Evaluation of Pollution Sources to Lake Glenville
March 2007 – August 2016

Kimberlee K Hall, PhD

Environmental Health Program, Western Carolina University

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Executive Summary

Routine water quality assessments on 6 streams in the Upper Little Tennessee River Basin in the Lake Glenville area have been conducted. Quarterly monitoring of 7 sites was conducted between March 2007 and August 2016; one site was monitored for each of the following streams: Hurricane Creek, Mill Creek, Pine Creek, Cedar Creek, and Glenville Creek. Two sites were monitored on Norton Creek during the same period. The data demonstrate that the streams vary spatially and temporally in their extent of water quality impairments, suggesting the influence of climate and the effects of land use activities within the area. Typically, water flow and volume were lowest during the summer and fall months compared to the winter and spring, which is likely an influencing factor in overall water quality in the monitored streams.

Results demonstrate that nutrient concentrations are influenced by land use patterns, specifically as it relates to agricultural activity and soil erosion. Based on analysis of spatial and temporal trends, overall water quality in the 6 monitored streams near Lake Glenville is acceptable and within established ambient water quality standards. However, it appears that there are multiple important sources contributing to the concentration of nutrients in the Upper Little Tennessee River basin near Lake Glenville. Continued monitoring will allow us to evaluate the stability of seasonal variation and provide additional data that may improve our ability to discriminate between source locations.

Based on the results in this study, none of the monitored streams flowing into Lake Glenville have exhibited pollutant levels that would greatly affect lake water quality. The influence of agricultural waste runoff and soil erosion on stream water quality should be further investigated but it is probable that any decline in lake water quality is related to activities in and around the lake rather than to pollution inputs from the monitored streams.

Introduction

The Little Tennessee River Basin includes most of Graham, Macon, Swain, and Jackson Counties along with small portions of Cherokee and Clay counties. The basin encompasses 1,797 square miles which includes the Cullasaja, Nantahala, Tuckasegee, and Cheoah Rivers. Approximately 90% of the land is forested land with less than 5% consisting of urban or developed land use patterns, which are concentrated in and around Franklin, Sylva, Cullowhee, Highlands, Bryson City, and Robbinsville. More than half of the land in the basin is in the Great Smoky Mountains National Park or the Nantahala National Forest.

The Little Tennessee River basin is further classified into Upper and Lower portions. Lake Glenville is located in the Upper Little Tennessee River basin (HUC 06010202). Six streams within the Upper Little Tennessee River basin that discharge into Lake Glenville were monitored by The Friends of Lake Glenville in conjunction with the UNC-Asheville Environmental Quality Institute (EQI) from 2007 to 2016 to assess overall water quality and identify sources of impairment (Table 1).

Table 1. Lake Glenville monitoring sites

H-1	Hurricane Creek at Norton Road bridge crossing
N-1	Norton Creek at North Norton Road bridge crossing
M-1	Mill Creek at bridge 0.2 miles downstream from North Norton Road bridge crossing
P-1	Pine Creek at Pine Creek Road bridge crossing
C-1	Cedar Creek at Bee Tree Road bridge crossing
G-1	Glenville Creek at Tator Knob Road culvert crossing
N-2	Norton Creek upper watershed above Grassy Camp

Materials and Methods

Water samples were collected quarterly from 2007 to 2016 by members of The Friends of Lake Glenville and transported to UNC-Asheville Environmental Quality Institute (EQI) for analysis. Collected water samples were analyzed for the following parameters: pH, ammonia (NH_3) nitrate (NO_3^-) phosphate (PO_4^3), total suspended solids (TSS), turbidity, conductivity, and alkalinity. Flow measurements from the US Geological Survey (USGS) gauging station on Little Tennessee River at Prentiss (USGS 03500000) were used to determine relative flow for the sites in the Lake Glenville area. Although gauging stations only truly represent the streams on which they are located, the flow measurements collected by this gauge station are assumed to be a reliable method for determining the influence of flow on water quality at each stream site. Specific details regarding sample collection and transport, and laboratory analysis methodology were not available to the author of this report. Any data value recorded by EQI as less than the method detection limit was substituted with a value of one-half of the stated detection limit for statistical analysis purposes.

Using the data gathered by EQI for The Friends of Lake Glenville, various statistical analyses were performed in an effort to (1) characterize the water quality of each stream site in relation to established water quality standards and (2) identify the effects of precipitation, stream water level, seasonality, land use, and temporal trends on water quality.

Results and Discussion

This discussion is based on data collected between March 2007 and August 2016. No collection occurred during 2010. Trends in water quality become more evident with every year of continuous monitoring and contribute to a shaper image of conditions present in streams and watersheds. Continued collection of water quality data over time allows for the identification of changing conditions and areas of concern, which can contribute to financially and politically sound decision making for effective water resource management.

It is important and necessary to compare sites within the mountain area to understand how water quality from each stream ranks within the region. With this information local governments, organizations, and individuals can compare areas with similar problems or successes and exchange information regarding remediation or protection plans. It will also be helpful to note improvements or deteriorations in stream water quality over time as a result of changes in population density, industrial development, topography, and land use patterns. Each of these factors must be taken into consideration when comparing stream water quality. A discussion of the stream sites relative to specific water quality parameters follows.

A statistical analysis of the effects of stream water level, temporal changes, and seasonality on water quality parameters at individual sites has been included in this discussion. This analysis is used to determine if changes in concentrations or levels of a parameter change in relation to flow, time, and season. Trends observed in these data and interpretations of what may have contributed to those trends are suggested.

