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Clearcutting in Appalachia: Impacts on Stream Water Quality in an Appalachian Watershed

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Keywords

clearcutting, GIS, water quality, Appalachia, environmental studies

Disciplines

Environmental Health and Protection | Environmental Sciences | Water Resource Management

Comments

Written for ES 400: Senior Capstone.

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ES 400 - Senior Capstone

Environmental Studies Department

Gettysburg College

12/11/19

Honor Pledge:
I affirm that I have upheld the highest principles of honesty and integrity in my academic work and have not witnessed a violation of the honor code.

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Abstract

Clearcutting forests has the potential to impact the water quality of high water headwater streams. In this study, we measured the effect of forest clearcut events on parameters of stream water quality within Michaux State Forest. The watershed of two streams included 2.1% and 11.6% of the total catchment in clearcuts, while the other 4 watersheds had no clearcuts. We measured pH, electrical conductivity, total suspended solids, and nitrate (ppm) and phosphate (ppm) concentrations from six different tributary streams. Mann-Whitney U tests maintain no statistical difference observed between pH (U= 4.00, p= 1.00), temperature (U=1.00, p=0.165), electrical conductivity (U=2.00, p=0.355), suspended solids (U=2.00, p=0.325), nitrate concentration (U=2.00, p=0.264), or phosphate concentration (U=2.00, p=0.340). However, post-hoc analysis confirms stream 6 as an upper outlier for electrical conductivity (EC= 86.8 uS). This may be due to this site's proximity to a busy road. These results suggest that there is no significant impact of clearcutting on stream water quality in Michaux State Forest. However, further repetition of this experiment would be necessary to make this conclusion statistically robust.

Introduction

The word Appalachia evokes images of burning coal mines, coursing railroads through the mountains, and exploding dynamite. According to politicians, the media, and many Americans, coal is the region's greatest asset. However, this was not always the case. The public land use in America is closely tied to the history. Appalachia was a major source of natural resources for the Reconstruction era (Bolgiano 1998). As mountains were blown through and railroads constructed, these extensive supplies were suddenly accessible. In the national parks, new strategies for land use management developed.

Nearly all of the old growth forests of Appalachia were clearcut in the 18th and 19th centuries in the wake of industrialization and urbanization. Appalachia, while remaining "wild," was responsible for furnishing the cities of the east coast with the necessary natural resources, including timber and coal. After this initial widespread clear cut, resources from secondary succession were handled differently. In the early 20th century, selective harvesting of trees in which rangers manually marked trees to be cut down was the industry standard (Bolgiano 1998). However, later research indicated this was not very conducive to a healthy and productive tree population. Many times, diseased and low-value trees were left to compete with and effectively stunt new growth of other tree seedlings. Valuable species such as oak trees, which need plenty of sun when sprouting, could not grow because old growth trees impeded their path (Bolgiano 1998). In 1964, the U.S forest service officially switched to clear cutting as a forest management strategy. Clearcutting is also known as even-aged management and results in groupings of entire blocks of trees of the same age (Bolgiano 1998). It is worth noting that the US forest service began to focus on timber production more heavily following this switch. By allowing more valuable species to grow in somewhat controlled circumstances, the national parks were able to monetize their natural resources while also effectively managing ecosystem health.

There are several pertinent implications of clear cutting on stream water quality and water quality. Trees and riparian buffer zones that border streams directly influence the supply of nutrients in stream water due to physiological demand for nutrients such as nitrogen and phosphorus (Dosskey et al. 2010). Clearcutting can also cause consequential temperature increase in stream water, which has critical implications on the ecology of Appalachian streams (Brown & Krygier 1970).

Forests are a nutrient sink, sequestering nitrogen in the form of nitrate and ammonium, phosphorus in the form of phosphate, and other essential ions from soil and rainwater. Forest and herbaceous vegetation can exhibit nitrogen uptake rates of up to 170 kgN/ha/year; thus there are significant consequences to eliminating vegetation and clearcutting forests. This includes a significant decrease in net nutrient assimilation by the vegetation, and consequential leaching of influx nutrients from the soil into stream water (Dosskey et al. 2010). Spatial patterns of riparian vegetation growth are sensitive to the amount of water exposure it experiences as well as the direction of water flow and whether the stream is a braided or a meandering stream. These events can lead to water quality changes over time (Mercier et al. 2017; Pennsylvania Department of Conservation and Natural Resources 2014).

