Relationship Between Longitudinal and Temporal Streamwater Chemistry Across Streams

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Abstract

Local streams and rivers pose a significant role in providing habitats for certain plant and animal species, filtering pollutants from groundwater inputs, and drinking water sources for surrounding communities. As urban development rises around streams, stream channels become incised and separated from their floodplains. The solution to this problem is stream restoration. The purpose of this research was to determine the relationship between longitudinal and temporal streamwater chemistry across urban restored streams. A focus on carbon-nitrogen and base cation concentration analyses across three restored streams was used in conjunction with hydraulic measurements and stream channel geometry to better understand spatial and temporal relationships among and between the streams. Streamwater samples, discharge calculations, land use types, and streamflow sensor data were collected and analyzed during water quality monitoring. Spatial and temporal monitoring was conducted at Paint Branch, Campus Creek, and Scotts Level Branch, three restored streams local to Northern and Central Maryland. It is hypothesized that by comparing measurements through space, time, and across streams, similar trends in water chemistry will be identified longitudinally in a stream. The hypothesis was explored through analyses of field data collection and USGS Stream Gauge data. A total of 31 longitudinal sampling sites across all three streams paired with hourly water sampling provides data for water chemistry analysis. Measurements of stream bed width and depth were made at Scotts Level Branch for longitudinal discharge variance calculations. Specific conductance, pH, total dissolved solids (TDS), water temperature, dissolved oxygen (DO), and oxygen reduction potential (ORP) were also measured during field sampling surveys.

Significant longitudinal variations in stream chemistry and pollutant concentrations were found along each stream (ranging from 0.6223 mg/L to 2.795 mg/L, 7.45 mg/L to 35.7 mg/L, and 9.25 mg/L to 28.8 mg/L for N, Ca, and Mg, respectively). As discharge increased downstream at Scotts Level Branch, base cation concentrations and TDS measurements generally decreased, likely due to dilution. Additionally, similar variations in water chemistry and pollutant concentrations were found among streams, but there were unexpectedly large variations in stream chemistry over 24-hr sampling periods (particularly during storm events). Streamwater chemistry in Paint Branch and Campus Creek responded similarly to precipitation events on a temporal scale. There appeared to be a dilution of base cations with increased streamflow followed by an increase in base cations after a storm, likely due to groundwater recharge. Paint Branch and Scotts Level Branch both dilute TDS downstream, but Campus Creek shows little linear variation, possibly due to its smaller relative size.

Overall, this research demonstrates that streamwater chemistry can vary substantially temporally and spatially, particularly during storm events. Most ongoing water quality monitoring efforts focus on sampling at a fixed location ranging from weekly to monthly sampling intervals. However, results of this work suggest that more finely sampled systems are required to capture the spatial and temporal variations in urban streamwater chemistry in order to appropriately monitor and evaluate the effects of pollution and watershed management.

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Introduction

Streams evolve in concert with and in response to surrounding ecosystems. Changes within a surrounding ecosystem, whether natural or through anthropogenic behaviors, have an impact on a stream system's physical, chemical, and biological characteristics (Walsh et al., 2005; Paul & Meyer, 2001; FISRWG, 1998). Groundwater flowing from roads and parking lots into storm drains is rarely treated and represents nonpoint source pollution (Mayer et al., 2010). This means that groundwater, filled with trash and other pollutants, can be directed to storm drain outfalls located nearby local river and stream networks, and can have a great impact on the quality of its water and surrounding environment (Roy & Bickerton, 2012). Stream restoration is a billion-dollar industry and is growing around the world (Bernhardt et al., 2005). Most stream restoration projects in and around Maryland strive to improve water quality (Newcomer Johnson et al., 2016), as many streams ultimately empty into the Chesapeake Bay (Chang et al., 2021).

It is well known that rivers and streams are formed as groundwater flows towards the base level of erosion (Gaur et al., 2015), which is generally the lowest elevation in the landscape. Similarly, many public sewage drain pipes are commonly buried near streams in urban developments (Kaushal & Belt, 2012) as the pipes need to run downhill for gravitational flow. The problem with this is that as the stream network begins to slow down, discharge increases from urban areas, and the channel widens with age, the banks and stream bed are subject to erosion. If the sewage drain pipes are placed too close to the stream, the pipes can become exposed due to erosion contributing to sewage leaks. When exposed, the pipes are subject to weathering, which may result in rusting and breaking of the pipes. This would heavily pollute the stream network and may require expensive rehabilitation efforts (Bonneau et al., 2017; Kaushal & Belt, 2012). Some restorations work to protect and maintain nearby sewage drain pipes in surrounding stream watersheds to prevent groundwater from the incursion of excess pollutants.

There is growing work in investigating how water quality changes along stream flow paths over time including studies such as Fernald et al. (2006), Kaushal et al. (2014), and Smith et al. (2017), Deemy & Rasmussen (2017), and Lintern et al. (2018). Many studies have focused on carbon and nitrogen, but more work needs to be done on base cations. One study found that base cation concentrations in urban streams were up to 60 times greater than in agricultural and forest streams, with road salt and carbonate weathering from impervious surfaces suggested as potential sources (Kaushal et al., 2017). In addition, less is known about diurnal cycles of water chemistry in urban streams (Kaushal et al., 2020). Scholefield et al. (2005) noticed concerted patterns in phosphorus, nitrate, nitrite, discharge, and water temperature over an intensive 90-hour monitoring campaign at the Taw River in the Southwest U.K. Although select nutrient concentrations were positively correlated to river flow, the most abundant base cations in water were not studied.

The goal of this study was to explore the relationships in stream chemistry across multiple streams by focusing on measurements of longitudinal chemistry and hourly measurements through diurnal cycles, while also considering stream hydrology. The monitoring explored two hypotheses. The first hypothesis states that there is variability across space and time of stream chemistry in a restored stream due to changes in hydrological flow. For this hypothesis, the concentrations of base cations and pollutants were expected to change as water moved further downstream and discharge increased. This would have been represented as either an increase or decrease in concentrations of ions during and after storm events compared to baseflow conditions. In addition, this could have also been represented by either an increase or decrease in specific conductivity, total dissolved solids, pH, or salinity further downstream as discharge increased. The null hypothesis would state that stream chemistry is not impacted by changes in streamflow, which would be represented by no change in longitudinal chemistry with increasing discharge.

The second hypothesis states that by comparing data through space and time, similar trends in water chemistry and pollutant concentrations can be identified from one stream to another. This hypothesis suggests that two or more streams can act and respond similarly to one another across various spatial and temporal scales (urban streams are not idiosyncratic in their biogeochemistry and there is some potential for spatial and temporal patterns to emerge across sites). This may have been represented by similar downstream or hourly pollutant concentration trends from one stream to another. The null hypothesis would state that there are no similar trends in downstream water chemistry from one restored stream to another.

This study was distinct in that it explored base cation relationships with diurnal cycles and variations in longitudinal sampling. The study also compared temporal variations with spatial variations across three urban restored streams to find potential response patterns related to identifying pollution sources (such as construction sites along streams) and the potential for nutrient retention along stream reaches with stormwater management controls. Analysis of diurnal variations in stream chemistry with respect to discharge may pose additional support for stream restoration research needed to accurately monitor changes in water quality over time.

Site Descriptions

Site Maps

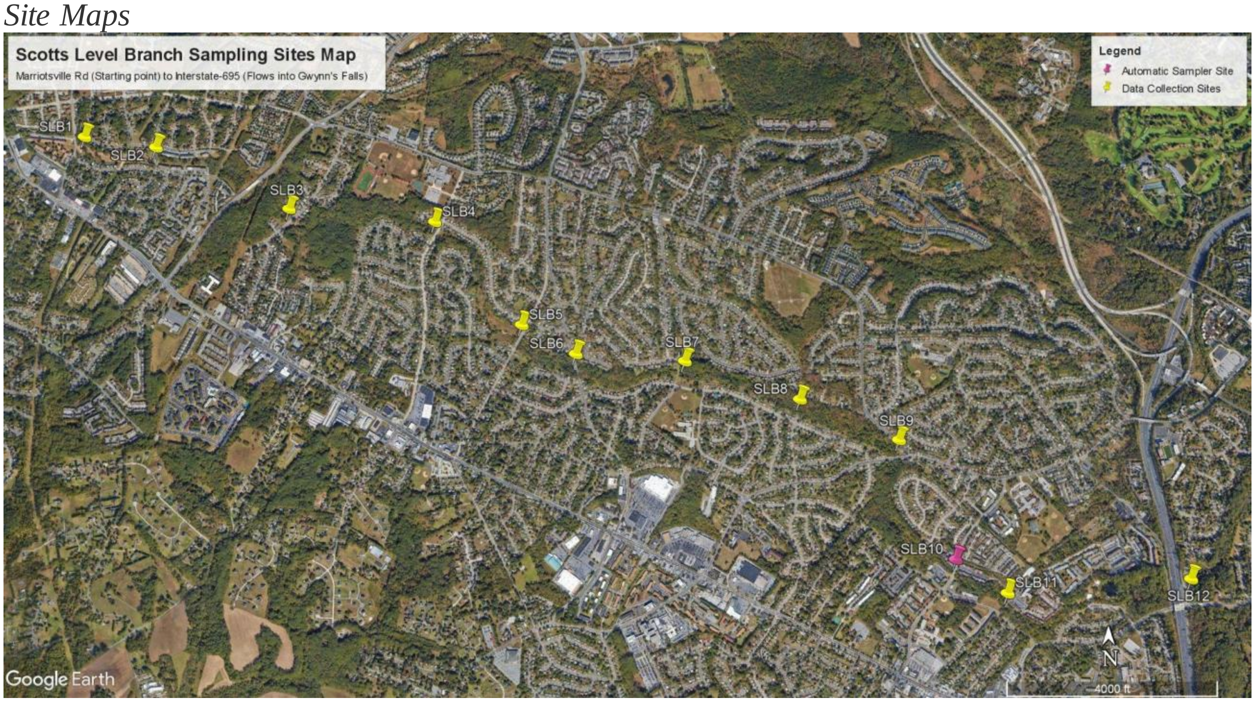


Figure 1. Satellite map of Scotts Level Branch with data collection site markers. The pink site marker represents the automated stream sampler location.

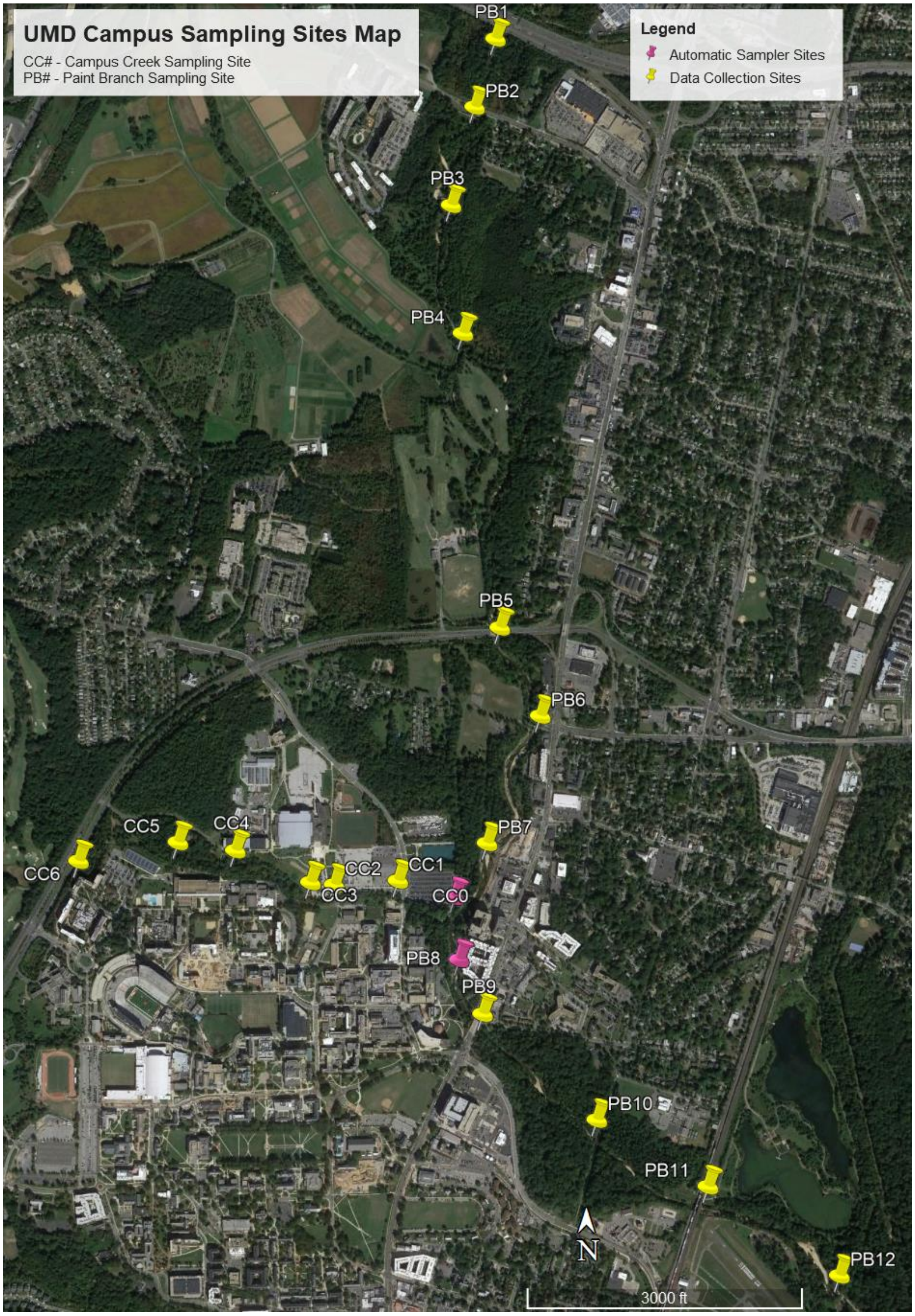


Figure 2. Satellite map of Campus Creek (CC) and Paint Branch (PB) with data collection sites marked. Pink site markers represent automated stream sampler locations. The University of Maryland, College Park campus is seen in the southwestern corner of the map. Additional aerial geologic maps are available for reference in Appendix A.

Floodplain Reconnections at Scotts Level Branch

Scotts Level Branch (SLB), mapped in Figure 1, is an 8.7 km stream that winds through residential neighborhoods in western Baltimore County, Maryland, and has a drainage area of about four-square miles. Twelve sites along the length of the stream that cover both restored and unrestored sections were identified for this experiment. The Baltimore County Department of Environmental Protection and Sustainability is currently working to restore large portions of Scotts Level Branch with floodplain reconnection strategies. The restoration has been broken down into sections to keep the project manageable and more cost effective.

In Baltimore County's restoration project at Scotts Level Branch, the primary physical changes to the stream network have been floodplain reconnections. A stream's floodplain is the relatively flat adjacent land that experiences occasional or periodic flooding. A disconnected floodplain is one that has become hydrologically separated from the stream it surrounds (Boyd, 2015). A floodplain can become separated from the stream through channel incision or through alterations in streamflow by dams or the deposition of natural levees. Channel incision, or downcutting, is the steepening of stream channel walls, commonly due to increased urban runoff carving the streambed faster than the floodplain can respond (Shields Jr. et al., 2010). Floodplain reconnections are carried out to help bring stability to the stream channel. Eroded stream banks and their floodplains are graded down to a wider, lower elevation in hopes of controlling the speed of erosion and flooding. Large rocks and tree logs are placed in the stream channel to control the flow of water and protect areas susceptible to erosion. The floodplains are then replanted with trees, grasses, and wildflowers native to Maryland in hopes of bringing the stream network back to a natural balance. Floodplain reconnections can keep the floodplain from experiencing flash flooding during precipitation events and will return the stream network to a more balanced state (McMahon et al., 2021).

Floodplain Reconnection at Paint Branch

Paint Branch (PB), mapped in Figure 2, is a 22.5 km stream that flows through Montgomery County and Prince George's County, Maryland, and is a tributary to the Anacostia River, which feeds into the Chesapeake Bay. Paint Branch has a drainage area of about thirty-square miles. This study explored the lower 5.35 km section of the stream, beginning downstream of Interstate-495 and ending just upstream of the Anacostia River. Montgomery County Department of Parks' (2021) Stream Restoration Program, regulated by a National Pollutant Discharge Elimination System (NPDES) permit, strives to restore deteriorating stream channels and protect their surrounding infrastructures at various Parks throughout Montgomery County. The restoration at Paint Branch is still being constructed at the time of this study. For the best chance at stream recovery, the program is utilizing techniques such as reforestation, floodplain enhancements, and rock and wood revetments (sloped structures along banks) to help protect the channel from further erosion. The Army Corps of Engineers also performed floodplain reconnections along the Paint Branch watershed (USACE, 2018). Reconnection strategies were divided into 3 categories; reconnect by lowering the stream bank, reconnect by raising the streambed, and create a new channel. Each of these strategies decrease incision along the stream channel and reconnect it to the surrounding floodplain further preventing flashy flows and flooding of the channel during precipitation events.

Regenerative Stormwater Conveyance at Campus Creek

Campus Creek (CC), mapped in Figure 2, is a 1.4 km stream flowing through the northern end of the University of Maryland, College Park campus. Campus Creek acts as a tributary to Paint Branch, entering about halfway down the studied section, just upstream of site PB8. The restoration at Campus Creek was designed to address stormwater runoff and erosion in the creek (Carmichael, 2020). Regenerative Stream Conveyance (RSC) was used to calm the flow of water through the stream. With this strategy, a series of step pools were built to slow the water movement downstream, which in turn prevents further erosion (Duan et al., 2019). The area surrounding the stream has also been reconfigured to a low-lying, shallow floodplain that is designed to act as an overflow zone with heavier rains.

Methods

Three streams in northern and central Maryland, Scotts Level Branch, Campus Creek, and Paint Branch, were researched and mapped in this study. Paint Branch is the largest stream, both in length and average width, followed by Scotts Level Branch and then Campus Creek. Downstream flow direction in all three streams is relative to the flow across the Piedmont to the Coastal Plain. Each was sampled longitudinally at seven to twelve synoptic sites based on the study area size. An automated stream sampler was also placed at each site to collect diurnal stream chemistry data. In order to explore the role of streamflow, discharge calculations were performed at Scotts Level Branch during sampling in March of 2021. Carbon-nitrogen content, base cation concentrations, and discharge in relation to longitudinal downstream distance were analyzed in this study.

Monitoring Design

In order to test the hypotheses, measurements were collected at 31 locations across all three streams: 7 along Campus Creek, 12 along Paint Branch, and 12 along Scotts Level Branch. During monitoring, water samples were collected from the stream channel at each site while travelling downstream. A handheld probe was also used for additional water chemistry measurements (temperature, conductivity, pH, etc.) at the time of water sample collection. All streamwater samples were collected just upstream from streets crossing over the channel, except at site SLB12, where samples were collected downstream of Interstate-695 for the purpose of easier access to the channel.

Automated stream samplers were placed in locations where noteworthy diurnal cycle data were predicted to be measured. An automated sampler was set at site CC0 on Campus Creek because the site is downstream of multiple campus parking lots near its confluence with Paint Branch and is potentially the most impacted site by groundwater inputs. An auto-sampler was placed at site PB8 on Paint Branch because it is downstream of the Campus Creek input and provides data on the mixture of the two streams. An auto-sampler was positioned at site SLB10 on Scotts Level Branch because it is the same location as a United States Geological Survey (USGS) Stream Gauge, so the data from this experiment can be analyzed with respect to USGS findings.

Discharge calculations were performed at Scotts Level Branch during the first visit only, in March 2021. At each data collection site, stream velocity measurements were collected to calculate discharge values, and channel width and depth measurements were collected to build cross-sectional plots. Relationships between stream chemistry and discharge with respect to longitudinal distance from headwaters were assessed.

Tools and Equipment

ISCO brand Full-size or Compact Portable Automated Samplers were used for hourly water sample collections at each stream. One of two handheld probes was used at each stream for additional water chemistry measurements during longitudinal sampling. During spring and summer field days, an Oakton handheld pH meter was used to determine specific conductivity (µS/cm at 25 °C), pH level, temperature (°C), salinity (ppt), and total dissolved solids (TDS, ppm) in the water. A YSI brand Multiparameter Digital Water Quality Meter was used after the field monitoring on September 2, 2021, which allowed for the added measurements of oxygen reduction potential (ORP, mV) and dissolved oxygen (DO, mg/L).

Some basic measuring tools required for the discharge calculations at Scotts Level Branch included a ruler and a yardstick for stream depth measurements, and a tape measure for spanning the stream at each data collection site. Tent stakes or large rocks were used for securing the tape measure at each stream bank. Any measurements taken in centimeters were converted to inches during data evaluation. To measure stream velocity, a Hach FH950 Portable Flow Meter System (acoustic velocity flow meter) was used, with each measurement taken at two thirds of the depth of the water at each collection site. A velocity measurement taken at two thirds depth is accepted as the mean for the vertical velocity curve, as it is based on theory and has acceptable accuracy (Holmes et al., 2001). This method provided an appropriate evaluation of the stream's depth-average velocity, as surface velocity would not be the same as stream bed velocity with varying stream bed roughness.

A cell phone was used to determine latitude and longitude at each data collection site, and to verify the time each sample was collected. A digital camera was used for documenting data collection procedures and important site features. All data (except images) were written in pen in water-resistant field notebooks at the time they were collected.

Aside from field data collection, multiple resources were used to collect additional important information. The USGS database provided stream conditions over time via Stream Gauge data collection, as well as geologic maps of Maryland. The Maryland Topography Viewer, provided through the Maryland Mapping & GIS Data Portal, was used to determine site elevations by using a Light Detection And Ranging (LiDAR) map.

In the laboratory, a Shimadzu brand Total Organic Carbon (TOC-L) analyzer and a Shimadzu Inductively Coupled Plasma - Optical Emission Spectrometer (ICP-OES) were utilized for water sample processing and analysis methods similar to Haq et al. (2018), Galella et al. (2021), and Kaushal et al. (2019). The TOC-L measures Carbon-Nitrogen concentrations in each sample, providing inorganic carbon, non-purgeable organic carbon, and total nitrogen data for this study. The ICP-OES measures element concentrations in each sample. The most abundant cations present in water, calcium (Ca), magnesium (Mg), potassium (K), and sodium (Na), were analyzed in this study.

Field Data Collection

Before visiting a stream, research began with a survey of the stream and its floodplain via satellite maps. Potential water sampling sites were found and recorded. Further research was conducted to determine the restoration background, techniques, scheduling, and any previous studies or results linked with the stream.

Photograph 1. Stream sample collection at Site SLB10. Photograph provided by Carly Maas. Additional stream sampling photographs available for reference in Appendix B.

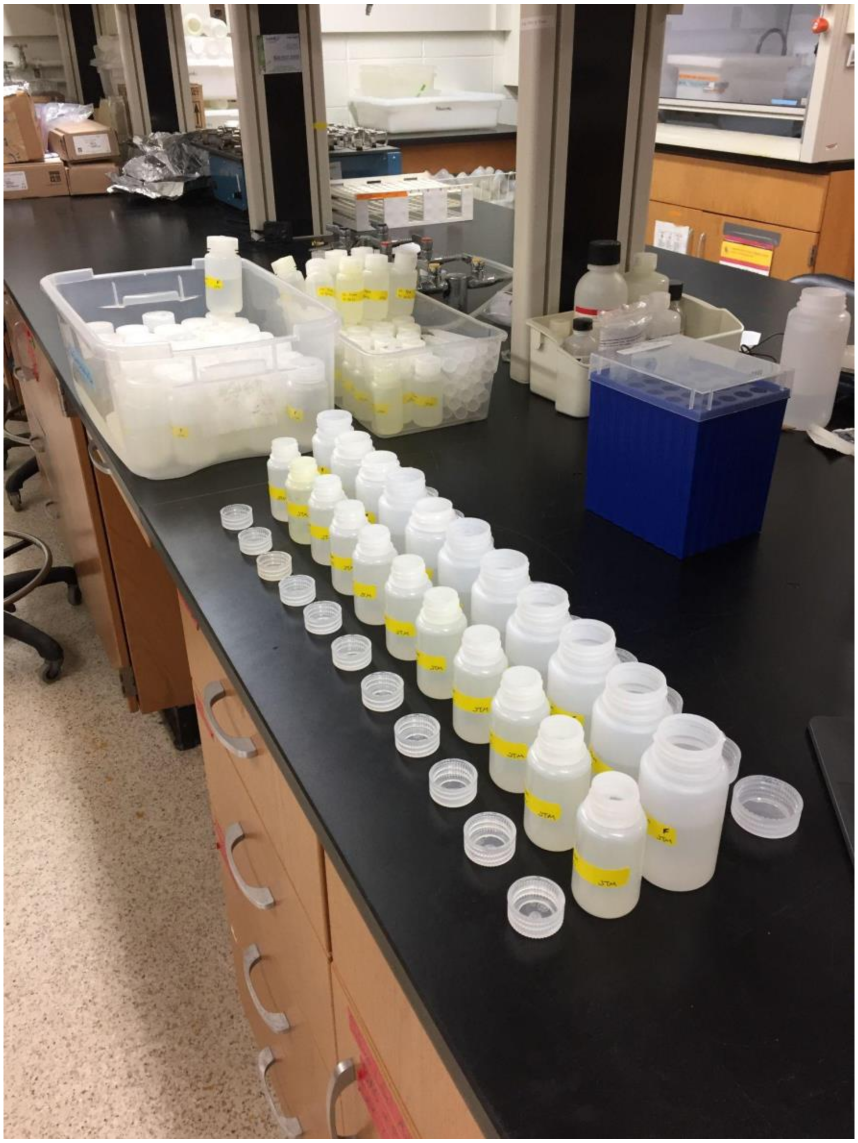
On a field data collection day, a 150 mL sample bottle for every site, along with a water chemistry probe and a pair of latex gloves were transported to the field site. At each site and while wearing gloves, the sample bottle was opened, rinsed out three times in the stream, and filled with water from the channel on the fourth submersion. The bottle was then tightly closed and labelled for future identification from other samples. The probe was then submerged in the streamwater to its required depth and held still until its readings were steady. Probe measurements were recorded in a water-resistant field notebook along with the time of the data collection and any important notes to remember about the site. A table of water chemistry data from the March collection at Scotts Level Branch is available as reference in Appendix C. Once all stream sites were sampled, all the samples were brought back to the laboratory where they were filtered, acidified, and processed.

