Assessing Impacts Due to Small Impoundments in North Carolina to Support 401 Certification Policies

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Executive Summary

North Carolina (NC) currently has difficulty fully assessing the risks to streams when considering 401 Certification applications for small (surface area of 10-100 acres) impoundments of headwater (≤3rd Strahler order) streams. Results from a Tennessee study (Arnwine 2006), NC monitoring data, and the existing literature suggested that this type of authorized activity can have negative effects on water quality and aquatic life uses in impounded streams. This raised concerns at NC Division of Water Quality (NC DWQ) regarding possible environmental risks with such projects in NC, such as loss of protected uses within the impounded section of the stream or below the impounded reach. However, available data collected on small headwater impoundments specifically in NC were sparse. In cases where 401 Certifications were being sought to build these types of small impoundments, the NC DWQ 401 Certification Unit was uncertain how to assess the effects on water quality of these projects. Funding was obtained from the US EPA Region IV Wetland Program Development Grant program to fund this study in order to determine effects on water quality and aquatic life use associated with these impoundments and their downstream reaches in order to make informed regulatory decisions regarding these types of projects.

The study design was based on monitoring upstream, within, and downstream of small headwater impoundments within the Blue Ridge and Piedmont ecoregions (Griffith 2002) within NC. Results from the upstream, flowing reach at each site served as a reference to which downstream data were compared. This design allowed the upstream site to provide a control for water quality, land use, drainage area, and other conditions within each watershed. A range of indicators were selected for monitoring: field parameters (dissolved oxygen, water temperature, pH, specific conductance, and transparency), water chemistry (nutrients, chlorophyll-*a*, turbidity), benthic macroinvertebrates, periphyton biomass, and habitat assessments. Twelve sites were identified, six each in the Blue Ridge and Piedmont ecoregions. Land use within the study watersheds was predominantly forested in the Blue Ridge ecoregion. Piedmont watersheds showed more heterogeneity and included varying amounts of developed and planted/cultivated (agricultural) land use. Data collections occurred primarily during the growing season (April-October) 2011, though temperature data loggers were deployed for a full year, from May 2011-May 2012.

Temperature was a universal concern for these types of systems. Exceedences of the NC water quality standards for temperature were extremely widespread throughout the year. Bottom-only and combined top/bottom dam releases resulted in a seasonal shift in the timing of these exceedences. The bottom and combined releases also were associated with increased chlorophyll-*a* and suspended sediment concentrations and stream substrate embeddedness downstream of the dams, and the bottom release site had some of the lowest downstream D.O. levels in the study. Within impoundments, D.O. concentrations below the applicable standards were in some cases very close to the surface (generally 2m, though one reading was at 1m).

Nutrient enrichment and primary productivity increased within impoundments and downstream. Enrichment within Piedmont impoundments was demonstrated by over half of NC Trophic Score Index (NCTSI) ratings being eutrophic, though chlorophyll-*a* concentrations did not exceed the applicable NC water quality standard. Increases in downstream concentrations of nitrogen at Piedmont sites suggest that these impoundments act as a nutrient source to downstream reaches. Blue Ridge sites exhibited low eutrophication levels, but 50% of samples from designated trout waters exceeded the more stringent chlorophyll-*a* standard associated with this surface water classification. For both ecoregions, chlorophyll-*a* concentrations showed a significant increase at downstream stations as compared to the background levels at the corresponding upstream stations, which was unexpected as measureable levels of chlorophyll-*a* are rarely found in lotic systems in NC except for in large rivers. Periphyton biomass also increased below impoundments as compared to upstream, which concurs with results from other studies of headwater systems.

The benthic macroinvertebrate communities showed a sharp increase in tolerance levels and a decrease in the number of unique taxa within impoundments. While this was expected, the complete lack of taxa within three Blue Ridge impoundments was troubling, as there are a number of taxa that are adapted to living in these low-oxygen or even anoxic conditions. Fewer taxa (as compared to the upstream sites) and more tolerant communities were also found downstream of impoundments. While changes to functional feeding groups were not significant in our data, they did suggest that shifts in community structure occur and support other findings, such as increases in phytoplankton (as measured by chlorophyll-*a*) and periphyton biomass downstream of impoundments. Differences in habitat between upstream and downstream stations did not account for the changes seen in benthic communities.

Field observations noted a lack of flow below two of the dams during late summer sampling visits. Several other instances of heavy iron-oxidizing bacterial growth at downstream stations were mentioned in field notes, which suggests poor flow conditions and low oxygen levels. .

Land use appeared to be a poor predictor of instream conditions. One site showed elevated values for nitrogen and suspended solids and had a stressed benthic community in spite of having an almost entirely forested watershed. The site with the most planted/cultivated land use in the study had acceptable results for most parameters, including a relatively low level of eutrophication. Two other sites that had the largest amount of developed land use in their watersheds exhibited quite different gradients of responses.

Recommendations for additional work include a fuller characterization of downstream effects, including addressing the spatial extent of effects below the dam, i.e., how far downstream are effects detectable. More detailed benthic macroinvertebrate data would be helpful for fully addressing aquatic life use support. Additional monitoring of bottom or combined top/bottom dam release structures would be useful to determine if the limited data we collected on these types of systems are applicable on a wider scale.

As NC regulatory agencies review future applications for headwater stream impoundments, it would be helpful to have assessment data on the current water quality conditions in the streams being proposed for impounding. Our data suggest that systems that are already highly stressed are more likely to have issues with degradation to the point of loss of designated uses. Impoundments of designated trout streams should be approached with extreme caution, as these waters have much more stringent water quality standards for temperature and chlorophyll-*a* and so had a higher incidence of standard exceedence in our study.

I. Introduction

North Carolina (NC) currently has difficulty fully assessing the effects on water quality when considering 401 Certification applications for small (surface area of 10-100 acres) impoundments of headwater (≤3rd Strahler order) streams. Results from a Tennessee study (Arnwine 2006) suggested that this type of authorized activity can have negative effects on water quality and aquatic life uses in impounded streams. This has raised concerns at NC Division of Water Quality (NC DWQ) regarding possible environmental risks with similar projects in NC, such as loss of uses within the impounded section of the stream or below the impounded reach. However, available data collected on small headwater (first- to third-order stream) impoundments specifically in NC were sparse. In cases where 401 Certifications were being sought to build these types of small impoundments, the DWQ 401 Certification Unit was uncertain how to assess the effects on water quality associated with these projects. Funding was obtained from the US EPA Region IV Wetland Program Development Grant program to fund this study in order to determine water quality and aquatic life use impacts associated with these impoundments and their downstream reaches in order to make informed regulatory decisions regarding these types of projects.

Background

North Carolina has few natural lakes and those that exist are located in the coastal area of the state. A large number of artificial impoundments exist throughout the state to serve a wide range of purposes, including public water supplies, fire suppression, recreation, aesthetics, irrigation, hydroelectric power, and flood control. These lentic (impounded) systems can also provide ecosystem services that are different than those provided by lotic (flowing stream) systems, such as sediment removal and habitat for wildfowl, reptiles, amphibians, and sport fish. Impoundments can also provide economic benefits, such as those associated with recreational use and increases in the property tax base. However, the literature suggests that impounding flowing streams may have some negative effects on water quality, both within the impounded reach and downstream (see Baxter 1977 for an overview). One concern is nutrient enrichment, which can increase primary productivity by algae and plants, which in turn can lead to decreased oxygen, increased pH, increased chlorophyll-*a* concentrations, impacts on fish communities, effects on aesthetics/recreational use, and taste and odor problems for water supplies. And while impoundments may provide suitable habitat for wildfowl and sportfish, it may be at the detriment of native species. For example, loss of habitat and isolation of populations due to dams are considered the most serious impacts to the endangered Cape Fear shiner (*Notropis mekistocholas*) (USFWS 2004), which is endemic to the Piedmont region of NC. Changes to instream conditions below dams, such as decreases in dissolved oxygen and alterations of temperature and flow regimes, have been shown to have deleterious impacts on a variety of instream biota (Poff 1997).

Impoundments also lead to fragmentation of watersheds. This can lead to stress on instream species or even local extirpation or extinction (Neves 1990, Vaughn 1999). The serial discontinuity concept (Ward 1983) addressed the impact of dams on instream dynamics and noted that the spatial placement of a dam—within a headwater stream versus a higher order river—will result in different instream effects in accordance with concepts outlined in the river continuum (Vannote 1980) and nutrient spiraling concepts (Webster 1979). Vannote proposed that headwater streams (i.e., first- to third-Strahler order) are generally allochthonous (primary energy sources are located outside of the stream) and so are dependent on receiving nutrient and carbon inputs from the land. These constituents are naturally moved down the stream network and the instream dynamics become more autochthonous, or more "independent" of the terrestrial landscape. According to Ward, dams in headwater systems interrupt these natural transitions, resulting in local effects downstream of dams such as removal of fine particulate matter (e.g., the most readily available carbon sources to headwater food webs), increases in the ratio of photosynthetic (e.g., algae) to heterotrophic organisms, decreases in biotic community diversity, and increases in nutrient levels. Ward proposed that dams on larger (fifth-order) streams also cause many of these same effects to different degrees, with notable exceptions of *decreases* in temperature (with an assumption of deep-water releases) and nutrient levels below dams.

This project was intended to address a variety of these concerns resulting from impounding free-flowing waters to create small artificial reservoirs, and to determine if these impoundments are likely to cause issues with respect to complying with existing water quality standards, including the state administrative code's narrative anti-degradation standard (15A NCAC 02B .0201, Antidegradation Policy), and to gain a better understanding of the combined effects of nutrient regimes, temperature changes, dissolved oxygen levels, and habitat impacts on instream communities. Secondarily, results are being compared to existing research to determine if results from these studies may be considered applicable to NC waters.

Extent of impoundments in NC

In NC, natural lakes are limited to the coastal plain region of the state. Artificial impoundments, however, are extremely common in NC and primarily located in the Piedmont and Blue Ridge ecoregions (Griffith 2002) (Figure 1). According to the US Army Corps of Engineers' National Inventory of Dams (USACE, Accessed October 2012), there are 3,382 dams in NC. Over half of these are small (dam height <25 feet, n=1,796), and the great majority are privately owned (n=3,074) with earthen dams (n=3,154), and a stated primary purpose of recreation (n=2,426). Construction dates have been identified for slightly over half (n=1,834), with the great majority having been built since 1950 (Figure 2). However, the NC Division of Energy, Mineral, and Land Resources' Dam Safety Program database shows 5,612 dams statewide (NC DEMLR, accessed October 2012). The disparity is likely due to the criteria for dams tracked by each program; for example, the USACE inventory generally only includes dams that are high hazard (likely to cause loss of human life or property damage in the case of failure), dams ≥25 feet in height and >15 acre-feet of storage, or dams >6 feet in height and ≥50 acre-feet of storage (http://geo.usace.army.mil/pgis/f?p=397:1:0, accessed January 21, 2013).

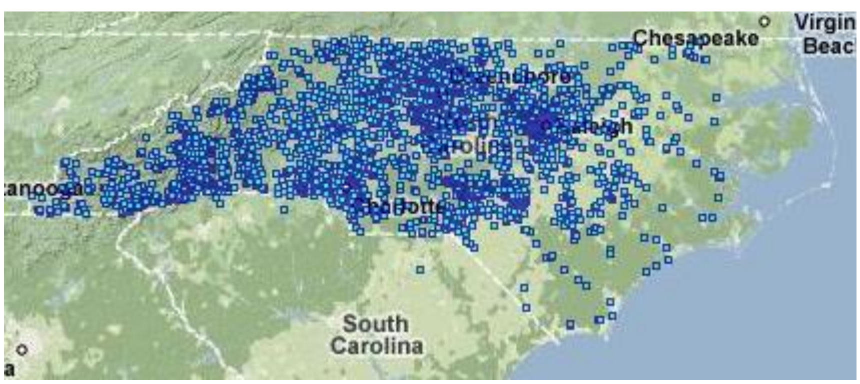


Figure 1 Location of NC dams from the USACE National Inventory of Dams. Image adapted from USACE, http://geo.usace.army.mil/pgis/f?p=397:3:837413223002001::NO::P3_STATES:NC

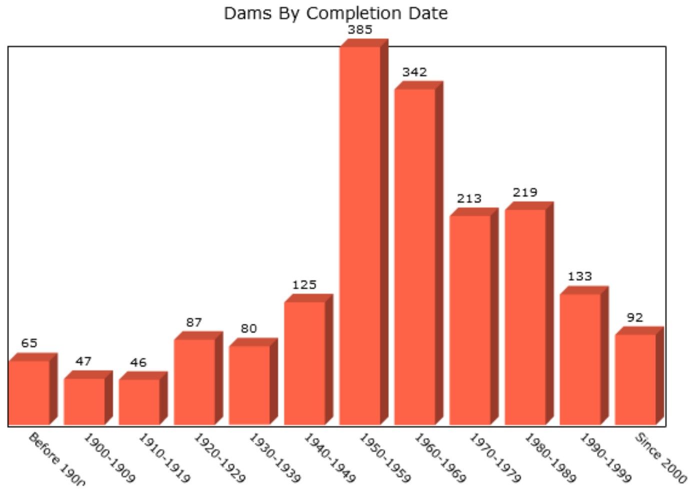


Figure 2 Completion date for NC dams (where known). Image provided by USACE, http://geo.usace.army.mil/pgis/f?p=397:3:837413223002001::NO::P3_STATES:NC.

Impaired freshwater acreage in NC

Data collected by NC DWQ suggests that artificial impoundments can have water quality issues. Analysis of the 2010 NC Integrated Report and accompanying GIS shapefile (NC DWQ 2010a) showed that 24% of the assessed freshwater acres within the state (or 51,475 of a total 214,634 acres) have been determined to be impaired, primarily due to exceedences of the chlorophyll-*a* standard. An additional 2,734 acres were assessed as "Not Rated" with notations of "Potential Standard Violation" (2,312 acres) or "Data Inconclusive" (422 acres). Assessment units showed a wide variety of sizes in terms of acreage but a lack of statistically significant differences ($p<0.05$, Wilcoxon rank sum test) between distributions of assessment unit acreage by use support status suggests that the latter is not tied to the former, i.e., neither large nor small impoundments are more or less likely to show water quality impairments. It should be noted that these assessment units do not refer to individual impoundments in many cases. For example, large reservoirs will often be broken into smaller units based on the individual drainages feeding into the reservoir, so these results are not necessarily immediately applicable to small headwater impoundments.

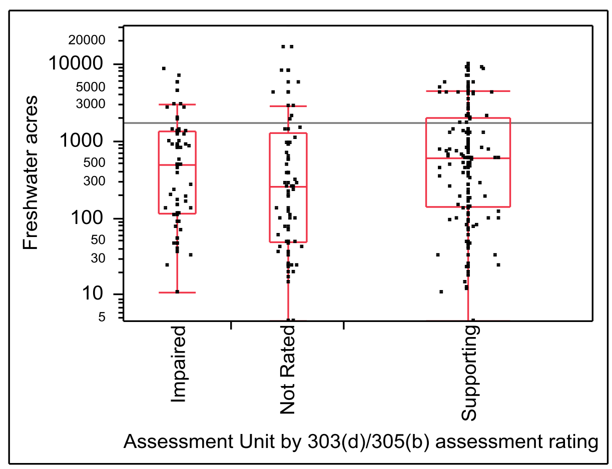


Figure 3 Distribution of Assessment Unit areas by Integrated Report (303(d)/305(b)) category

Existing NC monitoring data

The NC DWQ has an ongoing monitoring program, the Ambient Lakes Monitoring Program (ALMP), which samples approximately 160 lakes and impoundments, generally municipal water supplies, across the state on a rotating 5-year basis, i.e., a subset of sites are sampled each year for five years and the cycle begins again. Each year's data are summarized in Basin Assessment Reports (see http://portal.ncdenr.org/web/wq/ess/reports). A subset of these data that were collected between 1995-2005 from 95 water supply reservoirs in the Piedmont and Blue Ridge ecoregions of the state were analyzed by the NC Environmental Management Commission. The report (NC EMC 2006) stated that 14% of the reservoirs showed indications of eutrophication (nutrient enrichment), 15% had aquatic weed infestations significant enough to warrant treatment, and 6% had taste and odor problems that required additional treatment before they could be processed for drinking water.

In order to characterize impoundment conditions on a fairly large scale within the state, in 2008 NC DWQ Program Development Unit staff obtained data from the period of 1981-2006 for the entire Yadkin-PeeDee River basin (USGS Hydrologic Unit [HU] 0304). This HU covers a large area in central NC, primarily within the Piedmont ecoregion but also portions of the Blue Ridge and Southeastern Plains. The data set represented results from 28 impoundments having a wide range of sizes. Results (Appendix 1) were compiled for dissolved oxygen (DO) concentration and saturation, pH, specific conductance, Secchi transparency, water temperature, and specific conductance and were split into two groups based on the impoundment's surface area (< or >100 acres). Distributions for each of the field parameters were not significantly different for the two groups, with the exception of pH. For this parameter, differences were due to four lakes located in the Sand Hills ecoregion that would naturally be expected to exhibit low pH. Additional comparisons were made by grouping by volume (< or > 100×10^6 m^3), watershed size (< or >4000mi^2), and average depth (< or > 17 ft.), and no significant differences were seen for any of these additional groupings. The lack of differences in these measures based on size is in agreement with the findings from the Integrated Report data analysis discussed in the previous section.

Further calculations of exceedences of screening values were completed using the entire, ungrouped data set. For dissolved oxygen saturation, a screening value of 110% was used (NC DWQ 2003); values above this level are generally considered indicative of algal blooms. Of the >7000 surface DO saturation readings in the data set, 52% were above the screening value. The percentage of readings not meeting the selected pH criteria (6-9 SU) was 17%, but again, these occurred within the Sand Hills impoundments that would naturally be expected to have low pH values. Very few exceedences of screening values for DO concentration and water temperature were noted. However, chlorophyll-*a* data showed that 18% of samples were above the screening value of 40 µg/L (the NC water quality standard). Half of the impoundments had >10% of their samples above the screening value.

This analysis was intended as a cursory survey of impoundment water quality in NC in order to determine a course of action in addressing concerns about permitting additional impoundments (particularly in headwaters) in the state. The results did suggest that enrichment of impoundments within the state was not an uncommon occurrence, and at least in this data set, statistically significant differences were not present when using multiple measures of impoundment size.

Probabilistic monitoring of streams below small impoundments in Tennessee

The Tennessee Department of Environment and Conservation published results of a large, probabilistic-design project to determine instream effects below artificial impoundments of small, headwater systems across

Tennessee (Arnwine, 2006). A total of 75 sites were selected from across the state in proportions equivalent to impoundment frequency within each level 4 ecoregion. The monitoring effort addressed chemical, physical, aquatic life, and habitat assessments below impoundments. Results were compared to state water quality standards and state-specific screening values derived from regional, first-order stream reference sites. Major findings were:

- The great majority of sites failed to meet reference guidelines for aquatic insects in the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT; generally the most intolerant taxa) for both number of taxa (96%) and abundance (86%). When examining all taxa, 87% of sites did not meet taxa richness guidelines and showed a general shift towards more tolerant communities.
- Insufficient flow was present to support aquatic life below approximately 39% of monitored impoundments. During site reconnaissance, lack of flow below dams was the most common reason (32%) given for disqualification of candidate study sites.
- Approximately 50% of monitored streams showed signs of active bank instability.
- Instream habitat was degraded, primarily due to sediment deposition, at 80% of sites.
- Nutrients were elevated and dissolved oxygen concentrations were lower as compared to reference condition.
- Violation of temperature water quality standard criteria was relatively rare (8 of 75 sites), though 69% of sites were above the 90th percentile of reference values.
- Total suspended solids (TSS) were elevated above reference values at approximately half of the study sites.
- Nutrients exceeded regional reference standards for ammonia (~80% of sites), total phosphorus (~75%), TKN (~65%), and nitrite+nitrate (~40%).
- Periphyton density was greater than reference levels at approximately half of sites.
- Stressors may persist for as far as 1/4-mile downstream of dams.

Each of these effects was found within multiple ecoregions in Tennessee. The authors concluded that these small, headwater impoundments have deleterious effects on downstream reaches throughout the state.

II. Methods

Overall Approach

The study design was based on monitoring upstream, within, and downstream of small headwater impoundments within the Blue Ridge and Piedmont ecoregions within NC. These ecoregions were selected as artificial impoundments are predominantly located in these areas of the state. Also, NC DWQ 401 Certification staff from these areas of the state had voiced concern and requested additional guidance when reviewing these types of permitted projects.

Results from the upstream, flowing reach at each site served as a reference to which downstream data were compared. This design allowed the upstream site to provide a control for water quality, land use, drainage areas, and other conditions within each watershed. Any differences seen downstream could then be more definitively tied to the presence of that particular impoundment in that particular location in that particular stream. A range of indicators were selected for monitoring:

- *Field measurements, including dissolved oxygen (DO), water temperature, pH, and specific conductance (SC)*: Except for SC, these parameters have associated numerical water quality standards. Water transparency (Secchi depth) was also collected within impoundments.
- *Water temperature data loggers*: Continuous data loggers were employed to measure temperature over the course of a full year to determine compliance with NC water quality standards for this parameter.
- *Analytical samples, including total Kjeldahl nitrogen (TKN), nitrite + nitrate (NOx), total phosphorus (TP), chlorophyll-a, and total suspended solids (TSS)*: Chlorophyll-*a* is the only parameter with an associated numerical water quality standard. These data, in combination with Secchi depth, were used to calculate a NC-specific trophic level index, the NCTSI.
- *Benthic macroinvertebrates*: Known areas of the substrate were sampled within stream riffles and at one location within the impoundments. Taxa were identified to the lowest practical taxonomic level and the number of individuals per taxa was normalized as number/m^2 for analysis.
- *Periphyton biomass*: Periphyton, also referred to as *aufwuchs*, is composed primarily of algae (including diatoms) but also includes the bacteria and fungi that grow on aquatic substrates. While its extent is affected by many factors (e.g., stream velocity, available sunlight, available substrate), periphyton is an indicator of the lower trophic levels containing both the primary producers and decomposers.
- *Habitat assessments*: A standard habitat assessment was used at upstream and downstream lotic reaches to determine if instream conditions such as substrate composition, embeddedness, bed stability, and instream structure showed significant changes below the impoundments. This information was also helpful for interpretation of benthic macroinvertebrate and periphyton data.
- *GIS data*: Land use and elevation data were obtained for delineation of the drainage area for each sampling station and to determine the percent contribution of major land use types (e.g., forest, development, agriculture).

Each site (impoundment) had four sampling locations: upstream/lotic (station A), upper impoundment/lentic (station B), lower impoundment/lentic (station C), and downstream/lotic (station D). All stations were sampled for chemical and physical field parameters and laboratory samples three times during the growing season (April-October) of 2011. Benthic macroinvertebrates and periphyton were sampled once at stations A, B, and D during this time period. Habitat assessments were performed at stations A and D once, concurrent with benthic macroinvertebrate sampling. Temperature data loggers were deployed at A, C, and D for the period of May 2011 to May 2012.

Details of analytical methods, sample handling, and QA/QC procedures were previously detailed in the project Quality Assurance Project Plan (NCDWQ 2011a) but a summary of methods is provided below.

Field sites

Study sites were identified within the Piedmont and Blue Ridge ecoregions, as these are the areas of the state where impoundments are most common. Selection criteria for included: <100 acres in size; location in or near the headwaters of a stream network; presence of a perennial, wadeable, flowing stream above and below the impounded area; and reasonable access for sampling activities (preferably on public lands or where permission could be obtained from private landowners). Primary sources for prospective sites included impoundments currently or previously monitored by the NC DWQ Ambient Lakes Monitoring Program; the NC Division of Energy, Mineral, and Land Resources Dam Inventory (NC DEMLR 2012); public lands (e.g., state parks); and visual inspection of USGS topographic maps and aerial photography. Landowners of the prospective sites were contacted to obtain permission for access. Sites were then visited to ground-truth that the sites met the stated criteria, were accessible, and a small boat could be launched in the impoundment. Twelve sites were identified.

Site locations are shown in Figure 4 and described in Table 1. Most were clearly located in the Piedmont or Blue Ridge ecoregion but several sites (DEV, BROY, and SOUT) lay on the boundary between the two ecoregions. For these sites, onsite conditions were used to definitively assign them to an ecoregion for the study based on the predominant stream characteristics and features seen. The final twelve sites were evenly split between the Piedmont and Blue Ridge ecoregions. Information about the year built, surface area, and discharge/release type (top, bottom, or combined) were obtained from the NC DEMLR Dam Inventory. Release types were verified on-site where possible.

Four monitoring stations (A, B, C, and D) were established at each site, for a total of 48 for the project. In cases where more than one stream fed the impoundment, the dominant (larger) stream was selected for monitoring. Upon initial sampling visits, station coordinates were recorded using a WAAS-enabled recreational grade GPS receiver (DeLorme Earthmate PN-40). Photos were taken at each station to document conditions. The distance downstream from the dam for each site's station D varied widely, though most were in the range of 100-200m; however, they were as close as <50m and as far downstream as ~750m.

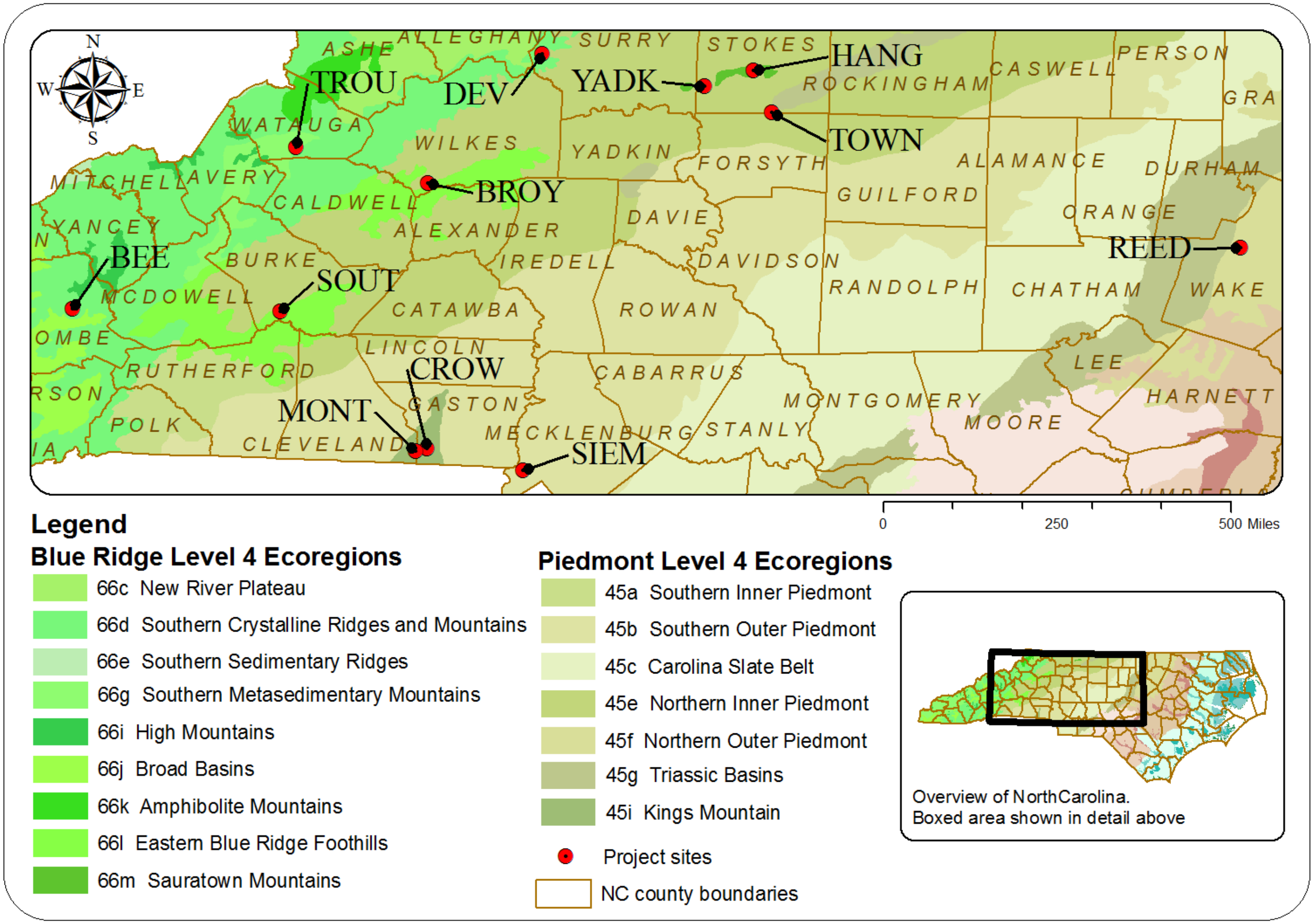


Figure 4 Study site locations in NC

Table 1 Project site descriptions. Dam ID, year built, and surface area obtained from the NC DEMLR dam database unless otherwise noted. Age indicates age at the time of data collections.

Project ecoregion	Site Code	Site Name	EPA Ecoregion Level 4 [1]	Dam ID	Year Built	Age (years)	Surface Area (acres)	Release Type [4]	Stream classification(s) [5]
Blue Ridge	BEE	Bee Tree Reservoir	66d	BUNCO-006	1927	84	41	T	WS-I HQW; C
	BROY	Lake Broyhill	45e [2]	WILKES-050	2000	11	135	T, B	C
	DEV	Devotion	66d [2]	SURRY-031	1936	75	54	T	B Tr ORW
	HANG	Hanging Rock	66m	STOKE-016	1938	73	12	T	B ORW; B
	SOUT	South Mountain State Park	66l [2]	BURKE-003	1950	61	13	T	C HQW
	TROU	Trout Lake	66g	WATAU-005	1971	40	14	T	WS-II B Tr HQW
Piedmont	CROW	Crowders Mountain State Park	45i	GASTO-003	1961	50	12	B	C
	MONT	Lake Montonia	45i	CLEVE-017	1933	78	26	T, B	B HQW
	REED	Reedy Creek Lake	45f	WAKE-014	1955	56	20 [3]	T	B NSW
	SIEM	Siemens	45b	MECKL-042	1965	46	12	T	C
	TOWN	Town Fork Creek	45e	STOKE-098	1981	40	27 [3]	T	C
	YADK	Little Yadkin River	45e	STOKE-060	1977	34	49	T	C

[1] Key to ecoregions (Griffith 2002): 66l: Eastern Blue Ridge Foothills, 45i: Kings Mountain, 45e: Northern Inner Piedmont, 45f: Northern Outer Piedmont, 66d: Southern Crystalline Ridges and Mountains, 66m: Sauratown Mountains, 66g: Southern Metasedimentary Mountains, 45b: Southern Outer Piedmont

[2] These sites and their watersheds were on or near the boundary between the Blue Ridge and Piedmont ecoregions. Site conditions were used to determine most appropriate category for this study.

[3] Acreage calculated using GIS and aerial photos.

[4] T = top-only release; B = bottom-only release; T,B = combined top and bottom releases

[5] Stream classifications are assigned by NC DWQ and designate the protected uses. All waters of the state are protected for basic uses (e.g., aquatic life, secondary recreation). Streams protected for only these basic uses carry a C classification. B waters are additionally protected for primary/organized recreation. WS-I and WS-II are additionally protected for use as water supplies. The supplemental classification Tr indicates an additional protected use for trout survival and reproduction. HQW and ORW indicate waters of high or outstanding quality. NSW indicates designated nutrient-sensitive waters.

Two project sites have been monitored by the NC DWQ ALMS program: REED and BEE. REED has been monitored since 1991, and has shown increases in overall enrichment since that time. Noted issues for this lake include lower water clarity, algal blooms, and infestations by the invasive aquatic plant, *Hydrilla* (NC DWQ 2011b). This site was previously impaired for aquatic weeds and a TMDL has been developed (NC DWQ 2006). BEE was last sampled in 2007 (NC DWQ 2008) and was found to generally have low productivity, though this increased slightly in late summer due to an increase in chlorophyll-*a* and a decrease in water clarity. It is currently listed as fully supporting its designated uses.

Chemical field and analytical sampling methods

All samples and measurements at stream stations (A and D) were taken just below the water surface in well-mixed areas. Chemistry samples at B and C were collected as spatial composites over the photic zone (defined as twice the Secchi depth). Field measurements at B and C were taken as a vertical profile, starting just below the surface and repeated at every meter to bottom. All samples and measurements were taken in accordance with NC DWQ standard operating procedures (NC DWQ 2011b, NC DWQ 2012a). Samples that were non-detects (ND) were reported as <Reporting Limit (RL). Data from NDs were analyzed using the reported RL.

Assessment of impoundment trophic level was determined using the NC Trophic State Index (NCTSI), an empirically-derived metric that was developed specifically for NC and is currently used by the NC DWQ ALMP (NC DWQ 2012a). This dimensionless numerical score reflects the level of nutrient enrichment (eutrophication) within assessed lakes and impoundments.

Calculation of the NCTSI uses the following equation:

$$NCTSI = TON_{Score} + TP_{Score} + SD_{Score} + CHL_{Score}$$

where:

TON_{Score} = ((Log(total organic nitrogen in mg/L) + 0.45)/0.24) * 0.90
TP_{Score} = ((Log(total phosphorus in mg/L) + 1.55)/0.35) * 0.92
SD_{Score} = ((Log(Secchi depth in inches) - 1.73)/0.35) * -0.82
CHL_{Score} = ((Log(chlorophyll-*a* in ug/L) - 1.00)/0.48) * 0.83

Ammonia (NH_3) was not sampled in this study so TON was estimated with TKN, which runs the risk of slightly overestimating TON since TKN contains not only organic nitrogen but ammonia (NH_3) as well. In well-oxygenated surface waters, the concentration of NH_3 is generally fairly low, as it is quickly oxidized to NO_2^- which in turn is oxidized to the more stable NO_3^-. The resulting score allows assignment of a trophic classification, with oligotrophic lakes and impoundments having the lowest primary productivity/nutrient enrichment. Hypereutrophic systems have the highest levels. Eutrophic systems have the potential for degradation of water quality, with symptoms including algal blooms, fish kills, or excessive sedimentation, and are more common in the Piedmont ecoregion of the state (NC DEHNR 1992).

Table 2 NC Trophic State Index (NCTSI) scores and associated trophic level classifications

NCTSI Score	Trophic classification
< -2.0	Oligotrophic
-2.0 - 0.0	Mesotrophic
0.0 - 5.0	Eutrophic
> 5.0	Hypereutrophic

This project calculated the NCTSI for each sampling station (2/impoundment) to examine relative changes within the impoundments sampled. This differs slightly from the ALMS program, which calculates a single NCTSI based on average nutrient, Secchi depth, and chlorophyll-*a* values from all sampling stations on a single waterbody.

Temperature data loggers

In addition to temperature measurements taken during field visits, Onset HOBO Pendant UA-002-64 data loggers were deployed at stations A, C, and D at each site and temperature recorded every 30 minutes from the period of May 2011 to May 2012. In stream sections, data loggers were attached to rebar that had been driven into the bed in a flowing section of the stream. In impoundments, they were suspended below a small buoy. Data were retrieved in the field several times throughout the project using an Onset HOBO waterproof shuttle. The loggers were immediately re-deployed after download. Data were downloaded from the shuttle to a PC in the office using Onset HOBOWARE software, exported to text files, and compiled into a single data set for analysis.

Benthic macroinvertebrate sampling

NC does not have associated water quality standards for biological communities, though bioclassifications developed from benthos data are commonly used by NC DWQ for assessments of aquatic life use support. While NC DWQ has standard methods for stream assessment using benthic macroinvertebrate community sampling, these methods are only applicable to flowing, lotic systems and are not adaptable to lentic systems, since the targeted habitats simply do not exist in impoundments and lakes.

This study selected alternative methods based on sampling known areas at each location to enhance data comparability between lotic and lentic stations. Sampling known areas and single habitats in streams is currently relatively uncommon for regulatory agencies, but it is the primary method used for quantitative sampling of both streams (using a Surber sampler) and lakes (using a Ponar dredge) in the literature (Merritt 2008). Guidance exists for lake and reservoir assessments using dredge samples (US EPA 1998) and rapid bioassessment methods state that Surber sampling is still appropriate for regions with cobble-dominated substrates and riffle/run habitats (Barbour 1999). Similar methods are still in use for lake sampling in Florida (Fore 2007) and estuaries (MD DNR 2009), and have been used in other recent studies (Santucci 2005). Many lentic-adapted species do exist (Merritt 2008), but characterization of expected taxa and their relative abundance has not been performed by NC DWQ.