Acidity and Alkalinity

pH is used to measure acidity and is an important water quality parameter because it has the potential to seriously affect aquatic ecosystems. Slight fluctuations in pH can interfere with the reproduction of aquatic organisms or result in their death. The ambient water quality standard for pH is between 6.0 and 9.0, although natural pH in area streams generally ranges from 6.5-7.2. Values below 6.5 may indicate the effects of acid precipitation or other acidic inputs, and values above 7.5 may indicate industrial discharge. Although the Norton Creek upper watershed site had an average pH reading of 6.5, no average pH reading below 6.5 or above 7.2 were observed in any creek (Figure 1).

Examination of temporal trends in pH demonstrates variability over time, specifically increases in average pH for all streams except Mill Creek (Figure 2). Despite the decrease in average pH in Mill Creek between 2015 and 2016, all streams remained within the ambient water quality standard. The increasing trend in pH may be the result of emission and discharge controls from power plants, resulting in reduced acid deposition. Annual stream flow variations are not a factor, as they are not accounted for in trend analysis. There are no seasonal trends related to pH at the stream sites.

Figure 1. Mean pH levels at each monitoring site, March 2007 – August 2016

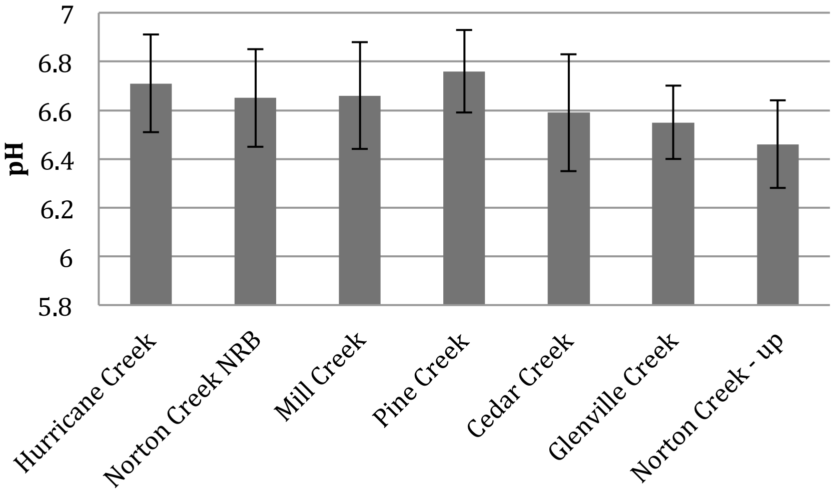
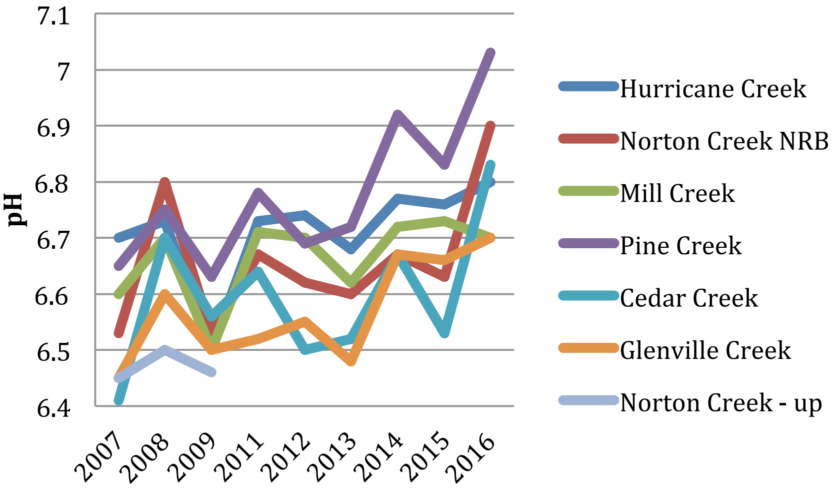


Figure 2. Mean pH at each monitoring site by year, March 2007 – August 2016



Alkalinity is the measure of the pH buffering capacity of a water or soil. High alkalinity waters are generally better protected against acid inputs from sources such as acid rain, organic matter, and industrial effluent. Waters with an alkalinity below 30mg/L are considered to have low alkalinity. The observed mean alkalinity concentrations demonstrate low alkalinity in all monitored creeks (Figure 3). These low levels are largely the result of bedrock, soils, and precipitation patterns in the Glenville area. The Glenville area streams also exhibit lower levels of pollutants compared to many other area streams, and pollutants can also affect alkalinity levels. While no extreme high or low pH levels were observed at any site, minimum alkalinity concentrations at several sites have been almost exhausted.

Low alkalinity concentrations have been consistently observed during the study period. Examination of temporal trends in alkalinity demonstrates variability over time, specifically decreases in mean alkalinity concentrations in all streams since the initiation of the study period in 2007. With the exception of Cedar Creek, alkalinity concentrations have been increasing in all creeks since 2009 (Figure 4), which corresponds to a decrease in average flow. Reduced water flow and volume can concentration the ions that compose the alkalinity buffering system. There are no seasonal trends related to alkalinity.