In tandem with the loss of an essential nutrient sink, a lack of trees or vegetation can also degrade water quality due to an increase in water flow from unchecked inputs of rainfall and erosion (Dosskey et al. 2010). Disturbances of soil composition, loss of deep-root trees, and a decrease of woody material may lead to polluted water quality due to more sediment and organic material falls into the streams (Pennsylvania Department of Conservation and Natural Resources 2016). Deposits of oil and natural gas formed from decayed organisms common in the Pennsylvanian Silurian and Devonian rocks can also leach into waterways and cause changes of water quality (Pennsylvania Department of Conservation and Natural Resources 2014). These changes in water chemistry and stream flow dynamics can have serious implications upon the biotic and abiotic features of a stream ecosystem as well as human health (Dosskey et al. 2010).

One study examined the long-term effects of clearcutting on the nutrient and ion concentration of streams in Hubbard Brook Experimental Forest and provided many interesting insights relevant to our research interests in Michaux State Park, including a cohesive data set describing a large increase in the concentration of all major ions except for ammonium, sulfate and bicarbonate (Likens et al. 1969). A similar study conducted in 1974 examined streams surrounding a clear cutting event in West Virginia within one watershed (Aubertin and Patric 1974). Researchers measured various nutrient concentrations, stream pH, temperature, and turbidity, as well as stream flow, over the course of several years following the clear cut and revegetation process. This paper found seemingly conclusive evidence that even-aged forest management can be beneficial to a forest ecosystem, and does not significantly impact water quality (Aubertin and Patric 1974).

Study Site:

Big Pine Flat Ridge is a physical feature of Franklin County, Pennsylvania along the northern terminus of the Blue Ridge Mountains with GPS coordinates of 39.96 (latitude), -77.476 (longitude) with an approximate elevation of 621 meters above sea level (Pennsylvania Department of Conservation and Natural Resources 2017; Pennsylvania Department of Conservation and Natural Resources 2018; Figure 1; Figure 2). Big Pine Flat Ridge is a popular tourist and outdoor recreational destination due to its rich biodiversity and unique, rocky landscape (Gates and Valentino 1991; Pennsylvania Department of Conservation and Natural Resources 2018).

Big Pine Flat Ridge is mainly composed of dry oak forests with an abundance of pine, dwarf eucalyptus, and sassafras trees along the ridge tops - mixed pine and oak forest types can be found along lower elevations of the region. Wetlands and vernal pools can also be found throughout many regions of Big Pine Flat Ridge such as near bodies of water, acting as part of the riparian buffer of the hydraulic and ecological system (Pennsylvania Department of Conservation and Natural Resources 2018).

Given the results of prior studies regarding the effects of clearcutting on stream water quality and morphology, we are interested in seeing how clear cutting will impact watersheds in Michaux State Forest. Motivating questions include a) How is stream nutrient concentration affected by proximity to a clearcut site? b) How do parameters of water quality such as pH, temperature, electrical conductivity and total suspended solids differ within each watershed? Seeking to better understand and analyze how this dramatic land-use change impacts water quality and physical stream features can help to inform future land use management decisions.

Methods:

GIS and Data Analysis:

Research sites were selected and marked based on their proximity to various different streams in the study area in Michaux State Forest. Using the Google My Maps Application, the survey route and the location of all six research sites were geolocated and marked according to the exact coordinates.The map was then download as a KMZ file and uploaded to ArcMap as a geodatabase layer that was converted to a shapefile (Table 1; Figure 3).

We used ArcGIS to determine the characteristics of the watersheds of the observed streams, namely the percentage of forest cover and percentage of clear cut areas within each watershed. The following shapefile data layers were downloaded in preparation for the GIS analysis: Pennsylvania state boundary, national land cover, Pennsylvanian streams, and watersheds (Table 1). The land cover, streams, and watersheds were clipped to the Pennsylvania state boundary shapefile in order to make data analysis more simplified and constrained to a smaller area. The Michaux State Forest boundary was selected from a shapefile of Pennsylvanian forests and used to display our targeted research site. The different land cover types were then reclassified with the following system: Forest (1), scrubs (2), Long Pine Run Reservoir (3) (Figure 3).

New shapefiles of clearcut areas within the study area were then created in order to obtain information of the area of clearcut space relative to the area of streams and the total area of land within the study site. We then modified the watersheds shapefile to include only areas upstream of our sampling location. We did this in order to accurately portray the flow of smaller watersheds that the original shapefile overlooked (Figure 3). Following this, we calculated the areas and percentage of clearcut and stream areas to the total study area in addition to the length of streams within watershed study sites.