At stream stations (A and D), a Surber sampler with an opening measuring 12”x12”was used for sample collection. This sampler combines a vertical drift net with a metal frame as its base. The base was set firmly in the substrate with the net opening facing upstream. Within the frame, the bed was disturbed for approximately 30 seconds and large rocks and logs were scrubbed to dislodge any organisms, which would then drift into the net. This is very similar to using a D-frame net for collecting a kick sample but the use of the Surber sampler ensures that a consistent and quantifiable area of habitat is sampled at each location. Two or three subsamples were taken at each station, the number of subsamples was recorded, and subsamples composited. The final sample consisted of the organisms and detritus in the net, which were removed and placed in a container and preserved with 70% ethanol.

At lentic stations, sample collections consisted of deploying a petite Ponar dredge with an 8” x 8” opening from a small boat. Field staff selected sampling locations that were in or near the historic (now flooded) channel. The dredge was dropped and the sediment sample was retrieved. Several dredge samples were taken at each location due to the anticipated low density of organisms and the number of samples was recorded. Samples were rinsed on-site in a D-frame net to remove fine sediments. All dredge samples for a particular station were composited into a single sample container and preserved with 70% ethanol.

All samples were transported to the lab in Raleigh, NC. Project staff picked the individual samples (i.e., removed macroinvertebrates from sediment and debris), transferring all organisms found to a labeled vial of 70% ethanol. Each station's samples were then identified by a trained NC DWQ aquatic entomologist to the lowest practical taxonomic level. For Ephemeroptera, Plecoptera, Trichoptera, Odonata, Coleoptera, and Megaloptera, this was generally the genus or species level. Diptera (including Chironomidae) and Mollusca were generally only identified to genus level and Oligochaetes to the family level. For each station, the biologist provided project staff with a taxa list, number of individuals for each taxon, and the corresponding tolerance value (TV) for each taxon (NC DWQ 2010c). The data for each location were then normalized by dividing the number of individuals of each taxon by the total area that was sampled. The area-normalized data (number of individuals/m^2) were used for data analysis.

Data analysis was a modification of the NC DWQ biotic index (BI) calculation (NC DWQ 2010c). The standard method uses relative abundance, where rare taxa (1-2 individuals/sample) are assigned n=1; common taxa (3-9 individuals/sample) assigned n=3; and abundant taxa (>9 individuals/sample) assigned n=10. Final BI for a sample is then calculated as: $\frac{\sum (TV_i)(n_i)}{N}$ where TV_i is the tolerance value for each taxa i (ranging from 1.0-10.0, with lower numbers indicating less tolerant taxa); n_i is the number of individuals observed for taxa i; and N is the total number of individuals within the sample. The analysis was adapted such that the total, normalized numbers of individuals per unit area (n/m^2) were used for n_i in the calculation of the BI, rather than a relative abundance. Also, in cases where a sample contained no organisms, they were treated as “non-detects” (analogous to non-detects in analytical chemistry results) and assigned a value equal to the “detection limit”, i.e., equivalent to a single individual with the highest TV (10.0) being found within a sample. Given the differences in sampling methods and BI calculation, these data are not appropriate for application of bioclassifications (rating Excellent, Good, Good-Fair, Fair, or Poor), but relative differences in BI are still valid for comparison of impoundment and downstream stations to upstream/reference.

Stream habitat assessments
A standard NC DWQ Habitat Assessment protocol (NC DWQ 2010c) was used. The Mountain/Piedmont version of the form was used at all sites. The method assesses channel modification, instream habitat types and quality, bottom substrate composition, embeddedness, pool and riffle frequency and quality, bank vegetation and stability, and vegetated riparian zone width and quality. It provides a numerical score ranging from 1 to 100, with higher values associated with better instream and near-stream conditions. Only lotic stations (A and D) were assessed, as the method is not applicable to lentic systems.

Periphyton biomass
Periphyton biomass was included as an additional enrichment response metric that could be performed at all sampling stations and would complement the measurement of chlorophyll-*a*, a surrogate indicator for phytoplankton. For our study, artificial substrates (ceramic tiles) were attached to cinder blocks using epoxy cement. The blocks were then deployed in May 2011 at three stations at each site: stations A and D, and within

the impoundment, near the shore and at a similar depth to the lotic stations. These were retrieved after 2-3 weeks. Tiles were removed from the cinder block, individually placed in zipper-type storage bags, labeled, and placed on ice. Samples were transported to the NC DWQ Algal and Aquatic Plant Assessment Program lab and frozen (stored at <0°C) until analysis to minimize chances of additional algal growth. To prep samples for analysis, all growth on the face of the tile was removed using a razor blade, synthetic tooth brush, and deionized water. Rinsate was collected in a large beaker. Once the tile appeared to be clean, the rinsate was brought up to a known volume (generally 300mL) and the volume recorded. Tile area was measured and recorded. All replicates from each sampling location were kept separate. Samples were stored at 4°C until they could be analyzed the following day. Gravimetric analysis was performed according to Standard Methods for Ash-Free Biomass (Standard Methods 1998; method 10300 Periphyton), but basically consisted of filtering a volume (generally 100mL) of the sample through a prepared (pre-ashed and weighed) glass fiber filter, drying at 180°C to constant mass, weighing, igniting at 500°C in a muffle furnace to burn off organic material, and re-weighing. Analytical duplicates were performed for 1 out of every 12 samples. Results were corrected for the volume filtered and the tile area and reported in g/m^2.

Screening criteria

NC has a number of numerical water quality standards for chemical and physical constituents of the waters of the state, including for temperature, dissolved oxygen concentration, pH, TSS, and chlorophyll-*a*. These are used for determining use support assessment (303(d)/305(b)) reporting activities (detailed in NCDWQ 2010b). Additional screening criteria that do not have associated water quality standards are used throughout this document as appropriate. This includes screening values for specific conductance that were previously developed by the NC DWQ. Specific screening values and their sources are noted in the appropriate areas of the Results and Discussion section.

GIS data sources and analyses

The field-collected latitudes and longitudes for the sampling stations were downloaded and converted to an ESRI ArcGIS 9.3.1 shapefile. Watershed boundaries for each sampling station were produced using the ESRI ArcHydro data model and the upstream contributing areas were calculated. The base Digital Elevation Model (DEM) source was the National Elevation Dataset (NED) 1-arc-second DEM, which was re-projected to NC State Plane meters and then pre-processed to fill sinks (depressions in the DEM). Land use and percent imperviousness for each watershed were derived from the National Land Cover Database (NLCD) 2006. Categories used were the standard NLCD Class/Values: Water, Developed, Barren, Forest, Shrubland, Herbaceous, Planted/Cultivated, and Wetland. Percent coverage for each of these categories was calculated in ArcGIS.

In NC, stream reaches are assigned unique identifiers (the AU number) and appropriate stream classifications. These determine the applicable protected uses and therefore the water quality standards that they must attain. The stream classifications were obtained from the latest ArcGIS shapefile (downloaded from the NC DWQ Planning Section, http://portal.ncdenr.org/web/wq/ps/csu/maps, accessed September 2012). During this process it was found that several sampling locations were actually not depicted on the shapefile. In these cases, they were assigned the stream classification of the first downstream waterbody shown on the GIS layer.

Data analysis

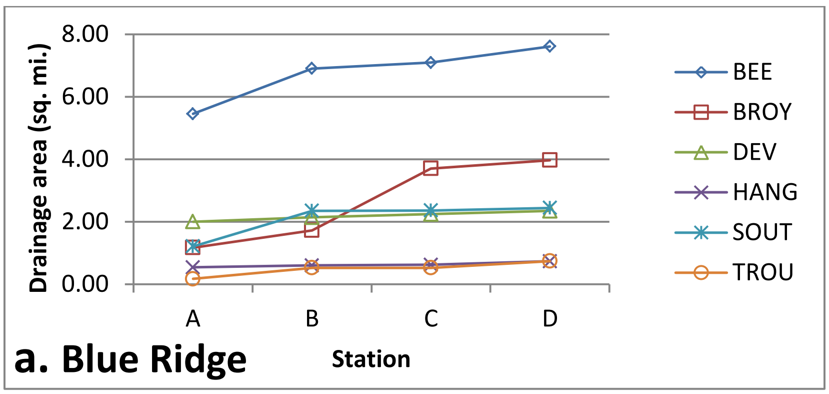
Data analyses were performed using SAS JMP 10.0 statistical software. Summary statistics were calculated and distributions visually examined. Statistical comparisons of distributions of individual variables were performed using non-parametric methods (Kruskal-Wallis, Spearman's ρ). Matched pairs analyses between each site's upstream reference and corresponding impoundment and downstream stations were performed using the Wilcoxon Signed Rank test, a nonparametric equivalent to the paired t-test for mean differences. The Kruskal-Wallis and Wilcoxon tests are based on ranking data rather than comparing measures of central tendency, and so reduce the assumptions (e.g., normal distributions; equal variances) required for the data set and also have the added benefit of being relatively insensitive to outliers or extreme values. Unless otherwise specified, a significance level of α=0.05 (e.g., a confidence limit of 95%) was used.

III. Results and Discussion

Site characteristics

This section provides summaries of site characteristics; more detailed station information and maps (including aerial photographs) are provided in Appendix 2.

Drainage areas at downstream stations (D) ranged from 0.73 $mi.^2$ to 7.61 $mi.^2$ for Blue Ridge sites (Figure 5a). Piedmont sites in general had smaller drainage areas (range 0.36 $mi.^2$ to 4.67 $mi.^2$) (Figure 5b). When reviewing changes in drainage area from upstream to downstream at each site, the majority showed small, gradual increases. Exceptions included YADK in the Piedmont, and BEE, BROY, and SOUT in the Blue Ridge. These sites each had an additional tributary draining to the impoundments (see maps, Appendix 2). Changes in drainage area and stream order can cause natural variation in instream conditions and biological community structure (Vannote 1980).



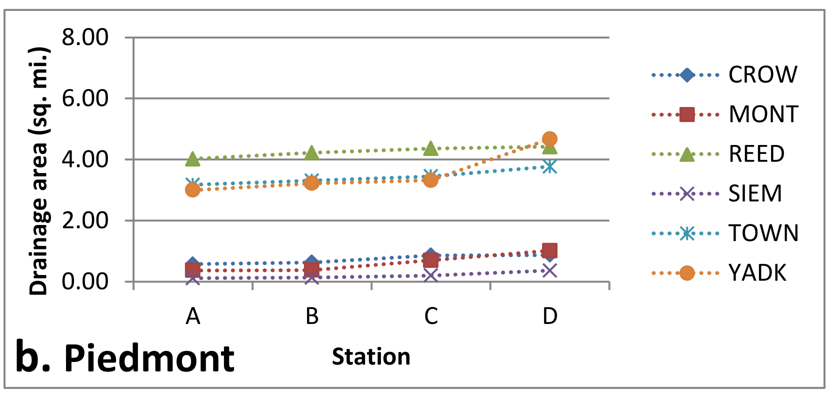
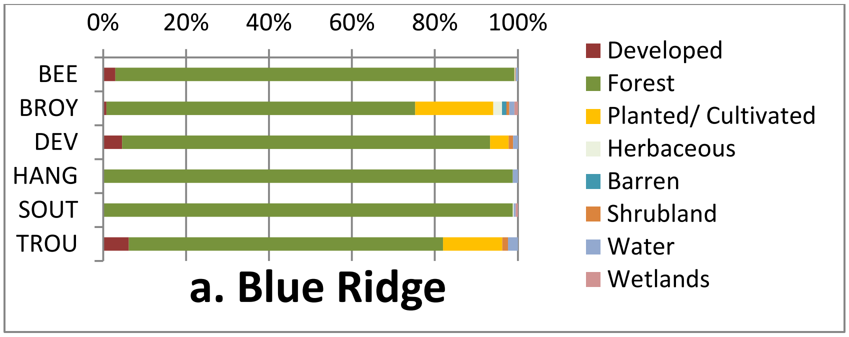


Figure 5 Drainage area (sq. mi.) for individual sampling stations for Blue Ridge (a) and Piedmont (b) sites

Land use within the Blue Ridge watersheds was predominantly forested. Small amounts of developed land use were seen at BEE (3.0%), DEV (4.6%), and TROU (6.2%). Planted/cultivated (agricultural row crops and pasture) was only seen in three Blue Ridge watersheds and ranged from 4.5-19%. Piedmont sites showed slightly more diversity in terms of land use, with REED and SIEM showing high developed land uses. The remaining Piedmont sites were dominated by forested land use. Planted/cultivated was seen in appreciable amounts (>5%) at three Piedmont sites (REED, TOWN, and YADK).



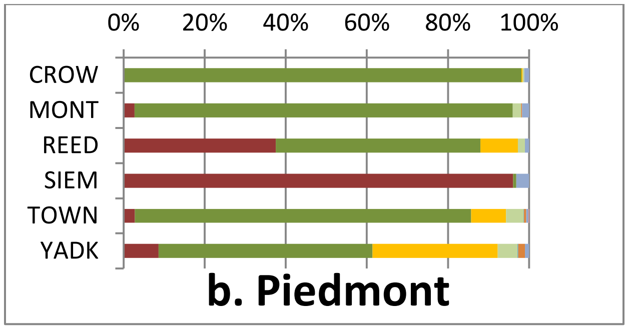


Figure 6 Watershed land class as percent of total area for Blue Ridge (a) and Piedmont (b) sites

Individual stations at each site did not show appreciable variation between the upstream and downstream stations (A and D), particularly for the three main land use classes of interest (developed, forested, planted/cultivated). MONT showed a 7.4 percentage-point decrease in forested land use at station D, but it still made up 89% of the landscape in this watershed. SIEM showed a 7.4 percentage-point decrease for developed land use, though it still made up 92.6% of watershed area at station D. Comparison of percentages of land use between upstream and downstream stations showed no statistically significant differences, so differences between stations at each site will more likely be due to another factor. Similarly, differences in response variables for between-site comparisons will likely be independent of land use for the majority of locations (exceptions include REED, SIEM, and YAD), due to the predominance of forested/natural conditions in the majority of watersheds.

Table 3 Change in watershed land use from upstream (station A) to downstream (station D) for developed, forested, and planted/cultivated classes.
Negative values indicate an overall decrease; positive values an overall increase; N/A indicates that that land use is not present in the watershed.

Ecoregion	Site	Percentage point change		
		Developed	Forested	Planted/ Cultivated
Blue Ridge	BEE	-0.6	-0.2	0.1
	BROY	0.4	2.5	-8.3
	DEV	-0.3	-1.0	-0.7
	HANG	0.4	-2.6	N/A
	SOUT	0.0	-1.9	0.1
	TROU	7.5	-6.3	-1.4
Piedmont	CROW	-0.0	-2.0	-0.1
	MONT	1.0	-7.4	N/A
	REED	-3.4	3.8	-0.9
	SIEM	-7.4	3.1	N/A
	TOWN	0.2	-0.6	-1.3
	YADK	-0.2	1.1	-4.2

Water chemistry

As noted in Methods and Materials, three sampling visits were completed during the growing season (June - October) of 2011 for most sites/stations, with four exceptions:

- BEE, stations B and C: Impoundment stations were not sampled during the late summer due to low water levels, which made boat launch impossible.
- MONT, station D: No late season sample due to lack of flow downstream of dam; there was no discharge from impoundment.
- SIEM, station A: No late season sample due to lack of water in channel.

The objective of this section is to provide an initial examination of overall upstream to downstream trends within the data set. Site- and station-specific issues are noted where relevant. Full data sets are provided in Appendix 4.

Chemistry data were analyzed by ecoregion because of basic differences in baseline conditions due to physical differences (such as geology, climate, and slope) between the two physiographic regions. The majority of graphs show distributions by sampling station for each parameter using box-and-whisker plots. A blue line is used to connect the means for each station to facilitate with identifying upstream-to-downstream changes. Note that though the means are provided, the statistical analysis method used was a non-parametric method based on data ranks and is the more appropriate method for determining significant differences between stations. All matched pairs results are included in Appendix 3.

Data are graphically presented using a consistent symbology for sites. The legend shown in Figure 7 is applicable to all graphs in the Water Chemistry section unless otherwise noted.

Marker	Ecoregion	Site code
○	Blue Ridge	BEE
□	Blue Ridge	BROY
◇	Blue Ridge	DEV
×	Blue Ridge	HANG
△	Blue Ridge	SOUT
+	Blue Ridge	TROU
•	Piedmont	CROW
■	Piedmont	MONT
◆	Piedmont	REED
▼	Piedmont	SIEM
▲	Piedmont	TOWN
▶	Piedmont	YADK

Figure 7 Master legend for graphs

Field measurements

NC has numerical water quality standards associated with DO concentration, pH, and temperature; these will be used for comparison in this section. Discussion of additional temperature data from long-term data logger deployment are discussed in a later section ("Water temperature, annual patterns").

Unless otherwise stated, comparisons between lotic and lentic sites were made using near-surface (depth ≤0.5m) readings. It can be safely assumed that lentic waters, such as the impoundments studied, generally have some level of stratification throughout most of the year, with deeper waters being lower in DO, near-surface waters exhibiting changes in pH in response to algal blooms, and a continuum of temperature readings with generally more stable temperature regimes near-bottom. In order to make "apples-to-apples" comparisons only surface readings are being used for this section, with the exception of an additional analysis of D.O.

The NC water quality standard for pH (15A NCAC 02B .0211) states that pH should be normal for waters of the area, generally between 6.0-9.0 s.u. Surface pH readings were all within this range (Figure 8). High values (>8.0 s.u.) were recorded at several stations at the Blue Ridge sites HANG and BROY and at the Piedmont site REED. When comparing matched pairs analysis on individual sites (e.g., impoundment and downstream stations vs. upstream/reference for each sampling visit), the only significant difference found was a decrease in pH when comparing downstream (D) to lower impoundment (C) for Blue Ridge sites. Overall, lotic pH readings (including upstream/reference stations) seemed slightly elevated in the Piedmont; median values are generally at or below 7.0 for streams in this region of the state (NC DWQ 2012b).

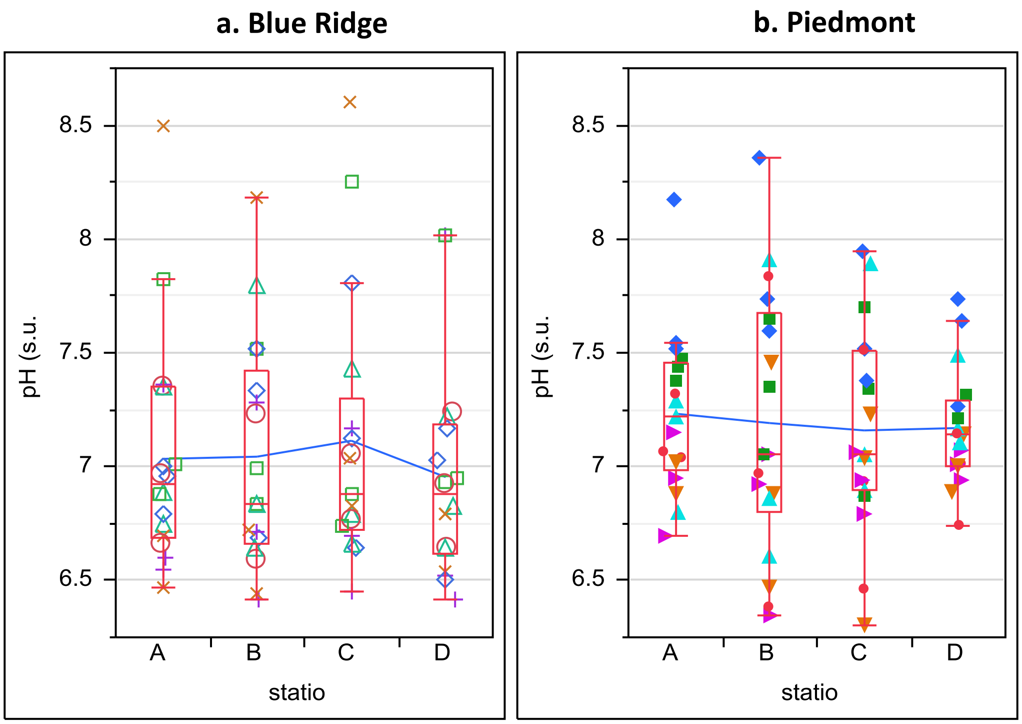


Figure 8 pH (s.u.) distributions by station for Blue Ridge (a) and Piedmont (b) sites.

Specific conductance (SC) is often considered a quick, inexpensive, and reliable relative measure of water quality. There is great natural variability due to, for example, geology and soils, so it has no associated water quality standard in NC. Past work by NC DWQ has shown that this measurement correlates well with bioclassifications from benthic macroinvertebrate community assessments in the Blue Ridge and Piedmont ecoregions (Gale 2011) and screening values were developed for “High Quality Waters", "Waters of Concern", and "Indeterminate Waters" (Table 4). These will be used as benchmark values for this report.

Table 4 Specific conductance (µS/cm at 25°C) screening values developed for NC streams.

Ecoregion	High Quality	Indeterminate	Waters of Concern
Blue Ridge	<41	41-66	>66
Piedmont	<78	78-229	>229

For upstream/reference (A) and impoundment (B, C) stations in the Blue Ridge (Figure 9a), nearly all values were below the "high quality" criteria of 41 µS/cm at 25°C, though several high readings were noted (all from BROY). A large overall jump in specific conductance was noted downstream (D) and several readings (from BROY and BEE) were at or above the upper "Waters of Concern" criterion of 66. The jump for BEE is notable as upstream values were quite low. BEE's watershed is almost completely forested due to its use as awater supply for the city of Asheville, NC. Matched pair analysis confirmed a significant increase at downstream stations (D) as compared to impoundments (B-C).

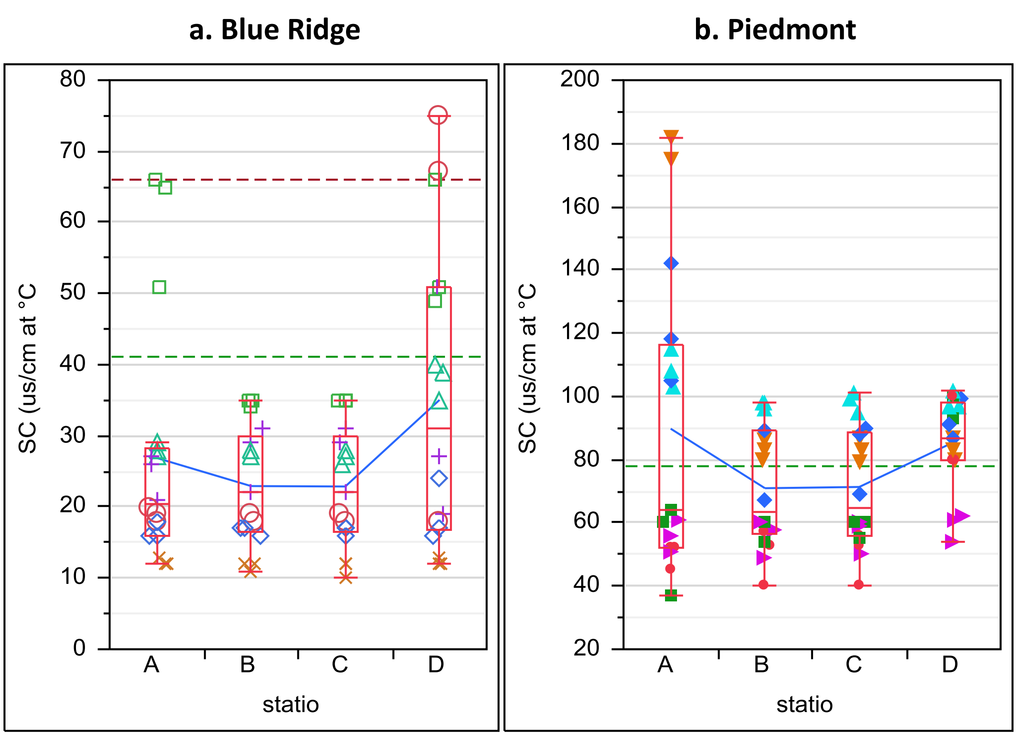


Figure 9 Specific conductance (uS/cm at 25°C) distributions by station for Blue Ridge (a) and Piedmont (b) sites. Green dashed line represents upper screening value for high quality waters; dashed red line represents lower limit of waters of concern (not shown for Piedmont).

As expected, Piedmont sites (Figure 9b) showed higher SC values than the Blue Ridge, though the median values for A, B, and C were below the ecoregion's high quality water criterion (78 µS/cm at 25°C). Downstream (D) was the only location to have a median value above this screening value. High background values for SC occurred upstream (A) at the sites showing high percentages of developed land use (REED, SIEM) as well as one location that had been inundated by beaver dams (TOWN). The impoundments (B, C) seemed to mitigate for these high values, which was confirmed with matched pairs analysis, though SC at the downstream (D) station showed a significant increase over the values seen in the impoundment. No changes were detected within the impoundments.

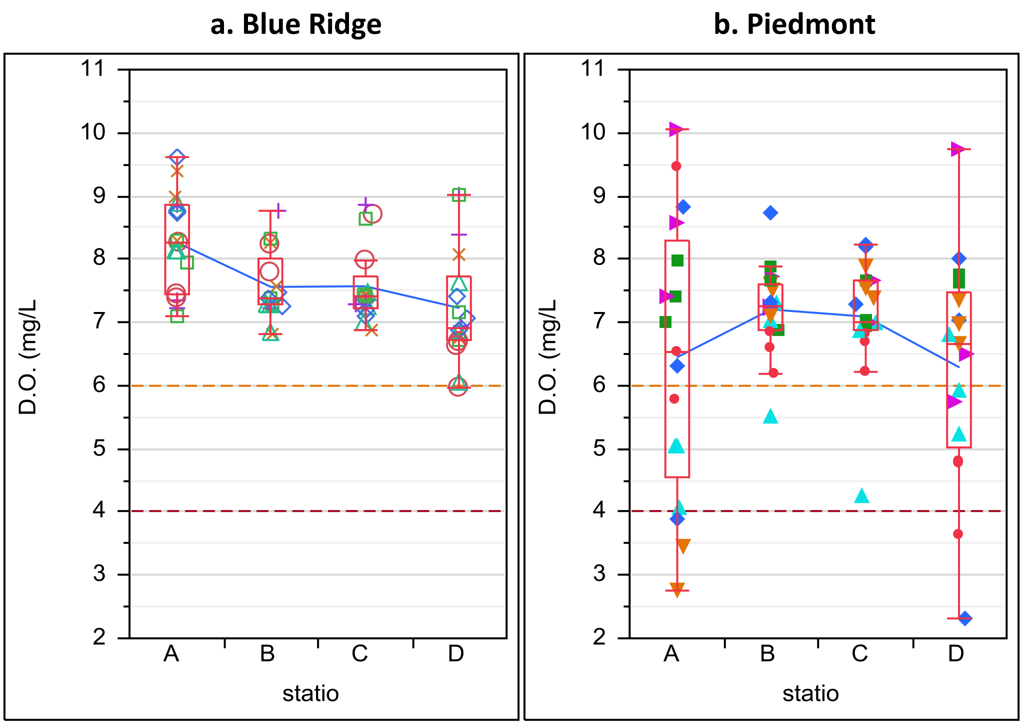


Figure 10 Dissolved oxygen (D.O.) concentration (mg/L) distributions by station for Blue Ridge (a) and Piedmont (b) ecoregions.
The orange dashed line corresponds to the NC water quality standard of 6.0 mg/L for designated Trout waters; the red dashed line corresponds to the NC water quality standard of 4.0 mg/L for all waters of the state.

Surface D.O. levels (Figure 10a) for Blue Ridge sites were good overall with a grand mean of 7.7mg/L, though concentrations as compared to upstream (A) were significantly lower at all other stations (B, C, D). No values below applicable water quality standards (6.0mg/L for designated Trout waters; 4.0mg/L for all other waters) were recorded.

Piedmont sites showed a slightly lower overall grand mean for D.O. (6.8mg/L), due in part to some very low values seen at upstream and downstream lotic stations (A, D), including several values below the water quality standard of 4.0mg/L. The only bottom release dam (CROW) had some of the lowest downstream D.O. readings. Matched pairs analysis indicated a significant increase within the impoundment (both B and C) compared to upstream (A) and a corresponding decrease downstream (D) as compared to the impoundment (B and C). A possible explanation for this increase may be increases in algal activity within these impoundments.

Within impoundments, it was expected that as depth increased, DO concentration would decrease and low oxygen or anoxic conditions would be expected to naturally occur near the bottom. However, when plotting D.O. by depth and station (Figure 11). , D.O. levels reach concentrations below applicable water quality standards at very shallow depths in certain cases. Exceedences of both the C and Tr standards began occurring at just over 2m in depth in the Blue Ridge; this is particularly troubling given the relatively high background levels (median 8.2mg/L) seen at the upstream stations in this ecoregion. Relatively shallow poorly oxygenated waters were also seen at Piedmont sites, though these may be at least in part due to low oxygen levels at upstream sites.

a. Blue Ridge **b. Piedmont**

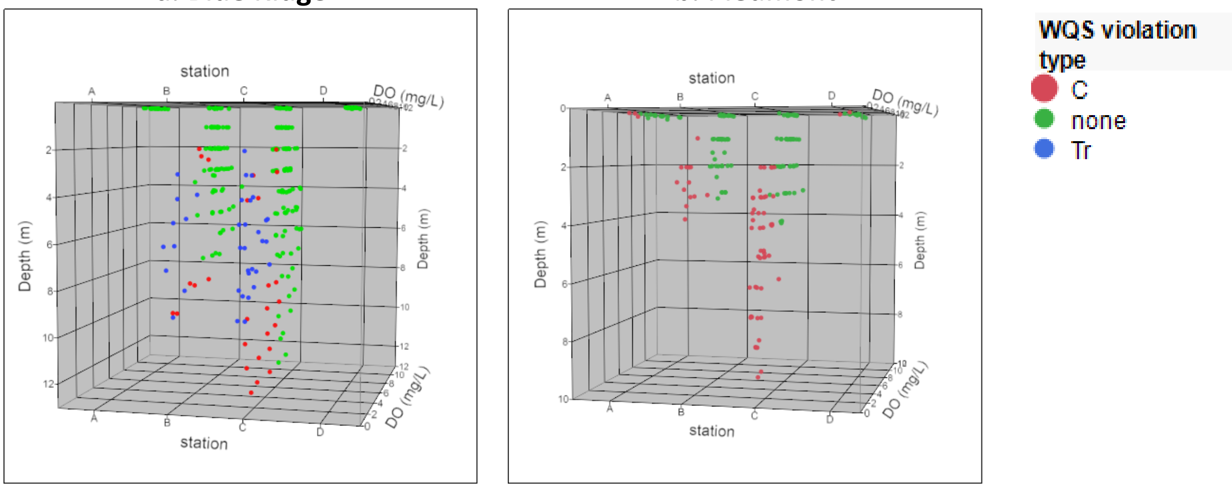


Figure 11. Dissolved oxygen (DO) concentrations (mg/L) by depth for stations A-D, for Blue Ridge (a) and Piedmont (b). Green markers indicate that applicable water quality standard is being met; red markers indicate that C class instantaneous reading is not being met; blue markers indicate that neither the C nor Tr instantaneous values are being met (for waters classified as Tr only).

Water temperature will be dealt with more thoroughly in a later section, but a summary of surface field measurements is presented in Figure 12. As would be expected when converting a flowing lotic system to a slower and less shaded lentic system, temperatures rose significantly within the impoundments for all sites. Though overall Piedmont sites tended to be warmer, overall upstream to downstream patterns were nearly identical for both ecoregions, suggesting that this parameter responds similarly regardless of the area of the state. Impoundments were significantly warmer than upstream. Below the impoundments, temperatures, though cooler than within impoundments, were still significantly different from upstream (A). Piedmont sites also showed a significant increase within impoundments (C > B). It should be noted that the increase in temperatures in downstream locations was likely not affected by canopy; habitat assessments (discussed in a later section) did not show a clear pattern of loss or gain in relative canopy cover between upstream and downstream stations which suggests that warmer water is being discharged from the impoundment.

The associated water quality standards for temperature vary depending on the area of the state (mountains and upper piedmont [MUP] or lower piedmont [LP]) and stream classification. MUP waters have a maximum allowable temperature of 29°C, LP maximum is 32°C, and designated trout (Tr) waters (such as sites DEV and TROU) have a maximum allowable value of 20°C. Piedmont sites showed few exceedences of the LP standard, and all were at SIEM. Exceedences of the MUP standard occurred at Blue Ridge sites BROY and SOUT. Of more concern was the relatively common occurrence of the exceedence of the trout standard at DEV within and below the impoundment (B, C, and D). TROU also exhibited exceedences within the impoundment (B and C).

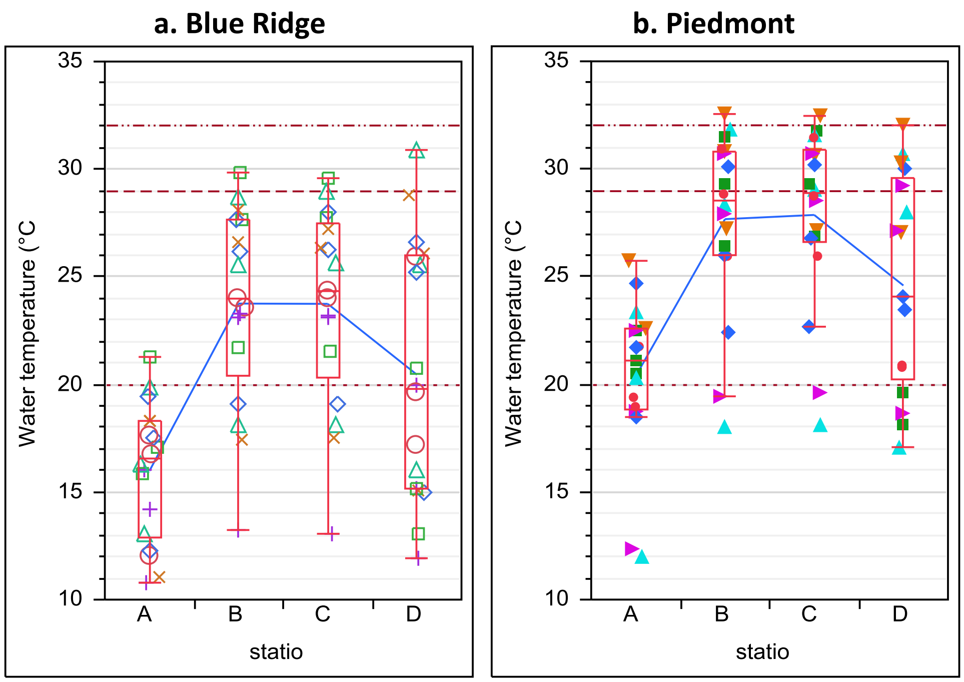


Figure 12 Water temperature (°C) distributions by station for the Blue Ridge (a) and Piedmont (b). The dashed lines represent the water quality standards for Trout waters (20°C), Mountain/Upper Piedmont (29°C), and Lower Piedmont (32°).

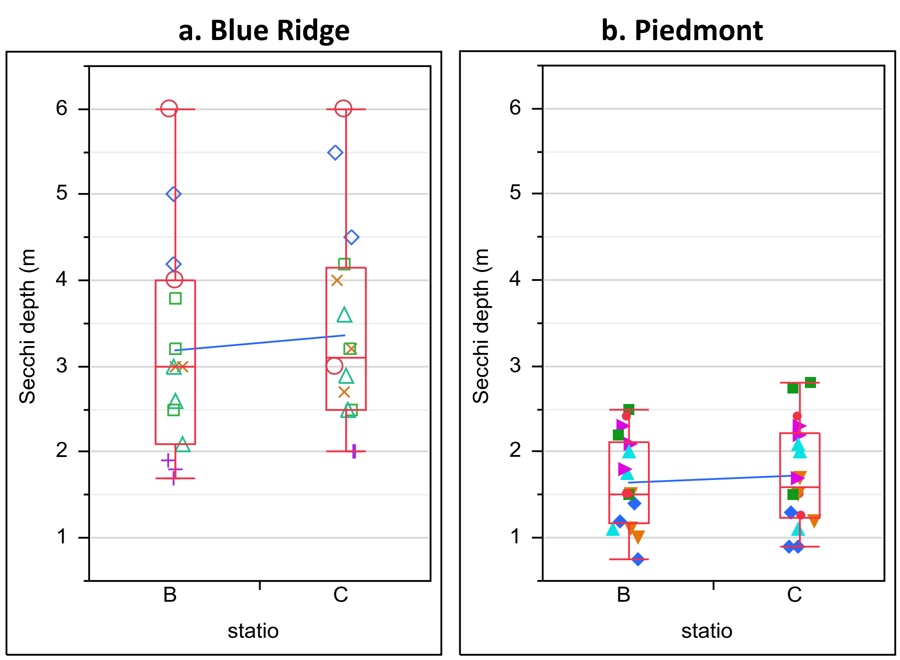


Figure 13 Secchi depth (m) distributions by station for Blue Ridge (a) and Piedmont (b).

