STREAM RESPONSE TO HUMAN IMPACT IN THE SOUTHERN BLUE RIDGE MOUNTAINS

by

KATIE PRICE

(Under the Direction of David S. Leigh)

ABSTRACT

This study addresses the effects of forest conversion on streams of the southern Blue Ridge. The primary objective was to determine which stream morphological, sedimentological, and water quality parameters respond to modest levels of disturbance in small highland streams. Basin forest cover was used as a proxy for human impact. Two pairs of lightly- and moderately-impacted sub-basins of the upper Little Tennessee River were identified for comparison. Reach characteristics (e.g. slope and riparian cover) were aligned within the pairs. A thorough suite of sedimentological and morphological parameters was measured along a 40X reach of each stream. Water quality data were collected twice monthly between September 2003, and February 2004. The moderately-impacted streams showed finer bed texture, lower dissolved oxygen, and higher suspended and dissolved solids, nitrate, turbidity, temperature, and specific conductivity than the lightly-impacted streams. The moderately impacted streams were narrower and demonstrated lower width/depth ratios than their lightly-impacted counterparts.

INDEX WORDS: mountain streams, water quality, sedimentology, morphology, human impact, basin-scale, Blue Ridge

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CHAPTER 1

INTRODUCTION AND LITERATURE REVIEW

Our primary objective was to identify which stream morphological, sedimentological, and water quality parameters have responded to modest levels of forest conversion in small, highland streams of the southern Blue Ridge. This was achieved by comparing attributes of streams that have experienced contrasting levels of human impact. Two pairs of tributaries to the upper Little Tennessee River were identified for comparison. End members of the range of regional forest cover (70-100%) were sought for the creation of pairs of lightly- and moderately-impacted streams. Lightly-impacted streams were 90-100% forested, while moderately-impacted streams were 70-80% forested. The methodology was rooted in established techniques and aimed toward repeatability, for the purposes of long-term monitoring and comparison with data from other basins. Special attention was paid to isolating human impact as the variable accounting for apparent differences. Water quality response to impact is addressed in Chapter 2, and sedimentological and morphological differences between the lightly- and moderately-impacted streams are covered in Chapter 3. Thorough literature reviews are provided Chapters 2 and 3, while a summarized background is presented here.

Prevailing water and sediment fluxes largely determine stream channel morphology (Mackin, 1948; Knox, 1987). Human landscape alteration generally changes one or both of these factors. Obvious, direct alterations of streams include channelization, reservoir construction, flow diversion, and draining of wetlands. Via less obvious mechanisms, anthropogenic impact on streams occurs through land uses that alter basin hydrology and sedimentology (Hirsch et al., 1990). While these impacts may be less obvious than direct channel influences, they are no less significant (Brooks and Brierley, 1997). Channel dimensions adjust to variances in flow and sediment yield resulting from local and upstream changes (Lane et al., 1982). Basin-scale vegetation cover is a key determinant of the hydrologic and sedimentological characteristics of streams (Saxton and Schiau, 1990; Knighton, 1998), and thus influences channel morphology (Hupp and Osterkamp, 1996). Land modification that involves widespread removal or conversion of basin vegetation has been repeatedly shown to alter flow characteristics and to change the amount of sediment introduced to stream systems (Wolman, 1967; Trimble, 1974; Knox, 1987; Walling, 1995). Channel adjustment potentially includes destruction of bedforms, resulting in homogenization of stream biotic habitat (Wohl, 2000).

As a prime example of anthropogenic vegetation change, forest clearance commonly results in intensified hillslope erosion and increased sediment input to streams (Knighton, 1998). Increased sedimentation due to removal or conversion of protective vegetation cover is accelerated by road construction, row-crop agriculture, larger and more frequent debris flows in steep basins, and poor management practices (Walker, 1991; Slaymaker, 2000; Wohl, 2000). Channel instability and widening has been linked with deforestation in many parts of the world (e.g. Bennett and Selby, 1978; Gregory, 1995; Brooks and Brierley, 1997). A major consequence of accelerated input of sediment to streams is the choking of gravel and cobble interstices. 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). Riffle embeddedness and the associated habitat homogenization and alteration of biotic assemblages have been correlated with decreased bank and basin vegetation cover in the southern Appalachian Highlands (Jones et al., 1999; Sutherland et al., 2002; Roy et al., 2003a,b). The U.S. EPA (1990) has identified increased sediment loading due to human activity as the paramount problem affecting surface waters. Accelerated sedimentation in smaller basins propagates through stream systems, eventually contributing to main-stem river habitat impairment and lake sedimentation problems.

Changes in water quality may also accompany deforestation in many basins. Suspended sediment concentrations are proportional to a stream's turbidity, and research in southern Appalachian Highland streams has shown that stream baseflow turbidity may serve as an indicator of degradation (Sutherland et al., 2002; Walters et al., 2003a,b). Water temperature generally rises with vegetation removal, and the concentrations of many chemical constituents are affected both directly and indirectly by human land use (Dunne and Leopold, 1978; Meybeck, 1998; Jackson et al., 2001; Paul 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), and are thus associated with increased sedimentation due to human land use. Excessive nutrients in the form of nitrogen and phosphorous compounds can cause overgrowth of algae and aquatic plants, which, in turn, potentially impairs macroinvertebrate and fish habitat (Heinz Center, 2002).

This study addresses the effects of forest clearance on streams of the southern Blue Ridge, a region that has received relatively little attention with respect to human impact on streams. This region facilitates investigation of stream response to modest levels of disturbance, whereas most research has focused on either direct stream impacts or on stream response to complete conversion of native forests to agricultural or urban landscapes.

CHAPTER 2

COMPARATIVE WATER QUALITY OF LIGHTLY- AND MODERATELY-IMPACTED SOUTHERN BLUE RIDGE MOUNTAIN STREAMS[1]

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[1] Price, K. and Leigh, D.S. To be submitted to *Environmental Monitoring and Assessment.*

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 consist of physically similar stream reaches, in order to isolate forest conversion as the primary driver of water quality differences. 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. Significant differences in suspended and dissolved solids, nitrate, specific conductivity, turbidity, temperature, and dissolved oxygen were observed between the lightly- and moderately-impacted streams in both pairs, whereas no significant differences were demonstrated in orthophosphate and ammonium concentrations. Mean suspended solids concentrations of the moderately-impacted streams were nearly triple those of the lightly-impacted streams (6.89 vs. 2.41 mg/L and 13.72 vs. 4.57 mg/L). Nitrate concentrations were almost an order of magnitude greater in the moderately-impacted streams (0.160 vs. 0.029 mg/L and 0.401 vs. 0.047 mg/L). Mean specific conductivity values of moderately-impacted streams were more than double those of the lightly-impacted streams (29.0 vs 7.2 μS/cm and 29.5 vs. 8.1 μS/cm, whereas the means of the moderately impacted streams were 29.0 and 29.5 μS/cm. Dissolved solids concentrations in the moderately-impacted basins were more than double those of the lightly-impacted basins (29 vs. 13 mg/L and 38 vs. 12 mg/L). A 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 differences in forest cover are correlated with stream

water quality carries implications for stream management in this rapidly developing mountainous region.

INTRODUCTION AND BACKGROUND

Human impact affects water quality via numerous pathways. Point-source pollution is the most direct mechanism by which human activity alters water quality and is the most easily regulated. Non-point source runoff, however, has been shown to be a major contributor of sediment and chemical contaminants that impair aquatic ecosystems (Novotny and Olem, 1994). Human alteration of naturally forested areas generally results in decreased infiltration and increased surface runoff, which indirectly impacts stream water quality and aquatic ecosystems. Deforestation, agriculture, road development, and urbanization are examples of land uses that have been shown to indirectly impact streams (Hirsch et al., 1990; Wohl, 2001; Walling and Fang, 2003). These and other land uses typically involve removal or alteration of stream basin vegetation. Basin-scale vegetation cover is a key determinant of the hydrologic and sedimentological characteristics of streams (Saxton and Schiau, 1990; Knighton, 1998), and basin-scale vegetation has been shown to influence stream water chemistry (Swank, 1988; Paul 2001).

Forest removal commonly results in intensified hillslope erosion and increased sediment input to streams (Knighton, 1998; Slaymaker, 2000). Land use that involves widespread removal of basin vegetation repeatedly has been shown 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). Increased sediment input due to disturbance of protective vegetation cover is accelerated by road construction, row-crop agriculture, larger and more frequent debris flows in steep basins, and poor management practices (Walker, 1991; Slaymaker, 2000; Wohl, 2000; Jackson et al., 2001). Although increased sediment yield from human impact is well expressed by flood events, baseflow turbidity, which is a proxy for suspended solid concentration, may also serve as an indicator of basin disturbance (Sutherland et al., 2002; Walters et al., 2003a).

In addition to sediment input, many other water quality parameters have been associated with basin vegetation change. Water temperature rises with the removal of shade vegetation, and the 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). Excessive nutrients in the form of nitrogen and phosphorous compounds can cause overgrowth of algae and aquatic plants, which can impair macroinvertebrate and fish habitat (Heinz Center, 2002).

Stream biota are affected by changes in sediment and nutrient inputs to streams resulting from alteration of basin vegetation. Increased sedimentation has been shown to be highly detrimental to aquatic ecosystems (Waters, 1995). Basin-scale land cover has been demonstrated as a predictor of fish assemblage structure (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. Partial redundancy analysis of Michigan stream traits identified basin-scale geomorphic 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, 2003b) demonstrated correlations between basin-scale land cover and the biotic integrity of aquatic macroinvertebrates, and Walters et al. (2003a, 2003b) linked landscape characteristics with fish species assemblages.

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 variation with 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 intercorrelated 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, 2003b; Walters et al., 2003a, 2003b). 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 optimal, basins that have experienced extremes of development (i.e. "pristine" versus disturbed) can be used to identify differences between the least-impacted and most heavily-impacted stream basins in a given region, and this approach is applied in this study. 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). Of the numerous parameters that have been linked with water quality and stream biotic health, those of focus for this study include suspended solids concentration, dissolved solids concentration, turbidity, water chemistry (nitrate, ammonium and orthophosphate concentrations), temperature, dissolved oxygen, and specific conductivity.

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 (Hibbet, 1966; Swank, 1988). There are few data available for southern Blue Ridge streams, which thus become the focus of this study. Furthermore, the relatively low magnitude of human impact in Blue Ridge streams has avoided the focus of previous studies that concentrate on either extensive agricultural land use or heavily urbanized areas.

Study Area

The upper Little Tennessee River drains part of the southern Blue Ridge physiographic province of northeast Georgia and western North Carolina (Figure 2.1). In the absence of human land use, this region would be very nearly 100% forested (Yarnell, 1998), and classification of Landsat™ imagery indicates that the basin was approximately 82% forested in 1998 (Table 2.1). 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). 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, urbanization, road construction, and second home development in high relief areas of the basin. 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 sub-basins within the upper Little Tennessee drainage provides a unique opportunity to assess stream response to modest levels of human impact in the southern Blue Ridge. Most of this region has historically experienced 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 lower relief areas like the Piedmont have been experiencing for decades. This allows for synoptic assessment of human 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 quartz dioritic gneiss and biotite gneiss (Robinson et al., 1992), and the landscape has been highly dissected by fluvial processes and mass wasting events. 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). Specific study sites are located in Macon County, North Carolina, and Rabun County, Georgia (Figure 2.1).

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 variability as the primary driver of water quality differences. 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 key objectives of this study were as follows: 1) Identification of streams whose basins represent end-members of regional forest cover, 2) alignment of physical stream reach parameters for the creation of pairs of lightly- and moderately-impacted basins, and 3) identification of stream water quality differences correlated with the amount of basin forest cover.

METHODS

Site Selection

Two pairs of lightly- and moderately-impacted basins were chosen for comparison on the basis of percentage of forested land in their drainage basins (Figure 2.2; see Table 2.2 for basin attributes). 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 (but is not limited to) roads, pasture, cropland, and residential and 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 ArcView® 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 estimated 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. ArcView® software and USGS 7.5-minute DRGs were used for drainage basin delineation and calculation of drainage area. Because some stream traits have been shown to be closely correlated with reach-scale vegetation, comparable vegetation cover (9-12%) within a 10 m buffer of the streams within each pair was sought. Riparian vegetation conditions were estimated from 1990s NAPP images.

In order to isolate human impacts from natural variation, stream study reaches (40 times average wetted width) with equivalent hydrologic and physical characteristics were established within each pair (Table 2.2). 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 Pope et al. (2001). Gradient was measured between riffle tops using a Topcon® high precision electronic total station and standard survey techniques. Total basin relief within each pair is comparable, and all four streams flow predominantly eastward. The bedrock geology of all four streams is consistent, and the annual precipitation and temperature are equivalent among the basins. "Pool-riffle" channel morphology characterizes all four streams under the Montgomery and Buffington (1997) classification scheme. Using the Strahler (1952) stream ordering system applied to blue-line stream networks on USGS 7.5-minute DRGs, the pair of smaller basins (7-8 km^2) is comprised of second-order streams, while the larger basins (15-18 km^2) are third-order streams. 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).

The location of the sampling site for Keener Creek was 130 m downstream from the confluence of an un-buffered 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 un-buffered 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 nearly totally forested. This second site was established solely for the purposes of comparison with the downstream site on Keener Creek; no comparisons are drawn between this site and Rocky Branch.

Baseflow 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. On these three occasions, 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 twice monthly over the six-month period (*n* =12). 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:

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.

C*hemical 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.

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.

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 rather uniform precipitation across 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 un-buffered tributary to Keener Creek, at 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 flood event.

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). All weights were measured using an Ohaus® high-precision balance. Glass fiber filters (0.7 µm porosity) were pretreated prior to sample filtration by rinsing each with 500 ml of distilled water, burning at 550°C for one hour, cooling in a desiccator, and weighing. Glass beakers for TDS analysis were thoroughly rinsed with distilled water, oven dried at 105°C, and weighed prior to sample filtration.

The following laboratory methods were used for analysis of each baseflow and stormflow sample collection:

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 (typically 2.0 to 2.5L).

Suspended sediment concentration (SSC) and organic solids: 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.

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.

Chemical constituents: Water chemistry samples were analyzed for nitrate, ammonium, and orthophosphate content by the USDA Forest Service Coweeta Hydrologic Research Station Chemical Analysis Laboratory.

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, and the non-normally distributed parameters were normalized using natural log, $\log_{10}$, square root, or reciprocal transformations. 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. Paired t-test were run for temperature and dissolved oxygen, to reduce the effects of the large ranges due to annual variability. Additional parametric t-tests were run to compare the two Keener Creek sampling sites (upstream and downstream). However, note that the downstream site is the basis of comparison with Rocky Branch, the moderately-impacted member in the pair of smaller streams.

RESULTS

Baseflow Comparison of Lightly- and Moderately-Impacted Streams

Highly significant differences were found between the lightly- and moderately-impacted streams for TSS, SSC, organic solids, nitrate, SC, turbidity, TDS, temperature, and DO (Tables 2.3 and 2.4; raw data are provided in Appendix A). Orthophosphate and ammonium were not significantly different between the pairs. The details of the results are presented below.

