EFFECTS OF FOREST CONVERSION ON BASEFLOWS IN THE SOUTHERN APPALACHIANS: A CROSS-LANDSCAPE COMPARISON OF SYNOPTIC MEASUREMENTS

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Abstract. Basin forest cover is understood to influence stream baseflow in a variety of ways, most significantly via increased soil infiltration and increased evapotranspiration (ET). Extensive forestry experimentation has consistently demonstrated a negative relationship between forest cover and baseflow, attributed to ET losses associated with greater forest cover. However, it is unclear whether this relationship can be extrapolated to larger spatial and temporal scales. Spatially, larger basins may contain greater subsurface storage capacity, potentially overriding the effects of ET losses on baseflow and contributing to a positive relationship between forest cover and baseflow. Temporally, non-forest land uses may be associated with pronounced soil modification, reducing infiltration and baseflow discharge, again resulting in a positive relationship between forest cover and baseflow. This study addresses the relationship between forest cover and baseflow in mesoscale sub-basins of the upper Little Tennessee River basin in Rabun County, Georgia and Macon County, North Carolina. Ten pairs of basins ranging from three to 33 km^2 were created by aligning key physical traits (e.g. basin size, aspect, and total relief), while allowing forest cover to differ within the pairs. Three series of synoptic measurements were conducted in July and August, 2005. In most pairs, greater baseflow per unit area was associated with higher forest cover, and an overall positive relationship was demonstrated between forest cover and baseflow among all twenty sub-basins. However, difference of means test results indicate a lack of statistical significance between baseflow of more forested vs. less forested stream basins. This study was conducted as a preliminary assessment for a larger study evaluating surface controls on baseflow in the southern Blue Ridge, and further research will evaluate the mechanisms driving the positive relationship between baseflow and forest cover in this region.

INTRODUCTION

Baseflow refers to streamflow sustained between precipitation and snowmelt events, contributed from subsurface storage reservoirs such as bedrock, saprolite, alluvium, or soil. Baseflow is influenced by natural factors such as climate, geology, relief, soils, and vegetation. Human impacts on the landscape may modify some or all of these factors, in turn affecting baseflow timing and quantity. A scientific understanding of watershed processes and baseflow is critical to effective water quantity policy and management. Population growth is associated with increasing demands on freshwater resources for industry, agriculture, and human consumption, and water shortages are not uncommon in the United States, even in humid regions. A firmer grasp on the controls of baseflow is pivotal in issues of contaminant dilution (Barnes and Kalita, 2001), stream ecology (Konrad and Booth, 2005), and adequate water supply to population centers (Hornbeck et al., 1993). Human waste allocation requires accurate estimation of baseflow discharge (Smakhtin, 2001), and contaminants that enter stream systems via soil or groundwater storage are most highly concentrated during baseflow. These factors carry negative implications for stream biota and human consumption if baseflows are reduced (Barnes and Kalita, 2001).

Despite the ever-increasing importance of understanding baseflow, the controls on baseflow remain poorly understood. Geology, topography, and land use separately have been demonstrated to exert strong influence on baseflow, but their relative influences and interaction remain unclear. There is inconsistency in the literature as to whether watershed forest cover increases or decreases baseflow discharge, and the issue of how these and other issues relate to watershed scale remains a major unresolved problem in the hydrologic sciences (Johnson, 1998; Smakhtin, 2001; Burns et al., 2005).

Objectives

This study was conducted to collect exploratory data as part of a larger project addressing geomorphic and anthropogenic controls on stream baseflow in the southern Appalachians. The primary objective was to compare baseflow discharge of streams whose basins represent end members of the range of forest cover observed in upper Little Tennessee River sub-basins.

STUDY AREA

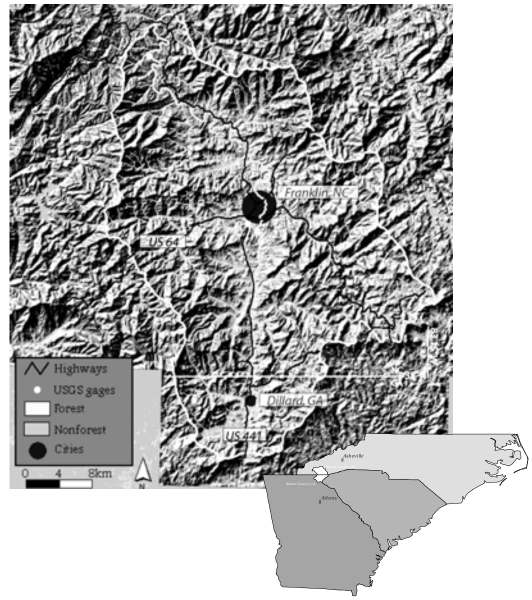
This research will be focused on the Little Tennessee River basin in Macon County, North Carolina and Rabun County, Georgia (Figure 1). This area provides an ideal setting for addressing linkages between surface characteristics and baseflow for several key reasons: 1) The mountainous relief in this area is associated with pronounced topographic variability, allowing comparison of diverse morphometric settings. 2) Substantial portions of the basin are protected in National Forests, resulting in a wide range of sub-basin land use characteristics from total forest to predominantly agricultural or low-to medium-density urban. 3) There exists an acute need for heightened understanding of stream response to human impact in this rapidly developing region, due to the presence of many threatened aquatic species (Sutherland et al., 2002). 4) The presence of the Coweeta Hydrologic Laboratory and Long Term Ecological Research Station (LTER) in the central portion of the study basin allows for a larger quantity and variety of related background data (climate, geology, soils, land cover, etc.) than are available for other locations in the southern Blue Ridge. 5) The region is underlain by crystalline bedrock, avoiding complicated hydrology associated with porous or soluble terrain.