Secchi depth (Figure 13) was taken only at impoundment sites (B, C). Higher water clarity is indicated by higher depths. Matched pairs analysis indicated a significant increase in Secchi depth at C for Blue Ridge sites. These impoundments tended to be deeper as well.

Suspended residues

Total suspended residue results were predominantly reported by the NC DWQ Laboratory Section as non-detects (NDs; 73% of samples). While the majority of these were reported using a detection limit of 6.2 mg/L, 11% of the total number of samples (15 of 140) were reported as <12.0 mg/L due to laboratory QA procedures related to duplicate analyses. This varying reporting limit adds additional uncertainty; statistical analyses presented in this section should be interpreted with care.

Blue Ridge sites overall showed low TSS concentrations (Figure 14a), with almost all samples within the impoundments being reported as NDs. Downstream (D) stations showed a larger proportion of detectable levels of TSS, ranging from the detection limit (6.2) to 16mg/L. Piedmont sites (Figure 14b) had a larger proportion of reportable concentrations. In this case, a clear pattern of lower values within the impoundments (B, C) was noted and confirmed using matched pair analysis. Both upstream and downstream sites had cases of high TSS values (>50mg/L). The two highest values noted were from CROW during the September sampling event (A: 130 mg/L; D: 255 mg/L), and this site had a consistent pattern of TSS results at D that were greater than the upstream site. This was the only location with a bottom release. While the change in flow regime of impoundments naturally encourages settling of suspended sediments, the bottom release at this location may be moving sediments back into suspension below the dam.

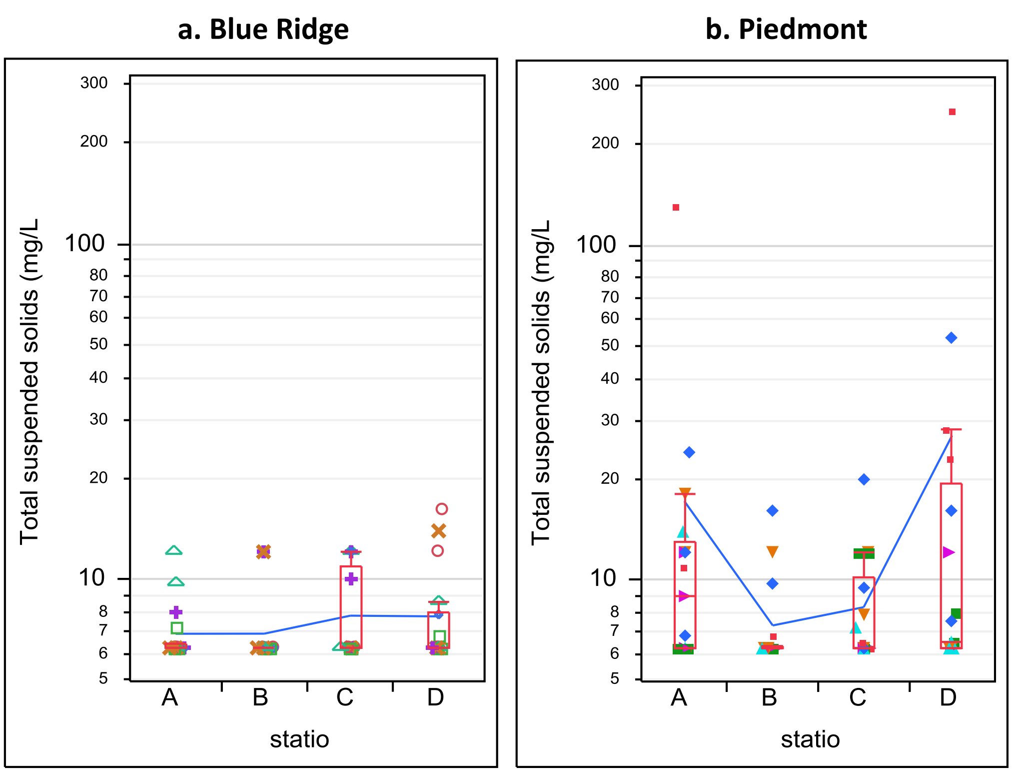


Figure 14 Distributions of total suspended sediment (TSS) concentration (mg/L) by station for Blue Ridge (a) and Piedmont (b).

Nutrients

Relatively large percentages (64-71%) of results were reported as non-detects (NDs) for nitrite + nitrate (NOx) in both ecoregions (primarily impoundment stations; reporting limit [RL] 0.02mg/L) and for total Kjeldahl nitrogen (TKN) in the Blue Ridge (RL 0.20mg/L).

TKN (mg/L as N) showed an apparent increase within impoundments as compared to upstream reference in both ecoregions. For station D, Blue Ridge sites for the most part exhibited a drop in TKN except at BROY (a combined release dam), which exhibited an increasing trend from upstream to downstream. In the Piedmont, TKN was significantly increased from upstream for sites B, C, and D and there was not a significant change at D as compared to impoundment sites. All values >1.0 from D stations were from CROW (an entirely forested catchment; bottom release only) and REED, though the single high background value at A was also from CROW. Since TKN includes ammonia (NH_3) as well as organic nitrogen, it is possible that the elevations at CROW-D were due to higher NH_3 concentrations due to the bottom release, though the upstream spike suggests that another source for TKN may be present within this watershed

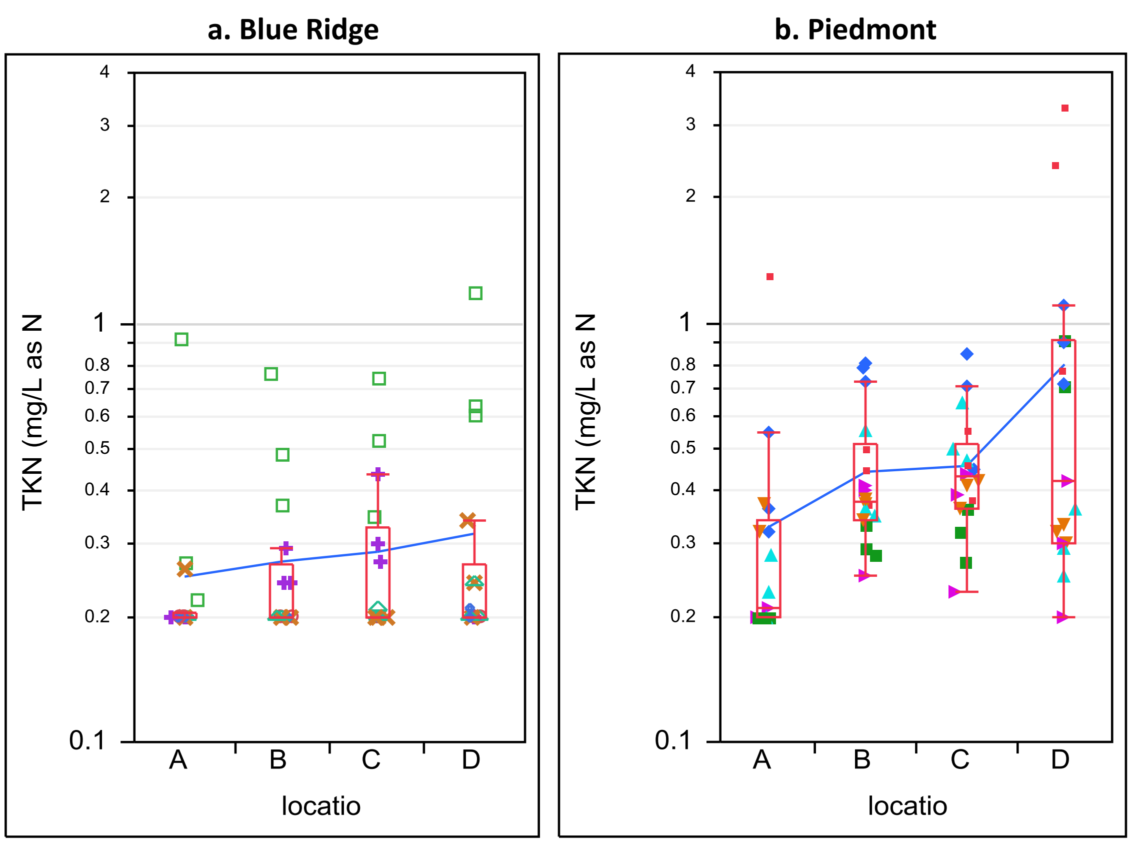


Figure 15 Total Kjeldahl nitrogen (TKN; mg/L as N) distributions by station for the Blue Ridge (a) and Piedmont (b). Note log scale on y-axis.

NOx (mg/L as N) was lower in the impoundments as compared to upstream (Figure 16), possibly due to conversion to another form of nitrogen. NOx is the most readily bioavailable form of nitrogen, so the drop may be due to uptake by aquatic plants or phytoplankton. The concentration of NOx was rarely measurable at stations B and C within either ecoregion, though values increased above RLs below the impoundments. For both ecoregions these levels represented a significant decrease below upstream concentrations. The high upstream values of NOx at Blue Ridge sites were from those that contained some planted/cultivated land use (BROY, TROU). Concentrations of NOx were elevated at BROY-A, compared with other Blue Ridge sites during each of the three sampling visits, suggesting that results are not due to acute applications of fertilizers but to more chronic conditions, such as the presence of pastured livestock in the watershed. For the Piedmont, REED and YADK showed the highest upstream concentrations; these were 2 of the 3 Piedmont sites that contain planted/cultivated land use. A similar pattern for NOx was seen for Blue Ridge sites: almost all concentrations dropped to or near the RL, though values were generally low even at the upstream site.

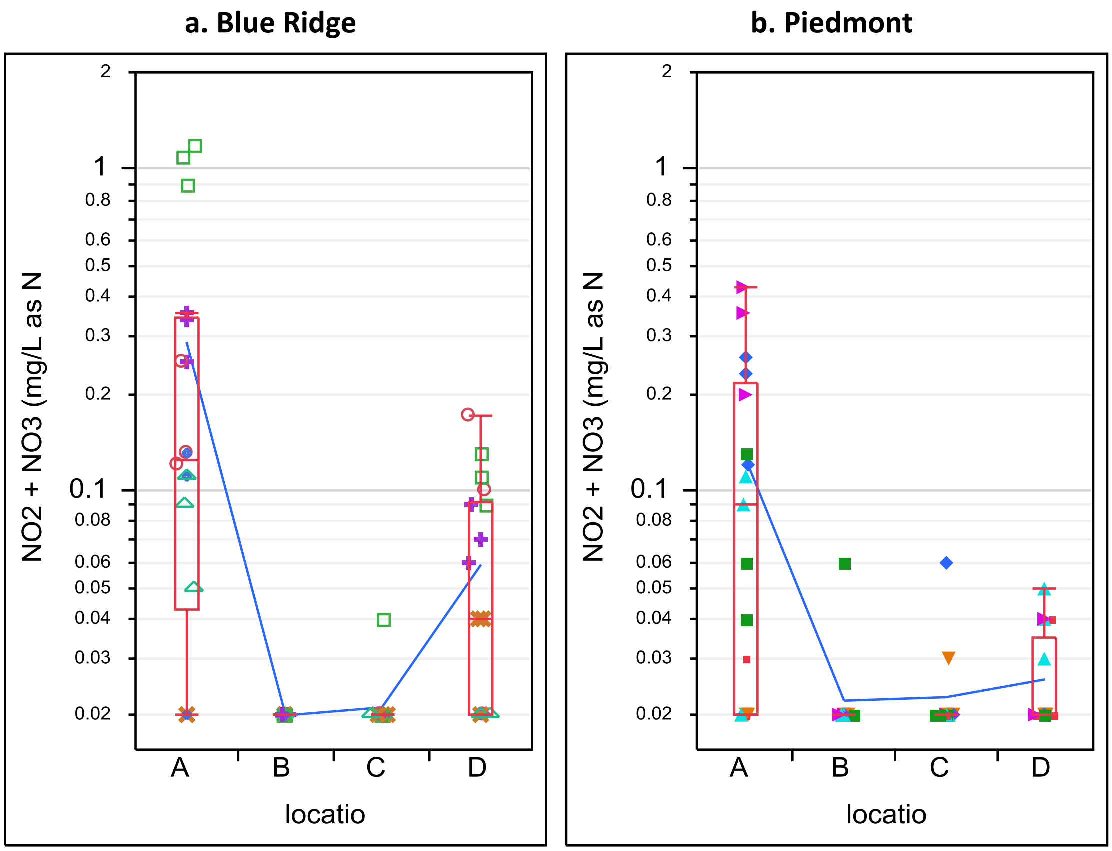


Figure 16 Nitrate + nitrite (NOx; mg/L as N) distributions by station for the Blue Ridge (a) and Piedmont (b).

Across all Blue Ridge sites, total phosphorus (TP, mg/L as P) (Figure 17) dropped to or near the detection limit of 0.02mg/L within the impoundment, a significant decrease compared to A. While the graph seems to suggest an increase below the dam, this was not statistically significant. TP at Blue Ridge lotic stations (stations A and D) was highest at BROY, which was one of the sites with appreciable planted/cultivated land use. Instream concentrations were higher in the Piedmont, with the only significant differences occurring between downstream (D) and the impoundment (B only). High lotic values were seen for REED and SIEM (both of which had relatively large percentages of developed land use), but the highest values were from CROW, and entirely forested watershed. Also of interest is that YADK, with a mix of developed, planted/cultivated, and forested land use, showed consistently low TP concentrations.

The minimal overall significant changes in TP between stations (i.e., concentrations are fairly consistent as you go from upstream to downstream) suggest that it is not acting as the limiting nutrient, as is usually assumed to be the case in lentic systems.

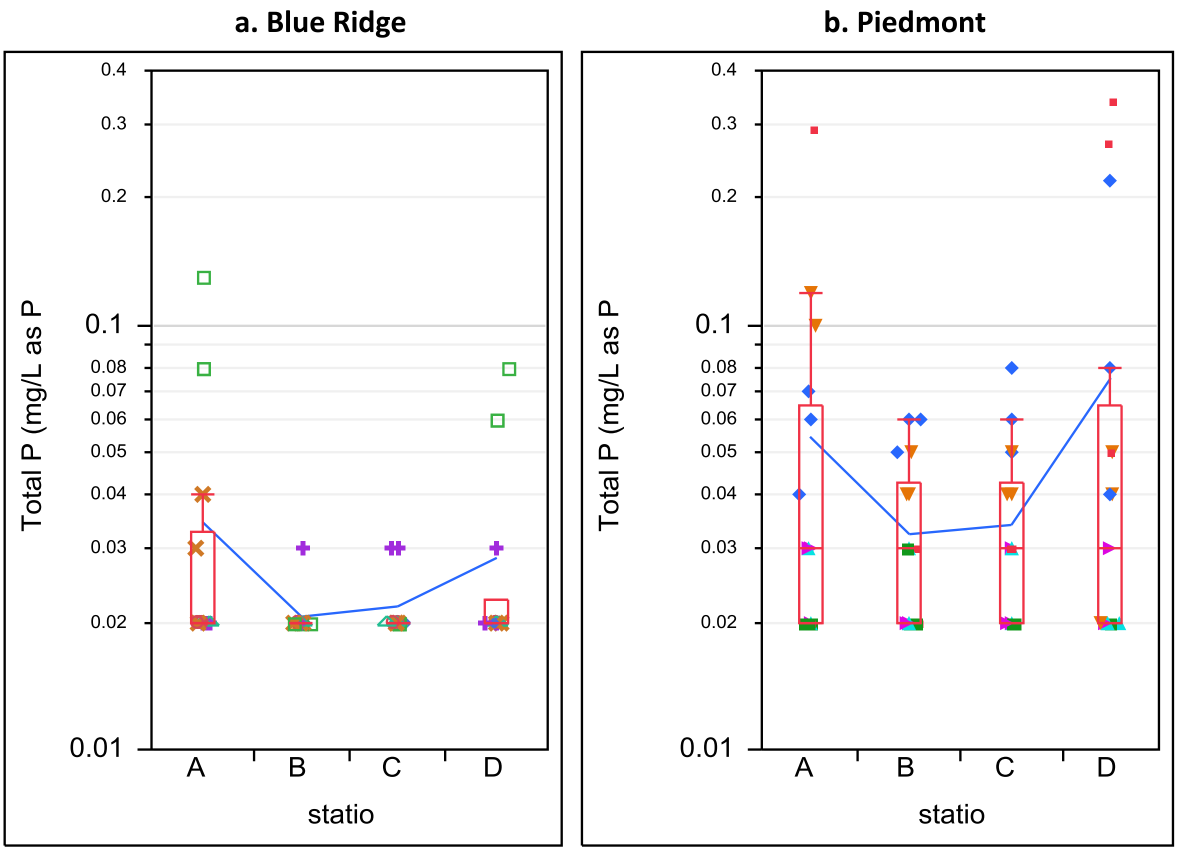


Figure 17 Total phosphorus (TP; mg/L as P) distributions by station for the Blue Ridge (a) and Piedmont (b).

Chlorophyll-a

NC water quality standards associated with chlorophyll-*a* are a maximum allowable concentration of 40 µg/L for all waters of the state, and a more stringent limit of 15 µg/L for those impoundments which carry the Tr (trout) supplemental classification. This second limit is applicable to two of the Blue Ridge sites, DEV and TROU.

Both ecoregions showed identical patterns of low concentrations in the upstream reference reaches (A) and significant increases in the impoundment not only as compared to A but also between impoundment stations (B, C) (Figure 18). Concentrations at D were significantly higher than upstream as well. Only in the Blue Ridge were levels at D significantly lower than within the impoundment. The high levels seen in D (particularly at Piedmont sites) were not anticipated, as measurable concentrations of chlorophyll-*a* are rarely seen in lotic waters of the state, particularly smaller headwater streams. Chlorophyll-*a* is an indicator for suspended algae (phytoplankton), which prefer slow and/or deep water. Generally measureable concentrations are only found in large rivers or within impoundments in NC and that is generally where sampling occurs, though increases below impoundments and natural lakes have been noted elsewhere (Ward 1983). Lotic chlorophyll-*a* sampling is extremely uncommon in NC water quality monitoring programs and no data from below impoundments could be identified for comparison.

Within the Blue Ridge, no exceedences of the 40 µg/L standard were noted and concentrations were generally low, particularly at the upstream reference sites (A). However, 3 exceedences of the Tr standard of 15 µg/L were seen at TROU (B and C combined); this represents 50% of samples taken from within this impoundment. A fourth exceedence occurred at BROY.

In the Piedmont, mean values appeared to increase downstream (D), though this primarily due to higher values from sites CROW and REED. CROW showed an increasing trend in concentration going from upstream to downstream, i.e., readings at D were higher than even within the impoundment. This was the only exclusively bottom release impoundment in the study. REED also showed increases in downstream chlorophyll-*a* as compared to the impoundment for 2 of 3 sampling events. The two recorded exceedences of the water quality standard of 40 µg/L were at the downstream stations of these two sites. Three additional samples at or near 40 were recorded at REED-C.

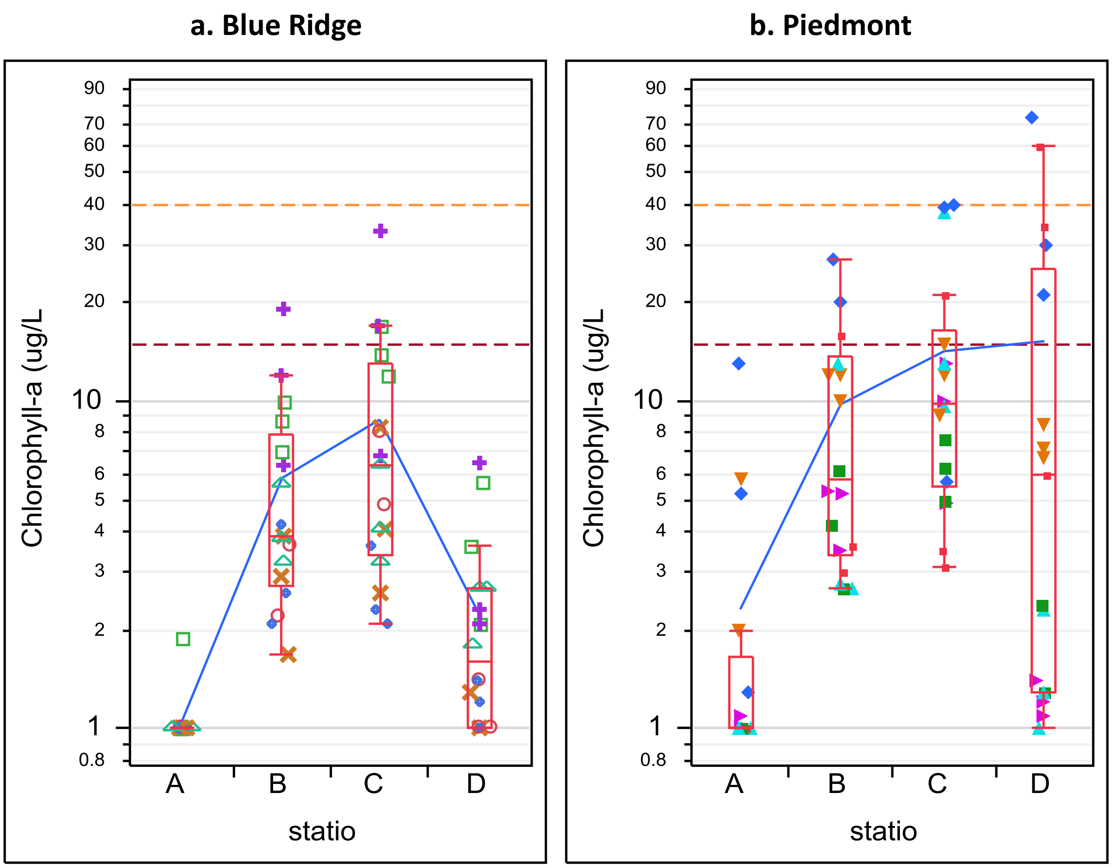


Figure 18 Distributions of chlorophyll-*a* (µg/L) by station for the Blue Ridge (a) and Piedmont (b). Dashed line at 40 µg/L corresponds to the water quality standard for all waters. Dashed line at 15 µg/L corresponds to the water quality standard for designated Tr (trout) waters.

NC Trophic State Index (NCTSI)

The NCTSI was calculated for each sampling event for each of the two sampling stations within each impoundment. When comparing results from stations B and C within each ecoregion, no significant differences were found (data not shown), so results from both stations were grouped (Figure 19). Blue Ridge sites generally showed low levels of nutrient enrichment as measured by the NCTSI, though isolated incidences of eutrophic conditions (NCTSI>0) occurred at BROY (both stations, June 2011) and TROU (station C, July 2011). Note that these are two of the Blue Ridge sites which contained planted/cultivated land use.

Piedmont sites were significantly more enriched. For this ecoregion, land use was a poor explanatory variable; the two most Developed sites (REED, SIEM) and those with planted/cultivated land use (REED, TOWN, and YADK) showed varying levels of eutrophic conditions, and the site with the highest planted/cultivated land use (YADK) actually exhibited some of the lowest NCTSI scores in the Piedmont.

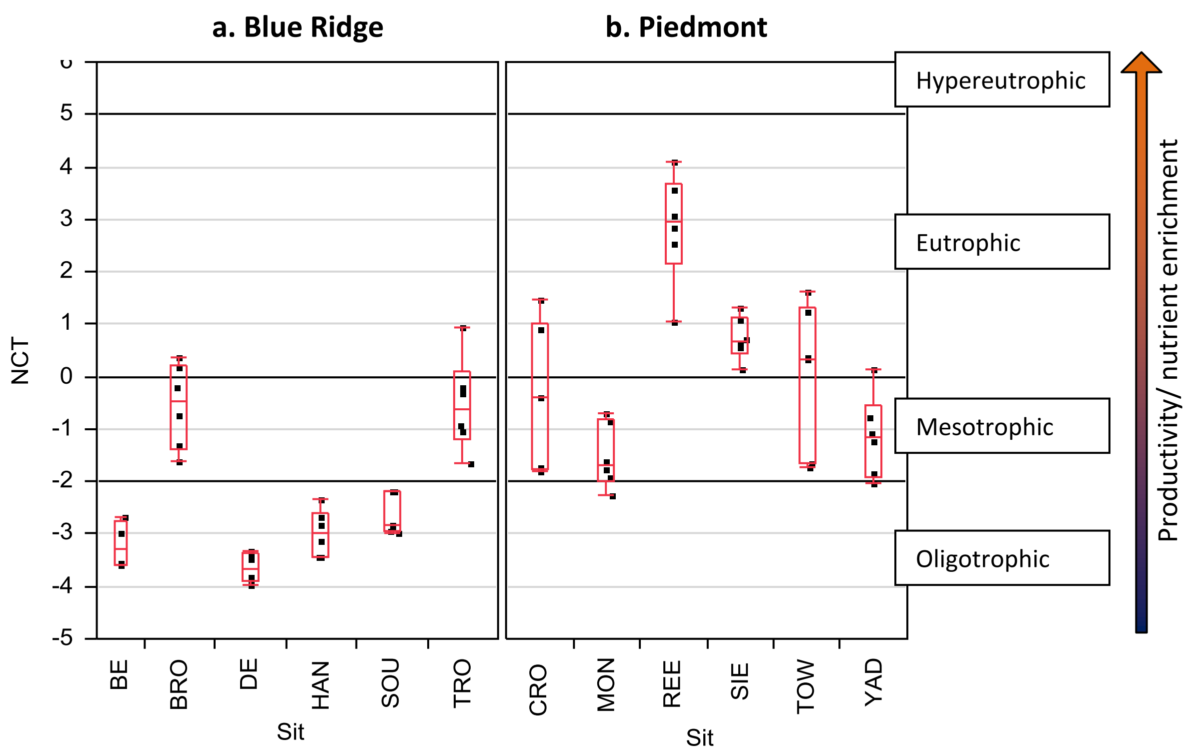


Figure 19. NCTSI scores for Blue Ridge (a) and Piedmont (b) impoundment sites.

Periphyton biomass

Multiple artificial substrates were deployed and successfully retrieved at 10 of 12 upstream locations, the exceptions being REED and TOWN. The substrates at REED-A were displaced by storm events, and though re-positioned at least once, they could not be located when the station was visited for retrieval. Substrates were not deployed at TOWN-A due to beaver ponds. Loss of these upstream/reference stations limited the Piedmont data set to only four complete sites, so data from both ecoregions were combined for analysis. For impoundment stations, only HANG-C suffered total data loss, likely due to vandalism. All downstream stations had 2-4 replicates. No screening criteria are available for this type of data, so analysis was focused on differences in periphyton biomass between stations.

Biomass (g/m^2) results for all replicates (excluding REED and TOWN stations) for both ecoregions are shown in Figure 20, and full data sets are provided in Appendix 4. Data suggest that biomass increases within impoundments, as would be expected due to changes in flow regime, and was confirmed with matched pairs analysis. Downstream concentrations also increased in comparison to upstream and though the median was higher than within the impoundments, they were statistically equivalent to impoundment levels. These sustained elevated levels of biomass in downstream reaches were not anticipated as impoundments are often thought of as nutrient sinks that can result in nutrient deprivation of downstream reaches. The shift from more laminar back to turbulent flow patterns were also anticipated to reduce total biomass in the downstream sites, though management of discharge rates by the dam may mitigate for scour associated with storm events. However, in the Tennessee study (Arnwine 2006), 22% of summer surveys below impoundments showed periphyton densities that were "excessive" as compared to regional reference values. A similarly designed upstream/downstream study in Spain (Camargo 2005) also showed increased periphyton biomass below dams, all of which had deep-water releases, and concluded that these systems can act as nutrient sources, rather than sinks. And, as noted previously, the serial discontinuity conceptual framework (Ward 1983) suggested that while impoundments on larger streams may result in nutrient starvation of downstream reaches, in headwater streams the response would be elevated nutrient concentrations and primary producers below the dam. Our results concur with these other studies.

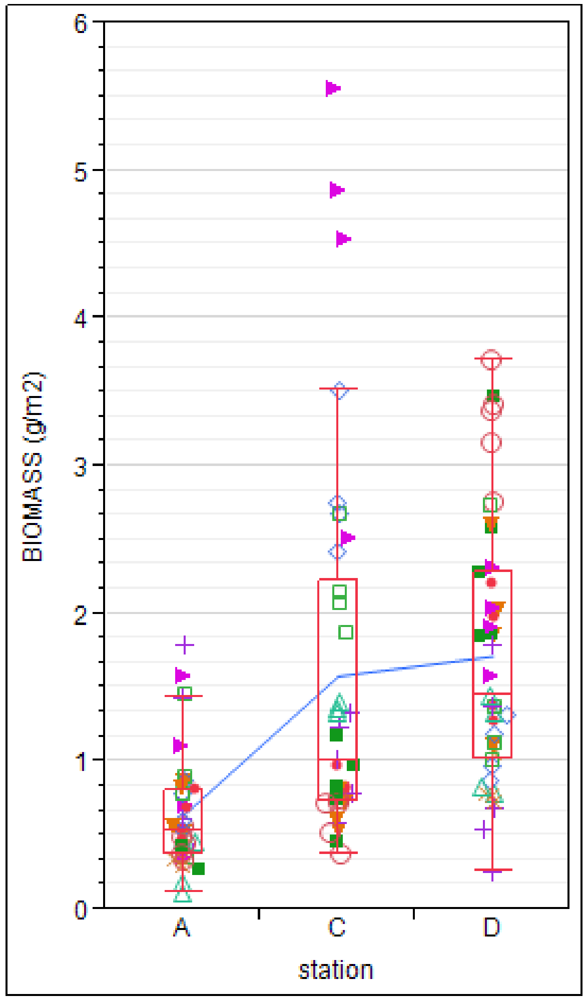


Figure 20 Distributions of all periphyton biomass replicates for all sites, excluding TOWN and REED.

While NC does not have reference values for periphyton, our data suggest that regardless of watershed or ecoregion, there is a significant increase in periphyton growth at impoundment and downstream sites as compared to upstream/reference.

Benthic macroinvertebrate data

Benthic macroinvertebrate (benthos) samples were not obtained from two Piedmont sites due to the presence of beaver ponds (TOWN) or lack of water (SIEM) at the time of sampling. Since the result was only four sites within the Piedmont with a complete data set, data from both ecoregions were grouped for analysis. Four additional stations were sampled but did not result in collection of any live organisms. Three were from impoundments (BEE-B, BROY-B, and DEV-B) and one was from downstream (MONT-D). The MONT-D station was noted to have dense growths of iron oxidizing bacteria, which suggests that dissolved oxygen levels and/or stream discharge were low during the sampling event. One additional impoundment station (CROW-B) contained only a single taxon, which does not have an associated tolerance value (TV).

Table 5 Number of taxa by site and station

Ecoregion	Site	Number of taxa by station			Net change	
		A	B	D	B-A	D-A
Blue Ridge	BEE	30	0	21	-30	-9
	BROY	40	0	24	-40	-16
	DEV	29	0	17	-29	-12
	HANG	29	4	18	-25	-9
	SOUT	24	5	20	-19	-4
	TROU	29	10	31	-19	+2
Piedmont	CROW	4	1	10	-3	+6
	MONT	22	5	0	-17	-22
	REED	22	11	25	-11	+3
	YADK	40	6	24	-34	-16

A summary of the number of unique taxa identified at each station is presented in Table 5 and complete taxa lists are provided in Appendix 4. The most obvious pattern is that taxa richness, a basic measure of species diversity, drops drastically within impoundments. While a definite change in the number of taxa was expected to be seen within impoundments, several Blue Ridge sites had no macroinvertebrates in the samples. This was unexpected. While fewer lentic-tolerant taxa exist than in flowing streams, there are still a variety of midges (Family: Chironomidae) and worms (Order: Oligochaete) that are physically adapted to these conditions, even in the deep profundal waters below the photic zone. For example, some Chironomid species have developed hemoglobin-like compounds that store oxygen. The sites where no organisms were found also had some of the highest number of taxa of all upstream stations. Once the lotic conditions were restored below the impoundments, most sites still exhibited lower diversity than at their respective upstream reference sites. Matched pairs analysis confirmed an overall trend of a decrease in taxa at stations B and D as compared to the upstream station. Notable site-specific exceptions were CROW, TROU, and REED, though CROW had an exceptionally small number of taxa at its upstream reach (A). It should be noted that examination of the upstream reach at CROW in January 2013 found this stream to exhibit poor flow, the NC DWQ stream identification method suggested that it may be intermittent, and few benthic taxa were found in our cursory survey (limited to a single Psephenid and several winter stoneflies). The low diversity is likely due to the poor flow conditions.

Table 6 Number and percentage of unique EPT taxa found at each sampling station

Ecoregion	Site	Number of EPT (EPT as % of total) taxa by station		Net change
		A	D	D-A
Blue Ridge	BEE	11 (37%)	10 (48%)	-1
	BROY	15 (38%)	6 (25%)	-9
	DEV	15 (52%)	4 (24%)	-11
	HANG	12 (41%)	8 (44%)	-4
	SOUT	17 (71%)	11 (52%)	-6
	TROU	16 (55%)	13 (42%)	-3
Piedmont	CROW	3 (75%)	1 (10%)	-2
	MONT	6 (27%)	0 (0%)	-6
	REED	3 (14%)	3 (12%)	0
	YADK	20 (50%)	10 (42%)	-10

The least tolerant aquatic insect families are generally considered the Ephemeroptera, Plecoptera, and Trichoptera (EPT). No EPT taxa were found within impoundments; these samples contained only Chironomidae, other Diptera, Oligochaetes, and a single nematode. Examining EPT for upstream (A) and downstream (D) (Table 6) showed a significant net decrease at all sites in both total number of EPT taxa and percentage of total taxa, with the exception of REED, which showed no change.

A modified biotic index (BI) was calculated, as described previously in the Methods section, using "non-detect" values for samples that contained no organisms. The BI takes into account taxa diversity, abundance, and tolerance to stressors. Lower BI values indicate less tolerant benthic communities, and therefore fewer stressors, at a site. Distributions (Figure 21) suggest that macroinvertebrate communities become highly intolerant within impoundments and overall do not recover to upstream levels below the dam for the majority of sites. These observations were confirmed and found to be statistically significant using matched pairs analysis.

Shifts in community structure can also be seen by analyzing functional feeding groups, such as filter feeders, grazers, and shredders. These groups were selected for analysis to test anticipated or observed effects of impoundments on downstream reaches, specifically: increases in fine suspended matter and planktonic organisms; increases in periphyton biomass; and decreases in coarse organic matter. Filter feeders, as the name suggests, passively collect fine particulate matter or planktonic organisms from the water column. Increase in abundance of these types of organisms is generally assumed to occur below dams. Grazers are morphologically evolved to scrape food, such as periphyton, off the stream substrate. Shredders obtain their food from the surface of coarse particulate matter, such as leaves. If impoundments are causing changes to the relative amounts of these food sources in the streams, then shifts should be seen within the percent contribution of each of these groups to the total number of individuals in the benthic samples.