Figure 3. Mean alkalinity concentrations at each monitoring site, March 2007 – August 2016

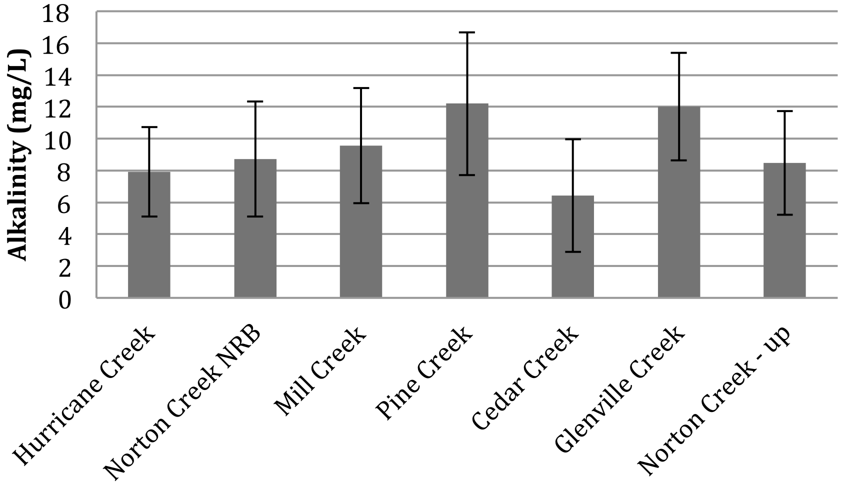
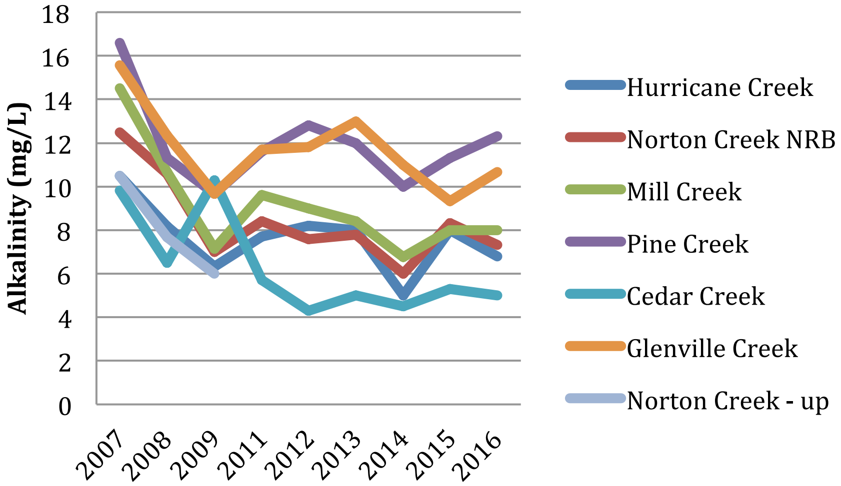


Figure 4. Mean alkalinity concentrations at each monitoring site by year, March 2007 – August 2016



Turbidity and Total Suspended Solids (TSS)

Turbidity is a measure of visual water clarity and is a measure of the presence of suspended particulate matter. Turbidity is an important parameter for assessing the viability of a stream for trout propagation. Trout eggs can withstand only slight amounts of silt before hatching is impaired. Fish that are dependent on sight for locating food are also at a great disadvantage when water clarity declines. To minimize the likelihood of such negative impacts, the standard for trout-designated waters is 10 NTU and the standard to protect other aquatic life is 50 NTU. Mean turbidity measurements in all creeks are below the 10 NTU trout-designated water standard (Figure 5).

Temporal trends in turbidity demonstrate a significant increase in 2013 in all streams except Hurricane and Cedar Creeks (Figure 6). Turbidity in these streams exceeded the 10 NTU standard for trout designated waters but did not exceed the other aquatic life standard. These increases were likely influenced by precipitation events and increased flow, as the greatest flow at the Little Tennessee River at Prentiss gauging station measured an average flow of 897 cubic feet per second (cfs) during that year. All streams demonstrate a decline in turbidity between 2015 and 2016, which corresponds to a decrease in flow. The lowest flow rate observed during the study occurred in 2016 and measured 148 cfs. With the exception of Hurricane and

Glenville Creeks, the greatest turbidity concentrations were observed during the winter months. This may be due in part to the lack of vegetative cover during these months, which can leave soil exposed and prone to erosion. Turbidity was greatest during the summer and fall months for Hurricane Creek and Glenville Creek, respectively.

Figure 5. Mean turbidity levels at each monitoring site, March 2007 – August 2016

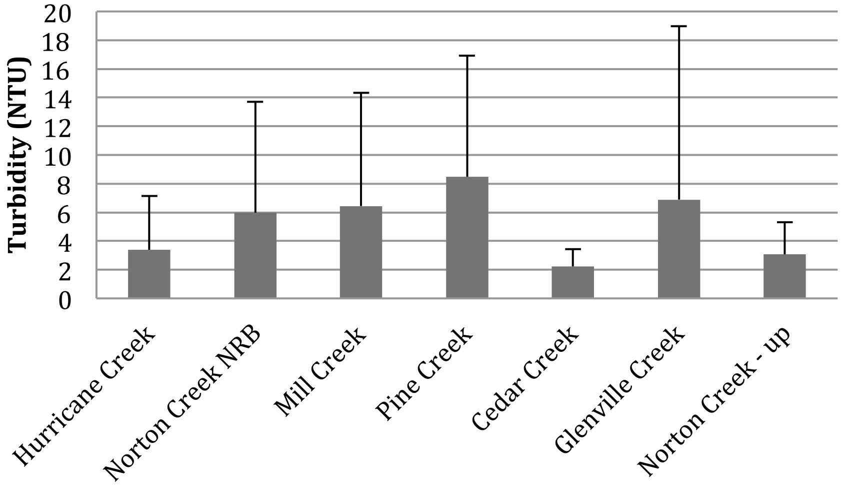
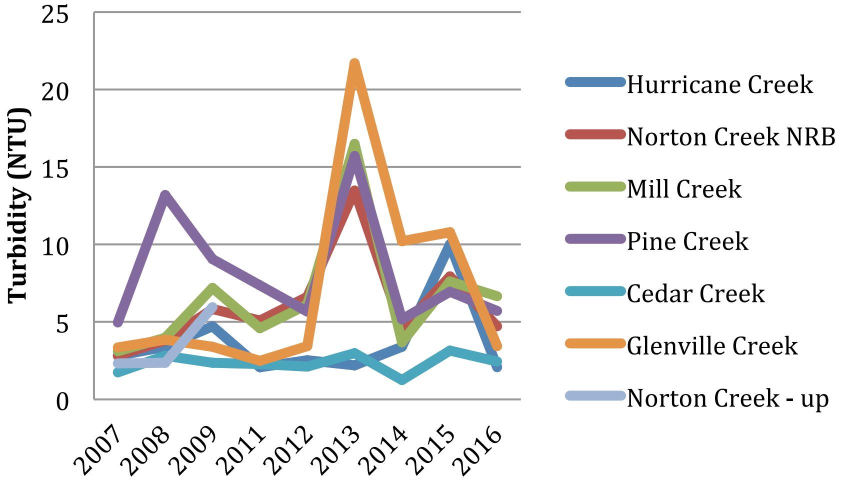