Water Quality Measurements:

Water quality testing of six streams in Big Pine Flat of Michaux State Forest was conducted and repeated throughout three field days: September 27, October 4th, and October 22nd, 2019. We sampled on three occasions to ensure that we sampled the streams under varying hydrological conditions. Our first field day was conducted following rainfall after a month-long dry period, while the next day had more steady, representative streamflow, and the third day had low water levels. Temperature, electrical conductivity and pH measurements were taken on site. 1L samples were collected from each site in areas of rapid flow to prevent any data biases attributed to nutrient and debris accumulation in slow moving, standing waters. Nitrate and phosphate measurements were made using a LaMotte water testing kit, and conducted according to the instruction manual provided by the kit (LaMotte Nitrogen 2018; Lamotte Phosphate 2018). Stream water was analyzed for total suspended solids by filtering 500mL of stream water by vacuum filtration, and weighing filters on a Mettler Toledo analytical balance after an air drying period of approximately 24 hours (Standard Operating Procedure for: Total Suspended Solids 2018). In order to elucidate significant differences between stream water quality parameters in clearcut versus non-clearcut watersheds, we used a Mann-Whitney U nonparametric statistical test to analyze the effects of clearcutting on water quality. Potential outliers within our dataset were analyzed using stem and leaf plots.

Results

Watersheds ranged in size from 1.86 km^2 to 8.74 km^2 (Table 3). Watersheds 2 and 3 were the only watersheds to contain clear cut areas (Table 3; Figure 3). Statistical analysis through a Mann-Whitney U test (Table 2; Figures 4-8) determined that there was not a statistical difference between clear cut and non-clear cut streams in pH (U= 4.00, p= 1.00), temperature (U=1.00, p=0.165), electrical conductivity (U=2.00, p=0.355), suspended solids (U=2.00, p=0.325), and nitrate (U=2.00, p=0.264) and phosphate (U=2.00, p=0.340) (Table 2). These streams each reported average temperatures between 12-14.5°C with variation attributed to seasonal weather changes (Figure 4). Each stream reported similar pH conditions between 7.2-7.7 with very little variation across streams (Figure 5). Nutrient concentrations also presented very little variation, with nitrate concentrations ranging between 0.25-0.33ppm and phosphate concentration ranging between 1-2ppm (Figure 6). Nitrate levels were consistently lower than phosphate concentrations throughout all streams (Figure 6). Site 6 had conductivity that was more than five times higher than other sites, a statistically significant outlier (Figure 7). Electrical conductivity data reported a significant upper outlier at site six after analysis through a stem and leaf plot (Figure 7). With an average 86.8uS, site six conductivity was significantly greater than the other five sites which reported conductivity measurements below 18.2uS (Figure 7). The accumulation of total suspended solids within stream water was almost negligible, with an average less than $1.4x10^{-5}$ g/mL found within each stream across three field days (Figure 8). There was a significant amount of variation found within total suspended solids data likely due to the small sample size and environmental effects that could have influenced the quantity of suspended solids on our given field days, such as drought and rainfall.

Discussion

Land use management is one of the foremost practical applications of forest ecology. As knowledge in this scientific field has progressed, so too have management strategies in order to sustainably conserve natural resources in the United States (Figure 1; Figure 2). Both biotic resources such as trees and abiotic resources like water and minerals have been utilized by the park service for human use (Figure 3). The removal of simply one of these components can alter the functionality of a system due to the complex network of relationships and interactions that compose forest systems. Specifically, changes in under- and overstory can lead to major shifts in Appalachian forest ecosystems, which includes but is not limited to water use and nutrient content (Figure 6; Figure 7; Swank and Webster 2003). This study focused on the connection between tree populations and stream water quality using the drastic change of a clear cutting event as a case study of the effects of drastic changes in forest ecology.

There was a lack of significant difference in stream water quality in streams that were located within the same watershed as a clear cut area and streams that were not (Table 2; Table 3). These findings support the null hypothesis that clear cutting does not have an effect on water quality despite the close proximity of two clearcut sites to two watershed study areas (Table 2; Figure 3). Despite watershed 3 having the smallest area, it still had the greatest amount of percentage of watershed within a clearcut area due to the positioning and region of the watershed. Only watershed 2 and 3 had a percentage of intersection of watershed and clearcut area due to the way the research study areas were established (Table 3; Figure 3). Previous studies have found that clear cutting is beneficial for primary tree growth and is prescribed in some areas forests for which canopy cover prevents new growth (Swank et al. 2014). In particular, clear cutting appears to favor shade intolerant, woody pioneering species (Swank and Webster 2003).

However, these positive consequences were not necessarily transferable to other systems within a forest ecosystem. As nutrient sinks, the sudden removal of trees could have caused these nutrients to be deposited in nearby water sources, but this does not appear to be the case (Figure 8). Previous studies saw a temporary uptick in nutrient content in adjacent streams following a clear cutting event, but this lasted for less than three years (Swank and Webster 2003). The results of this study align with existing literature. Another factor that can be altered due to a lack of tree roots to filtrate waterways is pH, however, this was not the case for our study as pH remained between 7-8 for all stream sites on average (Figure 5; Swank and Webster 2003).