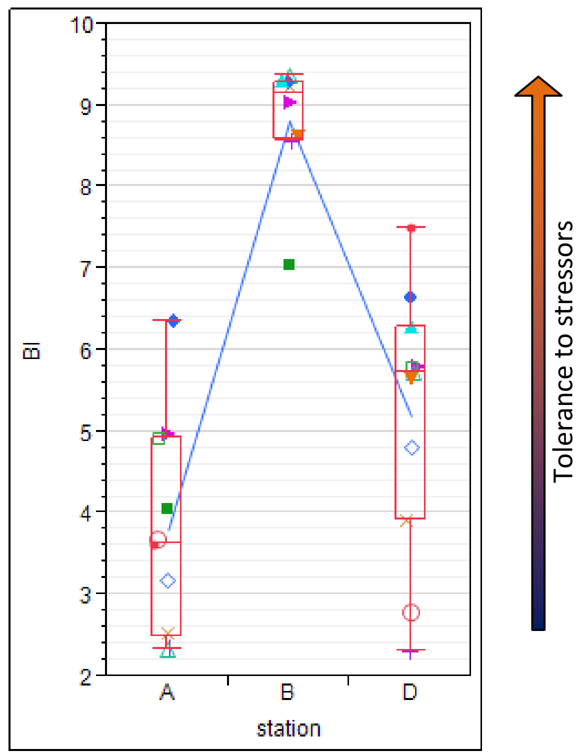
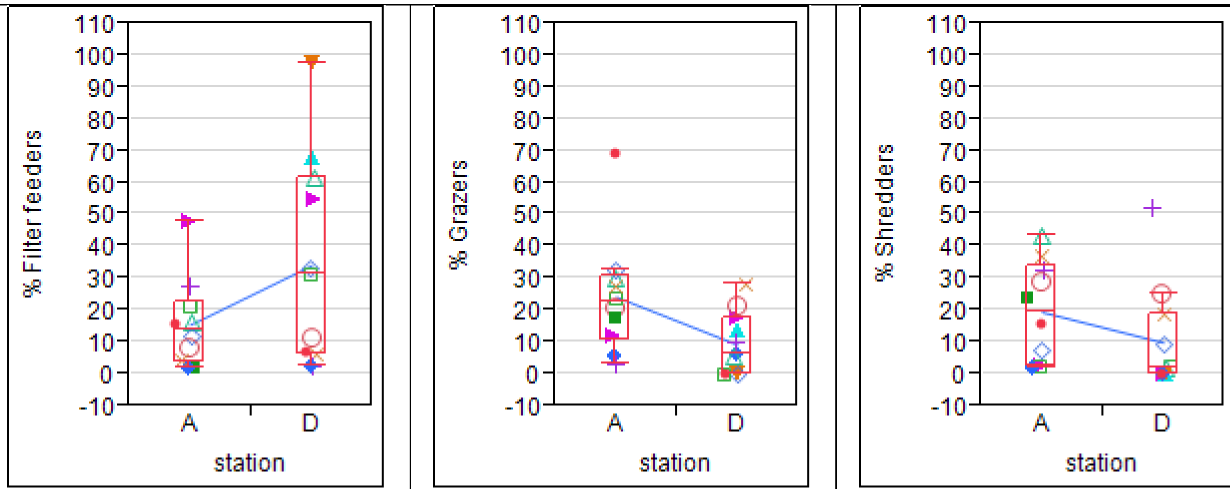


Figure 21 Distributions of Biotic Index (BI) for upstream (A), impoundment (B), and downstream (D) samples. Higher values indicate more tolerant benthic communities, i.e., the presence of greater stressors.

Figure 22 shows the percent of total individuals that are filter feeders (a), grazers (b), or shredders (c) at upstream (A) and downstream (D) stations. These data suggest that our hypotheses are correct, which provides evidence that such changes are occurring in these systems. While these relationships were not found to be statistically significant when analyzed with matched pairs analysis, they do suggest a trend.



a. Filter feeders b. Grazers c. Shredders

Figure 22 Functional feeding groups as percent of total individuals for upstream (A) and downstream (D) stations. Groups are filter feeders (a), grazers (b), and shredders (c).

Habitat assessments

When examined by ecoregion, the Piedmont sites had lower overall habitat scores for both upstream and downstream stations (Figure 23). There were no significant differences when comparing score distributions between upstream and downstream stations, suggesting that any differences seen in biological communities were not due to differences in habitat.

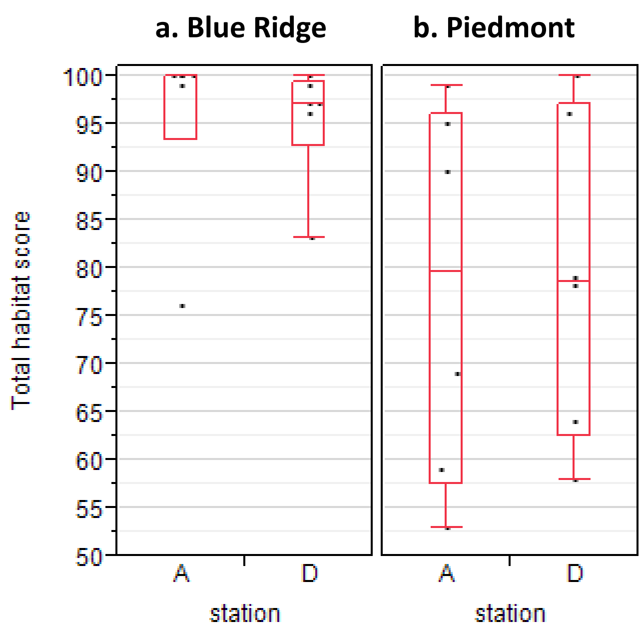


Figure 23 Habitat assessment scores by ecoregion for upstream (A) and downstream (D) stations

When analyzed on a site-by-site basis, the direction of net change for each site (Table 7) showed no overall pattern as to whether habitat scores showed negative, positive, or no change. The largest changes occurred at Piedmont sites with either bottom (CROW) or combined (MONT) releases. Both of these sites lost the majority of points at downstream stations because of increases in substrate embeddedness and poor quality pools (see Appendix 4 for subscores), which would be related to increases in fine sediment deposition. The extremely large result for TSS at CROW-D (255mg/L) in September 2011 was previously discussed. Elevated TSS values would explain poor downstream substrate scores for this site. TOWN showed the greatest improvement in habitat scores, likely due to the extremely poor quality habitat upstream due to presence of beaver dams at that station. BROY, another combined release dam, also saw a large increase in habitat quality downstream.

As a whole, though, these data suggest that the presence of the impoundment has no predictable or detectable effect on instream habitat condition, though this contradicts other studies (Arnwine 2006, Kondolf 1997, Ward 1993). This suggests that overall, any differences between biological communities (benthic macroinvertebrates, periphyton) between upstream and downstream were likely not due to differences in habitat quality but to other factors, such as water quality, temperature, or flow regime changes.

Table 7 Summary of upstream and downstream habitat assessment scores by site.

Ecoregion	Site	Upstream	Downstream	Screening criterion	Downstream - Upstream	Net change
Blue Ridge	BEE	100	83	10	-17	-
	BROY	76	96	7.6	20	+
	DEV	100	97	10	-3	0
	HANG	99	100	9.9	1	0
	SOUT	100	99	10	-1	0
	TROU	100	97	10	-3	0
Piedmont	CROW	99	79	9.9	-20	-
	MONT	95	64	9.5	-31	-
	REED	69	58	6.9	-11	-
	SIEM	59	78	5.9	19	+
	TOWN	53	96	5.3	43	+
	YADK	90	100	9	10	+

Water temperature, annual patterns

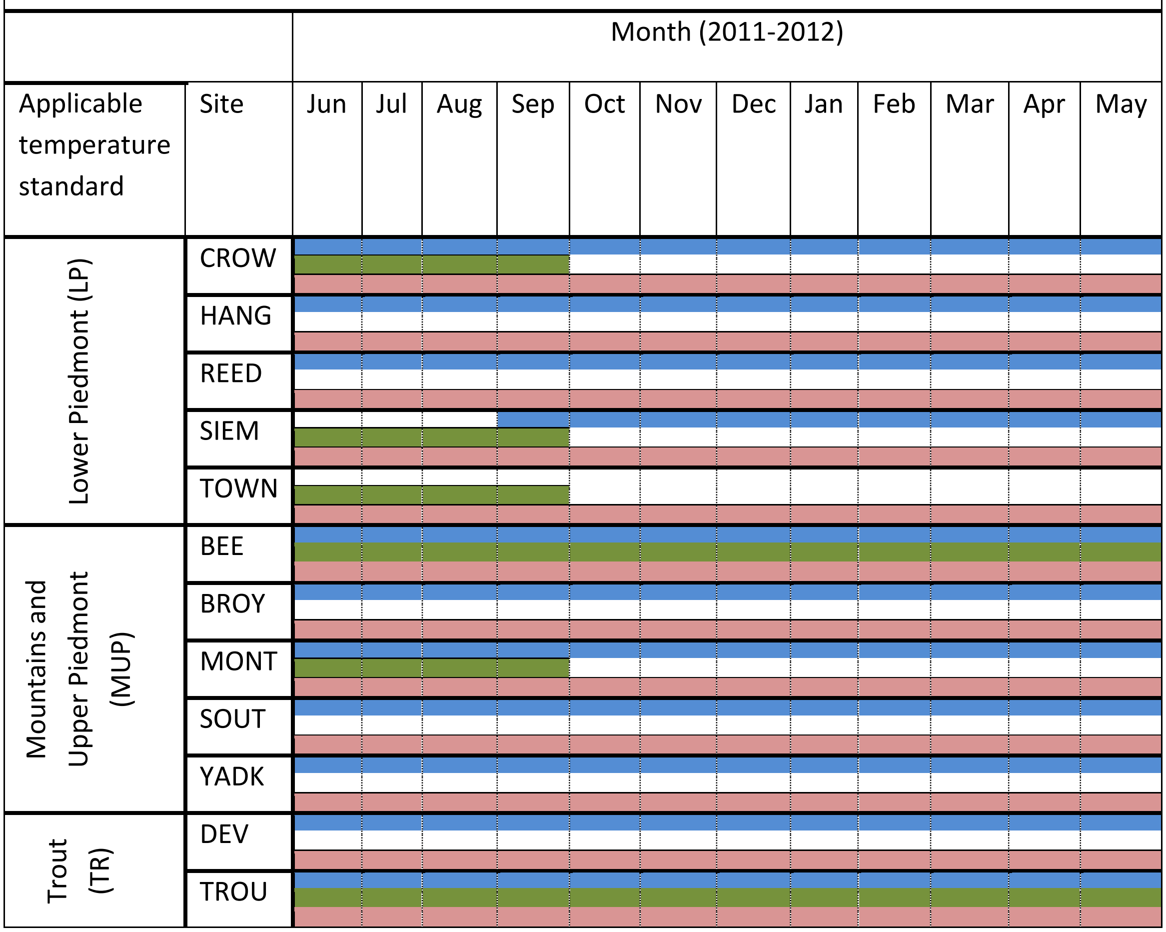
Temperature was one of the larger concerns in this project. Continuous monitoring using data loggers was intended to examine seasonal effects and determine attainment of NC water quality standards, which state:

"Temperature: not to exceed 2.8 degrees C (5.04 degrees F) above the natural water temperature, and in no case to exceed 29 degrees (84.2 degrees F) for mountain and upper piedmont waters and 32 degrees C (89.2 degrees F) for lower piedmont and coastal plain Waters; the temperature for trout waters shall not be increased by more than 0.5 degrees C (0.9 degrees F) due to the discharge of heated liquids, but in no case to exceed 20 degrees C (68 degrees F)" (15A NCAC 02B .0211).

Sites will be grouped and discussed according to these temperature standard groups (Mountain and Upper Piedmont [MUP], Lower Piedmont [LP], and Trout [TR]) (Table 8), as was done in the early discussion of temperature under field measurements.

We experienced a large number of equipment losses due to vandalism and natural events. Only 2 of 12 loggers within impoundments were retrieved at the end of the project (i.e., had a full year of temperature data). An additional five sites had partial data from the impoundment, roughly covering the period of June-September 2011. Ten of twelve sites had complete data coverage from both upstream (A) and downstream (D) sampling stations. No upstream data were collected for site TOWN due to beaver dams in this reach, and equipment failure led to loss of summer 2011 data at SIEM upstream. Data availability for each site is shown in Table 8.

Table 8 Temperature logger data availability by site. Blue = upstream; green = impoundment; pink = downstream; no color = no data for that month.



Results for difference of daily mean temperature between impoundments (C) and upstream (A) are summarized in Table 9 and Figure 24. Exceedences were widespread for all sites: 100% of days in June, July, and August exceeded the criteria at all sites with differences reaching as much as 7-9°C. Data availability was spottier in September and October, but all available data showed 100% exceedences for these months in the LP and MUP. The one TR site also showed high exceedence rates (87%, 39%) for these months and throughout the winter (November- January; March) as well.

Table 9 Percent of days by month where daily mean impoundment temperatures were >2.8°C warmer than upstream. LP = lower Piedmont; MUP = mountains and upper Piedmont, TR = designated trout water. “B” indicates bottom dam release; “TB” indicates a combined top/bottom release; all others are top release only. "ND" indicates no data for that month.

Temp. standard	Site	2011							2012				
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
LP	CROW (B)	100	100	100	100	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
	SIEM	100	100	100	100	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
MUP	BEE	100	100	100	100	100	73	19	10	7	6	47	29
	MONT (T/B)	100	100	100	100	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
	SOUT	100	100	100	100	100	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*	*ND*
TR	TROU	100	100	100	87	39	0	0	0	0	42	83	100

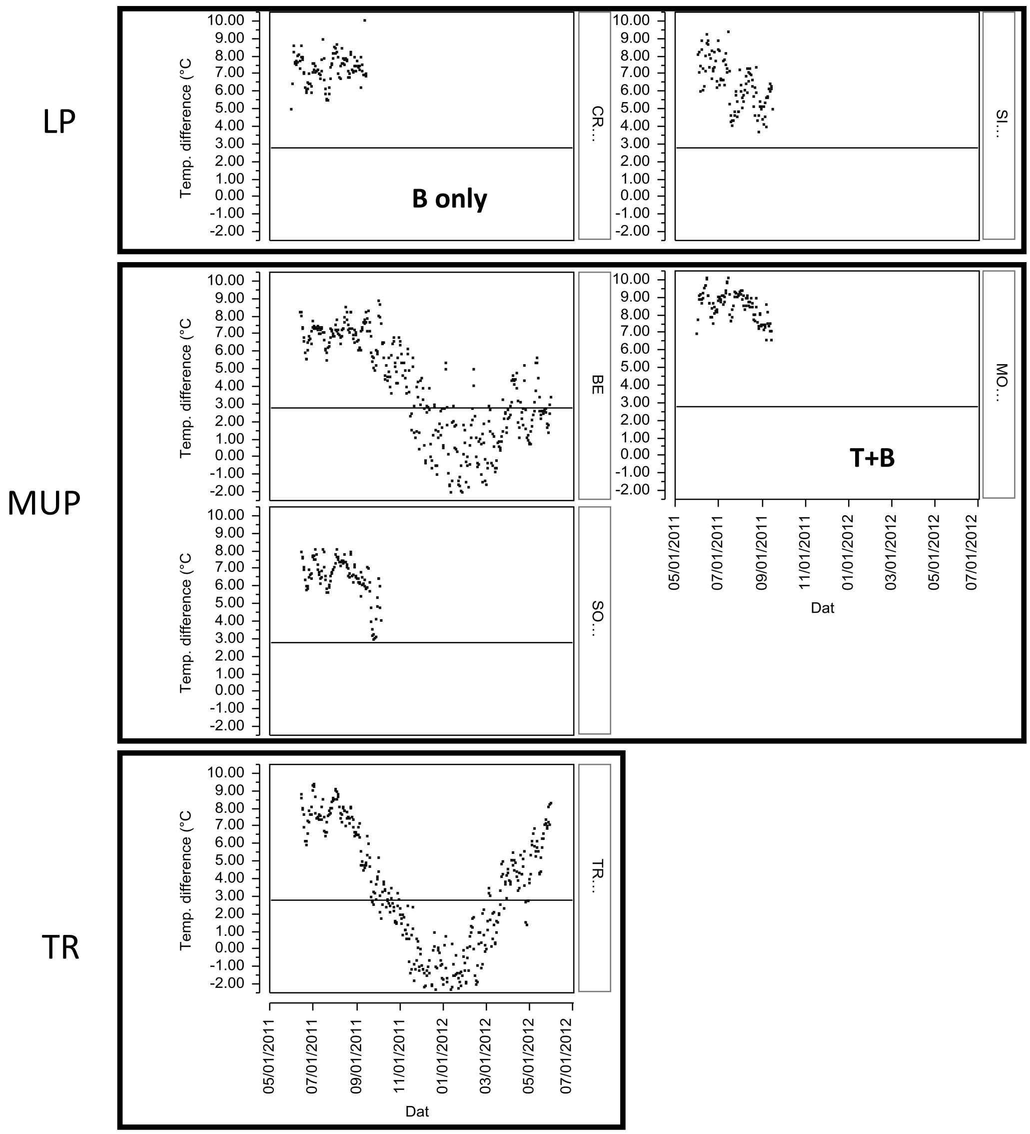


Figure 24 Difference in daily mean temperature between impoundment and upstream by site for Lower Piedmont (LP), Mountains/Upper Piedmont (MUP), and Trout (TR). The reference line at 2.8°C corresponds to the NC water quality standard for maximum allowable change. “B only” indicates bottom only release. “T+B” indicates combined top and bottom release. All other sites were top release only.

Downstream (station D) temperatures were also compared to upstream (station A). Interpretation of these data was complicated by the type of dam release. Of our project sites, one had a bottom release, two had a combined top and bottom release, and the remaining nine had top release only.

When comparing downstream to upstream, exceedence of the 2.8°C standard was not as ubiquitous as in the impoundment, but was still fairly significant (Table 10, Figure 25). Top release sites showed very high levels of exceedences. Sites with combined releases (BROY, MONT) fared better in the summer months, though BROY more commonly had exceedences during the winter and spring. The one bottom release site (CROW) had significant levels of temperature exceedences throughout the year. All three of these sites were also notable for having much *colder* water (up to 8-12° less) during the hottest months of the year. While this does not exceed a water quality standard, it does raise concerns over its ecological effects on native instream species.

Table 10 Percent of days by month where daily mean downstream temperatures were >2.8°C warmer than upstream daily mean temperature. "ND" indicates no data for that month. (B) indicates bottom release; (T/B) indicates both top and bottom releases. All other impoundments had top releases only.

Temp standard	Site	2011							2012				
		Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May
LP	CROW (B)	40	13	0	17	58	33	13	6	14	81	100	39
	HANG	100	100	100	100	61	17	0	0	0	48	47	100
	REED	67	39	81	80	45	17	6	13	14	23	93	86
	SIEM	*ND*	*ND*	*ND*	63	84	3	0	0	7	84	100	100
MUP	BEE	100	94	87	63	16	10	3	6	7	13	67	100
	BROY (T/B)	0	16	0	0	0	3	29	19	7	6	20	65
	MONT (T/B)	0	0	0	0	0	0	0	0	0	0	0	0
	SOUT	100	100	100	100	87	7	0	0	0	65	100	100
	YADK	48	100	97	90	77	40	13	10	7	6	87	90
TR	DEV	100	100	55	83	26	27	19	6	3	23	97	100
	TROU	100	100	81	40	0	0	0	0	0	10	20	100

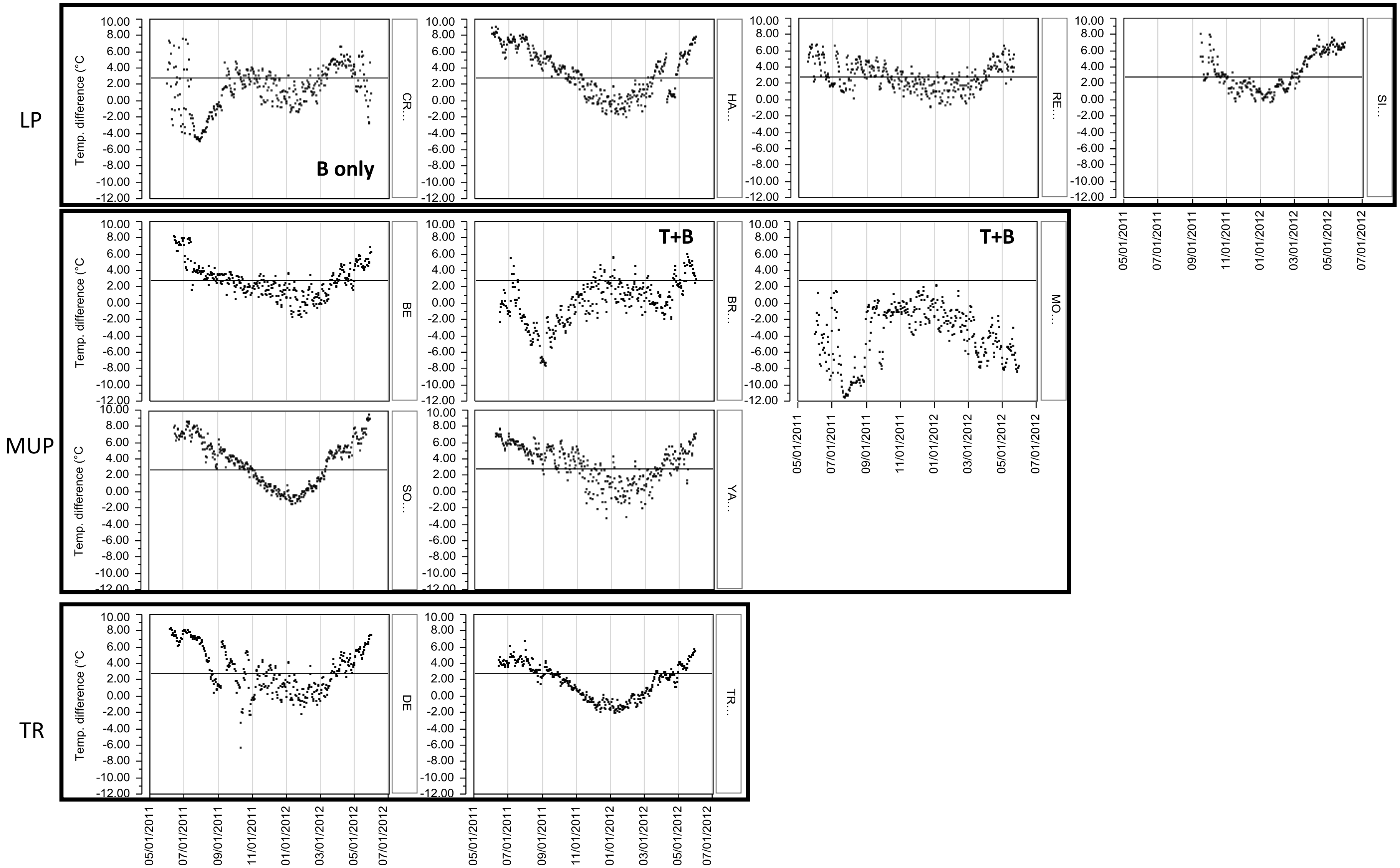


Figure 25 Difference in daily mean temperature between downstream and upstream by site for Lower Piedmont (LP), Mountains/Upper Piedmont (MUP), and Trout (TR). "B only" indicates bottom dam release; "T+B" indicates combined top and bottom dam releases. All other sites are top dam release only. Horizontal lines correspond to the 2.8°C temperature change in the NC water quality standards.

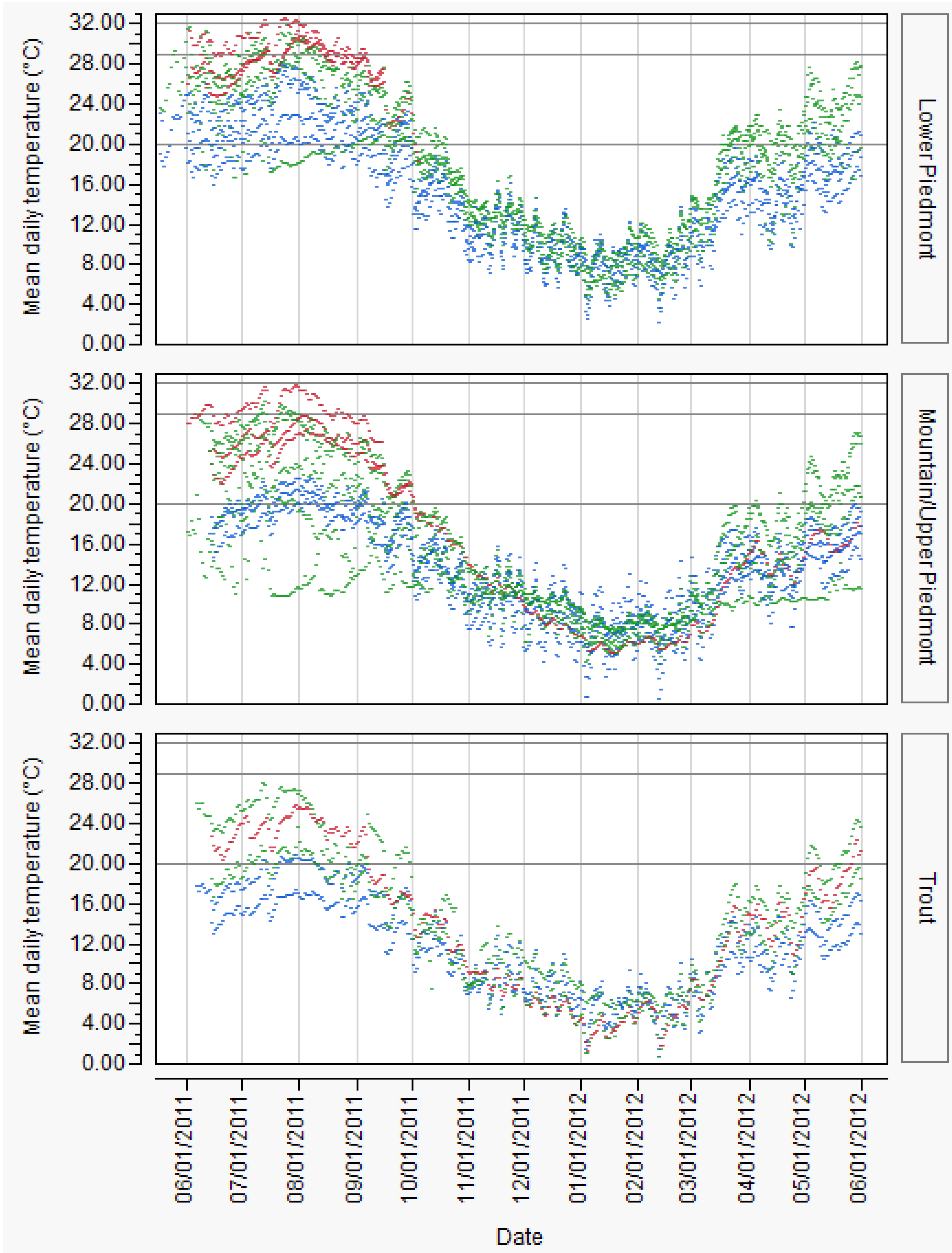


Figure 26 Daily mean water temperatures for upstream (blue), impoundment (red), and downstream (green), grouped by applicable temperature standard criteria. Horizontal lines indicate applicable standards for Lower Piedmont (32°C), Mountains/Upper Piedmont (29°C), and Trout waters (20°C).

Upstream, impoundment, and downstream data were graphed (Figure 26) as a time series to examine trends of attainment of the *maximum temperature* standard for each temperature region. For the majority of Lower Piedmont sites (CROW, HANG, REED, TOWN), the 32°C standard was rarely exceeded, though REED exhibited low frequency elevation (2.5-7% of readings/month) for May through July. For the remaining LP site (SIEM), 29.5% of July 2011 readings within the impoundment were >32°C, compared to <1% upstream.

In the Mountain/Upper Piedmont, values >28°C were seen in two impoundments (MONT, SOUT) out of the total five. Elevations in MONT-C occurred throughout the entire period of monitoring (June-September) and on 90% of days. Elevation at SOUT-C was more limited, with only 12% exceeding the standard and they followed a regular pattern of increase through early August and then a reduction, suggesting a response to weather conditions. SOUT-D also showed elevations above the standard, but interestingly they did not temporally overlap SOUT-C's exceedences, but instead were earlier in the summer (throughout July; 19% of days for the month, though only 5% of the 379 days for which data were collected) and showed no overall pattern. YADK-D showed elevations in temperature sporadically through June, July, and August (40% of days during this month; 9% of the total 386 days monitored).

Designated trout (TR) waters showed extremely high levels of exceedences of the 20°C maximum. DEV actually had high rates of exceedence at its upstream site (11% of the 388 days). Fewer incidences (5% of 379 days) occurred at TROUT-A. However, downstream of impoundments the rates of exceedence increased to 39% (of 388 days) for DEV-D and 15% (of 379 days) for TROU-D. For DEV-D, these occurred almost uninterrupted from early June through the end of September (87% of days during these months). TROU-C, the only TR site with impoundment data, exceeded the standard uninterrupted from the time of deployment (June 14) through September 6, or a yearly total of 29% of 379 days. These data suggest that exceedences of the very stringent TR temperature standard will occur and adding additional stressors (such as impoundments) will worsen the situation. For example, even though TROU-A had a fairly low rate of exceedences, the impoundment showed elevations for several months straight, which in turn led to an increased rate of exceedences at TROU-D.

Summary of significant changes in matched pairs analysis

While tables of all matched pair results are provided in Appendix 3, a visual summary of significant ($p<0.05$) differences found in matched pair analyses is shown in Table 11. Arrows are used to represent the relative change for the two stations being compared. Red indicates that the direction of change is generally considered unfavorable. Green indicates that the direction of change is generally considered favorable. These are not intended to imply that the net change for the indicator exceeded screening values or water quality standards, just the direction of change. Some parameters (TN:TP, pH, periphyton) are represented with black arrows; for these indicators, neither direction of change would be considered favorable or unfavorable.

When examining nutrient changes by ecoregion, it appears that nutrients are handled somewhat differently in the two geographic areas. As noted previously, Blue Ridge impoundments tended to act as nitrogen sinks and in the Piedmont they appeared to act as a nitrogen source. Within the Blue Ridge, total nitrogen (TN = TKN + NOx) varies significantly at almost every matched pair (e.g., A-B, A-C, A-D, B-C, B-D, C-D), with a net decrease in TN at D compared to A. A nearly identical pattern exists with NOx, suggesting that overall TN declines are due to loss of NOx. These data suggest that nitrogen is being sequestered within the impoundments; a likely mechanism would be conversion of NOx to NH_3, which would occur under anoxic conditions, such as those found deeper in the impoundments. Aquatic vegetation could be another source for nutrient sequestration, but no significant growths were observed at Blue Ridge sites.

Conversely, in the Piedmont TN is fairly stable from site-to-site, with a net increase in TN at D as compared to A, suggesting that the impoundment acts as a TN source to the downstream reach. In the Piedmont, the direction of NOx fluxes are mirrored by TKN fluxes, suggesting that in these systems nitrate is being taken up by phytoplankton (i.e., converted to organic nitrogen), which should be reflected in higher primary productivity measures as compared to Blue Ridge sites. The higher NCTSI scores and chlorophyll-*a* concentrations at Piedmont sites support this. TP did not show many significant changes as compared to TN, particularly in Blue Ridge sites, suggesting that it is not acting as a limiting nutrient in these systems as is commonly assumed. Another possibility not addressed in this study is dissolved organic carbon (DOC) limitation in these systems; DOC was not sampled due to the relatively high reporting limits of the NC DWQ laboratory for this parameter but this can be a driver for primary productivity as well.

Different responses at Blue Ridge and Piedmont sites were also seen for DO concentration (decreases in impoundments in the Blue Ridge, increases in impoundments in the Piedmont). Specific conductance (SC) showed a decrease in impoundments (B, C) only in the Piedmont, but both ecoregions showed increases in SC downstream (D) as compared to upstream (A).

Table 11 Summary of significant ($p<0.05$) differences found in matched pair analyses. A, B, C, and D are monitoring stations. Red indicates the change is in an unfavorable direction; green indicates a change in a favorable direction; black indicates the direction is neither favorable nor unfavorable. Blank cells indicate no significant change. "-" indicates that comparisons were not made for that matched pair and parameter.

	BLUE RIDGE						**PIEDMONT**					
	B-A	C-A	C-B	D-A	D-B	D-C	B-A	C-A	C-B	D-A	D-B	D-C
DO % saturation				↓	↓	↓					↓	↓
DO concentration	↓	↓		↓			↑	↑			↓	↓
pH						↓						
SC					↑	↑	↓	↓			↑	↑
Temperature	↑	↑		↑	↓	↓	↑	↑	↑	↑	↓	↓
NOx	↓	↓		↓	↑	↑	↓	↓		↓	↑	
TKN							↑	↑		↑		
TN	↓	↓	↑	↓	↑					↑		
TP	↓										↑	
TN:TP				↓			↑	↑				
Chlorophyll	↑	↑	↑	↑	↓	↓	↑	↑	↑	↑		
Secchi	-	-	↑	-	-	-	-	-		-	-	-
NCTSI	-	-	↑	-	-	-	-	-	↑	-	-	-
TSS							↓	↓			↑	
Benthic taxa richness (all sites)	↓	-	-	↓	↑	-	↓	-	-	↓	↑	-
BI (all sites)	↑	-	-	↑	↓	-	↑	-	-	↑	↓	-
Periphyton (all sites)	↑	-	-	↑		-	↑	-	-	↑		-

IV. Summary and Recommendations

Summary

Impoundments provide a range of benefits for human uses and also can mediate for water quality issues such as excess sediment loads. However, research and existing data also suggest that they can cause deleterious effects within impounded reaches and downstream below the dams. Our results suggest that these are complicated systems that provided sometimes unpredictable or unexpected results.

Temperature exhibited very similar patterns for both ecoregions and suggests that this parameter, and its associated water quality standard, should be a universal concern for these types of systems. Exceedences of the NC water quality standards for temperature were widespread throughout the year. Attempting to mediate for the downstream impacts of temperature changes by using a bottom-only or combined top/bottom dam release resulted in a seasonal shift to when these exceedences occurred. These bottom and combined releases also were associated with increased chlorophyll-*a* and suspended sediment concentrations and stream substrate embeddedness downstream of the dams, and the bottom release site had some of the lowest instream D.O. levels in the study. Within impoundments, D.O. concentrations below the applicable standards were in some cases very close to the surface (generally 2m, though one reading was at 1m). Higher temperatures play a role in this, as increasing temperature lowers the amount of oxygen that will remain in solution. D.O. has great diurnal variability due to biological activity, and our data reflect a "best case scenario" in that measurements were taking during the day when sunlight would encourage algal photosynthesis and oxygen production. These results suggest that at times there is very little volume within these impoundments that has appropriate D.O. levels to support aquatic life.

Nutrient enrichment, primary productivity, and eutrophication increased within impoundments but also had a downstream effect. Enrichment within Piedmont impoundments was demonstrated by over half of NCTSI scores indicating eutrophic conditions, though chlorophyll-*a* concentrations did not exceed the applicable water quality standard. The mirrored patterns of NOx and TKN in Piedmont systems suggested that bioavailable nitrogen is readily converted to organic nitrogen, presumably through uptake by phytoplankton within these systems. Increases in downstream concentrations of nitrogen suggest that these impoundments actually acted as a nutrient source to downstream reaches. Blue Ridge sites exhibited low eutrophication levels, as indicated by their NCTSI scores, but 50% of samples from designated trout waters exceeded the more stringent chlorophyll-*a* standard associated with this surface water classification. For both ecoregions, chlorophyll-*a* concentrations showed a significant increase at downstream stations as compared to the background levels at the corresponding upstream stations. At Piedmont sites there was no significant decrease in chlorophyll-*a* downstream as compared to in the impoundments; values remained flat after the transition from lentic back to lotic water. Another unexpected finding was an increase in periphyton biomass below impoundments as compared to upstream, though further research showed that this concurs with the results from other studies.

The benthic macroinvertebrate communities showed an expected sharp increase in tolerance levels and a decrease in the number of unique taxa within impoundments. While this was expected, the complete lack of taxa from three Blue Ridge sites was troubling, as there are a number of taxa that are adapted to living in these low-oxygen or anoxic conditions. Downstream sites also showed more tolerant communities and fewer taxa than upstream sites. While changes to functional feeding groups were not significant in our data, they do suggest that shifts in community structure occur and support other findings, such as increases in phytoplankton downstream (chlorophyll-*a*) and increases in periphyton biomass. Differences in habitat between upstream and downstream stations did not account for any of the changes to benthic communities so they must be due to another cause.

Overall, Piedmont sites generally showed more hallmarks of water quality degradation within the impoundments and downstream, though background conditions in the Piedmont also suggested higher levels of stress than in the Blue Ridge, even if the watershed was in a relatively natural (forested) state.

Flow was not monitored during this study, but field observations noted a lack of flow below the dams on at least two sampling visits. Several instances of heavy iron-oxidizing bacterial growth at downstream stations were mentioned in field notes, which suggest that flow was poor with low oxygen levels. Post-study observations of the upstream reach of one site (CROW) found that this location exhibited poor flow and may actually be an intermittent stream, which may explain the relatively stressed benthic communities found at this site in spite of having a completely forested catchment.

