Environmental Monitoring and Assessment (2006) **120**: 269–300
DOI: 10.1007/s10661-005-9060-1

COMPARATIVE WATER QUALITY OF LIGHTLY- AND MODERATELY-IMPACTED STREAMS IN THE SOUTHERN BLUE RIDGE MOUNTAINS, USA

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(Received 7 November 2004; accepted 7 October 2005)

Abstract. For less-developed regions like the Blue Ridge Mountains, data are limited that link basin-scale land use with stream quality. Two pairs of lightly-impacted (90–100% forested) and moderately-impacted (70–80% forested) sub-basins of the upper Little Tennessee River basin in the southern Blue Ridge were identified for comparison. The pairs contain physically similar stream reaches, chosen for the purpose of isolating forest conversion as a potential driver of any detected differences in water quality. Streams were sampled during baseflow conditions twice monthly over a six-month period from September 2003 through February 2004. Parametric *t*-tests were run for each parameter measured between the lightly-and moderately-impacted streams within each pair. Statistically significantly higher mean values of suspended and dissolved solids, nitrate, specific conductivity, turbidity, and temperature were observed in the moderately impacted streams versus the lightly impacted streams in both pairs, while dissolved oxygen levels were lower in the moderately-impacted streams. No significant differences were demonstrated in orthophosphate or ammonium concentration. A near-bankfull runoff event on February 6, 2004, was sampled for stormflow values, and the results support baseflow findings. The water quality of these streams is very good when compared with lower relief areas like the Piedmont, and none of the parameters measured in this study exceeds levels of known threat to stream biota. However, the demonstration that moderate reductions in forest cover are associated with stream water quality degradation carries important implications for stream management in this rapidly developing mountainous region.

Keywords: Appalachian, human impact, land use, mountain stream, stream, suspended sediment

1. Introduction and Background

Basin-scale land use affects stream water quality in numerous ways. Land use that involves widespread removal of basin vegetation has been shown repeatedly to alter flow characteristics and to change the amount of sediment introduced to stream systems, particularly during flood events (Wolman, 1967; Trimble, 1974; Knox, 1987; Meade, 1990). Deforestation, agriculture, road development, and urbanization are examples of land uses that impact stream quality (Hirsch *et al.*, 1990; Wohl, 2001; Walling and Fang, 2003). These and other land uses typically involve removal or alteration of stream basin vegetation, which generally results in decreased infiltration and increased surface runoff. Increased surface runoff, in turn, is associated with accelerated contaminant and sediment input to streams, often degrading stream water quality and impairing aquatic ecosystems. Stream concentrations of many chemical constituents are affected both directly and indirectly by human land use (Dunne and Leopold, 1978; Meybeck, 1998; Paul *et al.*, 2001; Jackson *et al.*, 2001). In controlled experiments in southwestern North Carolina, Swank (1988) demonstrated increases in stream nitrate concentration with removal of forest cover. Phosphorous compounds tend to enter stream systems bound to sediment during runoff events (Dunne and Leopold, 1978; Shirmohammadi *et al.*, 1996). Thus, increased sediment yield due to vegetation change is commonly associated with increased phosphorous input. Excessive nutrients in the form of nitrogen and phosphorous compounds can cause overgrowth of algae and aquatic plants, which potentially alters habitat suitability for endemic fauna, in large part due to decreased dissolved oxygen concentrations (U.S. EPA, 1997; Heinz Center, 2002).

Increased sedimentation has been shown to be highly detrimental to aquatic ecosystems (Waters, 1995). A major consequence of accelerated input of fine sediment to streams is the infilling of gravel and cobble interstices. Choking of benthic habitat with fine sediment introduced by human activities such as agriculture, timber harvest, and road building has been well documented (Everest *et al.*, 1987; Meehan, 1991; Walling *et al.*, 2003). Abundant fine sediment in gravel interstices interferes with invertebrate habitat (Richards and Bacon, 1994) and with salmonid incubation and emergence (Kondolf, 2000). In pool-riffle channels, the infilling of riffles with fine sediment deteriorates critical habitat and nesting sites for many aquatic organisms (Diamond *et al.*, 2002). In small southern Appalachian streams, Jones *et al.* (1999) found increases in riffle embeddedness with decreasing riparian forest cover, and, consequently, decreased habitat diversity. Loss of habitat diversity via influx of fine sediment can lead to homogenization of species assemblage structure, with increasing abundance of generalist species at the expense of endemic and/or sensitive species (Wang *et al.*, 1997; Kennan, 1999; Scott and Helfman, 2001).

As landcover and sediment yield are inextricably linked, it follows that several studies have demonstrated basin-scale land cover to be a strong predictor of biotic assemblage structure (e.g. Roth *et al.*, 1996; Wang *et al.*, 1997). Sutherland *et al* (2002) found basin-scale traits to be predictors of fish spawning behavior at varied levels of disturbance in the southern Appalachian Mountains. Partial redundancy analysis of Michigan stream traits identified basin-scale variables as distinct indicators of macroinvertebrate assemblage structure and variability of stream habitat (Richards *et al.*, 1996). In Etowah River tributaries in the north Georgia Piedmont, Roy *et al.* (2003a,b) demonstrated correlations between basin-scale land cover and the biotic integrity of aquatic macroinvertebrates, and Walters *et al.* (2003a,b) linked landscape characteristics with fish species assemblages. Native species in highland stream systems may be particularly vulnerable to replacement by generalist species in response to increased sediment input, as endemic species in these systems have a higher likelihood of requiring coarse substrate that is often characteristic of undisturbed mountain streams (Wohl, 2000).

Although it is widely recognized that a better understanding of stream sedimentological and hydrologic response to human impact in sensitive high relief regions is of great importance, characterization of these systems is problematic. Studies are limited that link basin-scale disturbance with stream quality and biota, largely because the methodologies are not well established and because of difficulties in controlling the varied types of land uses as correlates of stream quality. Controlled experimentation is not usually possible at the basin-scale, and isolating drivers of differences between streams in natural settings is equally complicated. In situations where controlled experimentation is not possible or appropriate for assessment of stream water quality change due to basin-scale impact, it is useful to compare attributes of streams draining basins affected by contrasting levels of human disturbance. This approach avoids complications associated with discriminating the effects of specific land uses, which are often correlated with geomorphic parameters and/or obscured by varying stream responses and lag times (Clark and Wilcock, 2000). Kennan and Ayers (2002) studied fish, macroinvertebrate, and algal assemblages in 36 New Jersey streams whose basins ranged from 3 to 96% urban. Analysis of 32 sub-basins of the Etowah River drainage on the north Georgia Piedmont along a land use gradient from urbanized to mostly forested demonstrated that basin-scale land cover and geomorphic variables were good predictors of stream habitat and biota (Leigh *et al.*, 2002, Roy *et al.*, 2003a,b; Walters *et al.*, 2003a,b). Etowah River basin data also highlighted basin-scale forest cover as a particularly useful predictor of water quality parameters. In situations where development of a continuous land use gradient is not feasible, basins that have experienced extremes of development (i.e. reference versus disturbed) can be used to identify differences between the least-impacted and most heavily-impacted stream basins in a given region. The establishment of a reference stream of best regional conditions allows the approximation of baseline conditions against which to compare more impaired streams (U.S. EPA, 2000), and such an approach is employed herein. The parameters that serve as the focus of this study include suspended solids concentration, dissolved solids concentration, turbidity, water chemistry (nitrate, ammonium, and orthophosphate concentrations), temperature, dissolved oxygen, and specific conductivity. These stream traits were chosen because of their established linkages with stream water quality and biotic integrity.

Stream response to human land use can be highly variable. The complexity of factors contributing to this variability generally precludes the use of data from basins within a given region for accurate prediction of stream response in a characteristically different area. For this reason, human influence on stream condition most effectively occurs on a local or regional scale (Hibbert, 1966; Swank, 1988). There are few data available for southern Blue Ridge streams, which are the focus of this study. This region provides a rare opportunity to assess stream response to moderate levels of human impact, as opposed to heavily-studied water quality impairment from intensive agriculture or urbanization.

1.1. Study Area

The upper Little Tennessee River drains part of the southern Blue Ridge physiographic province of northeast Georgia and western North Carolina (Figure 1). In the absence of human land use, this region would be very nearly 100% forested (Yarnell, 1998), and classification of Landsat^{TM} imagery indicates that the basin was approximately 82% forested in 1998 (Table I). Evidence suggests the earliest human impact in this region dates to the Late Archaic period (ca. 3000 years ago), when the upper Little Tennessee River basin experienced limited amounts of Native American forest clearance and subsistence crop cultivation (Delcourt *et al.*, 1986; Delcourt and Delcourt, 2004). Extensive timber harvest was occurring in the basin by the 1880s (Ayers and Ashe, 1904), and federal acquisition of Appalachian land for the establishment of protected national forests began in 1911 (Walker, 1991; Yarnell, 1998). Human disturbance on private land persists in the form of forest clearance, agriculture, low- to medium-density urbanization, road construction, and second home development. However, a substantial portion of the basin is located in the Nantahala and Chattahoochee national forests, where development has been restricted since the 1930s. The presence of both protected and unprotected areas within the upper Little Tennessee drainage provides an opportunity for comparative assessment of streams experiencing contrasting levels of human impact. Historical impact in this region has typically taken the form of episodic, short-lived disturbance as forest clearing punctuated by periods of regrowth. Many areas within the unprotected portion of the upper Little Tennessee River basin currently are facing development and urbanization pressures that have affected lower relief areas like the Piedmont for many decades. This allows for assessment of human

TABLE I
Upper little tennessee river basin land cover

Class	Area (km^2)	% of Basin
Water	6.91	0.59
Forest	961.89	82.15
Non-forest vegetated	37.59	3.21
Low density urban	27.75	2.37
Medium density urban	6.67	0.57
High density urban	0.00	0.00
Other	127.63	10.90

Classification of 1998 Landsat^{TM} image provided byBarrie Collins, The University of Georgia, Institute of Ecology.