Interestingly, this paper cites the role of nitrogen-fixing microbes as being vital to this transition, sequestering extra nitrogen that had originally been held by trees (Swank and Webster 2003).

In interpreting these results, it is important to understand that our methods were imperfect with caveats that can inhibit confidence. Our results are based off of data collected within simply 3 field days throughout the course of 2 months, thus it is possible that the data is skewed due to seasonal changes and variation in weather patterns, such as a drought during our first day of data collection (Figure 4). Also, in preparing sampling sites, we had to eliminate one stream site since it was found to be at the confluence of streams 3 and 4. This very small sample size is not necessarily representative of a cumulative effect of clearcutting on stream water quality, and thus these results should be synthesized with numerous studies in order to get a more holistic understanding of how clear cutting events impact stream water quality.

Our results indicate that current conservation efforts are not counterproductive with respect to water quality on public lands. Michaux State Forest has relatively high water quality for Southern Pennsylvania (Environmental Protection Agency 2014), which appears to remain uncompromised despite clear cuts that are executed nearby. This is a positive result that would support continuation of clear cutting as a land management strategy. The results of this study can be added to the multitude of research on the positive consequences of clear cutting on primary growth.

Despite the fact that we didn't find evidence of an impact of clearcuts on water quality, there are still nuances in the data which suggests possible trends that can be explored in further studies. In the electrical conductivity parameter, there was one data point which deviated far from the mean value (Figure 7). Stream site 6 was a significant outlier among all of the stream

E.C. measurements (Figure 7). This outlier should be noted especially because of its unique location. This stream site was the only one located adjacent to a major road (Figure 3). Further studies could explore the effects of road proximity on stream water quality. Trees are extremely vital to the forest ecosystem, especially as a nutrient sink. The fact that the nutrients that are usually held in trees do not seem to be deposited in the water can beg the question of where exactly the nutrients go. Swank and Webster (2003) cited nitrogen-fixing bacteria as showing evidence of taking on this burden, which they provided as a possible explanation. Further research could expand the scope of this study to include microbial interactions to give a more holistic view of the complex network that exists in forest ecosystems.

Because of the issues in the execution of this study, repetitions would be ideal in order to draw more statistically sound conclusions. In the conceptualization of this study, more sites should be identified that would be within watershed boundaries of selected clear cut sites. More sites in general would benefit this study so that further statistical analyses could be conducted to either support or reject the null hypothesis. In this study, the small sample size restricted our ability to conduct statistical analyses because we could not assume even distribution with only six data points.

Conclusion

Our results suggest that clearcutting has no significant consequences on stream water quality in streams within Michaux State Forest. In synthesis with findings from other studies, our data supports that clearcutting as a form of forest management can be viewed as beneficial since it both encourages primary growth in deciduous tree species and has no observable consequences on water quality in this region of Appalachia. However, further repetition of these methods should be carried out in order to conduct statistical analysis of a stratified random sample in which specified points were chosen for an all-inclusive area of study. Further studies should focus chiefly on this when exploring other potential relationships connecting clear cutting and nearby water quality.

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Appendix

Table 1.GIS Data Sources

Name	Who Created	Time Valid For	Description
National Land Cover	Pennsylvania Spatial Data Access - PAMAP	2016	High-resolution land cover dataset for Commonwealth of Pennsylvania. 12 land cover classes were mapped: background, water, emergent wetlands, tree canopy, scrub/shrub, low vegetation, barre, structures, impervious surfaces, roads, tree canopy, roads
Pennsylvania State Boundary	PennDot	2019	Feature shapefile layer of Pennsylvania state as of 2019 measured in kilometers
Michaux State Boundary	PA Department of Conservation and Natural Resources	2010	Boundary for state forests in PA in 2010, State boundary coverage updated frequently. Derived from survey descriptions and adjusted to GPS boundary corners.
Streams	Pennsylvania Spatial Data Access - PAMAP	2007	Hydrography (streams, rivers) combined by PAMAP Program from data supplied by many Pennsylvania county governments
Watersheds	Pennsylvania Spatial Data Access - PAMAP	2007	Watersheds within Pennsylvania state boundary line
Study Sites	Self-Made	2019	Total 6 water quality study sites located in Michaux State Forest within Cumberland, Franklin, and Adams County; data includes description of road of site and general site observations including detritus and geologic features

Table 2: Mann-Whitney U test results depicting statistical difference between clearcut and non-clearcut stream variables of pH, temperature, electrical conductivity, suspended solids, and nitrate and phosphate concentrations.