Anecdotally, land use appeared to be a poor predictor of instream conditions. The site CROW showed elevated values for TKN, TSS, NOx, and had a stressed benthic community in spite of being located in a state park and having an almost entirely forested watershed. YADK, the site with the most planted/cultivated land use in the study, had fairly acceptable results for most parameters. This site had some of the lowest NCTSI scores of all Piedmont samples. SIEM and REED had the largest amount of developed land use in their watersheds, yet exhibited quite different gradients of responses, with results from REED suggesting more stressed instream conditions than SIEM.

Conclusions and Recommendations

- Temperature and chlorophyll-*a* data from designated trout streams (NC stream classification of Tr) suggest that it is very difficult for these streams to meet the more stringent water quality standards for these stream types, even in relatively undisturbed watersheds. While our study provided a limited data set, results suggest that impounding designated trout streams should be considered only with great caution, and projects should provide strong cases for purpose and need. The much more stringent water quality standards for designated trout waters make them difficult to attain, even in relatively undisturbed watersheds.
- Additional work is needed to understand how far downstream these impacts persist. The Tennessee study (Arnwine 2006) suggested that impacts can continue for as far as 1/4 mile downstream of the dam. The distance downstream of station D was not addressed in our analyses since reliable data on this measure were not collected. Additionally, we did not address the effect of tributaries between the dam and sampling site, which can mitigate for some of the degradation of instream conditions (Ward 1983). Fully addressing these spatial and geographic issues would likely provide more detailed information on how far downstream impacts go. This information is needed before regulatory agencies can address the risks associated with downstream effects when reviewing 401 certification applications for these types of projects. It could also provide information on better options for siting dams within the stream network to minimize impacts (e.g., just above a confluence with a tributary).
- NC DWQ has obtained additional funding from the US EPA Wetland Program Development Grant to collect additional benthic macroinvertebrate data, including determination of bioclassifications, in streams above and below impoundments. While the BI used in this study was useful in comparing

relative levels of stress of downstream lotic and lentic sections in comparison to upstream stations, the data collected in the upcoming study would allow definitive determination of use support, as bioclassifications are tied to the 303(d)/305(b) regulatory process for assessment of use attainment of the state's waters.

- Additional work is needed to fully address dam release types. While bottom and combined top/bottom releases were included in this study, the sample size was very small. These releases also did not mitigate for the significant increases in temperature at our study sites and resulted in other issues, such as increases in the concentrations of sediment and chlorophyll-*a* being discharged from the dam.
- We did not address issues such as fish passage within this study, though this may be of less concern in headwater systems. We also did not address impacts to non-insect benthic species such as mussels. However, we believe that issues with impacts to these groups would be better addressed by other agencies (e.g., NC Wildlife Resources Commission, U.S. Fish and Wildlife Service) who have the appropriate technical knowledge in these areas. We do believe that impacts of impoundments have been well-established as being of concern to these types of organisms, but decisions on siting impoundments in streams that support species of concern or endangered species should be left to these agencies.
- To determine if land use has an effect on instream conditions, sites with a wider range of watershed land uses should be examined. Our sites were relatively homogenous in terms of land use (predominantly forested, particularly in the Blue Ridge) which may have made these relationships (if they exist) undetectable. This homogeneity suggests that differences seen between sites cannot always be attributable to land use, good or bad. There were sites with completely forested watersheds (e.g., CROW) that showed issues with one or more parameters even at the upstream/reference site. Other sites (e.g., YADK), though they had significant amounts of developed and/or planted/cultivated land use, faired fairly well. Streams have been shown to show varying resiliencies to changes in land use (Allan 1997; Poff 1997) so limiting different land uses within the watersheds of impoundments may not be a guarantee of water quality protection. More important may be an assessment of the current level or stress on a stream before it is impounded. For example, if temperatures or other physical and chemical measures are already elevated or biological community metrics indicate significant stressors, the additional impact of the impoundment may be enough to cause a degradation of instream conditions to the point where designated uses can be impaired. It would be prudent to have the current water quality of a stream characterized and the data submitted with 401 certification applications to allow regulatory agencies to make informed decisions based on site specific information.

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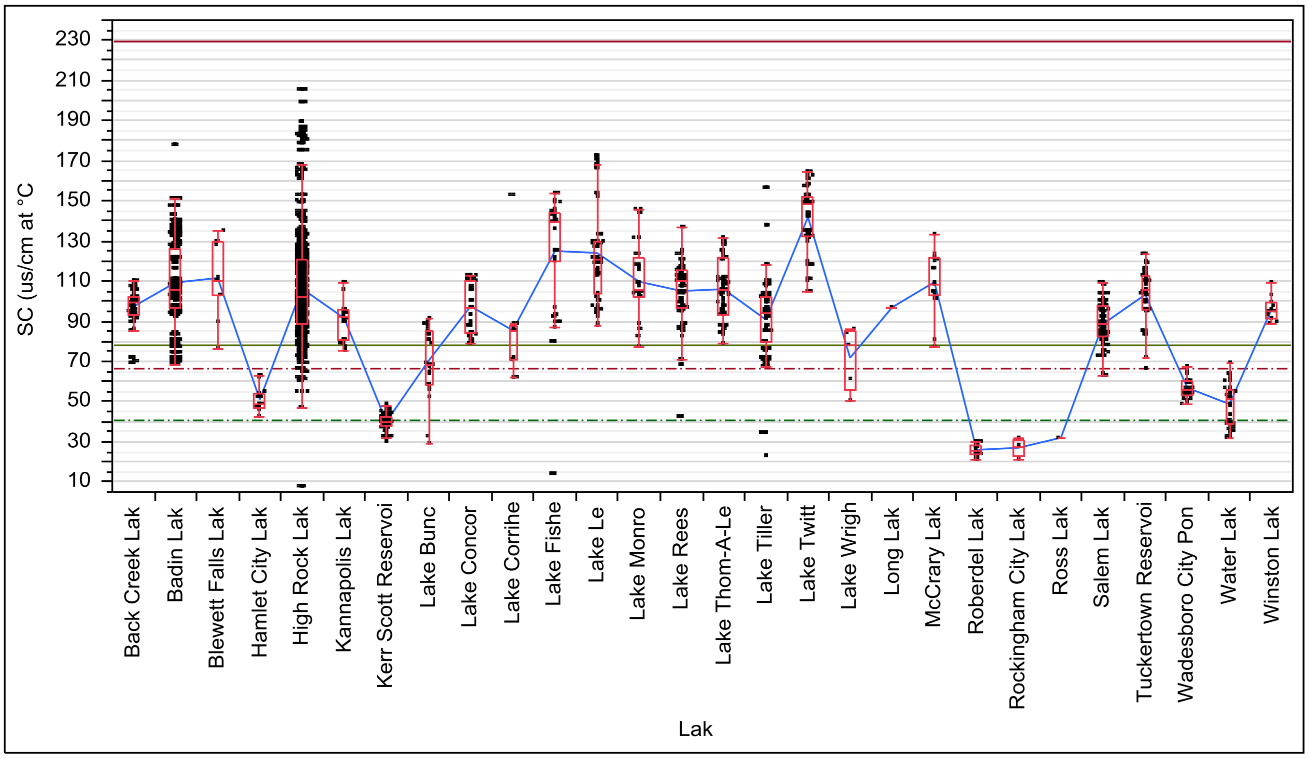
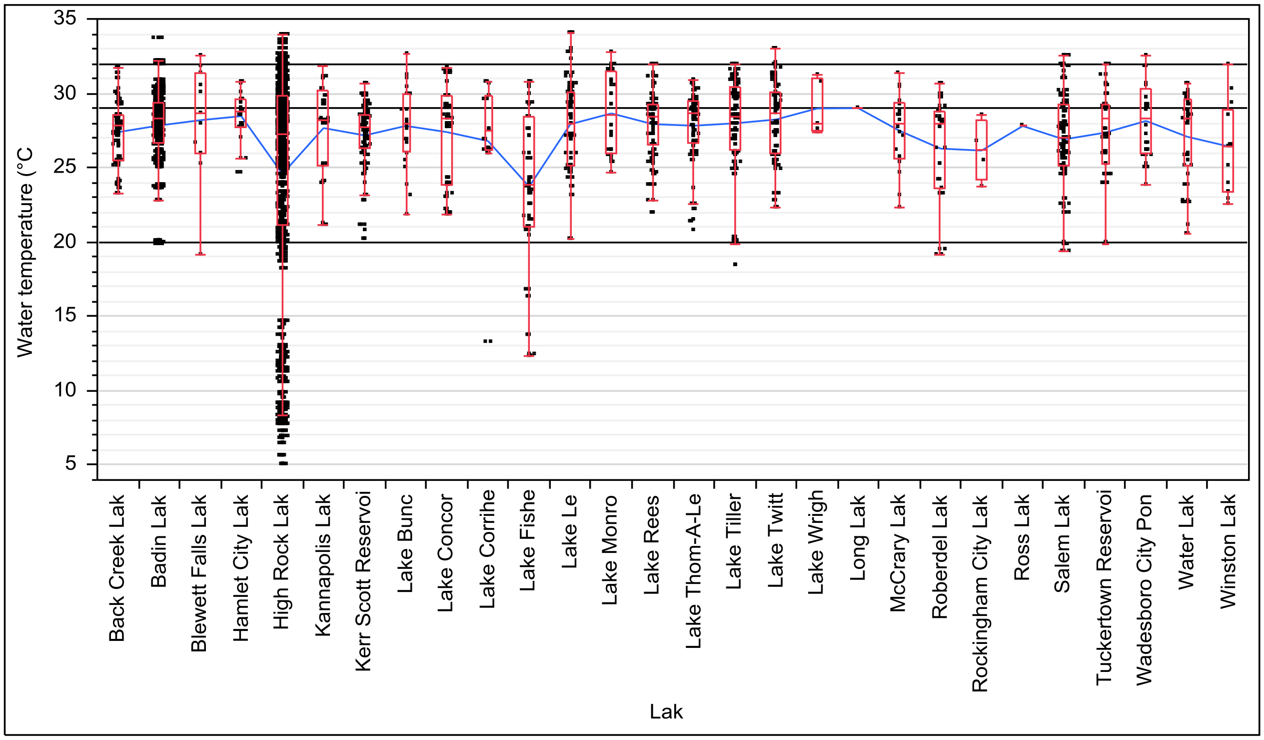
Appendix 1: NC DWQ ALMP data summaries

One of the motivating factors for this project was an observation of regular exceedences of applicable water quality standards in impoundments monitored by NC DWQ. The data presented in this Appendix represent all available surface field measurements from impoundments in the Yadkin River basin, located primarily within the Piedmont ecoregion (central portion) of NC from the period of 1981-2006. Summaries of the distributions of surface readings of field measurements are presented below. Blue lines connect the mean values for each impoundment.

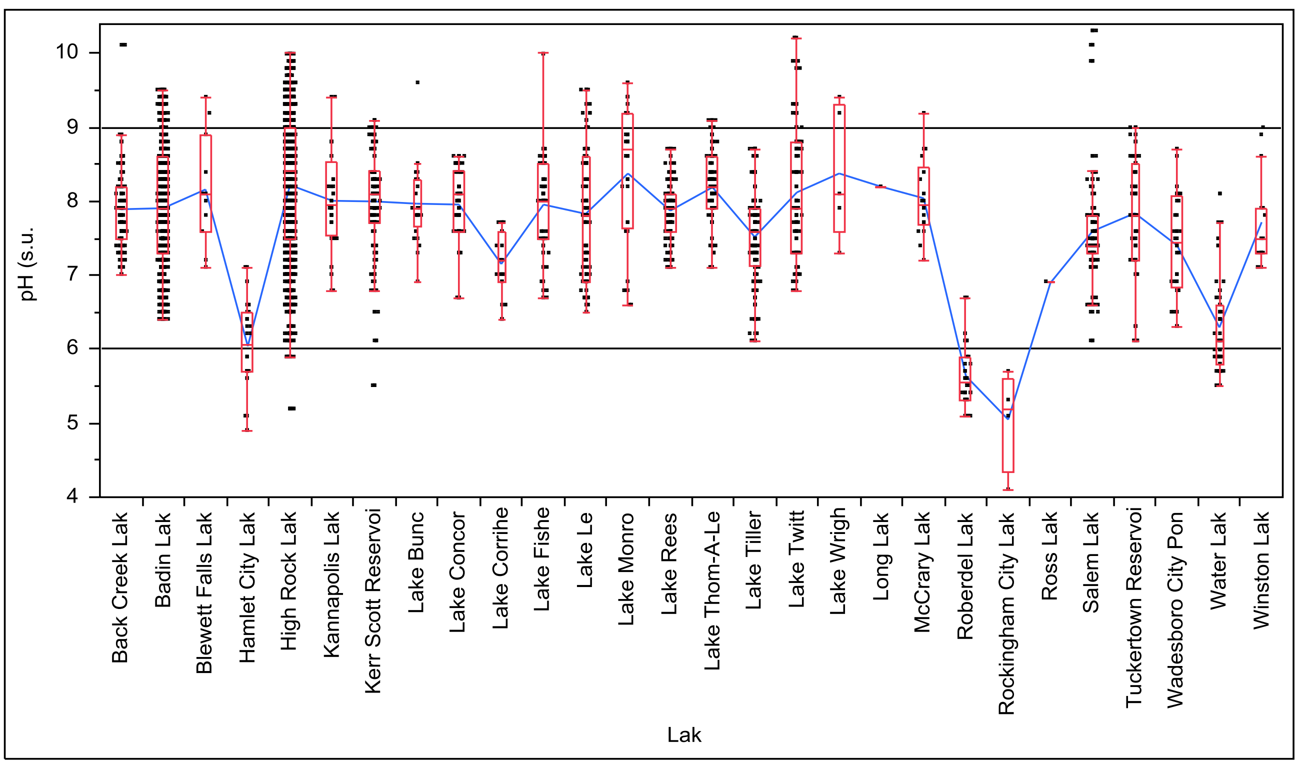
Specific conductance (SC;µS/cm at 25°C): Reference lines on graph represent screening values for SC for Blue Ridge and Piedmont ecoregions. Low values for SC (<41 for Blue Ridge; <78 for Piedmont) suggest good water quality. Higher values (>66 for Blue Ridge; >229 for Piedmont) suggest that there may be water quality concerns.



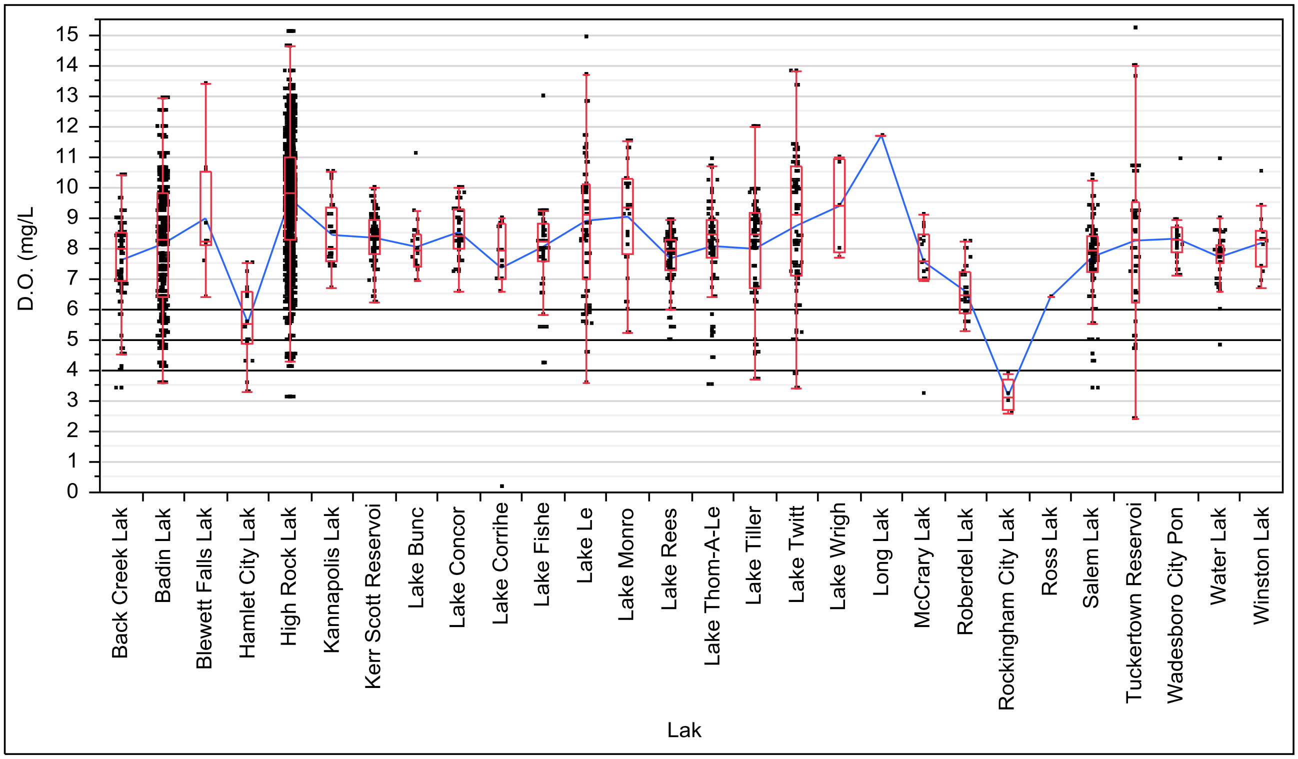
Water temperature (°C): Reference lines represent the NC water quality standards for maximum allowable temperature for the Lower Piedmont (32°C), Mountains/Upper Piedmont (29°), and Trout waters (20°).



pH (standard units): Reference lines represent NC water quality standards for minimum (6.0) and maximum (6.0) values.



Dissolved oxygen (D.O.) concentration (mg/L): Reference lines represent minimum values specified in NC water quality standards for daily mean (5.0), instantaneous (4.0), and trout waters (6.0).



Dissolved oxygen (D.O.) saturation (%): Reference line represents 110%, the screening value recommended for identification of possible algal blooms (see NC DWQ 2003).

Appendix 2: Station information

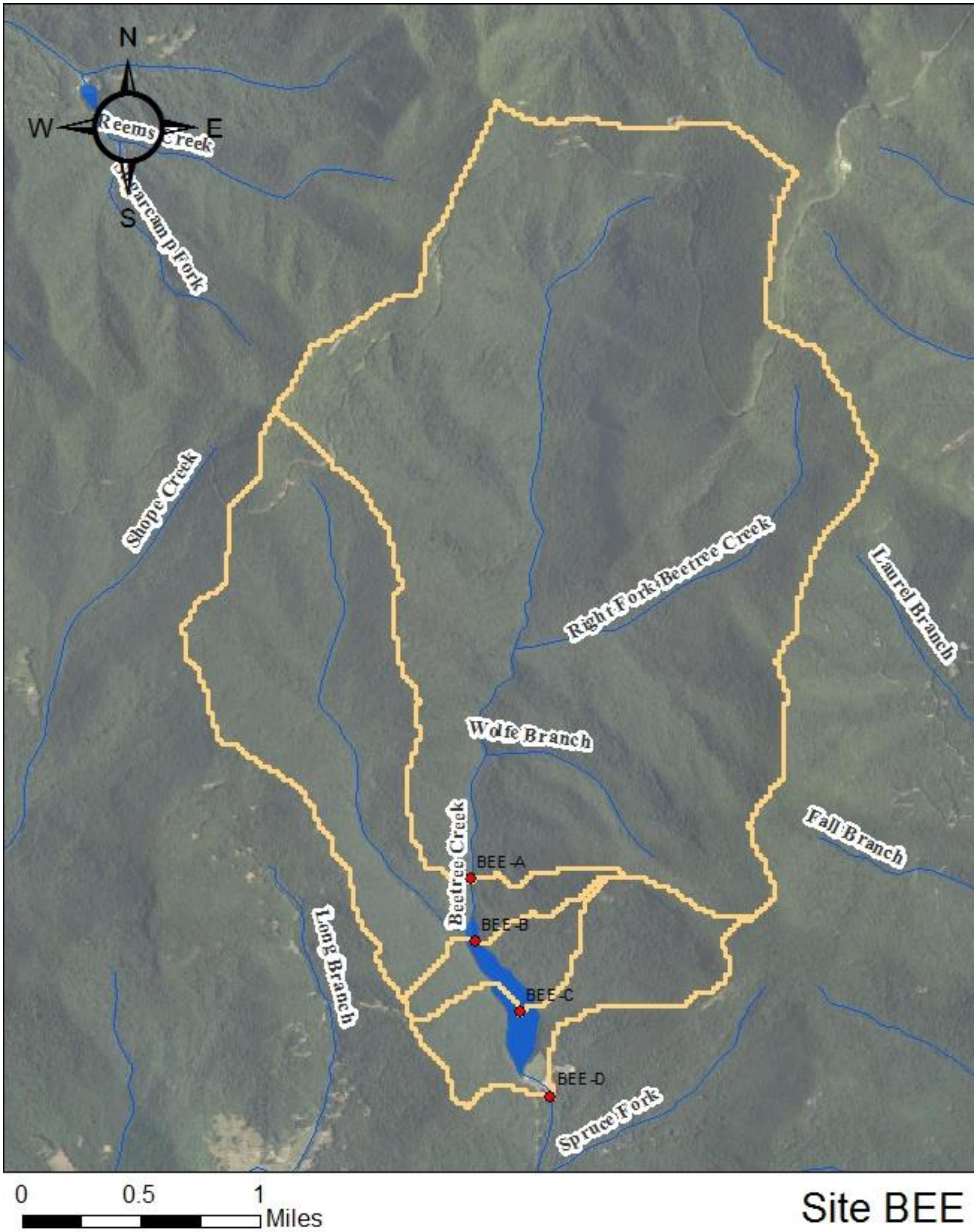
More detailed information on sampling station locations, drainage areas, and watershed land use are given in the table below. Aerial maps of each site follow, showing station locations, streams and impoundments (as depicted in the USGS National Hydrography Database [NHD]), and watershed boundaries (derived from digital elevation models).

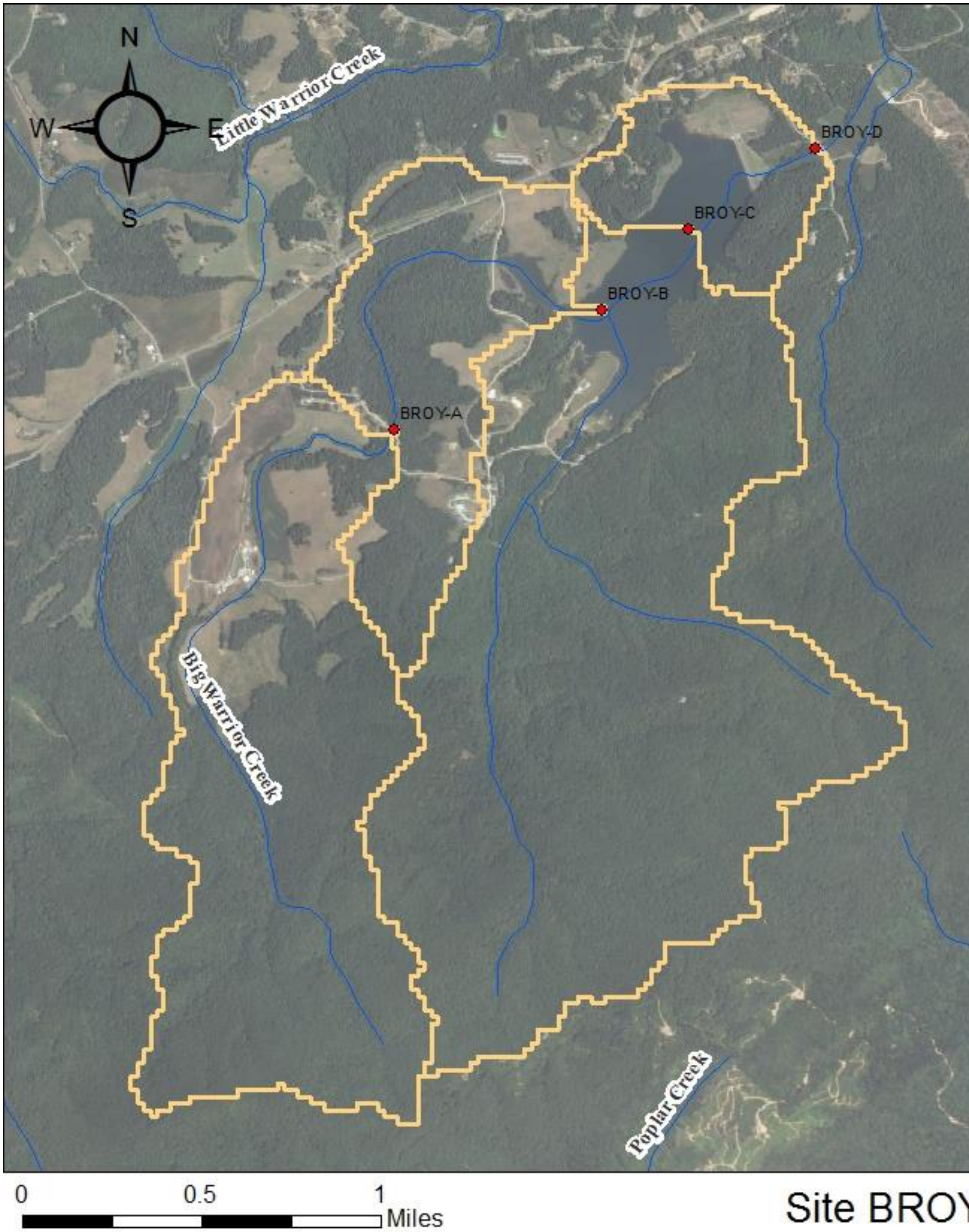
Station tables

Project ecoregion	Site	Site name	Station	Latitude	Longitude	Drainage area (mi^2)	Watershed land use, % by category			
							Developed	Forested	Planted/ Cultivated	Other
BLUE RIDGE	BEE	Bee Tree Reservoir	A	35.6531	-82.4055	5.45	3.4	96.4	0	0.2
			B	35.6496	-82.4050	6.9	3.0	96.7	0	0.2
			C	35.6452	-82.4016	7.09	2.9	96.5	0	0.5
			D	35.6401	-82.3986	7.61	2.8	96.2	0.1	0.6
	BROY	Lake Broyhill	A	36.0321	-81.3026	1.17	0.3	74.4	23.4	0.2
			B	36.0369	-81.2928	1.72	1.5	70.3	23.4	2.7
			C	36.0412	-81.2888	3.7	0.7	79.4	14.2	3.3
			D	36.0440	-81.2820	3.97	0.7	76.9	15.1	12
	DEV	Devotion	A	36.4527	-80.9384	2	4.7	89	4.9	1.3
			B	36.4483	-80.9320	2.14	4.6	89.2	4.6	1.6
			C	36.4451	-80.9304	2.24	4.5	88.5	4.4	2.6
			D	36.4426	-80.9278	2.34	4.5	88	4.2	3.3
	HANG	Hanging Rock State Park	A	36.3882	-80.2719	0.54	0	100	0	0
			B	36.3897	-80.2695	0.6	0	99.5	0	0.5
			C	36.3914	-80.2688	0.62	0	99	0	1
			D	36.3956	-80.2683	0.73	0.4	97.4	0	2.2
	SOUT	South Mountain State Park	A	35.6361	-81.7464	1.21	0	100	0	0
			B	35.6393	-81.7492	2.35	0	99.3	0	0.7
			C	35.6400	-81.7498	2.36	0	99.1	0	0.9
			D	35.6417	-81.7524	2.44	0.0	98.1	0.1	1.5
	TROU	Trout Lake	A	36.1554	-81.7023	0.17	0	83.4	13.5	3
			B	36.1525	-81.7012	0.52	8.7	72.3	15.7	3.3
			C	36.1530	-81.7007	0.52	8.6	72.2	15.7	3.5
			D	36.1579	-81.6935	0.74	7.5	77.1	12.2	3.2

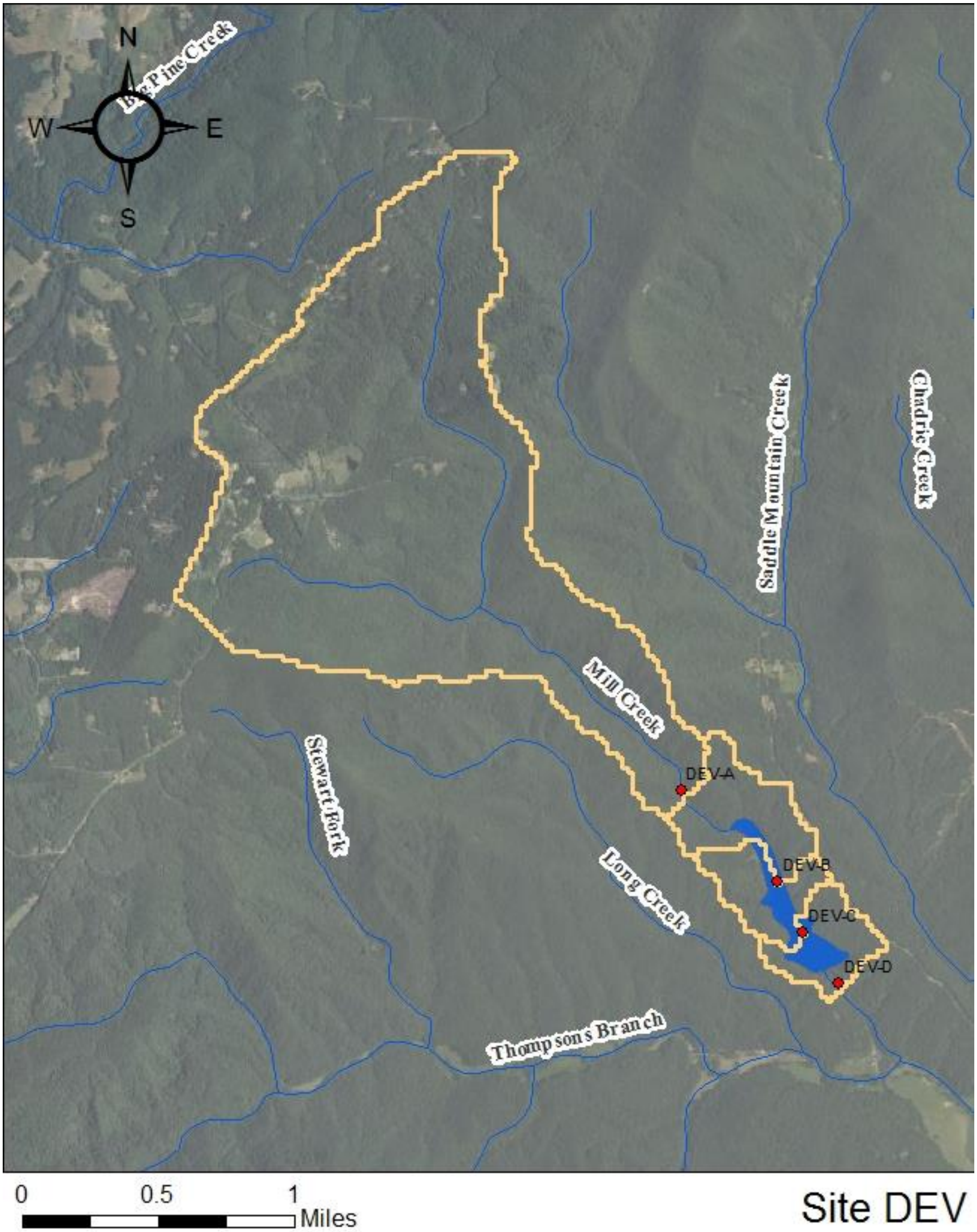
Project ecoregion	Site	Site name	Station	Latitude	Longitude	Drainage area (mi^2)	Watershed land use, % by category			
							Developed	Forested	Planted/ Cultivated	Other
PIEDMONT	CROW	Crowders Mountain State Park	A	35.2083	-81.2942	0.57	0.1	99.6	0.3	0
			B	35.2090	-81.2918	0.63	0.1	99.1	0.3	0.6
			C	35.2094	-81.2912	0.86	0.1	97.9	0.2	1.5
			D	35.2106	-81.2905	0.87	0.1	97.6	0.2	1.6
	MONT	Lake Montonia	A	35.1998	-81.3251	0.37	2.6	96.4	0	0
			B	35.1988	-81.3272	0.38	2.6	95.5	0	0.9
			C	35.2007	-81.3290	0.7	1.8	95.1	0	2.2
			D	35.2022	-81.3298	1.01	3.6	89	0	2.4
	REED	Reedy Creek Lake	A	35.8328	-78.7452	4.02	39.5	48.2	9.8	0.9
			B	35.8369	-78.7463	4.22	37.8	50.2	9.3	0.9
			C	35.8384	-78.7460	4.36	36.6	51.6	9.0	1
			D	35.8402	-78.7439	4.42	36.1	52.1	8.9	1.3
	SIEM	Siemens	A	35.1424	-80.9860	0.11	100.0	0	0	0
			B	35.1417	-80.9882	0.13	100.0	0	0	0
			C	35.1418	-80.9896	0.2	98.0	0	0	2
			D	35.1412	-80.9917	0.36	92.6	3.1	0	4.3
	TOWN	Town Fork Creek	A	36.2532	-80.2126	3.17	2.7	83.2	9.2	0.8
			B	36.2570	-80.2114	3.31	2.7	83.2	8.9	0.9
			C	36.2610	-80.2124	3.45	2.6	82.8	8.5	1.8
			D	36.2637	-80.2120	3.77	3.0	82.6	7.9	1.8
	YADK	Little Yadkin River	A	36.3515	-80.4219	3	8.9	52.2	32.8	1.6
			B	36.3459	-80.4209	3.22	8.5	52.9	31.7	2.4
			C	36.3426	-80.4222	3.32	8.2	53	30.8	3.4
			D	36.3404	-80.4188	4.67	8.6	53.3	28.7	3.3

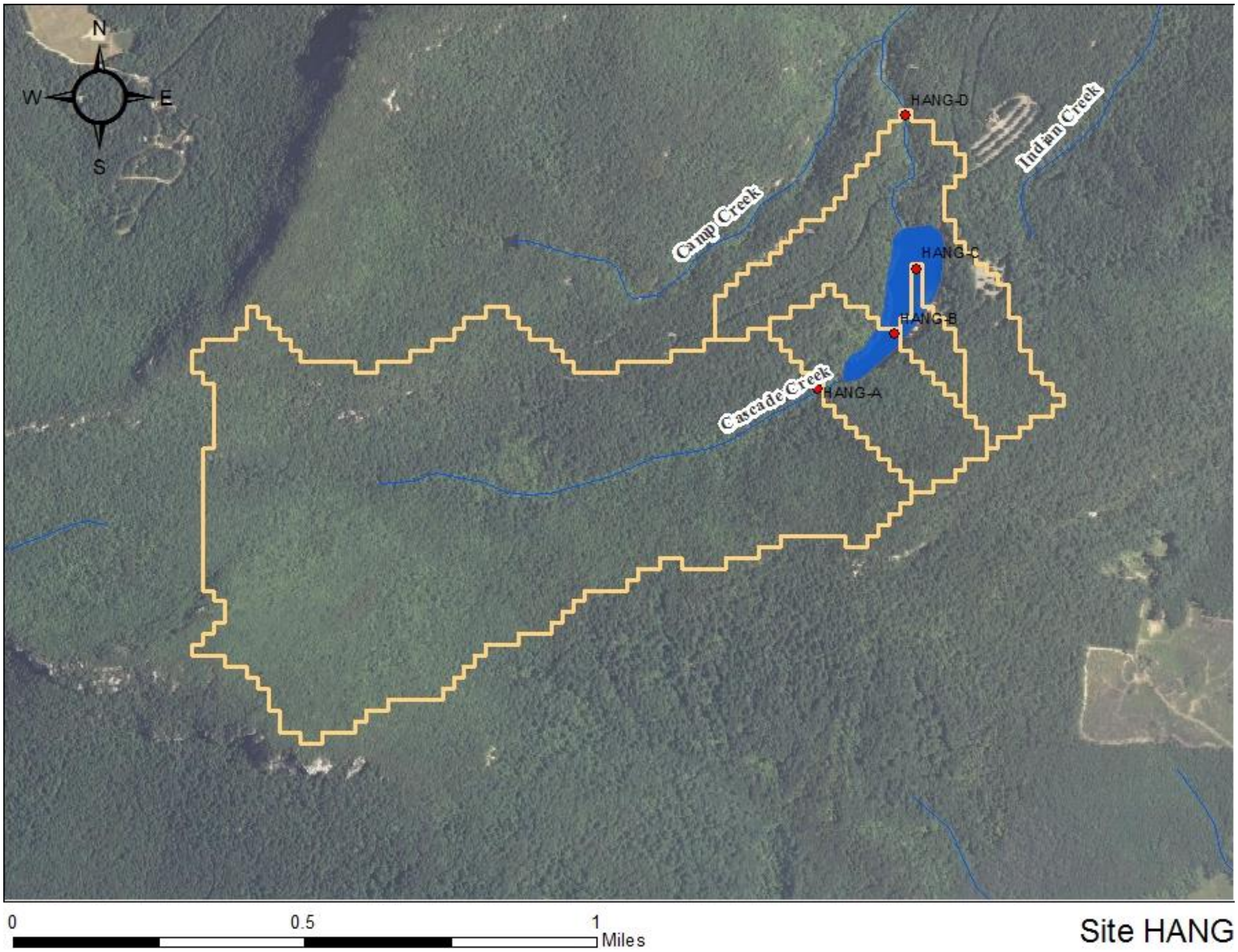
Station maps: Blue Ridge




N
W
E
S
Little Warrior Creek
BROY-D
BROY-C
BROY-B
BROY-A
Big Warrior Creek
Poplar Creek
0
0.5
1
Miles

