SCALES AND ARRANGEMENTS OF LARGE WOOD IN STREAMS OF THE BLUE RIDGE MOUNTAINS

by

CARRIE KILLEEN JENSEN

(Under the Direction of David S. Leigh)

ABSTRACT

The project purpose is to examine large wood variability in streams of the Blue Ridge Mountains as a function of landscape characteristics at different spatial and temporal scales. Riparian forested area was analyzed latitudinally by buffer width and longitudinally upstream with additional land cover and geomorphic variables to identify factors and scales that most influence wood distributions. The 10 m riparian buffer of the reach is most important for predicting wood loads, although forest cover and development upstream also correlate with large wood. The relationship between riparian vegetation and wood weakens in bigger streams, as fluvial transport becomes more common and people are less likely to clear channels. An appropriate buffer width is not evident, but even one-tree buffers maintain some wood by discouraging wood removal. Resurveys demonstrate that large wood is most dynamic in forested reaches and primarily changes function in floods to store sediment and organic matter.

INDEX WORDS: Large wood, Riparian vegetation, Buffer width, Blue Ridge Mountains

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CARRIE KILLEEN JENSEN

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CARRIE KILLEEN JENSEN

Major Professor: David S. Leigh

Committee: C. Rhett Jackson
Thomas R. Jordan

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

Large wood—defined as greater than 0.1 m in diameter and 1 m in length (Keller and Swanson, 1979; Fetherston et al., 1995)—is a critical geomorphic agent in the lotic system that impacts channel morphology as well as stream biota. Large wood aids in pool creation (Montgomery et al., 1995; Wood-Smith and Buffington, 1996), can cause local channel widening (Keller and Swanson, 1979; Nakamura and Swanson, 1993; Leigh, 2010), stores sediment (Marston, 1982; Nakamura and Swanson, 1993) and organic matter (Bilby and Likens, 1980; Trotter, 1990; Webster et al., 1994), increases hydrologic connectivity with ground water (Lautz et al., 2006; Sawyer et al., 2011), and amplifies channel bed roughness to dissipate excess energy and slow the velocity of peak flows (Keller and Swanson, 1979; Trotter, 1990; Curran and Wohl, 2003). Flow deflection around wood pieces creates zones of sediment deposition and scour that enhance channel complexity and, thus, physical habitat heterogeneity necessary for fish and other aquatic organisms (Hilderbrand et al., 1998; Gerard and Reich, 2000; Roni et al., 2002). With the realization that adequate wood loads are essential for stream health, large wood has increasingly become a focus of stream restoration efforts (Roni et al., 2002). The scientific and stream management communities are currently striving to understand both the natural and human-caused variation in large wood distributions in order to ensure appropriate amounts for well-functioning streams.

Previous research demonstrates that wood loads vary with geomorphic variables such as channel size, pattern, and geometry (Piégay and Gurnell, 1997; Gurnell et al., 2002), yet are also largely a function of qualities of the riparian forest. The successional stage (Hedman et al., 1996; Diez et al., 2001; Keeton et al., 2007), species (Beechie et al., 2000), management (Beechie et al., 2000; Diez et al., 2001), and patterns of disturbance (Bragg, 2000; Nakamura et al., 2000) of the riparian community are all contributing factors to large wood production for streams. Aside from channelization and other direct modifications to streams, alteration of the riparian vegetation and catchment development are among the most deleterious and most common human impacts on the fluvial system.

Though numerous studies examine the relationship between land cover characteristics and wood distribution, comparatively few extend this investigation to different spatial and temporal scales of influence. A common assumption in large wood research is that local processes in the immediate vicinity of the reach are of primary concern, as fluvial transport of wood from upstream can be a relatively minor input for small streams (May and Gresswell, 2003). Several studies tabulate or model source distances of large wood from upslope in an effort to identify the riparian buffer width that provides the majority of wood to the channel (McDade et al., 1990; Van Sickle and Gregory, 1990; Reid and Hilton, 1998; Benda et al., 2002; May and Gresswell, 2003); this approach elucidates variation at the latitudinal scale of wood recruitment processes, but the limited scope does not include factors further upstream or in the watershed that can affect wood transport and retention (Gurnell et al., 2002). The longitudinal scale of landscape disturbances that propagate down the stream network are seldom considered at all, unless in the context of a major structure such as a dam (Angradi et al., 2004). Watershed-wide land cover is generally only addressed in studies of biotic integrity (Roth et al., 1996; Walsh et al., 2007; Walters et al., 2009), despite findings that the flow regime, channel morphology, water quality, and sediment load typical of streams in more urban or disturbed watersheds can greatly impact the fluvial transport and breakdown of large wood (Gurnell et al., 2002; Finkenbine et al., 2006). Finkenbine et al. (2006) observe that large wood decreases significantly with greater than 20% impervious area in the watershed. Temporal dynamics are also frequently excluded from analysis, although Hedman et al. (1996) and Wallace et al. (2001) indicate historical forests are the main source of current in-channel large wood in some cases. Given the scarcity of attempts to integrate the myriad of landscape controls on wood variability, both Swanson (2003) and Hassan et al. (2005) call for a more holistic perspective in the study of large wood that extends beyond the scope of the reach.

While further work is necessary to more fully address the large wood question, the existing literature remains significantly biased towards the Pacific Northwest due to concerns over the degradation of salmon habitat (Fetherston et al., 1995; Hassan et al., 2005). The Appalachian Mountains and southeastern United States generally are under-represented in this field with some exceptions (Golladay and Webster, 1988; Hedman et al., 1996; Wallace et al., 2001). Aside from the distinct climate and geology of the southeastern United States, this region was subject to European settlement more than a century earlier than the western part of the country. Extensive agriculture and logging in the area mean that, unlike the Pacific Northwest, few old-growth forests remain. It is important to include the Southeast in the large wood conversation, as conclusions from other study areas may not hold true for this region.

The research presented here uses multiple spatial and temporal scales of landscape analysis to contribute to the understanding of large wood variability in streams of the Blue Ridge Mountains. This objective was accomplished by examining land cover through time—both latitudinally across and longitudinally along the riparian buffer as well as throughout the watershed—in conjunction with additional geomorphic and human-attributed variables. The findings provide insight into the processes that determine wood loads in the Blue Ridge Mountains and can inform the appropriate scale of stream management for large wood.

1. Study Area

The Upper Little Tennessee River basin encompasses 1,130 km^2 of the Southern Blue Ridge Mountains in Macon County, North Carolina (Figure 1). The Blue Ridge Mountains form the eastern edge of the Appalachian Mountains that extend from northern Georgia to Pennsylvania. Characteristic bedrock of the Southern Blue Ridge is primarily metamorphic (gneiss) and of the late Proterozoic to early Paleozoic age (Robinson et al., 1992). Denudation and chemical weathering of the bedrock have resulted in steep slopes, thick saprolite deposits, and acidic, nutrient-poor soils (Pittillo et al., 1998). Elevation in the basin ranges from 530 to 1,660 m above sea level. The mean annual temperature at the low-elevation Coweeta Hydrologic Laboratory climate station in the southern part of the study area is 12.72 ºC, with a mean January temperature of 3.13 ºC and a mean July temperature of 21.91 ºC (SERCC, 12/01/1942 through 04/30/2012). The average annual precipitation at Coweeta is 178.6 cm, with most rainfall occurring in the winter and early spring (SERCC, 12/01/1942 through 04/30/2012). Total annual precipitation tends to be greatest at high elevations and at more southerly latitudes (Price and Jackson, 2007).

Much of the Upper Little Tennessee Basin is forested, with large tracts of land belonging to the Nantahala National Forest. Valley bottoms generally consist of agricultural and residential land uses, although regional growth in recent decades has extended residential development to mountain-sides in some cases (Kirk et al., 2012). Franklin, North Carolina is the only urban center in the area (Figure 1). Vegetation includes mostly successional forests following timber

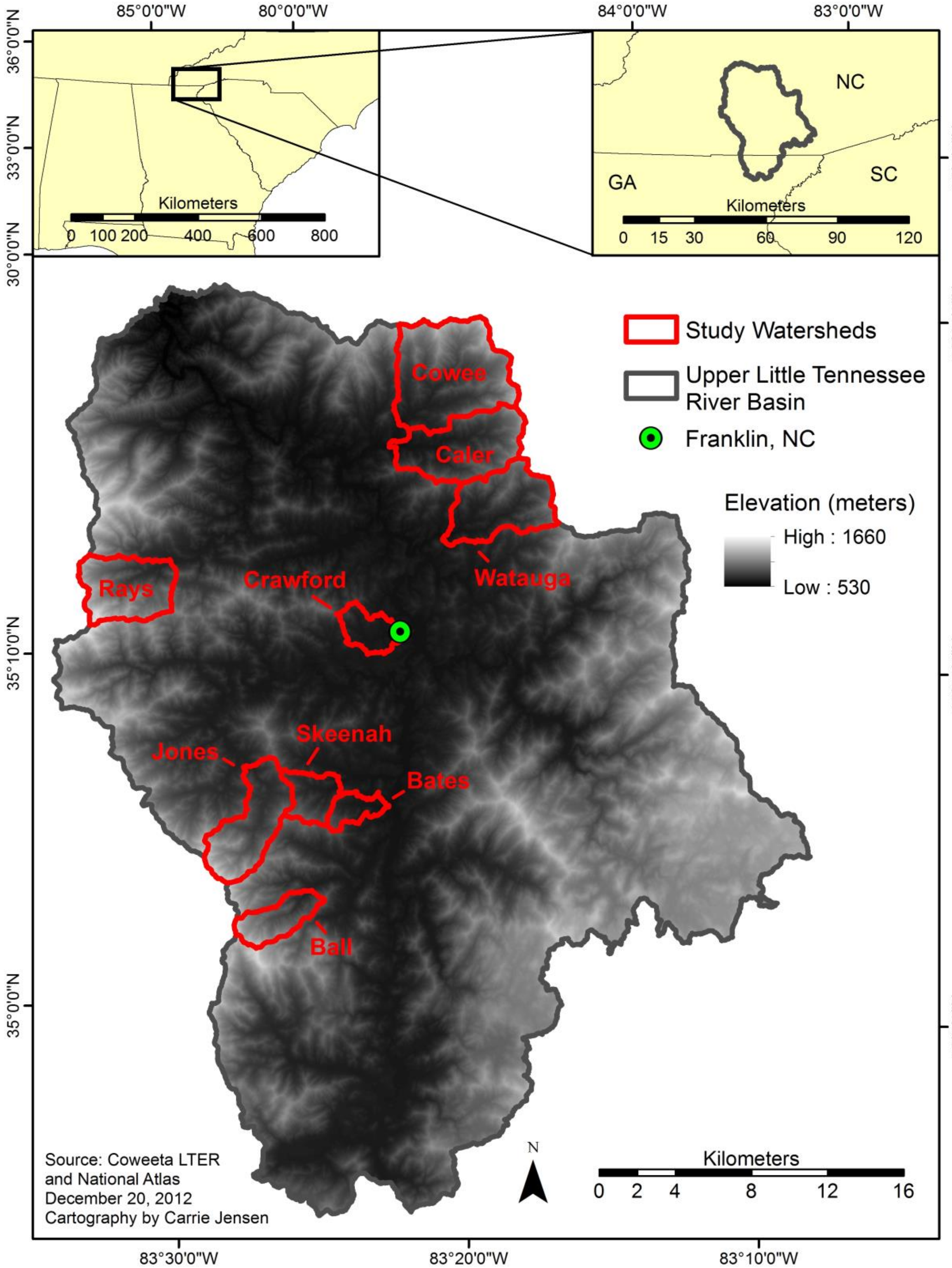


Figure 1 – Study area – Upper Little Tennessee River basin.

harvest and other disturbances such as the chestnut blight in the last century. Oak association forests are common below 1,500 meters elevation, with pine stands on xeric ridges (Pittillo et al., 1998). Rhododendron (*Rhododendron maximum*) is prevalent throughout the southern Appalachians and prevents establishment of shade-intolerant trees in the riparian zone (Vandermast and Van Lear, 2002). The shade-tolerant eastern hemlock (*Tsuga canadensis*) is able to grow alongside rhododendron and is common around streams (Vandermast and Van Lear, 2002). However, the hemlock woolly adelgid (HWA) is currently extirpating eastern hemlock populations and severely alters riparian vegetation communities (ref. see Coweeta online catalog).

This project examines fifty stream reaches in the Upper Little Tennessee catchment that were identified during previous research efforts associated with the Coweeta Long-Term Ecological Research (LTER) project. Intensive channel information was gathered by members of the Coweeta LTER on five to seven stream reaches within each of nine watersheds in order to characterize regional trends. The watersheds range in size from 5.3 to 29.1 km^2 and were chosen to correspond to one of four categories of development: forested, mostly forested with valley development, mostly forested with mountain-side development, and urban (Table 1). The reaches were selected to provide a representative sample of streams in terms of drainage area, channel size, and riparian vegetation. The decision to use the existing Coweeta LTER reaches allows access to the wealth of data already available on the streams in question, but also permits the contribution of new variables and measurements from this project to the dataset for future research.

Table 1 – Study watersheds.