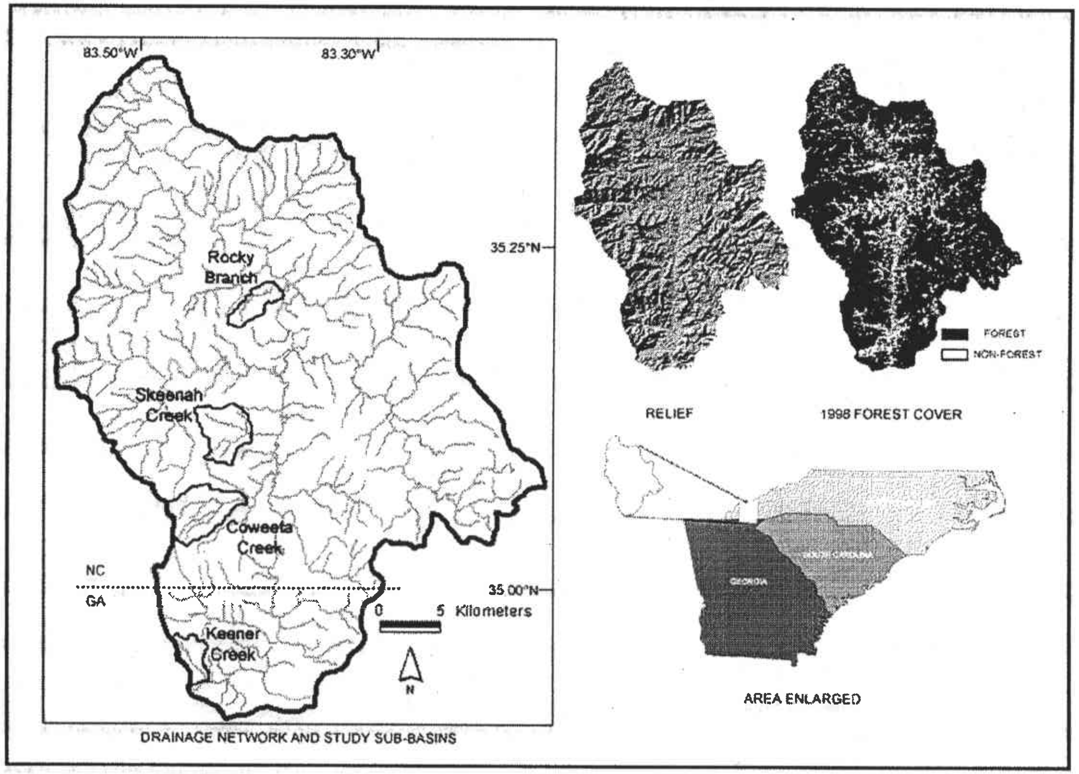

Figure 1. Study area: upper Little Tennessee River basin. Drainage area = 1164 km^2. Vertical exaggeration of relief = 3X. 1998 basin forest cover = 82%.

impact on streams during a stage of disturbance that has long passed in many regions.

The bedrock underlying the upper Little Tennessee River basin is predominantly quartz dioritic gneiss and biotite gneiss (Robinson *et al.*, 1992), and the landscape has been highly dissected by fluvial processes and mass wasting events, which have been estimated to recur approximately every 2500 years in the Appalachian Mountains (Eaton *et al.*, 2003). The upper Little Tennessee River flows due north and is fed by predominantly east- and west- flowing tributaries. The 30-year average annual precipitation at the Coweeta Experiment Station in the central portion of the study area is 183 cm, with a high monthly average of 20 cm occurring in March (NCDC, 2003). The 30-year average annual temperature is 12.7 °C, with average January and July temperatures of 2.7 °C and 22.1 °C, respectively (NCDC, 2003). Warm winter temperatures prevent a significant snowpack/snowmelt component to regional hydrology in this portion of the southern Blue Ridge. Specific study sites are located in western North Carolina (Macon County), and northeastern Georgia (Rabun County; Figure 1).

1.2. Objectives

The primary objective of this study was to identify water quality differences between southern Blue Ridge streams that have experienced contrasting levels of basin-scale impact. Sub-basins of the upper Little Tennessee River basin were inventoried using landcover-classified digital imagery and U.S. Geological Survey (USGS) 7.5-minute digital raster graphic maps (DRGs) to identify forest cover and drainage area, respectively. Basins at the lowest and highest ends of the range of regionally variable forest cover (70–100%) were sought for the purpose of creating pairs comprised of end-members of this range.

Following identification of potential study basins, a key objective was to assemble pairs of physically similar stream reaches (e.g. similar gradients and riparian cover), in order to isolate forest cover differences as potential drivers of any detected differences in water quality. Parameters with established linkages to stream biotic health were chosen for study. The methodology was rooted in established techniques and aimed toward repeatability, in order to allow for comparison of these data with past and future research.

The objectives of this study were as follows: 1) Identification of streams whose basins represent end-members of regional forest cover, 2) establishment of pairs of lightly- and moderately-impacted basins with physically similar stream study reaches, and 3) to test the hypothesis that stream water quality differences are associated with differences in stream basin forest cover.

2. Site Selection and Characteristics

Two pairs of lightly- and moderately-impacted basins were chosen for comparison on the basis of percentage of forested land in their drainage basins (Table II). Efforts were made to best represent the end members of the range of forest cover in tributaries of the upper Little Tennessee River (70 vs. 100%). Non-forested percentage was treated as an estimator of the percentage of land experiencing human impact, which includes roads, pasture, cropland, and residential and low- to medium-density urbanized areas. The selection of lightly- and moderately-impacted basins was based on analysis of historical sources and publicly available 1950s, 1970s, 1990, and 1998 land cover data from state and federal sources. Forest cover in the basins was measured using Esri Arc View® and Erdas Imagine® software for each year of available land cover data derived from Landsat™ imagery and aerial photographs. The 1998 forest cover of the lightly-impacted basins ranges from 90.0 to 95.7%, and the moderately-impacted basins range from 72.9 to 77.2% forested. Road density and road coverage, as additional indicators of level of human impact, were measured from 1990s National Aerial Photography Program (NAPP) images. None of the basins is known to contain significant areas of virgin forest, but the more forested basins have not been significantly altered since the 1930s. The basins were grouped into the following pairs on the basis of drainage area: 1) 7–8 km^2, and 2) 15–18 km^2. Arc View® software and USGS 7.5-minute DRGs were used for drainage basin delineation and calculation of drainage area. Reaches with comparable riparian vegetation cover (9–12%) within a 10 m buffer of the streams within each pair were chosen, to avoid complications from varying riparian condition in interpreting stream differences (Table II). Riparian vegetation conditions were estimated from 1995–6 NAPP images. The study reaches do not contain areas of direct livestock access to the stream.

In order to separate human impacts from natural differences, stream study reaches (40 times average wetted width) with approximately equivalent hydrologic and physical characteristics were established within each pair (Table II). The smaller pair consists of Keener Creek (lightly-impacted) and Rocky Branch (moderately-impacted), and the larger pair consists of Coweeta Creek (lightly-impacted) and Skeenah Creek (moderately-impacted). Flood discharge and gradient are controlling factors in a stream's ability to erode and transport sediment (Schumm, 1977; Knighton, 1998). For the purposes of site selection, drainage area was used as a proxy for flood discharge, as indicated by Knighton (1998) and Pope *et al.* (2001). Gradient was measured between riffle tops using a Topcon® high precision electronic total station and standard survey techniques (Table II). Total basin relief within each pair is comparable, and all four basins have a predominantly east-facing aspect. The bedrock geology is the same among all four basins, and the annual precipitation and temperature are equivalent among the basins. "Pool-riffle" channel morphology characterizes all four streams under the Montgomery and Buffington

TABLE II
Site attributes

		Coweeta (L)	Skeenah (M)	Keener (L)	Rocky (M)
Drainage area (km^2)		18.46	15.07	7.25	7.66
1998 basin land cover	*Forest*	95.7	77.2	90.0	72.9
(% of total area)	*Non-forest vegetated*	0.61	2.88	6.08	4.14
	Low density urban	0.36	3.5	0.23	6.47
	Medium density urban	0.01	0.19	0.09	0.38
	High density urban	0	0	0	0
	Water	0.09	0.55	0.01	0.57
	Other	3.22	15.1	3.88	19.07
1950 basin forest cover (% of total area)		94.9	62.9	92.0	66.9
Reach slope (Between riffle tops)		0.0108	0.0053	0.0056	0.0065
Riparian vegetation cover (%)*		12	11	11	9
Blue-line stream order		3	3	2	2
Trunk stream relief (m)		726	250	381	197
Drainage density (km/km^2)		0.95	0.8	0.57	0.64
Road coverage (% of basin area)	*Total*	5.10	4.02	0.86	3.34
	Paved	0.14	0.82	0.29	0.98
	Unpaved	4.95	3.20	0.57	2.36
Road density (km/km^2)	*Total*	6.61	6.45	1.15	7.50
	Paved	0.16	0.90	0.38	1.25
	Unpaved	5.45	5.55	0.77	6.25
Road/stream crossings	*Total*	30	36	5	15
	Paved	3	29	2	6
	Unpaved	27	7	3	9
Mean bed texture		Very coarse gravel ($\Phi = -5$ to -6)	Medium gravel ($\Phi = -3$ to -4)	Coarse gravel ($\Phi = -4$ to -5)	Fine gravel ($\Phi = -2$ to -3)
Sampling site coordinates	*E*	280,423	280,885	277,297	282,549
(UTM, NAD 83)	*N*	3,882,501	3,887,974	3,868,159	3,900,231

L = lightly-impacted; M = moderately-impacted.
*Within a 10 m buffer of stream 500 m above sampling site.
Classification of 1998 Landsat® image provided byBarrie Collins, Trie University of Georgia, Institute of Ecology.