Suspended solids: Differences in suspended solids between the lightly- and moderately-impacted streams in each pair are apparent through the descriptive statistics (Table 2.3) and supported by the t-test results (Table 2.4). SSC and organic solids comprise the TSS. The mean TSS of the moderately-impacted stream is approximately triple that of the lightly-impacted stream within both pairs (7 vs. 2 mg/L and 14 vs. 4 mg/L), and the majority of this difference is accounted for by suspended mineral sediment, rather than organic solids. The range of values for the various metrics of suspended solids is substantially larger in the moderately-impacted streams within each pair; for example, the ranges of TSS values of the moderately-impacted streams are 13 and 31 mg/L, while the ranges of both lightly-impacted streams are 7 mg/L. 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.

Chemical constituents: Mean baseflow nitrate values are 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), and the ranges of values are higher in the moderately-impacted streams (0.10 vs. 0.03 mg/L and 0.13 vs. 0.04 mg/L). The t-test results indicate significantly lower mean nitrate concentrations in the lightly-impacted streams. Baseflow orthophosphate levels are nil to nonexistent in all four streams, and the t-test results indicate no significant difference in the means within the stream pairs. Baseflow ammonium values were below detection limit for all streams, and no results are reported.

Other parameters: The temperature of the moderately-impacted stream in each pair was consistently higher than the lightly-impacted stream for all sample collections, which is reflected in the mean temperature values. 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.

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 are 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). Similar ranges of values were measured among the streams. Mean turbidity is 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), and a larger range of values is apparent in these streams than in their lightly-impacted counterparts (e.g. 8.6 vs. 2.8 NTU). Moderately-impacted stream TDS means are double to triple those of the lightly-impacted streams (29 vs. 13 mg/L and 38 vs. 12 mg/L), and, again, the ranges are greater in the streams draining less-forested basins (25 vs. 19 mg/L and 62 vs. 18 mg/L). Although the direction of difference is consistent for these variables (lightly-impacted stream means are lower than the moderately-impacted stream means in both pairs), the magnitude of difference is not consistently greater in one pair than the other for all of the variables.

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

Descriptive statistics demonstrate that the 0.53 km^2 un-buffered tributary that flows into Keener Creek via the cattle pasture increases the concentration of suspended solids and nitrate to the main stem, and serves to slightly lower the DO, while modestly raising stream temperature, SC, turbidity and TDS (Table 2.5). The mean TSS of the upstream site is 2 mg/L, while that of the downstream site is 4 mg/L. The mean nitrate values were low for both sites, but an increase from the upstream site (0.01 mg/L) to the downstream site (0.05 mg/L) was detected. The mean orthophosphate value for both sites was 0.00 mg/L. Ammonium levels were below accurate detection limit. The mean DO concentrations of the upstream and downstream sites are 11.55 and 11.16 mg/L, respectively. The mean temperature of the upstream site is 7.47°C and that of the downstream site is 8.15°C. The mean SC increases from 4.44 µS/cm at the upstream site to 6.95 µS/cm at the downstream site. Mean turbidity at the upstream site is 1.04 NTU, while that of the downstream site 1.79 NTU. Mean TDS concentration increases from 14.81 mg/L at the upstream site to 15.25 mg/L at the downstream site.

Although there were consistent differences observed between the water quality of the upstream and downstream sampling sites on Keener Creek, t-tests indicate that only the differences in SC, turbidity, and temperature are statistically significant (Table 2.6).

Stormflow Comparison of Lightly- and Moderately-impacted Streams

In addition to comparing February 6, 2004 stormflow parameters between the lightly- and moderately-impacted streams within the pairs, the stormflow values of each stream also are compared with baseflow measurements from February 5, 2004 immediately prior to the onset of precipitation (Table 2.7). The direction of differences between lightly- and moderately- impacted streams observed in the stormflow water quality parameters is consistent with the baseflow results described above.

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. 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 discharge values of the streams is 3.7-8.2 times greater than baseflow discharge measured on the previous day. While the magnitude of difference between stormflow and baseflow discharge is greater in Skeenah Creek (moderately-impacted) than Coweeta Creek (lightly-impacted), the relationship is reversed between Rocky Branch (moderately-impacted) and Keener Creek (lightly-impacted).

Stormflow suspended solids: As with baseflow suspended solids, all metrics of the stormflow suspended solids concentrations are higher in the moderately-impacted streams than the lightly-impacted streams. For example, the TSS of the moderately impacted streams is 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 correlates with the magnitude of difference between stormflow and baseflow discharge; the magnitude is greater in Skeenah Creek than Coweeta Creek and greater in Keener Creek than Rocky Branch.

Stormflow chemical constituents: All streams show an increase in nitrate from baseflow to stormflow, but the magnitude of difference between stormflow and baseflow values is not very pronounced and is inconsistent among the streams. The stormflow nitrate values of the moderately-impacted streams are higher than the lightly-impacted streams (0.21 vs. 0.09 mg/L and 0.48 vs. 0.09 mg/L). Stormflow orthophosphate values are increased from baseflow, and the moderately-impacted streams show 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 are 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 is more pronounced between the smaller streams (Rocky Branch and Keener Creek) than between the larger streams (Skeenah Creek and Coweeta Creek.)

Other stormflow parameters: The stormflow temperature of the moderately-impacted stream of each pair is higher than 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 exceeds that of the moderately-impacted stream (20+ vs. 13.42 mg/L and 15.05 vs. 10.47 mg/L). However, the collection times span 3 hours, and no interpretations can be made regarding magnitude of difference. The SC values of the moderately-impacted streams are 2.5-4 times greater than 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 is not pronounced, and the stormflow SC of Skeenah Creek is actually lower than the baseflow measurement from the previous day. In both pairs, the moderately-impacted stream turbidity values well exceed the lightly-impacted stream values (348 vs. 22 NTU and 284 vs. 158 NTU). The stormflow turbidity of all four streams is higher than baseflow, and, as with suspended solid concentrations, the magnitude of difference corresponds to magnitude of difference between baseflow and stormflow discharge. Although NTU are commonly used as a proxy for TSS, these stormflow turbidity measurements drastically underestimate the measured TSS for three of the streams. The stormflow TDS concentrations of the moderately-impacted streams are higher than the lightly-impacted streams (48 vs. 28 mg/L and 75 vs. 20 mg/L). The stormflow values of all four streams are higher than the baseflow values from the previous day, but the magnitudes of these differences are inconsistent.

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

Comparison of the stormflow results from the three Keener Creek stormflow sampling sites reinforces the findings from baseflow samples of Keener Creek upstream and downstream from the pasture tributary confluence (Table 2.8). The concentrations of suspended solids and nitrate, orthophosphate, and ammonium in the un-buffered tributary itself were higher than 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 un-buffered tributary was 199 mg/L, while the upstream main-stem concentration was 85 mg/L, and the downstream concentration was 149 mg/L. The differences are almost entirely attributable to the mineral sediment concentration (SSC), rather than organic solid concentration, the range of which is 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 accounts 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 do not adhere to this pattern; while the tributary values are 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 concentration is lower than both the tributary (34 mg/L) and the upstream site (21 mg/L).

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. This is evident upon comparison of the results of this study with data from research conducted in the Etowah River basin on the northeast Georgia Piedmont (Paul et al., 2001; Walters et al., 2001; Leigh et al., 2002; Roy et al., 2003a, 2003b; Walters et al., 2003a, 2003b) and with USGS National Water Quality Assessment Program findings in the Apalachicola-Chattahoochee-Flint River basin (Frick et al. 1998).

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:

Turbidity and suspended 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 turbidity of even our moderately-impacted streams is quite low in terms of existing water quality criteria. Sutherland et al. (2002) observed mean 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 turbidity values of streams draining 87 and 78% forested basins were much higher (15.0 and 14.6 NTU). The turbidity values for Sutherland et al.'s (2002) less-forested basins were 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 27 to 80% 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 spawning activity. Peck and Garrett (1994) report 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 values of southern Blue Ridge streams observed in this study still fall 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 across a 10 NTU threshold.

Frick et al. (1998), Walters et al. (2001), and Roy et al. (2003a), report either SSC or TSS concentrations in mg/L for Piedmont tributaries to the Chattahoochee and Etowah rivers. Frick et al. (1998) report 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 is 5 and 10 mg/L. Based on the Chattahoochee tributary data, it appears that even the streams at the heavy extreme of development in the upper Little Tennessee River basin maintain lower suspended solids 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 key source of sediment entering stream systems, and many contaminants (particularly phosphorous compounds) enter stream systems in association with surface sediment transport. Human land use 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.

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 ranged from 0.03 to 0.40 mg/L. 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). Frick et al. (1998) reported a mean baseflow nitrate concentration of 0.15 mg/L for forested tributaries of the Chattahoochee River. Although these mean values are still well below the federal drinking water threshold, they are an order of magnitude greater than the mean nitrate concentrations observed in lightly-impacted, forested streams of the southern Blue Ridge (0.03 and 0.05 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 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. They found a much better correlation between ammonium concentration and reach-scale agricultural land use than any basin-scale land cover variable.

Other parameters: Comparison of temperature, DO, SC, and TDS values measured in upper Little Tennessee River tributaries with streams in other areas is problematic. Temperature and DO values vary with sampling time and season, and usually it is not possible to account for this variability for cross-study comparison. TDS and SC may naturally vary with local geology; for example, values from streams draining a region of carbonate bedrock cannot be accurately compared with streams draining crystalline terrain. There are no existing regulatory standards for these parameters against which to compare the upper Little Tennessee River values.

Although geological variability prevents assured cross-regional interpretation of higher SC values as indicative of decreased water quality, it is still useful to compare the results found in the streams of this study with results from elsewhere in crystalline terrain 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) fall 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).

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 correlated with several stream water quality parameters that have been identified as important for stream biotic integrity. The additional information from the upstream Keener Creek sampling site highlights 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, correlations between higher water quality and greater basin forest cover are apparent when Keener Creek is compared with Rocky Branch.

CONCLUSIONS

These results indicate 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 more 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.

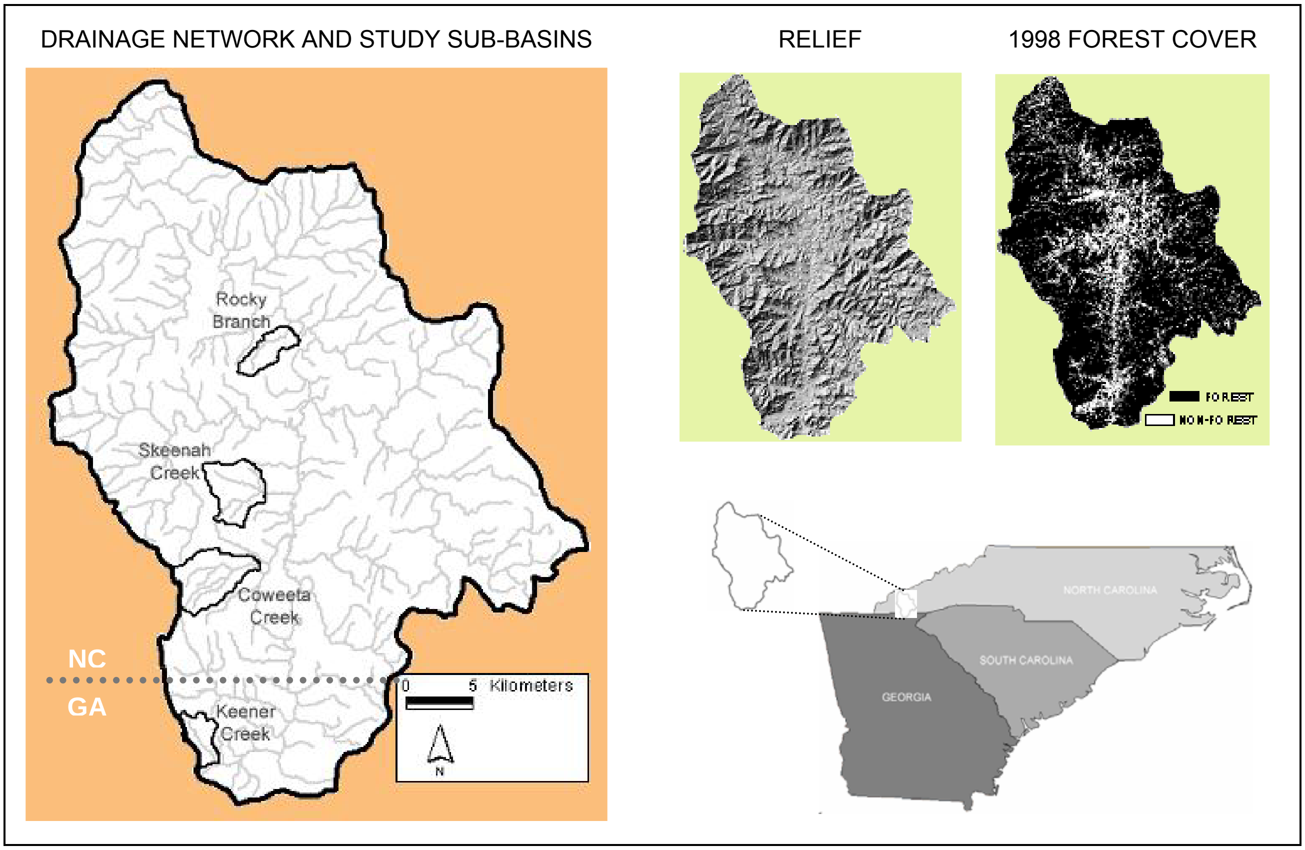

Figure 2.1. Study area – Upper Little Tennessee River basin

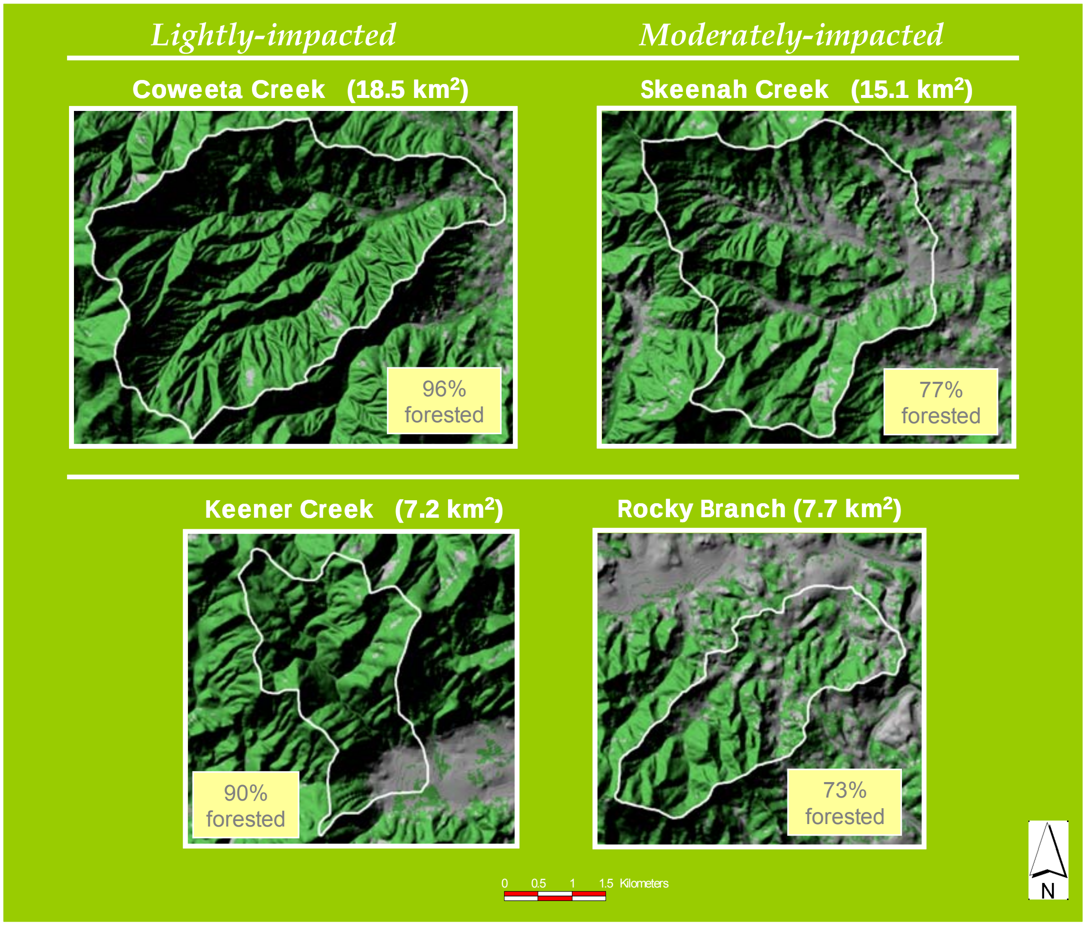

Figure 2.2. Study basins. Green areas represent forested land.