Variable	**U-value**	**p-value**
pH	4.000	1.000
Temperature	1.000	0.165
Electrical Conductivity	2.000	0.355
Suspended Solids	2.000	0.325
Nitrate	2.000	0.264
Phosphate	2.000	0.340

Table 3. Summary of GIS analysis by watershed, listed in the order of stream sites.

Watershed name (number)	**Stream length (km)**	**Watershed area (km^2)**	**% of watershed in clearcut**
1	0	8.74	0
2	0.06	4.38	2.1
3	0.02	1.86	11.6
4	0.09	2.14	0
5	0.05	5.17	0
6	0.14	2.58	0

Figure 1. Clearcut area within Michaux State Forest in Pennsylvania (Central Pennsylvania Forestry, 2013).

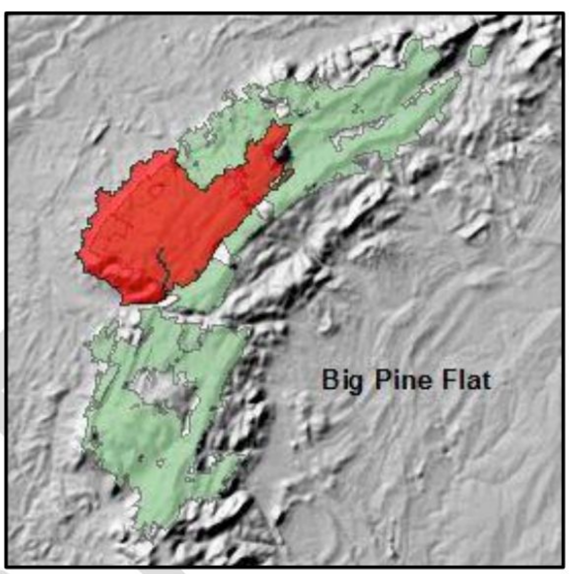

Figure 2. Research area of Big Pine Flat within the Michaux State Forest located in Cumberland,

