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Effects of land use on periphyton chlorophyll *a* concentrations and biomass in Adirondack Upland Streams

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ABSTRACT

In this study we examined bottom-up (light, nutrient availability) and habitat (stream velocity, stream depth) factors affecting benthic chlorophyll *a* and periphyton biomass in logged and Forest Preserve watershed streams located in the Adirondack Uplands. Chlorophyll *a* concentrations and ash-free dry mass on ambient substrate were measured in six Preserve and six logged catchments, five samples were taken per site. In a nutrient amendment experiment, porous artificial substrates containing nutrient agar treatments (agar only, N, P, N+P) were secured to the bottom of two streams (one Preserve, one logged), and chlorophyll *a* concentrations measured after 19 days. Biomass was significantly higher ($p=0.034$) in streams located in the Preserve. Chlorophyll *a* was marginally higher ($p=0.063$) in the Preserve sites. Stream velocity and depth were significant covariables for both chlorophyll *a* concentrations and biomass. Light, while different between lands uses ($p=0.045$), was not a significant covariable of periphyton standing stock. In the nutrient amendment experiment, all treatments in the Preserve stream showed higher chlorophyll *a* concentrations than in the logged stream ($p<0.001$). Treatments within the logged stream showed higher chlorophyll *a* concentrations for the N+P treatment only, and treatments within the Preserve stream were not different ($p=0.226$). Higher ambient nutrient concentrations in the Preserve stream may explain these results.

Key Words: Adirondack Upland streams, periphyton, canopy cover, land use.

INTRODUCTION

Aufuchs literally means "on plants" but are better defined as attached algae (Horne et al. 1994). They are the algae that grow on the substrate of lakes and streams; they grow on plants, debris, and rocks. This study focused on the periphyton growing on submerged stream rocks in Adirondack Upland streams. Research has shown that many stream aquatic insects depend on periphyton as their main food source, and therefore periphyton plays a vital role in primary production in the stream food chain (Fuller et al. 1986). The abundance of periphyton on stream substrates can affect the abundance of micro- and macro-invertebrates, which may in turn, affect vertebrates.

The populations of primary producers, such as periphyton, can be influenced by top-down and bottom-up factors (Kim et al. 2000). Factors such as sunlight and nutrient availability are considered bottom-up factors. Predation by invertebrates or vertebrates is a top-down factor. This study focused on the bottom-up and habitat (stream velocity and stream depth) factors affecting benthic chlorophyll *a* concentrations and biomass of periphyton in twelve Adirondack streams. The factors in this study included: light intensity, with stream velocity and depth as covariables, and nutrient limitations.

Forest management practices, including logging and clear-cutting, affect periphyton populations, especially when the logging occurs on the riparian buffer regions of the streams. Many studies have shown that once the initial turbidity caused by bank disturbance from tree harvesting settled, periphyton populations increased in streams due to decreased canopy cover (Boothroyd et al. 2004; Holopainen et al. 1992; Kiffney et al. 2003). Hansmann et al. (1972) analyzed periphyton algal communities before and after logging and found a shift in dominant diatom species.

Periphyton production in small, forested streams is potentially reduced due to the excessive shade from a closed riparian canopy (Kim et al. 1999). In some cases trees hanging over streams can intercept up to 95% of incoming solar radiation. Reduced solar radiation can decrease photon flux densities (PFDs) to levels below those required by periphyton for photo saturation (Hill et al.1995). Research on the effects of shade on periphyton in streams is limited, although, differing primary producer species demonstrate wide-range shade tolerance levels. According to Hill et al. (1995) periphyton adapting to shade conditions has had limited documentation in natural steams. McIntire et al. (1965) found increased efficiency in algae in artificial laboratory streams with shaded conditions. The algae adapted to shaded conditions and eventually became as efficient at photosynthesis as the algae with more direct light exposure

Nutrient limitation, specifically nitrogen and phosphorus limitation; can be important bottom-up factors affecting benthic chlorophyll *a* concentrations, and periphyton biomass (Rosemond et al. 1993). Many studies have been conducted where nitrogen and phosphorus were added to stream communities via methods utilizing drip points, or nutrient-diffusing artificial substrata, these studies found that either nitrogen, phosphorus, or both nutrients combined limited periphyton chlorophyll *a* concentrations and biomass (Coleman et al. 1990; Rosemond et al. 1993; Tate 1990.)