(1997) classification scheme. Using the Strahler stream ordering system applied to blue-line stream networks on USGS 7.5-minute DRGs, the study reaches in the pair of smaller basins (7–8 km^2) are second-order streams, while those in the larger basins (15–18 km^2) are third-order streams.

Using standard U.S. Department of Agriculture - National Resource Conservation Center (USDA-NRCS) terminology (Schoeneberger *et al.*, 2002), the average bank texture along the 40X reaches of the lightly-impacted streams is sandy loam. Both moderately-impacted streams demonstrated a predominance of both sandy loam and silt loam in the stream banks. The mean bed particle size of the study sites ranges from fine gravel to very coarse gravel, or phi (Φ) -2 to -6. Note that finer Φ classes are represented by a larger whole number due to a negative $\log_2$ transformation (see Krumbein 1934 or Kondolf *et al.*, 2003). Mean bed texture is finer in the moderately-impacted streams than in the lightly-impacted streams within each pair (Table II; Price and Leigh, in press). Within the larger stream pair, the mean bed particle size of Coweeta Creek classifies as very coarse gravel (Φ -5 to -6), and that of Skeenah Creek classifies as medium gravel (Φ -3 to -4). In the smaller pair, the mean bed particle size of Keener Creek is coarse gravel (Φ -4 to -5), compared with the fine gravel of Rocky Branch (Φ -2 to -3).

The location of the sampling site for Keener Creek was 130 m downstream from the confluence of a tributary (0.53 km^2 basin) draining a cattle pasture. The sampling site was selected on the basis of the criteria discussed above, in that this site provided the desired alignment of stream physical traits (e.g. drainage area and reach slope) with Rocky Branch. However, we feared that proximity of the sampling site to the direct impact affecting the tributary could potentially cloud interpretation of basin-scale drivers, and therefore we sought to generally assess the contribution of suspended sediment and chemical constituents of the pasture tributary. This was achieved by identifying a second sampling site on Keener Creek located 870 m upstream from the tributary confluence. The additional sampling site was located immediately downstream from the Chattahoochee National Forest boundary, where the upstream basin is essentially 100% forested, with exceptions being a small amount of road and bedrock outcrop coverage. This second site was established solely for the purposes of comparison with the downstream site on Keener Creek; no comparisons were drawn between this site and Rocky Branch.

3. Methods

3.1. Base flow data collection

Baseflow discharge was measured at an optimal transect across each stream on three separate occasions (10 October, 2003, 19 January, 2004, and 5 February, 2004) within a six-month period of water sampling spanning September, 2003 through February, 2004. For this study, conditions were considered baseflow provided the basin had experienced no runoff-generating precipitation over the preceding 72 hours. In the southern Blue Ridge, fall and winter storms are characteristically frontal and regional-scale, as opposed to highly localized convective storms, which generally are limited to the summer months. On the three sampling dates, the measurements of all four streams were collected within a six-hour period on the same day. Discharge was calculated from cross-sectional dimensions and velocity measurements at 0.6 depth taken at 10 equal intervals of stream width. Velocity was measured using a Marsh-McBirney Flowmate™ electromagnetic flow meter.

Water quality data were collected at least twice monthly over the six-month period ($n = 12$ or 13). For each collection, all four streams were sampled within a six-hour period during baseflow conditions. Samples and instrument data were consistently collected from a free-flowing glide unit of the channel under partial shade (30–40%). Sample collection of the upstream Keener site occurred twice monthly between November, 2003 and February, 2004 ($n = 8$). The following procedures were conducted at each locality for all sample collections.

3.1.1. *Suspended and Dissolved Solids*

A DH-48 depth-integrated sampler was used to collect samples from the water column for measurement of total suspended solids (TSS), suspended sediment concentration (SSC), organic concentration, and total dissolved solids (TDS). Samples were collected at 10, 30, 50, 70, and 90% of channel width. The samples were stored on ice during transport and refrigerated prior to analysis.

3.1.2. *Chemical Constituents*

A 500 ml grab sample was taken from the center of each stream, from which a 100 ml subsample was extracted and field-filtered with a 0.2 μm cellulose acetate syringe filter. Each filtered sample was treated with 3 drops of sulfuric acid, stored on ice during transport, and refrigerated prior to analysis.

3.1.3. *Other Water Quality Parameters*

An Orbico-Hellige™ turbidity meter was used to obtain a field measurement of the nephelometric turbidity units (NTU) of the grab samples. A Hydrolab® water quality meter was used to obtain field measurements of dissolved oxygen (DO), specific conductivity (SC), and temperature. The Hydrolab® was calibrated with standards prior to each collection. Efforts were made to avoid biasing these parameters via time of data collection; the mean sampling time of the 12 collections fell between 1:50 PM and 2:10 PM for all four streams, assuring equivalence of all diurnally variable metrics (Appendix A).

3.2. Stormflow Data Collection

In addition to baseflow data collection, the above water quality parameters were sampled as described above during a near-bankfull event on February 6, 2004, resulting from a frontal storm event with presumed uniform precipitation across the four stream basins. Additionally, one depth-integrated sample (for suspended and dissolved solids) and one grab sample (for turbidity and water chemistry) were taken from the middle of the pasture tributary to Keener Creek, 5 m upstream from its confluence with the main stem. Flood discharge was calculated using the same method as described above for baseflow discharge calculation. All samples and measurements were collected within a three-hour period during the rising limb of the stormflow event.

3.3. Laboratory analysis

Concentrations of TSS, SSC, organic solids, and TDS were measured using standard laboratory techniques within one week of each sample collection (U.S. EPA, 1983). The following laboratory methods were used for analysis of each baseflow and stormflow sample collection.

3.3.1. *Total Suspended Solids (TSS)*

The volumes of the five depth-integrated samples collected from each stream were recorded, and the samples were passed through pretreated 0.7 μm porosity glass fiber filters using a filtration funnel with a serrated filter platform. The filters were dried for at least one hour at 105 °C. The weight of solids retained on the filter was used to determine TSS concentration for each stream, based on the whole volume of water sampled (2.0 to 2.5L).

3.3.2. *Suspended Sediment Concentration (SSC) and Organic Solids (OS)*

Following TSS measurement, each filter was burned at 550 °C for one hour to volatilize the organic fraction of the solids. The weight of the sediment retained on the filters was used to determine the SSC of each stream, based on the whole volume of water sampled (2.0–2.5 L). The post-burn weight was subtracted from the weight of total solids to determine the concentration of organic solids.

3.3.3. *Total Dissolved Solids (TDS)*

The filtrate from the mid-channel depth-integrated sample was retained, and a 200 ml subsample was transferred to glass beakers and evaporated at 95 °C. The weight of the solids retained in the beakers was used to determine the TDS concentration of each stream.

3.3.4. *Chemical Constituents*

The USDA Forest Service Coweeta Hydrologic Research Station Chemical Analysis Laboratory analyzed water chemistry samples for nitrate, ammonium, and orthophosphate content. Values were adjusted using acid-treated and distilled water blanks run with each sample batch.

3.4. Data analysis

SigmaStat® statistical software (version 2.0) was used for all data analyses. Descriptive statistics were generated for the baseflow parameters measured at each sampling site. These parameters were checked for normality using the Kolmogorov-Smirnov test. Unpaired parametric t-tests were run to assess the differences of the means between the lightly- and moderately-impacted streams in each pair for all variables measured, with exceptions that paired t-tests were run for temperature and dissolved oxygen, to reduce the effects of large ranges due to annual variability. Additional parametric t-tests were run to compare the two Keener Creek sampling sites (upstream and downstream); the means of all variables other than temperature and dissolved oxygen were tested with unpaired t-tests. However, note that the downstream site of Keener Creek is the basis of comparison with Rocky Branch, the moderately-impacted member in the pair of smaller streams.

4. Results

Results are presented in categories of suspended and dissolved solids, temperature and dissolved oxygen, and chemical constituents. As turbidity and SC are often used as proxies for suspended solids and dissolved solids, respectively, those parameters are included in the suspended and dissolved solids category. Comparative baseflow results of the stream pairs are presented first, followed by comparative baseflow results of the two Keener Creek sampling sites, and, lastly, stormflow results from the stream pairs and the additional Keener Creek stormflow data. Complete baseflow and stormflow results are presented in Appendices A and B.