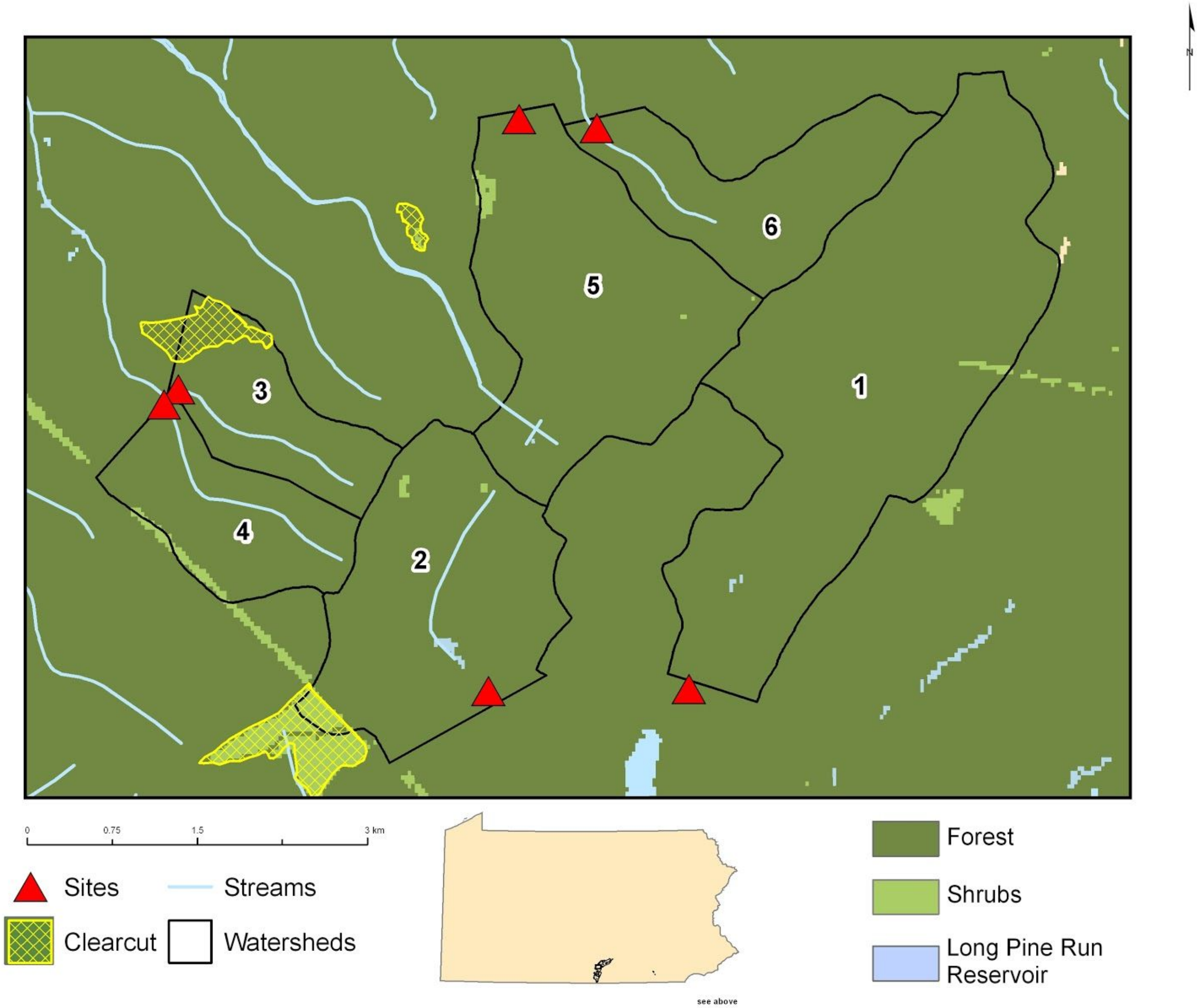

Figure 3. Six research watershed sites within Big Pine Flat along streambeds in Michaux State Forest with various hydrologic, geologic, and land cover features.

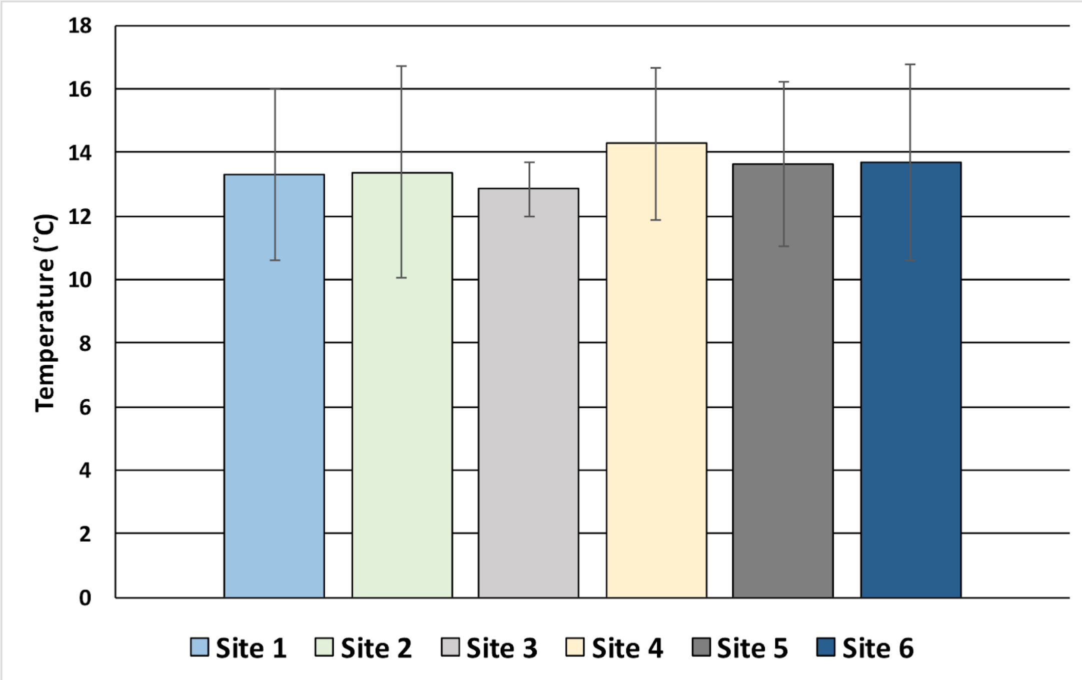

Figure 4. Temperature averages (℃) for each of the six sites within Michaux State Forest.