The objectives of this study were: (1) to determine if there was a difference in benthic chlorophyll *a* concentrations in streams located in logged versus Forest Preserve watersheds, (2) to determine if there is a difference in periphyton biomass in streams located in logged or Preserve watersheds, (3) to determine if nutrient treatment, nitrogen, phosphorus, and nitrogen and phosphorus combined, had differing effects on benthic chlorophyll *a* concentrations in one stream located in a Preserve watershed, compared with one stream located in a logged watershed.

This study focused on the bottom-up and habitat factors affecting benthic chlorophyll *a* and periphyton biomass in twelve Adirondack streams. Six were located in Preserve watersheds (not logged for 85+ years), and six streams located in logged watersheds (logged within the last 10-20 years) in the Adirondacks of New York.

METHODS

Study Site

This study was conducted in twelve first- and second-order streams located in the Adirondack Park, New York (Figure 1). The Preserve watersheds names and physical attributes are shown in Table 1, the logged watersheds names and areas are shown in Table 2.

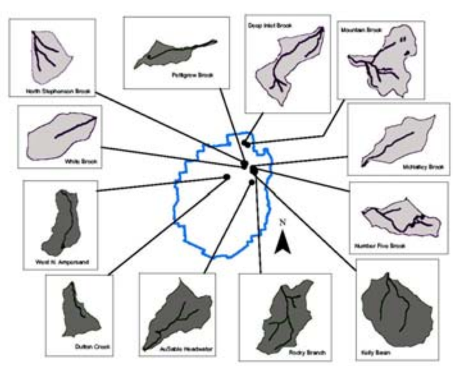

Figure 1. Map of the twelve watersheds, light grey represents logged watersheds, dark grey represents Forest Preserve watersheds located in the Adirondack Park.

Table 1. Preserved watershed names and watershed information.

Watershed	Area (km^2)	Perimeter (km)	Drainage (km/km^2)	Mean Slope (%)	Mean Elevation (m)
West North Ampersand	3.31	8.69	8.031	11.31	657.89
Pettigrew Brook	2.48	10.70	11.719	13.71	746.13
Dutton Creek	3.29	8.97	11.068	9.59	643.82
Ausable Headwater	3.41	8.98	6.216	18.44	895.38
Kelly Basin	4.33	8.21	7.634	15.10	751.96
Rocky Branch	4.59	10.29	1.12	10.70	772.56

Table 2. Logged watershed names and watershed information.

Watershed	Area (km^2)	Perimeter (km)	Drainage (km/km^2)	Mean Slope (%)	Mean Elevation (m)
Deep Inlet Brook	5.54	12.48	10.999	9.69	757.53
McNalley Brook	2.08	7.10	6.708	8.79	551.88
Mountain Brook	4.83	11.26	7.375	6.43	634.92
North Stephenson Brook	3.64	7.59	11.758	14.11	820.90
White Brook	3.06	7.23	12.032	16.94	883.93
Number Five Brook	3.90	9.33	7.89	8.74	634.51

Physical and chemical measurements

Five rocks were randomly chosen at each site from the middle of the stream and two 5.515 cm^2 periphyton scrapes taken from each rock. For each rock, the material from one scrape was collected onto a Whatman® glass fiber filter (1.5 µm nominal pore size), dried, weighed, and burned to yield measurements of Ash Free Dry Mass (AFDM). The material from the other scrape was collected onto Millipore® membrane filters (0.46 µm nominal pore size), and chlorophyll *a* was extracted and concentrations measured. At each site, flow rate was measured using a Global flow meter (Global Water

Instrumentation, Gold River CA), and depth was measured using a meter stick. A digital image was taken straight up into the canopy above each sampling site using a Sony MVC-FD91 digital camera. Following collection, all periphyton filters were placed on ice for transport to the laboratory.

Canopy pictures were converted to black and white using Paint Shop Pro® (Jasc Software). The resulting images were then imported to ArcView® (ESRI), and assigned a value to the brightness of each pixel. The threshold brightness value for open sky was chosen based on inspection of several black and white raster images. The attribute table for the grid was then exported, and the proportion of pixels representing open canopy in each image calculated using Microsoft Excel®.