4.1. Baseflow comparison of lightly- and moderately-impacted streams

Baseflow results indicated highly significant differences between the lightly- and moderately-impacted streams in TSS, SSC, organic solids, nitrate, SC, turbidity, TDS, temperature, and DO, while orthophosphate and ammonium were not significantly different between the pairs. No major construction, groundbreaking, or forest removal occurred in these basins during the six-month collection period, and these values can be assumed to reflect sustained conditions.

4.1.1. *Suspended and Dissolved Solids*

Statistically significant differences were demonstrated between all metrics of suspended and dissolved solids of lightly- and moderately-impacted streams in each pair (Figure 2A–E). The mean TSS of the moderately-impacted stream were approximately triple that of the lightly-impacted stream within both pairs (7 vs. 2 mg/L and 14 vs. 4 mg/L), and most of this difference was accounted for by suspended

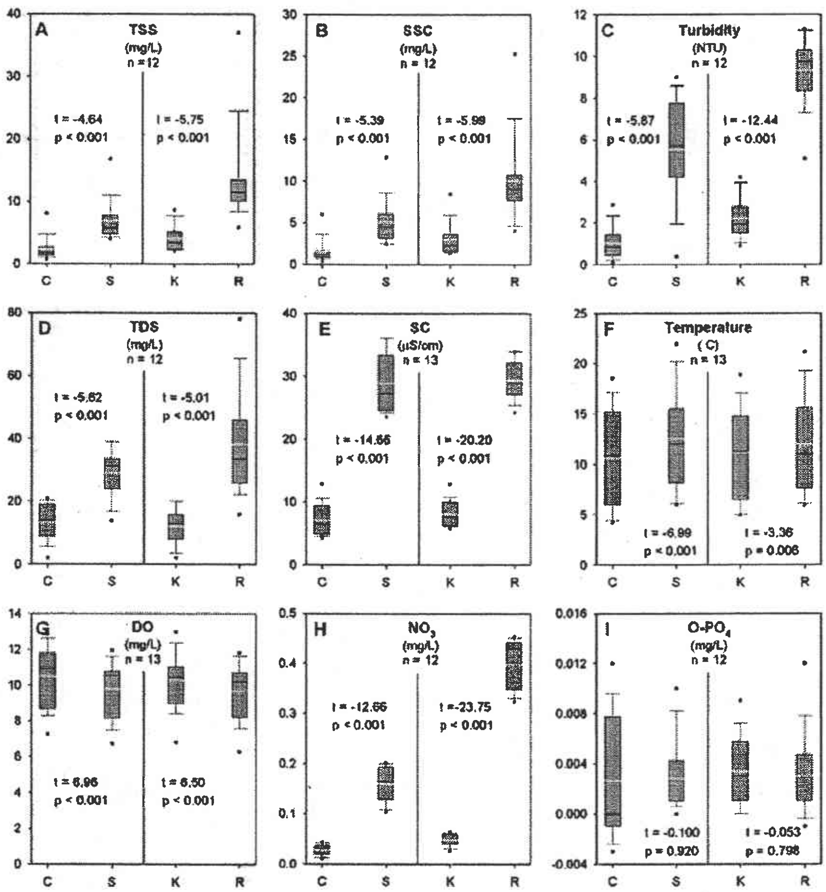

Figure 2. Baseflow water quality of stream pairs. Each boxplot represents one stream, with x-axis abbreviations as follows: C = Coweeta Creek, S = Skeenah Creek, K = Keener Creek, and R = Rocky Branch. Units of measure are presented in the graph titles. The vertical centerline of each graph divides the boxplots into the two respective stream pairs, which are portrayed in the order of lightly-impacted followed by moderately impacted. Parameter abbreviations: TSS = total suspended solids, SSC = suspended sediment concentration, TDS = total dissolved solids, SC = specific conductivity, and DO = dissolved oxygen. The dark line across each boxplot represents the median value for each stream, while the lighter gray line represents the mean. The horizontal edges of the box represent 25th and 75th percentiles, and the whiskers extend to 10th and 90th percentiles. Outliers are represented by square dots. Parametric difference of means test results are portrayed on the plot. Unpaired *t*-tests were run within each stream pair for each parameter, with the exception of temperature and dissolved oxygen, for which paired *t*-tests were run.

mineral sediment, rather than organic solids (Appendix A). Parametric t-test results for SC, turbidity, and TDS all demonstrated highly significant differences between the lightly- and moderately-impacted members of both pairs. The SC of the moderately-impacted streams was consistently much higher than that of the lightly-impacted streams. The mean SC values for the moderately impacted streams were more than triple the means of the lightly impacted streams (29.0 vs. 7.2 μS/cm and 29.5 vs. 8.1 μS/cm). Mean turbidity was at least four to five times greater in the moderately-impacted streams (5.5 vs. 1.0 NTU and 9.3 vs. 2.1 NTU). Moderately-impacted stream TDS means were double to triple those of the lightly-impacted streams (29 vs. 13 mg/L and 38 vs. 12 mg/L).

4.1.2. *Temperature and Dissolved Oxygen*

Moderately-impacted stream temperature was consistently higher than that of the lightly-impacted stream for each pair in all sample collections (Figure 2F). Paired t-tests indicated significant differences in mean temperature within both pairs. Similarly, values of DO (which is temperature-dependent) were consistently higher in the lightly-impacted member of each pair, and paired t-tests demonstrated significant differences (Figure 2G).

4.1.3. *Chemical Constituents*

Among the three measured nutrient inputs, nitrate was the only parameter indicated as significantly differing between lightly- and moderately-impacted streams (Figure 2H). Mean baseflow nitrate values were five to eight times higher in the moderately-impacted member of each stream pair (0.16 vs. 0.03 mg/L and 0.40 vs. 0.05 mg/L). T-test results indicated significantly higher mean nitrate concentrations in the moderately-impacted streams. Baseflow orthophosphate levels were nil in all four streams, and t-test results indicated no significant difference in means within the stream pairs (Figure 2I). Baseflow ammonium values were below accurate detection limit for all streams, and no results are reported.

4.2. Baseflow of Keener Creek – Upstream Sampling Site vs. Downstream Sampling Site

The tributary (drainage area = 0.53 km^2) that flows into Keener Creek via a cattle pasture (hereafter referred to as pasture tributary) increased the concentration of suspended and dissolved solids to the main stem (Figure 3 A–E). The tributary slightly lowered the DO, while modestly raising stream temperature (Figure 3F–G). Mean nitrate and orthophosphate values were low for both sites, but an increase from the upstream site to the downstream site was detected (Figure 3H–I). Ammonium levels were below accurate detection limit.

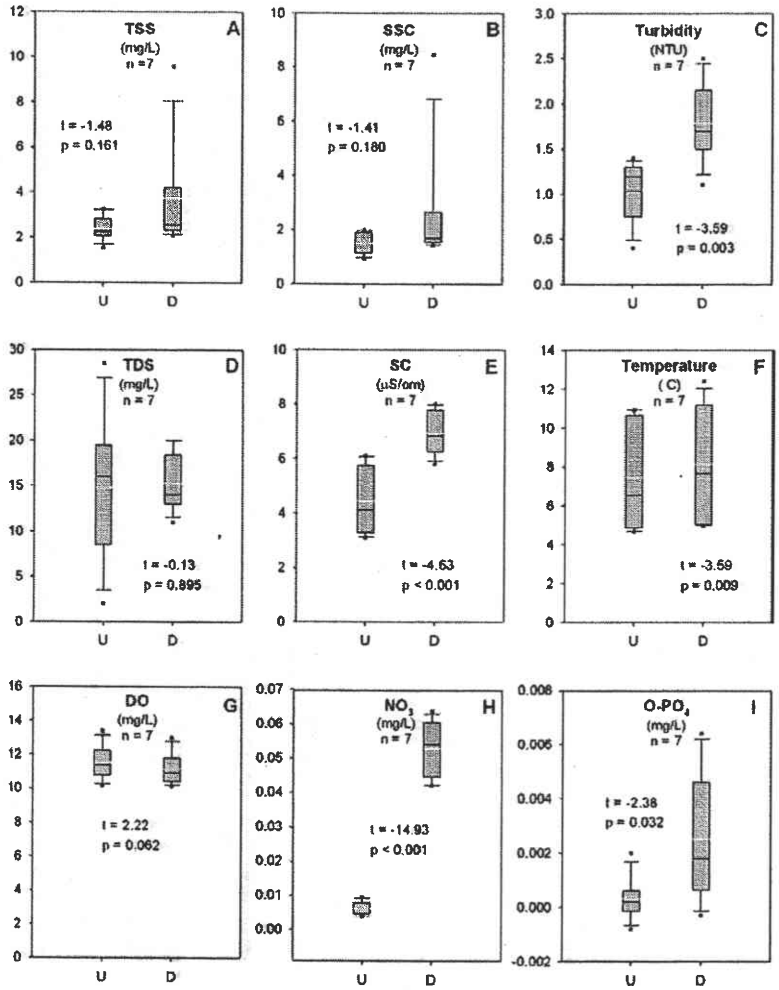

Figure 3. Baseflow water quality of Keener Creek: upstream and downstream sampling sites. Each boxplot represents one stream, with x-axis abbreviations as follows: U = upstream sampling site and D = downstream sampling site. Parameter abbreviations, boxplot characteristics, and difference of means test explanations are consistent with the Figure 2 legend.