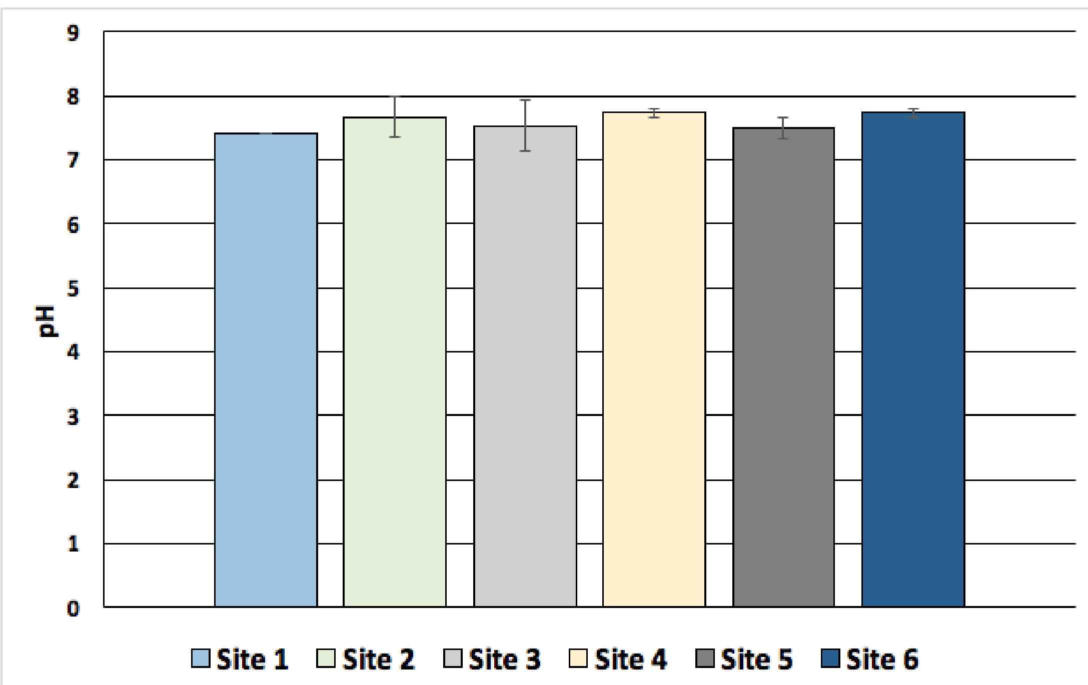

Figure 5. pH averages for each of the six sites within Michaux State Forest.

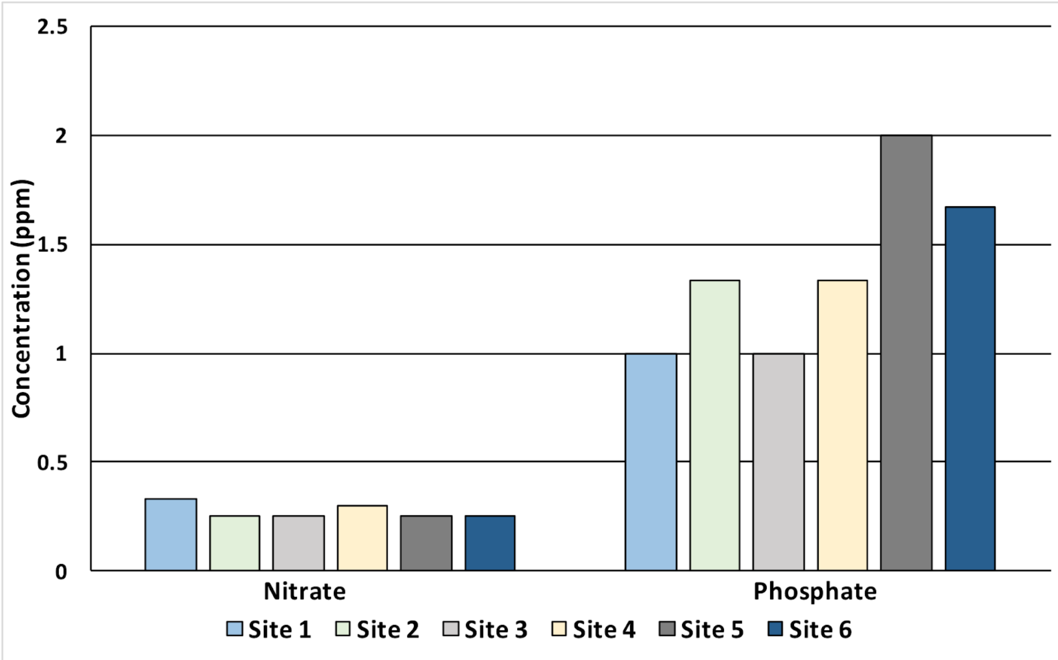

Figure 6. Nitrate and phosphate concentrations (ppm) for each site within Michaux State Forest.