The glass fiber filters were dried at 50°C for 24 hours, and then weighed. The filters were combusted at 550°C for 2 hours and reweighed to calculate AFDM by loss on ignition. The periphyton on the membrane filters was placed in 50mL reagent grade methanol for 24 hours, in a light proof cooler in a refrigerator. The following day the samples were centrifuged at 2,800 rpm for 2 minutes. The supernatant was colorimetrically analyzed in a Milton Roy Spectronic 401 according to the APHA method (APHA 1998). Wavelengths tested were: 630nm, 647nm, 664nm, and 750nm. The following formulas were used to calculate chlorophyll *a*(APHA 1998):

$$e_{664} = \frac{absorbance\ at\ 664nm - absorbance\ at\ 750nm}{spec\ \ path\ length\ in\ cm}$$

$$e_{647} = \frac{absorbance\ at\ 647nm - absorbance\ at\ 750}{spec\ \ path\ length\ in\ cm}$$

$$e_{630} = \frac{absorbance\ at\ 630nm - absorbance\ at\ 750nm}{spec\ \ path\ length\ in\ cm}$$

$$\text{Volume of chlorophyll } a \text{ in extract} = 11.85e_{664} - 1.54e_{647} - 0.08e_{630}$$

$$Chlorophyll\ a\ (mg/m^2) = \frac{chl\ a\ extract\ volume\ (L)}{area\ of\ \ filter\ or\ tubing\ (m^2) \times 1000}$$

A nutrient amendment experiment was performed using hollow Tee forms as in Coleman and Dahm (1990), with 2.5 cm of nutrient diffuser tubing exposed on each end of the Tee. The experiment was conducted in one logged stream (North Stephenson Brook), and one Preserve stream (Pettigrew Brook). For each site 12 Ts were constructed, 3 containing 15g agar solution with no additives, 3 containing 15g agar and 5 mol.L^{-1} $NaNO_3$, 3 containing 15g agar and 5 mol.L^{-1} KH_2PO_4, and 3 containing 15 g agar and 5 mol.L^{-1} $NaNO_3$ and 5 mol.L^{-1} KH_2PO_4 (Coleman & Dahm 1990). The nutrient agar solutions were poured into the bottom of the Tee forms, sealed with parafilm, and attached to the end of the Tee. The controls were placed farthest upstream, next the nitrogen and phosphorus treatments were placed approximately 15m downstream, and the combination nitrogen and phosphorus treatment were placed 15m downstream of that. The Tees were left in the stream from August 6, 2004 to August 24, 2004. Upon removal, the diffuser tubing was placed into 150 mL of reagent grade methanol and refrigerated. Chlorophyll *a* levels were calculated using the APHA method (APHA 1998). Statistical analysis of the data was performed using ANOVA.

RESULTS

Periphyton biomass was significantly higher (p=0.034) in the Forest Preserve streams. AFDM for the six logged sites was 2.402 ug/m^2, and for the six Forest Preserve sites was 3.406 ug/m^2 (Figure 2). Chlorophyll *a* was marginally higher (p=0.063) in the Forest Preserve streams. Chlorophyll *a* for the six logged sites was 1.715 ug/m^2, and for the six Forest Preserve sites was 3.2063 ug/m^2 (Figure 3). Light, while higher (p=0.045) in the logged sites 47.51%, compared with the Forest Preserve sites 41.84%, was not a significant covariable with respect to AFDM or chlorophyll *a* concentrations (Figure 4).

Periphyton biomass and chlorophyll *a* were higher in the Forest Preserve sites, while incoming light was higher in the logged sites. The AFDM in the Forest Preserve sites was 1.4 times higher than the logged sites, and the chlorophyll *a* was 1.99 times higher in the Forest Preserve sites. While the incoming light was higher in the logged sites, it was only 1.14 times.

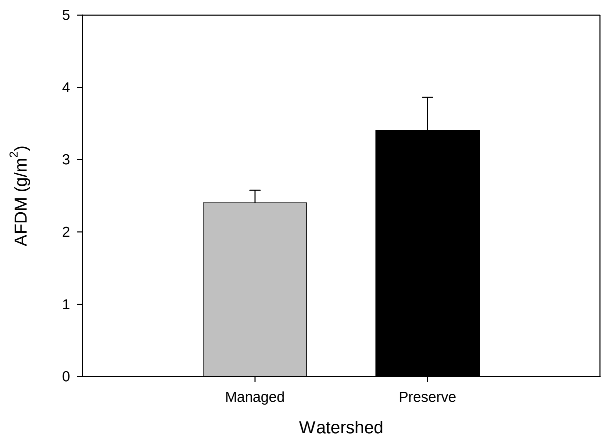

Figure 2. AFDM (g/m^2) in logged vs. Forest Preserve watershed streams (p=0.034).