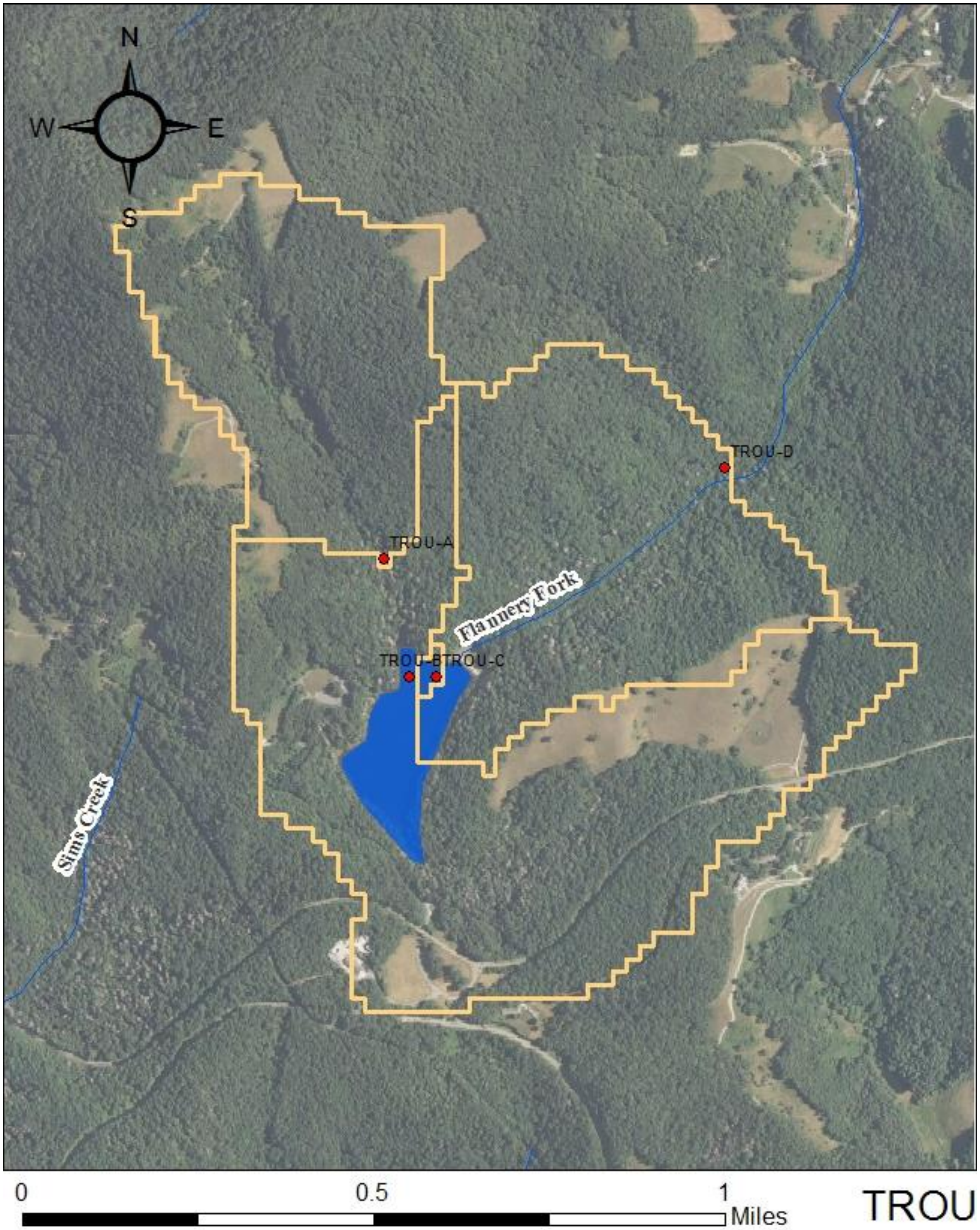
Site BROY


N
S
W
E
Big Pine Creek
Saddle Mountain Creek
Chadric Creek
Mill Creek
Stewart Fork
Long Creek
Thompsons Branch
DEV-A
DEV-B
DEV-C
DEV-D
0
0.5
1
Miles
Site DEV

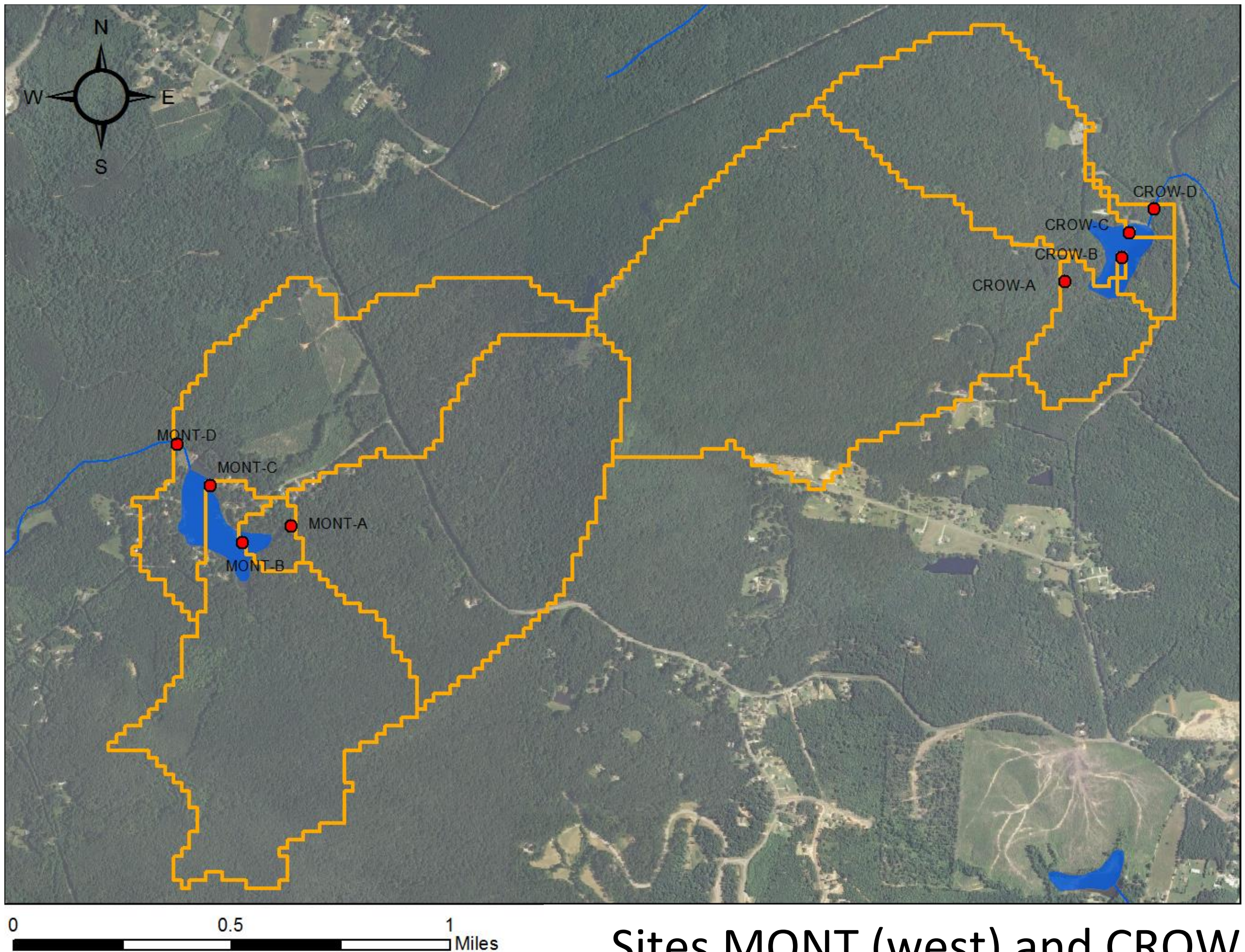

N
W
E
S
HANG-D
Indian Creek
Camp Creek
HANG-C
HANG-B
Cascade Creek
HANG-A
0
0.5
1
Miles
Site HANG


N
W
E
S
SOUT-D
SOUT-C
SOUT-B
SOUT-A
Shoal Creek
Clear Creek
Henry Fork
0
0.5
1
Miles

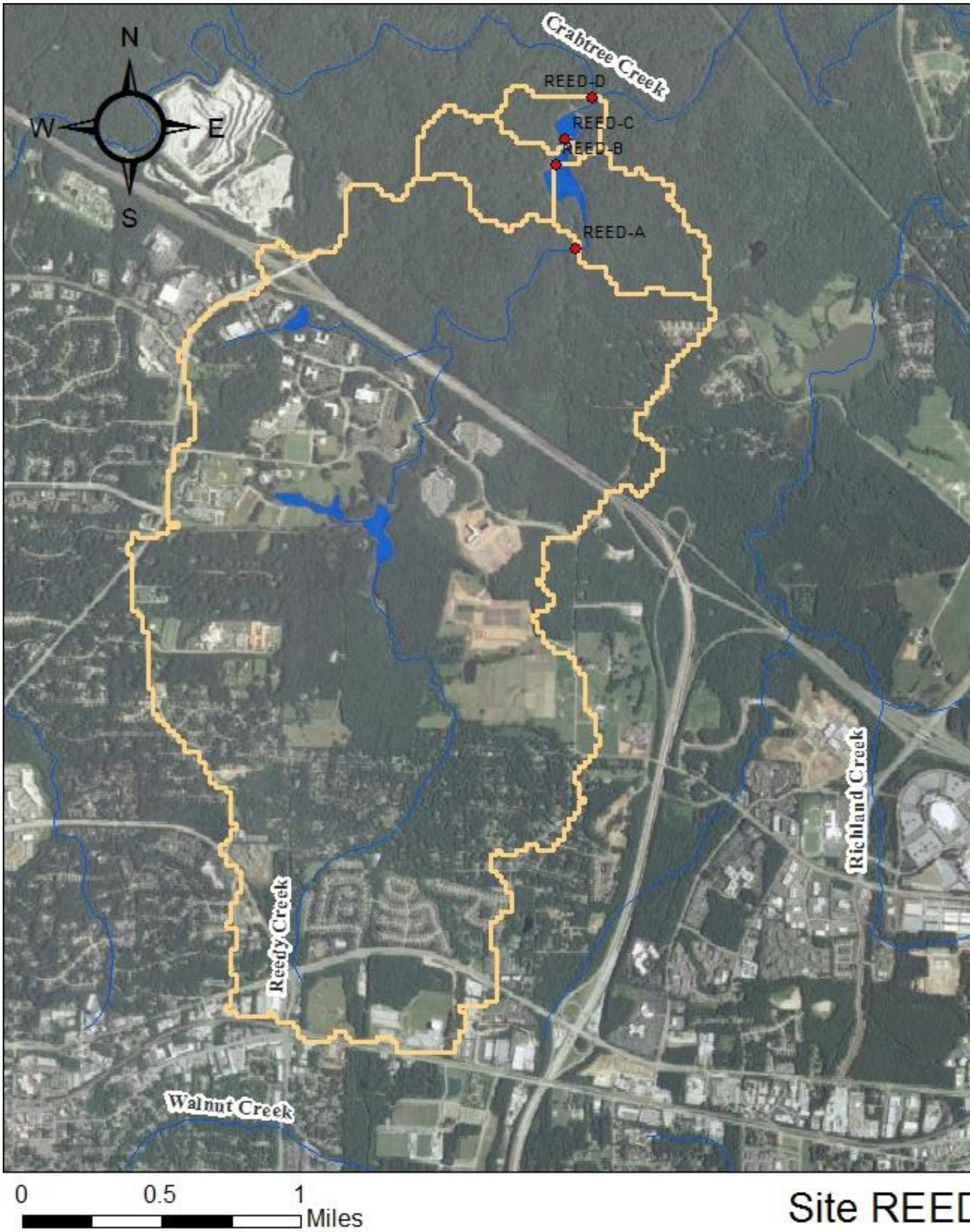
Site SOUT


N
W
E
S
TROU-D
TROU-A
Flannery Fork
TROU-B
TROU-C
Sims Creek
0
0.5
1
Miles
TROU

Station maps: Piedmont

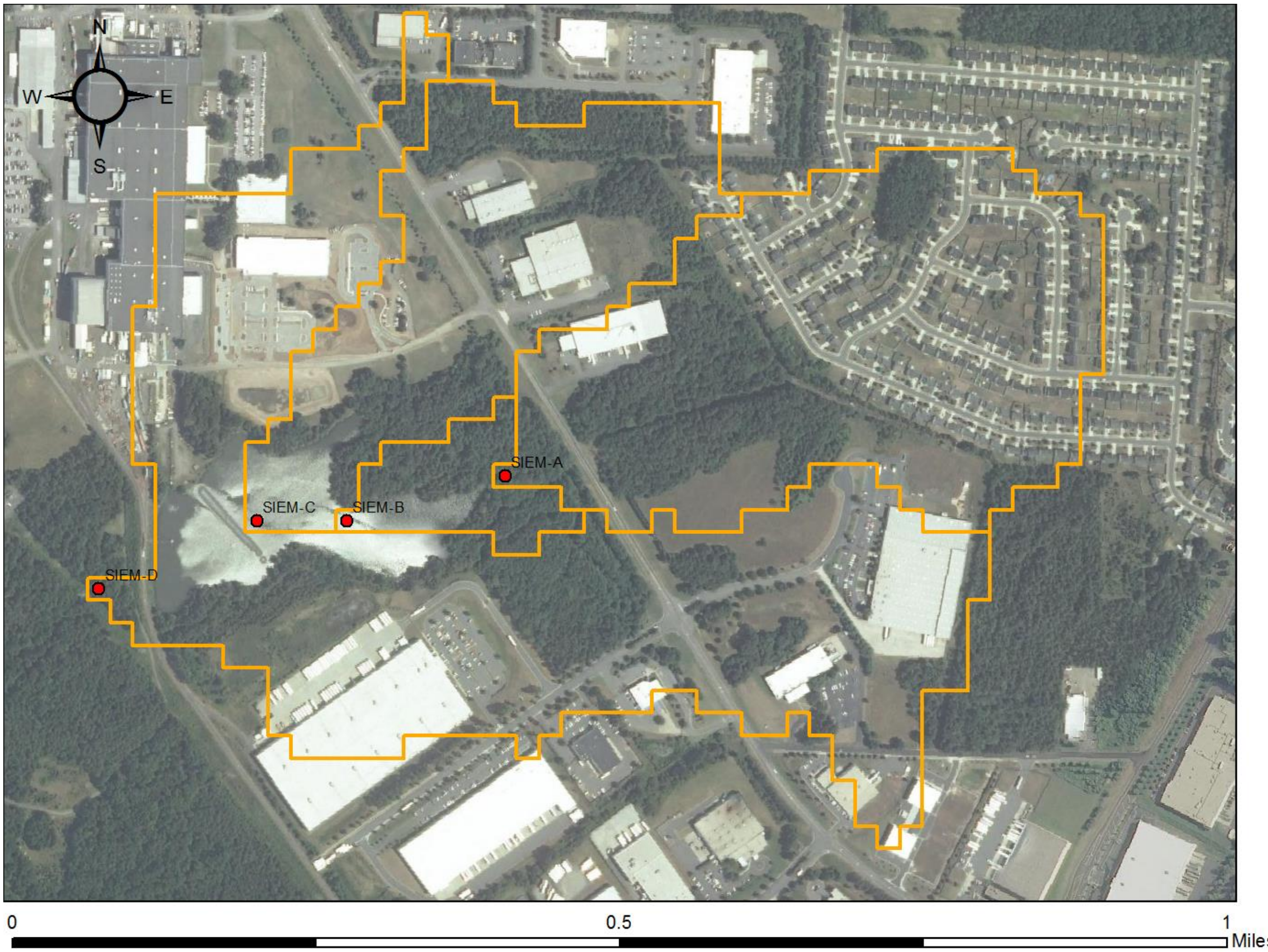


Sites MONT (west) and CROW



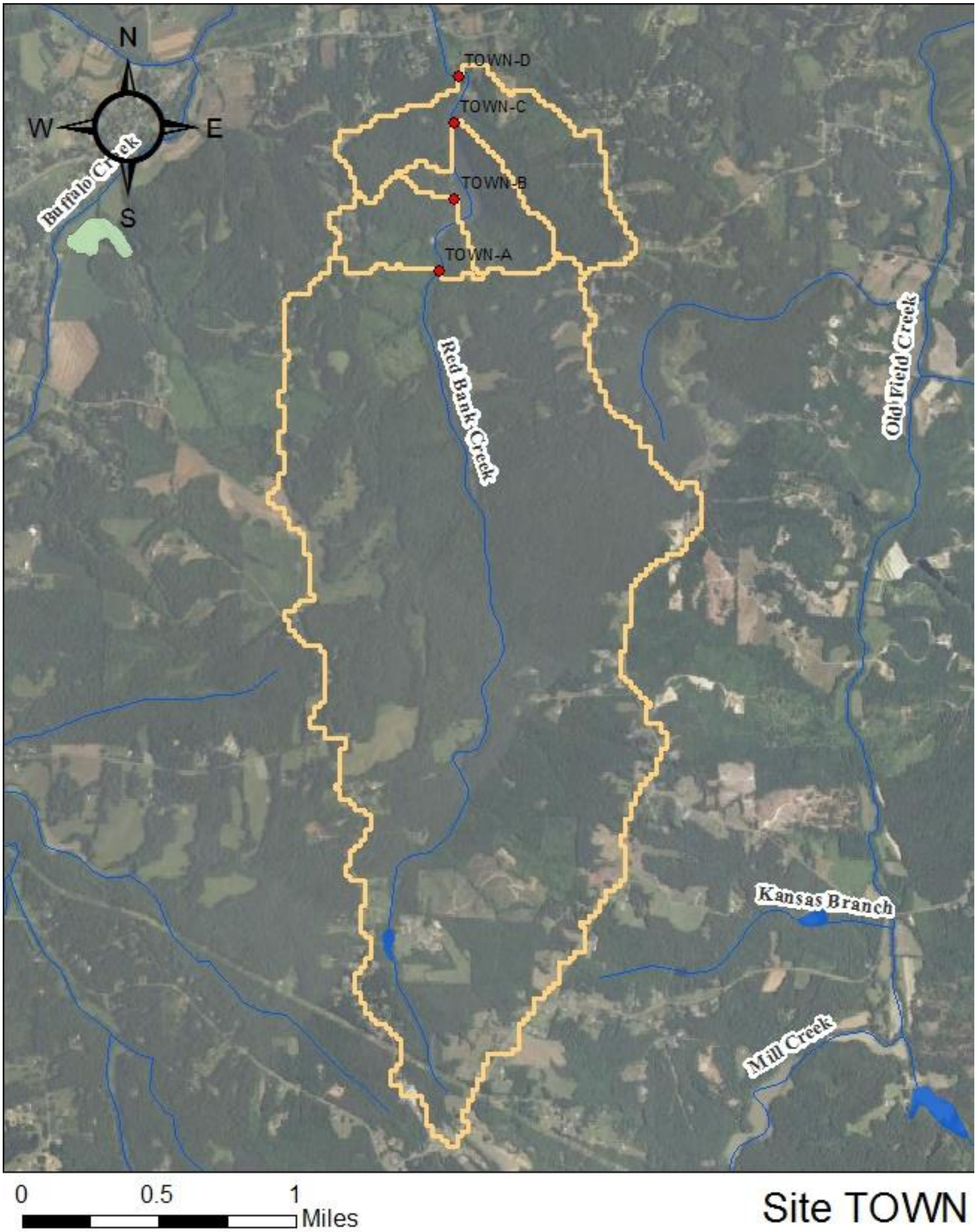
N
W
E
S
Crabtree Creek
REED-D
REED-C
REED-B
REED-A
Reedy Creek
Richland Creek
Walnut Creek
0
0.5
1
Miles

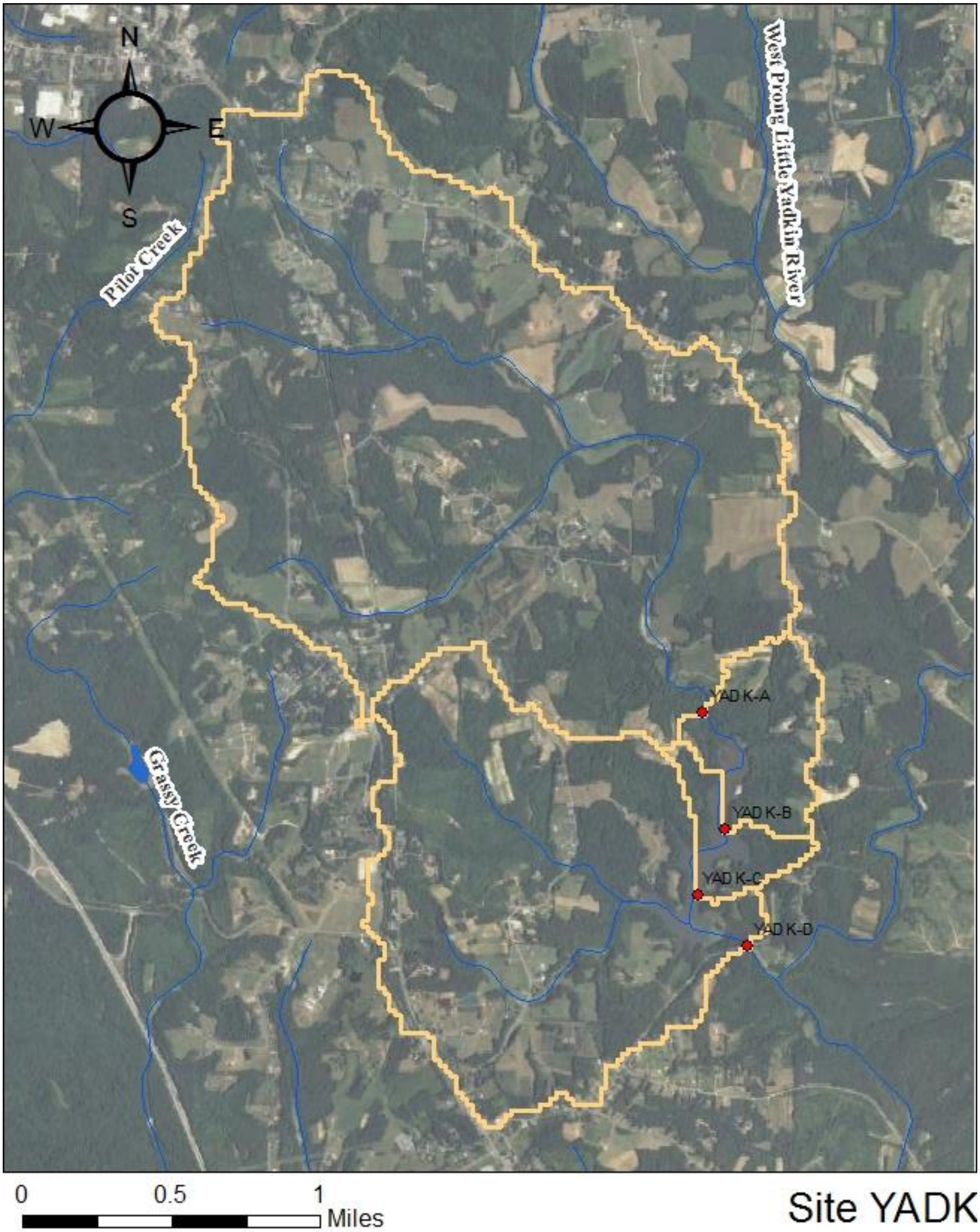
Site REED



Site SIEM

NOTE: Streams and impoundment for Siemens are not depicted in the National Hydrography Dataset (NHD)


N
W
E
S
Buffalo Creek
TOWN-D
TOWN-C
TOWN-B
TOWN-A
Red Bank Creek
Old Field Creek
Kansas Branch
Mill Creek
0
0.5
1
Miles
Site TOWN


N
W
E
S
Pilot Creek
West Prong Little Yadkin River
Grassy Creek
YAD K-A
YAD K-B
YAD K-C
YAD K-D
0
0.5
1
Miles
Site YADK

Appendix 3: Results from Matched Pair analyses

In order to put each station's results in the context of the upstream reference reach, comparisons were made between downstream sites (B, C, and D) and all applicable upstream sites (A, B, and C) by sampling event (date). In the case of vertical profiles in impoundments, comparisons of field parameters were made using surface values only. The differences were analyzed using the non-parametric Wilcoxon signed rank test to determine if a significant *decrease* or *increase* existed. Results are a probability (value between 0-1). This test relies on relative rankings instead of using model distributions (e.g., Z, t, F) and so does not require that data meet assumptions that are required for parametric statistics such as t-tests, Pearson's correlations, or ANOVA (e.g., normal distribution, equal variances, etc.). As this test is not often used in water quality analyses, it was felt that further notes on interpreting results from Wilcoxon signed rank tests would be helpful:

- Column headers indicate which stations are being compared, where A is upstream (lotic); B is upper impoundment (lentic); C is lower impoundment (lentic); and D is downstream of dam (lotic). Example: B-A is the difference of station B compared to A. All comparisons are done as downstream compared to upstream.
- Cells with "—" indicate that the comparison was not applicable; at least one of the sites did not have that data type collected.
- p > S gives the probability that the values at the downstream locations (B, C, or D) *are greater* than the upstream location (A, B, or C); a one-sided test. Equivalent hypotheses in a paired difference t-test would be $\mu_0 = 0$ and $\mu_A > 0$.
- p < S gives the probability that that the values at the downstream locations (B, C, or D) *are lower* than the upstream location (A, B, or C); a one-sided test. Equivalent hypotheses in a paired difference t-test would be $\mu_0 = 0$ and $\mu_A < 0$.
- While a significance level of 95% (α=0.05) is generally used throughout this report, "marginally significant" results (corresponding to a significance level between 90-95%, 0.10 > α > 0.05) are also highlighted below. ***Bold, italic*** indicates 95% significance level. *Italic* indicates 90% significance level.

	B-A	C-A	C-B	D-A	D-B	D-C
FIELD MEASUREMENTS						
Dissolved oxygen (DO) concentration (mg/L), BLUE RIDGE						
Test statistic (S)	-58.500	-48.000	16.000	-59.500	-30.500	-33.000
p > S	0.9981	0.9947	0.2324	0.9984	0.9203	0.9385
p < S	***0.0019***	***0.0053***	0.7676	***0.0016***	*0.0797*	*0.0615*
Dissolved oxygen (DO) concentration (mg/L), PIEDMONT						
Test statistic (S)	24.000	12.000	-17.000	-9.5000	-39.000	-33.000
p > S	0.1156	0.2809	0.8019	0.6794	0.9778	0.9533
p < S	0.8844	0.7191	0.1981	0.3206	***0.0222***	***0.0467***
Dissolved oxygen (DO) saturation (%), BLUE RIDGE						
Test statistic (S)	5.000	5.000	6.500	-32.000	-30.000	-27.000
p > S	0.3501	0.3501	0.2954	0.9990	0.9976	0.9932
p < S	0.6499	0.6499	0.7046	***0.0010***	***0.0024***	***0.0068***
Dissolved oxygen (DO) saturation (%), PIEDMONT						
Test statistic (S)	22.500	20.500	-0.500	2.500	-19.500	-18.500
p > S	***0.0098***	***0.0186***	0.5098	0.4229	0.9756	0.9678
p < S	0.9902	0.9814	0.4902	0.5771	***0.0244***	***0.0322***

	B-A	C-A	C-B	D-A	D-B	D-C
pH (SU), BLUE RIDGE						
Test statistic (S)	1.000	16.500	10.000	-9.500	-18.000	-40.500
p > S	0.4862	0.2256	0.3265	0.6654	0.7949	0.9724
p < S	0.5138	0.7744	0.6735	0.3346	0.2051	***0.0276***
pH (SU), PIEDMONT						
Test statistic (S)	-14.000	-23.500	-11.500	-16.500	7.500	13.000
p > S	0.7564	0.9037	0.7147	0.7945	0.3575	0.2602
p < S	0.2436	*0.0963*	0.2853	0.2055	0.6425	0.7398
Specific conductance (µS/cm at 25°C), BLUE RIDGE						
Test statistic (S)	-18.000	-23.500	-1.000	15.000	46.500	47.000
p > S	0.8640	0.9083	0.5000	*0.0674*	***0.0028***	***0.0027***
p < S	0.1360	*0.0917*	0.5000	0.9326	0.9972	0.9973
Specific conductance (µS/cm at 25°C), PIEDMONT						
Test statistic (S)	-47.500	-47.500	9.500	-5.500	47.000	51.000
p > S	0.9978	0.9977	0.2041	0.6140	***0.0008***	***0.0011***
p < S	***0.0022***	***0.0023***	0.7959	0.3860	0.9992	0.9989
Temperature (25°C), BLUE RIDGE						
Test statistic (S)	76.500	76.500	4.500	64.500	-57.500	-55.500
p > S	***<0.0001***	***<0.0001***	0.4153	***0.0005***	0.9977	0.9968
p < S	1.0000	1.0000	0.5847	0.9995	***0.0023***	***0.0032***
Temperature (25°C), PIEDMONT						
Test statistic (S)	68.000	68.000	43.500	59.000	-58.000	-59.000
p > S	***<0.0001***	***<0.0001***	***0.0111***	***0.0005***	0.9993	0.9995
p < S	1.0000	1.0000	0.9889	0.9995	***0.0007***	***0.0005***
Secchi depth (m), BLUE RIDGE						
Test statistic (S)	--	--	39.000	--	--	--
p > S	--	--	***0.0114***	--	--	--
p < S	--	--	0.9886	--	--	--
Secchi depth (m), PIEDMONT						
Test statistic (S)	--	--	15.000	--	--	--
p > S	--	--	0.1284	--	--	--
p < S	--	--	0.8716	--	--	--
ANALYTICAL CHEMISTRY						
Chlorophyll-*a* (ug/L), BLUE RIDGE						
Test statistic (S)	76.500	76.500	48.500	45.500	-76.500	-76.500
p > S	***<0.0001***	***<0.0001***	***0.0048***	***0.0001***	1.0000	1.0000
p < S	1.0000	1.0000	0.9952	0.9999	***<0.0001***	***<0.0001***
Chlorophyll-*a* (ug/L), PIEDMONT						
Test statistic (S)	68.000	62.000	38.500	60.000	-10.500	-13.000
p > S	***<0.0001***	***0.0002***	***0.0133***	***<0.0001***	0.6974	0.7359
p < S	1.0000	0.9998	0.9867	1.0000	0.3026	0.2641
NO_2+NO_3 (mg/L as N), BLUE RIDGE						
Test statistic (S)	-45.500	-45.500	0.500	-57.000	22.500	22.500
p > S	0.9999	0.9999	0.5000	0.9998	***0.0020***	***0.0020***
p < S	***0.0001***	***0.0001***	0.5000	***0.0002***	0.9980	0.9980

	B-A	C-A	C-B	D-A	D-B	D-C
NO_2+NO_3 (mg/L as N), PIEDMONT						
Test statistic (S)	-33.000	-33.000	0.500	-35.000	7.500	4.500
p > S	0.9995	0.9995	0.5000	0.9983	***0.0313***	0.2188
p < S	***0.0005***	***0.0005***	0.5000	***0.0017***	0.9688	0.7813
TKN (mg/L as N), BLUE RIDGE						
Test statistic (S)	5.000	9.000	9.000	8.000	5.500	2.000
p > S	0.2266	0.1250	*0.0781*	0.1484	0.3066	0.4390
p < S	0.7734	0.8750	0.9219	0.8516	0.6934	0.5610
TKN (mg/L as N), PIEDMONT						
Test statistic (S)	52.000	47.000	23.500	53.500	22.000	22.500
p > S	***0.0025***	***0.0063***	0.1166	***0.0005***	0.1342	0.1288
p < S	0.9975	0.9937	0.8834	0.9995	0.8658	0.8712
TN (mg/L as N), BLUE RIDGE						
Test statistic (S)	-52.500	-52.500	8.500	-59.000	22.500	14.500
p > S	0.9999	0.9999	***0.0469***	0.9983	***0.0239***	0.1650
p < S	***<0.0001***	***<0.0001***	0.9531	***0.0017***	0.9761	0.8350
TN (mg/L as N), PIEDMONT						
Test statistic (S)	18.000	19.500	23.500	35.500	23.000	23.500
p > S	0.1616	0.1643	0.1166	***0.0336***	0.1258	0.1181
p < S	0.8384	0.8357	0.8834	0.9964	0.8742	0.8819
TP (mg/L as P), BLUE RIDGE						
Test statistic (S)	-9.000	-10.500	1.500	-6.000	6.000	4.500
p > S	0.9531	0.9141	0.2500	0.9063	*0.0938*	0.1250
p < S	***0.0469***	*0.0859*	0.7500	*0.0938*	0.9063	0.8750
TP (mg/L as P), PIEDMONT						
Test statistic (S)	-15.000	-8.000	5.000	5.500	14.000	10.500
p > S	0.8936	0.7783	0.1563	0.3037	***0.0273***	0.1270
p < S	0.1064	0.2217	0.8438	0.6963	0.9727	0.8730
TN:TP ratio, BLUE RIDGE						
Test statistic (S)	-24.000	-23.000	0.500	-38.500	2.000	6.000
p > S	0.9088	0.8990	0.4688	0.9653	0.4465	0.3486
p < S	*0.0912*	0.1010	0.5313	***0.0347***	0.5535	0.6514
TN:TP ratio, PIEDMONT						
Test statistic (S)	47.000	43.000	-1.000	26.000	-23.000	-18.000
p > S	***0.0025***	***0.0125***	0.5149	*0.0941*	0.8767	0.8123
p < S	0.9975	0.9875	0.4851	0.9059	0.1233	0.1877
TSS (mg/L), BLUE RIDGE						
Test statistic (S)	-0.500	8.000	5.000	8.000	8.000	1.500
p > S	0.5000	0.1484	0.2266	0.2236	0.1563	0.4570
p < S	0.5000	0.8516	0.7734	0.7764	0.8438	0.5430
TSS (mg/L), PIEDMONT						
Test statistic (S)	-31.500	-30.500	8.000	6.500	18.000	16.000
p > S	0.9985	0.9838	0.1094	0.3356	***0.0332***	0.1403
p < S	***0.0015***	***0.0162***	0.8906	0.6644	0.9668	0.8597

	B-A	C-A	C-B	D-A	D-B	D-C
NC TROPHIC STATE INDEX (NCTSI)						
NCTSI, BLUE RIDGE						
Test statistic (S)	--	--	45.500	--	--	--
p > S	--	--	***0.0153***	--	--	--
p < S	--	--	0.9847	--	--	--
NCTSI, PIEDMONT						
Test statistic (S)	--	--	41.500	--	--	--
p > S	--	--	***0.0368***	--	--	--
p < S	--	--	0.9632	--	--	--
HABITAT ASSESSMENT						
Habitat assessment, BLUE RIDGE						
Test statistic (S)	--	--	--	-3.000	--	--
p > S	--	--	--	0.7031	--	--
p < S	--	--	--	0.2969	--	--
Habitat assessment, PIEDMONT						
Test statistic (S)	--	--	--	-0.500	--	--
p > S	--	--	--	0.5000	--	--
p < S	--	--	--	0.5000	--	--
BENTHIC MACROINVERTEBRATES						
Benthic macroinvertebrate taxa diversity (N; number of unique taxa), ALL SITES—samples with no organisms excluded from analysis						
Test statistic (S)	-27.500	--	--	-20.500	26.500	--
p > S	0.9990	--	--	0.9814	***0.0020***	--
p < S	***0.0010***	--	--	***0.0186***	0.9980	--
Benthic macroinvertebrate taxa diversity (N; number of unique taxa), ALL SITES —using N = 1 as "non-detect" value for stations that were sampled but no organisms in sample (i.e., one individual was found)						
Test statistic (S)	-27.500	--	--	-20.000	26.500	--
p > S	0.9990	--	--	0.9795	***0.0020***	--
p < S	***0.0010***	--	--	***0.0205***	0.9980	--
Benthic macroinvertebrate Biotic Index (BI), ALL SITES—samples with no organisms excluded from analysis						
Test statistic (S)	7.500	--	--	6.500	-7.500	--
p > S	***0.0313***	--	--	*0.0625*	0.9688	--
p < S	0.9688	--	--	0.9375	***0.0313***	--
Benthic macroinvertebrate Biotic Index (BI), ALL SITES—using BI = 10 as "non-detect" value for stations that were sampled but no organisms in sample (i.e., assume 1 organism with the highest TV [10.0] was found)						
Test statistic (S)	27.500	--	--	21.500	-24.500	--
p > S	***0.0010***	--	--	***0.0137***	0.9951	--
p < S	0.9990	--	--	0.9863	***0.0049***	--
Benthic macroinvertebrate, % filter feeders, ALL SITES						
Test statistic (S)	--	--	--	9.500	--	--
p > S	--	--	--	0.1504	--	--
p < S	--	--	--	0.8496	--	--
Benthic macroinvertebrate, % grazers, ALL SITES						
Test statistic (S)	--	--	--	-7.500	--	--
p > S	--	--	--	0.7871	--	--
p < S	--	--	--	0.2129	--	--

	B-A	C-A	C-B	D-A	D-B	D-C
Benthic macroinvertebrate, % shredders, ALL SITES						
Test statistic (S)	--	--	--	-11.500	--	--
p > S	--	--	--	0.8984	--	--
p < S	--	--	--	0.1016	--	--
PERIPHYTON BIOMASS						
Periphyton biomass (g/m^2), ALL SITES						
Test statistic (S)	21.500	--	--	18.000	1.500	--
p > S	***0.0039***	--	--	***0.0039***	0.4551	--
p < S	0.9961	--	--	0.9961	0.5449	--

Appendix 4: Data tables

This section provides detailed data by site for habitat assessments, periphyton biomass, field and analytical chemistry results, and benthic macroinvertebrate taxa lists. Sampling dates are provided where applicable.