Figure 6. Mean turbidity levels at each monitoring site by year, March 2007 – August 2016



TSS quantifies solids by weight and is heavily influenced by a combination of stream flow and land disturbances. Mountain streams in undisturbed forested areas such as those in the Little Tennessee River Basin tend to remain clear even after moderately heavy rainfall events. Areas with disturbed soil may have elevated TSS concentrations even after relatively light rainfall. As suspended solids settle to the streambed, they can bury and destroy benthic macroinvertebrates, the absence of which reduces the ecosystem diversity. Although there is no legal standard for TSS, concentrations below 30mg/L are generally considered low. All monitoring sites exhibited low TSS concentrations (Figure 7). Moderately heavy precipitation events and land disturbance can increase turbidity and TSS concentrations. The undisturbed forested areas and presence of riparian zones likely influenced the low turbidity and TSS concentrations.

Temporal trends in turbidity mirror those of turbidity by demonstrating a significant increase in all streams except Hurricane and Cedar Creeks during 2013 (Figure 8). TSS concentrations in these streams are still considered to be low but increases in TSS during 2013 were likely influenced by precipitation events and increased flow. This trend mirrors that of turbidity during 2013. All streams demonstrated a decline in TSS concentrations between 2015 and 2016, which corresponds to a decrease in flow. No seasonal trends in TSS concentrations were observed.

Figure 7. Mean TSS concentrations at each monitoring site, March 2007 – August 2016

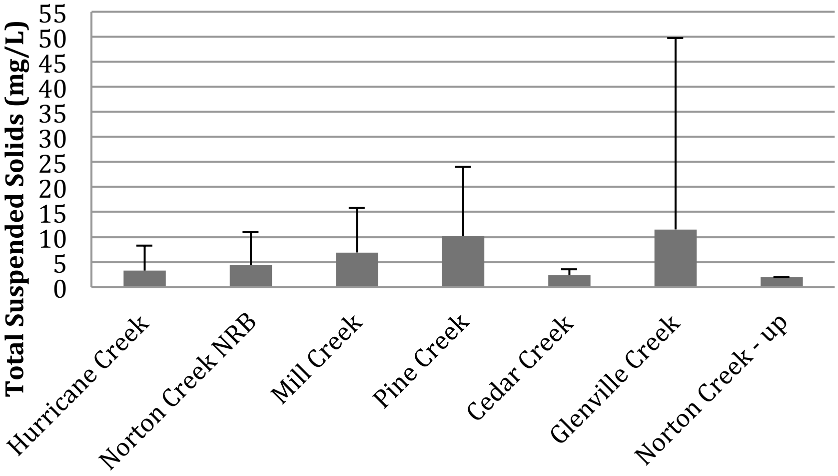
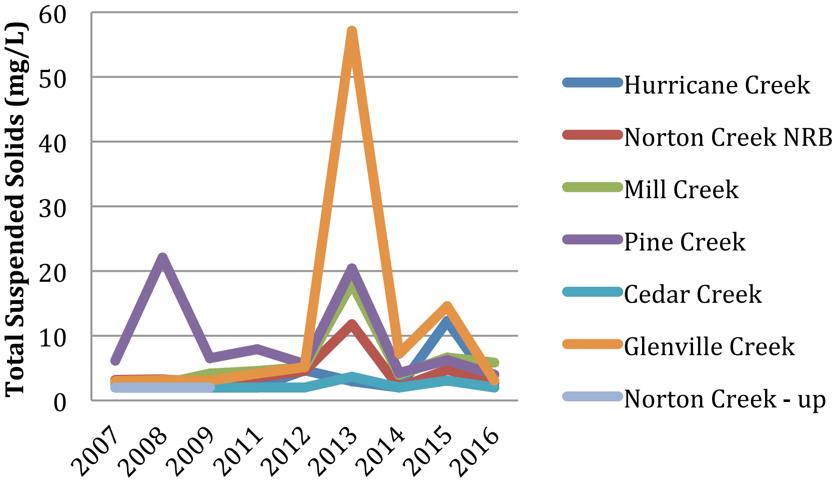


Figure 8. Mean TSS concentrations at each monitoring site by year, March 2007 – August 2016



Conductivity

Conductivity is used to measure the ability of water to conduct an electrical current. Samples containing dissolved solids and salts will form ions that will conduct an electrical current and the concentration of dissolved ions in a sample determines conductivity. Inorganic dissolved solids such as chloride, nitrate, phosphate, calcium, sulfate, iron, sodium, and aluminum will affect conductivity levels and local geologic conditions will influence the types and extent of dissolved ions. Elevated levels of conductivity are most often seen in streams receiving wastewater discharge, urban runoff, or eroded soils.