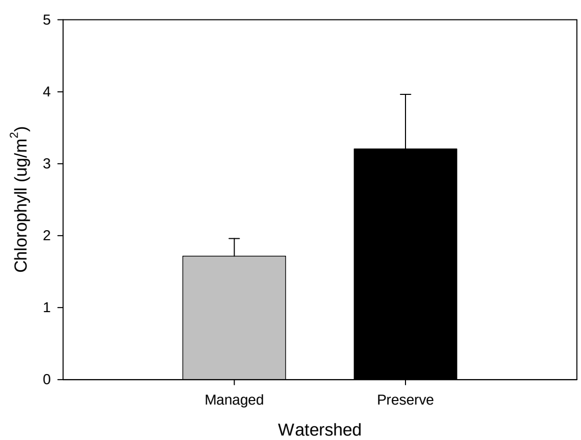

Figure 3. Chlorophyll *a* (ug/ m^2) in logged vs. Forest Preserve watershed streams (p=0.063).

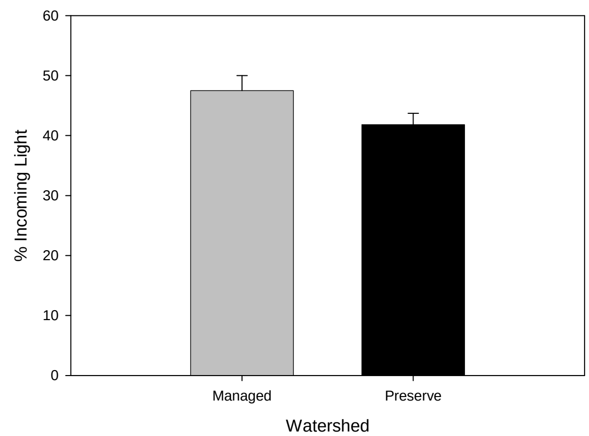

Figure 4. Incoming light (%) in logged vs. Forest Preserve watershed streams (p=0.045).

In the logged stream the nutrient amendment experiment illustrated typical results for an experiment conducted in a nutrient deficient stream. The highest chlorophyll *a* concentrations were with the addition of nitrogen and phosphorus combined. The sole nutrient treatments of nitrogen and phosphorus showed little effect on chlorophyll *a* concentrations.

The nutrient amendment experiment in the Forest Preserve site did not illustrate typical results for a nutrient deficient stream, but rather showed results of a nutrient rich stream. Overall the experiment showed higher levels of chlorophyll *a* for all treatments in the Forest Preserve stream (p=0.45) (Figure 5). The Forest Preserve site blank showed the highest chlorophyll *a* concentration, followed by the sole phosphorus treatment, and then the nitrogen and phosphorus combined treatment, and lastly the sole nitrogen treatment.

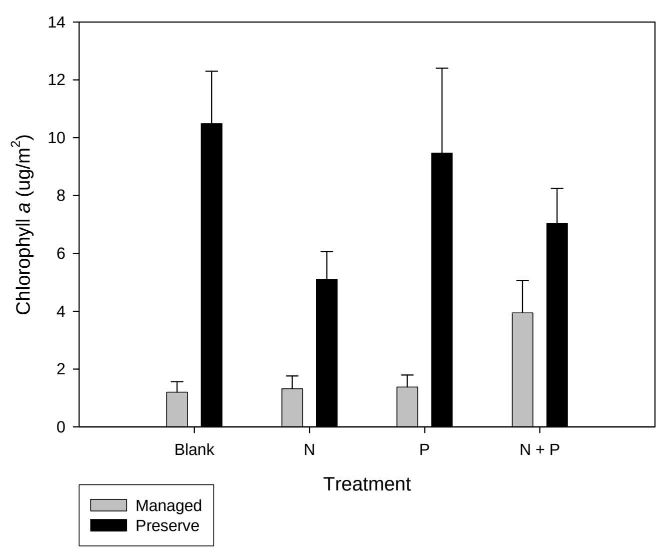

Figure 5. Nutrient amendment experiment managed vs. Forest Preserve streams. Logged vs. Forest Preserve (p<0.001), treatments within each site (p=0.226).