Watershed	Total Area (km^2)	Level of Watershed Development*
Ball	7.16	F
Rays	14.69	F
Cowee	29.14	FV
Jones	15.58	FV
Skeenah	6.03	FV
Bates	3.68	FM
Caler	18.73	FM
Watauga	16.74	FM
Crawford	5.30	U

* F—mostly forested, FV—mostly forested with valley development, FM—mostly forested with mountain-side development, U—urban

CHAPTER 2

METHODS

1. Spatial Analysis Methods

1.1 *Riparian Buffer Delineation*

All spatial analysis was completed in ArcMap 10™. The stream network of the Upper Little Tennessee River Basin was represented by the National Hydrography Dataset (NHD) from the U.S. Geological Survey. Comparison of several surface water datasets showed the NHD most closely matches the stream network as evident in aerial imagery, often with exceptional accuracy of channel locations. The NHD does not include all first and second-order streams, but even the smallest headwater reaches in the study have flow lines that extend nearly 1 km upstream. For this reason, the resolution of the NHD should not be a limitation in the project. The georeferenced (UTM, 1983) locations of the upstream and downstream ends of each study reach were represented as points on the NHD flow line.

Polylines were traced over the flow lines to correspond to various longitudinal scales along the stream network: the study reach; 100, 500, and 1,000 m upstream of the study reach; and the entire watershed that drains to the downstream outlet point of the reach. Upstream lengths were measured starting from the upstream endpoint of the study reach and included all contributing tributaries. Any tributaries that enter the reach between the endpoints were considered upstream lengths, measured from the point of intersection with the reach. Watersheds were delineated from a flow accumulation model generated from a 10 m U.S. Geological Survey

Digital Elevation Model (DEM). The NHD was intersected with the watersheds to find the streams draining into each reach.

Buffers of three widths were created around the various study reaches, upstream length, and watershed stream features to examine the latitudinal scale of riparian land cover (Figures 2 and 3). A round buffer end was chosen to account for treefall into a reach from all possible directions. The narrowest buffer had a width of 3 m on each side of the stream to represent the "one-tree buffer," or strip of trees, that line some channels. It is critical to understand the function of this thin buffer for wood recruitment and retention, as isolated trees not only contribute wood, but also greatly influence local channel width and morphology (Davies-Colley, 1997; Jackson et al. submitted). The second buffer width is 10 m to estimate the height of small trees that can fall and reach the channel. McDade et al. (1990) found that 83% of hardwood and 53% of conifer pieces originate from within 10 m of the stream. The widest buffer had a width of 30 m to approach the height of the tallest trees in the region. An estimated 70-90% of riparian wood recruitment comes from within 30 m of the channel (Fetherston et al., 1995), and 30 m riparian buffers are a common metric in stream research (Roth et al., 1996; Diez et al., 2001; Kang and Marston, 2006).

1.2 *Land Cover Classification*

Forested and non-forested areas in the riparian buffers were digitized from aerial photographs over three time periods to incorporate the temporal dynamics of wood distributions. Classification keys for forest cover in each set of photographs are in Appendix A. The forested category includes tree cover of any species and maturity, provided the trees are old enough to form a recognizable crown in the photographs (Figures A1-A3 A). The non-forested category

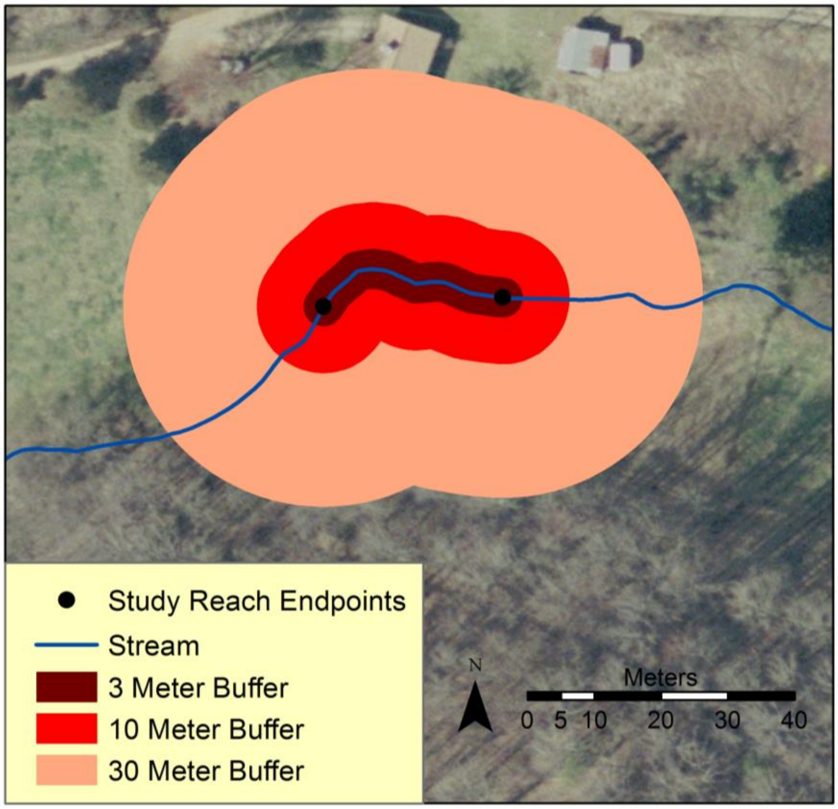


Figure 2 – Riparian buffer delineation 3, 10, and 30 meters wide around the stream network.

consists of all remaining land cover—bare ground, urban surfaces, grass, shrubs, agriculture, reservoirs, and small woody vegetation such as bushes (Figures A1-A3 B and C).

The current landscape was represented by true color, 30 cm pixel resolution aerial photographs from 2007, provided by Macon County (Figure A1). A 1984 set of historical photographs includes 1:58,000 scale, color-infrared images from the National High Altitude Photography (NHAP) Program (Figure A2). The photographs were downloaded from the U.S. Geological Survey and imported into ArcMap 10™ for georeferencing. There were some registration issues following georeferencing in which overlapping features in adjacent photographs do not line up, likely due to large distortions at the edges. When faced with the

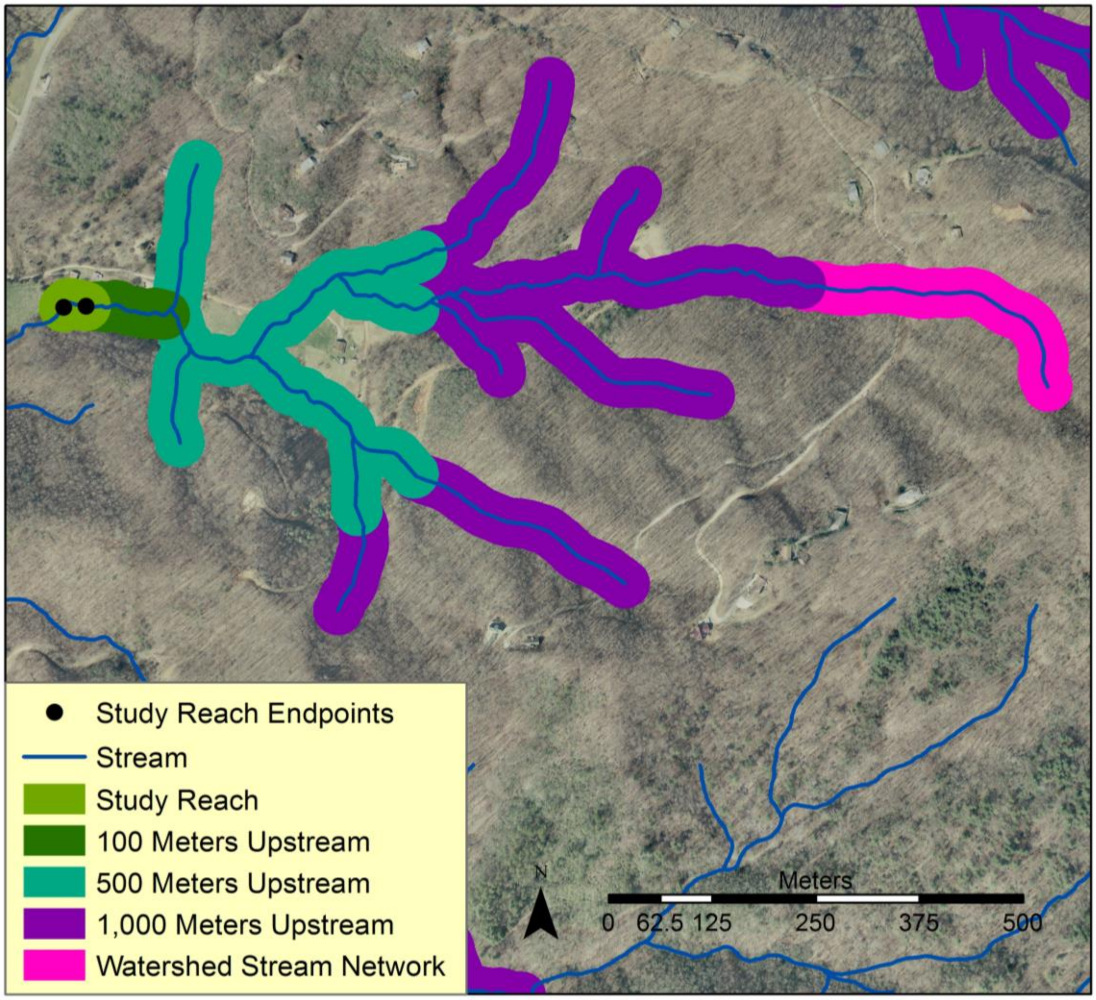


Figure 3 – Stream length delineation of the 30 m riparian buffer around the reach; 100, 500, and 1,000 meters upstream of the reach; and along the stream network of the entire watershed.

decision of which photograph to use for an overlapping area, digitizing followed the photograph that included all or most of the particular watershed to minimize inconsistencies within watersheds. The earliest set of historical imagery contains panchromatic aerial photographs from 1954 that were collected by the USDA at a scale of 1:20,000, and these were obtained from the Coweeta LTER as a georeferenced mosaic (Figure A3). There are two small areas of missing data in the 1954 photographs: a patch is obscured by tape in the Wayah Bald quadrangle, corresponding to the northeast corner of the Rays watershed, and distortion of the photograph prints hides the northeastern tip of the Greens Creek quadrangle in the Cowee watershed. In both cases, the area affected is small and occurs in heavily forested and fairly undeveloped regions. It is doubtful that any major land cover changes are included in the missing data.

Supervised and unsupervised classification were attempted on the three sets of aerial photographs in ERDAS Imagine™ but were unsuccessful at separating forested and non-forested area in especially the 1984 and 1954 photographs. Historical aerial photographs do not have the spectral bands available with satellite images for an accurate automated classification. While such classification may be practical for studies that use recent, high resolution imagery, manual digitizing was the best way to ensure consistency between the dates involved in this project. Polygons were digitized around forested and non-forested areas inside the 30 m buffer of the entirety of each watershed for the three time periods, as this extent includes all riparian buffer lengths and widths. Care was taken to completely fill the buffer and avoid polygon overlap. The digitizing was thoroughly checked for errors, and areal measurements of the three sets of polygons were within 0.0001 km^2 of each other after corrections were made.

The National Land Cover Database (NLCD) was chosen to represent watershed land cover because of data availability for the entire United States every four to six years from the Multi-Resolution Land Characteristics Consortium of the U.S. Geological Survey. The Database is generated from unsupervised classification of Landsat Enhanced Thematic Mapper Plus satellite images and consists of a 16-class land cover classification at 30 m spatial resolution. The NLCD of 2006 was used for the current landscape to correspond to the 2007 aerial photographs. The NLCD of 1986 was selected for the period to coincide with the 1984 photographs. Because the NLCD is created from satellite imagery, the Database does not extend into the 1950s.

Although watershed land cover can be determined from aerial photographs, the different types of imagery and classification methods introduce uncertainty when comparing across dates, so analysis was limited to the NLCD of 2006 and 1986.

1.3 *Identification of Stream Network Obstructions*

Obstructions in the stream network of the study watersheds that could potentially prevent wood movement downstream were visually identified in each set of photographs. Obstruction identification keys for each time period are in Appendix B. Culverts and bridges corresponding to roads were separated from reservoirs, pipelines, and other obstructions due to the large number of road crossings. Roads are pervasive in even the most forested watersheds, whereas other obstructions are less common and concentrate in urban, residential, and agricultural areas. It was reasoned that the two groups of obstructions may affect wood transport differently, as a dam, for example, is a more complete obstruction than a culvert.

Identification of locations where roads cross the NHD stream network was aided by several datasets. A dataset of street centerlines from Macon County shows most of the paved roads evident in the 2007 aerial photographs (Figure B1 A and B). Much of the study area is heavily forested and contains gravel and dirt roads maintained by the U.S. Forest Service as well as old logging roads. The "Eastern U.S.A. Transportation" shapefile from the FSGeodata Clearinghouse of the U.S. Forest Service includes most of the unpaved roads excluded from the street centerlines dataset. Careful visual inspection was still necessary, as driveways and informal roads in agricultural fields often have culverts at stream crossings, yet do not appear in roads datasets. Roads built after the creation of the dataset also required visual confirmation.

Finding roads in the historical aerial photographs was more difficult due to the lower resolution of the images and the lack of data to verify road locations (Figures B2 and B3 A). Datasets of roads for the Coweeta, Skeenah, Jones and Watauga watersheds in 1984 and for the Coweeta, Skeenah, and Jones watersheds in 1954 were created by Ryan Kirk (Kirk, 2009) and available from the Coweeta LTER. These datasets were used in conjunction with the more recent roads shapefiles to locate road crossings. The photographs were also thoroughly searched for roads not included in the datasets.