Photographs 2 and 3. Photographs of automated samplers in the field at Sites SLB10 (Left) and PB8 (Right).

Automated water samplers were occasionally operated in conjunction with field data collection days. The auto-sampler would be transported to its location on the stream either the day before a field collection day, or right before starting downstream sampling. The choice between the two options had little reasoning other than when time was available to make the trip. The sampler was placed on level ground somewhere near the edge of the channel, in some cases tied down to prevent movement from rising water levels during storms (Photograph 2). A ten-foot-long segment of quarter-inch clear tubing was connected on one end to the sampler pump, and the other end was placed in the stream and weighed down with stones. The auto-sampler was then programmed to collect 250 mL of streamwater every sixty minutes for the next twenty-four hours starting immediately. When the program started and the first sample was collected, the first interior sample bottle was checked for the correct amount of water, and the time was recorded for future analysis.

When returning to the automated sampler the following day, twenty-four 150 mL sample bottles were labelled and brought to the auto-sampler location. Every bottle in the sampler was paired with a 150 mL sample bottle, and the hourly stream samples were moved into the smaller bottles for easier transport of the auto-sampler out of the field (Photograph 3). Sample bottles were then brought back to the laboratory to be processed. The automated sampler was also brought back to the laboratory for cleaning.

Laboratory Practices



Photograph 4. Stream sample bottles being processed in the water chemistry laboratory for instrumentation preparation.

All samples were filtered and acidified once they reached the water chemistry laboratory. Each sample was pumped through pre-ashed 0.7 μm glass fiber filters using a vacuum. Sample bottles were cleaned, and filters were replaced between each sample to prevent cross contamination. Every 150 mL bottle was paired with its own 60 mL sample bottle with a matching label. 60 mL of each sample was transferred to the smaller bottle with a pipette. A new pipette was used for each sample to prevent cross contamination. With another pipette, 30.0 μL of nitric acid was put into 60 mL sample bottles to acidify them for long-term storage. Remaining samples in the 150 mL bottles were frozen to preserve carbon-nitrogen concentrations.

Acidified samples were analyzed with a Shimadzu brand Inductively Coupled Plasma – Optical Emission Spectrum (ICP-OES) to measure base cation (Ca^{2+}, K^{+}, Mg^{2+}, Na^{+}) concentrations. When a sample is run through the ICP-OES, inductively coupled plasma produces excited atoms, emitting wavelengths associated with specific elements (Yaculak et al., 2021). The amount of light emitted from a sample correlated to an element concentration in a sample. Non-acidified samples were analyzed with a Shimadzu brand Total Organic Carbon (TOC-L) analyzer to measure the inorganic and organic carbon content, as well as the total nitrogen concentration of each sample. Samples in the TOC-L were injected with an acid to transpose inorganic carbon to carbon dioxide (CO_2). The amount of carbon dioxide produced in a sample is equal to the inorganic carbon content. The organic carbon content was calculated by subtracting the inorganic carbon from total carbon in the sample. Total nitrogen concentrations were calculated by combusting each sample and passing it through a non-dispersive infrared detector (Yaculak et al., 2021).

Discharge Calculations

Stream discharge calculations were performed at Scotts Level Branch on Saturday March 27, 2021. At each data collection site, the same steps were followed for collecting field measurements. When arriving at each site, vehicles were parked on the shoulder of the road and the best way to access the stream channel was determined. While carrying the equipment down to the stream, the experimentation location was established. The testing site was chosen at a location that would best represent the stream, and by considering its accessibility. Site SLB12 (Scotts Hill Dr) was located just downstream of the Interstate-695 overpass. The latitude and longitude of the sample site, as well as the time of day that testing began at the site, were noted. Streamwater samples were collected at each site with a 150 mL bottle.

A long tape measure spanned across the stream to determine total stream width. The tape measure was held in place on both stream banks with tent spikes or with heavy rocks when necessary. From the stream width measurement, the most appropriately sized increments to use for depth, velocity, and cross-sectional measurements was decided. Generally, the stream was divided into one-foot increments for narrower sections of stream, and two-foot increments for wider sections. The depth of water, from surface to stream bed, was measured at each predetermined increment across the stream. A standard plastic ruler was used for stream depths 30 centimeters or less, as it was most accurate under those conditions. If the depth was deeper than 30 centimeters, a standard metal yardstick was used for measurements. Any local obstacles in the way of the stream bed were moved, when possible, for more accurate depth measurements representative of the stream bed, and then replaced after the measurement was taken. All stream width and depth measurements were recorded in a water-resistant field notebook. Measured cross-sectional plots are available for reference in Appendix D.

Photograph 5. Stream velocity measurements taken with an acoustic velocity flow meter at Site SLB5. Photograph provided by Christiana Hoff. Additional photographs of measuring stream velocity available for reference in Appendix B.

A Hach Flomate velocity flow meter was then placed at each predetermined increment to record local stream velocities. To save time in the field, the velocity meter was connected to its sensor and attached to the telescoping stand at the initial data collection site, then safely transported as one piece to each following site, and then disassembled at the end of the collection day. While taking the velocity measurements, the velocity meter and its sensor were always upstream of the operator so that the operator did not interfere with the flow of the water or the velocity meter's readings. At each increment, obstacles in the way of the velocity meter stand base were temporarily moved to provide it with a stable position. The sensor was then elevated to two thirds of the water's depth, or one third off the stream bed. This value was found through simple calculations and measured with the ruler or yardstick.

With the acoustic velocity meter turned on and the sensor facing upstream, the meter was given at least thirty seconds of uninterrupted measurement before the stream velocity reading was recorded. This amount of time lets the velocity meter stabilize, as well as lets the streamflow return to normal after trekking through and kicking up the water. After each streamflow measurement, the velocity was recorded in a water-resistant field notebook, and the next predetermined increment was measured. Once all velocity measurements were taken, it was then determined if any further measurements should be taken at different or smaller increments. This was only the case at one site, where the channel geometry queried closer measurements than originally decided upon. All discharge measurements calculated at Scotts Level Branch are available for reference in Appendix E.

Uncertainty

Laboratory Instrumentation

Blanks were analyzed as reference to determine possible sample contamination. Replicate samples were analyzed to determine instrument precision. Comparisons to external commercial check standards were used to assess instrument accuracy. The TOC-L has a detection limit of 4 µg/L for carbon measurements and 5 µg/L for nitrogen measurements, and a maximum reproducibility coefficient of variation of 1.5% (Shimadzu, 2011). The ICP-OES has uncertainties of 0.6, 0.6, 10, and 0.6 µg/mL for Ca, Mg, K, and Na, respectively (Sellers, 2014). The Oakton handheld pH meter has an accuracy of ±0.01 for pH, and ±1% of the full scale for conductivity, TDS, and salinity (Oakton, n.d.). The YSI handheld meter has an accuracy of ±0.1 mg/L for DO, ±0.2°C, 0.001 mS/cm for conductivity, ±0.1 ppt for salinity, ±0.2 units for pH, and ±20 mV for ORP (YSI, n.d.)

Discharge Calculations

Multiple measurements were taken at several locations to evaluate uncertainty. At Site SLB5, two experiments were conducted to test the relative accuracy of the velocity meter. For the first experiment, the site procedure was followed as normal, but velocity measurements across the stream were taken two separate times at the same, equal increments. Upon viewing the two data sets, the velocity meter was determined to be more consistent when reading higher streamflow velocities. At lower streamflow velocities, the velocity meter was more likely to show slightly different results, with the largest difference from the initial measurement to the second being ~0.05 feet per second.

The second uncertainty experiment at Site 5 was a float test. The goal was to determine the surface velocity of the stream and compare that calculation to the velocity meter's reading at two thirds of the stream's depth. Using two nearby pieces of bark and a stopwatch, the time it took for the bark to float 15 feet downstream was calculated. A quick calculation showed surface velocity at the center of the stream to be ~0.44 ft/sec, nearly twice the 0.23 ft/sec reading the velocity meter showed at two thirds depth in the same location. This made sense because the surface velocity of a stream is faster than the velocity at depth. By recording stream velocity at the same depth relative to the depth of the water at each measurement, readings were ensured that they were as consistent as possible.

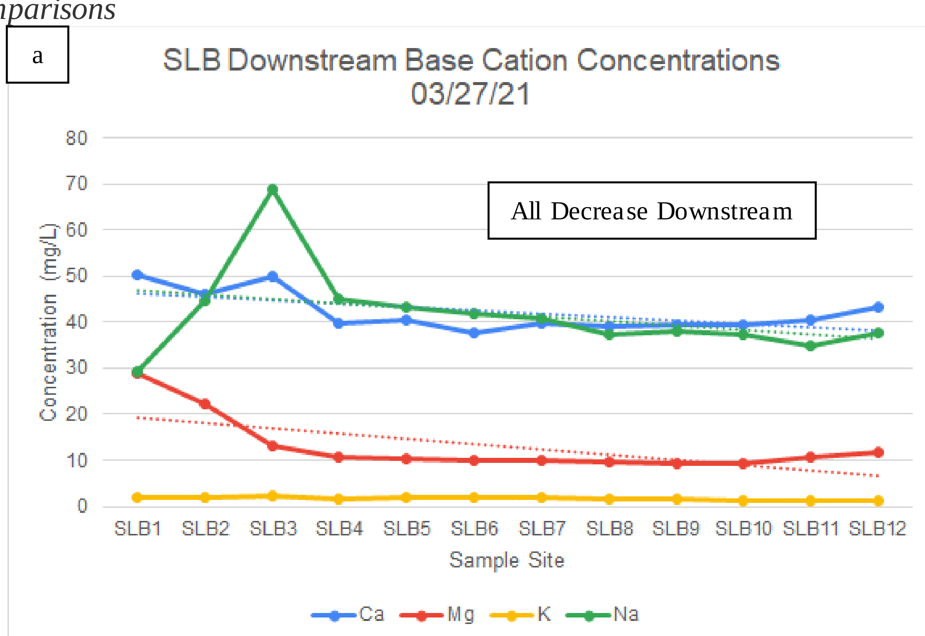
One aspect of the experiment that could have been improved to minimize uncertainty would have been to decrease the distance between the increments across the stream at each data collection site. Wider increments save time on wider sections of the stream, but also fall short on accurately representing the entirety of the channel structure. In order to get an accurate representation of the stream in one day, decreasing the increments was necessary. To experiment at all twelve sites that were planned for at Scotts Level Branch, as well as take smaller increments at each of those sites, would have ultimately come down to an issue with sufficient time to complete the analyses.

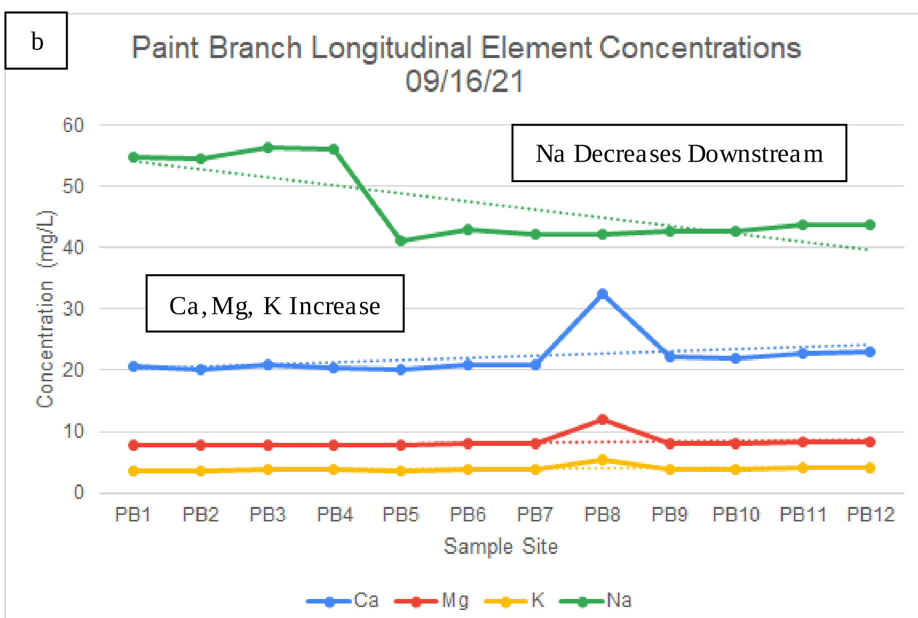
Monitoring Data vs USGS Stream Gauge Data

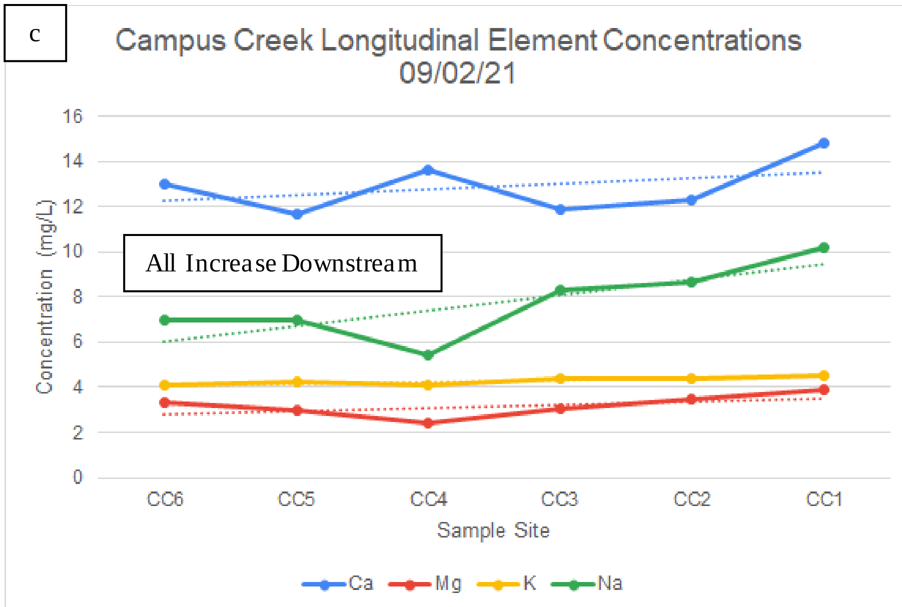
The USGS Stream Gauge is located at Site SLB10 along Scotts Level Branch. Among other data, this experiment covered stream discharge, average depth, pH, specific conductance, and water temperature, which are all documented by the USGS gauge. The calculated discharge at Site SLB10 through data collection was 2.919 cubic feet per second, just above the gauge's reading of around 2.35 cubic feet per second. The average measured stream depth at Site SLB10 was 0.46 feet, which is below the gauge's measurement of 0.83 feet. The measured pH, specific conductance, and water temperature were 8.41, 500 µS/cm, and 14.7 ^{O}C, respectively. This data can be compared to the gauge's respective readings of 8.2, 520 µS/cm, and ~14.8 ^{O}C. The data collected through the experiment were found to be similar to the readings of the USGS Stream Gauge. This provides insight to the accuracy of both the experimented data, along with the data collected by the gauge.

Results: Comparisons Across Streams

Spatial Comparisons







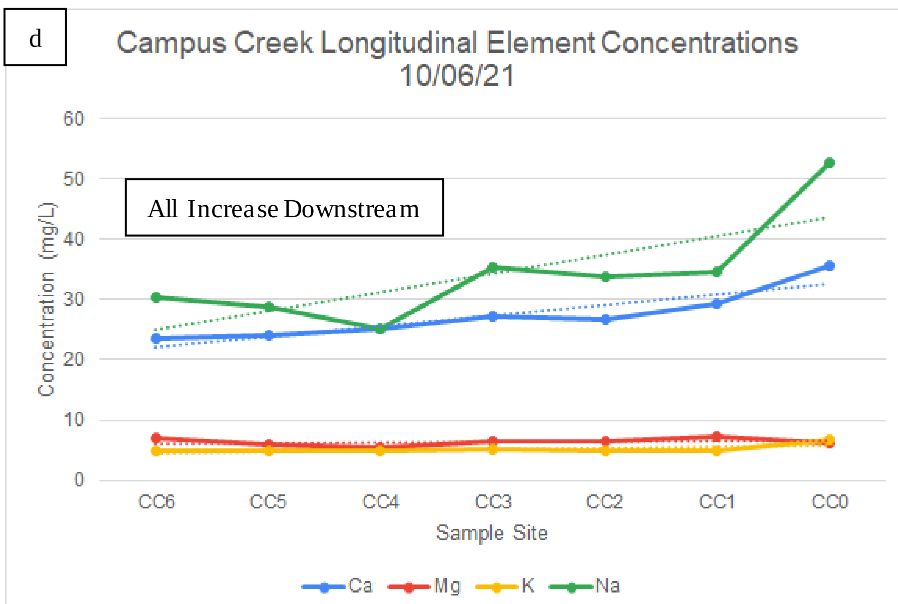
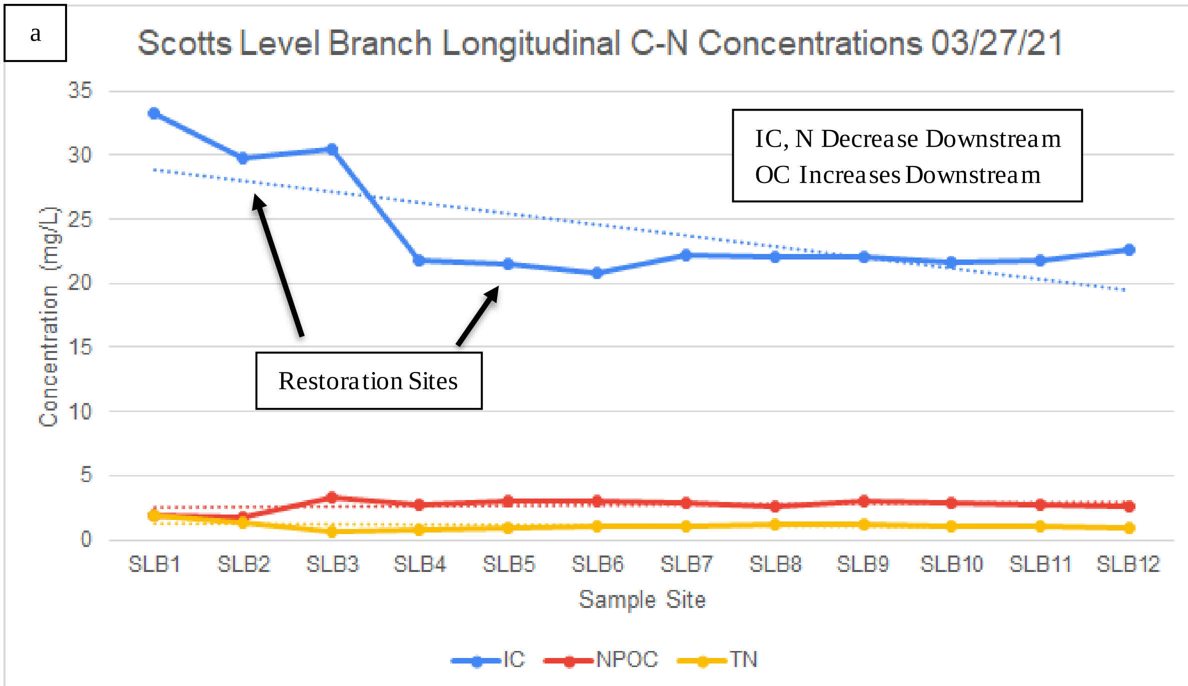
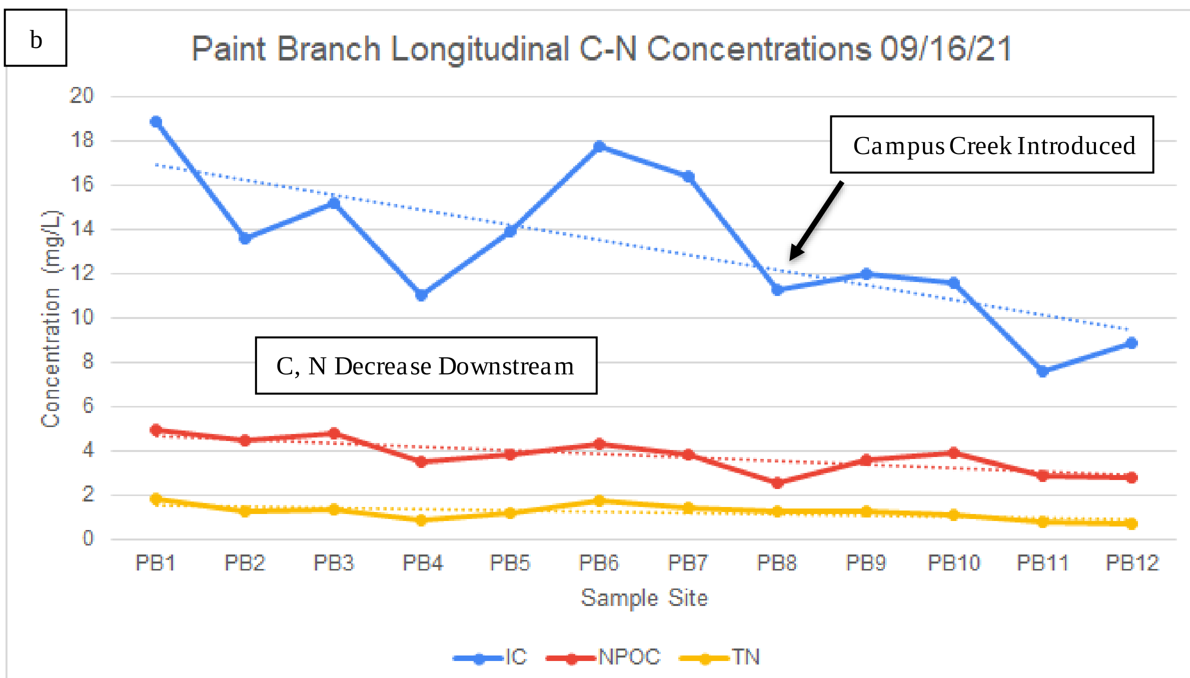


Figure 3. Base cation concentrations of downstream samples from Scotts Level Branch (a), Paint Branch (b), and Campus Creek (c,d).

Figure 3 shows the concentration of base cations at all three monitored streams. In Figure 3, there were all positive trends across two collection days at Campus Creek for samples taken about a month apart (3c,d). Base cation concentrations measured at Campus Creek during this monitoring experiment are comparable to two previous studies from Yaculak et al. 2021 and Silberstein et al., 2019. Similar positive trends were measured at Paint Branch for Ca, Mg, and K, but there was a contrasting negative trend for Na (3b). Paint Branch spikes in most measured base cation concentrations at Site PB8, which is just downstream of the Campus Creek input and a local construction site near the stream. Measurements at Scotts Level Branch, however, show all negative trends (a). This means that the stream is either diluting or retaining these base cations as water moves longitudinally through the channel.