DISCUSSION

The differences in incoming light between the logged streams and the Forest Preserve streams were predictable based on modern forest management practices. When an area is forested the overhead canopy is decreased due to the downed trees. The Forest Preserve streams in this study illustrated a 5.67% increase in canopy cover compared with the managed streams.

However, the % incoming light was not a significant covariable with respect to chlorophyll *a* concentrations. In the statistical analysis of the data there was no correlation between the amount of sunlight reaching the streambed and the concentration of chlorophyll *a* present. Kim et al. (1999) showed that incoming light was a significant covariable with respect to chlorophyll *a* concentrations. Periphyton biomass abundance was affected by increased incoming light, but to a much lesser extent. The authors stated, "Light accounted for 44% of the observed variation in chlorophyll *a* abundance. However, light accounted for only 1% of the observed variation in periphyton biomass" (Kim et al. 1999). With respect to that study, an explanation may be that the periphyton were predominately autotrophic. In this study the periphyton species may be predominately heterotrophic, which may explain why the additional sunlight had no overall effect on the chlorophyll *a* concentrations.

Boothroyd et al. (2003) had similar study results as Kim et al. (1999). Chlorophyll *a* concentrations differed significantly in heavily vegetated riparian zones versus recently logged riparian zones, again with the logged riparian zone of the stream showing the increased concentrations. In Boothroyd et al. (2003) there was also a significant increase in periphyton biomass in the logged zone, but the data showed considerable variation.

There is more than one possible explanation for the results of this study, autotrophic versus heterotrophic periphyton species may be one explanation. Another explanation could be that incoming light may not be the limiting bottom-up factor affecting benthic chlorophyll *a* concentrations and periphyton biomass in this study of Adirondack streams.

Phosphorus and Nitrogen can be limiting nutrients in stream ecosystems. Despite the light availability these nutrients can greatly reduce both benthic chlorophyll *a* concentrations and periphyton biomass. Both of these factors act as crucial bottom-up factors affecting periphyton growth. Coleman et al. (1990) found that in their study nutrient availability was the most important factor affecting benthic chlorophyll *a* concentrations. Tate (1990) found increases in both AFDM and chlorophyll *a* with nitrogen and phosphorus combined additions. The streams in that study illustrated both nitrogen and phosphorus limitations.

Higher ambient nutrients in the Forest Preserve streams compared with lower ambient nutrients in the logged streams may explain both the increased benthic chlorophyll *a* and increased periphyton biomass in the Forest Preserve streams (see Appendix 1,2). Nutrients may be the dominating bottom-up factor effecting chlorophyll *a* concentrations and biomass in these Adirondack streams. The average soluble reactive phosphorus (SRP) concentration in the Forest Preserve sites was 2.119 ppb, and the average for the logged sites was 0.488 ppb. The average nitrate (NO_3) concentration in the Forest Preserve sites was 0.30 ppm, while the average in the logged sites was 0.20 ppm. Phosphorus was 4.34 times higher and nitrate was 1.5 times higher in the Forest Preserve sites. Therefore, the higher biomass and benthic chlorophyll *a* concentrations found in the Forest Preserve sites might well be due to these higher ambient nutrient concentrations.

The nutrient amendment experiment showed that the logged stream, North Stephenson Brook was nutrient limited with respect to both nitrogen and phosphorus, while the Forest Preserve stream, Pettigrew

Brook was not. The blank treatment showed chlorophyll *a* concentrations of 1.20 (μg/m^2), the nitrogen treatment 1.31 (μg/m^2), the phosphorus treatment 1.38(μg/m^2), and the combined nitrogen and phosphorus treatment 3.94 (μg/m^2). The nitrogen treatment and the phosphorus treatment showed little increase in chlorophyll *a* concentration compared to the blank. The combined treatment resulted in more than a doubling in chlorophyll *a* concentrations, therefore it can be concluded that the periphyton in North Stephenson Brook, a logged site, is nutrient limited by both nitrogen and phosphorus. The Forest Preserve stream, Pettigrew Brook illustrated no nutrient limitation based on the nutrient amendment experiment. The blank treatment showed chlorophyll *a* concentrations of 10.49 (μg/m^2), the nitrogen treatment 5.10 (μg/m^2), the phosphorus treatment 9.47 (μg/m^2), and the combined nitrogen and phosphorus treatment 7.04 (μg/m^2). The blank showed the highest chlorophyll *a* concentrations, this suggests that the Forest Preserve stream has overall higher primary productivity regardless of the addition of nutrients. The ambient phosphorus concentration of Pettigrew Brook were found to be approximately eighteen times higher than the ambient phosphorus concentrations of North Stephenson Brook (see Appendix 1,2). The phosphorus concentration in Pettigrew Brook was 5.559 ppb, while the phosphorus concentration in North Stephenson Brook was 0.305. The nitrate concentration in Pettigrew Brook was 0.25ppm, and 0.34 in North Stephenson Brook. While the nitrate concentration was 1.36 times higher in North Stephenson, it made little difference compared with the 18.23 times higher concentration of phosphorus in Pettigrew Brook. It can be concluded that Pettigrew Brook is not nutrient limited based on the nutrient amendment experiment and the ambient nutrient concentrations.

