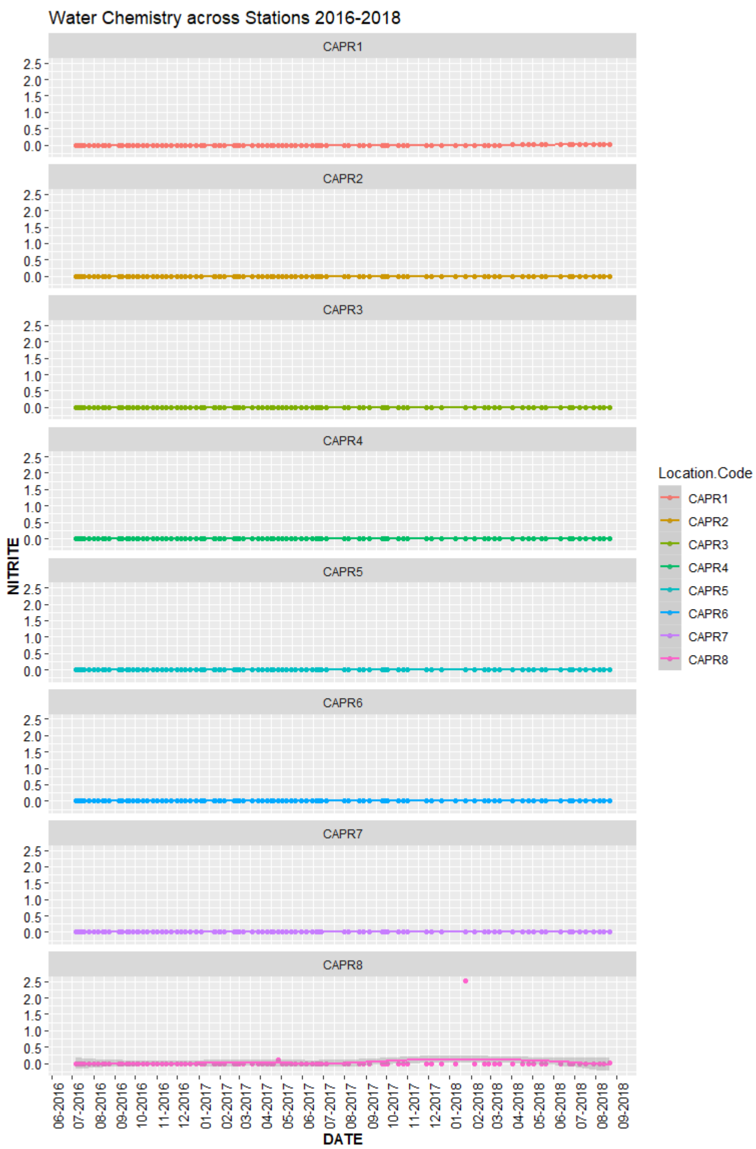
#NITRATE

```
p <- ggplot(`Ag_Data.df`, aes(date, NITRATE_W, group = Location.Code, color = Locatio
n.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("NITRATE") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



#NITRITE

```
p <- ggplot(`Ag_Data.df`, aes(date, NITRITE_W, group = Location.Code, color = Locatio
n.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("NITRITE") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```