The Little Tennessee River basin is located in the southernmost portion of the southern Blue Ridge physiographic province, which is characterized by crystalline bedrock and relatively high relief. The Little Tennessee basin is predominantly underlain by quartz dioritic and biotite gneiss (Robinson, 1992), and none of the bedrock types in this area significantly vary in hydrogeologic properties (Daniel and Payne, 1990). The minimally fractured bedrock is covered by a mantle of saprolite and colluvium 1-30 m thick (Southworth et al., 2003). Even the highest elevations in the southern Blue Ridge were unglaciated throughout the Pleistocene. Upland soils are primarily inceptisols (Yeakley et al., 1998). Soil infiltration capacity exceeds the most intense rainfall, leading to interflow dominance of hillslope hydrology (Helvey et al., 1972).

The 30 year average precipitation at the U.S. Forest Service Coweeta Experiment Station low elevation gage in the central portion of the basin is 183 cm; the wettest month is March (20 cm). 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).

In the absence of human land use, this region would be virtually 100% forest (Yarnell, 1998), with exceptions limited to bedrock outcrops and mountain peak balds. Evidence suggests the earliest human impact in the southern Blue Ridge occurred ca. 3000 years ago, during the Late Archaic period, characterized by minimal forest clearance in larger river valleys (Delcourt and Delcourt,

Figure 1. Upper Little Tennessee River basin



2004). The southern Blue Ridge has largely been spared the continuous, intense impacts of large-scale agriculture and urbanization observed on the adjacent Piedmont beginning in the 18th century. Between the late 1800s and early 1900s, the region experienced widespread timber harvest, prior to the onset of U.S. Forest Service and National Park Service protection (Yarnell, 1998). Classification of Landsat 7 data indicated that the Little Tennessee River basin was approximately 82% in 1998. Current human impact in unprotected portions of the basin mostly takes the form of agriculture and low- to medium-density urbanization in the broad valleys, although second home construction in the uplands is also an emerging development pressure in the region (Cho et al., 2003). No areas within the basin are characterized by high density urban development. Development forecasting models predict increasing building density and decreasing forest cover in coming decades (Wear and Bolstad, 1998).

METHODS

Inventory of upper Little Tennessee River tributaries yielded descriptions of 90 sub-basins. Nine pairs of stream basins were identified comprised of streams exhibiting similar size, aspect, maximum elevation, and total relief, in order to compare streamflow variability associated with differences in forest cover (Table 1). An tenth "control" pair exhibiting similar forest cover was included in the analysis.

Drainage area was calculated from U.S. Geological Survey (USGS) 7.5-minute digital topographic maps (DRGs). Forest cover of each basin was determined by from 2002 SPOT imagery (10 m pixel resolution). As-

Table 1. Stream attributes and mean area-normalized baseflow discharge

Stream	Area (km^2)	Forest (%)	max. elev. (m)	total relief (m)	ave Q/area
Jerry Cr.	3.39	48.5	975	331	0.025
Rickman Cr.	3.56	91.4	1129	470	0.050
Kelly Cr.	5.78	84.4	1245	599	0.035
Blacks Cr.	5.72	98.9	1173	491	0.037
Wallace Br.	5.8	78.5	1015	382	0.017
Keener Cr.	5.65	99.1	1102	431	0.045
Rocky Br.	7.79	70.9	1010	404	0.016
North Fork	8.08	93.6	1122	477	0.024
Mud Cr.	13.09	84.7	1431	775	0.061
Darnell Cr.	13.54	98.3	1402	744	0.049
Skeenah Cr.	15.86	77.3	1122	499	0.024
Coweeta Cr.	15.82	97	1550	870	0.043
Watauga Cr.	17.32	83	1239	625	0.018
Caler Fork	17.41	92.2	1355	741	0.014
Rabbit Cr.	22.87	68.8	1344	724	0.014
Tessentee Cr.	22.44	94	1447	769	0.040
Middle Cr.	29.12	81.8	1464	809	0.047
Tessentee Cr.	28.58	92.1	1447	802	0.041
Wayah Cr.	35.86	90.8	1631	965	0.027
Burningtown Cr.	32.06	91.9	1628	974	0.024

pect, maximum elevation and total relief were estimated from DRGs.