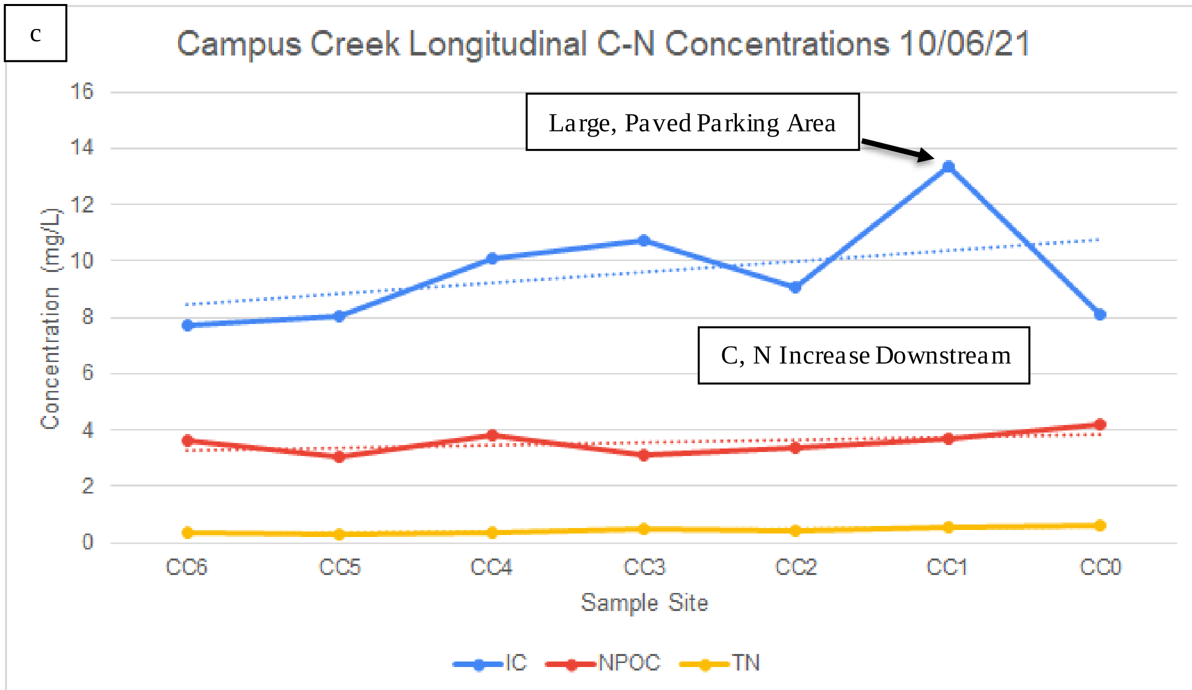
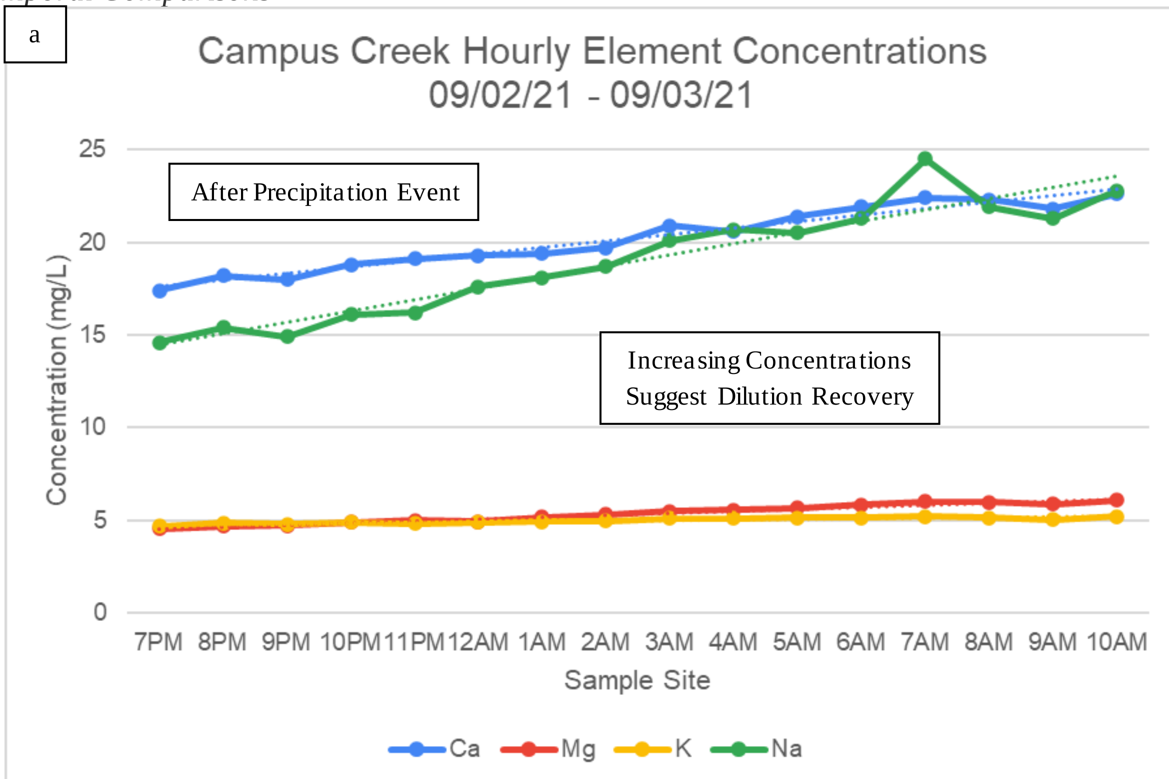


Figure 4. Carbon-nitrogen concentrations of downstream samples from Scotts Level Branch (a), Paint Branch (b), and Campus Creek (c). Inorganic carbon (IC), non-purgeable organic carbon (NPOC), and total nitrogen (TN) are plotted.

There were very little longitudinal variations in total nitrogen concentration at the three measured streams. A similar study found that differences in denitrification levels across forested and urban streams were not statistically significant either (Harrison et al., 2012). Longitudinal organic carbon measurements also show shallow trends and similar readings across all three streams. Campus Creek still has a slight increasing trend (4c), and Paint Branch has a slight decreasing trend downstream (4b), despite the minor variations. Inorganic carbon measurements are what differentiate these streams the most in Figure 4. Scotts Level Branch has the highest average inorganic carbon content of the three evaluated here and has an overall decrease in concentration longitudinally (4a). Paint Branch has the next highest average inorganic carbon content, also with an overall decreasing longitudinal trend (4b). Campus Creek has the lowest average inorganic carbon content of the three streams but has an overall increasing trend downstream (4c).

Temporal Comparisons



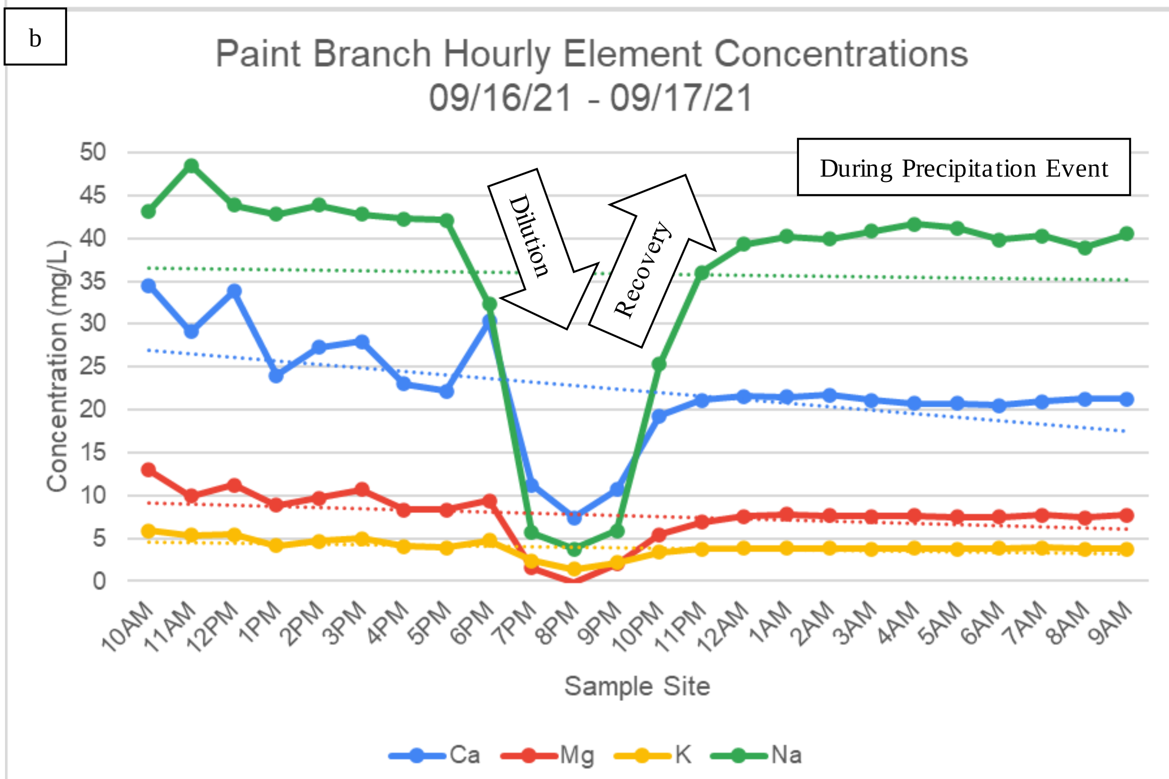


Figure 5. Base cation concentrations of hourly samples from Campus Creek (a) and Paint Branch (b).

Both plots in Figure 5 depict responses after rainstorms at each site. The automated sampler was placed at Campus Creek one day after Hurricane Ida passed through the area, and the rain had ceased. This puts the stream in a state of recovery (Reisinger et al., 2017), where the base cation concentrations were rising back to their normal state after being diluted with the rainstorm (5a). The plot for Paint Branch hourly base cation concentration data depicts a brief, but strong rainstorm in the evening that the auto-sampler was placed (5b). The nightly precipitation event is plotted below in Figure 6 by the USGS Stream Gauge. Unlike the Campus Creek data, Figure 6 provides information from before, during, and after the precipitation event passed through the area. Even with much higher concentrations of some base cations, Paint Branch became heavily diluted and recovered quickly when compared to the much slower recovery from Campus Creek.

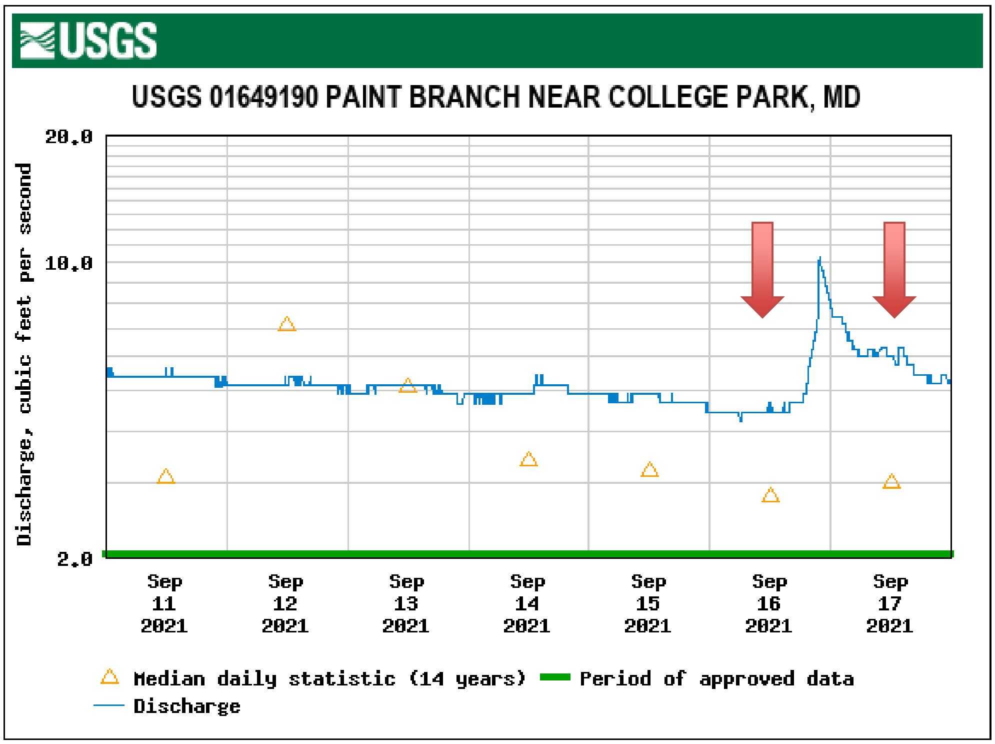
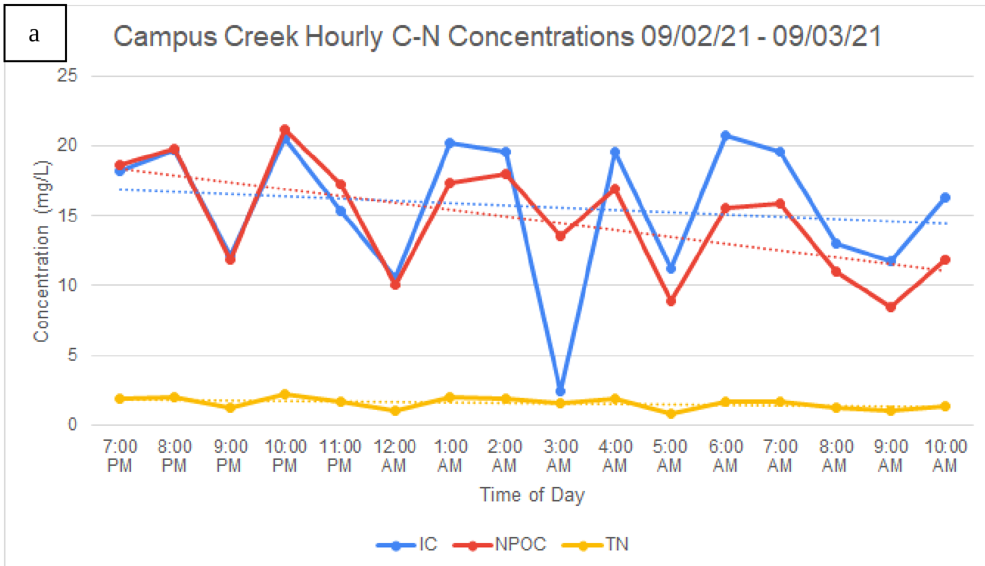


Figure 6. USGS Stream Gauge measurements of local stream discharge at Paint Branch. Red arrows represent the approximate start and end times of automated sampling.



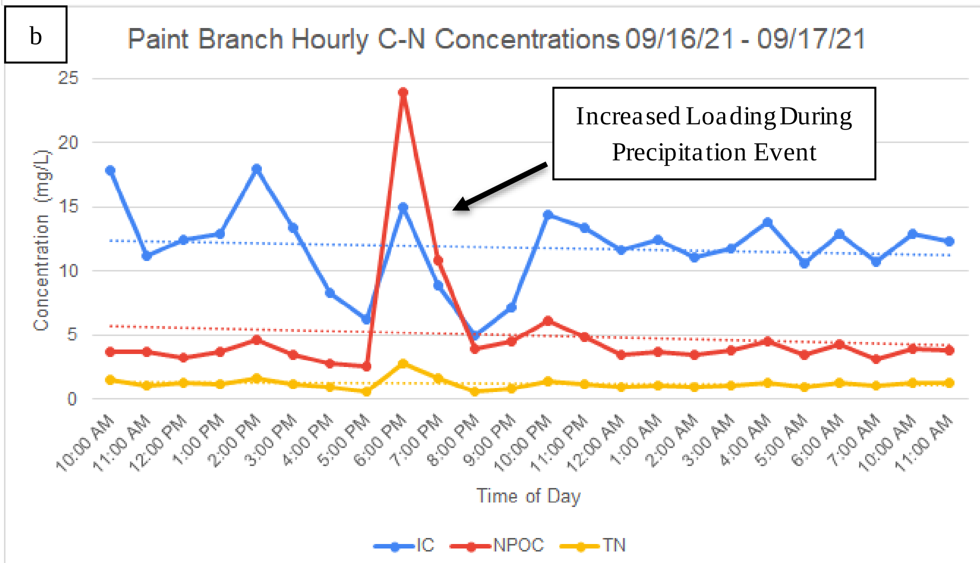


Figure 7. Carbon-Nitrogen concentrations of hourly samples from Campus Creek (a) and Paint Branch (b).

A notable pattern was found in the hourly carbon-nitrogen concentrations between Campus Creek and Paint Branch. Total nitrogen concentrations were very similar across both streams and showed minor variations over time. Inorganic carbon concentrations were very sporadic in both streams, though having overall horizontal trend lines as a function of time. The difference comes with the organic carbon content. At Campus Creek, the organic carbon content follows the inorganic content very closely, rising and falling similarly with every hour (7a). On the other hand, the organic carbon content in Paint Branch is much more constant compared to the hourly inorganic carbon (7b). This may be due to the differences in overall sizes of these two streams or the different inputs they have. In addition, neither carbon nor nitrogen content looks to be directly correlated with the diurnal cycle. A longer duration of sampling may be needed to see stronger patterning, but even at this scale variations from day to night should be noticed. A spike in all three carbon-nitrogen concentrations is seen at Paint Branch around 6:00 p.m. in the evening, with a dramatic increase in organic carbon from 2.597 mg/L to 23.93 mg/L (7b).

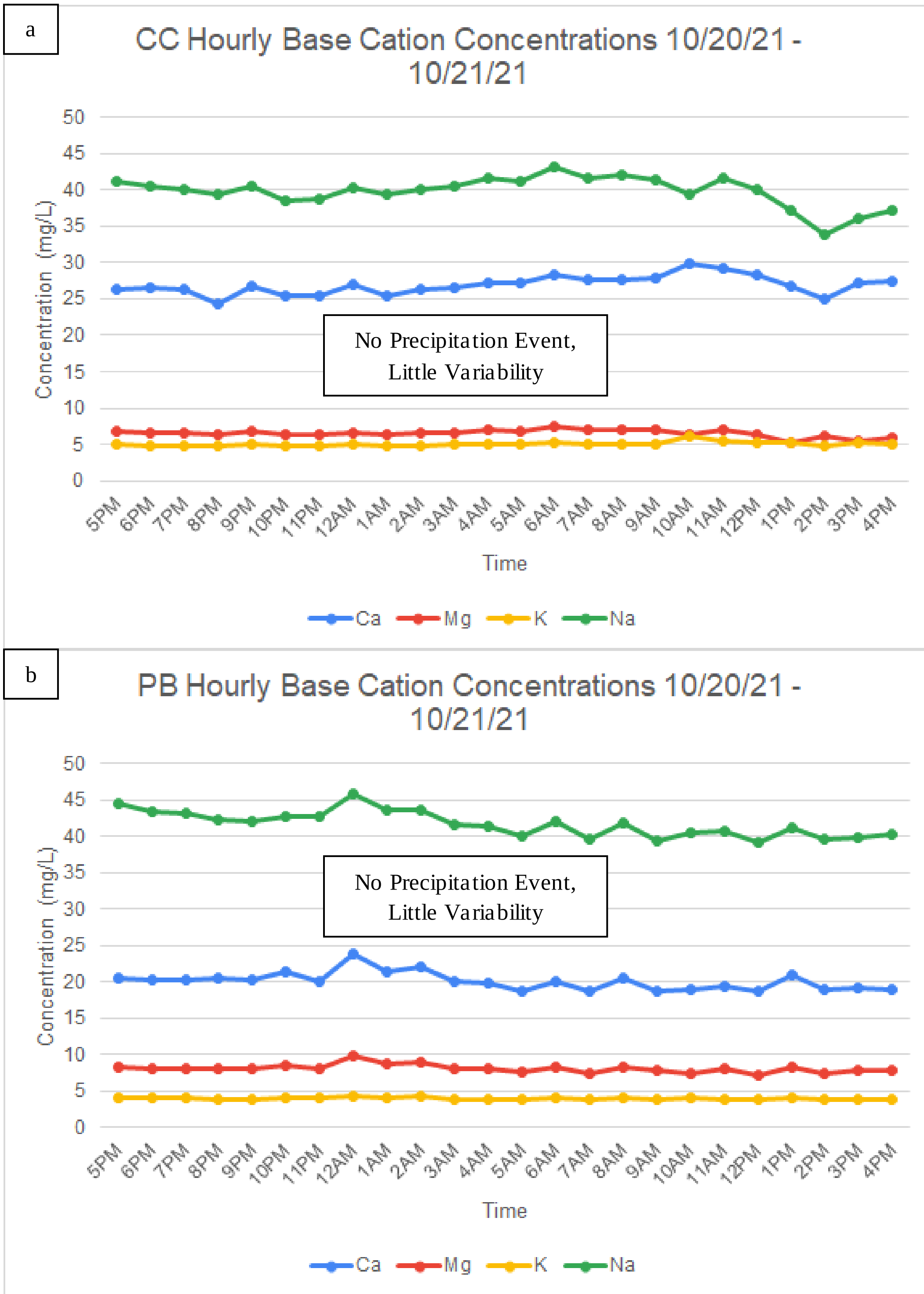


Figure 8. Base cation concentrations of hourly samples from Campus Creek (a) and Paint Branch (b). Two automated samplers were placed at the same time to provide the most accurate comparison between the two streams.

An accurate way to analyze the diurnal cycle between two streams for this study is to sample both at the same time. Two automated samplers were placed and started around the same time in order to examine how both streams acted under the same conditions. There were no precipitation events during the time of the sampling run, so analysis is focused on the natural baseflow of both streams. Campus Creek and Paint Branch base cation concentrations in their natural state were very similar to one another in that there was little variation through the diurnal cycle at both streams. Campus Creek (8a) has generally higher Ca and K concentrations (up to about 10 mg/L and 3 mg/L, respectively) than Paint Branch, and Paint Branch (8b) has generally higher Na and Mg concentrations (up to about 10 mg/L and 5 mg/L, respectively) than Campus Creek through the diurnal cycle.

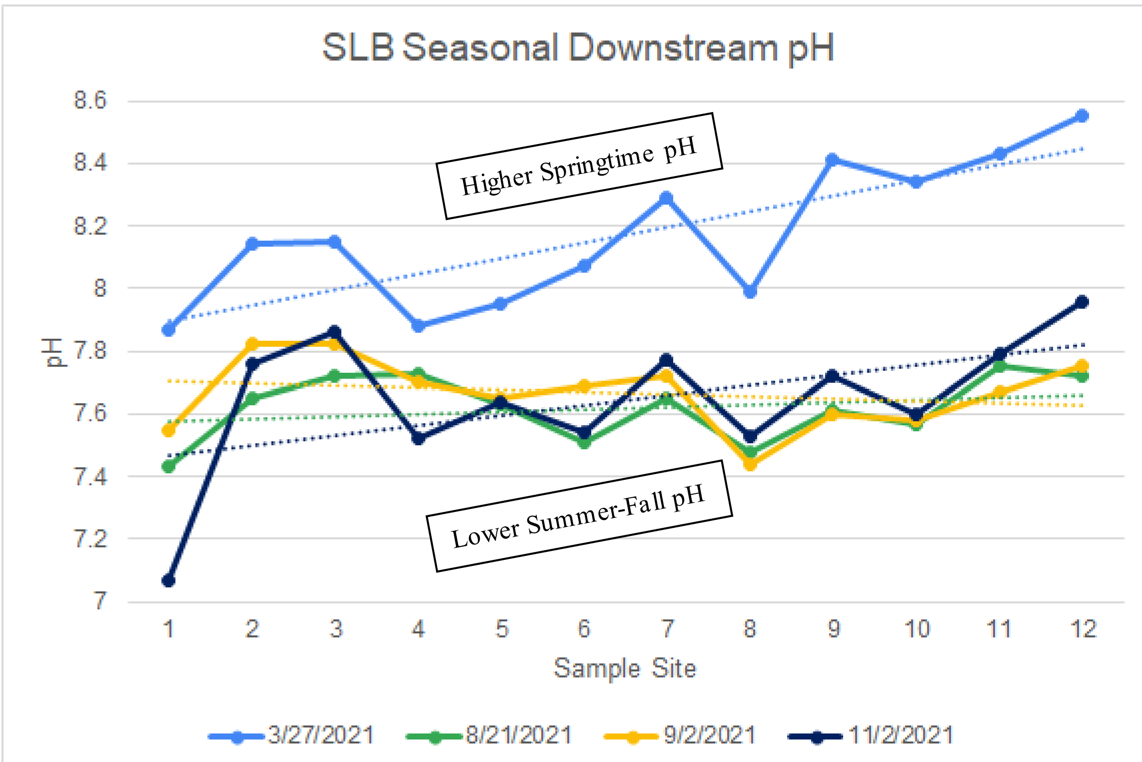


Figure 9. Comparison of pH measurements at each sampling site at Scotts Level Branch for each of the four sampling days.

Measured pH has a general increasing trend longitudinally downstream during the March, August, and November 2021 synoptics, but decreases slightly during the September synoptic. The overall pH is higher at Scotts Level Branch during March 2021 by anywhere from 0.15 to 0.83, relative to the other stream monitoring days.

Results: Longitudinal Variations at Scotts Level Branch

Stream Channel Characteristics

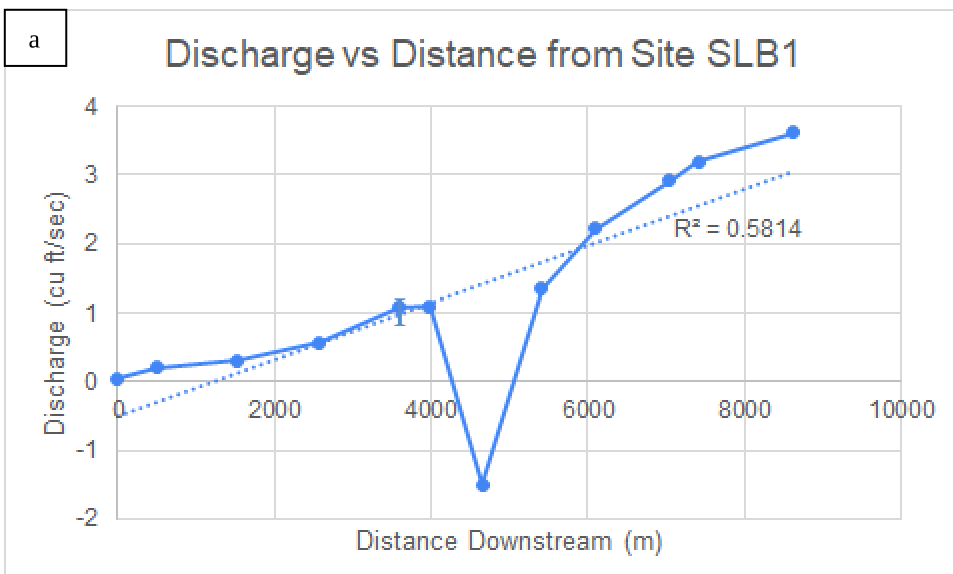
Figure 10. LiDAR imagery map of Scotts Level Branch with data collection site markers. Restored areas of the stream are marked in red. The first segment of the project was constructed between Site SLB4 and Site SLB5. The second segment was constructed between Site SLB1 and Site SLB2.