Other obstructions primarily consist of reservoirs and underground pipelines. In the 2007 photographs, most of these structures were denoted in the NHD as either an Artificial Path, in the case of a reservoir (Figure B1 A), or a Connector, in the case of a pipeline (Figure B1 B). The NHD designations also correspond well to obstructions in the 1984 photographs (Figure B2 B and C). However, the Dataset was less useful for the 1954 photographs, as the region had not yet undergone significant infrastructure development. The few reservoirs that do appear in 1954 were found by visual inspection and do not correspond to the NHD (Figure B3 B). The 2007 and 1984 photographs were also searched extensively for reservoirs and pipelines in addition to those indicated by the NHD. While several reservoirs were discovered, the visual search likely passed over some underground pipelines, especially in the earlier photographs.

1.4 *Quantification of Direct Human Influence*

Direct removal of large wood from the channel has been documented both in the study area (Sakura Evans, personal correspondence, January 23, 2013) as well as in other locations (Diez et al., 2001). While much more extensive research is necessary to understand the effects of wood removal on the stream system, for the purposes of this project, direct human manipulation of large wood was estimated with 2009 tax parcel data from Macon County. Parcels were divided into several types: agriculture, residential (in this case also including four medium density residential and two neighborhood mixed use polygons), commercial (also including one central commercial polygon), exempt (usually churches and government buildings), and none (primarily forested areas). The transportation network has no parcel type assigned. Although using parcels as an estimate of human influence is somewhat coarse, this variable does take into account not only the presence of people, but also the type of activities that occur on the land. Parcels within the 10 m riparian buffer were examined for all buffer lengths, as it was reasoned that visibility and accessibility of the stream were key in the decision to remove wood or not.

1.5 *Determination of Valley Side Slope Steepness*

Valley side slope steepness can greatly impact the amount and source-distance of wood that enters channels (McDade et al., 1989; Sobota et al., 2006). Side slope steepness in degrees was determined from a 6.67 m DEM derived from the North Carolina Department of Transportation LIDAR survey. Slope values in each of the riparian buffer lengths were analyzed to incorporate the same longitudinal element as the rest of the project, but analysis was limited to the 30 m width, as it was not deemed that, given the DEM resolution, partitioning slope steepness by 3 or 10 m widths would be meaningful or informative.

2. Statistical Analysis

Forested and non-forested areas were calculated for all combinations of riparian buffer lengths and widths. Areas were also determined for the NLCD land cover of each watershed and tax parcel types within the 10 m buffers. All areas were converted into percentages to account for reaches and watersheds of different sizes. The number of roads and other obstructions was tabulated at 100 m, 500 m, and 1,000 upstream of surveyed reaches and within the entire watershed, and the distance was found between the upstream end of the reach and the closest obstruction. Standard statistics were computed for the slope steepness values of pixels within the 10 m buffer width for all stream lengths, including the mean, standard deviation, coefficient of variation, skewness, kurtosis, and the 5^{th}, 25^{th}, 50^{th}, 75^{th}, 95^{th}, and $5^{th}/95^{th}$ percentiles. All data were exported into Microsoft Excel™ along with relevant channel morphology and drainage basin variables obtained from the Coweeta LTER to be explanatory variables for statistical analysis (Table 2). Data are logged in Appendix C.

The large wood measurements used as response variables are from earlier Coweeta LTER field work in 2010, in which all wood pieces greater than 0.1 m in diameter and 1 m in length were counted and measured. There are a multitude of ways to describe the amount of wood in a stream, including volume (Robison and Beschta, 1990; Beechie and Sibley, 1997), mass (Hedman et al., 1996), and surface area (Wallace et al., 2001), as well as different expressions of the linear frequency of wood pieces (Bilby and Ward, 1989; Robison and Beschta, 1990; Martin, 2001; Jackson and Sturm, 2002) and jams (Montgomery et al., 2003). Given the many methods for quantifying wood loads and distributions, response variables consisted of the number of pieces, average diameter, average length, and total volume per m channel length, m^2 channel area, and channel length in units of channel width ($L_{SR/30}$ in Table 3). Reach lengths were selected to equal 30 times the bankfull channel width, so the latter denominator of $length_{SR/30}$ was found by dividing the wood measurements by 30 to scale the variables by channel size. The large wood data are in Appendix D.

Table 2 – Parameters evaluated as explanatory variables.

Parameter	Units of Measurement	Description of Explanatory Variables
Riparian Forest Cover	Percent (%)	Forested area in the 3, 10, and 30 m buffers around the reach; 100, 500, and 1,000 m upstream; and along the stream network of the entire watershed
Land Cover	Percent (%)	NLCD land cover of the entire watershed area
Road Obstructions	Meters (m)	Distance to the nearest upstream road obstruction
	Number	Road obstructions 100, 500, and 1,000 m upstream and along the stream network of the entire watershed
Other Obstructions	Meters (m)	Distance to the nearest upstream other obstruction
	Number	Other obstructions 100, 500, and 1,000 m upstream and along the stream network of the entire watershed
Slope Steepness	Degree (º)	Standard statistics of slope in the 30 m buffer of the reach; 100, 500, and 1,000 m upstream; and along the stream network of the entire watershed
Tax Parcel	Percent (%)	Parcel types in the 10 m buffer of the reach; 100, 500, and 1,000 m upstream; and along the stream network of the entire watershed
Channel and Basin Geomorphology	Various	Position in the stream network, watershed characteristics, channel dimensions, floodplain width, sediment size

Variables were checked for normal distributions by viewing the histogram and using the Shapiro-Wilk W and Kolmogorov D tests for normality and log normality, respectively, in JMP Pro 10™. Non-normal variables were transformed when possible. Some of the remaining variables that did not respond to transformations contained many zero values so were converted into binary presence/absence data, as was the case of the tax parcel and several of the upstream

Table 3 – Response variables for statistical modeling. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30}$.

Response Variables	
Abbreviation	Description
P/m	Pieces/m Channel Length
D/m	Average Diameter (m)/m Channel Length
L/m	Average Length (m)/m Channel Length
V/m	Total Volume (m^3)/m Channel Length
P/m²	Pieces/m² Channel Area
D/m²	Average Diameter (m)/m² Channel Area
L/m²	Average Length (m)/m² Channel Area
V/m²	Total Volume (m^3)/m² Channel Area
$P/L_{SR/30}$	$Pieces/Length_{SR/30}$
$D/L_{SR/30}$	Average Diameter (m)/$Length_{SR/30}$
$L/L_{SR/30}$	Average Length (m)/$Length_{SR/30}$
$V/L_{SR/30}$	Total Volume (m^3)/$Length_{SR/30}$

obstruction variables. Riparian forest cover and watershed land cover were converted into categorical variables due to the high forested area of most watersheds. Based on the distribution of data, riparian forest cover was classified as low for less than 50% forested area, moderate for 50% to 90%, and high for greater than 90%. Watershed land cover classes were grouped into three categories due to low percentage values at many sites: forested, consisting of Deciduous, Evergreen, and Mixed Forest, as well as Woody Wetlands; developed, including Developed Open Space, Developed Low, Middle and High Intensity, and Barren Land; and non-forested but undeveloped, including Cultivated Crops, Pasture and Hay, Grassland and Herbaceous, Shrub and Scrub, and Open Water. Watershed forest cover was categorized as low at less than 85% forest cover, moderate at 85% to 95%, and high for greater than 95%. Development was classified as low for less than 1% developed area, moderate at 1% to 5%, and high for greater than 5%. Non-forested and un-developed area was considered low at less than 3%, moderate from 3% to 10%, and high at greater than 10%. All divisions were based on data distributions.

Examination of Pearson and Spearman rank scatterplot matrices and correlation values of the variables in JMP 10™ informed the elimination of redundant explanatory variables that were highly correlated with an r or ρ value greater than 0.7 as well as those showing non-significant ($p < 0.05$) correlations with the large wood measurements. A general linear model was created with the program R™ for each response variable from the remaining set of explanatory variables using forward selection and backward elimination procedures. Models were selected based on the lowest Bayesian Information Criterion (BIC) score with all explanatory variables significant with a p-value < 0.05. The resultant models were tested for multi-collinearity using the variance inflation factor (VIF), and model residuals were checked to ensure a normal distribution.

3. Field Methods

Repeat surveys of large wood in a subset of the study reaches can demonstrate the transience of wood loads in the region, as the total amount of wood at the coarse scale of the watershed may remain stable through time, but local disturbances (Montgomery, 1999; Bragg, 2000; Nakamura et al., 2000) cause variation at the scale of the reach. Following the methodology of the original data collection, all wood pieces in the bankfull channel greater than 1 m in length and 0.1 m in diameter were counted, the diameter and length of each piece were measured to the nearest 0.01 m, and the volume of wood was calculated, assuming the wood to be cylindrical in shape (Appendix E). The midpoint distance between the downstream end of the reach and the middle of each piece was measured with surveyor's tape, and it was noted if the wood was part of a jam or not. The function of wood was recorded as providing bank protection, sediment retention, organic matter retention, pool formation, a combination of more than one, or no function. Repeat surveys were done in thirteen of the fifty total study reaches (Table 4). One reach was included from each of the nine large watersheds (Fig. 1). Four more reaches were chosen to provide additional representation of the four categories of watershed development (Table 1). Reaches were otherwise selected to form a random sample stratified to ensure proportionate representation of channel size and riparian land cover (Table 4).

Table 4 – Field resurvey reaches. Divisions mark levels of watershed development.

Reach	Stream Length Surveyed (m)*	Riparian Cover
Ball 2	135	Forested
Rays 1	150	Forested
Rays 5	120	Forested
Cowee 2	120	Forested
Jones 6	30	Non-forested
Jones 7	165	One-tree Buffer
Skeenah 1	120	One-tree Buffer
Bates 3	30	Non-forested
Caler 5	45	Forested
Watauga 3	60	Non-forested
Watauga 6	90	Forested
Crawford 2	75	One-tree Buffer
Crawford 5	45	Forested

* The stream length surveyed equals 30 times the bankfull width (m).

Resurveys were completed on September 28 and 29, 2012 and again on January 19 and 20, 2013. The first repeat survey in late September was done to coincide with the supposed annual streamflow minimum around October 1, which marks the beginning of the new water year. The goal of the second survey was to determine the extent that wood loads change following floods with the potential to fluvially transport wood into or out of a reach and recruit wood into the stream by treefall or debris flows. Following a dry autumn, the final round of measurements was taken in January after three major storm flow events in the preceding weeks, as judged by discharge at the stream gauges on Cartoogechaye Creek near Franklin, North Carolina (USGS 03500240) and the Little Tennessee River near Prentiss, North Carolina (USGS 03500000). The events occurred on December 20 and 26, 2012 and January 16, 2013. Discharge peaked at 3,630 ft^3/s (102.79 m^3/s) at the Prentiss gauge and 2,200 ft^3/s (62.30 m^3/s) at the Cartoogechaye on January 16, 2013, corresponding to a recurrence interval of nearly 3 years and resulting in overbank flow as evidenced by sediment deposition on the floodplain.

CHAPTER 3

RESULTS

1. Landscape Change Through Time

Forest cover of the riparian buffer is not very different amongst the 3, 10, and 30 m widths, but is generally lowest at 30 m and highest at 3 m (Tables C1-C6). However, forested area tends to vary significantly more at the scale of the study reach. Such is the case of the Jones 7 reach, with 90% of the buffer forested at 3 m in 2007 but only 22% at 30 m (Figure 4).

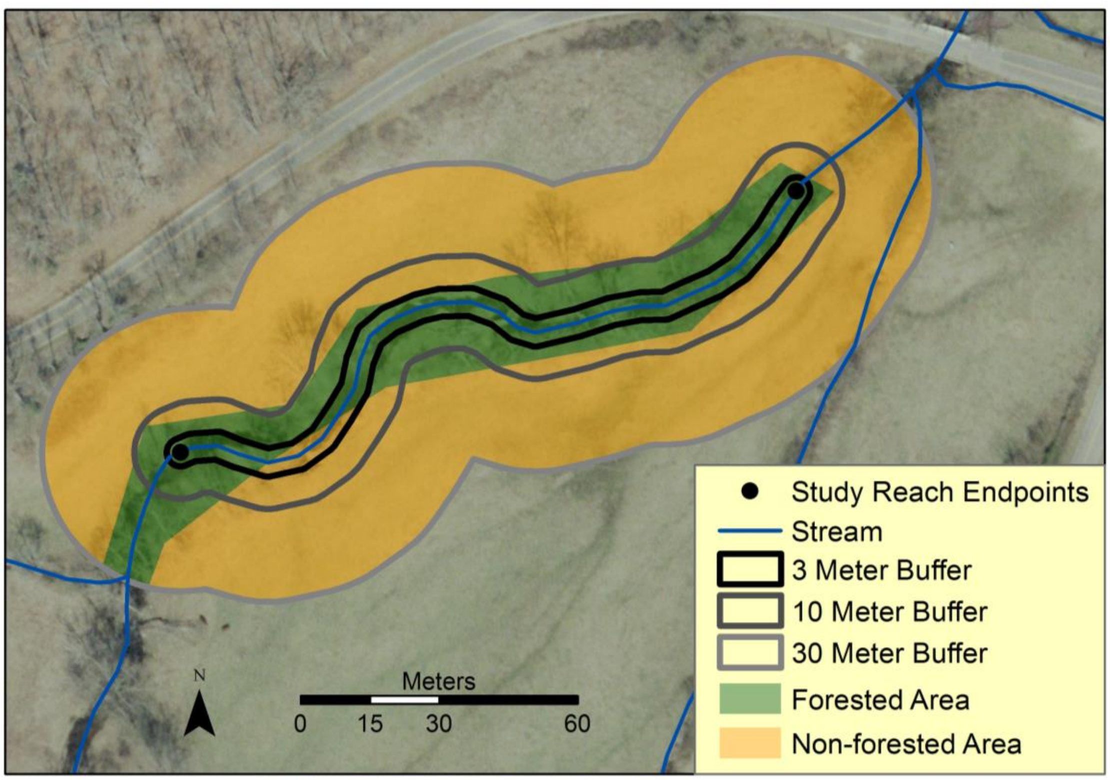


Figure 4 – Forest cover of 3, 10, and 30 meter riparian buffer widths around the Jones 7 reach in 2007.