Table 2.1

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™ image provided by Barrie Collins, The University of Georgia, Institute of Ecology

Table 2.2
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 (% OF TOTAL AREA)	*FOREST*	95.7	77.2	90.0	72.9
	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
STREAM ORDER**		3	3	2	2
ROAD COVERAGE (% OF BASIN AREA)	*TOTAL*	5.10	4.02	0.86	3.34
	PAVED	0.14	0.82	0.29	0.98
	UNPAVED	4.96	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	6.45	5.55	0.77	6.25
ROAD/STREAM CROSSINGS	*TOTAL*	30	36	5	15
	PAVED	3	29	2	6
	UNPAVED	27	7	3	9
SAMPLING SITE COORDINATES (UTM, NAD 83)	*E*	280,423	280,885	277,297	282,549
	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

**Strahler, 1952

Table 2.3

BASEFLOW DESCRIPTIVE STATISTICS

DISCHARGE

		COWEETA (L)	SKEENAH (M)	KEENER (L)	ROCKY (M)
DISHCARGE* (m^3/s)	***MEAN***	**0.551**	**0.318**	**0.207**	**0.120**
	STD. DEV.	0.204	0.110	0.024	0.040
	RANGE	0.392	0.212	0.048	0.077

SUSPENDED SOLIDS

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
TOTAL SUSPENDED SOLIDS (mg/L)	***MEAN***	**2.41**	**6.89**	**4.57**	**13.72**
	STD. DEV.	1.94	3.47	2.64	7.99
	RANGE	7.30	12.88	7.46	31.20
SUSPENDED SEDIMENT CONCENTRATION (mg/L)	***MEAN***	**1.64**	**5.09**	**3.02**	**10.10**
	STD. DEV.	1.48	2.84	2.03	5.49
	RANGE	5.56	10.43	7.03	21.27
ORGANIC SOLIDS (mg/L)	***MEAN***	**0.77**	**1.80**	**1.55**	**3.62**
	STD. DEV.	0.50	1.08	1.30	2.83
	RANGE	1.79	3.17	4.73	9.98

CHEMICAL CONSTITUENTS

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
NITRATE (mg/L)	***MEAN***	**0.029**	**0.160**	**0.047**	**0.401**
	STD. DEV.	0.011	0.034	0.012	0.050
	RANGE	0.034	0.098	0.038	0.125
ORTHOPHOSPHATE (mg/L)	***MEAN***	**0.003**	**0.003**	**0.003**	**0.003**
	STD. DEV.	0.005	0.004	0.003	0.003
	RANGE	0.015	0.011	0.009	0.013

OTHER PARAMETERS

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
TEMPERATURE** (°C)	***MEAN***	**10.66**	**12.52**	**11.13**	**12.03**
	STD. DEV.	4.91	5.08	7.74	4.93
	RANGE	14.36	15.96	13.89	15.16
SPECIFIC CONDUCTIVITY** (µs/cm)	***MEAN***	**7.2**	**29.0**	**8.1**	**29.5**
	STD. DEV.	2.7	4.7	2.1	3.2
	RANGE	8.7	12.4	7.2	9.7
DISSOLVED OXYGEN** (mg/L)	***MEAN***	**10.52**	**9.79**	**10.28**	**9.71**
	STD. DEV.	1.74	1.61	1.61	1.61
	RANGE	5.60	5.22	6.16	5.55
TURBIDITY (NTU)	***MEAN***	**1.0**	**5.5**	**2.1**	**9.3**
	STD. DEV.	0.8	2.5	1.0	1.7
	RANGE	2.8	8.6	3.3	6.2
TOTAL DISSOLVED SOLIDS (mg/L)	***MEAN***	**13**	**29**	**12**	**38**
	STD. DEV.	6	8	6	17
	RANGE	19	25	18	62

n = 12 per stream; * *n* = 3 per stream; ** n = 13 per stream; L = lightly-impacted; M = moderately-impacted

Table 2.4
BASEFLOW DIFFERENCE OF MEANS TEST STATISTICS

SUSPENDED SOLIDS

	COWEETA / SKEENAH (L/M)	KEENER / ROCKY (L/M)
TOTAL SUSPENDED SOLIDS[1] *n* = 12	t = -4.64***	t = -5.75***
SUSPENDED SEDIMENT CONCENTRATION *n* = 12	t = -5.39***	t = -5.99***
ORGANIC SOLIDS *n* = 12	t = -4.03***	t = -3.70***

CHEMICAL CONSTITUENTS

	COWEETA / SKEENAH (L/M)	KEENER / ROCKY (L/M)
NITRATE *n* = 12	t = -12.66***	t = -23.75***
ORTHOPHOSPHATE *n* = 12	t = 0.69	t = -0.053

OTHER PARAMETERS

	COWEETA / SKEENAH (L/M)	KEENER / ROCKY (L/M)
TEMPERATURE[2] *n* = 13	t = -6.99***	t = -3.36**
SPECIFIC CONDUCTIVITY *n* = 13	t = -14.66***	t = -20.20***
DISSOLVED OXYGEN[2] *n* = 13	t = 6.96***	t = 6.50***
TURBIDITY *n* = 12	t = -5.87***	t = 12.44***
TOTAL DISSOLVED SOLIDS *n* = 12	t = -5.62***	t = -5.01***

L = lightly-impacted; M = moderately-impacted

t = parametric t-test; T = Mann-Whitney Rank Sum non-parametric differnce of means test

* P < 0.05; ** P< 0.01; *** P ? 0.001

[1] The reciprocal transformation performed to normalize this parameter reversed the direction of the relationship as expressed by the test statistic

[2] paired t-test

Table 2.5

KEENER CREEK - BASEFLOW SAMPLING SITES UPSTREAM AND DOWNSTREAM FROM PASTURE TRIBUTARY CONFLUENCE

SUSPENDED SOLIDS

		UPSTREAM	DOWNSTREAM
TOTAL SUSPENDED SOLIDS (mg/L)	***MEAN***	**2.39**	**3.73**
	STD. DEV.	0.59	2.51
	RANGE	1.73	7.46
SUSPENDED SEDIMENT CONCENTRATION (mg/L)	***MEAN***	**1.50**	**2.71**
	STD. DEV.	0.40	2.38
	RANGE	1.06	7.03
ORGANIC SOLIDS (mg/L)	***MEAN***	**0.89**	**1.03**
	STD. DEV.	0.26	0.36
	RANGE	0.67	0.43

CHEMICAL CONSTITUENTS

		UPSTREAM	DOWNSTREAM
NITRATE (mg/L)	***MEAN***	**0.006**	**0.053**
	STD. DEV.	0.002	0.009
	RANGE	0.006	0.022
ORTHOPHOSPHATE (mg/L)	***MEAN***	**0.000**	**0.003**
	STD. DEV.	0.001	0.002
	RANGE	0.003	0.007

OTHER PARAMETERS

		UPSTREAM	DOWNSTREAM
TEMPERATURE (°C)	***MEAN***	**7.47**	**8.15**
	STD. DEV.	2.83	3.10
	RANGE	6.26	7.42
SPECIFIC CONDUCTIVITY (μs/cm)	***MEAN***	**4.44**	**6.95**
	STD. DEV.	1.25	0.89
	RANGE	3.00	2.20
DISSOLVED OXYGEN (mg/L)	***MEAN***	**11.55**	**11.16**
	STD. DEV.	1.07	1.00
	RANGE	3.25	2.89
TURBIDITY (NTU)	***MEAN***	**1.04**	**1.79**
	STD. DEV.	0.36	0.47
	RANGE	1.00	1.40
TOTAL DISSOLVED SOLIDS (mg/L)	***MEAN***	**14.81**	**15.25**
	STD. DEV.	8.51	3.41
	RANGE	26.50	9.00

n = 8 per stream

Table 2.6

KEENER CREEK - UPSTREAM AND DOWNSTREAM BASEFLOW DIFFERENCE OF MEANS STATISTICS

SUSPENDED SOLIDS

	UPSTREAM / DOWNSTREAM
TOTAL SUSPENDED SOLIDS	t = -1.48
SUSPENDED SEDIMENT CONCENTRATION	t = -1.79
ORGANIC SOLIDS	t = -0.72

CHEMICAL CONSTITUENTS

	UPSTREAM / DOWNSTREAM
NITRATE	t = -14.79***

OTHER PARAMETERS

	UPSTREAM / DOWNSTREAM
TEMPERATURE[1]	t = -3.59**
SPECIFIC CONDUCTIVITY	t = -4.63***
DISSOLVED OXYGEN[1]	t = 0.74*
TURBIDITY	t = -3.59**
TOTAL DISSOLVED SOLIDS	t = -0.11

n = 8 per stream

* $P < 0.05$; ** $P< 0.01$; *** P ? 0.001

[1] paired t-test

Table 2.7

STORMFLOW RESULTS

FEBRUARY 6, 2004 STORMFLOW RESULTS COMPARED TO FEBRAURY 5, 2004 BASEFLOW RESULTS

DISCHARGE

		COWEETA (L)	SKEENAH (M)	KEENER (L)	ROCKY (M)
DISCHARGE (m^3/s)	***STORMFLOW***	**2.661**	**3.227**	**1.897**	**0.792**
	BASEFLOW	0.715	0.441	0.234	0.165

SUSPENDED SOLIDS

		COWEETA (L)	SKEENAH (M)	KEENER (L)	ROCKY (M)
TOTAL SUSPENDED SOLIDS (mg/L)	***STORMFLOW***	**68.23**	**828.60**	**149.37**	**456.15**
	BASEFLOW	1.76	5.09	2.38	9.46
SUSPENDED SEDIMENT CONCENTRATION (mg/L)	***STORMFLOW***	**53.65**	**510.81**	**116.96**	**381.23**
	BASEFLOW	1.30	4.10	1.59	7.29
ORGANIC SOLIDS (mg/L)	***STORMFLOW***	**14.58**	**317.79**	**32.41**	**74.92**
	BASEFLOW	0.46	0.99	0.79	2.17

CHEMICAL CONSTITUENTS

		COWEETA (L)	SKEENAH (M)	KEENER (L)	ROCKY (M)
NITRATE (mg/L)	***STORMFLOW***	**0.090**	**0.207**	**0.091**	**0.480**
	BASEFLOW	0.040	0.200	0.060	0.440
ORTHOPHOSPHATE (mg/L)	***STORMFLOW***	**0.003**	**0.005**	**0.004**	**0.013**
	BASEFLOW	0.000	0.000	0.000	0.010
AMMONIUM (mg/L)	***STORMFLOW***	**0.060**	**0.060**	**0.030**	**0.180**
	BASEFLOW	-0.010	-0.050	-0.080	0.000

OTHER PARAMETERS

		COWEETA (L)	SKEENAH (M)	KEENER (L)	ROCKY (M)
TEMPERATURE (°C)	***STORMFLOW***	**6.77**	**7.93**	**7.07**	**7.53**
	BASEFLOW	4.48	6.00	4.98	5.98
SPECIFIC CONDUCTIVITY (µs/cm)	***STORMFLOW***	**7.5**	**20.2**	**7.3**	**30.2**
	BASEFLOW	5.5	23.6	6.3	24.3
DISSOLVED OXYGEN (mg/L)	***STORMFLOW***	**20+**	**13.42**	**15.05**	**10.47**
	BASEFLOW	10.77	10.64	10.44	10.20
TURBIDITY (NTU)	***STORMFLOW***	**22**	**348**	**158**	**284**
	BASEFLOW	0.4	8.4	1.5	8.2
TOTAL DISSOLVED SOLIDS (mg/L)	***STORMFLOW***	**28**	**48**	**20**	**75**
	BASEFLOW	8	18	17	16
COLLECTION TIME	***STORMFLOW***	**9.3**	**9.7**	**12.1**	**11.3**
	BASEFLOW	9.6	13.8	10.8	12.5

L = lightly-impacted; M = moderately-impacted

Table 2.8

STORMFLOW RESULTS - KEENER CREEK

PASTURE TRIBUTARY, UPSTREAM FROM THE CONFLUENCE, AND DOWNSTREAM FROM THE CONFLUENCE (MAIN SITE)

SUSPENDED SOLIDS	TRIBUTARY	UPSTREAM	DOWNSTREAM
TOTAL SUSPENDED SOLIDS (mg/L)	199.26	84.52	149.37
SUSPENDED SEDIMENT CONCENTRATION (mg/L)	163.45	59.71	116.96
ORGANIC CONCENTRATION (mg/L)	35.81	24.81	32.41

CHEMICAL CONSTITUENTS	TRIBUTARY	UPSTREAM	DOWNSTREAM
NITRATE (mg/L)	0.270	0.010	0.091
ORTHOPHOSPHATE (mg/L)	0.008	0.001	0.005
AMMONIUM (mg/L)	0.060	0.020	0.030

OTHER PARAMETERS	TRIBUTARY	UPSTREAM	DOWNSTREAM
TURBIDITY (NTU)	106	22	158
TOTAL DISSOLVED SOLIDS (mg/L)	34	21	20
COLLECTION TIME	12.2	12.1	12.3

CHAPTER 3

STREAM MORPHOLOGICAL AND SEDIMENTOLOGICAL RESPONSE TO HUMAN IMPACT IN THE SOUTHERN BLUE RIDGE MOUNTAINS[1]

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[1] Price, K. and Leigh, D.S. To be submitted to *Journal of the American Water Resources Association*

ABSTRACT

Stream morphological and sedimentological response to basin-scale impact has been well documented for intensively agricultural or urbanizing areas. However, sensitivity thresholds of streams to modest levels of disturbance are not well understood. This study addresses the influence of permanent forest conversion on streams of the southern Blue Ridge Mountains, a region that has received little attention with respect to human impact on stream channels. Study basins were chosen to represent the end members of the range of human impact in the area, with basin forest cover used as a proxy for level of impact (ranging from about 70-100% regionally). Two pairs of lightly-impacted (>90% forested) and moderately-impacted (70-80% forested) sub-basins of the upper Little Tennessee River were identified for comparison. Reach characteristics (e.g. slope, drainage area, and riparian cover) were aligned in each pair, in order to isolate forest cover as the primary driver of morphological and sedimentological differences. A suite of standard cross-sectional and longitudinal data was collected for each reach for characterization of stream sedimentology and morphology. Difference of means tests were used to identify parameters significantly differing between the lightly- and moderately-impacted streams in both pairs. Consistent and significant differences within both pairs were demonstrated in bankfull width/depth ratios, baseflow wetted width, and stream bed particle size both in the thalweg and throughout the channel. The moderately-impacted streams are narrower than the lightly-impacted streams, and the bed texture of the moderately-impacted streams is finer than that of the lightly-impacted streams. The moderately-impacted streams contain a higher percentage of < 2 mm particles in riffles, a metric which has been shown to be highly correlated with biotic integrity. Although this study has shown that human impact in these basins has resulted in an overall fining of bed texture, few conclusions can be drawn regarding stream morphological response to the levels of impact affecting the upper Little Tennessee River basin. Levels of disturbance in the southern Blue Ridge Mountains may be below

morphological sensitivity thresholds, or alternatively, morphological adjustment to disturbance may be more effectively addressed at a system-wide scale.