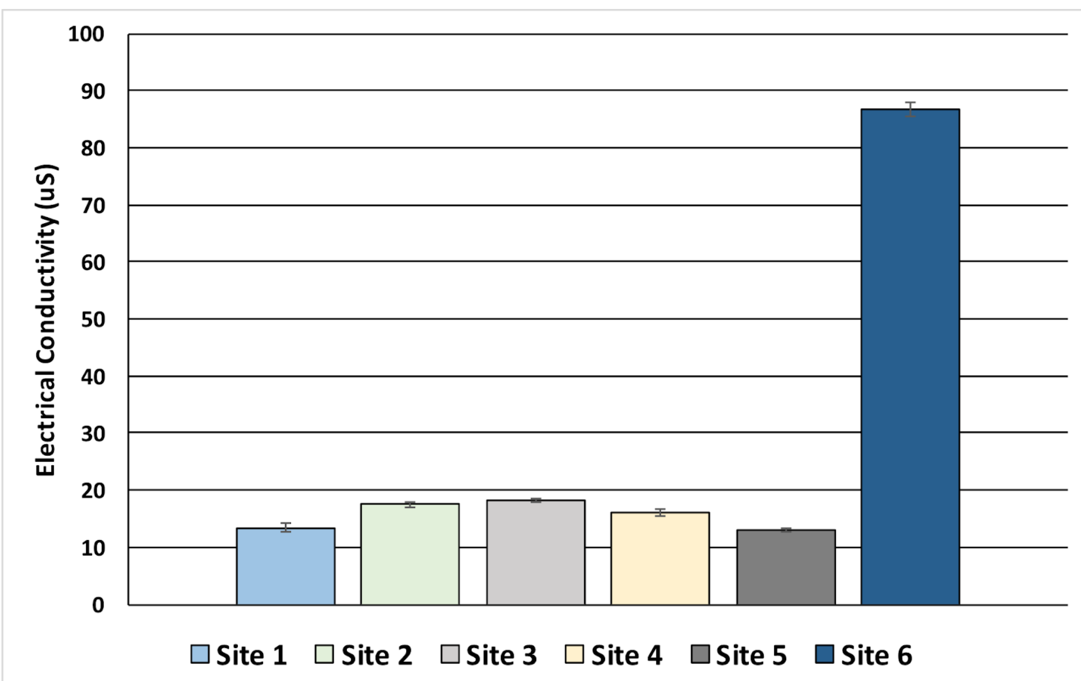

Figure 7 Electrical conductivity averages (µS) for each site

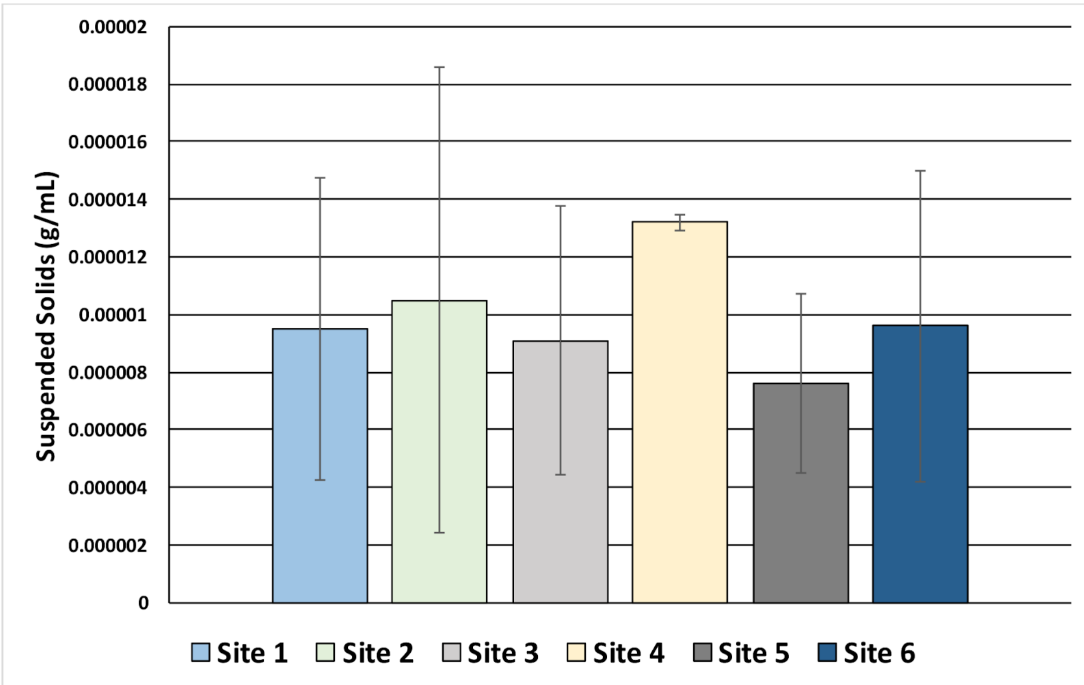

Figure 8. Suspended solids averages (g/mL) for each site within Michaux State Forest.