Crawford—the only watershed considered urban (Table 1)—has the lowest overall forest cover for all three dates and buffer widths, ranging from 45 to 55% forested (Table C6). The two forested watersheds, Ball and Rays, consistently have the highest forest cover of at least 95%.

The riparian buffer of the study area as a whole has become more forested over the last several decades, increasing from 80.88% of the 30 m buffer in 1954 to 84.12% in 2007 (Table C6). This change is most marked closer to the stream, as the 3 m buffer shows the largest growth in forested area over time (Table C7). Ball and Rays maintained or slightly lost forest over the three dates, given that these watersheds were already at nearly maximum forest cover. There was considerable afforestation of the riparian buffer in several of the more developed watersheds between 1954 and 2007, possibly corresponding to agricultural abandonment near streams. Increases in forest cover are generally greatest from 1954 to 1984, although Watauga exhibits more growth in forested area between 1984 and 2007, perhaps owing to later abandonment of croplands and pasture than the rest of the study area. Figure 5 demonstrates the shift in landscape through time at the Jones 2 and Jones 3 study reaches. The 30 m riparian buffer intersected agricultural fields in 1954 and was 68% forested; afforestation near the stream made the buffer 86% forested in 1984 and 100% forested in 2007, as land use changed away from agriculture.

The NLCD indicates that watershed land cover in both 1986 and 2006 predominantly consists of deciduous forest, although developed land comprises a considerable portion of some subwatersheds in Crawford and, to a lesser extent, Watauga (Tables C8-C11). Comparison of the two dates shows an overall increase in developed and barren land, a notable decrease in pasture and hay, more shrub and grasslands, and a drop in deciduous forest together with a rise in evergreen and mixed forest (Table C12). Figure 6 illustrates several of these land cover changes near the Watauga watershed outlet; development both expands and intensifies, pastures and

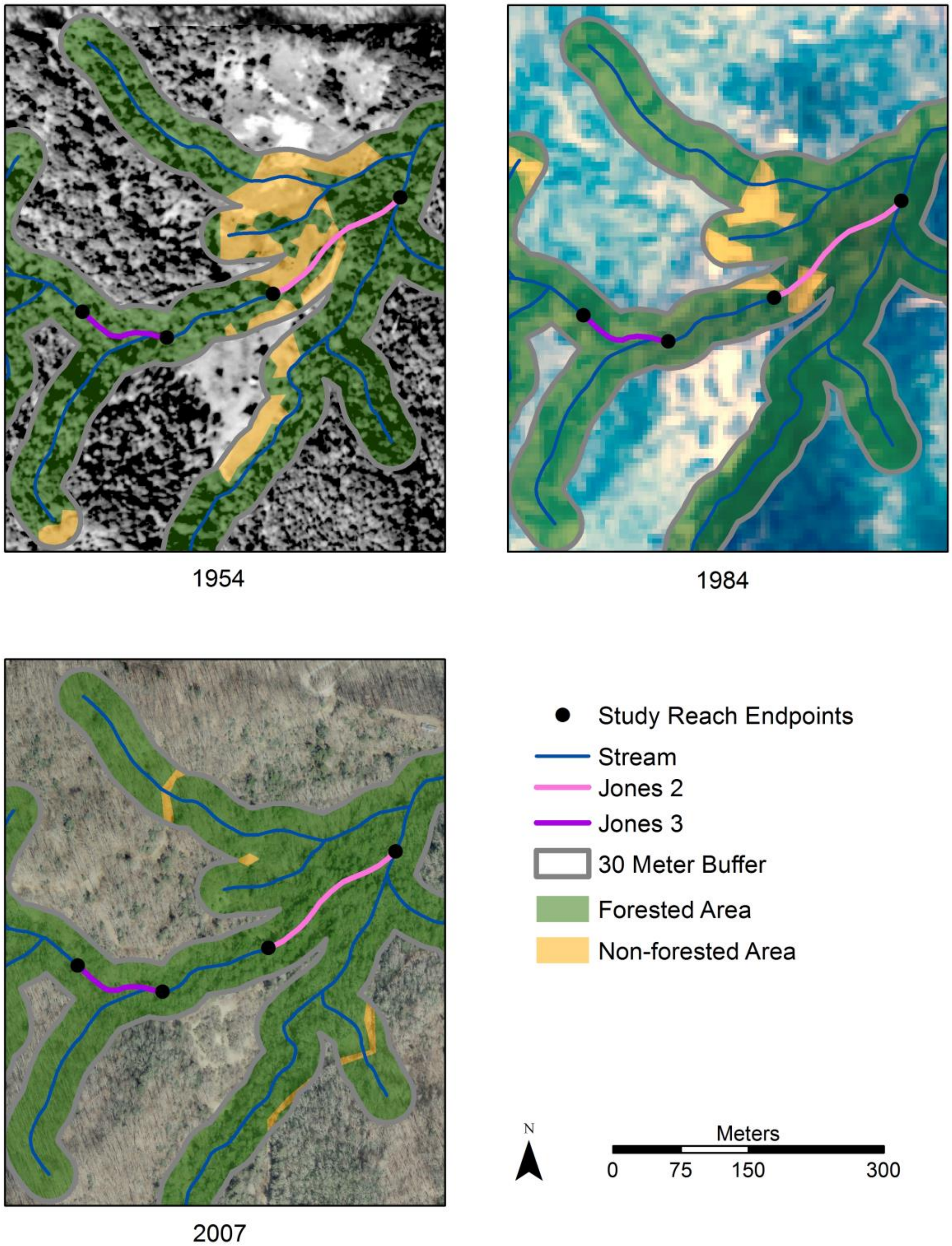


Figure 5 – Change in riparian forest cover at the Jones 2 and Jones 3 reaches from 1954 through 2007.

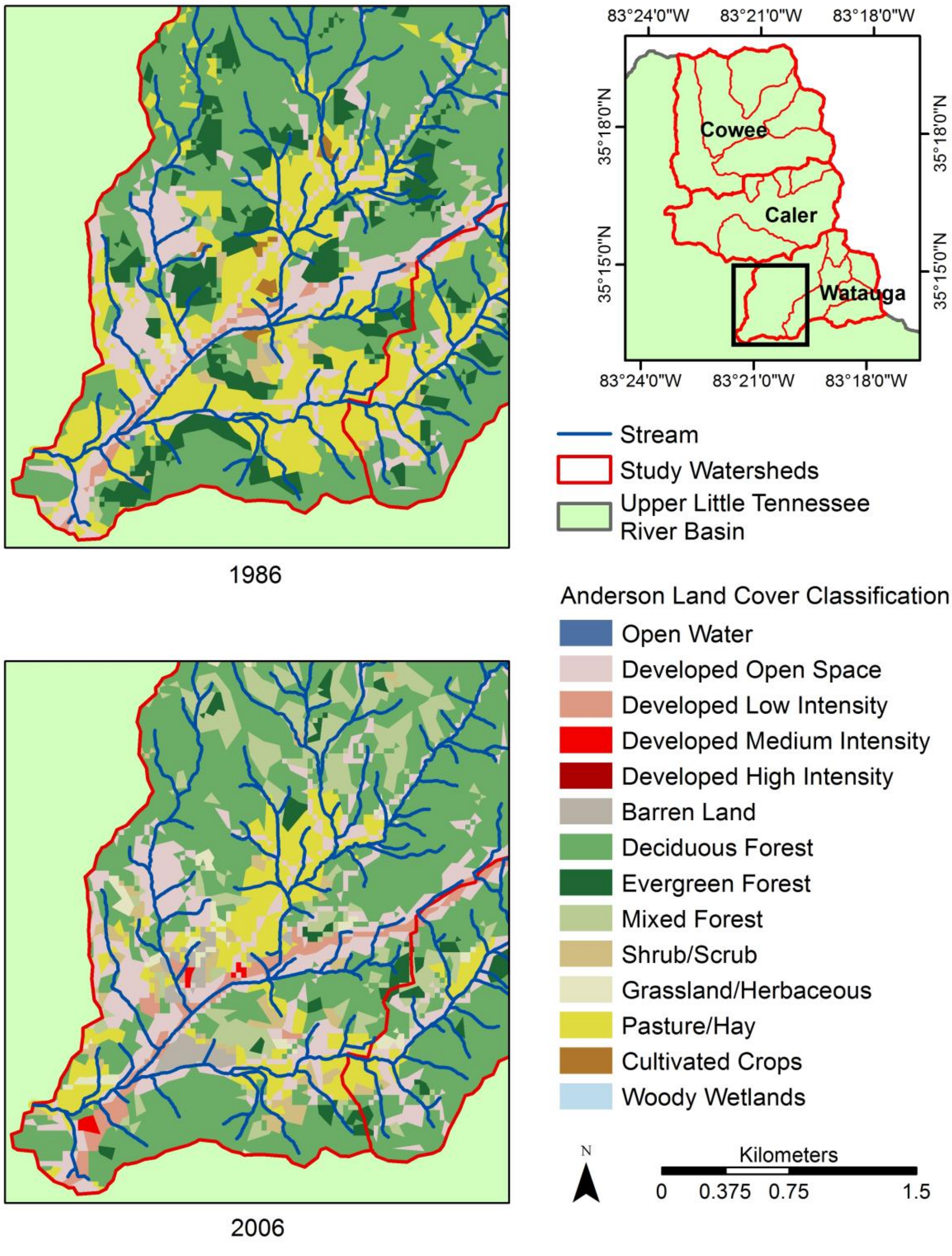


Figure 6 – NLCD land cover in the lower portion of the Watauga watershed in 1986 and 2006.

croplands shrink, new shrub and barren lands appear, and the landscape is more fragmented. Nevertheless, total forested area—calculated by combining deciduous, evergreen, and mixed forest—grew slightly in the study area from 1986 to 2006 (Table C13).

There is generally good agreement between the results of the manual digitizing and the NLCD classification, with 87% of the 30 m buffers, corresponding to the 2007 photographs and 2006 NLCD, matching (Table C14). Most of the discrepancies are where areas were digitized as forested but classified as non-forested, accounting for 8% of inconsistencies between the two methods. This occurrence may be the result of residential and other developed areas with some tree cover being entirely classified as non-forested in the NLCD due to the spatial resolution. More developed watersheds appear to be more prone to this type of misclassification, which accounts for 25% of the buffer area in Crawford (Figure 7 A). Areas digitized as non-forested and classified as forested are less common, but tend to be in heavily forested areas with small pockets of development or roads, as is the case with the Ball headwaters (Figure 7 B). For the purposes of this project, the NLCD could be used instead of digitizing in heavily forested watersheds such as Ball or Rays, as more than 95% of the area coincides between the methods (Table C14). Correspondence between digitizing and NLCD goes down with increasing landscape heterogeneity and is lowest for Crawford at 69%.

Both road crossings and other stream obstructions increased over time, with the average distance from the reach to the nearest obstruction decreasing from 218.5 m in 1954 to 160 m in 2007, the average number of upstream obstructions growing from 39 to 68, and the total number of obstructions in the study area nearly doubling (Tables C15-C18). Figure 8 demonstrates the proliferation of obstructions in a formerly undeveloped tributary of Crawford. All three dates represent a conservative estimate of the actual number of obstructions, as it was impossible to

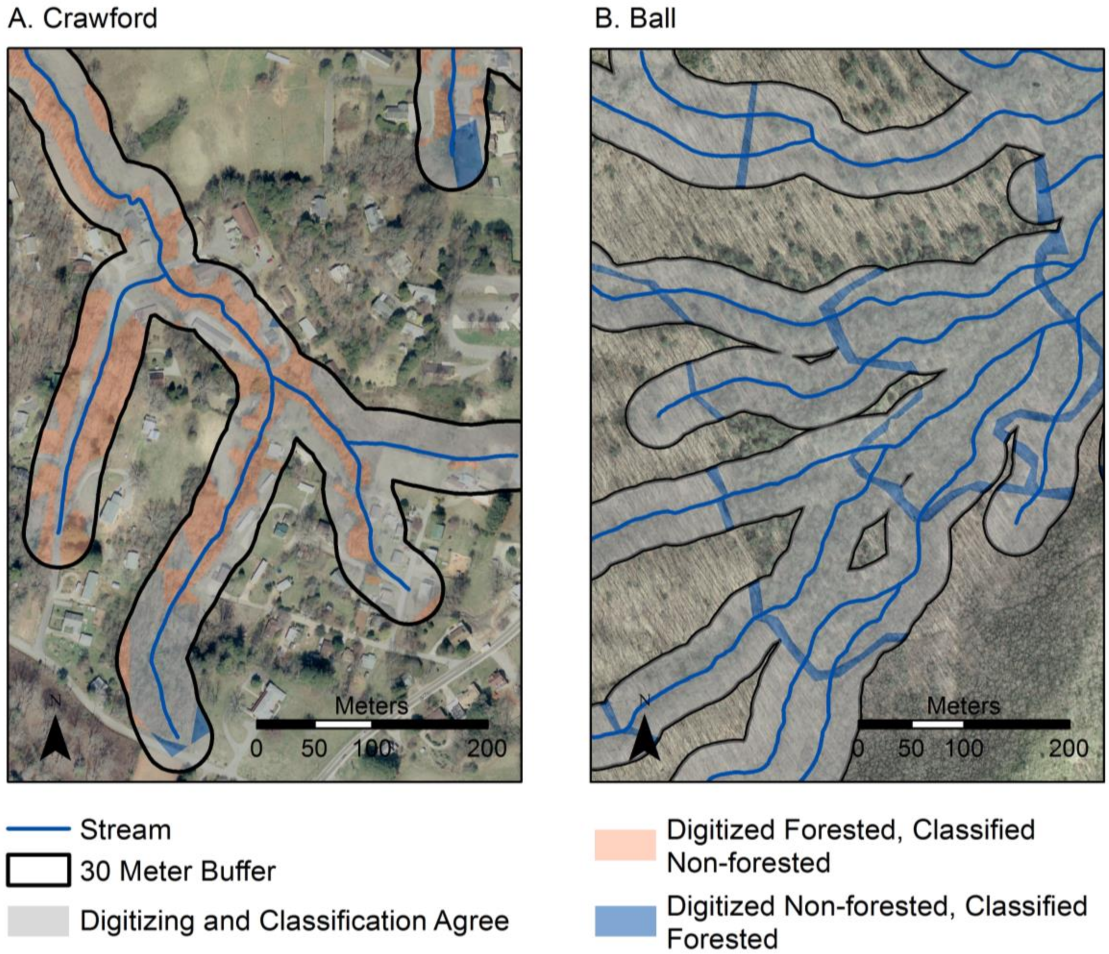


Figure 7 – Discrepancies between manual digitizing and the NLCD classification in 2007 in the Crawford (A) and Ball (B) watersheds.

find all driveways, culverts, and pipelines from aerial photographs, especially given that much of the study area is heavily forested. Less confidence is further granted to the obstruction counts from 1984 and 1954, as vastly inferior spatial resolution of the photographs means that features that may have been evident in the 2007 images were likely missed.