INTRODUCTION

In this study we consider the effects of forest clearance on streams of the southern Blue Ridge Mountains, a region that has received little attention with respect to human impact on stream channels. In addition, this region facilitates analysis of the response of streams to relatively modest levels of deforestation, whereas other studies have tended to focus on widespread and complete conversion of native forests to agricultural or urban landscapes. Our primary objective was to determine which, if any, stream morphological and sedimentological parameters respond to modest levels of disturbance in small, highland streams of the southern Blue Ridge.

Stream channel morphology is primarily controlled by prevailing water and sediment fluxes (Mackin, 1948; Knox, 1987; Magilligan and McDowell, 1997). Human alteration of the landscape generally changes one or both of these factors. Obvious, direct alterations of streams include channelization, reservoir construction, flow diversion, and draining of wetlands. Via less obvious mechanisms, anthropogenic impact on streams occurs through land uses that alter basin hydrology and sedimentology (Hirsch et al., 1990). While these impacts may be less obvious than direct channel influences, they are no less significant (Brooks and Brierley, 1997). Channel dimensions adjust to variances in flow and sediment yield resulting from local and upstream changes (Lane et al., 1982). Basin-scale vegetation cover is a key determinant of the hydrologic and sedimentological characteristics of streams (Saxton and Schiau, 1990; Knighton, 1998), and thus influences channel morphology (Hupp and Osterkamp, 1996). Land modification that involves widespread removal of basin vegetation has been repeatedly shown to alter flow characteristics and to change the amount of sediment introduced to stream systems (Wolman, 1967; Trimble, 1974; Knox, 1987; Walling, 1995; Brooks and Brierley, 1997).

Channel adjustment may include destruction of bedforms, resulting in homogenization of stream biotic habitat (Wohl, 2000).

As a prime example of anthropogenic vegetation change, forest clearance commonly results in intensified hillslope erosion and increased sediment input to streams (Knighton, 1998). Increased sedimentation due to removal of protective vegetation cover is accelerated by road construction, row-crop agriculture, larger and more frequent debris flows in steep basins, and poor management practices (Walker, 1991; Slaymaker, 2000; Wohl, 2000). Channel instability and widening has been linked with deforestation in many parts of the world (e.g. Bennett and Selby, 1978; Gregory, 1995; Brooks and Brierley 1997).

Forest removal for agriculture was widespread in the eastern United States by the 1800s. Replacement of native forest with cropland generally results in increased runoff paired with increased sediment supply (Walling, 1995; Kuhnle et al., 1996). Higher erosion rates associated with deforestation commonly result in channel bed aggradation and accelerated floodplain deposition (Knighton, 1998). Decades of poor farming practices resulted in widespread upland erosion and increased floodplain sedimentation, as demonstrated by studies on the Piedmont (Trimble, 1974; Jacobson and Coleman, 1986). Knox (1977) related increased baseflow channel width of small streams to increased flood magnitudes resulting from agricultural land use in Wisconsin. Concurrently, channel bed aggradation resulted from increased bedload supply, leading to increasing width/depth ratios in these streams (Knox, 1977). Although agricultural impacts on sedimentology and channel morphology have been extensive, many of these impacts have abated with improved farming practices and soil conservation efforts, which have been commonly employed in the U.S. since the 1940s (Knox, 2001).

One of the most intensive anthropogenic impacts on channel morphology and sedimentology is urbanization. Urbanizing landscapes require land cover modification, and this usually takes the form of either forest removal or conversion of formerly agricultural land to urban land uses. Direct modifications such as piping and flow diversion often accompany urbanization, and system-wide hydrologic changes, such as a decrease in drainage density, may result from these and other alterations (Dunne and Leopold, 1978). Urbanization involves a wide range of impacts, and specific stream response depends on many factors, especially proximity to disturbance and the degree and rate of land use change (Doyle et al., 2000). The increased percentage of impervious surface and decreased drainage density associated with urbanization result in higher peak flows during runoff events. Though the natures of impact and stream response to urbanization are highly variable, several key patterns have emerged. Initial construction phases of urbanization often result in increased sediment input to streams, leading to bed aggradation (Wolman, 1967; Leopold 1973; Robinson 1976). However, as the influx of construction-sourced sediment wanes and basin impervious coverage increases, the magnitude of low-recurrence interval floods may increase to many times that of the pre-urbanization hydrologic regime (Hollis, 1975; Dunne and Leopold 1978; Hirsch et al., 1990; Knighton, 1998). This is often accompanied by a decrease in sediment supply below pre-urbanization levels, due to extensive coverage of the landscape with impervious surfaces that offer no source of sediment (Knighton, 1998). Stream response to increased flood magnitude and decreased sediment supply is generally channel enlargement, which has been demonstrated in many urban areas (Wolman, 1967; Hammer, 1972; Leopold 1973; Robinson, 1976; Gregory et al., 1992; Doyle et al., 2000). Amount of channel enlargement may depend on age, type, and degree of urbanization (Hammer, 1972; Roberts, 1989).

Highland Streams

Because of lower population densities, human impacts in mountainous regions often differ from those related to intensive agriculture or urbanization discussed above. Development pressures are typically lower in mountainous regions than in lower-relief areas, in part due to difficulty of access and higher likelihood of landscape protection on public lands. Indirect human impacts in high relief areas include timber harvest, road building, grazing, and limited agriculture (Wohl, 2000). Though the nature and extent of impact may differ from low-relief areas, stream responses to human activity in mountain basins also are largely a product of changes in water and sediment yield. Mountain stream systems are particularly sensitive to external influences, as small to moderate changes in discharge or sediment supply can alter stream sedimentology and morphology (Montgomery and Buffington, 1997).

Timber harvest and associated road building are among the most-studied and highest-impact human activities in high relief regions. Exposure of soil via forest removal increases susceptibility to surface erosion of slopes (Johnson and Beschta, 1980). Timber harvest is also associated with a reduction of interception and infiltration, thereby increasing overland flow and furthering soil erosibility. Jackson et al. (2001) demonstrated lower median bed particle size in un-buffered streams following clearcut harvest than reference stream conditions, and bed sediment fining was linked with population decline of some amphibian species. Channel capacity increases have been demonstrated in association with higher peak flows due to forest removal in mountain basins (Hartman et al., 1996; Heede, 1991). Wood-Smith and Buffington (1996) found differences in channel habitat unit distribution between pristine streams and those impacted primarily by timber harvest and associated road building in southeastern Alaska. Road construction is associated with slope destabilization and increased sediment input to streams (Reid and Dunne, 1984; Sah and Mazari, 1998). Road density and related sediment sources were found to account for 51% of the sediment loading of impaired southern Blue Ridge streams (Pruitt et al., 2001).

A major consequence of accelerated input of fine sediment to streams is the infilling of gravel and cobble interstices. Choking of salmonid spawning gravels 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 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. In the same region, Sutherland et al. (2002) indicated higher riffle embeddedness and lower relative abundance of benthic crevice- and gravel-spawning fishes with decreasing basin-scale forest cover. Riffle macroinvertebrates in tributaries to the Etowah River in northern Georgia demonstrated a higher sensitivity to landcover change and sediment input than those adapted to pool or bank habitats (Roy et al., 2003).

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. Specific stream response to forest removal is dependent on the complex interaction of many factors, particularly climate, geology, stream gradient, mode of disturbance, and intensity/extent of vegetation change (Wohl, 2000). Due to the complexity of stream response to disturbance, data from basins within one region cannot necessarily be used to accurately predict stream response in a characteristically different area. For this reason, assessment of human influence on stream condition most effectively occurs on a local or regional scale (Hibbet, 1966; Swank, 1988). In order to fully assess the nature of stream response to forest removal, sedimentology and channel morphology ideally would be monitored from the onset of impact under controlled experimentation. This generally is not possible, particularly 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, it is useful to compare attributes of streams draining moderately-impacted basins to those whose basins have experienced relatively low levels of human land use. When large numbers of sites can be studied, this can be achieved by establishing a land use gradient (Kennan and Ayers, 2002; Walters et al., 2003a, b). In situations where the development of a land use gradient is not optimal, basins that have experienced extremes of development (i.e. "pristine" versus disturbed) can be used to identify differences between the least-impacted and most heavily-impacted streams within a region, and this approach is applied in this study. Basin forest coverage has been demonstrated as a useful predictor of stream habitat and biota (Leigh et al., 2002; Roy et al., 2003 a, b; Walters et al., 2003a, b), and is used herein as a proxy for human impact in the southern Blue Ridge. Many government agencies utilize reach-scale stream assessments for characterization of stream morphological and sedimentological condition (e.g. U.S. EPA Environmental Monitoring and Assessment Protocol (EMAP; Kaufmann and Robison, 1998) and USGS National Water Quality Assessment Program (NAWQA: Fitzpatrick et al., 1998), and this type of approach was used in this study.

Objectives

The primary objective of this study was to assess whether stream morphology and sedimentology respond to moderate basin-scale impact in the southern Blue Ridge. Our secondary objective was to identify which morphological and sedimentological parameters, if any, may serve as indicators of disturbance in this region. We sought to characterize stream morphology and sedimentology of 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. 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, in order to isolate forest cover variability as the primary driver of differences. 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.

Study Area

The upper Little Tennessee River drains part of the southern Blue Ridge physiographic province of northeast Georgia and western North Carolina (Figure 3.1). In the absence of human land use, this region would be very nearly 100% forested (Yarnell, 1998), and classification of Landsat imagery indicates that the basin was approximately 82% forested in 1998 (Table 3.1). 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). 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, urbanization, road construction, and second home development in high relief areas of the basin. 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 smaller basins within the upper Little Tennessee drainage provides a unique opportunity to assess stream response to modest levels of human impact in the southern Blue Ridge. Most of this region has historically experienced episodic, short-lived disturbance (forest clearing) punctuated by periods of potential recovery. Many areas within the unprotected, private land portion of the upper Little Tennessee River basin are facing rapid development and urbanization pressures that lower relief areas like the Piedmont have been experiencing for decades. This allows for assessment of human impact on streams at a stage of disturbance that has long passed in many regions.

The bedrock of the upper Little Tennessee River basin is primarily quartz dioritic gneiss and biotite gneiss (Robinson et al., 1992) covered by a mantle of saprolite and colluvium (1-10 m thick). The landscape has been highly dissected by fluvial processes and mass wasting events. 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 U.S. Forest Service Coweeta Experiment Station in the central portion of the basin 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). Specific study sites are located in Macon County, North Carolina, and Rabun County, Georgia (Figure 3.1).

METHODS

Site Selection

Two pairs of lightly- and moderately-impacted basins were chosen for comparison on the basis of percentage of forested land in their drainage basins (Figure 3.2; see Table 3.2 for basin attributes). 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 (but is not limited to) roads, pasture, cropland, and residential and 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 ArcView® 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 coverage, as additional indicators of the level of human impact, were estimated from 1995-6 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. ArcView® software and USGS 7.5-minute DRGs were used for drainage basin delineation and calculation of drainage area.

In order to isolate human impacts from natural variation, stream study reaches (40 times average wetted width) with similar hydrologic and physical characteristics were established within each pair (Table 3.4). 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 Pope et al. (2001). Streams were chosen to have comparable reach slopes. Reach gradient was measured using a Topcon high precision electronic total station and standard survey techniques. Total basin relief within each pair is comparable, and all four streams flow predominantly eastward. The bedrock geology of all four streams is consistent, and the annual precipitation and temperature are equivalent among the basins. "Pool-riffle" channel morphology characterizes all four streams under the Montgomery and Buffington (1997) classification scheme. Because some stream traits have been shown to be closely correlated with reach-scale vegetation, reaches with comparable riparian vegetation cover (9-12%) within a 10 m buffer of the streams within each pair were chosen. Riparian vegetation conditions were estimated from 1995-6 NAPP images. Based on the blue-line stream network on USGS 7.5-minute DRGs, the pair of smaller basins (7-8 km^2) is comprised of second-order streams, while the larger basins (15-18 km^2) are third-order streams (Strahler, 1952). The smaller pair (2-3 m average width) consists of Keener Creek (lightly-impacted) and Rocky Branch (moderately-impacted), and the larger pair (4-6 m average width) consists of Coweeta Creek (lightly-impacted) and Skeenah Creek (moderately-impacted).

Field Data Collection

The following procedures were followed at each stream, according to the spatial sampling design shown in Figure 3.3, in order to measure the parameters listed in Table 3.3. Many of these parameters have been shown to exert strong influence on stream habitat and the related biotic integrity of fishes and macroinvertebrates (Roy et al., 2003a, b; Walters et al., 2003a, b).

Establishment of study reach: The average wetted width of the reach was determined, rounded to the nearest meter, and the length of the study reach was designated as 40 times (40X) average width. Beginning at the base of the reach (0X), 11 transects were placed perpendicular to the channel at equal intervals of two times channel width, ending with 20 times channel width (20X), according to USGS-NAWQA methods for characterization of stream habitat (Fitzpatrick et al., 1998). An additional five transects were placed at equal intervals of four times channel width beyond the 20X transect, concluding with 40X, satisfying U.S. EPA-EMAP protocol (Kaufmann and Robison, 1998).

Stratigraphic Setting: A topographic survey of a transect that extended at least 35 m on either side of the stream was conducted at a representative location for each stream. Each of these extended transects was surveyed using a high precision electronic total station. A Giddings® hydraulic coring rig was used to probe 7.5 cm diameter cores from key valley features (e.g. terraces, floodplains) along the extended transect. Soil cores were described according to USDA terminology (Soil Survey Division Staff, 1993), and, where possible, charcoal and uncarbonized organic samples were removed for radiocarbon dating at the University of Georgia Center for Applied Isotope Studies. Soil descriptions were used to generate cross-sectional stratigraphy diagrams.