Conclusion

Standing stock biomass and Chlorophyll *a* were higher in the Forest Preserve streams, with stream velocity and water depth being significant covariables. Stream depth was a positively significant covariable, while stream velocity was a negatively significant covariable, with respect to biomass and chlorophyll *a* concentrations. Statistical analysis showed that increased stream depth resulted in increased periphyton biomass, and increased benthic chlorophyll *a* concentrations. While, increased stream velocity resulted in decreased periphyton biomass, and decreased chlorophyll *a* concentrations.

Percent incoming light was greater in the managed versus Forest Preserve watershed streams, however it was not a significant covariable, with respect to biomass and chlorophyll *a* concentrations. When incoming light was statistically analyzed with biomass and chlorophyll *a* concentrations there was no correlation. The nutrient amendment experiment showed higher primary productivity in the Forest Preserve stream, but no effect of the treatment. All of the treatments in Pettigrew Brook showed higher chlorophyll *a* concentrations compared with all the treatments in North Stephenson Brook. However, within North Stephenson Brook the combined nitrogen and phosphorus treatment showed an increase in chlorophyll *a* concentration as compared with the blank, the sole nitrogen treatment, and the sole phosphorus treatment.

It would be interesting to see additional research conducted on these Adirondack systems. A better understanding of the factors, whether bottom-up or top-down, affecting benthic chlorophyll *a* concentrations and periphyton biomass might be of most interest. This study has shown that in these twelve streams incoming light is not the bottom-up factor affecting chlorophyll *a* concentrations or biomass. This study has also shown that periphyton is not nutrient limited in Pettigrew Brook, but is nutrient limited in North Stephenson Brook.

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Appendices

Appendix 1. Preserved watershed names and stream nutrient data. Summer 2004.

Watershed Name	SRP (ppb)	K (ppm)	Ca (ppm)	Mg (ppm)	F (ppm)	Cl (ppm)	NO_3 (ppm)	SO_4 (ppm)
West North Ampersand	0.983	0.349	3.56	0.62	0.04	0.03	0.77	4.68
Pettigrew Brook	5.559	0.188	7.40	1.56	0.03	0.30	0.25	5.87
Dutton Creek	4.203	0.597	3.68	0.87	0.03	0.40	0.85	3.75
AuSable Headwater	0.164	0.137	3.24	0.42	0.01	0.29	-0.10	4.43
Kelly Basin	1.803	0.250	14.96	2.62	0.05	0.52	-0.14	7.60
Rocky Branch	0.00	0.158	12.44	1.38	0.03	0.31	0.15	6.10

Appendix 2. Logged watershed names and stream nutrient data. Summer 2004.

Watershed Name	SRP (ppb)	K (ppm)	Ca (ppm)	Mg (ppm)	F (ppm)	Cl (ppm)	NO_3 (ppm)	SO_4 (ppm)
Deep Inlet Brook	1.639	0.281	3.80	1.32	0.04	0.26	0.12	4.95
McNalley Brook	0.000	0.287	8.48	1.38	0.01	0.33	0.02	5.54
Mountain Brook	0.984	0.620	8.68	3.00	0.04	0.24	0.22	3.56
North Stephenson Brook	0.305	0.174	4.92	0.87	0.02	0.21	0.34	6.08
White Brook	0.000	0.157	4.36	0.58	0.00	0.27	0.35	4.40
Number Five Brook	0.000	0.306	9.14	1.94	0.03	0.33	0.13	4.42