Although there were consistent differences observed between the water quality of the upstream and downstream sampling sites on Keener Creek, *t*-tests indicated that only the differences in SC, turbidity, and temperature were statistically significant.

4.3. Stormflow comparison of lightly- and moderately-impacted streams

Water quality parameters were measured on February 6, 2004 during a near-bankfull storm runoff event. Stormflow water quality of lightly- and moderately-impacted streams is compared in this section. Additionally, the stormflow values of each stream are compared with baseflow measurements from February 5, 2004 immediately prior to the onset of precipitation (Figure 4). The direction of differences between lightly- and moderately- impacted streams observed in the stormflow water quality parameters was consistent with baseflow results shown above, with the exception of those parameters associated with differences in stream discharge.

4.3.1. *Stormflow Discharge*

In all three of the baseflow measurements, the discharge of the lightly-impacted stream in each pair was higher than its moderately-impacted counterpart

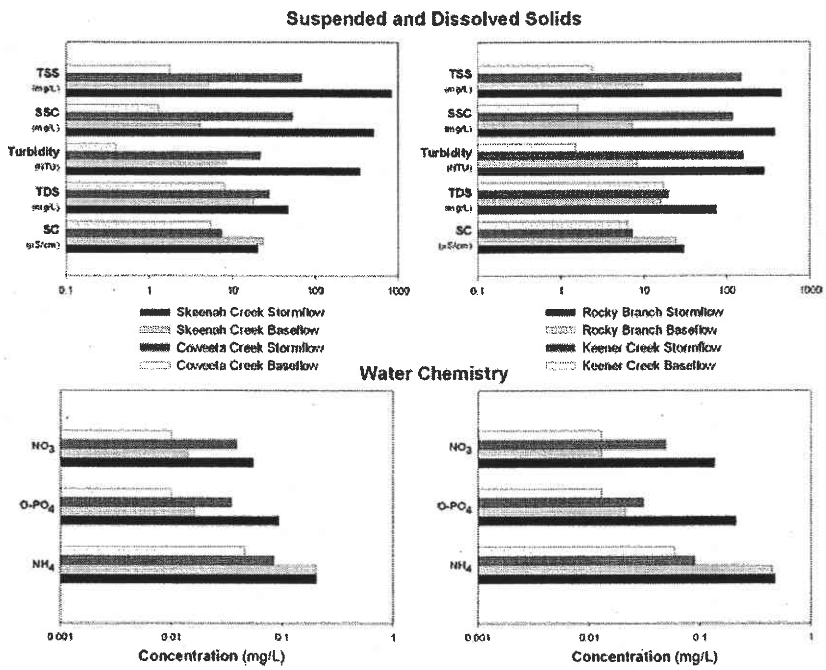

Figure 4. Comparison of stormflow and baseflow results of stream pairs. Stormflow measurements were made during a 3-hour period on February 6, 2004, during the rising limb of a near-bankfull flow event. Baseflow measurements were made on February 5, 2004, prior to the onset of precipitation. Parameter abbreviations are consistent with the Figure 2 legend.

(Appendix A). However, this relationship was not sustained during the runoff event, in which the discharge of Skeenah Creek (3.227 m^3/s) exceeded that of Coweeta Creek (2.661 m^3/s). The stormflow stream discharge values were 3.7–8.2 times greater than baseflow discharge measured on the previous day (Appendix B). While the magnitude of difference between stormflow and baseflow discharge was greater in Skeenah Creek (moderately-impacted) than Coweeta Creek (lightly-impacted), the relationship was reversed between Rocky Branch (moderately-impacted) and Keener Creek (lightly-impacted).

4.3.2. *Stormflow Suspended and Dissolved Solids*

As with baseflow suspended solids, all metrics of the stormflow suspended solids concentrations were higher in the moderately-impacted streams than the lightly-impacted streams. For example, the TSS of the moderately impacted streams was substantially larger than that of the lightly impacted streams within both pairs (829 vs. 68 mg/L and 456 vs. 149 mg/L). The magnitude of difference between stormflow and baseflow suspended solids of the individual streams corresponded to the magnitude of difference between stormflow and baseflow discharge; the magnitude was greater in Skeenah Creek than Coweeta Creek and greater in Keener Creek than Rocky Branch. The SC values of the moderately-impacted streams were 2.5–4 times greater than those of the lightly impacted streams (20.2 vs. 7.5 μS/cm and 30.2 vs. 7.3 μS/cm). The difference between stormflow and baseflow SC values was not pronounced, and the stormflow SC of Skeenah Creek was actually lower than the baseflow measurement from the previous day. In both pairs, the moderately-impacted stream turbidity values well exceeded the lightly-impacted stream values (348 vs. 22 NTU and 284 vs. 158 NTU). Turbidity of all four streams was higher in stormflow than in baseflow, and, as with suspended solid concentrations, the magnitude of difference corresponded to the magnitude of difference between baseflow and stormflow discharge. Although NTU are commonly used as a proxy for TSS, these stormflow turbidity measurements greatly underestimated the measured TSS for three of the streams. The stormflow TDS concentrations were higher in moderately-impacted streams than in lightly-impacted streams (48 vs. 28 mg/L and 75 vs. 20 mg/L). The stormflow values of all four streams were higher than baseflow values from the previous day, but the magnitudes of these differences varied.

4.3.3. *Stormflow Temperature and Dissolved Oxygen*

The stormflow temperature of the moderately-impacted stream of each pair was higher than that of the lightly-impacted stream (7.93 vs. 6.77 °C and 7.53 vs. 7.07 °C), and the DO of the lightly-impacted stream in each pair exceeded that of the moderately-impacted stream (20+ vs. 13.42 mg/L and 15.05 vs. 10.47 mg/L). However, collection times spanned three hours, and no interpretations can be made regarding magnitude of difference due to the diurnal variability of these parameters.

4.3.4. *Stormflow Chemical Constituents*

All streams showed an increase in nitrate from baseflow to stormflow, but the magnitude of difference between stormflow and baseflow values was not very pronounced and was inconsistent among the streams. The stormflow nitrate values of the moderately-impacted streams were higher than the lightly-impacted streams (0.21 vs. 0.09 mg/L and 0.48 vs. 0.09 mg/L). Stormflow orthophosphate values increased from baseflow, and the moderately-impacted streams showed slightly higher values than the lightly-impacted streams (0.005 vs. 0.003 mg/L and 0.013 and 0.004 mg/L). Stormflow ammonium values, unlike baseflow values, exceeded detection limits. Values were substantially higher in the moderately-impacted streams (0.06 vs. 0.01 mg/L and 0.18 vs. 0.00 mg/L). For these water chemistry parameters, the magnitude of difference between the moderately- and lightly-impacted members of the pairs was more pronounced between the smaller streams (Rocky Branch and Keener Creek) than between the larger streams (Skeenah Creek and Coweeta Creek.)

4.4. Stormflow: Keener Creek – Upstream Sampling Site versus Downstream Sampling Site

Comparison of the stormflow results from the three Keener Creek stormflow sampling sites reinforced the findings from baseflow samples of Keener Creek upstream and downstream from the pasture tributary confluence (Figure 5). The concentrations of suspended solids and nitrate, orthophosphate, and ammonium in the pasture tributary were higher than in the main stem downstream from the confluence, and far greater than the values from the sampling site upstream from the confluence. The TSS in the pasture tributary was 199 mg/L, while the upstream main-stem concentration was 85 mg/L, and the downstream main-stem concentration was 149 mg/L. The differences were almost entirely attributable to the mineral sediment concentration (SSC), rather than organic solid concentration, the range of which was only 11 mg/L among all three sites (from 25 mg/L at the upstream site to 36 mg/L in the tributary). The much higher nutrient values in the tributary compared with values from the upstream sampling site accounted for the differences between the two main-stem sampling sites. The nitrate concentration was 0.27 mg/L in the tributary, while only 0.01 mg/L at the upstream site and 0.09 mg/L at the downstream site. Orthophosphate concentration was 0.008 mg/L in the tributary, 0.001 mg/L at the upstream site, and 0.005 mg/L at the downstream site. Ammonium concentration was 0.006 mg/L in the tributary, 0.002 mg/L at the upstream site, and 0.003 mg/L at the downstream site. The turbidity and TDS results did not adhere to this pattern; while the tributary values were far greater than the upstream site values (106 vs. 22 NTU and 34 vs. 21 mg/L), the downstream value of turbidity is higher than that of the tributary (158 vs 122 NTU), and the downstream value of 20 mg/L TDS

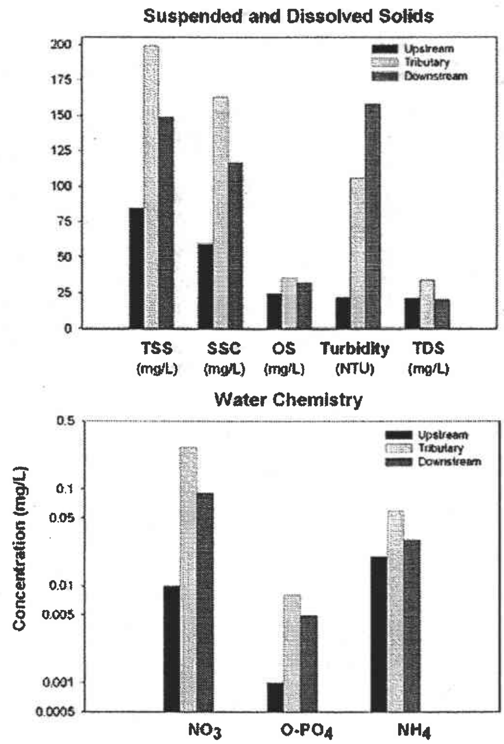

Figure 5. Comparison of stormflow results from three sampling sites on Keener Creek. Stormflow measurements from all three sites were made during a 30-minute period on February 6, 2004, during the rising limb of a near-bankfull event. While the main stem of Keener Creek has contiguous riparian zone and contains no livestock access, the tributary that enters the main stem between the upstream and downstream sampling sites contains cattle pasture with unfenced stretches and no riparian vegetation within its 0.53 km^2 basin.

concentration was lower than both the tributary (34 mg/L) and the upstream site (21 mg/L).