At Scotts Level Branch, the overall channel width and average depth both increase downstream. This is due to the channel responding to the accumulation of water entering the stream from the surrounding floodplain and groundwater. With increasing channel width and average depth, an increasing trend in the total cross-sectional area has also been established. The cross sections of each data collection site were graphed using width and depth field measurements to view the streambed geometry more easily. Graphed cross sections are available for review in Appendix D. Further analysis of longitudinal channel geometry at Scotts Level Branch is available in Appendix F.

Stream Hydrology and Discharge

The initial field data collection day at Scotts Level Branch fell on a Saturday morning, following a Wednesday rainstorm. The USGS Stream Gauge data for the week leading into the field day is discussed later in this study, and hydrographs for each sampling field day are available for review in Appendix G, with arrows pointing to the time of data collection. Small, urbanized streams are important transporters of organic matter and energy from local environments during storm events (Kaushal & Belt, 2012). The stream was studied during a recovery period after the storm event, so the aftermath of the heavy influx of rain and groundwater to Scotts Level Branch was not experienced. The USGS data provides information regarding the impact that such a large influx of water can have on the stream discharge and velocity. With the rainstorm, the height of the gauge positioned at Site SLB10 increased by 3.5 feet, from 0.7 to 4.2 feet. This is paired with a dramatically increased discharge measurement of about 1.5 cubic feet per second before the storm to just over 500 cubic feet per second after the storm. At the time of this experiment, the gauge height was at 0.8 feet, and the discharge was 2.919 cubic feet per second.

From headwaters to downstream, the discharge and average stream velocity show increasing trends in the data analysis at Scotts Level Branch. The site with the highest average velocity is Site SLB10 at 0.32 feet per second, and the site with the slowest average velocity is Site SLB1 at 0.01 feet per second. The calculated field discharge measurements increased at a steady rate downstream, with the exception of Site SLB7, where the discharge calculation came out to be -1.498 cubic feet per second (Figure 11a). This site was located at the base of an urbanized section of stream that had a concrete channel, and the water was flowing into a large pool at the end of the channel. Within the large pool, it could be seen that the surface water was not only flowing downstream, but also circling back around the pool to the concrete section. These upstream currents could be eddies or hydraulic currents. The cross sectional and discharge measurements were taken where the upstream current was stronger than the downstream current, producing what looks like a negative discharge calculation at the data collection location. This negative value skews the data analysis tables involving discharge and can easily be spotted in the Discharge vs Distance from Site SLB1 graph shown below (Figure 11). Clearly, the average channel discharge at Site SLB7 was not accurate, in part due to the complex flow paths within that segment of the stream. According to the discharge measurement at the end of the stream, Scotts Level Branch was feeding over 1,600 gallons of water per minute into Gwynn's Falls at the time of data collection.



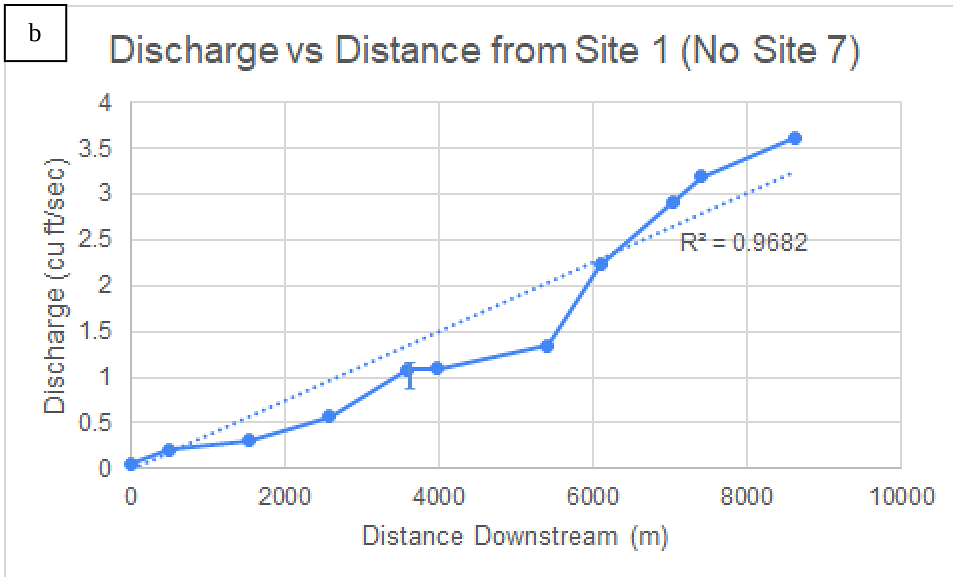


Figure 11. Plots of calculated discharge at each site represented by their distance from Site SLB1. The negative discharge measurement at Site SLB7 is included in the top plot (a) to show all calculated data, and not included in the bottom plot (b) to provide a more accurate representation of the overall stream discharge trend. An error bar is used for the Site SLB5 measurement to account for the ~10% error between the two recorded data sets. Additional downstream data at Scotts Level Branch is available for reference in Appendix H.

Relationship between Streamwater Temperature and Chemistry

The changes in water temperature and chemistry in relation to the rainstorm can also be examined using the USGS Stream Gauge data. The temperature, pH, and specific conductivity all decreased from before to after the rainstorm. The turbidity on the other hand, significantly increased with the storm. Stream discharge has a great impact on these factors. Through the field data collection, an increase can be seen in temperature and pH downstream, while specific conductivity decreases downstream.

Stream Loading

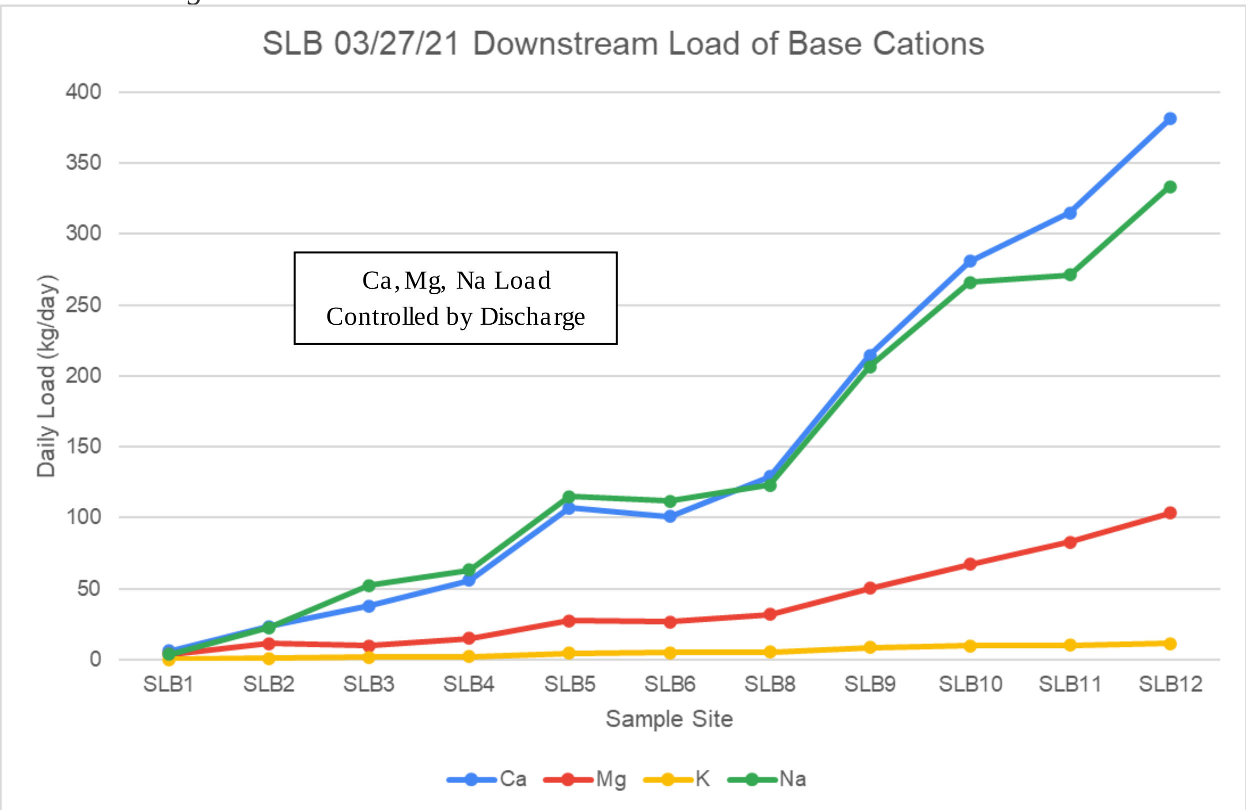


Figure 12. Downstream load of base cations at Scotts Level Branch. Site SLB7 is not included to separate the negative-discharge-based calculations linked to the site (explained in Figure 11).

Stream load refers to the solid matter carried by a stream (Strahler, 2006). Figure 12 expresses the amount of solid load that Scotts Level Branch carried passing through the sampling sites. Stream load is dependent on hydrologic stream factors, such as discharge, velocity, and the amount of water in the stream channel. Ca, Na, and Mg concentrations decrease further downstream, but load increases because mass transport is controlled by hydrology and increasing streamflow further downstream. K^+ does not show an increase because it is under strong biological control (Tripler et al., 2006). Streamflow exerts an important influence on concentrations and loads of most ions in these streams.

Discussion

Much time and effort is spent in analyzing urban water quality in watersheds and making assessments and evaluations. Relatively little is known about spatial and temporal variations among multiple elements and water quality measurements. It was found that (1) spatial and temporal variations were influenced by changes in streamflow and storm events, and (2) there could be similarities among some urban streams in the patterns and processes influencing water quality. Longitudinal patterns and underlying processes potentially controlling the monitored streams are explored in the sections below.

Longitudinal Variation

After assessing all the field data, one of the most important data analysis graphs to note is total dissolved solids (TDS) vs Distance from Site SLB1 (Figure 13) at Scotts Level Branch. The graph shows an overall decrease in TDS downstream as discharge increases. This analysis depicts a dilution in small organic and inorganic constituent concentrations in the water. This supports the first hypothesis, in that the data expresses a change in the longitudinal concentrations of the water's pollutants.

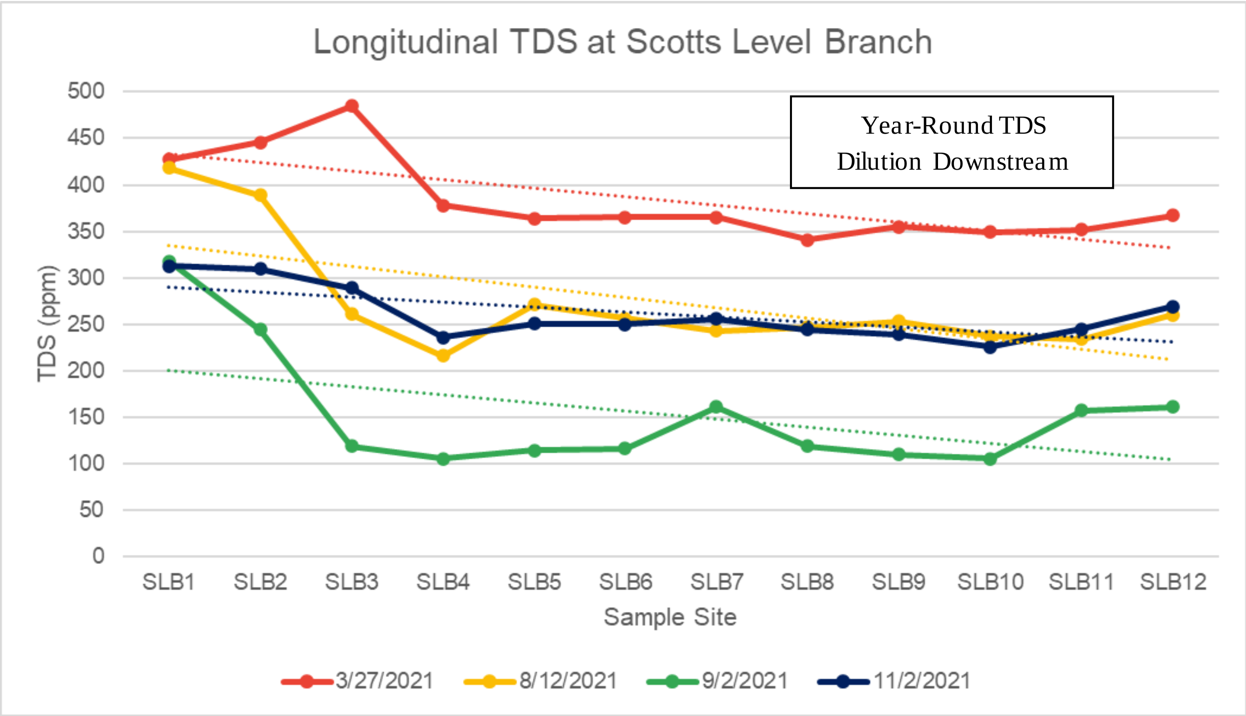


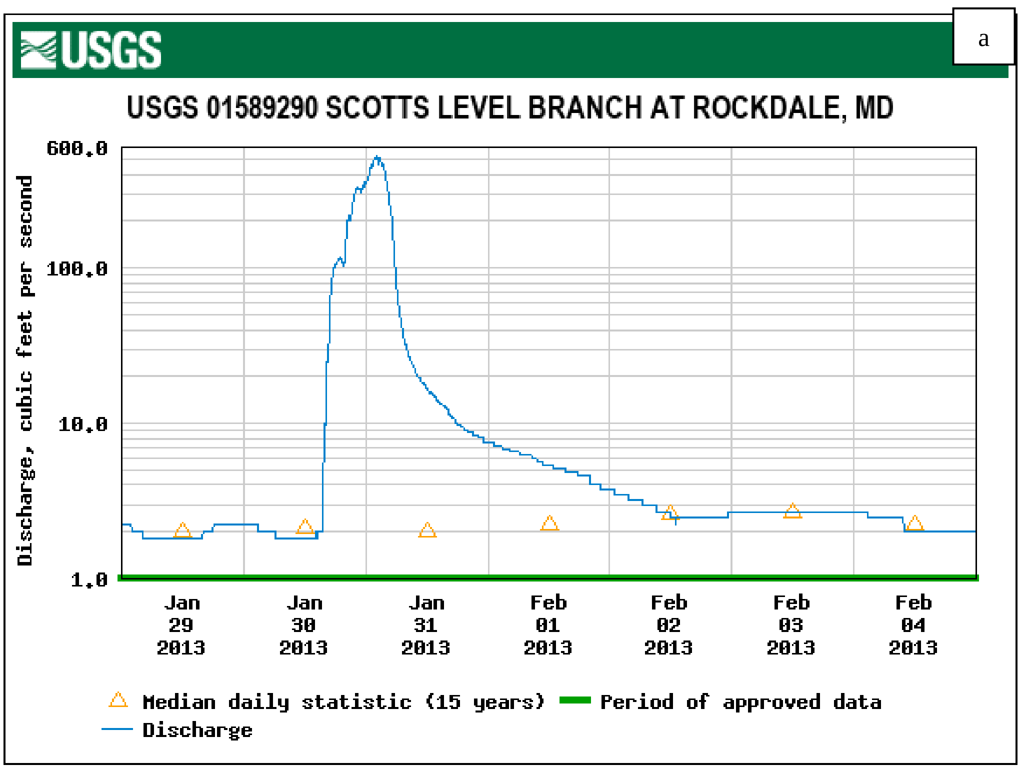
Figure 13. Data analysis plot depicting total dissolved solids in water samples relative to longitudinal distance downstream at Scotts Level Branch. A dilution in small organic and inorganic constituent concentrations in the water agree with the first hypothesis.

Changes in Streamflow Across Space-Time

The restoration at Scotts Level Branch began in 2014. In a 2012 study, six streams (two of each defined as either forested, unrestored urban, or restored urban) were explored, with Scotts Level Branch being one of the six streams (Newcomer et al., 2012). With the study being conducted before the start of the restoration project, Scotts Level Branch was considered an unrestored urban stream. A flashy stream is one that encounters sudden increases in flow shortly after the arrival of a precipitation event, and an equally sudden return to its usual conditions shortly after the end of the precipitation event (Hussein & Hameed, 2019). In the study, it was found that the unrestored urban streams (SLB) were subject to higher discharges during a storm, meaning they were more prone to flashy flows, than for either restored urban and forested streams (Newcomer et al., 2012). If an unrestored urban stream is more likely to show signs of flash flooding than a restored urban stream, then the restoration project at Scotts Level Branch should, as it continues, decrease the rapid changes in hydrograph readings during precipitation events.

The calculated discharge experiment at Scotts Level Branch completed in this study was conducted following a heavy precipitation event that is identified in the USGS hydrograph plot (Figure 14b). There was a relatively quick increase in streamflow when the precipitation event began, but a gentler decrease after the event ended. Figure 14 below shows two precipitation events of similar magnitude, one before the Scotts Level Branch restoration project, and one just prior to collecting field data. Both storms increase stream discharge to about 500 cubic feet per second, and then require two to three days for the stream to recover to its normal state. The two plots look strikingly similar, even with an eight-year gap between the events. This could mean that (1) the restoration project has had very little impact on the flashy hydrology of Scotts Level Branch; or (2) the restoration project is not yet far along enough to present strong changes in streamflow. The project has only restored two small sections of the stream to date, shown previously in Figure 10. With that in mind, further hydrograph data should be sought out with the continuation of the restoration project to form a better understanding of the project's impact.

One study evaluated the streamflow of Minebank Run, a small stream in central Baltimore County, Maryland similar to Scotts Level Branch, from pre- and post-restoration project analyses. The study found pre-restoration median storm depth and median storm peak discharge revealed higher values than those revealed by post-restoration analyses (Pennino et al., 2016). Data was only collected prior to and following the restoration project at Minebank Run to determine the impact of the project. The restoration at Scotts Level Branch has only undergone two small projects, so it is plausible that the restoration has not had its full impact on the overall streamflow to this point.



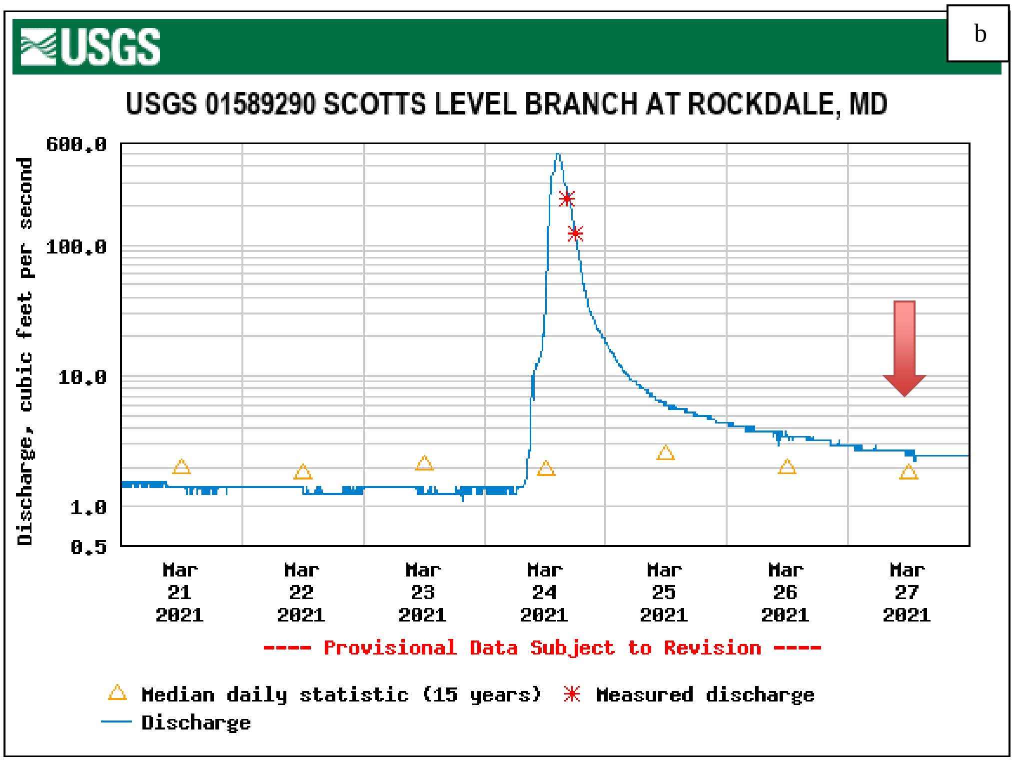


Figure 14. USGS Stream Gauge (Site SLB10) measurements of local stream discharge during two different precipitation events. The top plot (a) is dated about a year before the first restoration project at Scotts Level Branch. It represents a precipitation event of similar magnitude to the one shown in the bottom plot (b), dated around the time of data collection for this experiment. Red arrow points to date of field experiment data collection. Additional Scotts Level Branch USGS Stream Gauge data available in Appendix I.

Changes in Stream Temperature Across Space-Time

The temperature of water in a stream is subject to change via many factors, such as solar radiation, channel geometry, turbidity levels, groundwater inputs, and urbanization (Johnson, 2004). In a wider channel, where the banks are far enough apart for the tree canopy above to open, water temperature can increase as it absorbs heat from sunlight during the day. Direct solar radiation is the largest contributor to changes in daily water temperature (Vliet et al., 2013). In contrast to land, water is translucent, which means light can penetrate the surface layers and spread throughout (Bin Ahmad & Lockwood, 1979). This results in a daily temperature fluctuation responding to the amount of sunlight received by the water (Sinokrot & Stefan, 1993). Shallower stream depths are more easily influenced by solar radiation than deeper stream depths. A higher turbidity value also increases the temperature of water. Turbidity was measured at the USGS Stream Gauge. Turbidity is a measurement illustrating the relative amount of suspended solids in the water. The solid particles absorb sunlight more efficiently than the water they are suspended in, and then transfer the stored heat to the surrounding water (Paaijmans et al., 2008).

Water entering the stream from various water runoff inputs may influence a stream's temperature longitudinally. If water is entering a stream from a shaded, cooler area, the stream in turn shows lower overall temperatures. In contrast, if water is entering the stream from an open parking lot with no shade and a dark surface that absorbs sunlight, the stream will most likely show higher temperatures. Global urbanization, which affects climate change, influences groundwater temperature and quality. Urbanization can increase stream temperatures through deforestation, runoff from impervious surfaces, discharges from power plants and wastewater treatment facilities, and warming behind river impoundments (Kaushal et al., 2010).

Changes in Specific Conductance and Salinity Across Space-Time

Two aspects of the water chemistry explored were specific conductivity and salinity. Specific conductance is a measure of how efficiently a water sample can pass an electrical current. The standardized method of recording conductivity is to take the measurement when the water sample is at, or corrected to, 25 ^{O}C (U.S. Geological Survey, 2019). A standard temperature variable across all data allows for easier comparisons within the data as conductivity ratios change with temperature (Pawlowicz, 2008). The efficiency of a sample to pass an electrical current is directly associated with the concentration of ions in the water. These conductive ions can come from dissolved salts in the environment, as well as from chlorides, sulfides, and carbonate compounds (SWRCB, 2004). Salinity is the total concentration of all dissolved salts in a water sample and is directly correlated to specific conductance. As salts dissolve, electrolytes form ionic particles, with each one having a positive and a negative charge (Maheshwari & Agrawal, 2020). Because specific conductivity and salinity naturally go hand-in-hand with respect to temperature, a correlation between the two should be seen in the field data analysis. This is exactly what data analysis expressed. The Temperature vs Specific Conductivity and the Temperature vs Salinity data analysis graphs from all three streams follow similar patterns (Figure 15). Other than a few outliers, the specific conductance and salinity show similar patterns with respect to temperature.