Crawford and Watauga have the highest road crossing and other obstruction densities for each time period (Table C19). In the case of Watauga, a major highway runs through much of

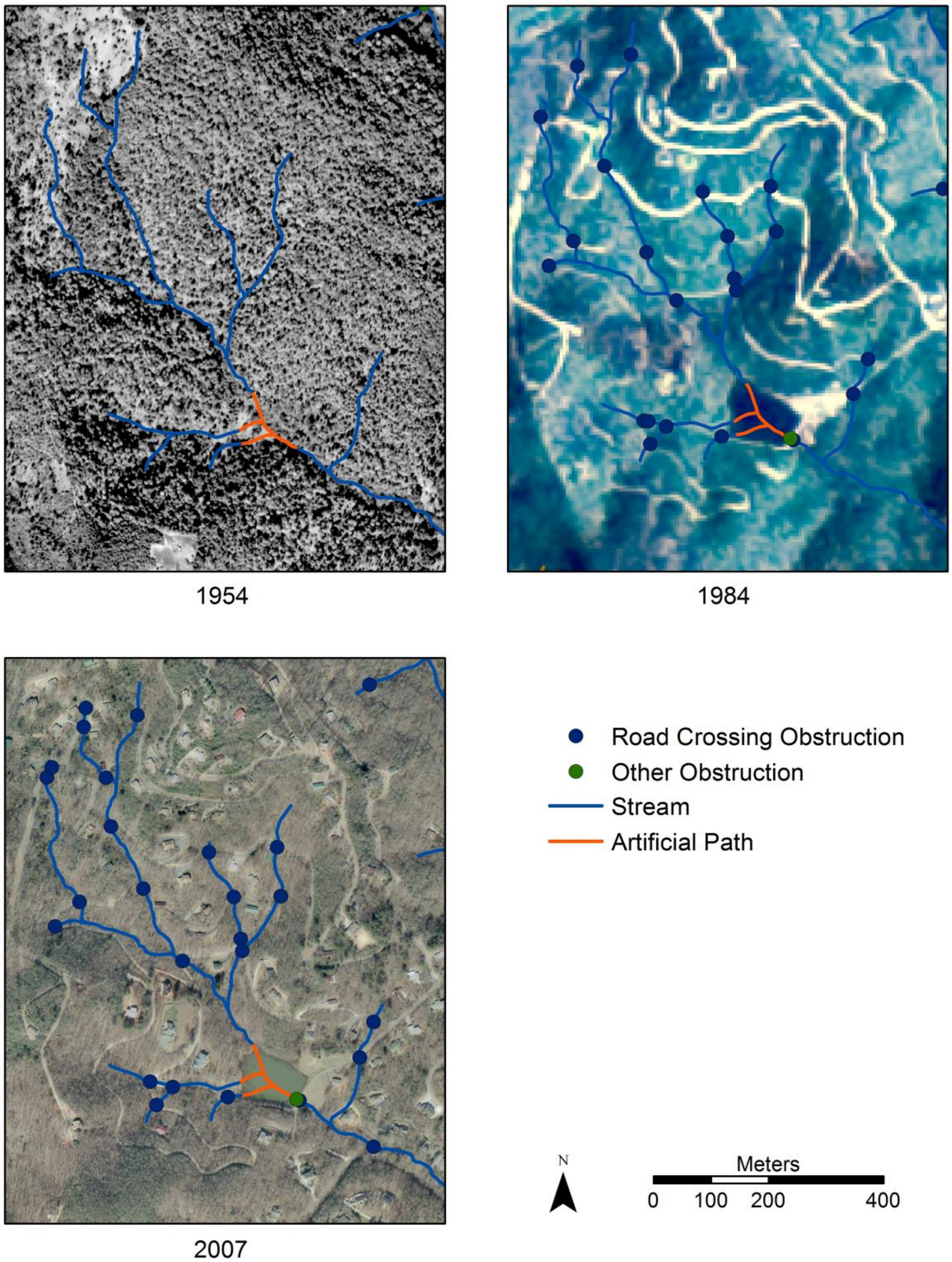


Figure 8 – Stream network obstructions in a tributary of the Crawford watershed from 1954 through 2007.

the watershed, accounting for most of the pipeline obstructions and many of the roads. These two watersheds also experienced the greatest growth in obstruction density, increasing from 12/km^2 in 1954 to 29/km^2 in 2007 in Crawford and from 13/km^2 to 24/km^2 in Watauga. Watersheds that underwent less development saw modest increases in obstructions of fewer than 5/km^2. Rays has the lowest obstruction density of under 9/km^2 in 2007. Although Ball is also predominantly forested, Cowee has a lower density of obstructions, despite having more development. Most of the road crossings in Ball are old logging or Forest Service roads, as the majority of the watershed lies in National Forest. This finding demonstrates that stream obstructions may be denser than expected, even in relatively unpopulated regions, due to the unpaved road network.

Slope steepness in the riparian buffer generally mirrors the categories of watershed development (Tables C20-C25). Ball and Rays have the highest steepness values with a mean of approximately 23º, while Crawford exhibits the lowest with an average steepness of 10º (Table C25). Such a correspondence is expected, as steep terrain in more forested watersheds likely made these locations less desirable for settlement. The tax parcels additionally reflect watershed development (Tables C26-C31). The forested watersheds almost exclusively have parcels of type None in the riparian buffer, which usually pertain to areas of National Forest. None or Residential types comprise the majority of buffers in the remaining watersheds, although Agriculture makes up over 10% of the riparian area in Cowee and Jones (Table C31). Crawford is the only watershed with significant Commercial area of 10%, and both Crawford and Watauga have notable amounts of land in roads that do not receive a parcel type designation. In the case of Watauga, the major highway that crosses the watershed explains the high percentage of roads.

2. Large Wood Response to Landscape Controls

2.1 *Graphical Analysis*

Graphical comparison of wood frequency and volume in the study reaches indicates a relationship with forest cover of the riparian buffer both around the reach and upstream (Figure 9). Large wood was quantified in terms of pieces and volume per m channel length, $length_{SR/30}$, and m^2 channel area in accordance with measurements utilized in previous research (Bilby and Ward, 1989; Robison and Beschta, 1990; Beechie and Sibley, 1997; Jackson and Sturm, 2002). Average diameter and length were excluded owing to low wood counts in several reaches that resulted in anomalous values; for example, the average diameter of 0.55 m for the Crawford 2 site is the largest out of all the reaches but only represents one piece of wood (Table D1).

The condition of the riparian buffer includes four categories: non-forested, a one-tree buffer surrounding the stream that roughly corresponds to the 3 m buffer, completely forested in the 30 m buffer with greater than 95% of the watershed-wide buffer upstream forested, and forested with less than 95% of the upstream buffer forested. The forested reaches were separated at 95% to account for roads or other small non-forested areas present in even the most forested watersheds. There was additionally a logical break in percent forested values at 95%. The forested reaches with greater than 95% of the upstream buffer forested will be referred to as those that are heavily forested upstream, and the reaches with less than 95% forest cover upstream will be referred to as those that are moderately forested upstream.

The three measures, channel length, channel area, and $length_{SR/30}$ have slightly different behaviors with increasing drainage area. Pieces and volume in forested reaches decrease subtly per m length and more notably per m^2 area (Figure 9 A-D) but demonstrate no association with drainage area per $length_{SR/30}$ (Figure 9 E-F). One-tree buffer and non-forested reaches, instead,

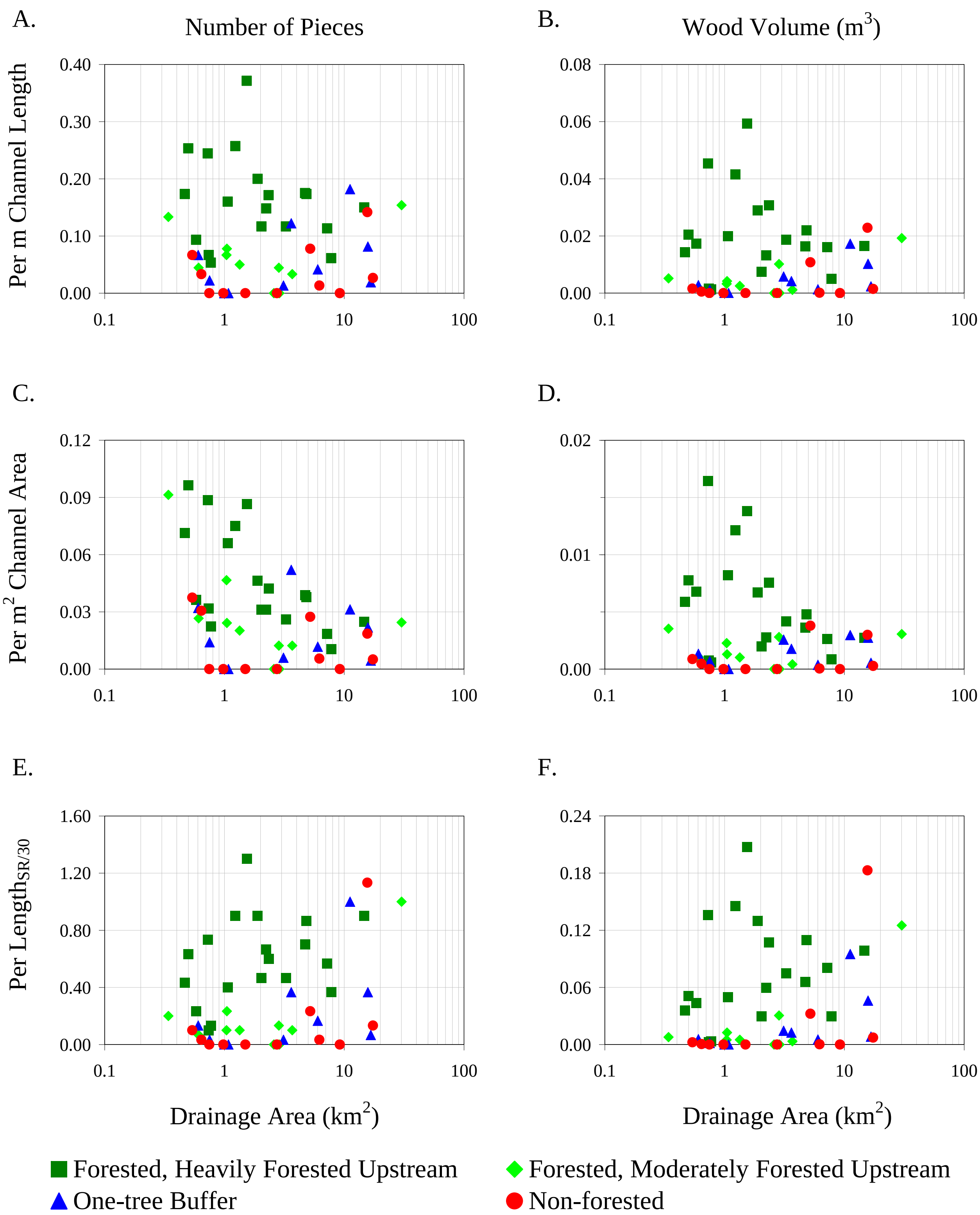


Figure 9 – Large wood frequency and volume per m channel length (A and B), m^2 channel area (C and D), and $length_{SR/30}$ (E and F) versus drainage area for different riparian conditions.

have greater amounts of wood in larger channels for all measures except pieces/m^2 channel area, which does not show a clear increase in wood with distance downstream (Figure 9 C). The increasing trend for one-tree buffer and non-forested reaches is most drastic for the $length_{SR/30}$ measure, likely reflecting the scaling by channel size and, thus, inherent incorporation of drainage area into the expression since channel width is very highly correlated to drainage area. The lack of association between pieces and volume per $length_{SR/30}$ in forested reaches instead of a negative relationship noted with the other two measures also indicates the tendency of this denominator to result in more positive values than would otherwise be expected.