The observed conductivity levels at each monitoring site are expected considering the undisturbed forested landscape and clay soils (Figure 9). The observed conductivity levels are slightly correlated with TSS ($r^2 = 0.64$), suggesting that the source of dissolved ions may be attributable in part to soil runoff (Figure 10). Conductivity levels also correlate with observed nitrate concentrations ($r^2 = 0.80$) to suggest that fertilizer runoff may also be a contributing factor to observed conductivity (Figure 11). Although elevated conductivity is not a problem in these streams, several sites show conductivity levels increasing over time. Most sites also have their greatest conductivity levels during the summer and fall months when flow measurements are lower compared to winter and spring. Reductions in flow, and ultimately water volume, can concentrate the ions contributing to conductivity and pollutants such as TSS and nitrates. Reduced water flow and volume, along with the influences of soil runoff, may be responsible for the observed conductivity levels.

Figure 9. Mean conductivity at each monitoring site, March 2007 – August 2016

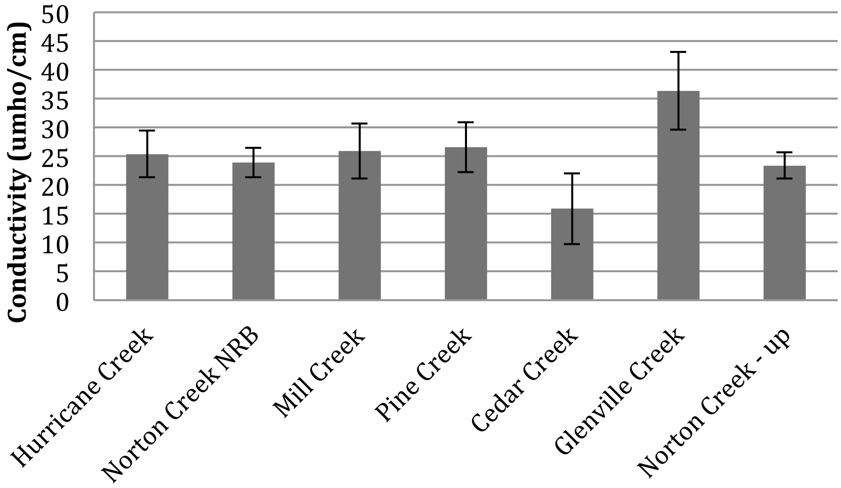


Figure 10. Correlation between mean conductivity and TSS concentrations at each monitored site March 2007– August 2016

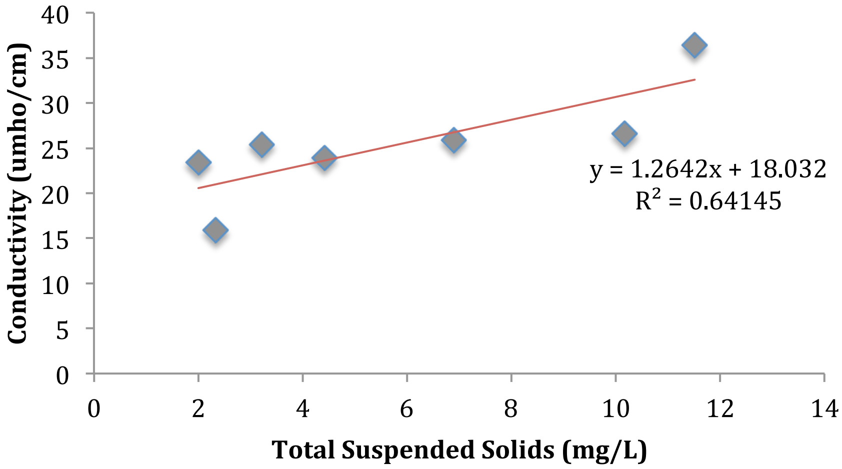
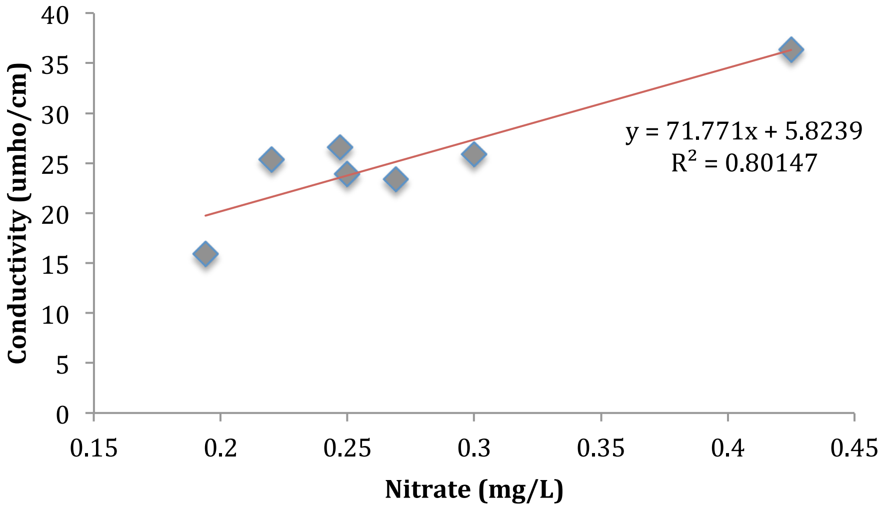


Figure 11. Correlation between mean conductivity and nitrate concentrations at each monitored site, March 2007 – August 2016



Nutrients (Orthophosphate [$PO4^{3-}$], Ammonia [$NH3^{+}$], and Nitrate [NO^{3-}])

Phosphorous is an essential nutrient for aquatic plants and algae, and is typically the limiting nutrient in most aquatic systems thereby restricting plant growth in an ecosystem. Phosphorous is introduced into water systems from soil, wastewater treatment systems, failing septic systems, and runoff from fertilized land. Excessive phosphorous stimulates excessive plant growth and results in eutrophication, a condition that can result in dissolved oxygen depletion in an aquatic ecosystem. Orthophosphate is the amount of phosphorous that is immediately available to plants or algae for biological assimilation. Generally, orthophosphate levels below 0.05 mg/L are sufficient to prevent eutrophication.