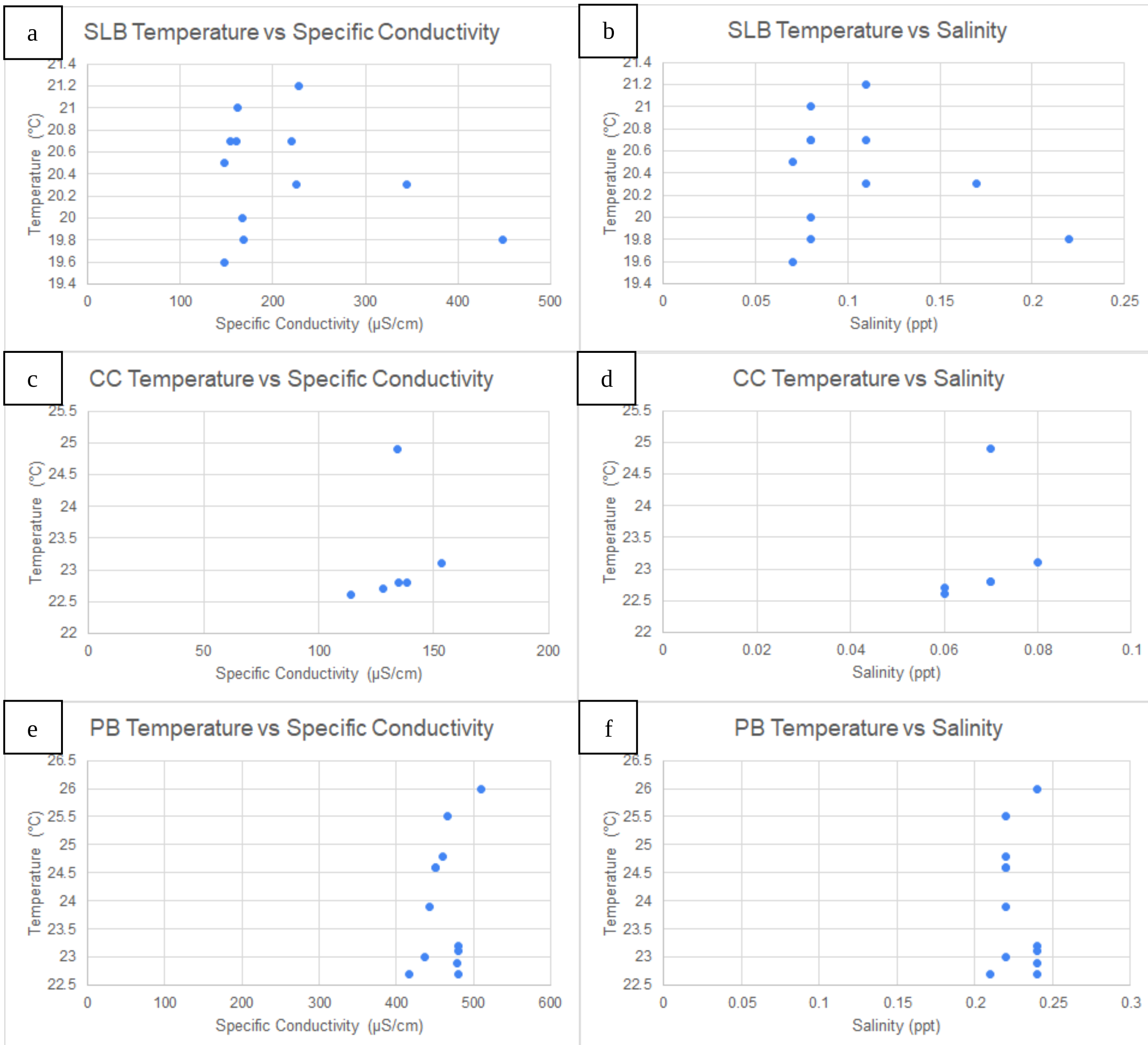


Figure 15. Plots showing specific conductivity and salinity relative to water temperature for each data collection site across all three streams. Similarities to review between plots are from left to right, not top to bottom (i.e., a to b, c to d, and e to f). Note that the plots from stream to stream do not share the same scale. Scotts Level Branch (a,b) and Campus Creek (c,d) data were collected on September 2, 2021. Paint Branch data (e,f) were collected on September 16, 2021. Similar data was also seen at Scotts Level Branch on March 27, 2021, which can be found in Appendix J.

Changes in pH Across Space-Time

The pH levels of the water were also explored, which can be heavily influenced by photosynthesis (Fuller & Davis, 1989). Plants and microorganisms in and around the stream network remove carbon dioxide from the water during photosynthesis, ultimately raising the pH level of the water. This results in a diurnal fluctuation in the pH level that inversely reflects the intensity of photosynthesis throughout the day. pH is highest during the middle of the day with the most direct sunlight feeding photosynthetic processes, and lowest just prior to sunrise. The USGS Stream Gauge data presents this very clearly, where prior to and following the rainstorm event, the pH can be seen fluctuating daily (USGS Figure 7, Appendix I). As seen previously in Figure 9, pH also varies from one season to the next. Measurements of pH were found to be higher than those measured in the late summer and fall months. This may be tied to recent snow melt recharging the stream with salt-laden groundwater. During winter months, road salts are spread to prevent urban surfaces from getting icy and therefore dangerous. With precipitation, salt filters into the groundwater, and eventually into local streams with groundwater. The increase in salinity of the groundwater has a subsequent effect of increased pH, which is known in part as Freshwater Salinization Syndrome (FSS) (Kaushal et al., 2018).

Oxygen Reduction Potential and *Dissolved Oxygen*

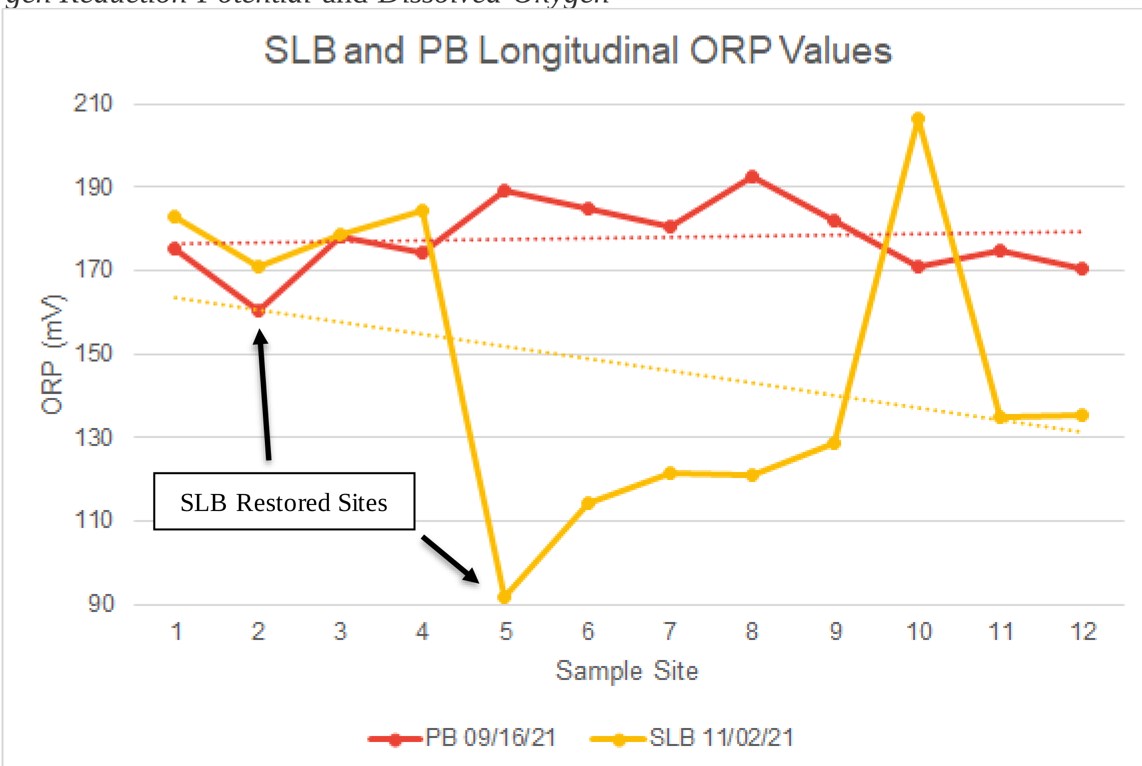


Figure 16. Oxidation-Reduction Potential (ORP) measurements at longitudinal sampling sites across Scotts Level Branch and Paint Branch.

Dissolved oxygen (DO) is the level of available oxygen in a water body for the consumption by organisms (Atlas 2021). At lower levels, organisms in the stream cannot survive approaching anoxic conditions. Oxygen reduction potential (ORP) measures the ability of water to oxidize or reduce a chemical. A higher ORP will exist in an oxidizing environment, while a lower ORP will exist in a reducing environment (Filer & Janick, 1998). DO and ORP values are positively correlated in water.

Local Anthropogenic Inputs

Photograph 6. Large building complex construction site along Paint Branch, upstream of Site PB7.

In the above photograph, taken from the Paint Branch floodplain, a large building is being constructed very close to the stream channel. This is one of many construction sites currently in the Paint Branch watershed at the time of the study. Construction near a stream can increase debris, TDS, and turbidity in the stream. Sudden spikes in longitudinal data may be caused by anthropogenic activity such as impervious sidewalks and parking lots, underground sewage pipes, or local rise in urbanization, like the one pictured above.

Sharp increases in organic matter concentrations in urban streams, like Paint Branch in Figure 7, could be due to leaky underground sewer systems. Many sewer systems tend to flow parallel to streams, as they need to flow downhill. Some sewer pipe joints can become leaky over time, depending on soil conditions and pipe material. When the sewer pipes leak, organic matter in the form of human waste seeps into the soil and mixes with the groundwater (Roehrdanz et al., 2017). During a rainstorm, like the one during this hourly synoptic, the precipitation soaks into the ground and pushes the pre-existing groundwater down slope. A mixture between a leaky sewer and the short rainstorm may account for the sudden spike at Paint Branch in Figure 7.

Conclusions and Broader Implications

Through experimentation and data analysis, it was found that the first hypothesis was supported by the data collected here: stream chemistry is impacted across space and time at each stream due to changes in streamflow. A change in longitudinal streamflow, explained by increasing longitudinal discharge calculations, is related to changes in stream chemistry. Figure 12 provides evidence that variations in three of the four base cations monitored in this study (Ca, Mg, and Na) were due to increasing longitudinal discharge. The USGS Stream Gauge data also depicts variations in specific conductance and turbidity in relation to increasing discharge during precipitation events. Discharge, as well as water chemistry and pollutant concentrations, is heavily impacted by precipitation events at all three monitored urban restored streams, in spite of their drastically different drainage areas.

In regards to the second hypothesis, stating that similarities will be seen between stream chemistry trends, both similarities and differences were found in stream chemistry between Campus Creek, Paint Branch, and Scotts Level Branch across space and time. For example, Scotts Level Branch and Paint Branch both showed a decrease in longitudinal inorganic carbon levels by about 30%, while Campus Creek had a 30% increase downstream. Measurements of organic carbon and total nitrogen did not express similar trends. Differences could be due to the varying sizes of each stream and their drainage basin areas. This data also provides feedback to the restoration planners at Campus Creek in that the RSC method used upstream was not effective enough for the small stream to retain inorganic carbon along its flowpath. Channel and floodplain size are linked with the number of stream inputs and outputs, the level of interaction with the riparian zone, and the groundwater filtering abilities of surrounding landscapes. It can be inferred that all three streams act and respond similarly to one another across various spatial and temporal scales. Data analyzed in this study infer that Paint Branch and Campus Creek have similarities in terms of baseflow conditions and pollutant concentrations.

This study provides insight regarding spatial and temporal relationships between streams, as well as restoration measures made on those streams. Stream restoration in some cases can be a high-dollar, time consuming project, but an improvement in water quality over time is well worth the expense. Studying these restorations provides scientists and engineers with more information on how various techniques affect the streams and water quality over time. With local communities pulling water from rivers such as the Potomac and the Patapsco and other water basins, the health of the small streams flowing into them must be protected.

Suggestions for Future Research

Each of the three streams studied in this experiment are currently in mid-restoration phases that all have an end goal of improving stream flow and water quality. All three streams should be continually studied to record any changes in these parameters as the restoration projects continue and after they have completed. If positive water quality results are found after restoration at a stream, it can be inferred that stream restoration is beneficial to local environments and should be given higher priority. This study found pollutant retention in all three restored urban streams, which can now be predicted with other restoration projects. If neutral or negative results are found after restoration, it can be inferred that either the techniques used as part of a project were insufficient, or that the restoration was not focusing on the correct issue.

There are very few studies that investigate longitudinal patterns downstream in urban environments, and even less that study diurnal cycles as well. The research performed in this study can advance the understanding of urban streams and better understand the behavior of urban streams, especially under climate change and higher impervious surface cover. By conducting a similar experiment to the one used in this study, both longitudinal and diurnal variations in stream chemistry can be further evaluated. Performing the experiment during different seasons or directly before and after precipitation events will provide additional evidence to address the hypotheses. The amount of water and its contaminants flowing through a stream channel at different times of the year should influence the stream's chemistry and discharge measurements. Reviewing the USGS Stream Gauge data throughout the calendar year will allow for a better understanding of how the stream behaves and fluctuates under various conditions over time. Similarly, gathering data at an unrestored stream prior to restoration can be beneficial for additional analysis of a wider group of streams. Pre-restoration characteristics are significant. This study was conducted over a year's time, so studying a group of streams for a longer duration may provide more data for a better understanding of how they react to restoration techniques over time. Also with longer durations, stream channel geometry and flow paths are more likely to show variation than what may be seen in shorter studies.

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Appendix A: Aerial Geologic Maps

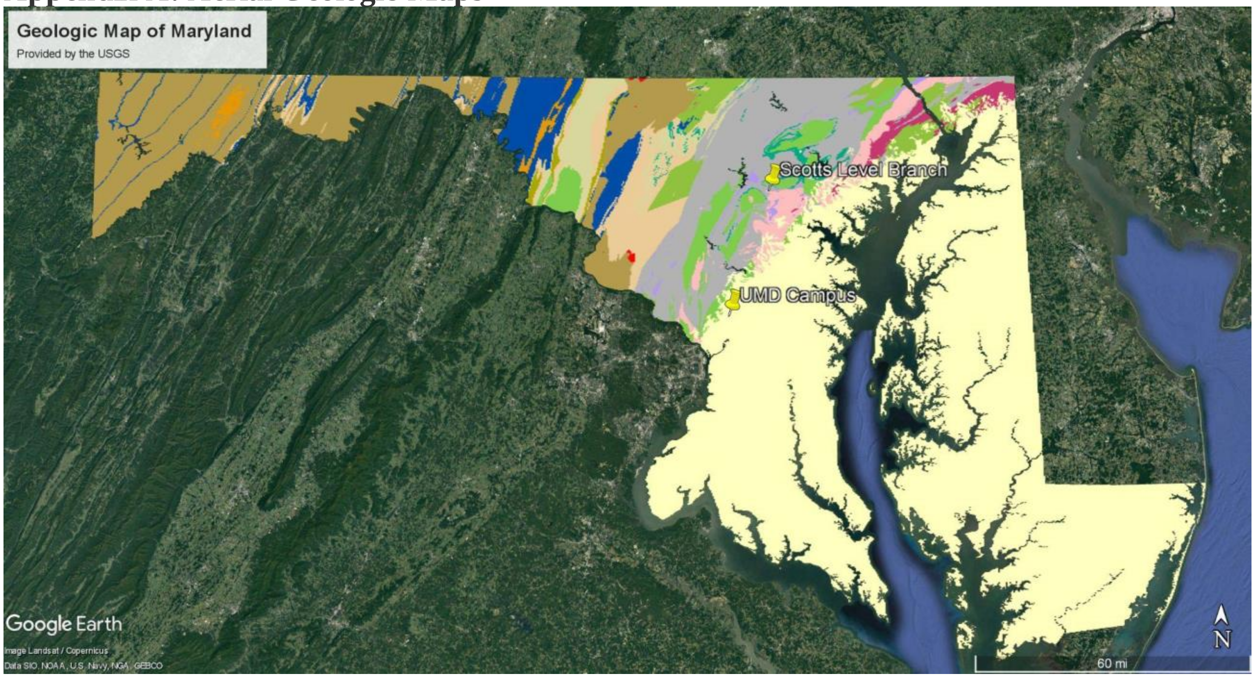


Figure M1. Geologic map of Maryland, provided by the USGS. Scotts Level Branch (upper yellow pin) covers two formations, the Wissahickon and the Baltimore Gabbro Complex. Both streams by the University of Maryland campus (lower yellow pin) are only in the Nanjemoy Formation.

Figure M2. Geologic Map of Scotts Level Branch and Surrounding Area with Data Collection Site Markers. Base geology is from the USGS.

Appendix B: Photographs from Data Collection

All field photographs below were taken and provided by Christiana Hoff.

Photograph 7. Site SLB3: "Tulsemere Rd"

Photograph 8. Site SLB4: "Offutt Rd"


Photograph 9. Site SLB6: “Brenbrook Dr”

Photograph 10. Site SLB7: “Greenway Bridge”

Photograph 11. Site SLB7: “Greenway Bridge”


Photograph 12. Site SLB7: “Greenway Bridge”

Photograph 13. Site SLB9: "Old Court Rd"

Photograph 14. Site SLB10: "Rolling Rd"


Photograph 15. Site SLB11: “Twin Lakes Ct"


Photograph 16. Paint Branch automated sampler location at Site PB8.

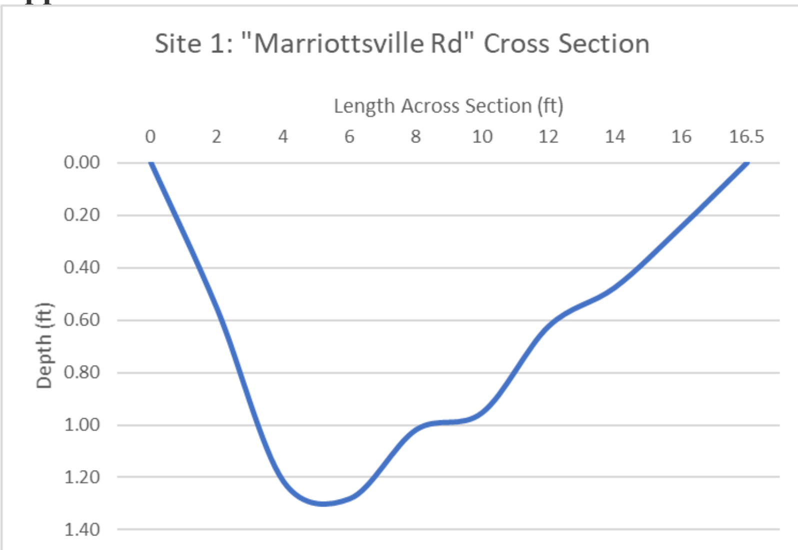
Appendix C: Chemistry Data at Scotts Level Branch

Name	Time	X Coordinate	Y Coordinate	Specific Conductivity (µS/cm)	pH
SLB_20210327_CMM1	8:14 AM	39.38417	-76.82215	596	7.87
SLB_20210327_CMM2	8:48 AM	39.38366	-76.81686	618	8.14
SLB_20210327_CMM3	9:15 AM	39.38027	-76.80743	680	8.15
SLB_20210327_CMM4	9:47 AM	39.37956	-76.79729	542	7.88
SLB_20210327_CMM5	10:14 AM	39.37397	-76.7912	522	7.95
SLB_20210327_CMM6	10:54 AM	39.37241	-76.78747	515	8.07
SLB_20210327_CMM7	11:22 AM	39.37202	-76.77998	504	8.29
SLB_20210327_CMM8	11:58 AM	39.36998	-76.77212	492	7.99
SLB_20210327_CMM9	12:48 AM	39.36159	-76.7618	500	8.41
SLB_20210327_CMM10	1:11 PM	39.36159	-76.7618	492	8.34
SLB_20210327_CMM11	1:39 PM	39.35992	-76.75811	516	8.43
SLB_20210327_CMM12	2:06 PM	39.36056	-76.74585	495	8.55

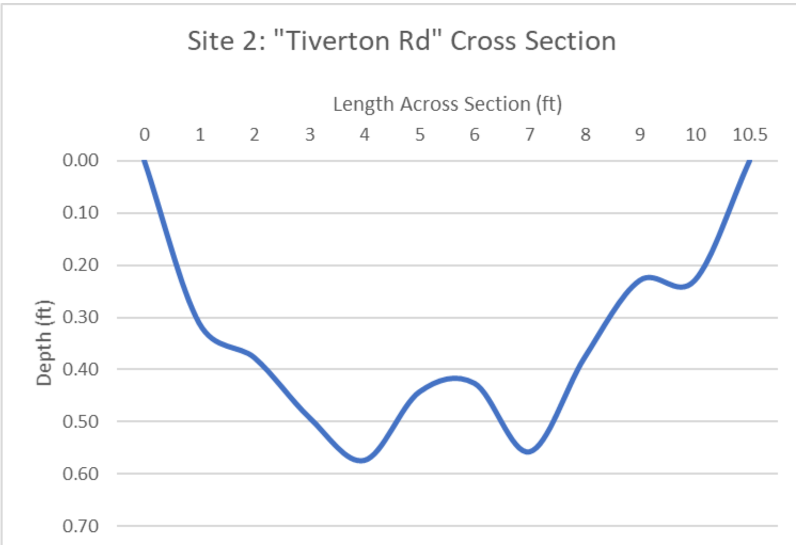
Temperature (°C)	Salinity (ppt)	TDS (ppm)	Distance from Site 1 (ft)	Discharge (cu ft/sec)	Elevation (m)
12.4	0.03	427	0	0.052	174
10.1	0.31	446	1610	0.208	169
12.3	0.34	485	5000	0.312	164
13	0.27	378	8450	0.573	157
14	0.26	364	11760	1.084	153
14	0.26	365	13040	1.094	151
14.8	0.26	365	15255	-1.498	148
15.3	0.24	341	17750	1.346	147
14.7	0.25	355	19980	2.226	144
15.3	0.25	349	23080	2.919	138
15.7	0.25	352	24310	3.194	135
15.9	0.26	367	28300	3.614	117

Table C1. Stream chemistry data and additional data collection site notes at Scotts Level Branch on March 27, 2021. Each site was given a name for easy distinction outside of the field. The time listed is the time of day that measurements were initiated at the specific site. Distance from Site SLB1 for each site is a close approximation using careful mapping practices.

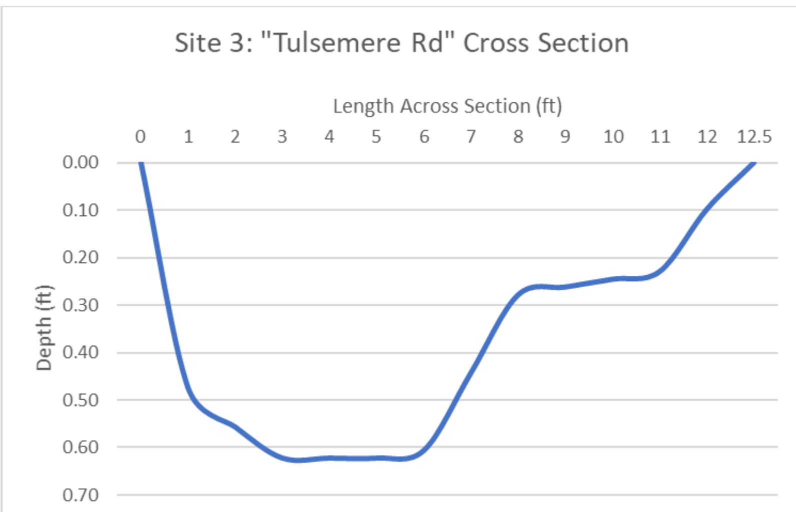
Appendix D: Scotts Level Branch Site Cross Sections