Habitat assessment

The NC Division of Water Quality habitat assessment is a 10-question field form. Subscores for each question are shown below, with the maximum number of points for each shown in parentheses. For details on the assessment, please refer to the NC DWQ Biological Assesement Unit's Benthos SOP at http://ncdenr.gov/web/wq/ess/bau.

Ecoregion	Site-Station	Date	Channel modification (5)	Instream habitat (20)	Bottom substrate (15)	Pool variety (10)	Riffle Habitats (16)	Bank stability (Left) (7)	Bank stability (Right) (7)	Light Penetration (10)	Riparian vegetation width (Left) (5)	Riparian vegetation width (Right) (5)	Total score (100)
BLUE RIDGE	BEE-A	7/19/2011	5	20	15	10	16	7	7	10	5	5	100
	BEE-D	7/19/2011	3	18	15	10	16	7	7	0	5	2	83
	BROY-A	7/20/2011	5	15	14	10	7	7	7	7	2	2	76
	BROY-D	7/20/2011	5	20	11	10	16	7	7	10	5	5	96
	DEV-A	7/12/2011	5	20	15	10	16	7	7	10	5	5	100
	DEV-D	7/12/2011	4	20	15	10	14	7	7	10	5	5	97
	HANG-A	7/18/2011	5	20	14	10	16	7	7	10	5	5	99
	HANG-D	7/18/2011	5	20	15	10	16	7	7	10	5	5	100
	SOUT-A	7/19/2011	5	20	15	10	16	7	7	10	5	5	100
	SOUT-D	7/19/2011	4	20	15	10	16	7	7	10	5	5	99
	TROU-A	7/20/2011	5	20	15	10	16	7	7	10	5	5	100
	TROU-D	7/20/2011	5	20	15	10	16	7	7	10	2	5	97
PIEDMONT	CROW-A	7/11/2011	5	19	15	10	16	7	7	10	5	5	99
	CROW-D	7/11/2011	4	19	4	4	14	7	7	10	5	5	79
	MONT-A	7/11/2011	4	19	14	10	14	7	7	10	5	5	95
	MONT-D	7/11/2011	4	16	4	4	10	7	7	2	5	5	64
	REED-A	7/6/2011	4	16	4	8	3	7	7	10	5	5	69
	REED-D	7/6/2011	3	20	4	4	3	6	6	2	5	5	58
	SIEM-A	7/12/2011	5	11	1	8	0	7	7	10	5	5	59
	SIEM-D	7/12/2011	5	8	15	0	16	7	7	10	5	5	78
	TOWN-A	7/13/2011	5	5	1	8	0	7	7	10	5	5	53
	TOWN-D	6/8/2011	5	16	15	10	16	7	7	10	5	5	96
	YADK-A	7/13/2011	5	15	12	10	14	7	7	10	5	5	90
	YADK-D	7/13/2011	5	20	15	10	16	7	7	10	5	5	100

Periphyton biomass

The biomass (g/m^2) for each periphyton replicate and mean of all replicates by station are shown below. “ND” indicates no data.

Ecoregion	Site-Station	Rep 1	Rep 2	Rep 3	Rep 4	Mean biomass (g/m2)
BLUE RIDGE	BEE-A	0.3248	0.3761	0.5268	0.4444	0.4180
	BEE-B	0.5128	0.7308	0.7179	0.3761	0.5844
	BEE-D	2.7521	3.5641	3.1624	3.3675	3.2115
	BROY-A	0.3590	0.7863	1.4701	0.9060	0.8804
	BROY-B	2.1538	2.0855	1.8803	2.6838	2.2009
	BROY-D	1.0256	1.1282	1.3846	2.7436	1.5705
	DEV-A	0.8718	0.5983	0.7863	0.5470	0.7009
	DEV-B	2.6838	2.7521	2.4274	3.5214	2.8462
	DEV-D	0.9744	1.3162	0.8718	1.1966	1.0898
	HANG-A	0.3419	0.4957	0.3419	0.3077	0.3718
	HANG-B	ND	ND	ND	ND	ND
	HANG-D	0.7350	0.7692	0.7863	1.0598	0.8376
	SOUT-A	0.1880	0.1197	0.4786	0.4615	0.3120
	SOUT-B	1.3333	1.3675	1.4017	ND	1.3675
	SOUT-D	1.4530	1.3333	0.7863	0.8376	1.1026
	TROU-A	1.6154	0.3932	0.6154	0.3932	0.7543
	TROU-B	0.6883	1.0256	1.2308	1.3333	1.0695
	TROU-D	0.6838	0.5470	1.5898	0.2564	0.7693
PIEDMONT	CROW-A	0.6838	0.8205	0.4786	0.5470	0.6325
	CROW-B	0.8376	0.8205	0.8155	0.9744	0.8620
	CROW-D	1.9825	2.2051	1.2821	1.3846	1.7136
	MONT-A	0.2735	0.4274	ND	ND	0.3505
	MONT-B	0.4615	1.1795	0.8612	0.8376	0.8350
	MONT-D	1.8633	3.4701	2.5897	2.2821	2.5513
	REED-A	ND	ND	ND	ND	ND
	REED-B	1.7607	1.9829	2.2602	1.9186	1.9806
	REED-D	0.6496	0.7521	1.3162		0.9060
	SIEM-A	0.8177	0.5641	0.5128	0.8547	0.6873
	SIEM-B	0.5983	0.7179	0.8034	0.5299	0.6624
	SIEM-D	1.8547	2.0256	2.5943	1.1026	1.8943
	TOWN-A	ND	ND	ND	ND	ND
	TOWN-B	1.8974	1.3790	0.8333	1.2436	1.3383
	TOWN-D	1.4139	1.2963	1.6303	0.7692	1.2774
	YADK-A	0.7009	1.5726	0.3419	1.1111	0.9316
	YADK-B	5.5556	2.5128	4.8718	4.5385	4.3697
	YADK-D	1.5726	2.3077	1.9145	2.0342	1.9573

Chemistry (Field measurements and analytical parameters)

Note that data are broken into two tables by ecoregion. The calculated NCTSI is provided where applicable. See text for calculation method.

BLUE RIDGE SITES

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
BEE-A	6/13/2011	0.1	7.45		6.97		18	16.71	<1.0	0.13	<0.20	<0.02	<6.2	
BEE-A	7/19/2011	0.1	8.25	89.6	6.66		20	17.62	<1.0	0.25	<0.20	<0.02	<6.2	
BEE-A	10/5/2011	0.1	7.37	90.7	7.35		19	11.97	<1.0	0.12	<0.20	<0.02	<6.2	
BEE-B	6/13/2011	0.1	8.24		7.23	4	18	23.95						
BEE-B	6/13/2011	1	8.28		7.14		18	23.53						
BEE-B	6/13/2011	2	8.37		7.17		18	22.39						
BEE-B	6/13/2011	3	8.7		7.05		21	20.68	2.2	<0.02	<0.20	<0.02	<6.2	-3.56
BEE-B	7/19/2011	0.1	7.8	94	6.59	6	19	23.52						
BEE-B	7/19/2011	1	7.88	95.6	6.54		19	23.47						
BEE-B	7/19/2011	2	7.88	95.7	6.6		19	23.43						
BEE-B	7/19/2011	3	8.04	97.2	6.59		20	23.19	3.6	<0.02	<0.20	<0.02	<6.2	-3.60
BEE-C	6/13/2011	0.1	8.7		7.05	6	18	24.34						
BEE-C	6/13/2011	1	8.2		7.06		19	23.84						
BEE-C	6/13/2011	2	9.01		7.1		19	23.1						
BEE-C	6/13/2011	3	9.65		7.25		19	22.04						
BEE-C	6/13/2011	4	9.73		7.3		18	20.28						
BEE-C	6/13/2011	5	9.52		7.34		18	18.68						
BEE-C	6/13/2011	6	10.56		7.36		17	16.32						
BEE-C	6/13/2011	7	10.54		7.41		17	15.22						
BEE-C	6/13/2011	8	10.48		7.36		17	13.84						
BEE-C	6/13/2011	9	10.01		7.23		18	12.88						
BEE-C	6/13/2011	10	9.6		7.3		18	11.66						
BEE-C	6/13/2011	11	8.84		7.28		18	10.63						
BEE-C	6/13/2011	12	8.57		7.27		19	9.81	8.1	<0.02	<0.20	<0.02	<6.2	-2.99
BEE-C	7/19/2011	0.1	7.98	98.3	6.77	3	19	23.97						
BEE-C	7/19/2011	1	8.01	98	6.74		19	23.91						
BEE-C	7/19/2011	2	8	98.4	6.74		19	23.84						
BEE-C	7/19/2011	3	8.27	100.5	6.71		19	23.41						
BEE-C	7/19/2011	4	8.2	99.8	6.66		19	23.13						
BEE-C	7/19/2011	5	9.11	108	6.7		19	22.55						
BEE-C	7/19/2011	6	8.95	105.5	6.62		19	21.81						
BEE-C	7/19/2011	7	8.12	91.6	6.66		19	21.22						
BEE-C	7/19/2011	8	7.37	82.2	6.63		20	19.6						
BEE-C	7/19/2011	9	7.77	83.1	6.65		18	17.14						
BEE-C	7/19/2011	10	7.83	80.5	6.65		18	15.23						
BEE-C	7/19/2011	11	7.38	72.2	6.64		19	13.81						
BEE-C	7/19/2011	12	6.63	62.6	6.61		19	12.54	4.8	<0.02	<0.20	<0.02	<6.2	-2.68
BEE-D	6/13/2011	0.1	6.68		6.92		18	25.91	1.4	<0.02	<0.20	<0.02	<12.0	
BEE-D	7/19/2011	0.1	5.95	67	6.64		67	19.62	<1.0	0.17	<0.20	<0.02	<6.2	
BEE-D	10/5/2011	0.1	6.63	71	7.24		75	17.21	<1.0	0.1	<0.20	<0.02	<6.2	
BROY-A	6/14/2011	0.1	8.3		7.82		51	17.09	<1.0	0.9	0.27	0.08	7.2	
BROY-A	7/20/2011	0.1	7.1	83	6.88		66	21.28	1.9	1.1	0.93	0.13	<6.2	
BROY-A	10/4/2011	0.1	7.94	82.6	7.01		65	15.83	<1.0	1.2	0.22	0.08	<6.2	
BROY-B	6/14/2011	0.1	8.33		7.52	2.5	35	27.67						

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
BROY-B	6/14/2011	1	8		7.61		35	27.68						
BROY-B	6/14/2011	2	6.58		7.46		38	26.67						
BROY-B	6/14/2011	3	1.15		7.42		44	16.56						
BROY-B	6/14/2011	4	0.4		7.49		44	11.06						
BROY-B	6/14/2011	5	0.33		7.5		51	9.31	8.8	<0.02	0.77	0.02	<6.2	0.16
BROY-B	6/14/2011	6	0.3		7.45		60	8.15						
BROY-B	7/20/2011	0.1	7.3	99.5	6.84	3.2	35	29.84						
BROY-B	7/20/2011	1	7.53	101.7	6.86		35	28.87						
BROY-B	7/20/2011	2	7.59	101.7	6.99		35	28.32						
BROY-B	7/20/2011	3	7.27	94.5	6.94		35	27.5						
BROY-B	7/20/2011	4	3.66	46.4	6.9		36	25.57						
BROY-B	7/20/2011	5	2.6	28.3	7.1		38	19.01						
BROY-B	7/20/2011	6	0.65	5.5	7.18		43	14.38	10	<0.02	0.49	0.02	<6.2	-0.73
BROY-B	7/20/2011	7	0.31	2.8	7.25		50	10.96						
BROY-B	10/4/2011	0.1	7.39	86.7	6.99	3.8	34	21.74						
BROY-B	10/4/2011	1	7.49	87.6	6.98		35	21.49						
BROY-B	10/4/2011	2	7.43	86.4	7.04		36	21.3						
BROY-B	10/4/2011	3	7.6	86.8	7.02		35	20.45						
BROY-B	10/4/2011	4	7.53	85.4	6.99		35	20.31						
BROY-B	10/4/2011	5	7.29	82.8	7		35	20.2						
BROY-B	10/4/2011	6	7.3	82.8	7.01		35	20						
BROY-B	10/4/2011	7	5.24	40.9	6.97		38	18						
BROY-B	10/4/2011	7.6							7.1	<0.02	0.37	<0.02	<6.2	-1.62
BROY-B	10/4/2011	8	1.52	10.7	6.89		66	12.11						
BROY-B	10/4/2011	9	0.48	3.9	6.91		81	10.33						
BROY-C	6/14/2011	0.1	8.64		8.25	2.5	35	27.76						
BROY-C	6/14/2011	1	8.32		8.37		35	27.78						
BROY-C	6/14/2011	2	1.29		8.26		42	17.99						
BROY-C	6/14/2011	3	0.93		8.51		38	12.56						
BROY-C	6/14/2011	4	0.38		8.42		46	9.54						
BROY-C	6/14/2011	5	0.27		8.15		52	8.12	12	0.04	0.75	0.02	<6.2	0.35
BROY-C	7/20/2011	0.1	7.44	101	6.74	3.2	35	29.54						
BROY-C	7/20/2011	1	7.21	96.5	6.8		35	28.87						
BROY-C	7/20/2011	2	7.42	97.9	6.94		35	28.09						
BROY-C	7/20/2011	3	6.8	89.1	6.87		34	27.35						
BROY-C	7/20/2011	4	2.56	31.7	6.79		37	24.8						
BROY-C	7/20/2011	5	2.79	31.3	6.9		37	19.64						
BROY-C	7/20/2011	6	0.62	5.4	6.95		41	14.4						
BROY-C	7/20/2011	6.4							17	<0.02	0.53	0.02	<6.2	-0.21
BROY-C	7/20/2011	7	0.28	2.5	6.98		45	12.06						
BROY-C	7/20/2011	8	0.2	1.7	7		48	10.54						
BROY-C	7/20/2011	9	0.19	1.7	6.9		64	9.3						
BROY-C	10/4/2011	0.1	7.42	86.8	6.88	4.2	35	21.57						
BROY-C	10/4/2011	1	7.64	87.2	6.94		35	20.7						
BROY-C	10/4/2011	2	7.75	87.3	6.95		35	20.53						
BROY-C	10/4/2011	3	7.69	88	6.92		35	20.38						
BROY-C	10/4/2011	4	7.65	87.3	6.94		35	20.31						
BROY-C	10/4/2011	5	7.45	84.4	6.95		35	20.19						
BROY-C	10/4/2011	6	6.32	71.4	6.95		35	19.96						
BROY-C	10/4/2011	7	1.71	13	6.95		45	15.91						

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
BROY-C	10/4/2011	8	0.53	4.3	6.89		59	11.78						
BROY-C	10/4/2011	8.4							14	<0.02	0.35	0.02	<6.2	-1.31
BROY-C	10/4/2011	9	0.25	2.3	6.93		72	10.15						
BROY-D	6/14/2011	0.1	9.02		8.02		51	15.2	2.1	0.11	0.61	0.06	<6.2	
BROY-D	7/20/2011	0.1	7.16	80.8	6.93		49	20.77	3.6	0.09	0.64	0.06	<6.2	
BROY-D	10/4/2011	0.1	6.72	66.3	6.95		66	13.04	5.7	0.13^{J3}	1.2	0.08	6.8	
DEV-A	6/6/2011	0.1	8.75		6.96		16	17.53	<1.0	0.11	<0.20	<0.02	<6.2	
DEV-A	7/12/2011	0.1	8.72	95.5	6.79		18	19.44	<1.0	0.13	<0.20	<0.02	<6.2	
DEV-A	10/4/2011	0.1	9.62	92.5	7		16	12.25	<1.0	0.02	<0.20	<0.02	<6.2	
DEV-B	6/6/2011	0.1	7.48		7.33	5	17	26.13						
DEV-B	6/6/2011	1	7.41		7.28		17	25.75						
DEV-B	6/6/2011	2	8.71		7.24		17	23.61						
DEV-B	6/6/2011	3	9.98		7.27		17	20.48						
DEV-B	6/6/2011	4	11.39		7.37		16	16.04						
DEV-B	6/6/2011	5	11.02		7.36		16	13.16						
DEV-B	6/6/2011	6	9.48		7.23		16	10.84						
DEV-B	6/6/2011	7	7.39		7.33		17	9.69						
DEV-B	6/6/2011	8	5.45		7.28		18	8.35	2.1	<0.02	<0.20	<0.02	<6.2	-3.82
DEV-B	7/12/2011	0.1	7.27	94.5	6.69	4.2	16	27.66						
DEV-B	7/12/2011	1	7.27	94.8	6.7		15	27.68						
DEV-B	7/12/2011	2	8.45	103.8	6.72		16	25.72						
DEV-B	7/12/2011	3	8	97.3	6.69		17	24.12						
DEV-B	7/12/2011	4	7.37	88.7	6.65		16	22.75						
DEV-B	7/12/2011	5	8.98	100.2	6.78		17	19.23						
DEV-B	7/12/2011	6	8.62	85	6.67		16	13.49						
DEV-B	7/12/2011	7	6.38	58.2	6.74		17	11.02						
DEV-B	7/12/2011	8	3.8	31.2	6.67		18	9.35						
DEV-B	7/12/2011	8.4							2.6	<0.02	<0.20	<0.02	<6.2	-3.48
DEV-B	7/12/2011	9	1.51	11.5	6.66		20	7.88						
DEV-B	10/4/2011	0.1	7.37	80.8	7.52	5.5	17	19.07						
DEV-B	10/4/2011	1	7.28	80.8	7.52		17	19.04						
DEV-B	10/4/2011	2	7.12	77.7	7.58		17	18.83						
DEV-B	10/4/2011	3	7.03	77.2	7.51		17	18.77						
DEV-B	10/4/2011	4	7.11	78.7	7.43		17	18.73						
DEV-B	10/4/2011	5	7.17	79.2	7.45		17	18.73						
DEV-B	10/4/2011	6	7.11	77.8	7.46		17	18.6						
DEV-B	10/4/2011	7	7.05	76.7	7.46		17	18.24						
DEV-B	10/4/2011	8	3.26	20.3	7.29		20	14.57						
DEV-B	10/4/2011	9	1.58	10.3	7.2		35	8.97	4.2	<0.02	<0.20	<0.02	<6.2	-3.40
DEV-C	6/6/2011	0.1	7.36		7.81		17	26.22						
DEV-C	6/6/2011	1	7.3		7.7		17	25.7						
DEV-C	6/6/2011	2	9.56		7.66		17	23.24						
DEV-C	6/6/2011	3	10.13		7.66		17	20.26						
DEV-C	6/6/2011	4	11.15		7.8		16	16.24						
DEV-C	6/6/2011	5	11.44		7.71		16	12.97						
DEV-C	6/6/2011	6	10.13		7.8		16	11.49						
DEV-C	6/6/2011	7	8.21		7.76		16	10						
DEV-C	6/6/2011	8	7.28		7.6		16	8.48						
DEV-C	6/6/2011	9	5.92		7.62		17	7.36						
DEV-C	6/6/2011	10	5.3		7.45		17	6.95	2.3	<0.02	<0.20	<0.02	<12.0	-3.85

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
DEV-C	6/6/2011	11	4.79		7.47		17	6.72						
DEV-C	6/6/2011	12	4.52		7.24		18	6.6						
DEV-C	7/12/2011	0.1	7.09	93.2	6.64	4.5	16	28.02						
DEV-C	7/12/2011	1	7.05	91.6	6.69		16	27.85						
DEV-C	7/12/2011	2	7.13	92.1	6.66		16	27.49						
DEV-C	7/12/2011	3	9	113	6.73		16	24.94						
DEV-C	7/12/2011	4	8.52	99.1	6.75		16	22.25						
DEV-C	7/12/2011	5	11.16	119.6	6.67		16	17.74						
DEV-C	7/12/2011	6	10.36	97.3	6.81		16	12.58						
DEV-C	7/12/2011	7	7.44	65.3	6.8		17	10.32						
DEV-C	7/12/2011	8	5.13	43.6	6.59		17	9.06						
DEV-C	7/12/2011	9	3.85	30.9	6.7		18	7.9	3.6	<0.02	<0.20	<0.02	<12.0	-3.31
DEV-C	7/12/2011	10	3.14	25.9	6.5		17	7.25						
DEV-C	7/12/2011	11	2.67	21.9	6.58		18	7.01						
DEV-C	7/12/2011	12	2.3	19.2	6.39		18	6.75						
DEV-C	10/4/2011	0.1	7.18	79.2	7.12	5.8	17	19.07						
DEV-C	10/4/2011	1	7.01	77.6	7.22		16	19.1						
DEV-C	10/4/2011	2	6.97	76.5	7.19		17	18.91						
DEV-C	10/4/2011	3	6.92	76.4	7.06		17	18.84						
DEV-C	10/4/2011	4	6.81	74.8	7.18		17	18.8						
DEV-C	10/4/2011	5	6.77	75.2	7.09		18	18.79						
DEV-C	10/4/2011	6	6.76	73.5	7.08		17	18.75						
DEV-C	10/4/2011	7	6.84	74.8	7.08		17	18.4						
DEV-C	10/4/2011	8	4.03	23.5	7.06		23	13.14						
DEV-C	10/4/2011	9	0.84	6.5	7.01		20	8.59						
DEV-C	10/4/2011	10	0.51	4.1	6.98		20	7.59						
DEV-C	10/4/2011	11	0.44	3.9	6.8		33	7.18						
DEV-C	10/4/2011	11.6							2.1	<0.02	<0.20	<0.02	<6.2	-3.97
DEV-C	10/4/2011	12	0.35	2.8	6.88		39	7.01						
DEV-D	6/6/2011	0.1	7.41		7.17		16	25.24	<1.0	<0.02	<0.20	<0.02	<6.2	
DEV-D	7/12/2011	0.1	6.89	88.6	6.5		17	26.59	1.4	<0.02	<0.20	<0.02	7.8	
DEV-D	10/4/2011	0.1	7.06	71.3	7.03		24	15.01	1.2	0.02	0.21	0.02	<6.2	
HANG-A	5/31/2011	0.1	9		8.5		12	18.31	<1.0	<0.02	0.26	0.04	<6.2	
HANG-A	7/18/2011	0.1	8.3	88.2	6.7		13	18.32	<1.0	<0.02	<0.20	0.02	<6.2	
HANG-A	10/3/2011	0.1	9.4	85.1	6.47		12	11.05	<1.0	<0.02	<0.20	0.03	<6.2	
HANG-B	5/31/2011	0.1	8.25		8.18	3	11	28.11						
HANG-B	5/31/2011	1	7.94		7.99		10	26.89						
HANG-B	5/31/2011	2	7.59		7.83		11	23.35						
HANG-B	5/31/2011	3	8.55		7.92		11	20.12						
HANG-B	5/31/2011	3.3	7.59		8		12	18.6	1.7	<0.02	<0.20	0.02	<6.2	-3.46
HANG-B	7/18/2011	0.1	6.82	85	6.72	3	12	26.64						
HANG-B	7/18/2011	1	6.58	79.7	6.83		12	25.95						
HANG-B	7/18/2011	2	6.42	77.6	6.82		12	25.35						
HANG-B	7/18/2011	3	6.9	79.3	6.87		12	24.65						
HANG-B	7/18/2011	3.5	4.95	59.1	6.8		14	23.84	3.9	<0.02	<0.20	<0.02	<12.0	-2.83
HANG-B	10/3/2011	0.1	7.56	79.2	6.44	3.3	12	17.44						
HANG-B	10/3/2011	1	7.63	79.2	6.47		12	17.35						
HANG-B	10/3/2011	2	7.69	79.1	6.57		11	17.27						
HANG-B	10/3/2011	3	7.93	84.5	6.53		12	16.49						
HANG-B	10/3/2011	3.3	8	84.5	6.37		11	16.77	2.9	<0.02	<0.20	<0.02	<6.2	-3.15

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
HANG-C	5/31/2011	0.1	7.4		8.6	2.7	10	27.2						
HANG-C	5/31/2011	1	7.73		8.51		10	25.92						
HANG-C	5/31/2011	2	8.6		8.43		11	23.43						
HANG-C	5/31/2011	3	8.93		8.58		11	19.56						
HANG-C	5/31/2011	4	7.04		8.61		13	16.17						
HANG-C	5/31/2011	5	3.42		8.51		14	12.93						
HANG-C	5/31/2011	6	0.69		8.35		24	11.29	4.1	<0.02	<0.20	0.02	<6.2	-2.69
HANG-C	7/18/2011	0.1	6.89	83.5	7.04	3.2	12	26.36						
HANG-C	7/18/2011	1	6.75	81.4	7.01		12	25.39						
HANG-C	7/18/2011	2	5.76	69.2	6.99		12	25.16						
HANG-C	7/18/2011	3	1.23	11.3	6.85		13	23.51						
HANG-C	7/18/2011	4	0.49	4.9	6.74		20	17.67						
HANG-C	7/18/2011	5	0.41	3.8	6.91		35	12.89	8.3	<0.02	<0.20	<0.02	<6.2	-2.33
HANG-C	10/3/2011	0.1	7.44	76.8	6.83	4	12	17.55						
HANG-C	10/3/2011	1	7.16	74.7	6.72		12	17.44						
HANG-C	10/3/2011	2	7.25	75.6	6.6		12	17.33						
HANG-C	10/3/2011	3	7.23	75.1	6.67		12	17.3						
HANG-C	10/3/2011	4	7.28	75.6	6.6		12	17.23						
HANG-C	10/3/2011	5	7.35	76	6.53		12	17.14						
HANG-C	10/3/2011	5.5	2.6	13.3	6.78		44	15.66	2.6	<0.02	<0.20	<0.02	<6.2	-3.43
HANG-D	5/31/2011	0.1	6.83		6.79		12	28.77	<1.0	0.04	<0.20	0.02	<6.2	
HANG-D	7/18/2011	0.1	6.76	83.7	6.79		13	26.11	<1.0	0.04	0.34	<0.02	<6.2	
HANG-D	10/3/2011	0.1	8.08	80.4	6.54		12	15.11	1.3	0.02	0.24	0.02	14	
SOUT-A	6/15/2011	0.1	8.14		6.89		27	16.32	<1.0	0.11	<0.20	0.02	9.8	
SOUT-A	7/19/2011	0.1	8.14	92.7	6.75		29	19.92						
SOUT-A	10/5/2011	0.1	8.9	87.5	7.35		28	13.04	<1.0	0.05	<0.20	<0.02	<12.0	
SOUT-B	6/15/2011	0.1	6.85		6.64	3	27	25.59						
SOUT-B	6/15/2011	1	6.7		6.66		27	25.44						
SOUT-B	6/15/2011	2	5.84		6.61		27	25.06						
SOUT-B	6/15/2011	3	8.46		6.71		25	20.35						
SOUT-B	6/15/2011	4	8.89		6.65		24	16.62						
SOUT-B	6/15/2011	5	6.18		6.67		28	13.09	3.8	<0.02	<0.20	<0.02	<6.2	-2.85
SOUT-B	7/19/2011	0.1	7.28	97.3	6.84	2.6	28	28.74						
SOUT-B	7/19/2011	1	7.42	95.7	6.8		26	26.95						
SOUT-B	7/19/2011	2	6.84	87.8	6.77		28	25.96						
SOUT-B	7/19/2011	3	5.82	71	6.8		27	24.1						
SOUT-B	7/19/2011	4	5.88	69.9	6.88		26	21.57						
SOUT-B	7/19/2011	5	4.84	44.2	7		28	16.22	3.2	<0.02	<0.20	<0.02	<6.2	-2.84
SOUT-B	10/5/2011	0.1	7.28	80.2	7.8	2.1	27	18.1						
SOUT-B	10/5/2011	1	7.29	78.9	7.76		27	18.9						
SOUT-B	10/5/2011	2	7.22	78.7	7.79		27	18.9						
SOUT-B	10/5/2011	3	7.13	78.1	7.7		27	18.8						
SOUT-B	10/5/2011	4	7.09	77	7.7		27	18.07						
SOUT-B	10/5/2011	4.2							5.6	<0.02	<0.20	<0.02	<6.2	-2.20
SOUT-B	10/5/2011	5	6.84	74.2	7.68		28	17.92						
SOUT-C	6/15/2011	0.1	6.99		6.66	3.6	26	25.61						
SOUT-C	6/15/2011	1	6.87		6.66		26	25.45						
SOUT-C	6/15/2011	2	6.38		6.66		28	24.67						
SOUT-C	6/15/2011	3	8.46		6.8		25	20.45						
SOUT-C	6/15/2011	4	10.11		6.87		24	16.17						

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
SOUT-C	6/15/2011	5	8.59		6.89		28	11.95						
SOUT-C	6/15/2011	6	6.47		6.88		28	9.64						
SOUT-C	6/15/2011	7	3.53		6.88		29	9.45						
SOUT-C	6/15/2011	7.2							4.1	<0.02	<0.20	<0.02	<6.2	-2.98
SOUT-C	6/15/2011	7.8	1.56		6.75		29	7.85						
SOUT-C	7/19/2011	0.1	7.48	100	6.79	2.9	28	28.93						
SOUT-C	7/19/2011	1	7.18	93	6.84		28	27.18						
SOUT-C	7/19/2011	2	6.93	87.6	6.82		28	26.05						
SOUT-C	7/19/2011	3	6.24	76.6	6.78		27	23.67						
SOUT-C	7/19/2011	4	7.2	82	6.88		26	20.2						
SOUT-C	7/19/2011	5	7.5	76.3	7		24	14.83						
SOUT-C	7/19/2011	5.8							3.2	<0.02	<0.20	<0.02	<12.0	-2.95
SOUT-C	7/19/2011	6	3.76	29.9	7.03		29	11.09						
SOUT-C	7/19/2011	7	1.17	7.7	7		48	9.6						
SOUT-C	10/5/2011	0.1	7.26	79.9	7.43	2.5	27	18.12						
SOUT-C	10/5/2011	1	7	77.4	7.4		27	18.13						
SOUT-C	10/5/2011	2	7.16	78.1	7.39		28	18.1						
SOUT-C	10/5/2011	3	7.09	77.6	7.42		27	18.08						
SOUT-C	10/5/2011	4	7.17	77.8	7.39		28	18.07						
SOUT-C	10/5/2011	5	6.89	73.2	7.39		28	17.9	6.4	<0.02	0.21	<0.02	<6.2	-2.20
SOUT-C	10/5/2011	6	3.59	24.4	7.38		30	16.02						
SOUT-C	10/5/2011	7	0.94	6.9	7.29		51	12.79						
SOUT-C	10/5/2011	7.8	0.42	3.6	7.17		72	10.18						
SOUT-D	6/15/2011	0.1	6.89		6.83		35	25.55	1.8	<0.02	<0.20	0.02	6.2	
SOUT-D	7/19/2011	0.1	6.05	84.2	6.64		39	30.87	2.7	0.02	0.24	0.02	8.5	
SOUT-D	10/5/2011	0.1	7.62	80.5	7.22		40	16.02	2.7	<0.02	<0.20	<0.02	<6.2	
TROU-A	6/14/2011	0.1	7.22		7.36		26	14.19	<1.0	0.34	<0.20	0.02	<6.2	
TROU-A	7/20/2011	0.1	7.35	77.7	6.55		27	16.01	<1.0	0.36	<0.20	<0.02	8	
TROU-A	10/6/2011	0.1	8.85	83.1	6.6		21	10.76	<1.0	0.25	<0.20	<0.02	<6.2	
TROU-B	6/14/2011	0.1	7.32		7.28	1.8	29	23.25						
TROU-B	6/14/2011	1	7.5		7.25		29	21.97						
TROU-B	6/14/2011	2	7.2		7.27		29	21.44						
TROU-B	6/14/2011	2.5	5.97		7.2		31	19.87	6.4	<0.02	0.24	0.02	<12.0	-1.65
TROU-B	7/20/2011	0.1	7.22	86	6.42	1.9	31	23.13						
TROU-B	7/20/2011	1	7.21	87	6.51		31	22.85						
TROU-B	7/20/2011	2	5.7	63.3	6.4		32	21.07						
TROU-B	7/20/2011	2.3	4.07	46.6	6.4		32	20.45	12	<0.02	0.29	0.02	<6.2	-0.92
TROU-B	10/6/2011	0.1	8.77	86.5	6.71	1.7	22	13.27						
TROU-B	10/6/2011	1	9	89.6	6.8		22	13.01						
TROU-B	10/6/2011	2	8.7	80.1	6.77		22	12.21	19	<0.02	0.24	0.03	<6.2	-0.31
TROU-C	6/14/2011	0.1	7.28		7.17	2	29	23.2						
TROU-C	6/14/2011	1	7.4		7.23		29	22						
TROU-C	6/14/2011	2	7.05		7.2		29	21.35						
TROU-C	6/14/2011	3	5.11		7.2		31	17.02						
TROU-C	6/14/2011	4	1.99		7.1		35	14.73	6.8	<0.02	0.27	0.03	<6.2	-1.05
TROU-C	7/20/2011	0.1	7.32	88.7	6.45	2	31	23.08						
TROU-C	7/20/2011	1	7.38	89.3	6.45		31	22.92						
TROU-C	7/20/2011	2	5.64	62.5	6.41		31	20.75						
TROU-C	7/20/2011	3	1	8.1	6.24		38	18.55						
TROU-C	7/20/2011	4	0.4	3.8	6.41		105	15.74	33	<0.02	0.44	0.03	10	0.93

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-*a* (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
TROU-C	10/6/2011	0.1	8.85	87.7	6.7	2	22	13.08						
TROU-C	10/6/2011	1	8.89	87.8	6.67		22	13.03						
TROU-C	10/6/2011	2	8.95	86.1	6.64		22	12.45						
TROU-C	10/6/2011	3	8.41	78.9	6.64		22	12.02						
TROU-C	10/6/2011	4	7.74	73.1	6.61		22	11.85	17	<0.02	0.3	0.03	<12.0	-0.19
TROU-C	10/6/2011	4.8	7.17	68	6.59		22	11.82						
TROU-D	6/14/2011	0.1	9.02		8.02		51	15.2	2.1	0.07	<0.20	0.02	<6.2	
TROU-D	7/20/2011	0.1	6.94	79.3	6.52		27	19.97	2.3	0.09	<0.20	0.03	<6.2	
TROU-D	10/6/2011	0.1	8.38	80.7	6.42		19	11.93	6.5	0.06	<0.20	0.02	<6.2	