There is no legal water quality standard for orthophosphate, but the Environmental Protection Agency (EPA) nutrient criteria for total phosphorous in rivers and streams in this ecoregion is 0.01 mg/L. Although orthophosphate is only one component of total phosphorous, observed concentrations at all monitored sites exceed the EPA nutrient criteria for total phosphorous. With the exception of Pine Creek, are streams are below the 0.05 mg/L concentration sufficient to prevent eutrophication (Figure 12). Pine Creek is located in proximity to agricultural activities suggesting that livestock waste storage may be a source of orthophosphate input. Slight correlations are observed between orthophosphate concentrations, and TSS concentrations and turbidity, suggesting that soil erosion is likely a contributor of orthophosphate to the streams.

Although the average orthophosphate concentrations observed during the study period are considered acceptable to prevent eutrophication, trend analysis demonstrates an increase in orthophosphate concentrations in all streams except Cedar Creek over the period of study (Figure 13). The lowest orthophosphate concentrations were observed during the winter months when the average flow was greatest at 650 cfs. Flow decreases through the spring, summer, and winter months and the reduced water volume may concentrate orthophosphate in the water column, thus explaining the lower concentrations observed during those months. While the impact of the observed elevated orthophosphate concentrations in these streams is not likely to directly contribute to eutrophication in Lake Glenville, it could negatively impact water quality in the stream systems.

Figure 12. Mean orthophosphate concentration at each monitoring site, March 2007 – August 2016

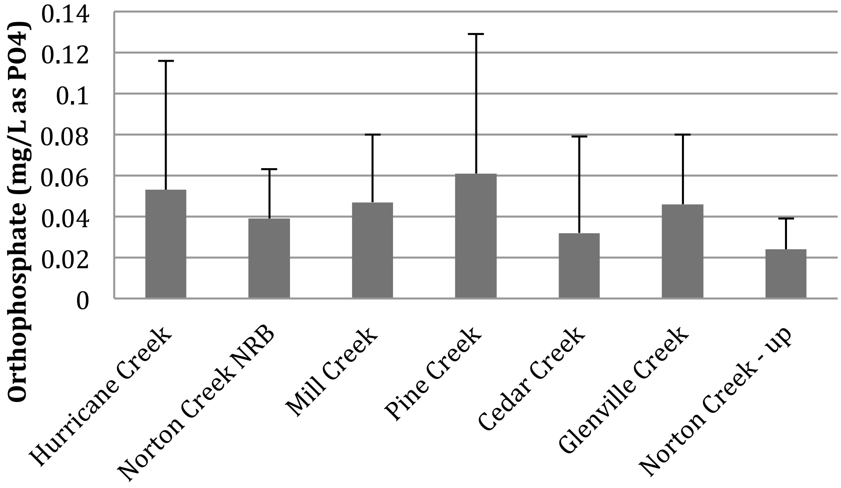
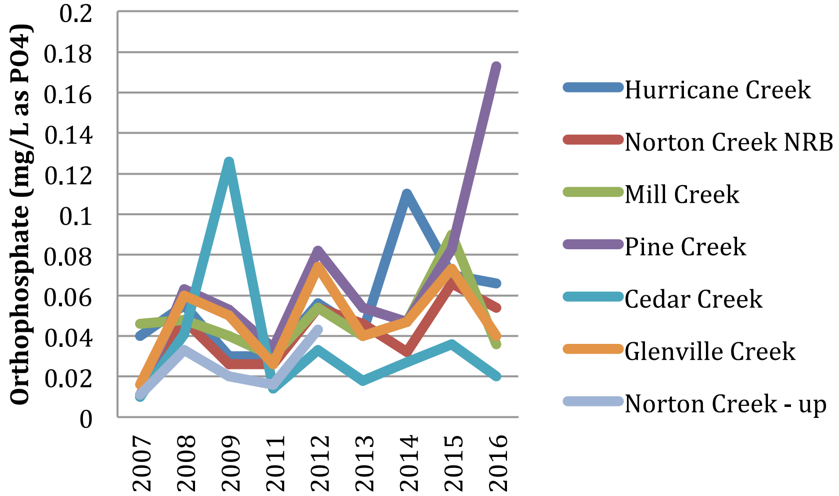


Figure 13. Mean orthophosphate concentrations at each monitoring site by year, March 2007 – August 2016



Ammonia is contained in decaying plant and animal remains and microbial decomposition of these organic wastes can release ammonia. The most likely sources of ammonia are agricultural runoff, livestock farming, septic drainage, and sewage treatment plants. The ambient concentration of ammonia in water is approximately 0.10 mg/L but concentrations are heavily influenced by water temperature and pH. Hurricane, Cedar, and, Norton Creeks exceed this “norm” but do not exceed the ambient total ammonia toxicity standard of 1.9 mg/L (Figure 14). Additionally, observed ammonia concentrations correlate with TSS concentrations suggesting that soil erosion in addition to agricultural runoff of livestock wastes may be a source of ammonia. Additionally, ammonia concentrations do not appear to be influenced by flow or seasonality to the same extent as orthophosphate concentrations.