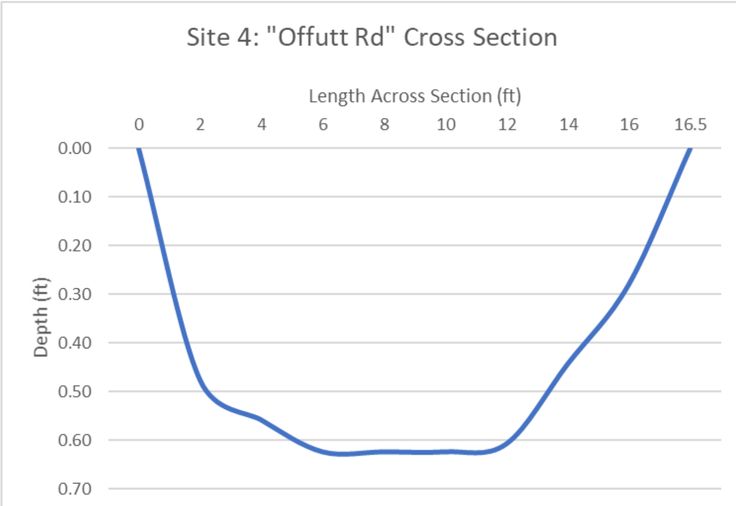
Plot CS01



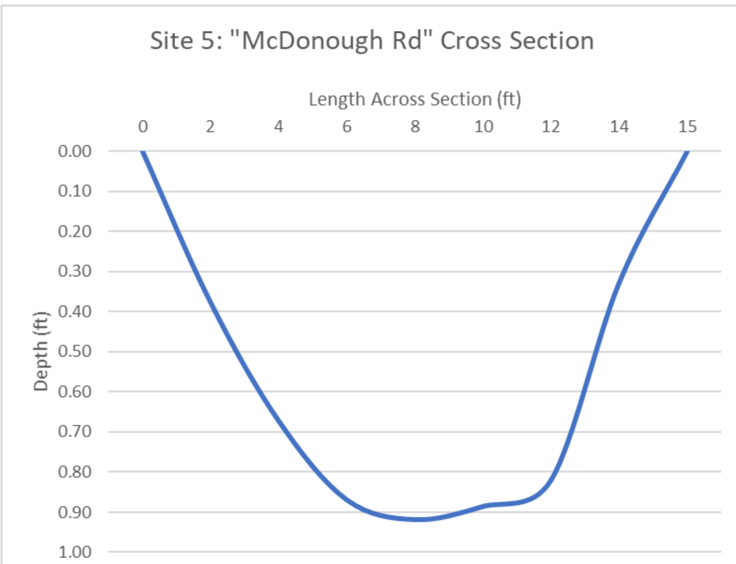
Plot CS02



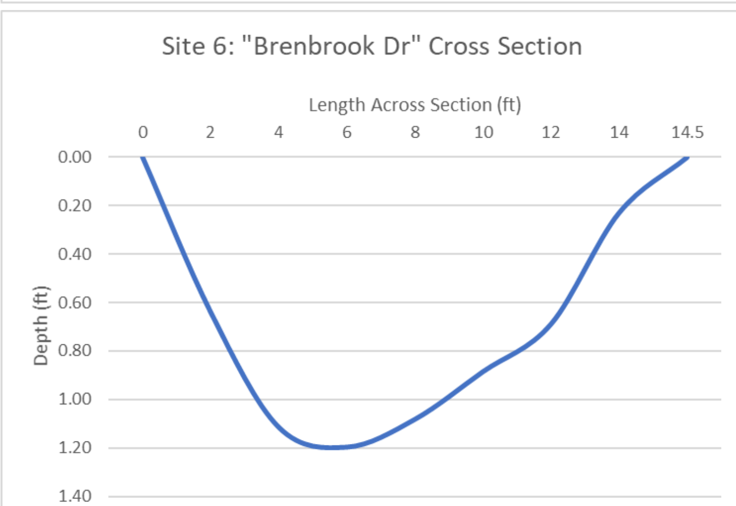
Plot CS03



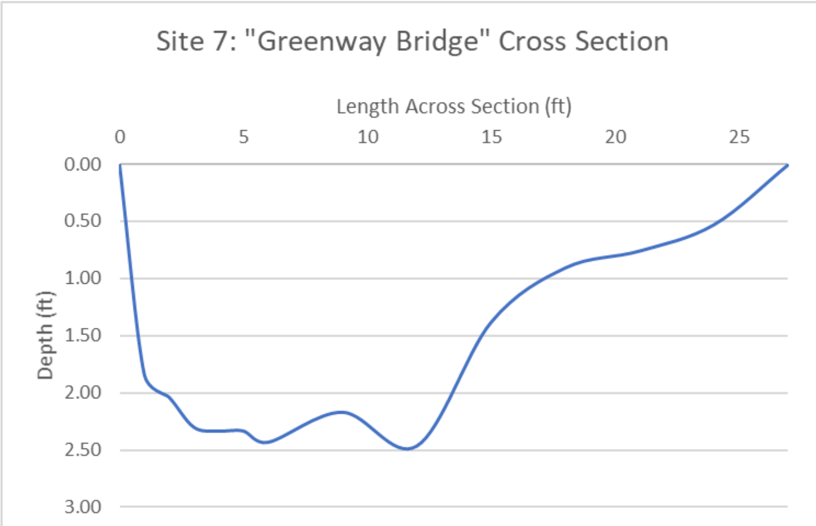
Plot CS04



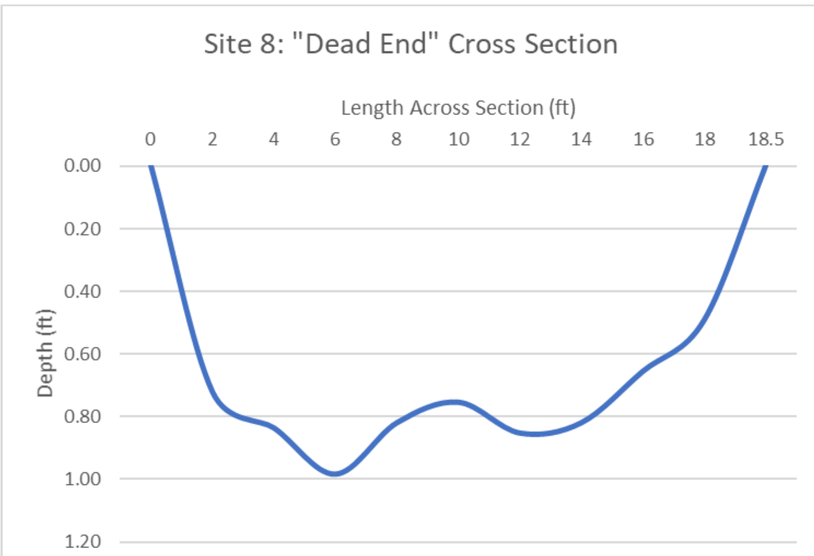
Plot CS05



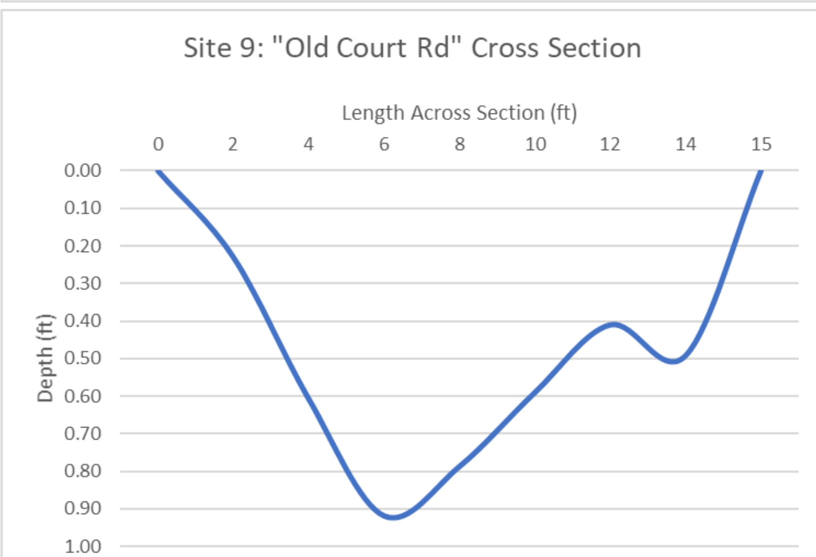
Plot CS06



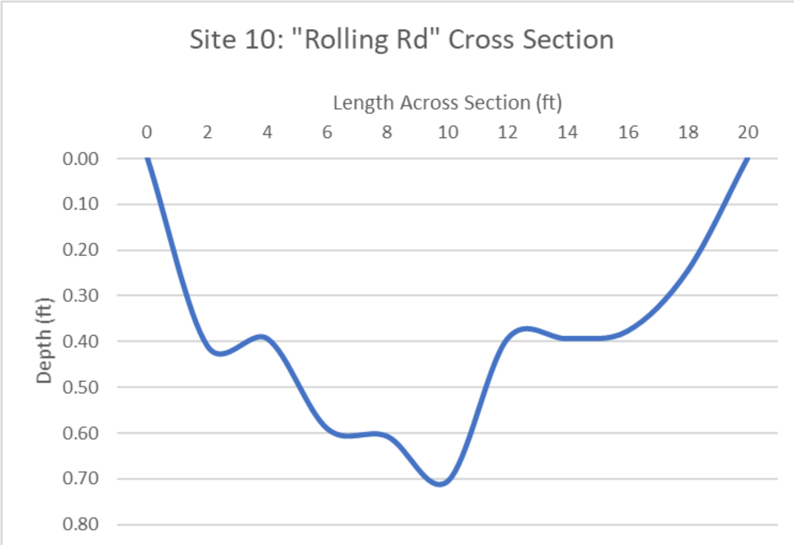
Plot CS07



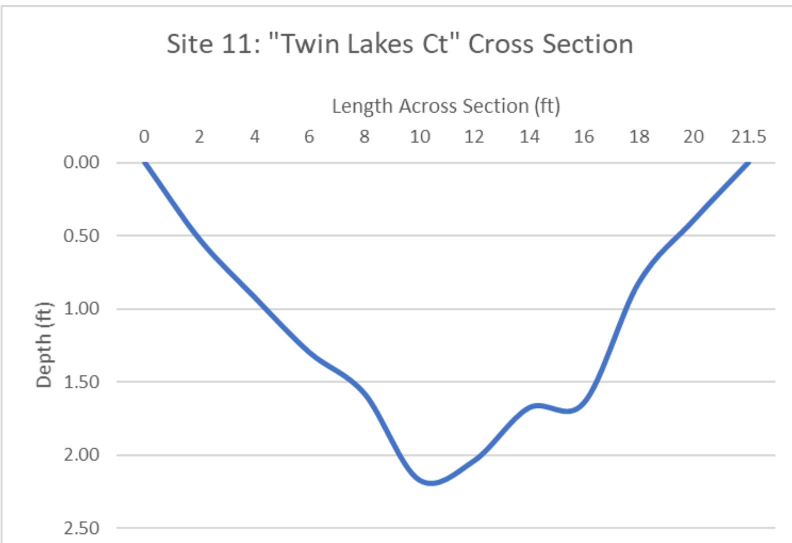
Plot CS08



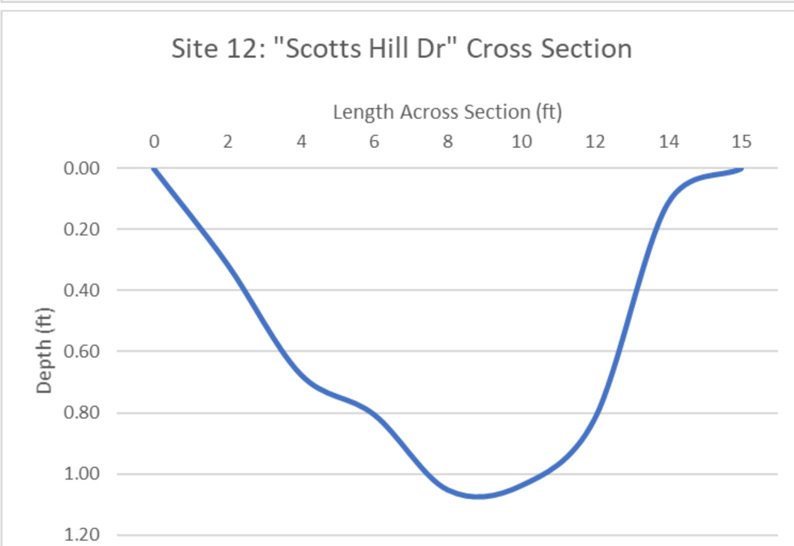
Plot CS09



Plot CS10



Plot CS11



Plot CS12

Appendix E: Discharge Data

Site 1: Marriottsville Rd							
~16.5ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	-0.02	17	0.56	1.12	-0.022	Not restored
4	2	-0.01	37	1.21	2.43	-0.024	
6	2	0.00	39	1.28	2.56	0.000	
8	2	0.01	31	1.02	2.03	0.020	
10	2	0.01	29	0.95	1.90	0.019	
12	2	0.02	19	0.62	1.25	0.025	
14	2	0.01	14.5	0.48	0.95	0.010	
16	2	0.05	7.5	0.25	0.49	0.025	
16.5				0.00			
Averages and Totals		**0.01**	**24.25**	**0.80**	**12.73**	**0.052**	<- Total Discharge (cu ft/sec)

Site 2: Tiverton Rd							
~10.5ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
1	1	0.07	9.5	0.31	0.31	0.022	Restored
2	1	0.18	11.5	0.38	0.38	0.068	
3	1	0.09	15	0.49	0.49	0.044	
4	1	0.04	17.5	0.57	0.57	0.023	
5	1	0.04	13.5	0.44	0.44	0.018	
6	1	0.00	13	0.43	0.43	0.000	Big Rock
7	1	0.02	17	0.56	0.56	0.011	
8	1	0.06	11.5	0.38	0.38	0.023	
9	1	0.00	7	0.23	0.23	0.000	
10	1	0.00	7	0.23	0.23	0.000	Plant Life
10.5				0.00			
Averages and Totals		**0.05**	**12.25**	**0.40**	**4.02**	**0.208**	<- Total Discharge (cu ft/sec)

Site 3: Tulsemere Rd							
~12.5ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
1	1	0.03	14.5	0.48	0.48	0.014	Crawfish
2	1	0.01	17	0.56	0.56	0.006	
3	1	0.00	19	0.62	0.62	0.000	
4	1	0.06	19	0.62	0.62	0.037	Not restored
5	1	0.15	19	0.62	0.62	0.094	
6	1	0.12	18.5	0.61	0.61	0.073	
7	1	0.11	13.5	0.44	0.44	0.049	
8	1	0.05	8.5	0.28	0.28	0.014	
9	1	0.06	8	0.26	0.26	0.016	
10	1	0.02	7.5	0.25	0.25	0.005	
11	1	0.01	7	0.23	0.23	0.002	
12	1	0.03	3	0.10	0.10	0.003	
12.5				0.00			
Averages and Totals		**0.05**	**12.88**	**0.42**	**5.07**	**0.312**	<- Total Discharge (cu ft/sec)

Table E1. Collected discharge data for Sites 1-3.

Site 4: Offutt Rd							
~16.5 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.03	14.5	0.48	0.95	0.029	
4	2	0.01	17	0.56	1.12	0.011	
6	2	0.00	19	0.62	1.25	0.000	Not restored
8	2	0.06	19	0.62	1.25	0.075	
10	2	0.15	19	0.62	1.25	0.187	
12	2	0.12	18.5	0.61	1.21	0.146	
14	2	0.11	13.5	0.44	0.89	0.097	
16	2	0.05	8.5	0.28	0.56	0.028	
16.5				0.00			
Averages and Totals		**0.07**	**16.13**	**0.53**	**8.46**	**0.573**	<- Total Discharge (cu ft/sec)

Site 5: McDonough Rd							
~15 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.03	11.5	0.38	0.75	0.023	Float test:
4	2	0.03	20.5	0.67	1.35	0.040	15 ft / 34 sec = 0.44 ft/sec
6	2	0.13	26.5	0.87	1.74	0.226	
8	2	0.19	28	0.92	1.84	0.349	Restored
10	2	0.23	27	0.89	1.77	0.407	
12	2	0.07	25	0.82	1.64	0.115	
14	2	0.00	10	0.33	0.66	0.000	
15				0.00			
Averages and Totals		**0.10**	**21.21**	**0.70**	**9.74**	**1.160**	<- Total Discharge (cu ft/sec)

Site 5: 2nd Test							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.00	11.5	0.38	0.75	0.000	***Flow meter less consistent***
4	2	0.01	20.5	0.67	1.35	0.013	***at lower velocities***
6	2	0.08	26.5	0.87	1.74	0.139	
8	2	0.19	28	0.92	1.84	0.349	
10	2	0.23	27	0.89	1.77	0.407	
12	2	0.06	25	0.82	1.64	0.098	
14	2	0.00	10	0.33	0.66	0.000	
15				0.00			
Averages and Totals		**0.08**	**21.21**	**0.70**	**9.74**	**1.008**	<- Total Discharge (cu ft/sec)

Site 6: Brenbrook Dr.							
~14.5 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.01	19.5	0.64	1.28	0.013	Not restored
4	2	0.02	34	1.12	2.23	0.045	
6	2	0.17	36.5	1.20	2.40	0.407	
8	2	0.15	33	1.08	2.17	0.325	
10	2	0.12	27	0.89	1.77	0.213	
12	2	0.06	21	0.69	1.38	0.083	
14	2	0.02	7	0.23	0.46	0.009	
14.5				0.00			
Averages and Totals		**0.08**	**25.43**	**0.83**	**11.68**	**1.094**	<- Total Discharge (cu ft/sec)

Table E2. Collected discharge data for Sites 4-6.

Site 7: Greenway Bridge							
~27 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
1	1	0.10	56	1.84	1.84	0.184	***More measurements due to***
2	1	0.15	62	2.03	2.03	0.305	***asymmetry of stream profile***
3	1	0.48	70	2.30	2.30	1.102	
4	1	0.39	71	2.33	2.33	0.908	***Channelized***
5	1	0.05	71	2.33	2.33	0.116	
6	1	0.02	74	2.43	2.43	0.049	
9	3	-0.12	66	2.17	6.50	-0.780	Not restored
12	3	-0.19	75	2.46	7.38	-1.403	
15	3	-0.21	42	1.38	4.13	-0.868	
18	3	-0.26	27.5	0.90	2.71	-0.704	
21	3	-0.09	23	0.75	2.26	-0.204	
24	3	-0.13	16	0.52	1.57	-0.205	
27				0.00			
Averages and Totals		**0.02**	**54.46**	**1.79**	**37.81**	**-1.498**	<- Total Discharge (cu ft/sec)

Site 8: Dead End							
~18.5 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	-0.02	22	0.72	1.44	-0.029	Lunch Site
4	2	0.04	25.5	0.84	1.67	0.067	
6	2	0.06	30	0.98	1.97	0.118	Not restored
8	2	0.06	25	0.82	1.64	0.098	
10	2	0.13	23	0.75	1.51	0.196	
12	2	0.29	26	0.85	1.71	0.495	
14	2	0.21	25	0.82	1.64	0.344	
16	2	0.02	20	0.66	1.31	0.026	
18	2	0.03	15	0.49	0.98	0.030	
18.5				0.00			
Averages and Totals		**0.09**	**23.50**	**0.77**	**13.88**	**1.346**	<- Total Discharge (cu ft/sec)

Site 9: Old Court Rd							
~15 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.12	7	0.23	0.46	0.055	Not restored
4	2	0.12	18.5	0.61	1.21	0.146	
6	2	0.28	28	0.92	1.84	0.514	
8	2	0.39	24	0.79	1.57	0.614	
10	2	0.29	18	0.59	1.18	0.343	
12	2	0.50	12.5	0.41	0.82	0.406	
14	2	0.15	15	0.49	0.98	0.148	
15				0.00			
Averages and Totals		**0.26**	**17.57**	**0.58**	**8.07**	**2.226**	<- Total Discharge (cu ft/sec)

Table E3. Collected discharge data for Sites 7-9.

Site 10: Rolling Rd							
~20 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.18	12.5	0.41	0.82	0.148	USGS Site
4	2	0.45	12	0.39	0.79	0.354	
6	2	0.56	18	0.59	1.18	0.661	Not restored
8	2	0.52	18.5	0.61	1.21	0.631	
10	2	0.37	21.5	0.71	1.41	0.522	
12	2	0.20	12	0.39	0.79	0.157	
14	2	0.44	12	0.39	0.79	0.346	
16	2	0.13	11.5	0.38	0.75	0.098	
18	2	0.00	7.5	0.25	0.49	0.000	
20				0.00			
Averages and Totals		**0.32**	**13.94**	**0.46**	**8.23**	**2.919**	<- Total Discharge (cu ft/sec)

Site 11: Twin Lakes Ct.							
~21.5 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.00	16	0.52	1.05	0.000	Not restored
4	2	0.02	28	0.92	1.84	0.037	
6	2	0.00	39.5	1.30	2.59	0.000	
8	2	0.09	48	1.57	3.15	0.283	
10	2	0.07	66	2.17	4.33	0.303	
12	2	0.09	62	2.03	4.07	0.366	
14	2	0.24	51	1.67	3.35	0.803	
16	2	0.34	50	1.64	3.28	1.115	
18	2	0.16	25	0.82	1.64	0.262	
20	2	0.03	12	0.39	0.79	0.024	
21.5				0.00			
Averages and Totals		**0.10**	**39.75**	**1.30**	**26.08**	**3.194**	<- Total Discharge (cu ft/sec)

Site 12: Scotts Hill Dr.							
~15 ft wide							
Distance from 0 (ft)	Length (ft)	Velocity (ft/sec)	Depth (cm)	Depth (ft)	Area of Each Increment (cu ft)	Discharge (cu ft/sec)	Notes
0				0.00			
2	2	0.15	9.5	0.31	0.62	0.094	***Downstream of bridge***
4	2	0.27	20.5	0.67	1.35	0.363	
6	2	0.45	24.5	0.80	1.61	0.723	Not restored
8	2	0.46	32	1.05	2.10	0.966	
10	2	0.43	31.6	1.04	2.07	0.892	
12	2	0.35	25	0.82	1.64	0.574	
14	2	0.01	3.5	0.11	0.23	0.002	
15				0.00			
Averages and Totals		**0.30**	**20.94**	**0.69**	**9.62**	**3.614**	<- Total Discharge (cu ft/sec)

Table E4. Collected discharge data for Sites 10-12.

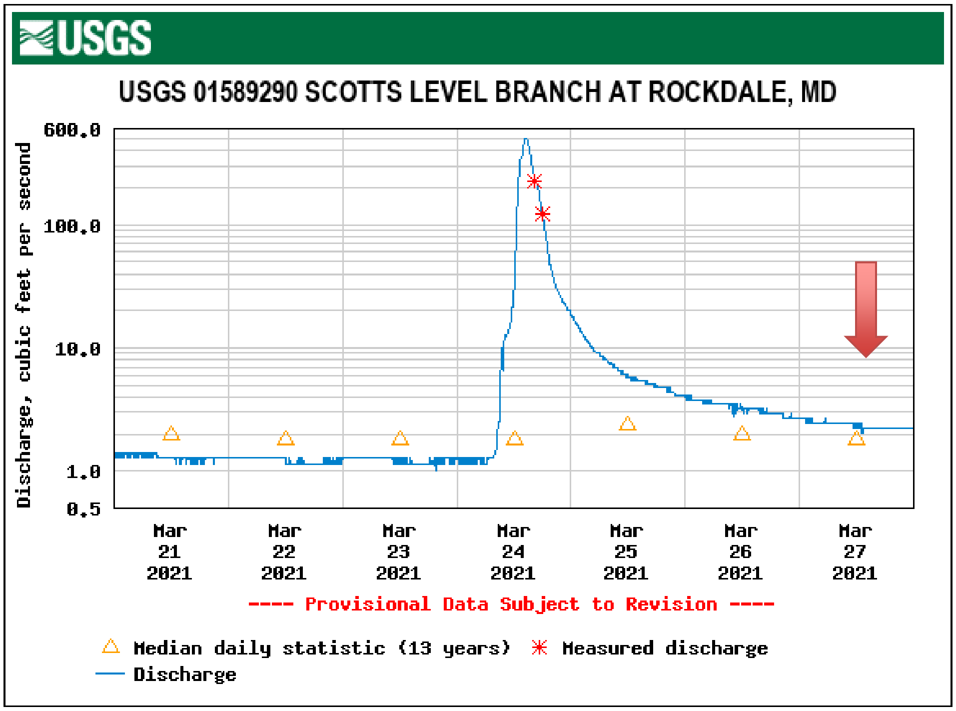
Appendix F: Scotts Level Branch Longitudinal Chanel Geometry Analysis

There were very few well-defined trends in streambed geometry from site to site, but some do share similarities. For example, Sites SLB4, SLB5, and SLB6 have smooth slopes without shelves or ridges. Also, the progression from Site SLB10 to SLB11 and from Site SLB11 to SLB12 have visually similar streambed geometries as well. Site SLB2 is both the overall narrowest at 10.5 feet and has the shallowest average depth at 0.40 feet, while Site SLB7 is both the overall widest at 27 feet and has the deepest average depth at 1.79 feet. Site SLB2 and Site SLB5 are the only two data collection sites that fall within Baltimore County's restoration project to this point. When examining stream channel characteristics, neither of those sites produced data that were substantially different or out of the ordinary in relation to the unrestored sites, as shown in the data table below.

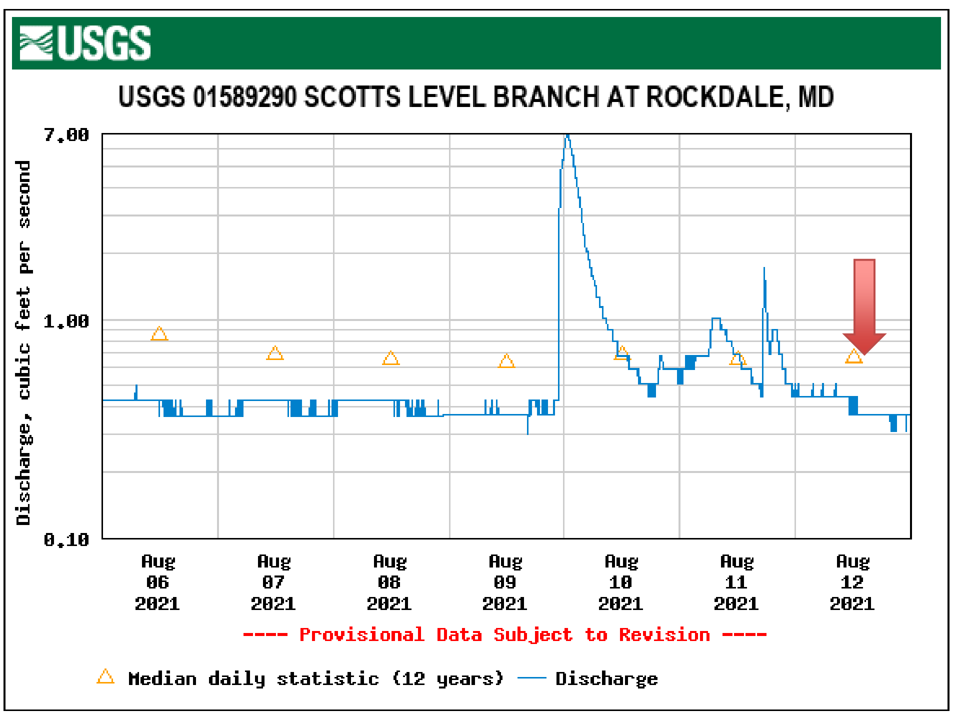
Site	Cross Sectional Area (cu ft)	Avg Depth (ft)	Total Width (ft)	Depth/Width Ratio	Avg Velocity (ft/sec)	Distance from Site 1 (m)
Site 1	12.73	0.80	16.5	0.05	0.01	0
Site 2	4.02	0.40	10.5	0.04	0.05	490
Site 3	5.07	0.42	12.5	0.03	0.05	1524
Site 4	8.46	0.53	16.5	0.03	0.07	2575
Site 5	9.74	0.70	15	0.05	0.09	3585
Site 6	11.68	0.83	14.5	0.06	0.08	3975
Site 7	37.81	1.79	27	0.07	0.02	4650
Site 8	13.88	0.77	18.5	0.04	0.09	5410
Site 9	8.07	0.58	15	0.04	0.26	6090
Site 10	8.23	0.46	20	0.02	0.32	7035
Site 11	26.08	1.30	21.5	0.06	0.10	7410
Site 12	9.62	0.69	15	0.05	0.30	8625

Table 1. Table of select physical hydrology parameters, and results of calculations, at the twelve field sites. Site SLB2 and Site SLB5 are highlighted to show sites located within the county project's restored areas.