Channel morphology: Bankfull cross-sections were measured at each transect; bankfull level was defined as the height of the first prominent alluvial surface characterized by vertical accretion facies (Williams, 1978) and noted as either a floodplain or terrace landform. Bankfull channel width was measured from the lowest alluvial surface, which was the floodplain in most cases. Bank edges and baseflow water surfaces were surveyed using a high precision electronic total station. Bank angles and conditions along the 40X reach were described according to the USGS protocol at each of the 16 transects, and these data were used to calculate a bank stability index (Fitzpatrick et al., 1998). Cross-sections of the wetted channel were measured with a steel tape and stadia rod at points situated in the thalweg and at 0, 25, 50, 75, and 100% of water width. Water depth, velocity, and channel habitat unit were recorded at each of these points. Channel unit classification (e.g. riffles, glides, pools) was based on U.S. EPA categories (Kaufmann and Robison, 1998). Velocity was measured using a Marsh-McBirney Flowmate™ electromagnetic flow meter at 0.6 depth. Measurements for cross-sectional characterization were summarized using two separate approaches: 1) descriptive statistics were generated for all 16 transects per stream (channel-full dimensions), and, 2) summary values were generated for those transects with active floodplain on either or both sides (bankfull dimensions).

A longitudinal profile of the thalweg was sampled along the entire length of each stream reach according to U.S. EPA protocol (Kaufmann and Robison, 1998). Thalweg samples included water depth, velocity (0.6 depth), and channel habitat unit observations at 81 equally-spaced points at intervals of one-half the average channel width (0.5X). In addition to the thalweg survey, an additional sample was drawn from a point selected at a random percentage of stream width at each of the 81 equally-spaced distances along the 40X reach. Water depth, velocity, and channel unit were recorded at each random point. Additionally, channel habitat unit coverage was hand mapped using the U.S. EPA habitat classification scheme (Kaufmann and Robison, 1998). These units were digitized using ArcView® software, and percentages of total surface area for each habitat type were calculated.

Floodplain dimensions and meander belt width were measured at each of the 16 cross-sections per stream, and the occurrence of other morphological features (e.g. natural and artificial levees) was noted. In order to compare meander belt development among streams of varied width, we calculated a ration of meander belt width divided by channel width for each stream.

Sedimentology: Bed particle size was recorded at each point along the thalweg profile and random points surveys. The intermediate axis of a randomly selected particle was measured at each point along the transects and random points survey, as in a Wolman pebble count (Wolman, 1954). In addition, the dominant phi size class (phi = $-\log_2$ diameter in mm) of the bed material within a 50 cm radius of each point along the transects, thalweg survey, and random points survey was visually assessed, in order to indicate the dominant clast size (by area) in the stream at each point.

As a measure of riffle embeddedness, the percent of riffle clasts smaller than 2 mm was determined for each stream by conducting a standard Wolman (1954) pebble count on a representative riffle within each 40X reach. Although bulk sampling of riffles to a depth of 10-20 cm has been indicated as a more accurate assessment of available habitat than surface point counts, to date no simultaneously accurate and practical method for bulk sampling of cobble bed streams has been demonstrated (Kondolf et al., 2003). Additionally, the particle diameter measurements from the random points survey were sorted by habitat unit, and the mean riffle particle size was determined for each stream along with the percent of particles smaller than 2 mm.

Discharge: 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). For this study, conditions were considered baseflow provided the basin had experienced no runoff-generating precipitation over the preceding 72 hours. In addition to baseflow data collection, flood discharge was measured during a near-bankfull event on February 6, 2004,that affected all four stream basins. The discharge measurements of all four streams were collected within a six-hour period on each of the four sampling days. Discharge was calculated from cross-sectional dimensions and velocity measurements at 0.6 depth taken at 10 equal intervals of stream width. Bankfull discharge at floodplain height was estimated using surveyed cross-sectional dimensions and the Manning equation, with Manning's "n" derived from the February 6, 2004, near-bankfull measured discharge.

Statistical Analysis

Descriptive statistics of each parameter were generated for each stream. The means of those parameters that showed a consistent relationship between the lightly- and moderately-impacted streams in both pairs (e.g. for a given parameter, the means of the lightly-impacted streams were either both lower or both higher than their moderately-impacted counterpart) were tested for statistically significant differences. In preparation for difference of means tests, data columns were checked for normality using the Kolgorov-Smirnov test. When possible, the parameters for which one or more stream was non-normally distributed were normalized using standard transformations ($\log_{10}$, natural log, reciprocal, or square root). Parametric t-tests were run for the normalized variables between the lightly- and moderately-impacted streams in each pair. For variables that failed to normalize when transformed, Mann-Whitney Rank-Sum non-parametric difference of means tests (to generate “T” values) were run between the lightly- and moderately-impacted streams in each pair. A threshold probability value (p) of 0.01 was used to define statistically significant differences.

RESULTS

This summary of results emphasizes parameters that showed differences in both stream pairs. The objective of this study was to identify indicators of basin-scale disturbance, and parameters for which opposite relationships were observed between the lightly- and moderately-impacted streams will not be addressed in terms of basin-scale forest cover. The lightly- and moderately-impacted streams in this study exhibited significant differences in baseflow wetted width, bankfull width/depth (to thalweg) ratio, dominant particle size in the thalweg and entire channel bed, and riffle particle size.

Reach Attributes

The average baseflow discharge values of the more forested streams were higher than those of the less-forested streams (Table 3.4), which contradicts assumptions that forest removal invariably increases baseflow water yield (Dunne and Leopold, 1978; Wohl, 2000). The measured near-bankfull discharge relationships were inconsistent between stream pairs. In one pair, the stormflow discharge of the moderately-impacted stream (Skeenah Creek; 3.23 m^3/s) exceeds the lightly- impacted stream (Coweeta Creek; 2.66 m^3/s). In the other pair, however, the stormflow discharge of the moderately-impacted stream (Rocky Branch; 0.79 m^3/s) remained lower than that of the lightly-impacted stream (Keener Creek; 1.90 m^3/s). Bankfull discharge estimates using Manning's equation indicate higher values for both lightly-impacted streams compared with their more moderately impacted counterparts (4.95 vs. 4.12 m^3/s and 2.84 vs. 1.04 m^3/s).

Reach valley and floodplain morphology are inconsistent among the pairs (Table 3.4). While lightly-impacted Coweeta Creek has a wider average meander belt width than moderately-impacted Skeenah Creek (34.55 vs. 11.57 m) and higher meander belt/channel width ratio (4.86 vs. 1.84), the opposite relationship is evident in the other pair. In lightly-impacted Keener Creek, the meander belt width is lower than that of moderately-impacted Rocky Branch (5.95 vs. 8.75 m), as is the meander belt/channel width ratio (1.30 vs. 3.92). Of the 32 banks measured along the transects, Coweeta Creek and Rocky Branch, the streams with the more extensive meander belt from each pair have fewer terraced banks (three and two, respectively) than Skeenah Creek (18) and Keener Creek (22). Of the 16 cross-sections per stream, all transects of Coweeta Creek and Rocky Branch contained floodplain on at least one side of the stream, while Skeenah Creek and Keener Creek had a floodplain on at least one side of the stream on 13 and 9 cross-sections, respectively (3 and 7 terraced cross-sections).

Glide is the dominant habitat unit of all four streams (Figure 3.4; Table 3.4). All four streams have areas of pool, glide, and riffle. Additionally, Coweeta and Skeenah creeks contain small areas of rapids. By both habitat coverage measurements (mapped percentage of surface area and percentage of sample points), the moderately-impacted streams have lower riffle coverage and higher glide coverage than the lightly-impacted streams.

The average bed particle phi class of the lightly-impacted streams is coarser than that of the moderately-impacted streams (Table 3.4). A greater percentage of fines is evident in all metrics of the less than 2 mm fraction in moderately-impacted Skeenah Creek than lightly-impacted Coweeta Creek. This relationship is generally true for the other pair, with the exception of the fines fraction of the random bed points survey clast diameter (mm) measurements, which is lower in Rocky Branch than in Keener Creek.

Stratigraphic Setting

The stratigraphic setting of all four sites is that of historical floodplain deposits inset between older (prehistoric) terrace deposits (Figure 3.5). Three chronostratigraphic units are recognized including: (1) terraced Pleistocene to Holocene alluvium; (2) prehistoric Holocene alluvium in a low terrace, and (3) historic alluvium in the modern floodplain. All three units are composed of graded sequences of bedload gravels that fine upward to sand, silt, and silt loam, but are distinguished by pedological traits and bounding surfaces. The oldest Unit 1 exhibits a well-expressed Bw horizon to incipient Bt horizon, whereas Unit 2 typically exhibits a youthful Bw horizon, and Unit 3 lacks B horizon development and commonly consists of unweathered stratified and laminated beds. Buried A horizons commonly are present in the top of Unit 2 and beneath the vertical accretion topfacies of Unit 3, which clearly distinguishes the boundary between those units. The historical drape of Unit 3b on top of Unit 2 is comparable at all four sites, and there is no apparent excess of historical sediment at the most impacted sites compared with the least impacted. The bedload facies of historical Unit 3 generally are at about the same elevation as the prehistoric bedload facies of Unit 2, indicating that these streams have not incised or degraded their beds significantly during historical time.

Cross-Sectional Characteristics

Cross-sectional descriptive statistics (Table 3.5) generally indicate either broad similarities or inconsistent directions of conditions between the pairs. Difference of means tests were run for those parameters for which the direction of difference between the lightly- and moderately-impacted streams was consistent in both pairs (Table 3.6). These t-tests indicate that only the bankfull width/depth (to thalweg) ratio and baseflow wetted width were significantly different in both pairs at the $p < 0.01$ level.

Bank characteristics did not appreciably differ between lightly- and moderately-impacted streams (Table 3.5A). No pattern emerged between level of impact and bank height, and although the mean bank angles of the impacted streams were higher than the lightly-impacted streams in both pairs, the difference was not statistically significant between the larger streams (Table 3.6A). The bank stability indices are roughly equal across all 4 streams, and all classify as "unstable" under Fitzpatrick et al.'s (1998) scheme.

Measurements for cross-sectional characterization were analyzed using two separate approaches. Descriptive statistics were generated for all 16 transects per stream (channel-full dimensions; Table 3.5B), and, additionally, summary values were generated for those transects with active floodplain on either or both sides (bankfull dimensions; Table 3.5C). By both methods, the depths to the thalweg and to the water surface showed inconsistent direction of difference between the lightly- and moderately-impacted streams. Although mean channel-full width and channel-full width/depth (to thalweg) ratios are higher in the lightly-impacted streams, these differences are not statistically significant. The bankfull widths and both variants of width/depth ratio are higher in the lightly-impacted streams, but not all of these differences are statistically significant. Only the bankfull width/depth ratio (to thalweg) differences are statistically significant in both pairs (Table 3.6A), with the lightly-impacted streams demonstrating higher bankfull width/depth ratios than their moderately-impacted counterparts. Statistical significance of differences possibly suffered due to reduced n values resulting from culling the terraced transects from Keener Creek and Skeenah Creek.

Baseflow Channel Dimensions

The only baseflow parameter that significantly differs between the lightly- and moderately-impacted streams in both pairs is wetted-width, which is greater in the lightly-impacted streams (Table 3.6B). The means of average cross-sectional and random points water depth are lower in the lightly-impacted streams than in their moderately-impacted counterparts, but these means are not significantly different (Table 3.6). Mean thalweg depth shows no consistent direction of difference. Velocity and Froude number means from both the thalweg and random points surveys are higher in the lightly-impacted streams, but these differences are not significant at the $p < 0.01$ level for both pairs.

Sedimentology

Dominant particle size class means from the random and thalweg longitudinal surveys indicate significantly smaller particle sizes in the moderately-impacted streams (Table 3.8). The mean diameter measurements from the random survey (in mm and phi units) are smaller in the moderately-impacted streams as well, but these differences are only significant at the $p < 0.05$ level, as opposed to $p < 0.01$ (Table 3.6C). The Wolman riffle pebble counts demonstrate significantly coarser riffle particle size in the lightly-impacted streams, and these streams have a lower percentage of riffle fines (Table 3.4). However, the differences in mean riffle particle size as determined by the riffles drawn from the random points and thalweg longitudinal surveys are not statistically significant. As the moderately-impacted streams have lower proportions of riffles than the lightly-impacted streams, statistical significance of differences may have suffered from the low n due to culling the riffle particle size measurements from the random and longitudinal surveys.

DISCUSSION

This study shows that human impact in these basins has resulted in an overall fining of bed texture, but few conclusions can be drawn regarding stream morphological response to the levels of impact affecting the upper Little Tennessee River basin. Although channel widening in response to intensive agriculture and urbanization has been well documented throughout the world, the modest differences in forest cover between these lightly- and moderately-impacted basins (70-80% vs. 90-100%) yield few statistically significant differences in morphological parameters. The lightly- and moderately-impacted streams in this study exhibited significant differences in baseflow wetted width, bankfull width/depth (to thalweg) ratio, dominant particle size in the thalweg and entire channel bed, and riffle particle size.

The majority of the morphological parameters measured in this study failed to demonstrate significant differences at the 0.01 probability level between lightly- and moderately-impacted streams in both pairs. The mean bankfull-width depth ratio (depth to thalweg) and mean baseflow wetted width of both of lightly-impacted streams were significantly higher than those of the moderately-impacted streams. The wider baseflow water width is explained by the higher baseflow discharge values in the lightly-impacted streams, especially considering that mean water depth values are not significantly different. Despite similar drainage areas, the baseflow of the more-forested streams contradicts widely accepted predictions that forest removal invariably increases baseflow water yield in response to decreased evapotranspiration. One possible explanation for lower width/depth ratios in the moderately-impacted streams is the possibility that greater sediment yield from erosive land use in these basins is accreting on the stream banks and floodplain surfaces, and that the specific land uses in these basins are not resulting in increased storm runoff to the extent necessary for the channel enlargement observed in other regions of moderately agricultural and urban areas. Our near-bankfull discharge measurements generally support this conclusion, and the estimated bankfull discharge using Manning's equation is higher in the lightly-impacted streams than the moderately-impacted streams. However, measured discharge values from the February 6, 2004 frontal storm indicated that slightly higher levels of runoff are affecting moderately-impacted Skeenah Creek compared to lightly-impacted Coweeta Creek. These two streams were sampled within 45 minutes of each other during the rising limb of the frontal runoff event, and their spatial proximity allows confidence that similar levels of precipitation affected both basins. The measured stormflow discharge of moderately-impacted Rocky Branch, however, remained lower than that of Keener Creek, which may indicate that the types of disturbance affecting the Rock Branch basin are not resulting in higher levels of surface runoff. The stormflow discharges of these two streams were also measured within a 45-minute interval, but their basins are not as spatially proximal as those of Skeenah Creek and Coweeta Creek, and it is possible that the amount of precipitation was not equal in time or space.

Differences in streambed sedimentology were much more readily apparent than were differences in channel morphology. All sedimentology metrics differed between lightly-and moderately-impacted streams, though diameter measurements from the random points survey were only significant at the $p < 0.05$ level, rather than the $p < 0.01$ threshold we established for designation of statistical significance. The Wolman pebble count in riffles showed significantly finer mean particle size in the moderately-impacted streams and higher percentages of < 2 mm particles in the riffles. It is evident that human impact in this region is contributing fine sediment to stream systems given previous suspended sediment measurements (Sutherland et al., 2002; Price and Leigh, in preparation), and that streams with higher basin forest cover show coarser average particle size. The riffle-specific Wolman pebble count produced clearer results than isolating the riffle fraction of the total-bed random points survey. This reaffirms that stratifying pebble counts by habitat units is indeed a superior approach to generalizing the entire stream bed (Wolman, 1954; Kondolf et al., 2003). In many highland pool-riffle systems the riffles are the most clearly bounded and most easily identified stream unit. Of the commonly used stream units, riffles have been shown to be the most highly sensitive to external disturbance (Roy et al., 2003b). For these reasons, perhaps stream bed particle size sampling for assessment of disturbance could be effectively limited to riffles, particularly in highland streams.