Figure 14. Mean ammonia concentration at each monitoring site, March 2007 – August 2016

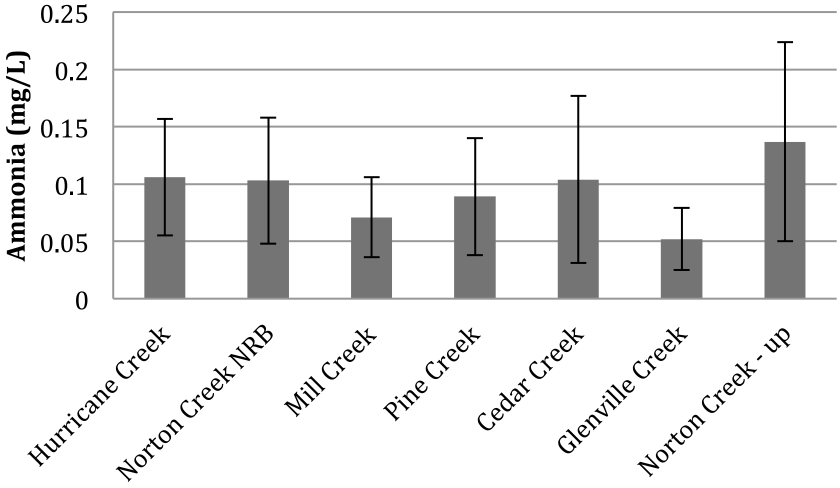
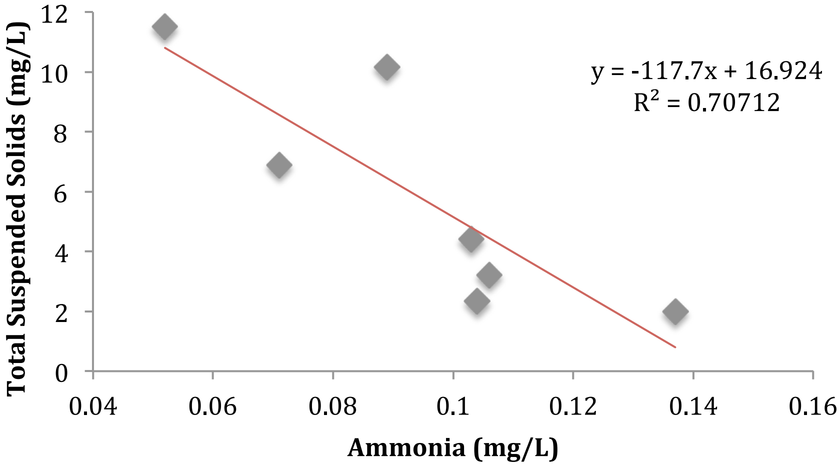


Figure 15. Correlation between mean total suspended solids and ammonia concentrations at each monitored site, March 2007 – August 2016



Like phosphorous, nitrate serves as an algal nutrient and can contribute to excessive plant growth and eutrophication. Common sources of nitrate include septic drainage and fertilizer runoff from agricultural land and domestic lawns. The ability of nitrate to more readily dissolve in water contributes to its increased likelihood of traveling in surface waters. As a result, nitrate is a good indicator of sewage or animal waste input. The ambient standard to protect aquatic ecosystems is 10mg/L and observed concentrations at all monitored sites are below this ambient standard (Figure 16). However, the EPA nutrient criterion for total nitrogen in rivers and streams in this ecoregion is 0.31 mg/L. Although nitrate is only one component of total nitrogen, observed concentrations in Glenville Creek exceed this EPA nutrient criterion for total nitrogen, thus making it more susceptible to eutrophication.

Nitrate concentrations have been increasing in all streams since 2014 (Figure 17). Observed nitrate concentrations do not correlate with TSS or turbidity concentrations suggesting that soil erosion is not a source of nitrate but rather agricultural runoff of wastes may be a contributing source of nitrate. It is likely that microbial oxidation of ammonia to nitrate via nitrification is a contributing factor to observed nitrate concentrations, as is the gradual decrease in flow during the latter years of the study. Nitrate concentrations were generally lowest during the winter months when the average flow was greatest.

Figure 16. Mean nitrate concentration at each monitoring site, March 2007 – August 2016