Baseflow discharge was sampled three times per stream during July and August 2005, with as many streams as possible sampled on individual days. No sampling period exceeded 1.5 days. Discharge was calculated as the product of channel cross-sectional velocity, which was measured using an electrmagnetic flow meter. Mean baseflow discharge values were normalized by basin area to allow cross-site comparison.

Statistical analyses included Spearman rank-sum correlation analyses comparing the individual relationships between mean baseflow discharge and forest cover, maximum elevation, and total relief. Pairwise difference of means tests were conducted comparing more forested vs. less forested basins (excluding the control pair).

RESULTS

A clear positive trend emerged between forest cover and baseflow discharge (Figure 2), but difference of means test results failed to indicate statistically significant differences ($p<0.05$) between mean area-normalized baseflow discharge of streams draining less- and more-forested basins (Parametric paired-sample test: $t=-1.87$, $p=0.099$, df=8; non-parametric Wilxocon signed ranks test: $Z=-1.48$, $p=.139$). Five of the ten pairs showed higher mean area-adjusted baseflow discharge associated with the more-forested basins, three of the ten pairs did not exhibit substantial differences, and only two pairs demonstrate higher baseflow in the less-forested pair member. Degree of difference in forest cover demonstrated a positive relationship with degree of difference in baseflow (Figure 3). Of the variables involved in this analysis, forest cover showed the strongest and only statistically significant correlation to mean area-normalized baseflow discharge (Table 2).

Table 2. Spearman correlation coeffients (r) with area-normalized baseflow *(n=20)*

Variable	r	p
area	-0.17	0.465
forest (%)	0.46	0.042
max elevation	0.31	0.186
total relief	0.26	0.263

Figure 2. Basin forest cover vs. mean baseflow discharge per unit area

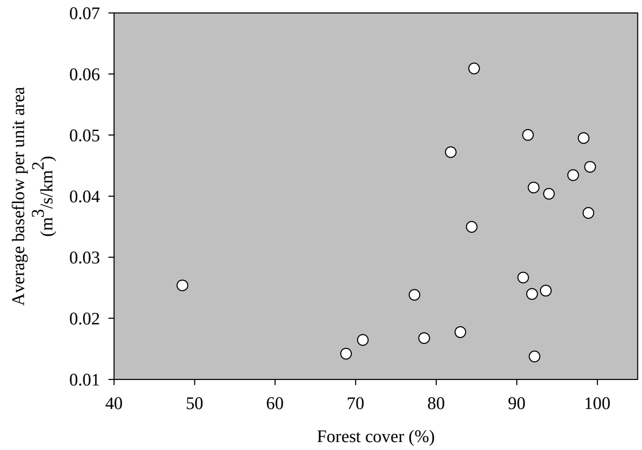
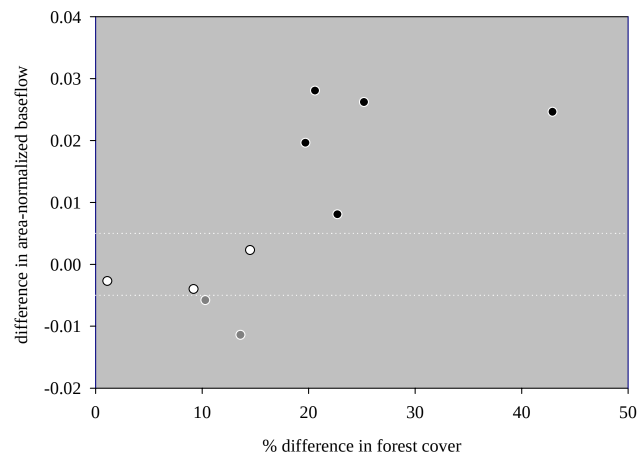


Figure 3. Within-pair difference in forest cover vs. difference in mean area-normalized baseflow



DISCUSSION AND CONCLUSIONS

The positive relationship observed between basin forest cover and baseflow discharge supports the hypothesis that forest cover is associated with greater infiltration and subsurface recharge, thereby increasing baseflow discharge. This relationship counters the idea that high evapotranspiration rates associated with forest cover override increases in infiltration and decrease baseflow. However, forest cover alone failed to sufficiently explain baseflow variability among these streams. While a positive trend was demonstrated, difference of means tests failed to indicate a statistically significant difference between the mean area-adjusted baseflow discharge values of less- and more-forested streams. The similarity in forest cover among these streams (most pairs differ by less than 30%) is likely at least partially responsible for the lack of significant difference.

Forest cover was most highly correlated with baseflow and demonstrated the only statistically significant relationship to baseflow among the variables that also included basin area, maximum elevation, and total relief. However, the correlation between maximum elevation and baseflow approaches statistical significance. This relationship suggests that increases in precipitation associated with higher elevations are apparent in baseflow values. The pairs that failed to demonstrate differences in baseflow or that demonstrated a negative relationship between forest cover and baseflow may be explained by basin morphometry. Further research will explore a more thorough suite of land use and topographic metrics and their relationships to stream baseflow.

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