5. Discussion

The results of this study demonstrate that land uses involving modest decreases in forest cover (18 to 22%) in stream basins can result in significant degradation of stream water quality. This study has identified several key parameters as indicators of disturbance resulting from human impact, and many of these parameters are consistent with findings from other studies in the southern Appalachian Highlands. Significant differences in TSS, SSC, organic solids concentration, nitrate, SC, turbidity, TDS, temperature, and DO were found between the lightly-and moderately-impacted streams in both pairs. Past research has shown that increases of these parameters are associated with decreasing water quality. Orthophosphate and ammonium were not shown to significantly differ with these modest differences in forest cover; the mean values of all four streams were extremely low.

The complexity of stream response to varied sorts of human impact limits comparison of these results to other studies that have focused on streams in the southern Appalachian Highlands, of which there are few. Prior related work, specifically in the upper Little Tennessee River basin, is extremely limited. While the levels of human impact affecting southern Blue Ridge stream basins has resulted in detectible reduction of stream water quality, the degree of impairment is low compared with streams draining more intensively disturbed lower-relief areas like the Piedmont.

Comparisons between the results of this study and findings from other studies in the southern Appalachian Highlands are outlined below for each parameter identified as an indicator of disturbance.

5.1. Suspended and Dissolved Solids

Most past research in the southern Blue Ridge has used turbidity to approximate suspended solids concentration. The U.S. EPA (2000) established a range of 0.325 to 8.725 NTU for "reference" stream conditions in the Blue Ridge. Of our four streams, only the baseflow turbidity of Rocky Branch fell outside of this range, and its mean value of 9.3 NTU does not exceed the threshold by a wide margin. This implies that the baseflow turbidity of even our moderately-impacted streams is quite low in terms of existing water quality criteria. Sutherland *et al.* (2002) observed mean baseflow turbidity values of 3.6 and 3.8 NTU for upper Little Tennessee River sub-basins that were 99 and 97% forested, respectively, while the mean baseflow turbidity values of streams draining 87 and 78% forested basins were much higher (15.0 and 14.6 NTU). Sutherland *et al.* (2002) found mean turbidity values in less-forested basins to be greater than the mean values of the moderately-impacted streams of this study (5.5 and 9.3 NTU), despite the fact that the forest cover of our basins was lower (77 and 73%). Interestingly, Sutherland *et al.* (2002) also observed higher baseflow turbidity values in their more-forested basins (99 and 97% forested) than we observed in our lightly-impacted stream basins (96 and 92% forested); the mean turbidity values of their reference streams were 3.6 and 3.8 NTU, while we observed mean baseflow values of 1.0 and 2.1 NTU in our lightly impacted basins.

Studies on the Piedmont have demonstrated higher baseflow turbidity values than those found in the streams of this study. Paul *et al.* (2001) reported a range of 2 to 17 NTU across Etowah River tributaries whose basins ranged from 80 to 27% forested. Walters *et al.* (2001) recognized strong correlations between turbidity and fish assemblage structure, identifying 10 NTU as a threshold of biotic impact. Walters *et al.* (2003a) reported baseflow turbidity values ranging from 2.7 to 17.8 NTU, and higher turbidity values were associated with changes in fish assemblages. Peck and Garrett (1994) reported a similar range of mean baseflow turbidity values from 31 upper Piedmont streams draining a largely agricultural region (6.5 to 14 NTU). While the mean baseflow turbidity of southern Blue Ridge streams observed in this study still fell below the 10 NTU threshold proposed by Walters *et al.* (2001), baseflow values exceeding 10 NTU were observed in Rocky Branch during multiple baseflow sampling events. There is reason to believe that further development in these stream basins could result in elevated turbidity values beyond a 10 NTU threshold.

Frick *et al.* (1998), Walters *et al.* (2001), and Roy *et al.* (2003a), reported either SSC or TSS concentrations in mg/L for Piedmont tributaries to the Chattahoochee and Etowah rivers. Frick *et al.* (1998) reported a mean baseflow SSC value from forested Piedmont basins as approximately 7 mg/L, with a range of 1 mg/L to nearly 100 mg/L. In the lightly-impacted Blue Ridge streams of this study, we observed baseflow ranges of 1 to 8 mg/L (Coweeta Creek) and 2 to 10 mg/L (Keener Creek). The maximum individual baseflow SSC observations for the moderately-impacted streams was 13 mg/L in Skeenah Creek and 25 mg/L in Rocky Branch, and the mean SSC values in these streams was 5 and 10 mg/L. Based on the Chattahoochee tributary data, it appears that even the streams at the high end of the range of development in the upper Little Tennessee River basin maintain lower suspended solid concentrations than reference streams on the Piedmont. Leigh *et al.* (2002) report a range of mean baseflow TSS values of 2 to 50 mg/L in Piedmont Etowah River tributaries ranging from 27 to 87% forested. The maximum value of baseflow TSS we observed was 37 mg/L in Rocky Branch.

Of particular note is the magnitude of difference in stormflow TSS concentration between the lightly- and moderately-impacted streams of this study. Stormflow TSS values in the lightly-impacted streams were 68 and 149 mg/L, and were far surpassed by the TSS of the moderately impacted streams (829 and 456 mg/L). Surface runoff events are a highly important source of sediment entering stream systems, and many contaminants (particularly phosphorous compounds) enter stream systems in association with surface sediment transport. Human land use exposes and mobilizes sediment and accelerates erosion during runoff events (Knighton, 1998). The U.S. EPA (1990) has identified increased stream sediment loading due to human activity as the paramount problem affecting surface waters. In addition to homogenizing aquatic habitat in tributaries, accelerated sedimentation via overland flow in smaller basins potentially propagates through stream systems, eventually contributing to main-stem river habitat impairment and lake sedimentation problems.

TDS and SC naturally vary with local geology; for example, values from streams draining a region of carbonate bedrock cannot be accurately compared with streams draining crystalline terrane. There are no existing regulatory standards for these parameters against which to compare the upper Little Tennessee River values.

However, it is still useful to compare the results found in the streams of this study with results from elsewhere in crystalline terrane in the southern Appalachian Highlands. Peck and Garrett (1994) reported a range of baseflow SC of 20 to 62 μS/cm in upper Piedmont streams impacted by poultry and cattle production. The range of SC values in our lightly-impacted streams was 4.3 to 13.0 μS/cm, and that of our moderately-impacted streams was 23.6 to 36.0 μS/cm. Paul *et al.* (2001) reported values ranging from 21 to 72 μS/cm in Etowah River tributaries, and Roy *et al.* (2003a) found SC values within this range to be indicators of macroinvertebrate integrity. The mean baseflow SC values of the lightly-impacted Blue Ridge streams in this study (7.2 and 8.1 μS/cm) fell below the minimum of this range. The mean baseflow SC values of the moderately-impacted streams (29.0 and 29.5 μS/cm) are at the low end of the range measured in the Etowah River basin, and, therefore, are not expected to be correlated with degradation of macroinvertebrate assemblages (Leigh *et al.*, 2002; Roy 2003a).

5.2. Temperature and dissolved oxygen

Comparison of temperature and DO values measured in upper Little Tennessee River tributaries with streams in other areas is problematic. These parameters vary with sampling time and season, and usually it is not possible to account for this variability for cross-study comparison.

5.3. Chemical constituents

The federal drinking water standard for nitrate concentration is 10.00 mg/L (U.S. EPA 1990), excesses of which the Heinz Center (2002) reported to only occur in intensive agricultural areas. Nitrate concentrations in the upper Little Tennessee River tributaries of this study did not begin to approach this threshold. The baseflow and stormflow nitrate values ranged from 0.00 to 0.48 mg/L, with the maximum value observed at the most impacted stream (Rocky Branch) during the February 6, 2004, runoff event. Mean baseflow nitrate concentrations were 0.029 and 0.047 mg/L in the lightly-impacted streams and 0.160 and 0.400 mg/L in the moderately-impacted streams. Flum and Nodvin (1995) showed predominantly forested stream basins in the Great Smoky Mountains National Park to have maximum nitrate values ranging from 0.00 to 0.100 mg/L. The highest nitrate values were observed in the higher elevation sampling sites, where higher denitrification rates of sediments have also been observed (Martin *et al.*, 2001). The mean maximum nitrate levels from Flum and Nodvin's (1995) lower elevation sites (the elevations of which are more comparable with our upper Little Tennessee River study sites than are the high elevation sites) was approximately 0.01 mg/L, which is lower than, but of the same magnitude as, our lightly-impacted stream values. The mean nitrate values of our moderately-impacted streams (0.160 and 0.400 mg/L) exceeds the maximum observed value in the protected Great Smoky Mountains National Park (approximately 0.1 mg/L), corroborating the possibility that the moderate amounts of forest removal in these basins is associated with increasing stream nitrate levels. Controlled forest experiments at the Coweeta Hydrologic Laboratory in the upper Little Tennessee River basin have shown an increase in nitrate from 0.01 mg/L in a 100% forested (white pine) basin to 0.67 mg/L in a treated basin at a stage of grass to forest succession (Swank, 1988).