Wood frequency and volume in heavily forested upstream reaches exhibit similar trends with distance downstream (Figure 9). Conversely, wood counts among moderately forested upstream, one-tree buffer, and non-forested reaches tend to plot above the relative position of the corresponding volume values, especially at low drainage areas, suggesting pieces at these sites are small. The condition of the riparian buffer appears to not only affect the trajectory of wood loads downstream but also the amount of wood in streams of a given watershed size. Heavily forested upstream reaches often plot above the other riparian categories for all expressions of wood count and volume. Moderately forested upstream reaches generally have less wood than heavily forested upstream reaches but more than one-tree buffer and non-forested sites, which have similarly low wood totals. These trends are clearer in small streams, with more deviation at larger drainage areas.

Comparison of bankfull width shows, unsurprisingly, a strong positive correlation with drainage area, but also distinct relationships for each of the riparian categories (Figure 10), as previously noted by Leigh (2010) and Jackson et al. (submitted). Reaches with watersheds of a similar size are widest with a heavily forested buffer upstream. Moderately forested upstream reaches are narrower than those that are heavily forested upstream, while one-tree buffer and non-forested reaches have the smallest widths.

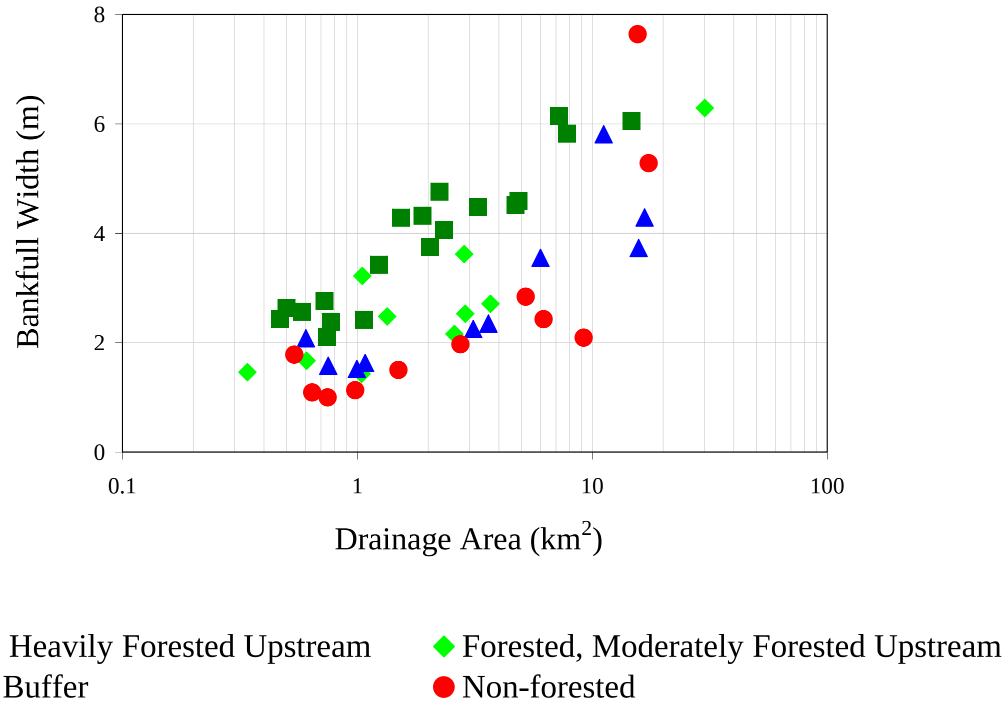


Figure 10 – Bankfull width versus drainage area for different riparian conditions.

Within each watershed, large wood frequency and volume demonstrate a complex relationship with both riparian cover and distance downstream (Figures 11-16). All of the reaches in Ball and Rays are heavily forested upstream, but wood loads are variable and peak between drainage areas of 1 and 2 km^2 for all measures. Wood nicely mirrors the riparian condition in some watersheds; in the case of Watauga, the two non-forested reaches have almost no wood, the one-tree buffer follows with a little more, and the two moderately forested upstream reaches have the greatest amount aside from the heavily forested site. However, large wood in other watersheds does not always correspond with riparian cover, as the maximum

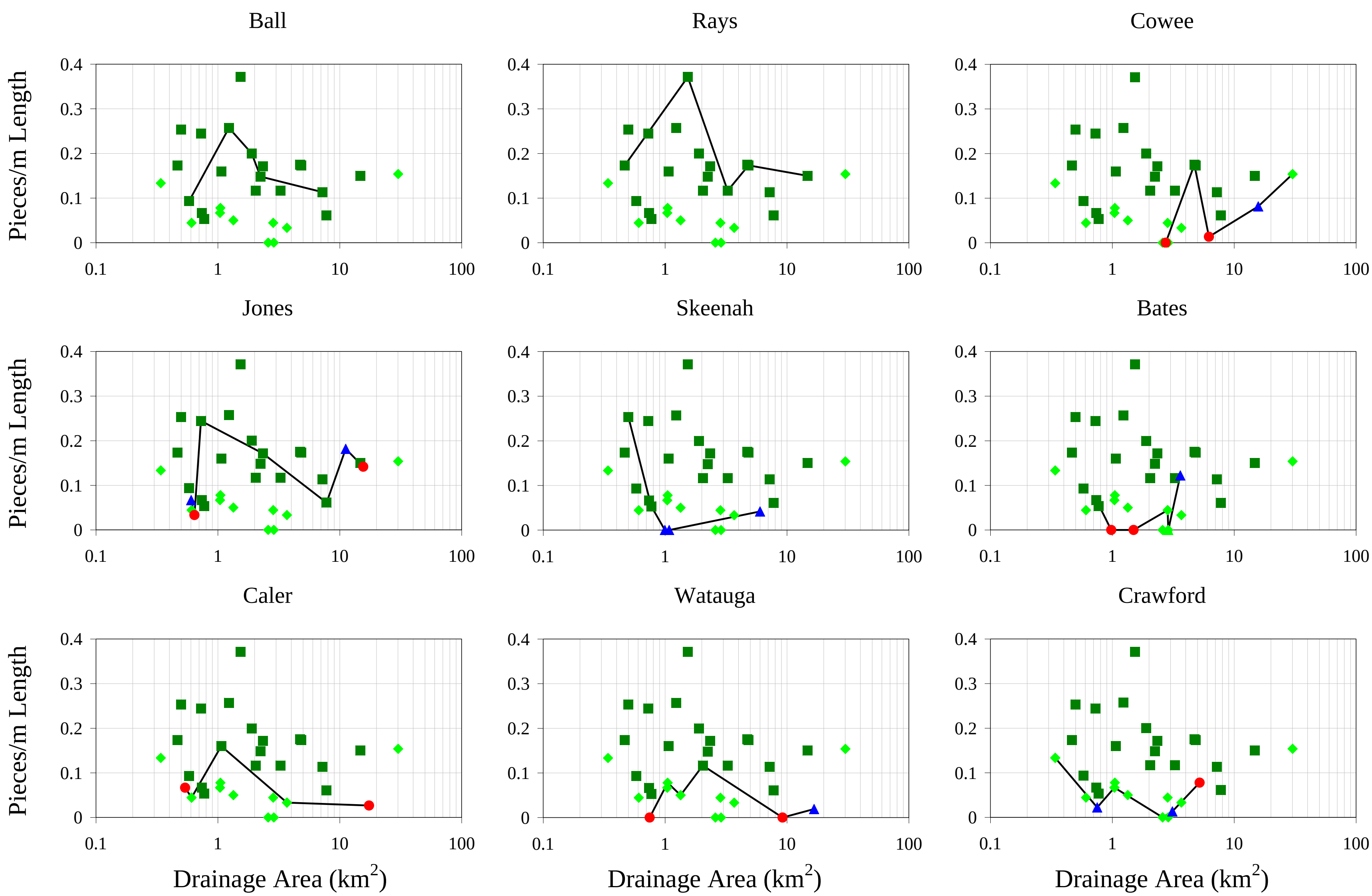


Figure 11 – Large wood count per m channel length versus drainage area by watershed for different riparian conditions.

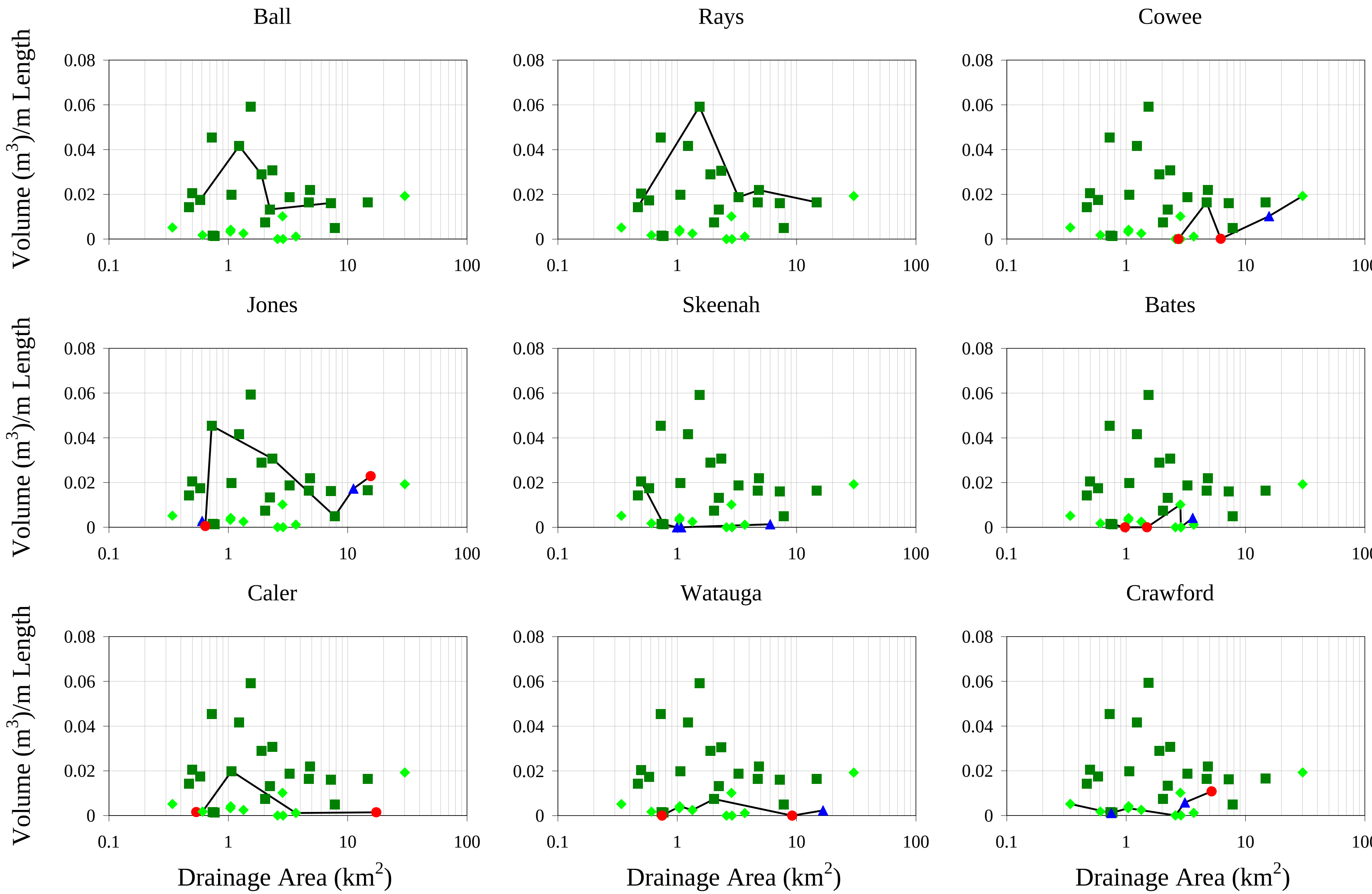


Figure 12 – Large wood volume per m channel length versus drainage area by watershed for different riparian conditions.