The differences in dominant particle size means from the random and thalweg surveys were highly significant. While questions of repeatability surround visual assessment methods for categorical particle size data (Kondolf et al., 2003), the estimation of dominant phi size class may provide more information regarding aquatic habitat availability within the entire channel than randomly-selected particle diameters. In this study, the dominant particle size means were successful indicators of basin disturbance. In cases where visual assessment of dominant particle size is desired, we recommend using standard Wentworth-scale phi size classes, in order to allow for comparison of results with particle size assessment from other methods. Such an approach was also proven to be highly successful in characterizing stream habitat suitability for specific types of fish assemblages (Walters et al., 2003a, b).

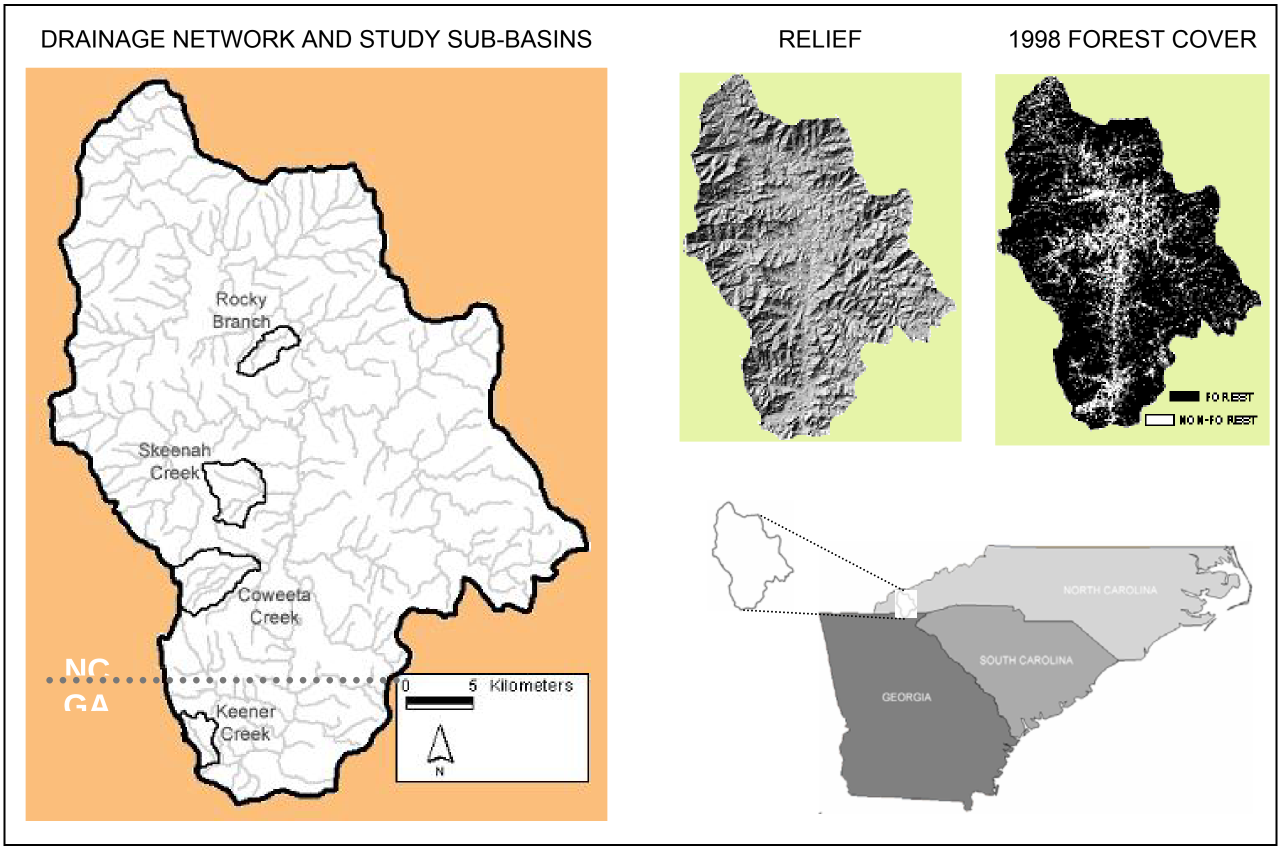
The fact that sedimentological differences were more significant than morphological differences suggests that bed sedimentology is more sensitive to disturbance and responds more quickly to basin changes than channel form. Indeed, Schumm (1973) indicates that due to the complexity of the fluvial system, it is not always possible to clearly identify morphological response to disturbance. Nagle and Clifton (1997) indicated lag times in morphological response to external changes as a possible explanation for an absence of differences between the morphology of streams pre- and post-exclusion of cattle. There exists the possibility that the morphology of the streams assessed in this study has yet to demonstrate adjustment to latetwentieth century disturbances. Another possibility is that the lightly-impacted basins never fully recovered to baseline conditions that existed prior to timber harvest that pre-dates federal protection, which began in 1911. In northern California, morphological adjustments to timber harvest have been shown to persist more than 100 years (Napolitano, 1998). However, the valley stratigraphy of our study sites indicates this is not likely the case for these streams. The stratigraphic settings of the sites failed to reveal any clear differences that distinguish the most- from least-impacted basins. All four sites appear to be in the final stage of channel and floodplain evolution indicated by Jacobson and Coleman (1986) for Piedmont streams that experienced pronounced sediment loading during the late 19th and early 20th centuries. They have accomplished moderate levels of lateral migration and construction of floodplains, rather than being entrenched channels confined by large amounts of top facies on the banks and valley floor. This may indicate that all four streams have "recovered" to comparable levels since the time of most widespread forest harvest that occurred circa 75-150 years ago. Furthermore, our results indicate that significant amounts of stream bed incision or aggradation cannot be detected in these upper Little Tennessee River tributaries in response to differing levels of human impact.

It is likely that, while appropriate for sedimentology, the reach scale of assessment does not always provide meaningful insight into system-driven responses to basin-scale impact. Due to pragmatic constraints such as land access and time/personnel limitations, thorough basin-scale assessments of a full suite of morphological parameters is not usually possible. Basin-scale modeling (Benda and Dunne 1997) can be used for prediction of channel response to catchment changes, and connectivity analysis has been used to address hierarchical levels of response to external changes (Brevard et al., 1997; Kondolf et al., 2002). Until recently, the low resolution of publicly available remotely sensed imagery has precluded its use for morphological assessment of small streams. However, advanced technologies are opening possibilities for systems approaches for studying morphological response. High resolution hyperspectral imagery has been used to measure some morphological parameters of mountain streams along reaches of several kilometers, far longer than most reach scale assessments allow (Marcus et al., 2003), and the application of light detection and ranging (LiDAR) data to high resolution morphological analysis is an especially promising direction of fluvial research (Downs and Priestnall, 2003). Each of these system-wide approaches incorporates some level of uncertainty, and none is appropriate for all parameters typically measured in morphological assessments. However, the use of these types of approaches can potentially improve reach scale assessments by providing a system-wide context for analysis (Piégay and Schumm, 2003).

Many common stream assessment methods call for collection of data for a wide variety of sedimentological and morphological parameters (e.g. U.S. EPA-EMAP and USGS-NAWQA). This approach is time consuming and perhaps unnecessary (Nagle and Clifton, 1997). The literature does not clearly validate collection of a thorough suite of morphological parameters at the reach scale, and it may be more efficient and advantageous for stream monitoring methods to focus on those parameters repeatedly demonstrated as sensitive to disturbance. This study has identified stream bed sedimentology as a key indicator, as others have (Jackson et al., 2001; Roy et al. 2003 a,b; Walters et al., 2003 a,b). Furthermore, streambed sedimentology is more closely associated with stream biotic habitat. The measurement of fewer parameters at more cross sections has been shown to be superior to few, highly detailed cross sections (Robison and Beschta, 1989). Studies have indicated that baseflow morphology, which is less subjective than bankfull morphology and more quickly assessed, can provide adequate information for certain objectives (Magilligan and McDowell, 1997; Nagle and Clifton, 1997). Government agencies have gravitated toward qualitative measures for ease and expedience (e.g. USDA Stream Visual Assessment Protocol (USDA-NRCS 1999) and U.S. EPA Rapid Bioassessment Protocol (Barbour et al., 1999)). However, Doyle et al. (2000) demonstrated that qualitative assessments, though faster, yield inferior results when compared against quantitative assessments. Thus, we would advocate use of a limited subset of quantitatively-assessed streambed characteristics, especially particle size, for development of the most precise and defendable measures of stream conditions as they relate to human-induced impact and degradation.

CONCLUSIONS

These results indicate that land use involving modest changes in basin-scale forest cover may cause significant differences in streambed sedimentology. However, morphological response to low levels of disturbance at our reach-scale of analysis is not clear. Careful alignment of reach characteristics of stream pairs allowed for isolation of differences in forest cover as the primary driver of stream differences. Streams draining the more moderately-impacted basins in this study (70-80% forest) demonstrate lower bankfull width/depth ratios, narrower baseflow wetted widths, and finer stream bed texture. While the sedimentology of these streams clearly differed, few conclusions can be drawn regarding morphological differences. Reach-scale assessment of stream bed sedimentology, particularly that of riffles, was shown to be a successful scheme for identification of differences. Riffle particle size and embeddedness have been shown to be linked with stream biotic integrity and to be highly sensitive to external disturbance. Perhaps these parameters are among the best indicators of stream response to human impact. The levels of impact affecting the upper Little Tennessee River tributaries may be below morphological sensitivity thresholds. Standard reach-scale assessment methodologies were followed for data collection, and this study indicates that these methods may not be optimal for assessment of morphological response to disturbance at the reach-scale of analysis.


DRAINAGE NETWORK AND STUDY SUB-BASINS

RELIEF

1998 FOREST COVER

Figure 3.1. Study area – Upper Little Tennessee River

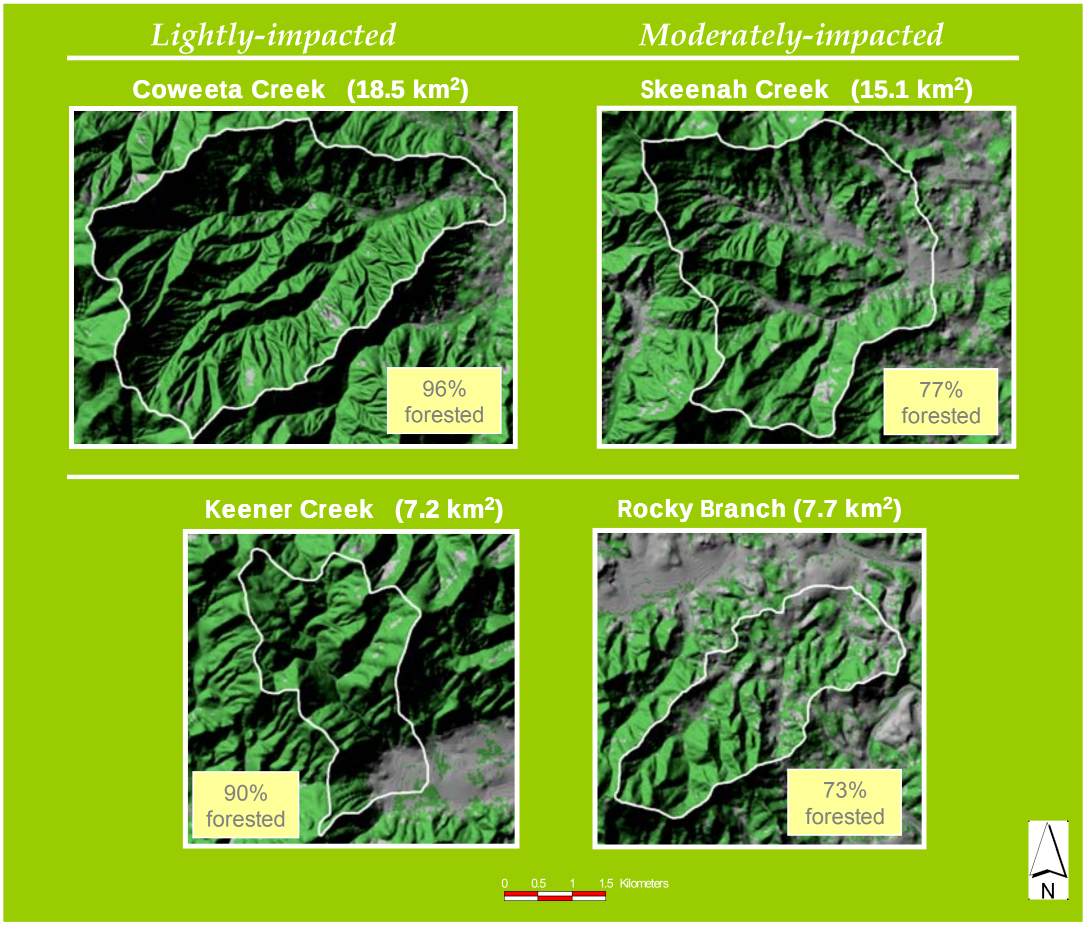


Figure 3.2. Study basins. Green areas represent forested land.