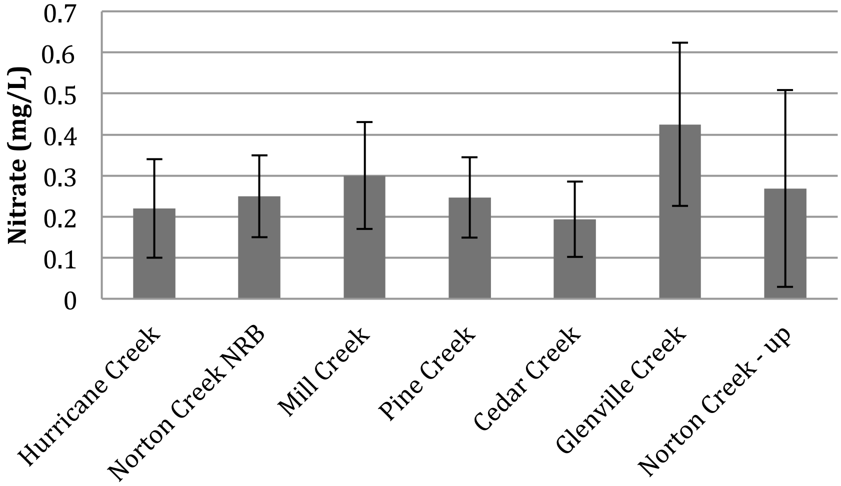
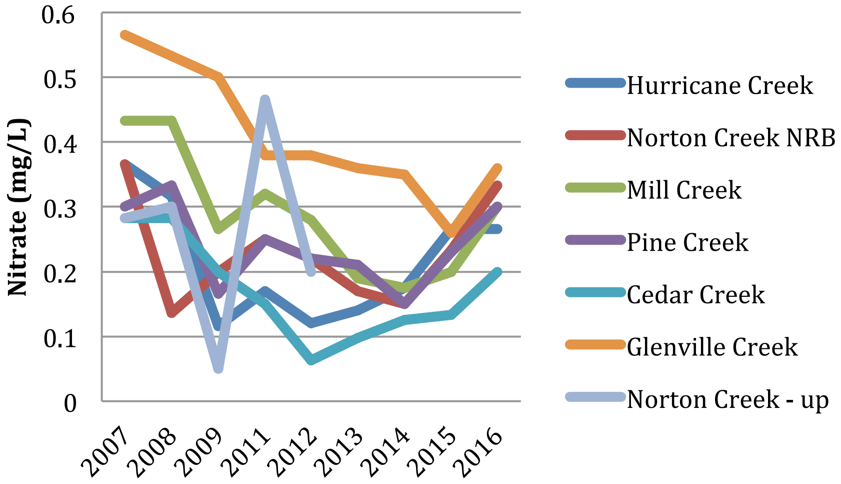


Figure 17. Mean nitrate concentrations at each monitoring site by year, March 2007 – August 2016



Conclusions

Chemical analysis of samples collected at Lake Glenville area sites was intended to characterize the water quality relative to ambient water quality standards. Such information can be useful to help identify problems and evaluate solutions relating to water quality. Characterizing the water quality of any area is a complex undertaking and data interpretation can be influenced by several factors. However, continued monitoring allows such challenges to be addressed and trends become more evident.

Based on the visual and statistical comparisons of spatial and temporal trends of stream data collected from March 2007 – August 2016, it appears that there are multiple important sources contributing to the concentration of nutrients in the Upper Little Tennessee River Basin near Lake Glenville. Continued monitoring will allow us to evaluate the stability of seasonal variation and provide additional data that may improve our ability to discriminate between source locations. Based on the results in this study, none of the monitored streams flowing into the lake have exhibited pollutant levels that would greatly affect lake water quality. The influence of agricultural waste runoff and soil erosion on stream water quality should be further investigated but it is probable that any decline in lake water quality is related to activities in and around the lake than to pollution inputs from the monitored streams.

Appendix A: Data Summary

Sample #:	the number of samples collected for each parameter
Low:	minimum value of any sample(s)
Mean:	average value for each site during study period
High:	maximum value of any sample(s)

pH: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	6.2	6.7	7.1
N-1	40	6.3	6.7	7.3
M-1	40	6.0	6.7	7.1
P-1	40	6.4	6.8	7.1
C-1	38	6.0	6.6	7.1
G-1	40	6.2	6.6	7.0
N-2	18	6.1	6.5	6.9

Alkalinity: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	3.0	7.9	16.0
N-1	40	4.0	8.7	19.0
M-1	40	4.0	9.6	19.0
P-1	40	2.0	12.3	24.0
C-1	38	2.5	6.4	19.4
G-1	40	6.0	12.1	23.0
N-2	15	6.0	8.5	16.0

Turbidity: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	0.5	3.4	24.0
N-1	40	1.6	6.0	50.0
M-1	40	1.2	6.4	50.0
P-1	40	2.1	8.5	50.0
C-1	38	0.5	2.3	6.6
G-1	40	0.5	6.9	75.0
N-2	15	1.3	3.1	10.0

Total Suspended Solids: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	2.0	3.3	32.8
N-1	40	2.0	4.4	42.4
M-1	40	2.0	6.4	53.6
P-1	40	2.0	10.2	71.6
C-1	38	2.0	2.3	8.4
G-1	40	2.0	11.5	245.2
N-2	15	2.0	2.0	2.0

Conductivity: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	16.8	25.5	36.6
N-1	40	17.1	24.0	28.7
M-1	40	17.4	25.9	40.7
P-1	40	17.7	26.6	38.0
C-1	38	9.8	16.0	49.0
G-1	40	20.5	36.5	46.9
N-2	15	17.9	23.5	26.3

Orthophosphate: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	0.01	0.05	0.38
N-1	40	0.01	0.03	0.09
M-1	40	0.01	0.05	0.19
P-1	40	0.01	0.06	0.44
C-1	38	0.01	0.03	0.30
G-1	40	0.01	0.05	0.17
N-2	21	0.01	0.02	0.06

Ammonia: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	0.04	0.11	0.27
N-1	40	0.03	0.10	0.30
M-1	40	0.02	0.07	0.19
P-1	40	0.03	0.09	0.31
C-1	38	0.04	0.10	0.44
G-1	40	0.03	0.05	0.15
N-2	21	0.04	0.14	0.31

Nitrate: March 2007 – August 2016

Site	Sample #	Low	Mean	High
H-1	40	0.05	0.22	0.38
N-1	40	0.05	0.25	0.50
M-1	40	0.05	0.30	0.70
P-1	40	0.05	0.25	0.50
C-1	38	0.05	0.19	0.40
G-1	40	0.10	0.42	0.80
N-2	21	0.05	0.27	1.2