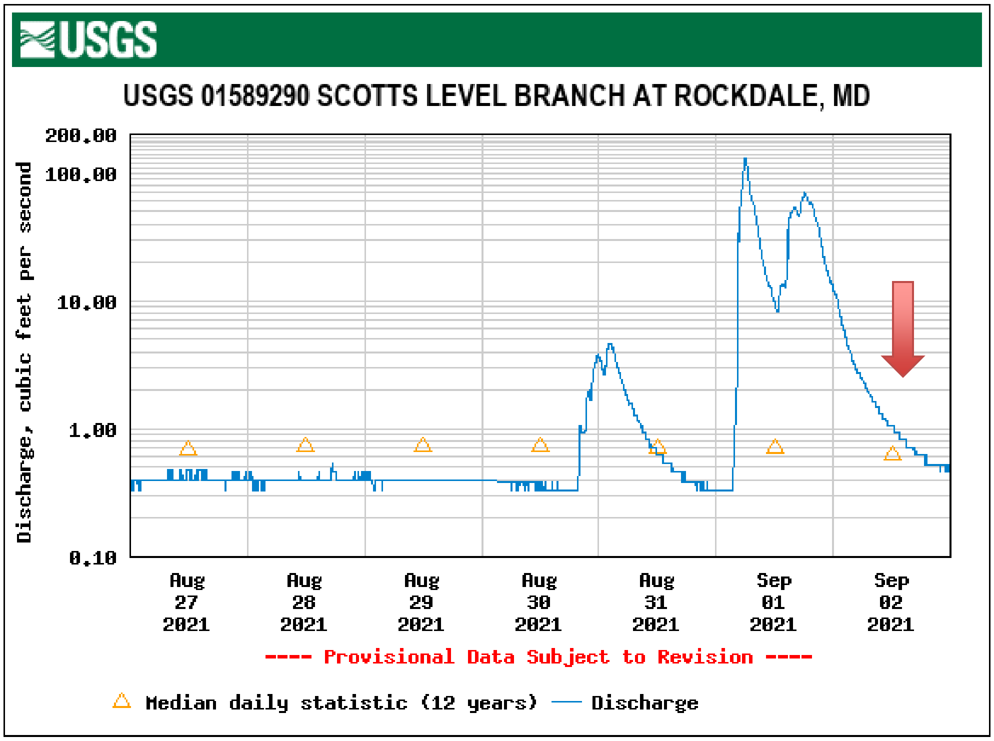
Appendix G: Data Collection Day Hydrographs



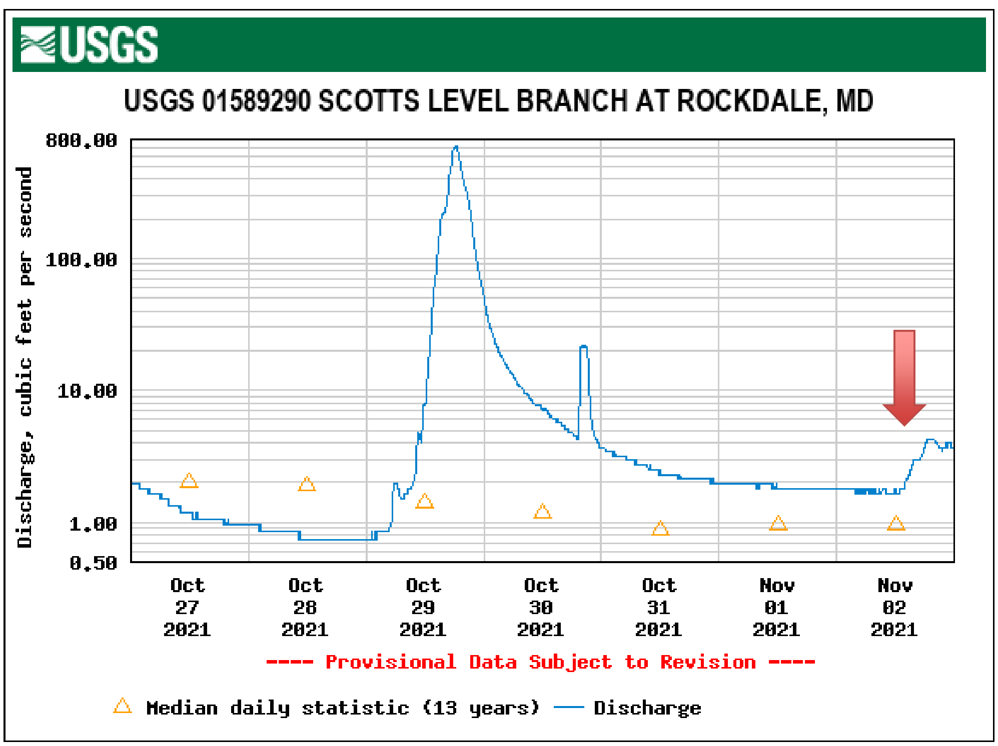
USGS Figure 1. USGS Stream Gauge (Site SLB10) measurements of local stream discharge at Scotts Level Branch. Red arrow shows date of field experiment data collection.



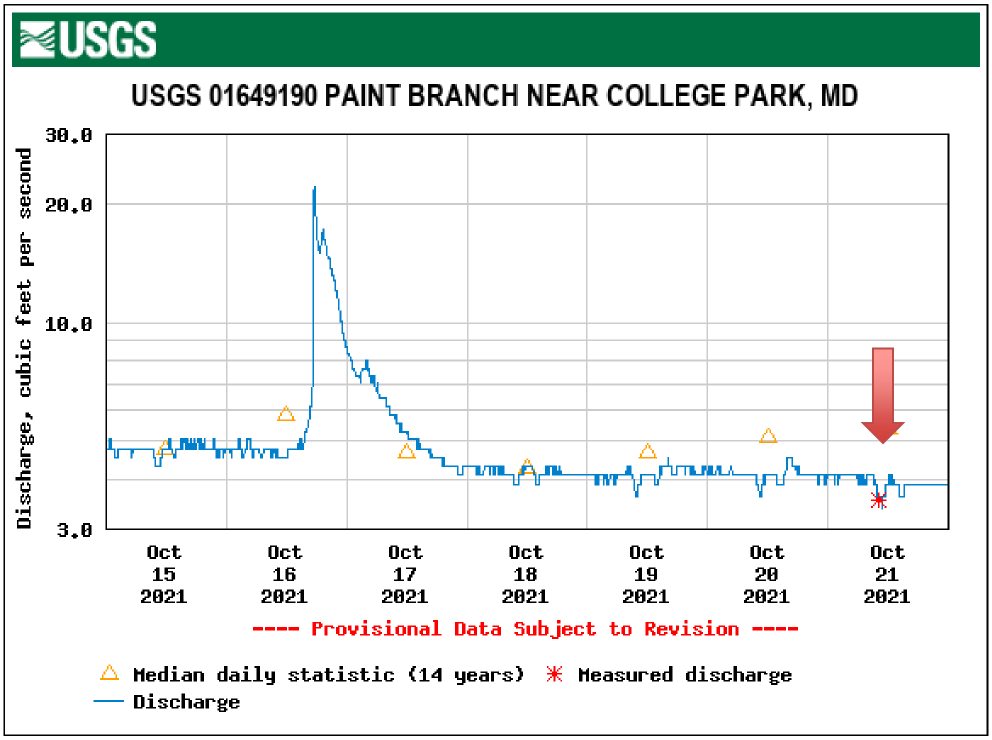
USGS Figure 2. USGS Stream Gauge (Site SLB10) measurements of local stream discharge at Scotts Level Branch. Red arrow shows date of field experiment data collection.



USGS Figure 3. USGS Stream Gauge (Site SLB10) measurements of local stream discharge at Scotts Level Branch. Red arrow shows date of field experiment data collection.

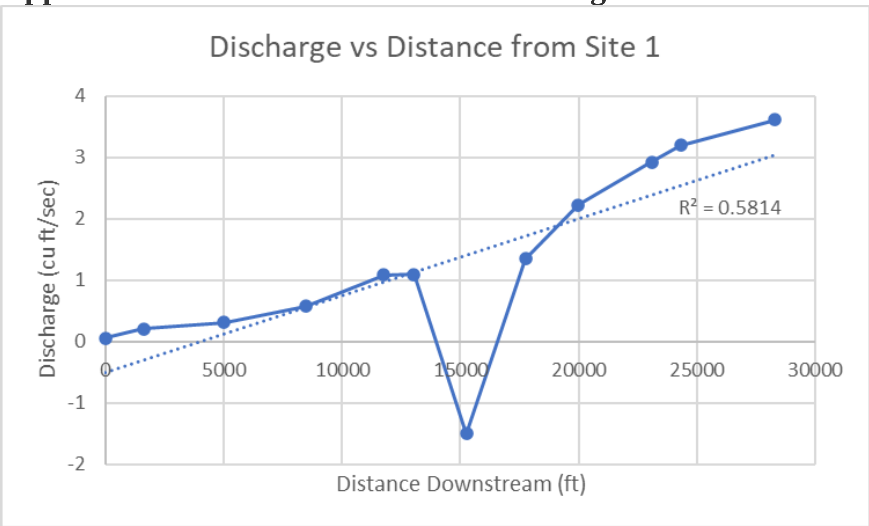


USGS Figure 4. USGS Stream Gauge (Site SLB10) measurements of local stream discharge at Scotts Level Branch. Red arrow shows date of field experiment data collection.

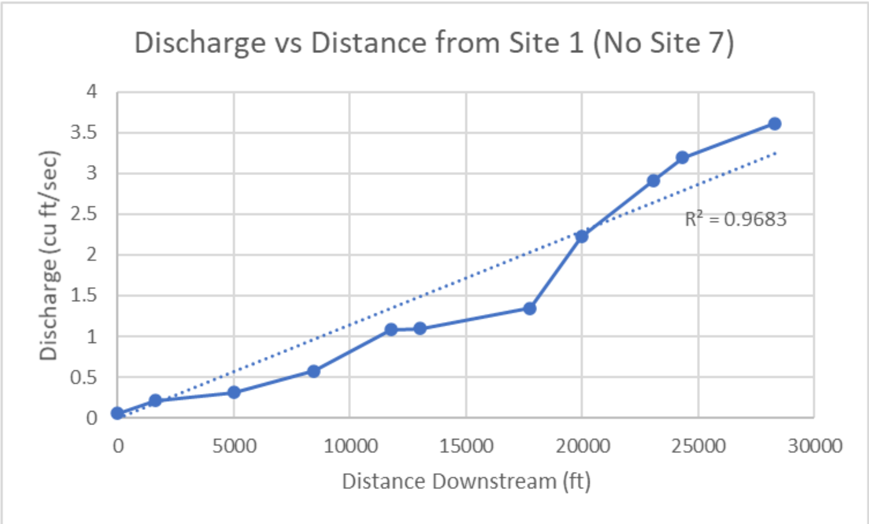


USGS Figure 5. USGS Stream Gauge measurements of local stream discharge at Paint Branch. Red arrow shows date of field experiment data collection.

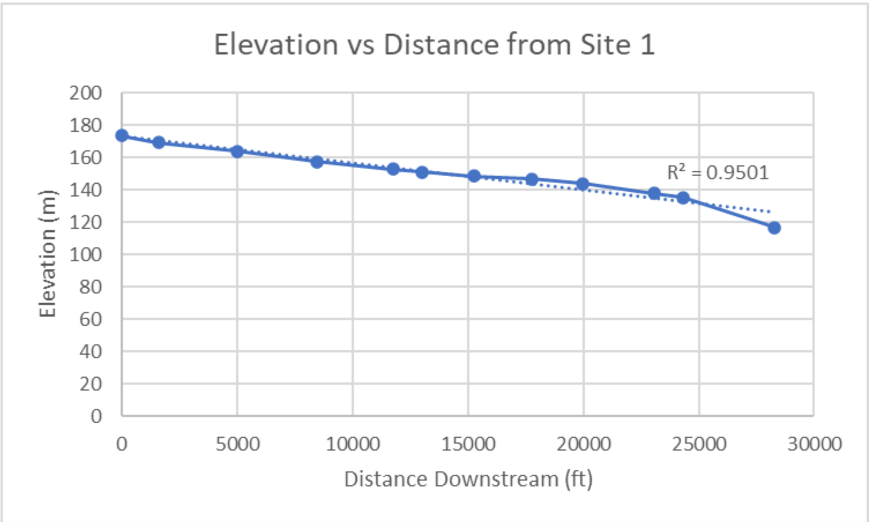
Appendix H: Scotts Level Branch Data Progression Downstream