Hybrid USGS-USEPA Stream Survey

TRANSECT DATA
-Channel-full cross-section *n* = 16
-Bankfull cross-section *n* = variable
-Bank condition *n* = 32
-Bank angle *n* = 32

0.5X RANDOM POINTS SURVEY
-Particle size (mm) *n* = 81
-Particle size (dominant phi class) *n* = 81
-Depth *n* = 81
-Velocity *n* = 81
-Habitat unit (e.g. pool, glide, riffle, or rapid) *n* = 81

THALWEG SURVEY
-Particle size (dominant phi class) *n* = 81
-Depth *n* = 81
-Velocity *n* = 81
-Habitat unit *n* = 81

OTHER DATA
-Reach slope (40X regression, 20Xregression, riffle tops)
-Particle size in riffles *n* = 100
-Baseflow discharge
-Floodplain width

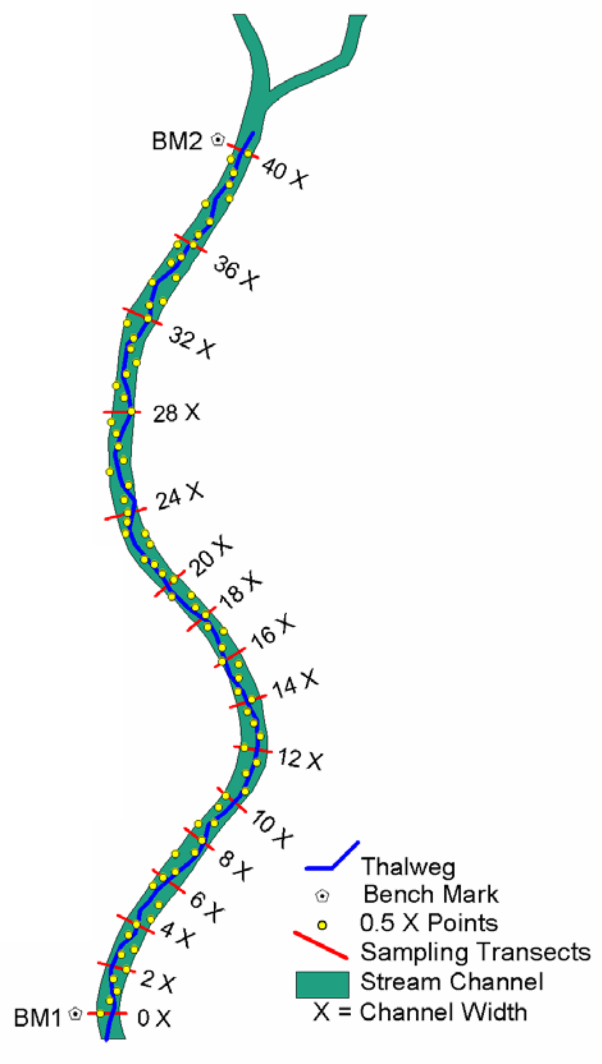


Figure 3.3. Field data collection

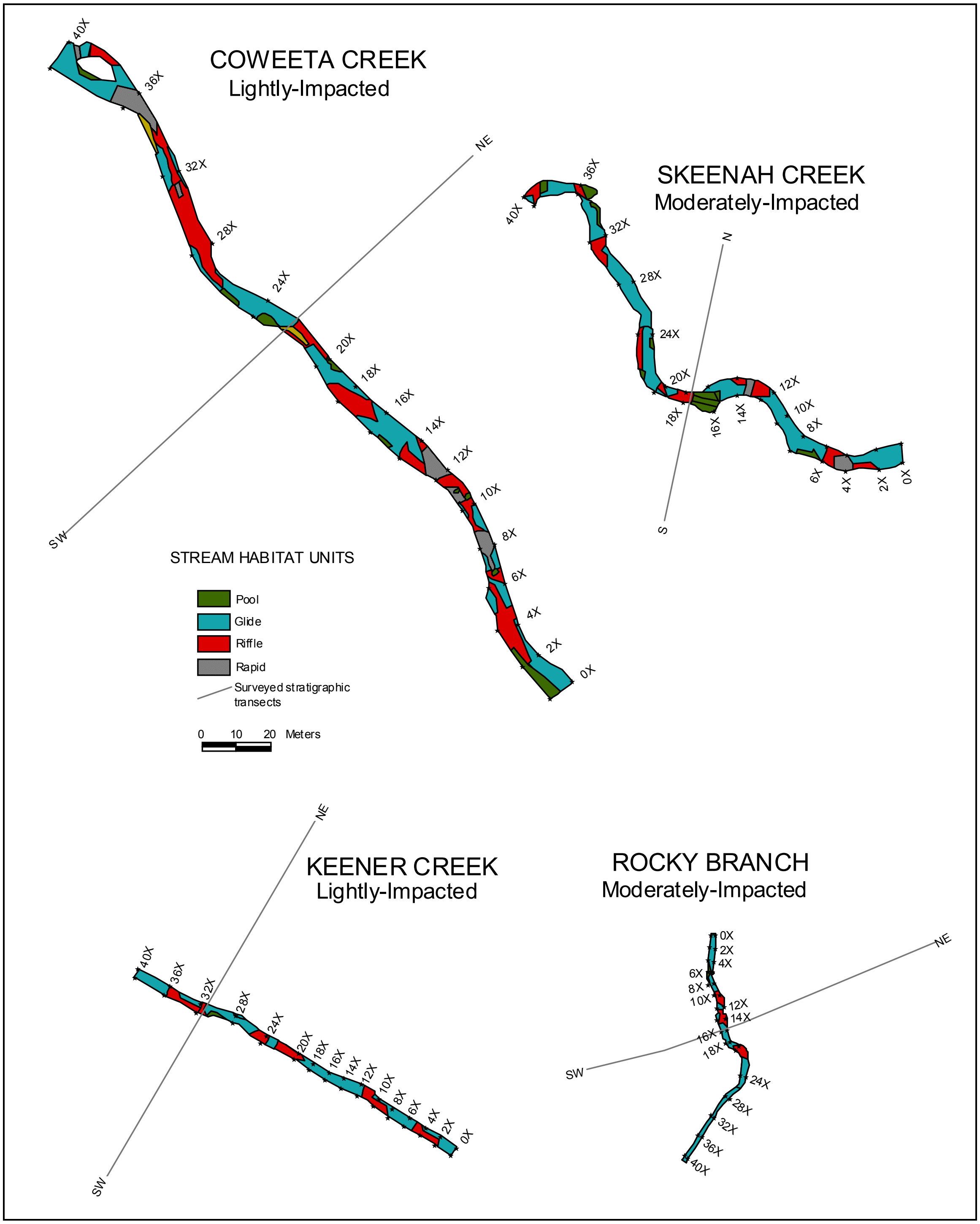


Figure 3.4. Channel habitat units. Moderately-impacted streams exhibited lower riffle coverage and glide predominance when compared with their lightly-impacted counterparts.

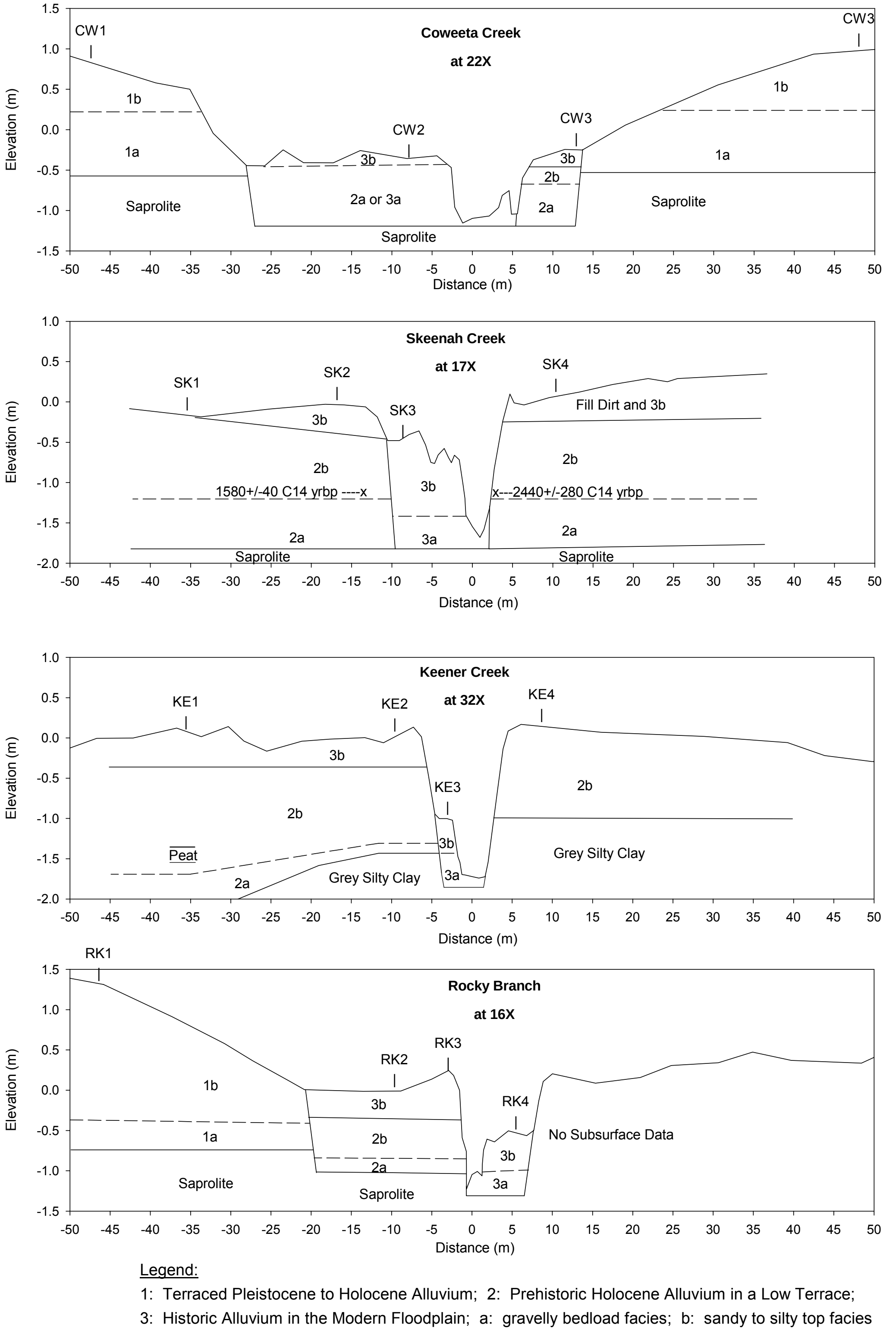


Figure 3.5. Stratigraphic cross sections of study sites. Surface labels (i.e. RK2) indicate core hole locations. The stratigraphy indicates that none of the four streams has aggraded or incised relative to prehistoric bed elevations.

Table 3.1

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™ image provided by Barrie Collins, The University of Georgia, Institute of Ecology

Table 3.2

BASIN 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 (% OF TOTAL AREA)	*FOREST*	95.7	77.2	90.0	72.9
	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
ROAD COVERAGE (% OF BASIN AREA)	*TOTAL*	5.10	4.02	0.86	3.34
	PAVED	0.14	0.82	0.29	0.98
	UNPAVED	4.96	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	6.45	5.55	0.77	6.25
ROAD/STREAM CROSSINGS	*TOTAL*	30	36	5	15
	PAVED	3	29	2	6
	UNPAVED	27	7	3	9
STREAM ORDER*		3	3	2	2
TRUNK STREAM RELIEF (m)		726	250	381	197
DRAINAGE DENSITY (km/km^2)		0.95	0.80	0.57	0.64
MAP SLOPE		0.0050	0.0076	0.0065	0.0045
40X USEPA SLOPE (REGRESSION)		0.0106	0.0056	0.0055	0.0060
20X USGS SLOPE (REGRESSION)		0.0118	0.0059	0.0025	0.0068
RIFFLE TOP SLOPE		0.0108	0.0053	0.0056	0.0065

L = lightly-impacted; M = moderately-impacted

*Strahler, 1952

Table 3.3
EXPLANATION OF PARAMETERS

Road Coverage: Road length X Road width (measured from 1995-6 NAPP images), expressed as a % of total basin area

Road Density: Road length (measured from 1995-6 NAPP images) / total basin area

Road Crossings: Tallied from overlay of blue-line stream network and road network (defined from 1995-6 NAPP images)

Trunk Stream Relief: Elevation between the basin divide (above the terminus of the map blue-line of trunk stream) and the stream reach

Drainage Density: Stream length (total blue-line length on USGS DRGs) / total basin area

Map Slope: Elevation / distance of stream derived from USGS DRG contours

40X Slope: Regressed from surveyed cross-sections along 40X reach

20X Slope: Regressed from surveyed cross-sections along 20X reach

Riffle Top Slope: Elevation / distance of stream between surveyed cross-sections transecting riffles near 0X and 40X

Riparian Cover: Woody vegetation cover as % of total area within a 10 m buffer 500 m upstream from 0X (measured from 1995-6 NAPP images)

Sinuosity: Stream length / valley length (measured from 1995-6 NAPP images)

Discharge: Calculated from 0.6-depth velocity, water depth, and horizontal channel distance at ≥10 points along a transect

Bankfull Width: measured from lowest floodplain surface

Bankfull Depth: measured from lowest floodplain surface to a) bottom of thalweg, and b) water surface

Channel-full Width: measured from lowest prominent vertical accretion facies (floodplain or terrace)

Channel-full Depth: measured from lowest prominent accretion facies to a) bottom of thalweg, and b) water surface

Habitat Coverage - % Area: Habitat units were mapped by field measurement, coverage was computed in ArcView®

Habitat Coverage - % Points: Random survey points were sorted by habitat unit, and % of total observations was calculated

% Particles < 2 mm: Percent of particles < 2 mm or > - 0.5 Φ was determined for each particle size parameter

Bank Height: Height from bottom of thalweg to top of lowest prominent vertical accretion facies

Bank Angle: Overall bank angle (measured with a Brunton compass)

Bank Stability Index: Computed from bank height, angle, texture, vegetation cover, and amount of erosion (Fitzpatrick et al., 1998)

Froude Number: Velocity (m/s) / √ (gravitational constant X depth (m))

Dominant Φ: Particle size class (whole phi interval) comprising modal % of surface area within a 50 cm radius of sample point

Riffle Fraction: Particle size measurements from sample points in riffles were culled from total column (random and thalweg surveys) and summarized

Meander Belt Width: Floodplain width + channel-full width

Meander Belt / Channel Ratio: (floodplain width + channel-full width) / channel width; used to standardize meander belt width by stream size

Table 3.4

REACH ATTRIBUTES

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
REACH BASE (0X) COORDINATES (UTM, NAD 83)	*E*	280,414	281,849	277,332	282,540
	N	3,882,480	3,887,962	3,868,128	3,900,283
RIPARIAN VEGETATION COVER (%)		12	11	11	9
SINUOSITY		1.07	1.21	1.02	1.08
AVERAGE BASEFLOW DISCHARGE* (m^3/s)		0.55	0.32	0.21	0.12
NEAR BANKFULL DISCHARGE (m^3/s)		2.66	3.23	1.90	0.79
ESTIMATED BANKFULL DISCHARGE (m^3/s)		4.95	4.12	2.84	1.04
AVERAGE BASEFLOW WATER WIDTH** (m)		6.35	4.82	3.27	1.97
AVERAGE BANKFULL WIDTH** (m)		7.58	6.88	4.76	2.42
AVERAGE BANKFULL THALWEG DEPTH** (m)		0.91	1.36	1.17	0.6
MAP SLOPE		0.0050	0.0076	0.0065	0.0045
40X USEPA SLOPE (REGRESSION)		0.0106	0.0056	0.0055	0.0060
20X USGS SLOPE (REGRESSION)		0.0118	0.0059	0.0052	0.0068
RIFFLE TOP SLOPE		0.0108	0.0053	0.0056	0.0065
AVERAGE MEANDER BELT WIDTH** (m)		34.55	11.57	5.95	8.75
MEANDER BELT WIDTH / CHANNEL WIDTH		4.86	1.84	1.30	3.92
TERRACED BANKS (OF 32)		3	18	22	2
TERRACED TRANSECTS (OF 16)		0	3	7	0
% POOL	*AREA*	7.03	11.62	1.25	1.68
	*POINTS****	7.40	14.81	4.93	2.46
% GLIDE	*AREA*	45.83	63.35	65.99	74.83
	*POINTS****	43.21	59.26	50.62	74.07
% RIFFLE	*AREA*	34.86	20.36	32.75	21.87
	*POINTS****	43.21	24.69	44.44	23.46
% RAPIDS	*AREA*	12.28	4.67	0.00	0.00
	*POINTS****	6.17	1.23	0.00	0.00
AVERAGE PARTICLE SIZE		very coarse gravel (Φ = -5 to -6)	medium gravel (Φ = -3 to -4)	coarse gravel (Φ = -4 to -5)	fine gravel (Φ = -2 to -3)
% PARTICLES < 2 mm	*CHANNEL BED (Φ)*	18.5	35.8	14.8	18.5
	CHANNEL BED (mm)	21.0	33.3	21.0	14.8
	THALWEG (Φ)	1.2	4.0	3.7	3.7
	RIFFLES(mm)	5.0	25.0	7.0	31.0