Nitrate values in Piedmont streams are consistently higher than those observed in Blue Ridge streams. Frick *et al.* (1998) reported a mean baseflow nitrate concentration of 0.15 mg/L for predominantly forested tributaries of the Chattahoochee River. These mean values are of similar magnitude to the moderately-impacted streams in this study and are an order of magnitude greater than the mean nitrate concentrations observed in lightly-impacted, forested streams of the southern Blue Ridge (0.029 and 0.047 mg/L). The highest Piedmont baseflow nitrate concentration reported by Frick *et al.* (1998) slightly exceeded 1.0 mg/L, observed in a basin impacted by poultry production.

Swank (1988) observed a small range of ammonium values (0.003 to 0.005 mg/L) across a wide variety of treatments at the Coweeta Hydrologic Laboratory in the upper Little Tennessee River basin, indicating that basin forest cover changes do not drive changes in ammonium concentrations of streams in this region. We found that the baseflow ammonium concentrations of even our moderately-impacted basins were below accurate detection limit. We observed ammonium increases with stormflow, but only the moderately-impacted streams contained substantial ammonium concentrations, which suggests the source of the ammonium was surface contamination of some of the non-forested land in those basins. In Etowah River tributaries whose basins ranged from 27–80% forested, Paul *et al.* (2001) observed a range of ammonium concentrations from 0.005 to 0.091 mg/L, and they found a much stronger correlation between ammonium concentration and reach-scale agricultural land use than any basin-scale land cover variable.

It is important to note that although significant differences were found between the lightly- and moderately-impacted streams in this study, comparison with Piedmont streams indicates that the differences associated with the modest amount of impact affecting the upper Little Tennessee River basin are not of a magnitude to trigger water quality concerns. However, many areas within the southern Blue Ridge are rapidly transforming from largely rural to suburban, the impacts of which have already manifested in the form of disturbance of stream fishes and macroinvertebrates (Sponseller *et al.*, 2001; Sutherland *et al.*, 2002). Development forecast models predict a continuation of population growth in this region (Wear and Bolstad, 1994), which will inevitably involve forest conversion. The results of this study indicate that such trends will result in further degradation of stream water quality if responsible planning is not a component of future development in the upper Little Tennessee River basin.

The differences demonstrated between 70–80% forested basins and 90–100% forested basins highlights the importance of exercising caution when designating "reference" streams. Stream management and restoration efforts commonly seek to re-establish pre-impact conditions, and these conditions are generally based on traits observed in reference streams. The results of this study suggest that the use of modestly disturbed basins as reference streams could lead to underestimation of stream impairment.

These results demonstrate that basin-scale human impact is linked with several stream water quality parameters that have been identified as important for stream biotic integrity. Careful alignment of stream basin characteristics and riparian conditions allows reasonable confidence that the water quality differences in these stream pairs are attributable to human impact. The additional information from the upstream Keener Creek sampling site serves to confirm the influence of basin-scale forest cover. Although our data show the water quality of Keener Creek is reduced by the impacts of the cattle pasture, these negative influences appear to be overridden by greater basin forest cover when Keener Creek is compared with Rocky Branch.

6. Conclusions

This study indicates that modest changes in basin-scale forest cover may result in significant differences in many stream water quality parameters. Careful alignment of the physical characteristics of stream pairs allowed for isolation of differences in forest cover as the primary driver of differences in stream water quality. Streams draining the moderately-impacted basins in this study (70–80% forest) demonstrate lower baseflow DO and higher levels of baseflow TSS, SSC, organic concentration, nitrate, turbidity, TDS, and temperature than streams draining lightly-impacted basins (90–100% forested). No significant differences in baseflow orthophosphate or ammonium concentrations were demonstrated. Higher levels of disturbance may be required to trigger response in these parameters, as the values of all four streams were negligible. Values measured during a near-bankfull runoff event confirm the baseflow results and suggest that baseflow measurement may be an adequate method of assessing overall water quality conditions. Many of the parameters shown to significantly differ between the lightly-and moderately-impacted basins have been linked with stream biotic integrity, but the level of impact in these upper Little Tennessee River tributaries is not yet high enough to raise great water quality concerns. However, the rapid development occurring in this region will likely result in further stream degradation beyond thresholds of biotic tolerance, and planning measures are encouraged. These results also indicate that identification of reference streams for establishment of baseline conditions should be highly conservative; the use of even modestly disturbed stream basins toward this end likely results in underestimation of impairment of disturbed streams.

Appendix A: Baseflow Water Quality Data

	Date	Time*	Temp (°C)	SC (μS/cm)	DO (mg/L)	NTU NTU	SSC (mg/L)	TDS (mg/L)	TSS (mg/L)	org. (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	$O\text{-}PO_4$ (mg/L)	Q (m^3/s)
Coweeta Creek	083003	13.0	18.55	10.0	8.54									
	091003	12.0	16.78	10.0	8.67	2.9	6.00	19	8.08	2.08	0.029	0.008	0.007	
	092603	14.0	15.58	9.3	8.65	2.1	1.83	20	3.08	1.25	0.031	−0.147	0.008	
	101003	15.0	15.14	13.0	7.26	0.8	1.00	16	1.60	0.60	0.017	−0.021	0.001	0.323
	102503	17.8	12.54	6.5	11.85	0.1	0.44	2	0.78	0.34	0.010	−0.012	−0.002	
	110903	9.5	11.18	6.4	11.54	0.3	0.76	19	1.27	0.51	0.013	−0.019	0.008	
	112503	15.5	10.83	4.6	11.80	1.5	1.50	14	2.47	0.97	0.031	−0.014	0.012	
	120603	13.5	6.25	4.6	12.86	1.4	1.14	11	1.88	0.74	0.037	−0.018	0.000	
	121903	17.7	4.19	4.3	12.61	0.5	1.12	14	1.41	0.29	0.037	−0.014	0.000	
	010304	17.3	10.52	5.0	11.04	0.9	2.63	7	3.38	0.75	0.025	−0.011	−0.001	
	011904	11.0	4.98	7.1	10.95	0.9	0.78	21	1.15	0.37	0.040	−0.012	−0.001	0.616
	020504	9.6	4.48	5.5	10.77	0.4	1.30	8	1.76	0.46	0.044	−0.011	−0.003	0.715
	022904	14.4	7.61	6.8	10.23	0.6	1.22	10	2.05	0.83	0.038	−0.019	0.001	
Ave		*13.9*	*10.66*	*7.2*	*10.52*	*1.0*	*1.64*	*13*	*2.41*	*0.77*	*0.029*	*−0.024*	*0.003*	*0.551*
StdDev		*2.8*	*4.91*	*2.7*	*1.74*	*0.8*	*1.48*	*6*	*1.94*	*0.50*	*0.011*	*0.039*	*0.005*	*0.204*
Keener Creek	083003	12.0	18.87	10.0	9.02									
	091003	11.0	16.68	10.0	8.89	4.2	4.90	5	7.20	2.30	0.039	0.007	0.009	
	092603	10.0	14.42	10.3	8.82	3.8	4.00	12	5.87	1.87	0.048	−0.014	0.004	
	101003	13.0	16.02	13.0	6.83	3.1	3.34	4	8.66	5.32	0.033	−0.023	0.001	0.186
	102503	15.0	13.53	6.8	10.79	0.9	2.37	2	3.29	0.92	0.026	−0.010	0.005	
	110903	11.7	12.40	7.7	10.96	2.5	2.29	20	3.91	1.62	0.042	−0.012	0.006	
	112503	16.7	11.25	5.8	10.88	2.0	3.03	20	4.55	1.52	0.064	−0.014	0.006	
	120603	15.5	6.96	6.2	12.24	1.9	1.64	13	2.28	0.64	0.061	−0.019	0.002	
	121903	15.7	5.11	7.4	12.99	1.5	1.73	11	2.69	0.96	0.060	−0.001	0.001	
	010304	15.0	11.13	6.3	11.35	2.3	8.45	13	9.55	1.10	0.042	−0.008	0.003	
	011904	18.2	4.99	7.9	10.35	1.1	1.50	15	2.09	0.59	0.051	−0.012	0.000	0.202

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(*Continued*)