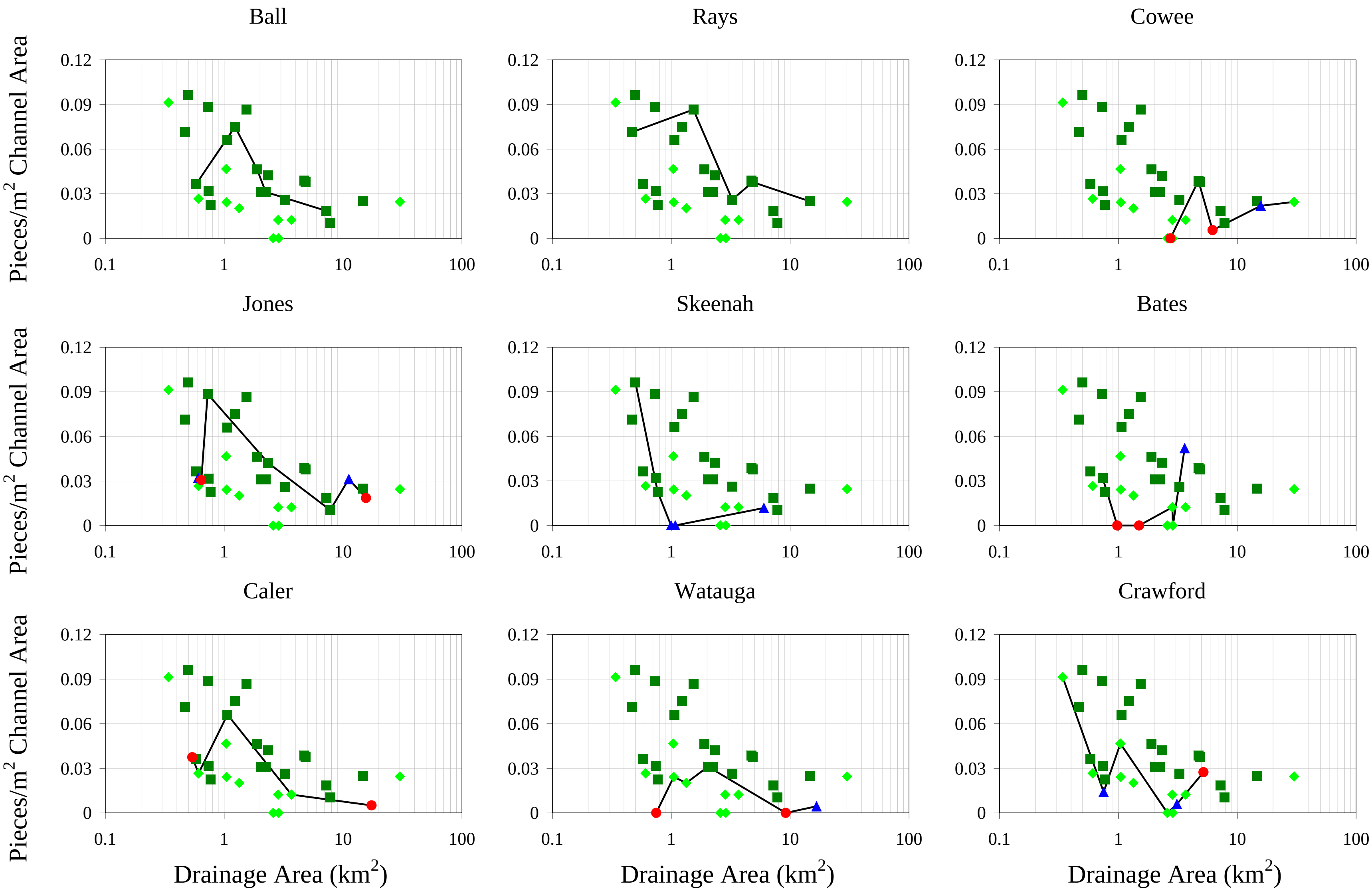


Figure 13 – Large wood count per m^2 channel area versus drainage area by watershed for different riparian conditions.

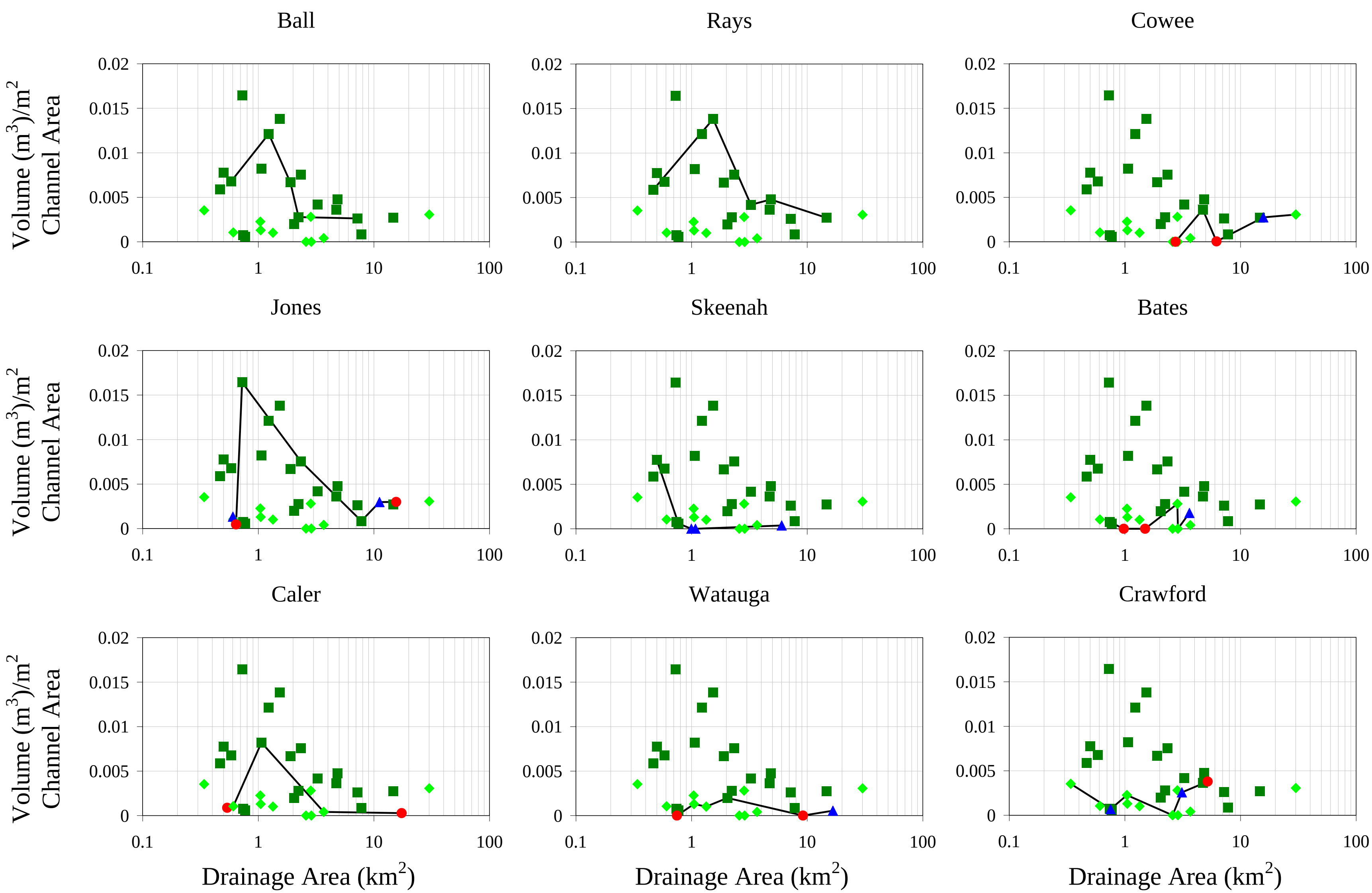


Figure 14 – Large wood volume per m^2 channel area versus drainage area by watershed for different riparian conditions.

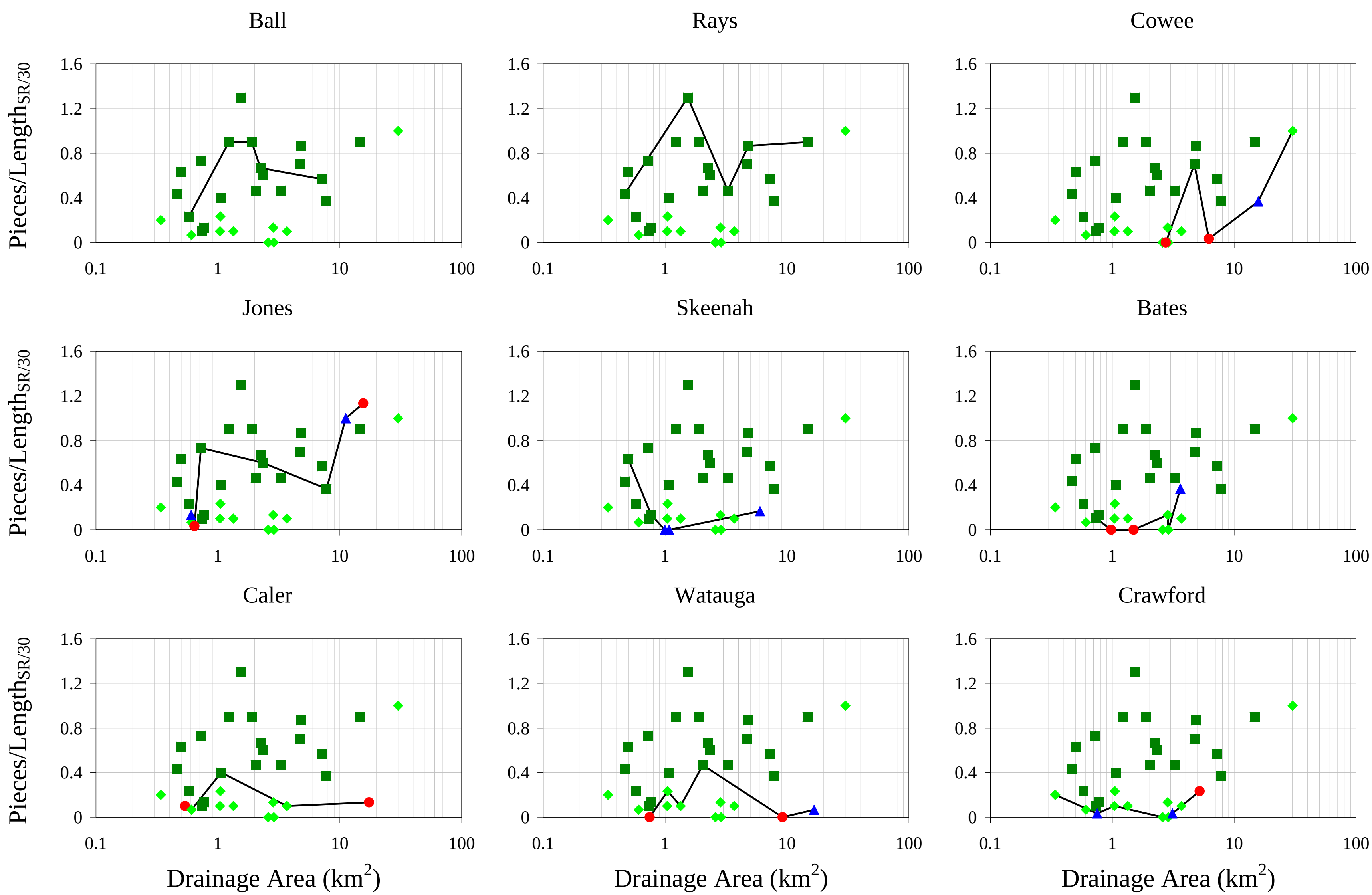


Figure 15 – Large wood count per length$_{SR/30}$ versus drainage area by watershed for different riparian conditions.

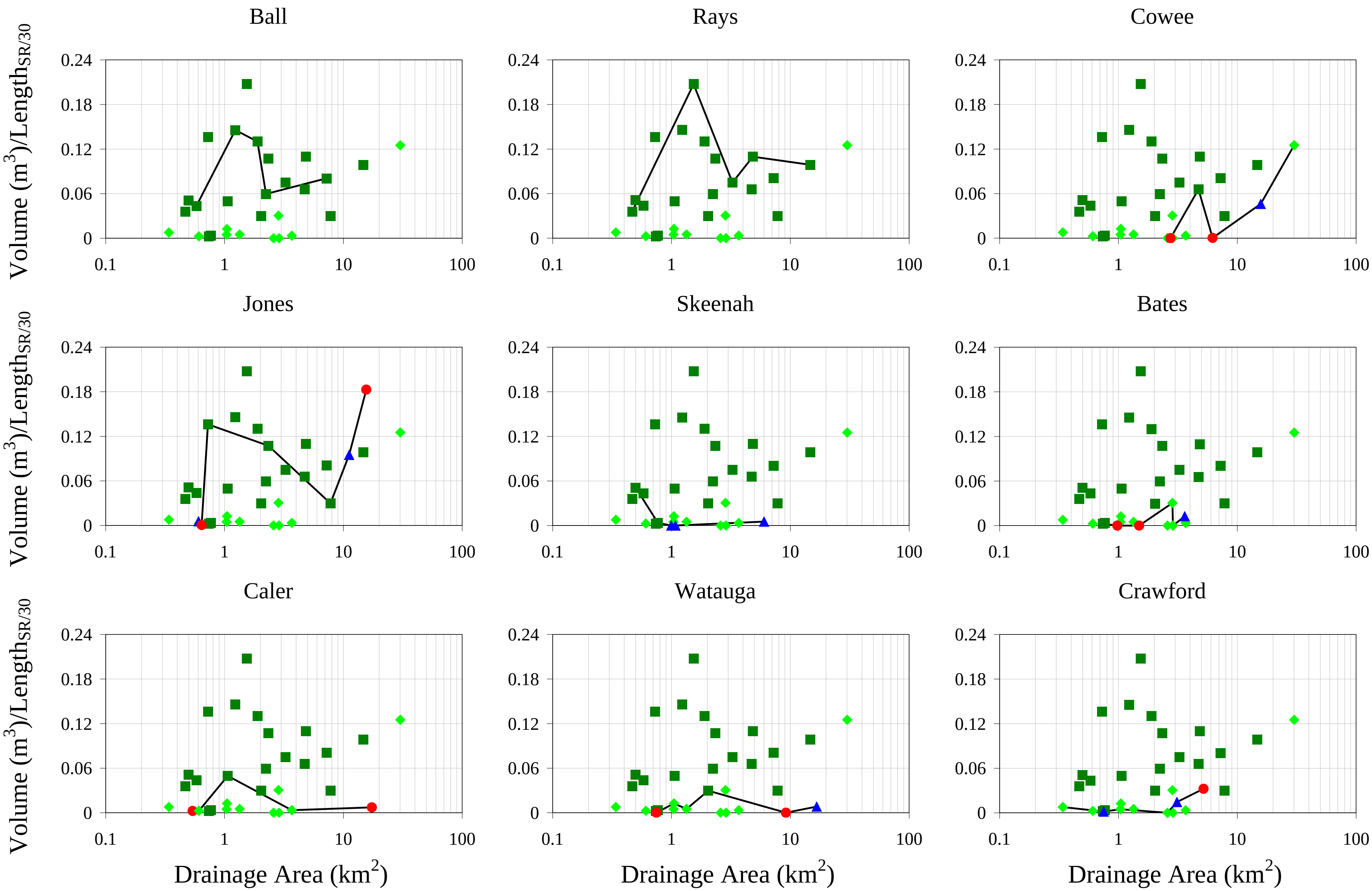


Figure 16 – Large wood volume per length$_{SR/30}$ versus drainage area by watershed for different riparian conditions.

wood count in Bates occurs in a one-tree buffer reach, and the peak wood volume in Crawford is found in a non-forested reach.