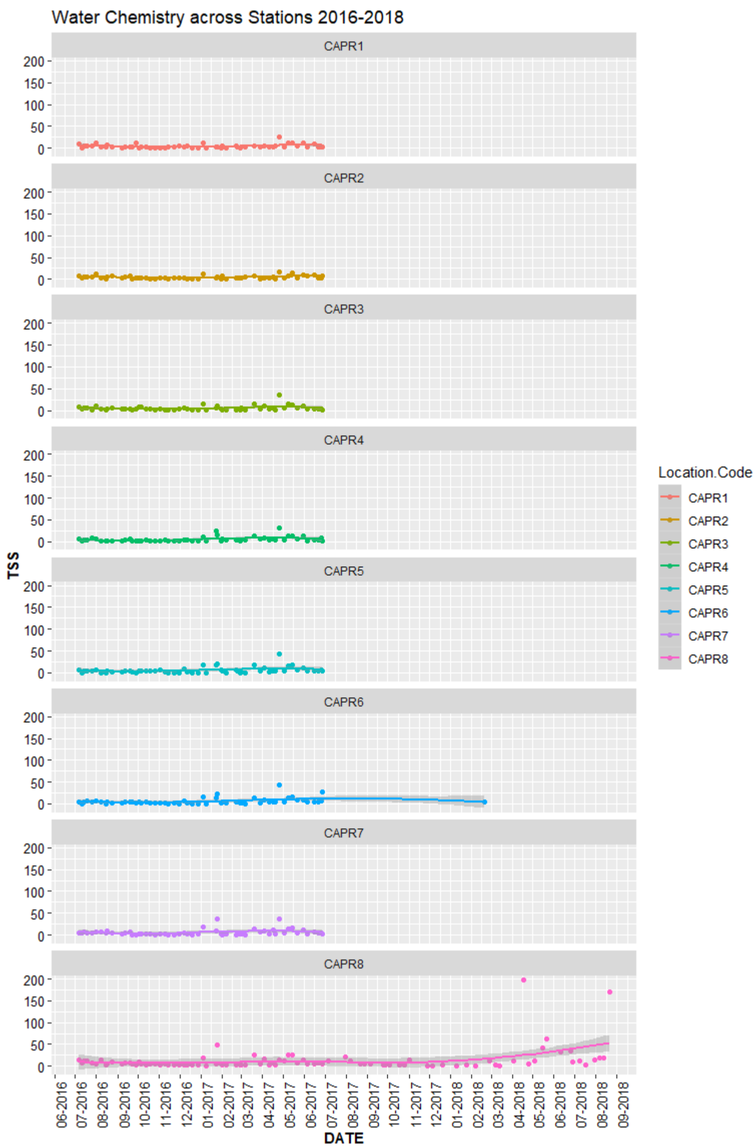


#TURBIDITY

```
p <- ggplot(`Ag_Data.df`, aes(date, TURBIDITY_W, group = Location.Code, color = Locat
ion.Code))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("TURBIDITY") + scale_fill_brewer(palette="BrBG")  +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") +
  geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```

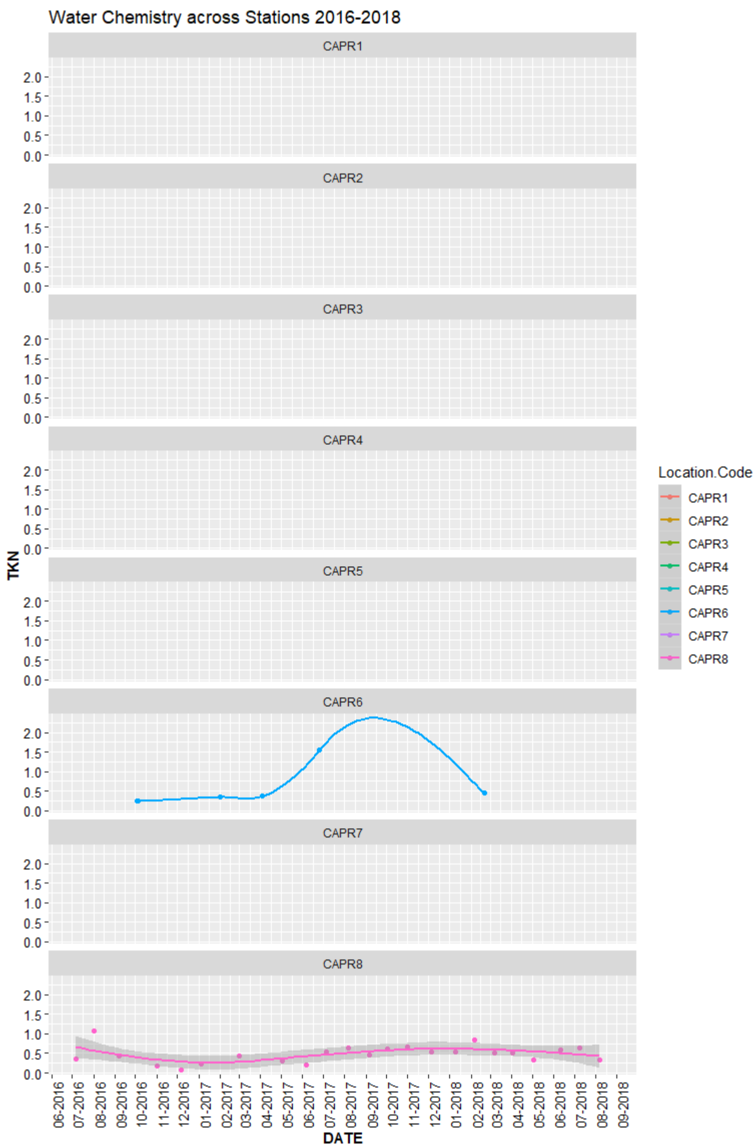
Cacapon Data TSS (too few values at this time)

```
p <- ggplot(`Ag_Data.df`, aes(date, TSS_W, group = Location.Code, color = Location.Co
de))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("TSS") + scale_fill_brewer(palette="BrBG")    +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") + geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



Cacapon Data TKN (too few values at this time)

```
p <- ggplot(`Ag_Data.df`, aes(date, TKN_W, group = Location.Code, color = Location.Co
de))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("TKN") + scale_fill_brewer(palette="BrBG")     +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") + geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```



Cacapon Data TN (too few values at this time)

```
p <- ggplot(`Ag_Data.df`, aes(date, TN_W, group = Location.Code, color = Location.Cod
e))
p + geom_point(aes()) + labs(title = "Water Chemistry across Stations 2016-2018") +
  xlab("DATE") + ylab("TN") + scale_fill_brewer(palette="BrBG")      +
  theme(axis.text.x=element_text(angle=90, size=10, color="black")) + theme(axis.text
.y=element_text(size=10, color="black")) +
  theme(axis.title=element_text(face="bold")) +  scale_x_date(date_labels = "%m-%Y",
date_breaks = "1 month") + geom_smooth() + facet_wrap(~Location.Code, ncol = 1)

## `geom_smooth()` using method = 'loess' and formula 'y ~ x'
```