	Date	Time*	Temp (°C)	SC (μS/cm)	DO (mg/L)	NTU NTU	SSC (mg/L)	TDS (mg/L)	TSS (mg/L)	org. (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	0-PO_4 (mg/L)	Q (m^3/s)
	020504	10.8	4.98	6.3	10.44	1.5	1.59	17	2.38	0.79	0.057	−0.008	0.000	0.234
	022904	15.5	8.38	8.0	10.10	1.5	1.42	13	2.42	1.00	0.047	−0.015	0.002	
Ave		*13.9*	*11.13*	*8.1*	*10.28*	*2.2*	*3.02*	*12*	*4.57*	*1.55*	*0.047*	*−0.011*	*0.003*	*0.207*
StdDev		*2.6*	*4.74*	*2.1*	*1.61*	*1.0*	*2.03*	*6*	*2.64*	*1.30*	*0.012*	*0.008*	*0.003*	*0.024*
Rocky Branch	083003	14.0	21.14	33.0	7.90									
	091003	12.0	18.81	32.0	8.24	11.3	25.30	78	37.10	11.80	0.363	0.017	0.012	
	092603	11.5	16.57	33.9	8.18	11.2	9.28	27	11.43	2.15	0.368	0.002	0.005	
	101003	12.0	15.37	34.0	6.30	8.4	4.89	49	10.38	5.49	0.324	−0.005	0.001	0.088
	102503	16.3	13.93	28.5	10.26	5.1	4.03	60	5.92	1.89	0.334	−0.011	−0.001	
	110903	10.5	12.44	30.9	10.69	10.2	8.24	43	10.70	2.46	0.343	−0.008	0.001	
	112503	13.0	11.01	26.4	10.83	9.5	9.54	34	12.09	2.55	0.434	0.000	0.004	
	120603	14.5	8.02	30.0	11.59	10.0	11.20	38	13.42	2.22	0.449	−0.004	0.001	
	121903	16.5	6.14	29.0	11.85	8.2	8.02	32	9.84	1.82	0.454	0.002	0.001	
	010304	16.8	10.99	27.4	10.57	10.4	14.23	25	19.12	4.89	0.437	−0.002	0.004	
	011904	17.1	6.44	27.8	9.76	9.5	8.79	33	11.56	2.77	0.430	0.006	0.005	0.108
	020504	12.5	5.98	24.3	10.20	8.2	7.29	16	9.46	2.17	0.444	0.000	0.000	0.165
	022904	13.3	9.56	25.7	9.79	10.0	10.34	25	13.58	3.24	0.437	−0.008	0.002	
Ave		*14.0*	*12.03*	*29.5*	*9.7*	*9.3*	*10.10*	*38*	*13.72*	*3.62*	*0.401*	*−0.001*	*0.003*	*0.120*
StdDev		*2.2*	*4.93*	*3.2*	*1.61*	*1.7*	*5.49*	*17*	*7.99*	*2.83*	*0.050*	*0.007*	*0.003*	*0.040*
Skeenah Creek	083003	13.0	21.96	36.0	7.68									
	091003	14.0	19.74	33.0	8.13	6.0	6.20	32	8.15	1.95	0.120	0.010	0.010	
	092603	13.0	17.33	34.5	8.16	7.6	5.98	39	7.53	1.55	0.153	−0.011	0.005	
	101003	11.0	14.93	36.0	6.75	4.2	2.57	34	4.39	1.82	0.110	0.002	0.001	0.229
	102503	17.3	14.92	29.7	10.57	2.6	2.49	39	6.50	4.01	0.104	−0.004	0.000	
	110903	10.0	12.06	30.8	10.87	6.2	4.45	14	5.68	1.23	0.163	−0.014	0.001	

(*Continued on next page*)

(*Continued*).

	Date	Time*	Temp (°C)	SC (μS/cm)	DO (mg/L)	NTU NTU	SSC (mg/L)	TDS (mg/L)	TSS (mg/L)	org. (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	0-PO_4 (mg/L)	Q (m^3/s)
	112503	13.5	12.48	24.6	10.56	9.0	6.78	31	8.52	1.74	0.199	−0.009	0.007	
	120603	13.8	8.48	27.3	11.53	5.4	4.53	29	5.85	1.32	0.202	−0.015	0.001	
	121903	17.2	6.15	24.5	11.97	7.9	4.69	33	5.66	0.97	0.179	−0.010	0.002	
	010304	16.1	11.37	25.9	10.80	4.2	12.92	25	16.88	3.96	0.155	−0.011	0.002	
	011904	16.3	7.36	26.1	10.01	4.5	3.16	33	4.00	0.84	0.174	−0.009	0.001	0.285
	020504	13.8	6.00	23.6	10.64	8.4	4.10	18	5.09	0.99	0.199	−0.005	0.001	0.441
	022904	13.9	10.02	24.3	9.55	4.5	3.19	23	4.44	1.25	0.156	−0.010	0.011	
Ave		*14.1*	*12.52*	*28.9*	*9.79*	*5.9*	*5.09*	*29*	*6.89*	*1.80*	*0.160*	*−0.007*	*0.003*	*0.318*
StdDev		*2.2*	*5.08*	*4.7*	*1.61*	*2.0*	*2.84*	*8*	*3.47*	*1.08*	*0.034*	*0.007*	*0.004*	*0.110*
Keener (Upstream)	092603								0.006	−0.014	0.002			
	101003								0.008	−0.020	−0.001			
	102503								0.005	−0.010	−0.001			
	110903	11.3	10.95	4.2	11.02	1.2	1.99	29	3.27	1.28	0.004	−0.016	0.000	
	112503	16.3	10.90	3.2	11.29	1.3	1.89	10	3.16	1.27	0.005	−0.019	0.001	
	120603	15.3	6.18	3.4	12.58	0.7	1.17	16	2.00	0.83	0.008	−0.018	0.000	
	121903	15.3	4.69	3.1	13.39	1.3	1.58	16	2.14	0.56	0.008	−0.015	0.002	
	010304	15.3	10.42	4.0	11.47	1.4	1.12	2	2.40	1.28	0.005	−0.013	0.000	
	011904	18.6	4.92	6.1	10.51	1.2	0.93	23	1.54	0.61	0.009	−0.011	−0.001	
	020504	11.6	4.78	5.5	11.97	0.8	1.90	16	2.08	0.18	0.004	−0.013	0.000	
	022904	15.8	6.90	6.0	10.14	0.4	1.43	7	2.51	1.08	0.007	−0.019	0.000	
Ave		*14.9*	*7.5*	*4.4*	*11.5*	*1.0*	*1.5*	*14.8*	*2.4*	*0.9*	*0.006*	*−0.015*	*0.000*	
StdDev		*2.4*	*2.8*	*1.3*	*1.1*	*0.4*	*0.4*	*8.5*	*0.6*	*0.4*	*0.002*	*0.003*	*0.001*	

*EST times converted to decimal expressions of an hour (e.g. 12:30 PM = 12.5) parameter abbreviations are explained in text.

Appendix B: Water Quality Data-Feb. 5, 2004 Baseflow and Feb. 6, 2004 Stormflow

	Date	Time*	Temp (°C)	SC (μS/cm)	DO (mg/L)	NTU	SSC (mg/L)	TDS (mg/L)	TSS (mg/L)	org. (mg/L)	NO_3 (mg/L)	NH_4 (mg/L)	O-PO_4 (mg/L)	Q (m^3/s)
Coweeta Creek	020504	9.6	4.48	5.5	10.77	0.4	1.30	8	1.76	0.46	0.044	−0.011	−0.003	0.715
	020604	9.3	6.77	7.5	20+	22	53.65	28	68.23	14.58	0.086	0.006	0.033	2.661
Skeenah Creek	020504	13.8	6.00	23.6	10.64	8.4	4.10	18	5.09	0.99	0.199	−0.005	0.001	0.441
	020604	9.7	7.93	20.2	13.42	348	510.81	48	828.6	317.79	0.206	0.064	0.050	3.227
Keener Creek	020504	10.8	4.98	6.3	10.44	1.5	1.59	17	2.38	0.79	0.057	−0.008	0.000	0.234
	020604	12.1	7.07	7.3	15.05	158	116.96	20	149.37	32.41	0.093	0.003	0.044	1.897
Rocky Branch	020504	12.5	5.98	24.3	10.2	8.2	7.29	16	9.46	2.17	0.444	0.000	0.000	0.165
	020604	11.3	7.53	30.2	10.47	284	381.23	75	456.15	74.92	0.482	0.183	0.129	0.792
Keener Creek: upstream site	020504	11.6	4.78	5.5	11.97	0.8	1.90	16	2.08	0.18	0.004	−0.013	0.000	no data
	020604	12.3	7.20	5.5	20+	22	59.71	21	84.52	24.81	0.016	0.009	0.000	no data
Keener Creek: trbutary	020604	12.2	no data	no data	no data	106	163.45	34	199.26	35.81	0.271	0.030	0.068	no data

*EST times converted to decimal expressions of an hour (e.g. 12:30 PM = 12.5) parameter abbreviations are explained in text.

Acknowledgments

Funding was provided by the National Science Foundation (NSF Award DGB-0218001) and The University of Georgia Research Foundation, Inc. This research was made possible by the support of those involved in the interdisciplinary Coweeta Long Term Ecological Response (LTER) Research Program. Allison Vogt collaborated in research design and fieldwork. Water chemistry analyses were coordinated by Jim Deal at the USDA Forest Service Coweeta Hydrologic Research Station Chemical Analysis Laboratory. Paul Bolstad, Barrie Collins, and Ryan Kirk provided land cover data. Indispensable feedback through all stages of the research was provided by C. Rhett Jackson, Kathleen C. Parker, and Albert J. Parker. An anonymons review's suggestions greatly improved the manuscript.

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