PIEDMONT SITES

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-a (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
CROW-A	6/1/2011	0.1	9.46		7.04		52	19.33	<1.0	<0.02	<0.20	0.02	11	
CROW-A	7/11/2011	0.1	6.53	74.4	7.06		52	21.7	<1.0	0.03	<0.20	<0.02	<6.2	
CROW-A	9/14/2011	0.1	5.78	62.3	7.32		45	18.89	<1.0	0.02	1.3	0.29	130	
CROW-B	6/1/2011	0.1	6.59		6.38	1.5	57	28.76						
CROW-B	6/1/2011	1	5.24		6.35		56	28.26						
CROW-B	6/1/2011	2	1.02		6.38		55	21.92						
CROW-B	6/1/2011	2.5	0.5		6.36		74	20.34	3.6	<0.02	0.45	0.03	<6.2	-0.41
CROW-B	7/11/2011	0.1	6.86	90.7	6.97	1.5	53	30.85						
CROW-B	7/11/2011	1	6.75	88.7	6.98		52	30.46						
CROW-B	7/11/2011	2	1.74	20.5	6.91		53	28.34						
CROW-B	7/11/2011	2.5	0.44	4.7	6.81		64	25.65	16	<0.02	0.5	0.03	6.8	0.89
CROW-B	9/14/2011	0.1	6.2	76	7.83	2.4	40	25.9						
CROW-B	9/14/2011	1	6.15	73.1	7.87		41	25.58						
CROW-B	9/14/2011	2	6.05	72.4	7.84		41	25.46						
CROW-B	9/14/2011	2.4	5.57	67.1	7.77		41	25.41	3	<0.02	0.37	0.02	<6.2	-1.80
CROW-C	6/1/2011	0.1	6.68		6.46	1.5	56	28.75						
CROW-C	6/1/2011	1	5.44		6.49		56	27.42						
CROW-C	6/1/2011	2	2.7		6.56		54	20.36						
CROW-C	6/1/2011	3	0.64		6.62		60	17	3.5	<0.02	0.46	0.03	<6.2	-0.39
CROW-C	6/1/2011	3.5	0.3		6.64		82	15.97						
CROW-C	7/11/2011	0.1	6.8	90.8	6.93	1.3	53	31.39						
CROW-C	7/11/2011	1	6.33	83.5	7		53	30.54						
CROW-C	7/11/2011	2	1.99	20.4	6.98		55	27.92						
CROW-C	7/11/2011	3	0.4	0.4	7.07		64	21.88						
CROW-C	7/11/2011	3.5	0.24	2.4	7.04		90	18.22	21	<0.02	0.56	0.03	6.5	1.46
CROW-C	9/14/2011	0.1	6.22	76.3	7.51	2.4	40	25.94						
CROW-C	9/14/2011	1	6.08	24.5	7.47		41	25.61						
CROW-C	9/14/2011	2	5.7	68	7.5		41	25.5						
CROW-C	9/14/2011	3	2.5	26.3	7.44		41	25.03						
CROW-C	9/14/2011	3.4	0.7	6.8	7.34		40	24.67	3.1	<0.02	0.38	0.02	<6.2	-1.73
CROW-D	6/1/2011	0.1	4.79		6.74		80	20.85	6	<0.02	0.78	0.05	28	

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-a (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
CROW-D	7/11/2011	0.1	4.77	53.3	7.01		100	20.78	34	<0.04	2.4	0.27	23	
CROW-D	9/14/2011	0.1	3.64	40	7.14		80	20.8	60	<0.02	3.30	0.34	255	
MONT-A	6/1/2011	0.1	7.98		7.38		64	21.1	<1.0	0.04	<0.20	<0.02	<6.2	
MONT-A	7/11/2011	0.1	7.4	85.5	7.44		60	22.49	<1.0	0.06	<0.20	<0.02	<6.2	
MONT-A	9/14/2011	0.1	7	78.3	7.47		37	20.46	<1.0	0.13	<0.20	0.02	<6.2	
MONT-B	6/1/2011	0.1	7.66		7.05	2.2	60	29.32						
MONT-B	6/1/2011	1	6.97		7		60	28.39						
MONT-B	6/1/2011	2	6.57		6.98		60	25.1						
MONT-B	6/1/2011	3	6.88		7.03		63	20.84	2.7	<0.02	0.28	<0.02	<6.2	-2.25
MONT-B	7/11/2011	0.1	6.89	92.6	7.35	2.5	60	31.46						
MONT-B	7/11/2011	1	6.92	92.3	7.37		60	30.67						
MONT-B	7/11/2011	2	6.12	81.2	7.36		60	30.04						
MONT-B	7/11/2011	3	3.21	27.6	7.34		62	28.28						
MONT-B	7/11/2011	3.8	0.57	5.5	7.36		74	22.21	4.2	<0.02	0.33	<0.02	<6.2	-1.78
MONT-B	9/14/2011	0.1	7.9	98.6	7.65	1.5	54	26.43						
MONT-B	9/14/2011	1	7.94	96.4	7.74		54	25.97						
MONT-B	9/14/2011	2	7.33	90.5	7.73		54	25.69						
MONT-B	9/14/2011	3	6.82	81.3	7.69		54	25.36						
MONT-B	9/14/2011	3.2	5.81	68.8	7.65		53	25.19	6.2	0.06	0.29	0.03	<6.2	-0.71
MONT-C	6/1/2011	0.1	7.03		6.87	2.8	60	29.36						
MONT-C	6/1/2011	1	7.07		6.9		60	28.43						
MONT-C	6/1/2011	2	6.75		6.91		59	25.98						
MONT-C	6/1/2011	3	6.35		7.04		61	20.23						
MONT-C	6/1/2011	4	5.27		7.13		64	15.53	6.3	<0.02	0.27	0.02	<6.2	-1.92
MONT-C	6/1/2011	5	2.72		7.22		61	11.27						
MONT-C	6/1/2011	6	3.99		7.17		66	9.48						
MONT-C	6/1/2011	7	0.61		7.12		73	8.23						
MONT-C	6/1/2011	8	0.36		7.01		115	7.9						
MONT-C	7/11/2011	0.1	6.94	93.3	7.34	2.8	60	31.75						
MONT-C	7/11/2011	1	6.68	89.3	7.35		60	31.58						
MONT-C	7/11/2011	2	6.16	80.2	7.38		60	30.07						
MONT-C	7/11/2011	3	2.2	26.3	7.34		62	27.72						
MONT-C	7/11/2011	4	0.68	6.9	7.38		67	21.7						
MONT-C	7/11/2011	5	0.38	3.6	7.56		66	15.74						
MONT-C	7/11/2011	5.5							5	<0.02	0.36	<0.02	<12.0	-1.60
MONT-C	7/11/2011	6	0.22	2.1	7.65		73	11.88						
MONT-C	7/11/2011	7	0.2	2	7.68		88	10.19						
MONT-C	7/11/2011	8	0.25	2.2	7.59		89	9.1						
MONT-C	7/11/2011	9	0.24	2.1	7.57		125	8.64						
MONT-C	9/14/2011	0.1	7.65	96.6	7.7	1.5	55	26.88						
MONT-C	9/14/2011	1	7.69	93.1	7.76		54	25.89						
MONT-C	9/14/2011	2	7.32	88.8	7.77		54	25.67						
MONT-C	9/14/2011	3	6.34	75.5	7.69		54	25.38	7.7	<0.02	0.32	<0.02	<12.0	-0.85
MONT-C	9/14/2011	4	4.05	47.2	7.63		55	24.85						
MONT-C	9/14/2011	5	1	8.9	7.66		59	20.93						
MONT-C	9/14/2011	6	0.41	3.8	7.7		77	14.44						
MONT-C	9/14/2011	7	0.26	2.4	7.73		91	11.92						
MONT-C	9/14/2011	8	0.23	2.1	7.72		111	10.15						
MONT-C	9/14/2011	8.8	0.22	1.7	7.68		150	9.44						
MONT-D	6/1/2011	0.1	7.76		7.32		93	19.63	1.3	<0.02	0.71	0.02	6.5	
MONT-D	7/11/2011	0.1	7.62	80.6	7.21		100	18.09	2.4	<0.02	0.92	<0.02	8	

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-a (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
REED-A	5/17/2011	0.1	8.83		8.17		105	18.52	5.2	0.12	0.36	0.06	24	
REED-A	7/6/2011	0.1	6.32	76.4	7.54		118	24.7	1.3	0.23	0.32	0.04	6.8	
REED-A	9/13/2011	0.1	3.88	43.1	7.52		142	21.7	13	0.26	0.55	0.07	12	
REED-B	5/17/2011	0.1	8.72		8.36	0.8	89	22.45						
REED-B	5/17/2011	1	2.69		8.09		83	20.78	27	<0.02	0.81	0.06	16	3.56
REED-B	7/6/2011	0.1	7.24	95.2	7.6	1.4	89	30.11						
REED-B	7/6/2011	1	6.84	88.2	7.61		91	29.86						
REED-B	7/6/2011	1.5	4.17	52.9	7.54		96	29.06	20	<0.02	0.73	0.06	<6.2	2.53
REED-B	9/13/2011	0.1	7.33	91.4	7.74	1.2	67	26						
REED-B	9/13/2011	1	5.21	51.9	7.73		68	25	27	<0.02	0.79	0.05	9.8	2.83
REED-C	5/17/2011	0.1	8.21		7.95	0.9	88	22.65						
REED-C	5/17/2011	1	8.07		7.83		88	22.6						
REED-C	5/17/2011	1.8							40	<0.02	0.85	0.08	20	4.08
REED-C	5/17/2011	2	1.78		7.68		130	18.43						
REED-C	7/6/2011	0.1	7.3	95.5	7.38	1.3	90	30.15						
REED-C	7/6/2011	1	7.26	96.5	7.44		91	29.96						
REED-C	7/6/2011	2	1.95	95.5	7.35		97	28.17						
REED-C	7/6/2011	2.6							39	<0.02	0.71	0.06	9.5	3.06
REED-C	7/6/2011	2.8	0.16	1.5	7.31		178	24.28						
REED-C	9/13/2011	0.1	8.24	101.3	7.52	0.9	69	26.8						
REED-C	9/13/2011	1	7.89	95.4	7.53		69	25.7						
REED-C	9/13/2011	1.8							5.7	0.06	0.45	0.05	<6.2	1.04
REED-C	9/13/2011	2	2.06	17.1	7.44		76	25.22						
REED-D	5/17/2011	0.1	8		7.74		87	24.1	21	<0.02	0.72	0.08	16	
REED-D	7/6/2011	0.1	7.03	93.5	7.64		91	30	74	<0.02	1.1	0.22	53	
REED-D	9/13/2011	0.1	2.31	27	7.26		99	23.49	30	<0.02	0.9	0.04	7.5	
SIEM-A	6/2/2011	0.1	3.44		6.88		175	22.63	5.8	<0.02	0.32	0.1	18	
SIEM-A	7/12/2011	0.1	2.74	34.4	7.02		182	25.75	2	<0.02	0.37	0.12	<12.0	
SIEM-B	6/2/2011	0.1	7.51		6.47	1.1	83	30.79						
SIEM-B	6/2/2011	1	6.73		6.56		83	30.49						
SIEM-B	6/2/2011	2	1.02		6.38		55	21.92	12	<0.02	0.37	0.05	<12.0	1.08
SIEM-B	7/12/2011	0.1	7.09	100.4	6.88	1.5	80	32.51						
SIEM-B	7/12/2011	1	7.31	103.2	6.92		79	32.18						
SIEM-B	7/12/2011	1.8	6.2	87.1	6.93		80	31.25	12	<0.02	0.38	0.04	6.2	0.55
SIEM-B	9/15/2011	0.1	7.6	97.3	7.46	1	86	27.18						
SIEM-B	9/15/2011	1	7.26	88.9	7.38		86	27.16						
SIEM-B	9/15/2011	1.5	6.73	86.4	7.38		85	27.02	10	<0.02	0.34	0.04	<6.2	0.65
SIEM-C	6/2/2011	0.1	7.88		6.3	1.2	83	30.62						
SIEM-C	6/2/2011	1	7.7		6.38		83	30.58						
SIEM-C	6/2/2011	2	5.47		6.43		83	29.4						
SIEM-C	6/2/2011	2.4							15	<0.02	0.41	0.05	<12.0	1.32
SIEM-C	6/2/2011	3	0.9		6.51		88	23.67						
SIEM-C	6/2/2011	3.5	0.37		6.52		103	22.57						
SIEM-C	7/12/2011	0.1	7.55	106.3	7.04	1.5	79	32.49						
SIEM-C	7/12/2011	1	7.02	95.5	7.07		80	31.65						
SIEM-C	7/12/2011	2	6.31	86.4	7.01		81	31.1						
SIEM-C	7/12/2011	3	4.64	62.9	7.02		82	30.69	12	<0.02	0.42	0.04	7.8	0.71
SIEM-C	7/12/2011	3.8	0.6	7.2	7		223	28.9						
SIEM-C	9/15/2011	0.1	7.37	95.1	7.23	1.7	87	27.14						
SIEM-C	9/15/2011	1	7.12	91.1	7.22		87	27.11						
SIEM-C	9/15/2011	2	6.52	81.6	7.24		87	27.03						

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-a (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
SIEM-C	9/15/2011	3	6.3	80.1	7.19		85	26.91	9	0.03	0.36	0.04	<6.2	0.12
SIEM-D	6/2/2011	0.1	6.97		6.89		83	30.3	6.7	0.02	0.3	0.05	<6.2	
SIEM-D	7/12/2011	0.1	6.65	94.1	7		80	31.99	7.2	0.02	0.33	0.04	<6.2	
SIEM-D	9/15/2011	0.1	7.35	95.3	7.14		87	27.05	8.4	<0.02	0.32	<0.02	<6.2	
TOWN-A	6/8/2011	0.1	5.04		7.29		108	20.29	<1.0	0.11	0.28	0.03	14	
TOWN-A	7/13/2011	0.1	4.07	53.1	7.22		103	23.39	<1.0	0.09	0.23	0.02	<6.2	
TOWN-A	10/4/2011	0.1	5.05	48.2	6.8		115	12.02	<1.0	<0.02	<0.20	0.02	<6.2	
TOWN-B	6/8/2011	0.1	7.31		6.61	1.8	96	28.32						
TOWN-B	6/8/2011	1	7.01		6.63		96	28.15						
TOWN-B	6/8/2011	2	1.7		6.66		98	22.85						
TOWN-B	6/8/2011	3	0.63		6.74		112	17.57	2.7	<0.02	0.35	0.02	<6.2	-1.65
TOWN-B	7/13/2011	0.1	7.05	98.8	7.91	2	98	31.88						
TOWN-B	7/13/2011	1	7.23	94.1	7.95		97	30.64						
TOWN-B	7/13/2011	2	4.55	60.1	7.88		101	29.13						
TOWN-B	7/13/2011	2.8	0.6	6.5	7.84		104	25.5	2.8	<0.02	0.36	0.02	<6.2	-1.71
TOWN-B	10/4/2011	0.1	5.52	60.3	6.86	1.1	98	18.04						
TOWN-B	10/4/2011	1	5.4	57.9	6.89		99	18.07						
TOWN-B	10/4/2011	2	5.3	56.8	6.88		99	17.9	13	<0.02	0.56	0.03	<6.2	1.23
TOWN-C	6/8/2011	0.1	7		7.05	2	95	29.06						
TOWN-C	6/8/2011	1	6.52		7.1		94	28.35						
TOWN-C	6/8/2011	2	4.45		7.22		87	23.44						
TOWN-C	6/8/2011	3	1.32		7.33		108	15.15						
TOWN-C	6/8/2011	4	0.41		7.29		142	12.91						
TOWN-C	6/8/2011	4.2							13	<0.02	0.47	0.03	<6.2	0.34
TOWN-C	6/8/2011	4.8	0.31		7.31		149	12.36						
TOWN-C	7/13/2011	0.1	6.89	95.8	7.89	2.1	99	31.63						
TOWN-C	7/13/2011	1	6.6	90.7	7.95		98	30.69						
TOWN-C	7/13/2011	2	4.59	58.4	7.87		98	28.18						
TOWN-C	7/13/2011	3	1.32	11.1	8.04		131	19.11						
TOWN-C	7/13/2011	4	0.36	3.5	8.07		187	13.89	38	<0.02	0.65	0.03	7.2	1.62
TOWN-C	7/13/2011	4.8	0.26	2.5	8.07		216	13.02						
TOWN-C	10/4/2011	0.1	4.26	46.4	6.9	1.1	101	18.13						
TOWN-C	10/4/2011	1	4.23	45.8	6.91		101	18.17						
TOWN-C	10/4/2011	2	4.2	45.1	6.93		101	18.15						
TOWN-C	10/4/2011	2.2							9.6	<0.02	0.5	0.02	<6.2	0.36
TOWN-C	10/4/2011	3	4.2	45.5	6.93		101	18.16						
TOWN-C	10/4/2011	4	3.16	30.4	6.87		114	18.04						
TOWN-D	6/8/2011	0.1	5.92		7.17		97	28.04	1.3	0.03	0.29	0.02	6.5	
TOWN-D	7/13/2011	0.1	5.24	73.2	7.49		97	30.75	<1.0	0.04	0.25	<0.02	<6.2	
TOWN-D	10/4/2011	0.1	6.83	73.2	7.11		102	17.08	2.3	0.05	0.36	<0.02	<6.2	
YADK-A	6/7/2011	0.1	8.58		6.95		56	18.75	<1.0	0.43	0.2	0.03	<6.2	
YADK-A	7/13/2011	0.1	7.41	88	6.7		61	22.47	1.1	0.36[J6]	0.21	0.03	9	
YADK-A	10/3/2011	0.1	10.06	94.2	7.15		51	12.37	<1.0	0.2	<0.20	<0.02	<12.0	
YADK-B	6/7/2011	0.1	7.72		6.35	2.3	60	27.89						
YADK-B	6/7/2011	1	7.33		6.43		60	27.93						
YADK-B	6/7/2011	2	8.42		6.45		61	25.48						
YADK-B	6/7/2011	3	7.03		6.48		68	16.27	5.2	<0.02	0.4	0.02	<6.2	-1.22
YADK-B	7/13/2011	0.1	7.26	98.6	7.05	2.1	58	30.7						
YADK-B	7/13/2011	1	6.85	93.7	7.08		58	30.5						
YADK-B	7/13/2011	2	5.83	76.2	7.08		59	28.59						
YADK-B	7/13/2011	3	1.37	15.9	7.05		66	23.3						

Site-Station	Date	Depth (m)	D.O. (mg/L)	D.O. (%)	pH (SU)	Secchi depth (m)	Spec. cond. (µS/cm at 25°C)	Water temperature (°C)	Chlorophyll-a (µg/L)	NO2 + NO3 (mg/L)	TKN (mg/L)	TP (mg/L)	TSS (mg/L)	NCTSI (stations B and C only)
YADK-B	7/13/2011	3.3	0.41	4.4	7.08		74	19.53	5.3	<0.02	0.41	0.02	<6.2	-1.07
YADK-B	10/3/2011	0.1	7.23	78.5	6.92	1.8	49	19.47						
YADK-B	10/3/2011	1	7.12	77.5	6.87		49	19.43						
YADK-B	10/3/2011	2	6.86	74.1	6.91		49	18.15						
YADK-B	10/3/2011	3	6.83	73.1	6.91		49	18.97	3.5	<0.02	0.25	<0.02	<6.2	-2.03
YADK-C	6/7/2011	0.1	7.66		6.79	2.3	60	28.49						
YADK-C	6/7/2011	1	7.51		6.83		60	28.02						
YADK-C	6/7/2011	2	10.36		6.88		62	24.7						
YADK-C	6/7/2011	3	10.95		7.01		61	16.73						
YADK-C	6/7/2011	4	2.81		7.1		63	10.72						
YADK-C	6/7/2011	4.6							10	0.02	0.39	0.02	<6.2	-0.77
YADK-C	6/7/2011	5	1.07		7.09		64	8.72						
YADK-C	6/7/2011	6	0.66		7.12		67	7.81						
YADK-C	6/7/2011	7	0.48		7.04		72	7.36						
YADK-C	7/13/2011	0.1	7	96.3	7.06	2.2	59	30.71						
YADK-C	7/13/2011	1	6.84	94.9	7.07		59	30.48						
YADK-C	7/13/2011	2	6.84	40.6	7.11		59	28.6						
YADK-C	7/13/2011	3	6.69	76.1	7.13		63	22.52						
YADK-C	7/13/2011	4	2.23	15	7.37		65	14.84						
YADK-C	7/13/2011	4.4							13	<0.02	0.44	0.03	6.2	0.13
YADK-C	7/13/2011	5	0.7	5.7	7.45		68	10.25						
YADK-C	7/13/2011	6	0.4	3.4	7.48		83	8.45						
YADK-C	7/13/2011	7	0.32	3.1	7.38		101	7.75						
YADK-C	7/13/2011	7.8	0.25	2.1	7.4		139	7.35						
YADK-C	10/3/2011	0.1	6.97	75.7	6.94	1.7	50	19.63						
YADK-C	10/3/2011	1	6.84	74.1	6.96		50	19.6						
YADK-C	10/3/2011	2	6.85	73.4	6.96		50	19.42						
YADK-C	10/3/2011	3	6.84	71.9	7		50	19.07						
YADK-C	10/3/2011	3.4							4.9	<0.02	0.23	<0.02	<6.2	-1.86
YADK-C	10/3/2011	4	5.71	58.5	6.91		52	18.79						
YADK-C	10/3/2011	5	1.58	11	6.83		97	11.03						
YADK-D	6/7/2011	0.1	6.49		7.01		62	27.15	1.4	0.02	0.42	0.03	<6.2	
YADK-D	7/13/2011	0.1	5.76	77.6	6.94		61	29.21	1.2	0.04	0.3	<0.02	<12.0	
YADK-D	10/3/2011	0.1	9.74	85.1	7.07		54	18.69	1.1	0.02	0.2	<0.02	<6.2	

Benthic macroinvertebrate taxa lists

The first table provide a summary of the benthic macroinvertebrate results including: number of taxa, number of individuals/m^2, and biotic index (BI) for all taxa and for Ephemeroptera, Plecoptera, and Trichoptera taxa (EPT). The following tables provide the taxa list and number of individuals for each taxon for Blue Ridge and Piedmont sampling stations.

			All taxa			EPT only			
Ecoregion	Site	station	# taxa	# individuals/ m2	BI	# EPT taxa	# EPT/ m2	EPTBI	Comment
BLUE RIDGE	BEE	A	30	449.13	3.67	11	191.93	2.77	
	BEE	B	0	0	--	0	0	--	No live organisms, empty midge cases only
	BEE	D	21	344.59	2.77	10	163.16	1.94	
	BROY	A	40	779.2	4.92	15	376.88	5.57	
	BROY	B	0	0	--	0	0	--	Dredge was deployed eight times; no organisms.
	BROY	D	24	1702.82	5.8	6	137.61	6.69	
	DEV	A	29	242.46	3.19	15	97.87	1.93	
	DEV	B	0	--	--	0	0	--	No live organisms, empty midge cases only
	DEV	D	17	227.37	4.82	4	90.53	4.75	
	HANG	A	29	510.32	2.53	12	253.54	1.65	
	HANG	B	4	68.9	9.25	0	0	--	
	HANG	D	18	86.88	3.92	8	29.84	3.21	
	SOUT	A	24	503.52	2.33	17	387.58	2.14	
	SOUT	B	5	113.76	9.38	0	0	--	
	SOUT	D	21	967.69	5.72	11	671.51	5.33	
	TROU	A	29	344.21	2.36	16	260.95	1.76	
	TROU	B	10	407.15	8.58	0	0	--	
	TROU	D	31	822.46	2.31	13	511	1.52	
PIEDMONT	CROW	A	4	23.36	3.62	3	19.74	3.07	
	CROW	B	1	8.13	--	0	0	--	Single taxon with no associated tolerance value
	CROW	D	10	104.97	7.5	1	7.25	2.5	
	MONT	A	22	166.86	4.06	6	238.73	2.27	
	MONT	B	5	97.6	7.06	0	0	--	
	MONT	D	0	0	--	0	0	--	No organisms found in sample. No flow, extensive iron oxidizing bacteria
	REED	A	22	315.14	6.37	3	27.14	6.72	
	REED	B	11	250.1	9.28	0	0	--	
	REED	D	25	214.58	6.64	3	10.86	6.7	
	SIEM	A	--	--	--	--	--	--	No sample, stream not flowing
	SIEM	B	8	77.33	8.62	0	0	--	
	SIEM	D	9	1850.7	5.65	6	1818.14	5.65	
	TOWN	A	--	--	--	--	--	--	No sample. Stream impounded by beaverdam.
	TOWN	B	3	81.3	9.3	0	0	--	
	TOWN	D	12	1144.56	6.29	3	941.62	6.45	
	YADK	A	40	1380.46	4.97	20	963.79	4.86	
	YADK	B	6	207.1	9.05	0	0	--	
	YADK	D	24	456.65	5.8	10	311.71	5.99	

BLUE RIDGE SITES

Taxa	BEE-A	BEE-B	BEE-D	BROY-A	BROY-B	BROY-D	DEV-A	DEV-B	DEV-D	HANG-A	HANG-B	HANG-D	SOUT-A	SOUT-B	SOUT-D	TROU-A	TROU-B	TROU-D
CHIRONOMIDAE																		
Chironomus spp											24			8			106	
Cladotanytarsus CF daviesi										4								
Cladotanytarsus spp												3						
Conchapelopia	4		7	25		199	11		4	7		5	7			11		33
Corynoneura spp			4				4											
Cricotopus bicinctus	4																	
Cryptochironomus fulvus				11		4												
Cryptochironomus spp										4							33	
Cryptotendipes spp																	8	
Diamesa spp				7														
Dicrotendipes modestus														41				
Dicrotendipes nervosus											24							
Einfeldia sp. A														8				
Einfeldia spp																	8	
Eukiefferiella brevicalcar															4			
Eukiefferiella claripennis						11												
Glyptotendipes spp																	24	
Microtendipes pedellus	4									4								
Microtendipes spp																		4
Nanocladius distinctus									15									
Nanocladius spp						4												
Natarsia spp				7														4
Nilotanypus spp									4									
Orthocladius clarkei gr							4											
Orthocladius lignicola																4		
Parametriocnemus lundbecki	58			25		225	7		36							22		7
Phaenopsectra spp						4												
Polypedilum aviceps				7						11		5			7			65
Polypedilum flavum				7		431	7		33									
Polypedilum halterale gr																	8	
Potthastia longimana	4																	
Procladius spp											16						163	
Rheocricotopus tuberculatus										4								
Rheotanytarsus pellucidus										11								
Rheotanytarsus spp						76												
Stempellinella spp			7															
Tanytarsus sp 1											4							
Tanytarsus sp 2												3					8	
Tanytarsus sp 3			15			47			4	15								
Tanytarsus sp 5							4											33
Tanytarsus sp 6	7																	
Tanytarsus sp O																		11
Thienemaniella spp						11												4
Tvetenia bavarica gr			4						4							7		
Tvetenia discoloripes sp 3									4									
Xenochironomus xenolabis															44			

Taxa	BEE-A	BEE-B	BEE-D	BROY-A	BROY-B	BROY-D	DEV-A	DEV-B	DEV-D	HANG-A	HANG-B	HANG-D	SOUT-A	SOUT-B	SOUT-D	TROU-A	TROU-B	TROU-D
Zavrelia spp																4		
COLEOPTERA																		
Anchytarsus bicolor									3	15		3						7
Ectopria nervosa	4																	15
Microcylloepus spp				29														
Optioservus spp			33	47			11			130		14	33					15
Oulimnius latiusculus	4		7	65									18					
Promoresia spp							4											
Psephenus herricki	58		29	15			36					5	44					
Stenelmis spp										7		3						7
EPHEMEROPTERA																		
Acentrella spp													15					
Baetis flavistriga				91		4									4			
Baetis intercalaris	4			54											4			
Baetis pluto				11			4								11			
Baetis tricaudatus																11		7
Dannella lita							4											
Epeorus dispar	7												18					
Ephemera spp																		4
Ephemerella dorothea							7			4								
Eurylophella spp				4														
Habrophlebia vibrans							7					5						
Heptagenia spp							4											
Isonychia spp				4														
Maccaffertium meririvulanum	11		4										4					4
Maccaffertium modestum				7		4						3	33		58			
Nixe spp							4									4		
Paraleptophlebia spp			25	7			7			22			4			29		25
Plauditus dubius gr				11														
Plauditus spp	18		54															
Serratella deficiens										4								4
Stenacron carolina																4		4
Stenacron interpunctatum							4											
MEGALOPTERA																		
Corydalus cornutus				4														
Nigronia serricornis				40		51			11									
Nigronia spp																4		
Sialis spp				4														
MISCELLANEOUS DIPTERA																		
Antocha spp				29									4					
Chaoborus punctipennis														24				
Chaoborus spp																	8	
Dicranota spp																		36
Dixa spp																4		
Empididae	4			11		7									7			
Hexatoma spp			15				29			29		3				4		22
Limnophila spp							4			4								
Nippotipula spp (Tipula)																4		
Palpomyia spp	4		4							4								
Simulium spp	7			4		420	11		7						22	4		7
Tipula spp				4		29							7					
MOLLUSCA																		
Elimia spp	11			15									4					40
Sphaerium spp	4																	7

Taxa	BEE-A	BEE-B	BEE-D	BROY-A	BROY-B	BROY-D	DEV-A	DEV-B	DEV-D	HANG-A	HANG-B	HANG-D	SOUT-A	SOUT-B	SOUT-D	TROU-A	TROU-B	TROU-D
ODONATA																		
Aeshnidae																18		
Argia spp	11																	
Lanthus vernalis																4		
Libellulidae	7																	
Ophiogomphus spp				7														
Stylogomphus albistylus	47									4								
OLIGOCHAETA																		
Ilyodrilus templetoni	4																	
Lumbriculidae	7		4	15		7	7		4	4		5			101			
Lumbriculus spp									11									
Nais spp							3											
Slavina appendiculata						11												
Specaria josinae				7		22												
Stylaria lacustris						7												
Tubificid no hair				4										33			41	
OTHER																		
Cura foremanii				11														
Lepidoptera															4			
Platyhelminthes				4														
Sperchon spp															4			
Spongilla spp															4			
Springtail										4								
PLECOPTERA																		
Acroneuria abnormis	94		29										7		11			15
Acroneuria spp												14						
Eccoptura xanthenes										4						4		
Leuctra spp	29		58			7	7		22	145			47		4	62		402
Perlesta spp	4			18		4	11					3	76					
Pteronarcys spp													15		4			
Remenus bilobatus																4		
Suwallia spp													4			4		
Tallaperla spp										29			62			25		15
Yugus bulbosus																7		
TRICHOPTERA																		
Ceratopsyche sparna				11					11				25			11		
Cheumatopsyche spp			11	138		69			54						239			4
Chimarra spp									4						235			
Diplectrona modesta			18				11			22		3	18			73		11
Dolophilodes spp	4		11	4			4						40		5			
Glossosoma spp				4			18			4						4		
Goera spp													11					
Hydropsyche betteni	15			7		51						3			98			
Hydropsyche venularis	11																	
Lepidostoma spp	4									11						4		
Lype diversa										4		5						
Molanna spp										4								
Neophylax oligius				7														
Oecetis georgia										4								
Polycentropus spp			4									3						
Rhyacophila carolina			4				7						7					7
Rhyacophila nigrita																7		7
Rhyacophila torva													4					
Wormaldia spp							4									7		

PIEDMONT SITES

Taxa	CROW-A	CROW-B	CROW-D	MONT-A	MONT-B	MONT-D	REED-A	REED-B	REED-D	SIEM-A	SIEM-B	SIEM-D	TOWN-A	TOWN-B	TOWN-D	YADK-A	YADK-B	YADK-D
CHIRONOMIDAE																		
Ablabesmyia mallochi							44		11						4			
Chironomus spp					6		3							24			61	
Cladopelma spp								12										
Cladotanytarsus spp							33		33									
Conchapelopia			33	7			16								11	29		4
Corynoneura spp							3								7			
Cryptochironomus spp					12		92	6	8								12	
Diamesa spp																4		
Dicrotendipes modestus											12							
Dicrotendipes neomodestus							5		5		4							
Dicrotendipes nervosus								6										
Diplocladius cultriger			4															
Einfeldia natchitocheae					61													
Glyptotendipes spp									14									
Goeldichironomus spp								37										
Microchironomus spp								6										
Microtendipes spp				11			25		3							7		
Natarsia spp											4							
Nilotanypus spp				4														
Orthocladius clarkei gr							3											
Parametriocnemus lundbecki			4	7												47		
Phaenopsectra spp							3											
Polypedilum aviceps															65	15		15
Polypedilum flavum			4									22			29			
Polypedilum halterale gr								12	3									
Polypedilum illinoense gr									3									
Procladius spp								79	3		12							
Pseudochironomus spp									22									
Rheotanytarsus spp				4			3					8			58			25
Stenochironomus spp																4		
Tanytarsus sp 10					12						8							
Tanytarsus sp 13							5											
Tanytarsus sp 2							5	6	16									
Tanytarsus sp 3			4				19											
Tanytarsus sp 5				4												11		
Tanytarsus sp 6				4					8									
Tribelos jucundum							3											
Tvetenia bavarica gr																4		
Tvetenia discoloripes sp3												3						
Zalutschia spp																	12	
COLEOPTERA																		
Macronychus glabratus																		4
Optioservus spp				4												33		
Peltodytes spp									5									
Promoresia spp																4		
Psephenus herricki				11												7		4
Stenelmis spp							16		5							15		25
EPHEMEROPTERA																		
Acentrella spp																		4

Taxa	CROW-A	CROW-B	CROW-D	MONT-A	MONT-B	MONT-D	REED-A	REED-B	REED-D	SIEM-A	SIEM-B	SIEM-D	TOWN-A	TOWN-B	TOWN-D	YADK-A	YADK-B	YADK-D
Acentrella turbida																25		
Baetis flavistriga							19									83		7
Baetis intercalaris																36		
Baetis pluto																54		11
Caenis spp									5							4		
Epeorus rubidus																15		4
Ephemerella dorothea																4		
Heptagenia julia																		18
Heptagenia marginalis																62		
Isonychia spp																15		
Maccaffertium meririvulanum				7														
Maccaffertium modestum															163	25		25
Maccaffertium pudicum	13																	
Paraleptophlebia spp																15		
Stenacron carolina				4												4		
Stenacron interpunctatum							3									4		
Tricorythodes spp												11						
MEGALOPTERA																		
Chauliodes pectinicornis			4															
Corydalus cornutus															7			
Nigronia fasciatus			4	4														
Nigronia serricornis				4														
Nigronia spp				40											4	105		18
MISC. DIPTERA																		
Antocha spp																22		22
Atherix lantha																		4
Bezzia spp									8									
Chaoborus punctipennis														33				
Chaoborus spp		8			6												61	
Empididae																		7
Forcipomyia spp									8									
Hexatoma spp				4												4		
Nippotipula spp (Tipula)				7														
Palpomyia complex								12			12							
Platytipula (Tipula)							5											
Simulium spp																58		7
MOLLUSCA																		
Elimia spp				4														
Ferrissia spp	4																	
Helisoma anceps									3									
Physella spp									3									
ODONATA																		
Ophiogomphus spp																7		
OLIGOCHAETA																		
Limnodrilus hoffmeisteri																	49	
Lumbriculidae			22				3		14						18	29		4
Nais spp								12										
Spirosperma nikolskyi											12							
Tubificid no hair			22				3	61	8		12			24		11		
OTHER																		
Erpobdella spp									16									
Microvelia																4		
Nematoda									3									

Taxa	CROW-A	CROW-B	CROW-D	MONT-A	MONT-B	MONT-D	REED-A	REED-B	REED-D	SIEM-A	SIEM-B	SIEM-D	TOWN-A	TOWN-B	TOWN-D	YADK-A	YADK-B	YADK-D
Nematode																	12	
Rhagovelia spp																		4
Sperchon spp																		4
PLECOPTERA																		
Eccoptura xanthenes																4		
Leuctra spp				29												29		
Perlesta spp	4															4		
Tallaperla spp				4														
TRICHOPTERA																		
Ceratopsyche sparna			7													156		25
Cheumatopsyche spp	4						5		5			826			775	417		141
Chimarra spp												4				7		
Dolophilodes spp				4														
Hydropsyche betteni												4			4	4		73
Hydropsyche decalda																		4
Hydropsyche rossi												826						
Hydropsyche venularis												148						
Mayatrichia spp									3									
Polycentropus spp				4														