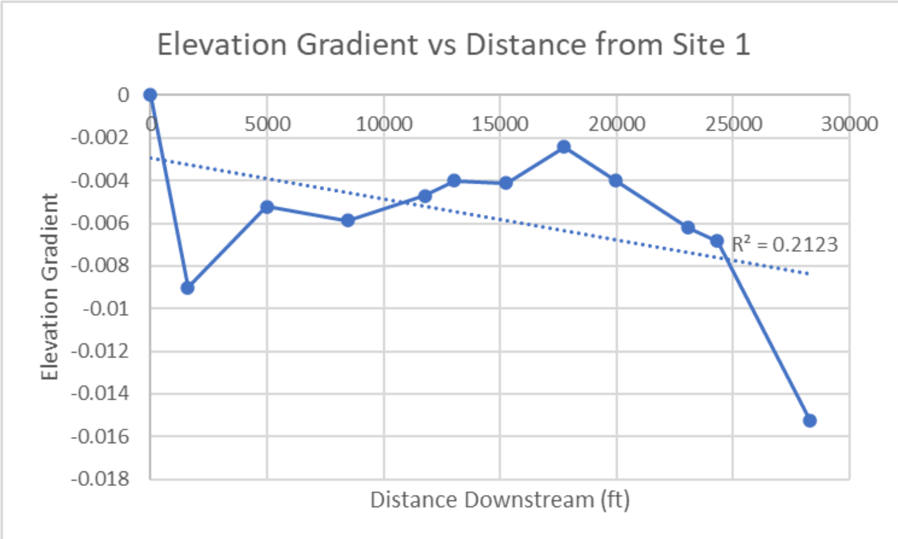
Plot 1



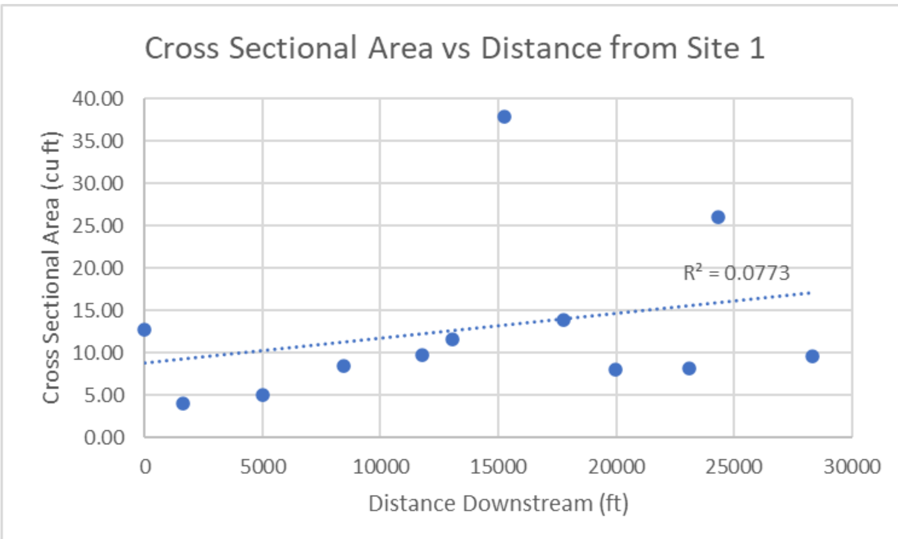
Plot 2



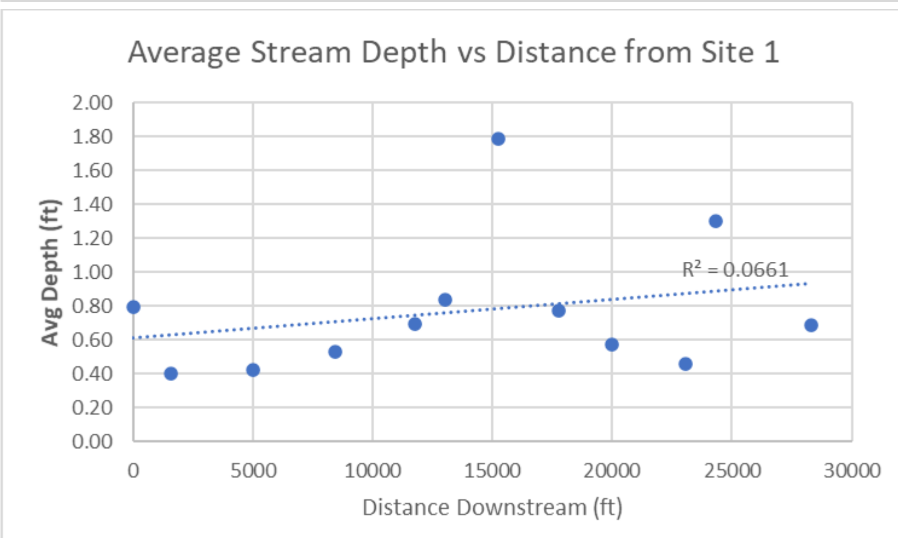
Plot 3



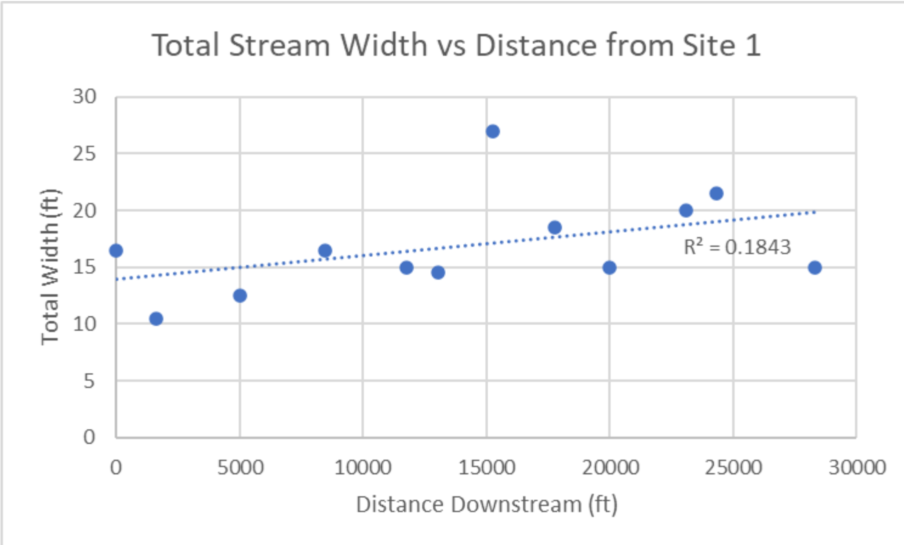
Plot 4



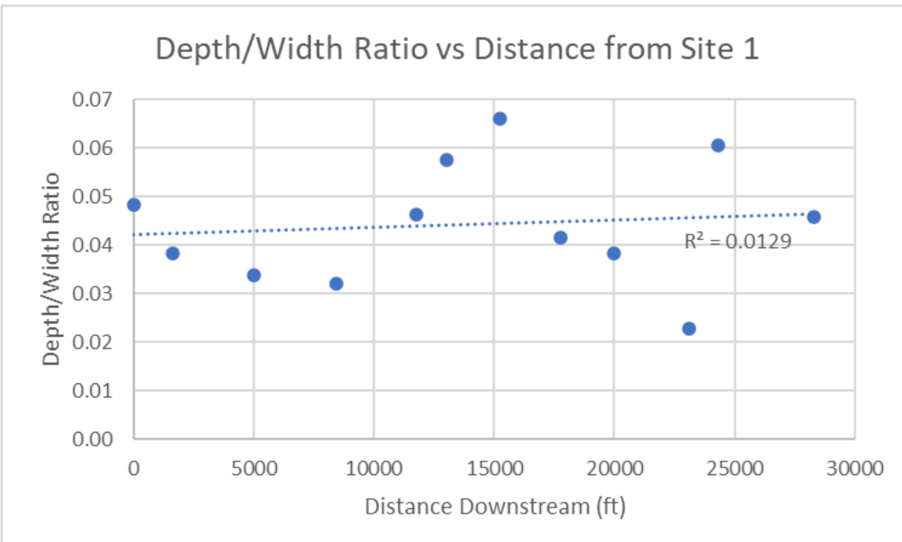
Plot 5



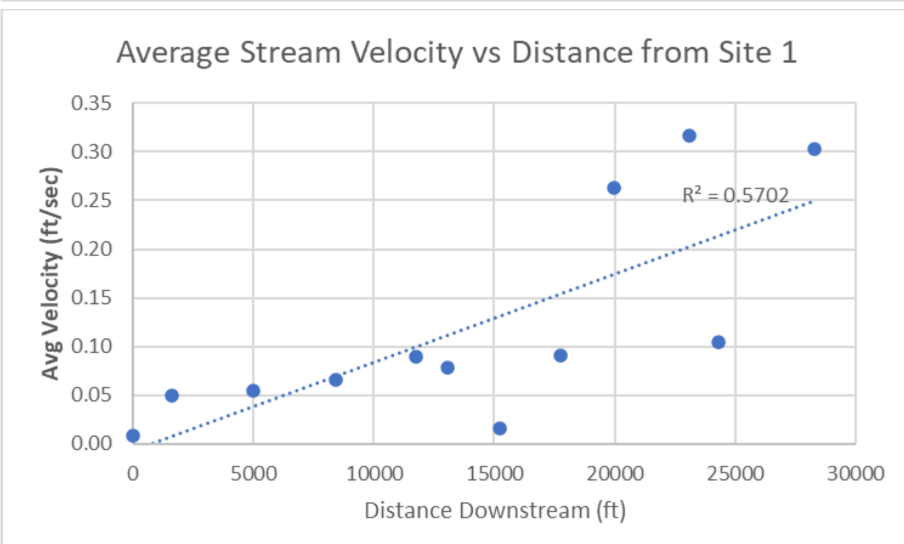
Plot 6



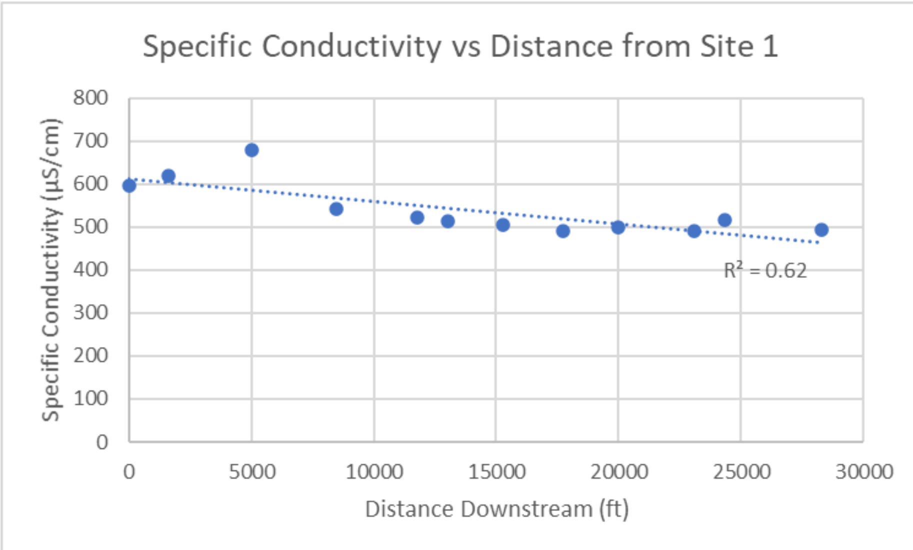
Plot 7



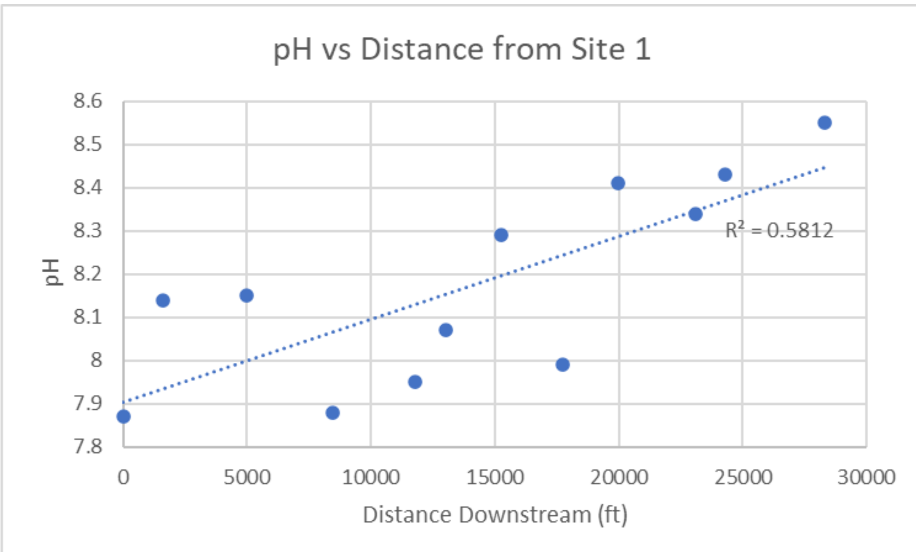
Plot 8



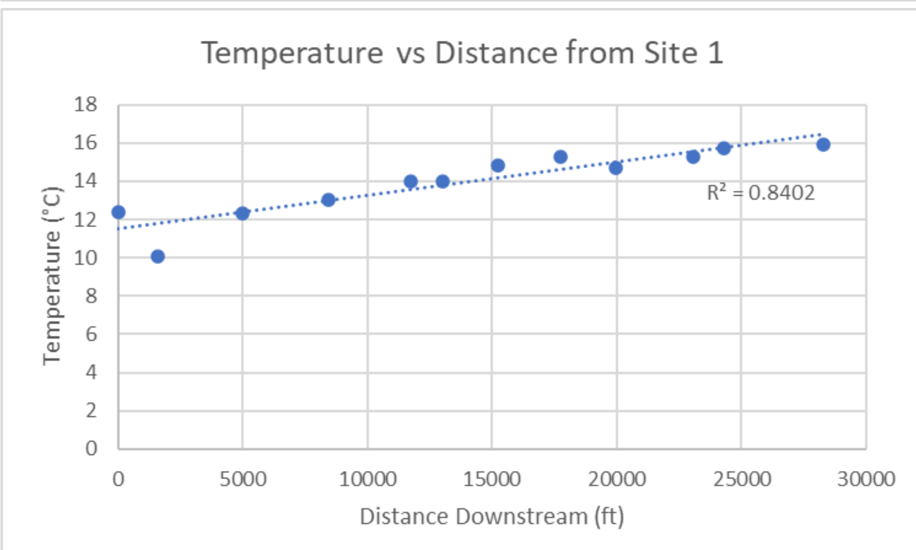
Plot 9



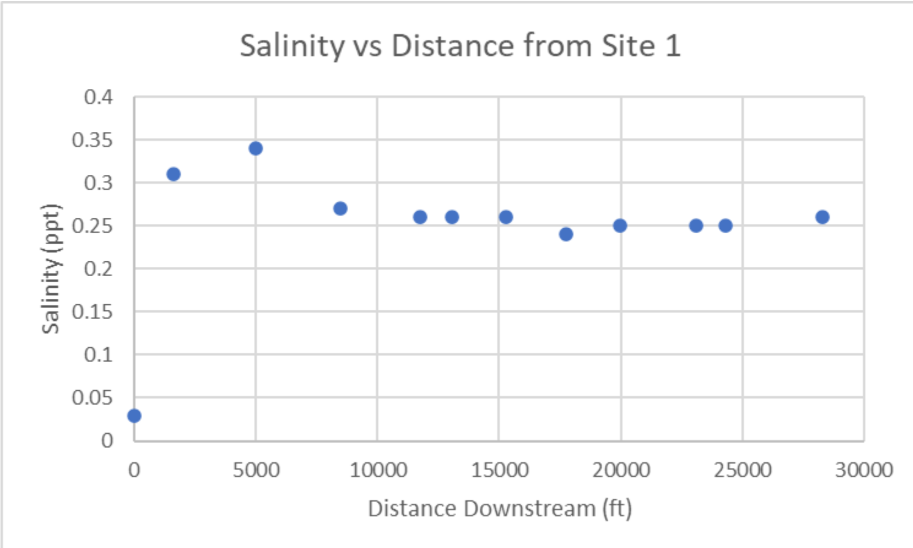
Plot 10



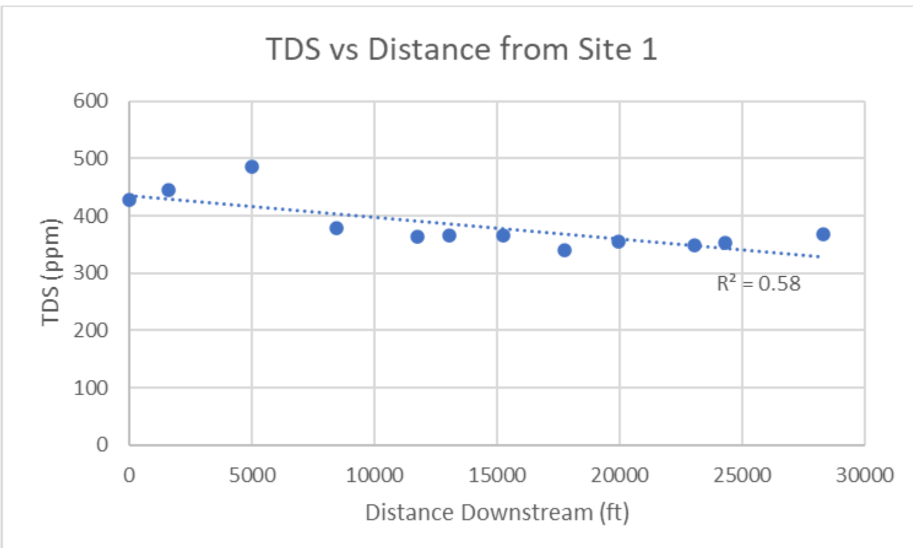
Plot 11



Plot 12

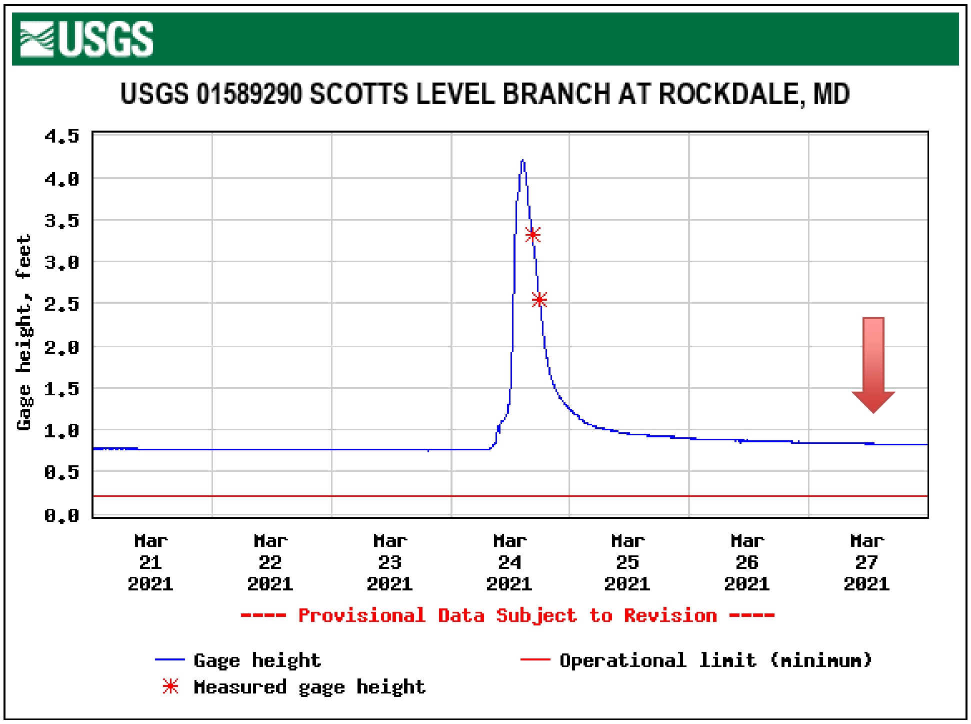


Plot 13

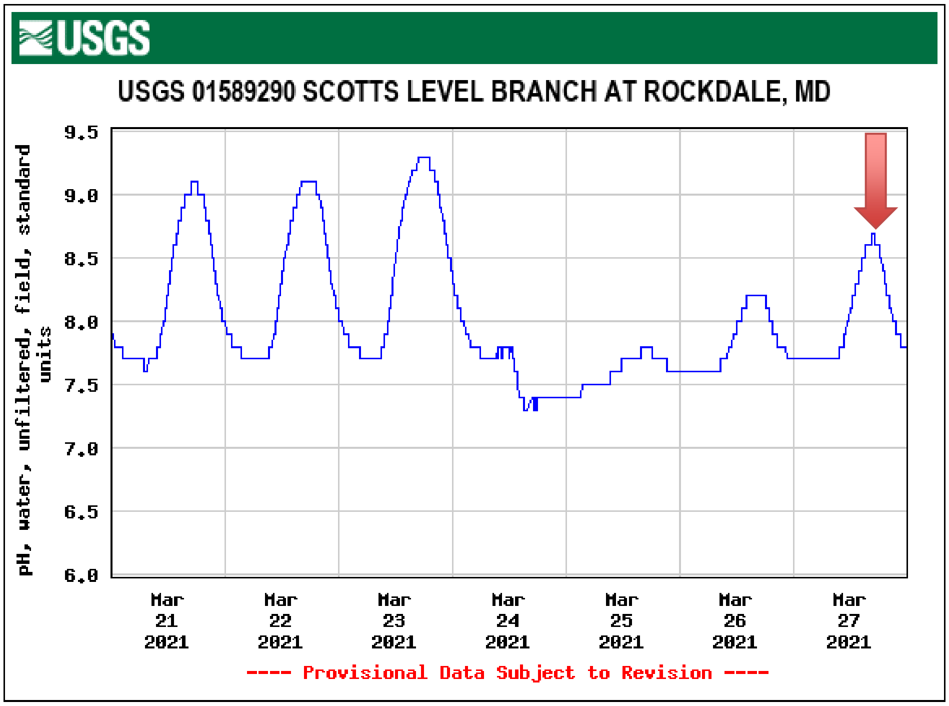


Plot 14

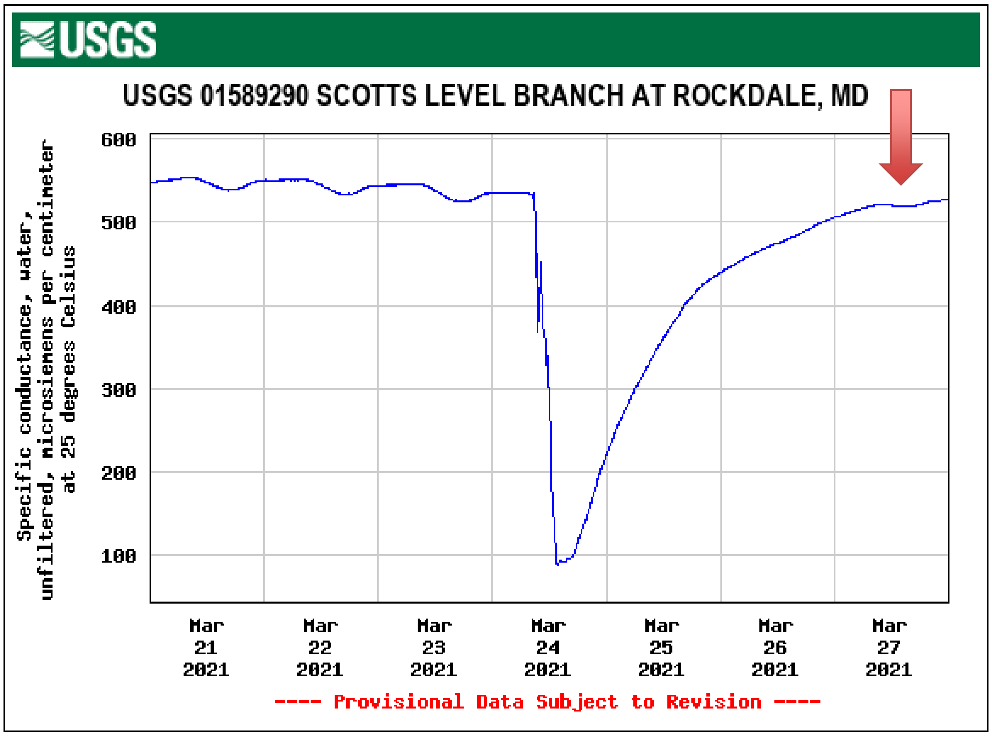
Appendix I: Scotts Level Branch USGS Stream Gauge Data



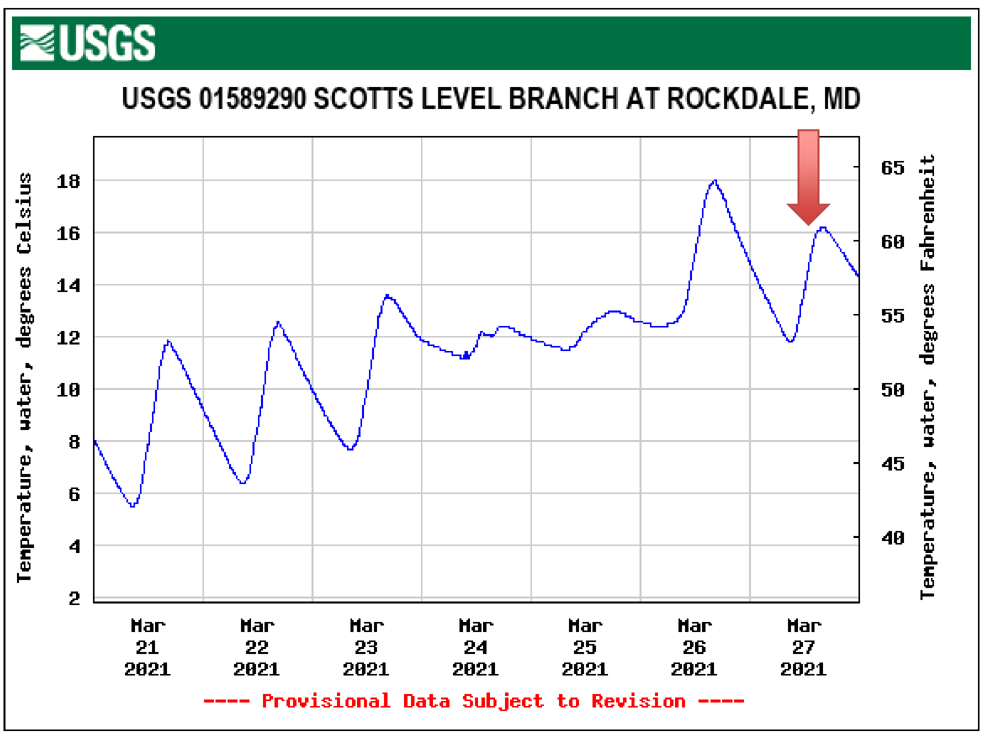
USGS Figure 6. USGS Stream Gauge (Site SLB10) measurements of local stream gauge height at Scotts Level Branch. Red arrow shows date of field experiment data collection.



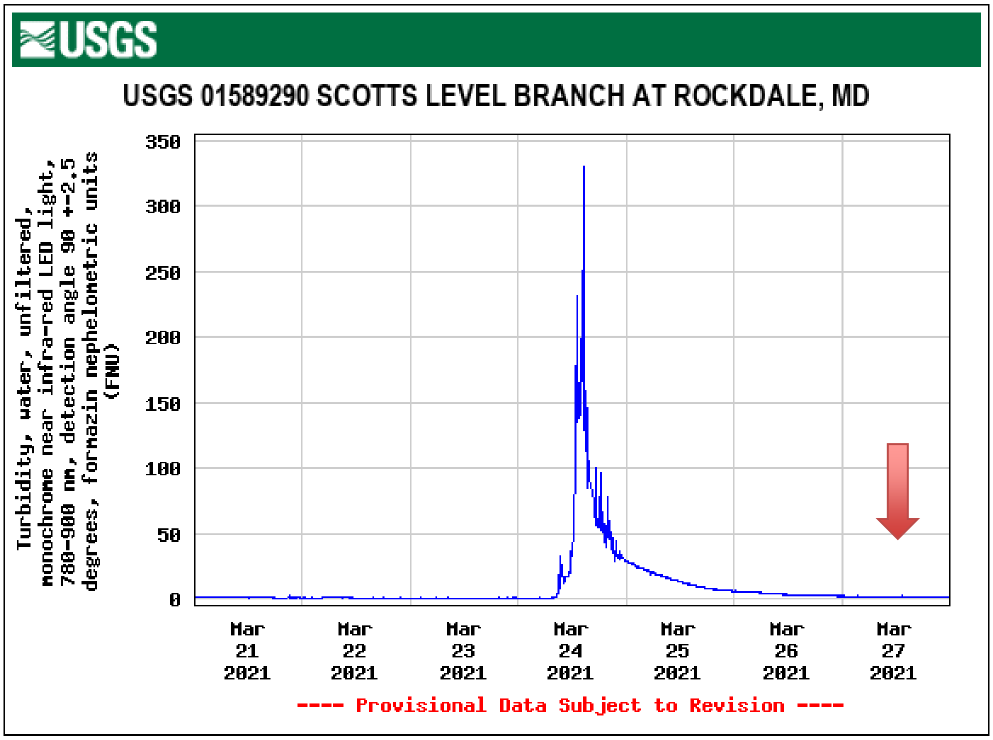
USGS Figure 7. USGS Stream Gauge (Site SLB10) measurements of local stream pH at Scotts Level Branch. Red arrow shows date of field experiment data collection.



USGS Figure 8. USGS Stream Gauge (Site SLB10) measurements of local stream specific conductance at Scotts Level Branch. Red arrow shows date of field experiment data collection.

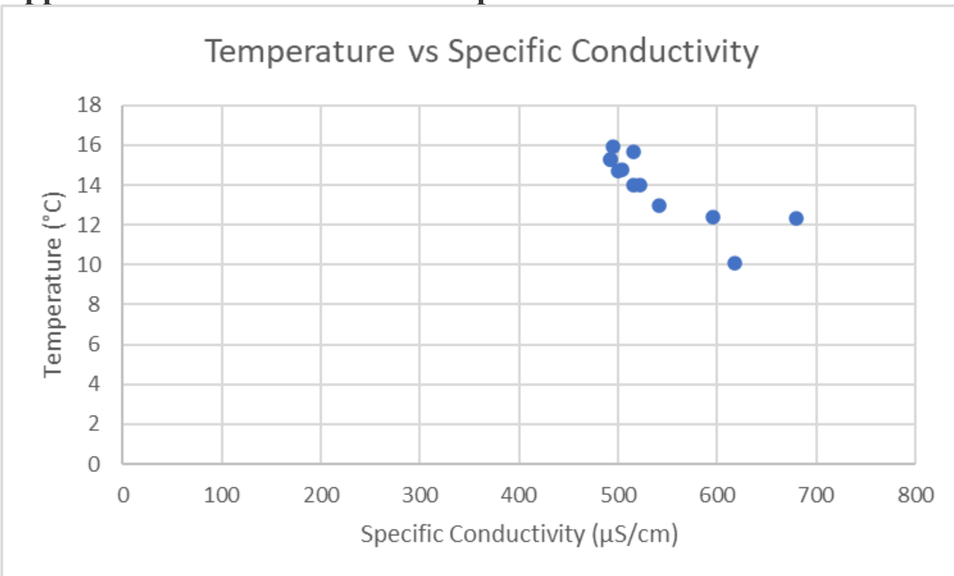


USGS Figure 9. USGS Stream Gauge (Site SLB10) measurements of local stream temperature at Scotts Level Branch. Red arrow shows date of field experiment data collection.

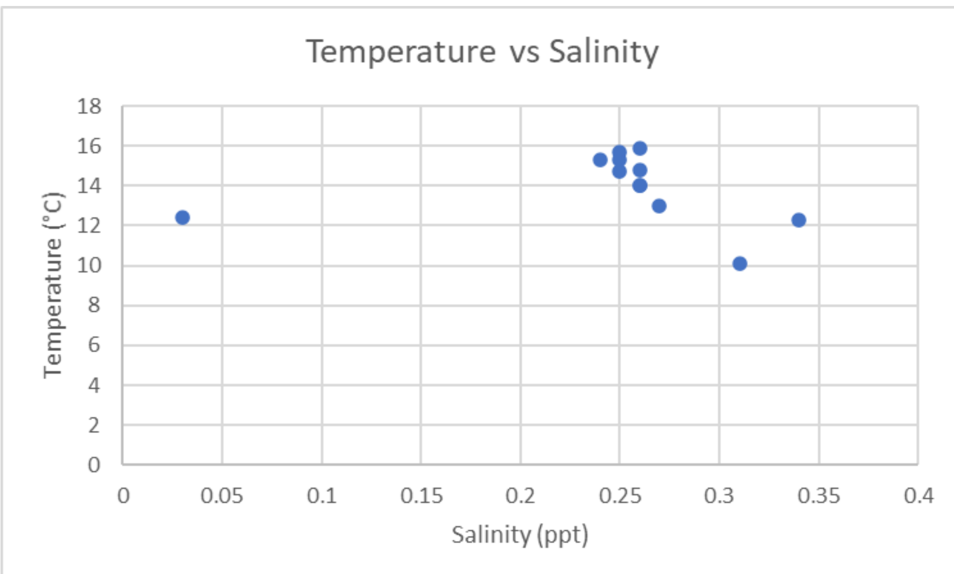


USGS Figure 10. USGS Stream Gauge (Site SLB10) measurements of local stream turbidity at Scotts Level Branch. Red arrow shows date of field experiment data collection.

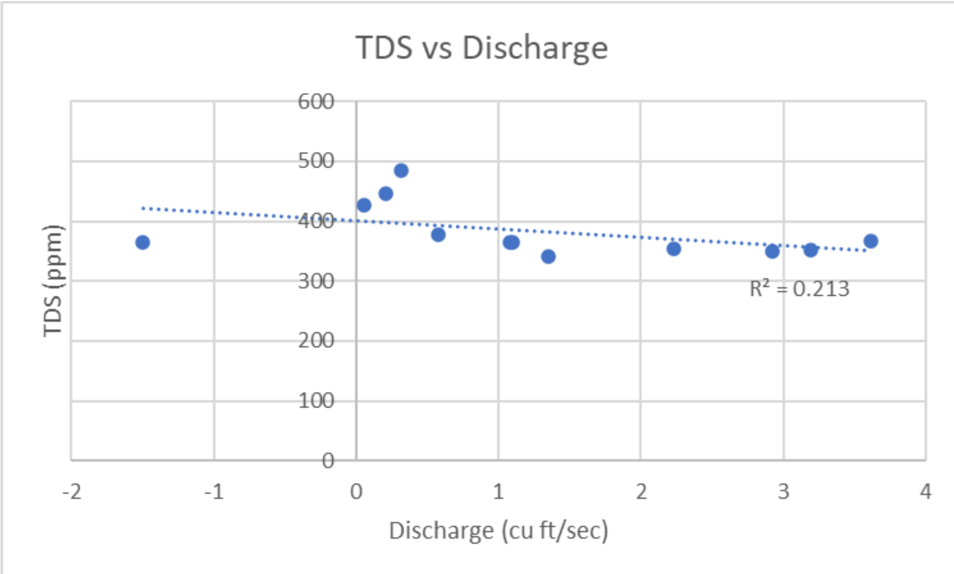
Appendix J: Other Interrelationships Between Field Parameters at Scotts Level Branch



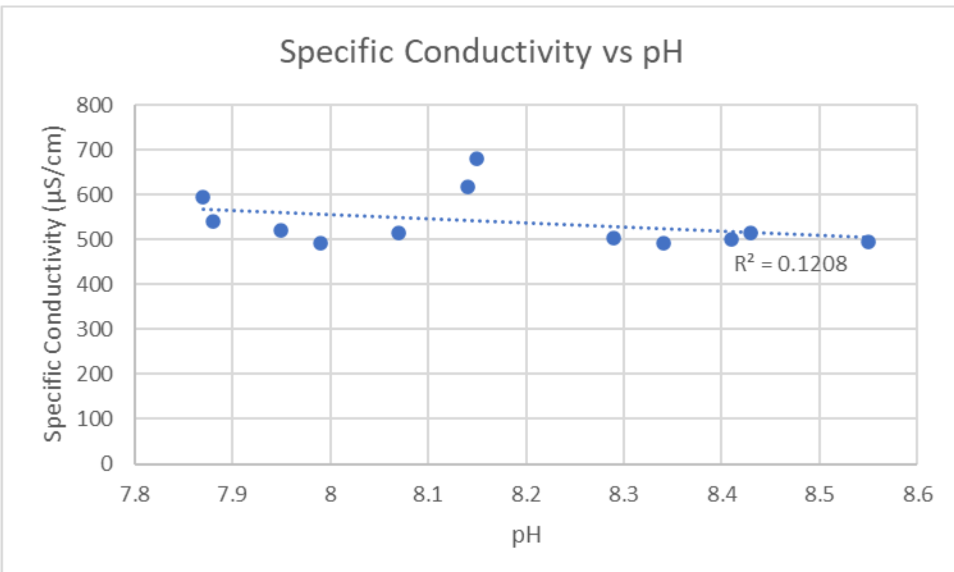
Plot 15



Plot 16



Plot 17



Plot 18