L = lightly-impacted; H = heavily-impacted

**n* = 3 per stream; **n= 16 per stream; ***n= 81 per stream

Table 3.5
CROSS-SECTION DESCRIPTIVE STATISTICS

A. BANK CHARACTERISTICS (*n* = 32 per stream)

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
BANK HEIGHT (m)	***MEAN***	**1.03**	**1.57**	**1.44**	**0.64**
	STD. DEV.	0.21	0.32	0.57	0.23
	RANGE	0.90	1.31	1.83	1.24
BANK ANGLE (º)	***MEAN***	**46**	**55**	**51**	**68**
	STD. DEV.	28	33	18	21
	RANGE	125	123	70	98
BANK STABILITY INDEX	***MEAN***	**11.6**	**12.3**	**11.8**	**11.8**
	STD. DEV.	1.7	1.6	1.2	1.0
	RANGE	6.5	6.5	5.0	5.0

B. CHANNEL-FULL DIMENSIONS* - ALL TRANSECTS (*n* = 16 per stream)

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
WIDTH (m)	***MEAN***	**7.58**	**6.88**	**4.76**	**2.42**
	STD. DEV.	2.27	1.87	1.43	0.68
	RANGE	9.25	7.19	5.58	2.34
DEPTH TO THALWEG (m)	***MEAN***	**1.01**	**1.36**	**1.17**	**0.60**
	STD. DEV.	0.15	0.32	0.59	0.10
	RANGE	0.54	0.98	1.59	0.29
DEPTH TO WATER SURFACE (m)	***MEAN***	**0.59**	**0.95**	**0.89**	**0.32**
	STD. DEV.	0.16	0.37	0.61	0.10
	RANGE	0.57	1.16	1.64	0.43
WIDTH/DEPTH RATIO (DEPTH TO THALWEG)	***MEAN***	**7.61**	**5.10**	**4.81**	**4.12**
	STD. DEV.	2.52	1.07	1.85	1.35
	RANGE	10.16	3.41	6.27	4.94
WIDTH/DEPTH RATIO (DEPTH TO WATER SURFACE)	***MEAN***	**13.66**	**7.96**	**7.98**	**8.33**
	STD. DEV.	5.37	2.69	5.10	3.55
	RANGE	18.08	11.38	19.33	13.40

C. BANKFULL DIMENSIONS**

		COWEETA (L) *n* = 16	SKEENAH (H) *n* = 13	KEENER (L) *n* = 9	ROCKY (H) *n* = 16
WIDTH (m)	***MEAN***	**7.58**	**6.34**	**3.94**	**2.42**
	STD. DEV.	2.27	1.51	0.57	0.68
	RANGE	9.25	4.54	1.63	2.34
DEPTH TO THALWEG (m)	***MEAN***	**1.01**	**1.23**	**0.69**	**0.60**
	STD. DEV.	0.15	0.29	0.19	0.10
	RANGE	0.54	0.98	0.67	0.29
DEPTH TO WATER SURFACE (m)	***MEAN***	**0.59**	**0.85**	**0.40**	**0.32**
	STD. DEV.	0.16	0.33	0.18	0.10
	RANGE	0.57	1.16	0.66	0.43
WIDTH/DEPTH RATIO (DEPTH TO THALWEG)	***MEAN***	**7.61**	**5.06**	**6.04**	**4.12**
	STD. DEV.	2.52	1.12	1.47	1.35
	RANGE	10.16	3.41	4.29	4.94
WIDTH/DEPTH RATIO (DEPTH TO WATER SURFACE)	***MEAN***	**13.66**	**8.24**	**11.26**	**8.33**
	STD. DEV.	5.37	2.87	4.57	3.55
	RANGE	18.08	11.38	16.29	13.40
FLOODPLAIN WIDTH (m)	***MEAN***	**13.49**	**2.35**	**0.59**	**3.16**
	STD. DEV.	9.58	3.58	0.99	2.28
	RANGE	37.00	12.80	3.09	9.00

L = lightly-impacted; H = heavily impacted

* = bank top; ** bankfull mesured where floodplain surfaces existed on either side of the stream

Table 3.6

DIFFERENCE OF MEANS TEST STATISTICS

A. BANK, CHANNEL-FULL, AND BANKFULL DIMENSIONS

	COWEETA / SKEENAH (L/H)	KEENER / ROCKY (L/H)
BANK ANGLE *n* = 32	T = 964	T = 786.5***
BANK STABILITY INDEX *n* = 32	T = 890**	T = 1032
CHANNEL-FULL WIDTH *n* = 16	t = 0.955	t = 5.895***
CHANNEL-FULL WIDTH/DEPTH RATIO (DEPTH TO THALWEG) *n* = 16	t = 3.666***	t = 1.198
BANKFULL WIDTH (m) *n* = varied	t = 1.691 *n:* Coweeta = 16; Skeenah = 13	t = 5.697*** *n:* Keener = 9; Rocky = 16
BANKFULL WIDTH/DEPTH RATIO (DEPTH TO THALWEG) *n* = varied	t = 3.998*** *n:* Coweeta = 16; Skeenah = 13	t = 3.490*** *n:* Keener = 9; Rocky = 16
BANKFULL WIDTH/DEPTH RATIO (DEPTH TO WATER SURFACE) *n* = varied	T = 114.0*** *n:* Coweeta = 16; Skeenah = 13	T = 152.0 *n:* Keener = 9; Rocky = 16

B. BASEFLOW CHANNEL DIMENSIONS

	COWEETA / SKEENAH (L/H)	KEENER / ROCKY (L/H)
WETTED WIDTH *n* = 16	t = 2.919**	t = 7.917***
AVERAGE WATER DEPTH (TRANSECTS) *n* = 16	t = -0.083	t = -2.852**
BASEFLOW WIDTH /DEPTH RATIO *n* = 16	t = 1.957	t = 6.025***
WATER DEPTH AT RANDOM POINTS *n* = 81	t = -1.702	t = -3.270***
VELOCITY AT RANDOM POINTS *n* = 81	t = 2.164*	t = 0.631
VELOCITY IN THALWEG *n* = 81	T = 8712.5***	T = 7.285*
FROUDE NUMBER AT RANDOM POINTS *n* = 81	t = 2.065*	t = 1.873
FROUDE NUMBER IN THALWEG *n* = 81	t = 5.88***	t = 2.266*

C. SEDIMENTOLOGY

	COWEETA / SKEENAH (L/H)	KEENER / ROCKY (L/H)
WOLMAN PEBBLE COUNT AT RANDOM POINTS (mm) *n* = 81	T = 7354.5*	T = 7205.5*
WOLMAN PEBBLE COUNT AT RANDOM POINTS (Φ) *n* = 81	T = 5848.5*	T = 5995*
WOLMAN PEBBLE COUNT IN RIFFLES (mm) *n* = 100	T = 11375.5***	T = 13474.5***
WOLMAN PEBBLE COUNT IN RIFFLES (Φ) *n* = 100	T = 8709***	T = 6619.5***
DOMINANT PHI SIZE AT RANDOM POINTS (INTERVAL DATA) *n* = 81	T = 5629.5***	T = 5698.5**
DOMINANT PHI SIZE IN THALWEG (INTERVAL DATA) *n* = 81	T = 4769.5***	T = 5493***

L = lightly-impacted; H = heavily-impacted

t = parametric t-test; T = Mann-Whitney Rank Sum non-parametric differnce of means test

* $P < 0.05$; ** $P < 0.01$; *** P ? 0.001

Table 3.7

BASEFLOW CHANNEL DESCRIPTIVE STATISTICS

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
WIDTH* (m)	***MEAN***	**6.35**	**4.82**	**3.27**	**1.97**
	STD. DEV.	1.73	1.17	0.28	0.59
	RANGE	6.58	4.47	1.27	2.40
AVERAGE WATER DEPTH ON CROSS SECTIONS* (m)	***MEAN***	**0.22**	**0.22**	**0.17**	**0.23**
	STD. DEV.	0.07	0.10	0.05	0.06
	RANGE	0.32	0.42	0.21	0.28
WIDTH/DEPTH RATIO*	***MEAN***	**31.70**	**24.18**	**21.55**	**9.88**
	STD. DEV.	13.69	8.57	7.04	6.00
	RANGE	43.47	29.35	24.70	24.58
WATER DEPTH AT RANDOM POINTS** (m)	***MEAN***	**23.36**	**26.07**	**19.32**	**23.00**
	STD. DEV.	12.60	11.63	8.82	6.85
	RANGE	58.00	58.00	46.00	30.00
WATER DEPTH IN THALWEG** (m)	***MEAN***	**41.41**	**38.90**	**27.00**	**27.12**
	STD. DEV.	13.00	12.10	9.01	6.76
	RANGE	60.00	57.00	40.00	40.00
VELOCITY AT RANDOM POINTS** (m)	***MEAN***	**0.44**	**0.35**	**0.46**	**0.44**
	STD. DEV.	0.31	0.22	0.23	0.23
	RANGE	1.18	0.94	0.93	1.06
VELOCITY IN THALWEG** (m)	***MEAN***	**0.70**	**0.42**	**0.60**	**0.53**
	STD. DEV.	0.25	0.19	0.19	0.20
	RANGE	1.27	1.10	0.92	0.99
FROUDE NUMBER AT RANDOM POINTS**	***MEAN***	**0.29**	**0.23**	**0.35**	**0.30**
	STD. DEV.	0.20	0.12	0.18	0.16
	RANGE	0.80	0.72	0.80	0.72
FROUDE NUMBER IN THALWEG**	***MEAN***	**0.37**	**0.23**	**0.39**	**0.33**
	STD. DEV.	0.16	0.12	0.14	0.14
	RANGE	0.74	0.62	0.64	0.67

L = lightly-impacted; H = heavily impacted

* *n* = 16 per stream; ** n = 81 per stream

Table 3.8
SEDIMENTOLOGY DESCRIPTIVE STATISTICS

		COWEETA (L)	SKEENAH (H)	KEENER (L)	ROCKY (H)
DOMINANT PHI SIZE IN THALWEG*	***MEAN***	**-6.3**	**-3.7**	**-4.8**	**-4.6**
(INTERVAL DATA)	*STD. DEV.*	1.4	2.9	1.6	1.1
	RANGE	12.0	13.0	13.0	7.0
	5TH %ILE	-7.5	-7.0	-5.5	-5.5
	50h %ILE	-6.5	-4.5	-5.5	-4.5
	95th %ILE	-5.5	-0.5	-2.6	-3.5
DOMINANT PHI SIZE AT RANDOM POINTS*	***MEAN***	**-5.1**	**-3.7**	**-4.1**	**-3.6**
(INTERVAL DATA)	*STD. DEV.*	2.5	2.9	2.1	1.7
	RANGE	9.0	12.0	13.0	7.0
	5TH %ILE	-8.0	-6.5	-5.5	-5.5
	50h %ILE	-5.5	-4.5	-4.5	-4.5
	95th %ILE	-0.5	-0.5	-0.5	-0.5
PARTICLE SIZE AT RANDOM POINTS* (mm)	***MEAN***	**64**	**42**	**32**	**21**
	STD. DEV.	65	49	46	28
	RANGE	37	210	375	224
	5TH %ILE	1	1	1	1
	50h %ILE	49	25	23	16
	95th %ILE	182	139	78	58
PARTICLE SIZE AT RANDOM POINTS* (Φ)	***MEAN***	**-4.6**	**-3.5**	**-3.7**	**-3.5**
	STD. DEV.	2.7	3.1	2.6	1.8
	RANGE	8.6	12.2	13.1	7.8
	5TH %ILE	-7.5	-7.1	-6.3	-5.8
	50h %ILE	-5.6	-4.6	-4.5	-4.0
	95th %ILE	0.0	0.0	0.0	0.0
WOLMAN PEBBLE COUNT IN RIFFLES** (mm)	***MEAN***	**61**	**45**	**35**	**9**
	STD. DEV.	51	51	28	8
	RANGE	290	215	146	34
	5TH %ILE	2	0	1	1
	50h %ILE	49	35	28	8
	95th %ILE	146	167	83	24
WOLMAN PEBBLE COUNT IN RIFFLES** (Φ)	***MEAN***	**-5.1**	**-3.4**	**-4.5**	**-2.3**
	STD. DEV.	2.4	3.9	1.7	1.7
	RANGE	12.7	12.2	7.2	5.1
	5TH %ILE	-7.2	-7.4	-6.4	-4.5
	50h %ILE	-5.6	-5.1	-4.9	-3.0
	95th %ILE	-0.5	4.5	0.0	0.0
RIFFLE FRACTION OF RANDOM POINTS SURVEY*** (mm)	***MEAN***	**90.4**	**64.7**	**34.0**	**30.4**
	STD. DEV.	77.1	47.3	27.3	18.2
	RANGE	373.0	166.0	120.0	71.0
	5TH %ILE	1.0	1.0	1.0	10.4
	50h %ILE	84.0	70.5	27.5	25.0
	95th %ILE	231.3	148.5	81.8	72.4

L = lightly-impacted; H = heavily impacted

* *n* = 81 per stream; ** n = 100 per stream; ****n* = 19 to 35

CHAPTER 4

CONCLUSIONS

The results of this study indicate that modest human-induced changes in forest cover may result in significant differences in stream water quality and stream bed sedimentology. However, few morphological differences between lightly- and moderately-impacted streams emerged. Careful alignment of reach characteristics allowed for isolation of differences in forest cover as the primary correlate of differences in stream traits.

Streams draining the moderately-impacted basins (70-80% forested) demonstrate higher levels of baseflow TSS, SSC, organic concentration, nitrate, turbidity, turbidity and riffle fines than streams draining lightly-impacted basins (90-100% forested). The moderately-impacted streams demonstrated lower D.O. and smaller mean bed particle size from longitudinal thalweg and random-points surveys. The baseflow wetted width and bankfull width/depth (to thalweg) ratios of the moderately-impacted streams were lower than those of the lightly-impacted streams. No other morphological parameters demonstrated significant differences. Differences were not statistically significant in baseflow orthophosphate or ammonium concentrations, as levels in all four streams were negligible. Values measured during a near-bankfull runoff event confirm baseflow results and suggest that baseflow measurement may be an adequate method of assessment of overall water quality conditions.

For the parameters that failed to indicate significant differences, response may require higher levels of disturbance, or the scale of assessment may need modification. Many of the parameters shown to significantly differ have been linked with stream biotic integrity, but the level of impact in these upper Little Tennessee River tributaries may not be high enough to raise great management concerns. However, rapid development is occurring in this region, and population growth is projected to continue at a steady or more rapid rate. Stream degradation may be pushed beyond thresholds of biotic tolerance and/or morphological response, and planning measures are encouraged. These results also indicate that parameters of water quality and sedimentology are sensitive to modest levels of disturbance, thus the identification of reference streams for establishment of baseline conditions should be highly conservative. The use of modestly disturbed stream basin toward this end likely results in underestimation of impairment of study streams.

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