Heavily forested upstream reaches have the highest wood frequency and volume per m length and m^2 area in each watershed, with the exception of a one-tree buffer site in Bates (Figures 11 and 13), a moderately forested upstream reach in Cowee (Figure 12), and a non-forested reach in Crawford (Figures 12 and 14). All three sites are at or near the watershed outlet. While forested reaches tend to have the maximum amount of wood in each watershed, secondary peaks sometimes correspond to one-tree buffer or non-forested reaches, as occurs for wood counts per m length in Jones and Crawford, respectively, that even surpass those in other forested reaches of the same watershed (Figure 11). These reaches, again, have larger drainage areas and are near the watershed outlet. Small one-tree buffer and non-forested reaches further upstream generally have negligible wood loads, except in the case of Jones and Caler for pieces per m^2 area (Figure 13). Some forested reaches also have very little or no wood, as is evident for both count and volume at one moderately forested upstream site in Bates and also one in Crawford (Figures 11-14).

Though heavily forested upstream reaches still have the greatest wood loads in most watersheds using the measure of $\text{length}_{SR/30}$, more exceptions occur (Figures 15 and 16). Moderately forested upstream, one-tree buffer, or non-forested sites have the most pieces and highest volume in Cowee, Jones, Bates, and Crawford. In all cases, the reaches are among the largest in the watershed, so values are subject to the aforementioned magnifying effect of this channel-scaled measurement that incorporates aspects of drainage area. However, the downstream trends and relative plot positions of wood amounts in other watersheds remains almost exactly the same, as is noted for Skeenah across all measures (Figures 11-16).

Both total wood count and volume for all reaches in a given watershed tend to decrease with the level of watershed development (Figures 11-16). Ball and Rays consistently have the most wood as the two primarily forested watersheds (Table 1). Cowee and Jones follow with the next largest amount of wood in the category of forested watersheds with valley development. The third mostly forested watershed with valley development, Skeenah, joins the mostly forested watersheds with mountain-side development and the only urban watershed, Crawford, in having overall low wood loads.

Bankfull width clearly demonstrates the influence of riparian vegetation in nearly all watersheds (Figure 17). Channel width increases almost monotonically in Ball and Rays with exclusively heavily forested upstream reaches. Widths in the watersheds with valley and mountain-side development generally increase in forested reaches, with maximum widening usually in heavily forested upstream reaches, and decrease in one-tree buffer and, most drastically, in non-forested reaches. The non-forested reach at the Jones outlet is an exception plotting above the forested reaches, although this stream is also the largest in the entire study. Bankfull widths in Crawford, on the other hand, show little variation with distance downstream and do not correspond with riparian condition.

2.2 *Statistical Modeling*

Many of the landscape explanatory variables from spatial analysis were highly correlated with each other. Study reach characteristics were usually similar to those 100 m upstream, and watershed-wide measurements were nearly the same as those 1,000 m upstream of the reach. Variables were also correlated over the three dates: for example, the more developed watersheds in 1954 and 1984 continued to have comparatively less forest cover and greater obstruction

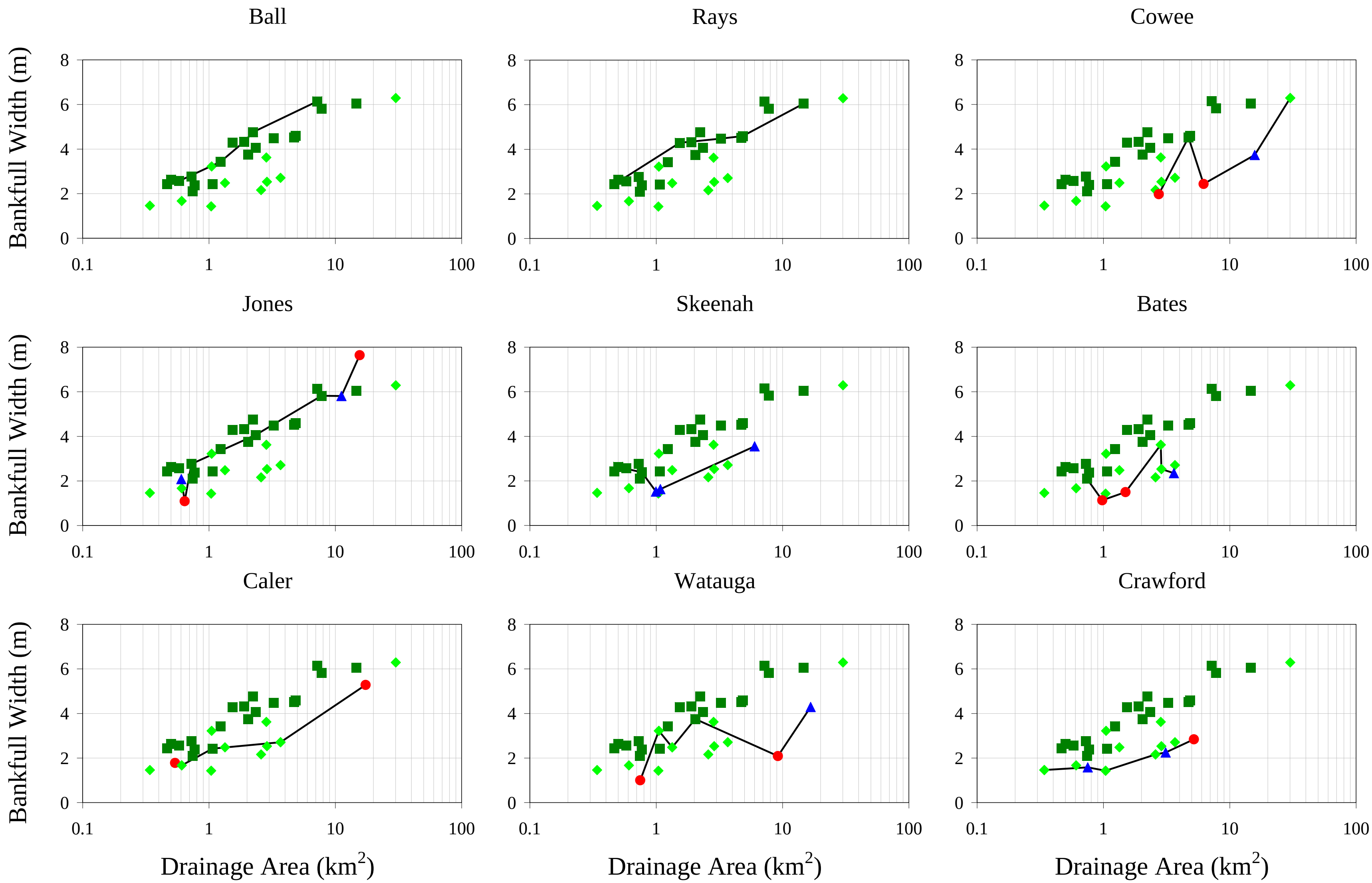


Figure 17 – Bankfull width versus drainage area by watershed for different riparian conditions.

densities than the others in 2007. It was, therefore, not always possible to identify a specific spatial or temporal scale as the most critical for large wood variability, so results are interpreted comparatively in terms of influences close to and directly affecting the reach versus those further away in distance or time.

The variables were separated into categories of watershed geomorphology, reach geomorphology, riparian land cover, basin land cover, obstructions, side slope steepness, and tax parcels to narrow down the variable pool. Variables in each category showing the best relationships with the large wood response variables and the least redundancy with each other were selected (Table 5). A Spearman rank correlation matrix was used due to the inclusion of categorical variables to demonstrate which parameters are correlated with a $\rho > 0.7$ and, therefore, cannot be in a model together because of collinearity (Table 6).

In an effort to identify the most important scale of riparian cover for large wood distributions, Spearman rank correlations between the forested area and wood response variables for all buffer lengths and widths were compared. Riparian conditions in 1954 and 2007 appeared most relevant to wood loads based on correlations, so the 1984 riparian cover variables were eliminated for the purposes of statistical modeling. Forest cover around the study reach had the strongest relationship with large wood out of all the lengths examined (Table 7). The riparian buffer 100 m upstream also generally had good correlations with the wood measurements but was not included in the final set of variables, because the reach and 100 m length were highly collinear. Longitudinal trends were similar among the three buffer widths and tended to demonstrate weaker relationships at progressively greater upstream lengths. Correlation values drop notably after the reach length for most of the response variables as more riparian area is considered.

Table 5 – Selected explanatory variables for statistical modeling. Divisions mark categories of influence: watershed geomorphology, reach geomorphology, riparian land cover, basin land cover, obstructions, side slope steepness, and tax parcels.

Explanatory Variables	
Abbreviation	Description
TSL	Total Stream Length
2YrFSP	Two Year Flood Stream Power*
Slope	Slope of the Study Reach
BW	Bankfull Width
AMBW	Average Meander Belt Width (m) **
d95	95th Percentile of Bed Sediment Size (mm)
SR_54_10m	Percent Forest Cover of the 10 m Study Reach Buffer in 1954 (%)
SR_07_10m	Percent Forest Cover of the 10 m Study Reach Buffer in 2007 (%)
WS_07_30m	Percent Forest Cover of the 10 m Watershed Buffer in 2007 (%)
For_86	Percent Forested Watershed Land Cover in 1986 (%)
NonDev_06	Percent Non-developed and Non-forested Watershed Land Cover in 2006 (%)
RD_54	Total Roads Upstream in 1954
RD_100_84	Total Roads 100 m Upstream in 1984
RD_500_07	Total Roads 500 m Upstream in 2007
SR_95	95th Percentile of Side Slope Steepness in the Study Reach (º)
WS_SD	Standard Deviation of Side Slope Steepness in the Watershed (º)
WS_595	5th/95th Percentile of Side Slope Steepness in the Watershed (º)
100_None	Percent None Parcel Type 100 m Upstream (%)
WS_None	Percent None Parcel Type in the Watershed (%)

* 2YrFSP = $(\text{Drainage Area})^{0.7}$ * Slope
** AMBW = Bankfull Width + Average Left Floodplain Width + Average Right Floodplain Width

Though the 1954 and 2007 study reach lengths were somewhat redundant, both were selected to incorporate the temporal aspect of riparian impacts on large wood. The watershed-wide buffer in 2007 was also kept to represent influences further upstream. The 500 m, 1,000 m, and watershed-wide lengths were all collinear and, therefore, had similar correlation coefficients for many of the wood variables. The watershed-wide buffer correlated least with the reach so

Table 6 – Spearman rank ρ correlations between explanatory variables. Highly correlated variables with $\rho > 0.7$ have a grey background. Divisions mark categories of influence: watershed geomorphology, reach geomorphology, riparian land cover, basin land cover, obstructions, side slope steepness and tax parcels.

	Spearman's ρ								
Explanatory Variables	TSL	2YrFSP	Slope	BW	AMBW	d95	SR_54_10m	SR_07_10m	WS_07_30m
TSL	1	0.36	-0.57	0.69	0.63	0.16	-0.19	-0.11	-0.06
2YrFSP	0.36	1	0.52	0.68	0.64	0.72	0.50	0.57	0.68
Slope	-0.57	0.52	1	-0.04	0.00	0.47	0.61	0.58	0.64
BW	0.69	0.68	-0.04	1	0.89	0.57	0.43	0.48	0.41
AMBW	0.63	0.64	0.00	0.89	1	0.57	0.38	0.41	0.39
d95	0.16	0.72	0.47	0.57	0.57	1	0.51	0.54	0.61
SR_54_10m	-0.19	0.50	0.61	0.43	0.38	0.51	1	0.83	0.50
SR_07_10m	-0.11	0.57	0.58	0.48	0.41	0.54	0.83	1	0.60
WS_07_30m	-0.06	0.68	0.64	0.41	0.39	0.61	0.50	0.60	1
For_86	-0.10	0.45	0.48	0.26	0.28	0.38	0.51	0.43	0.56
NonDev_06	0.09	-0.55	-0.54	-0.27	-0.30	-0.58	-0.41	-0.40	-0.82
RD_54	0.89	0.17	-0.64	0.53	0.45	0.04	-0.26	-0.22	-0.26
RD_100_84	0.46	0.14	-0.27	0.38	0.30	-0.08	0.01	0.10	-0.09
RD_500_07	0.22	-0.41	-0.51	-0.11	-0.11	-0.40	-0.28	-0.34	-0.67
SR_95	-0.11	0.57	0.62	0.34	0.30	0.46	0.75	0.66	0.45
WS_SD	0.65	0.47	-0.16	0.54	0.48	0.24	0.05	0.03	0.08
WS_595	-0.37	0.60	0.87	0.13	0.16	0.58	0.60	0.61	0.80
100_None	-0.11	0.60	0.61	0.44	0.44	0.59	0.67	0.69	0.81
WS_None	0.26	0.56	0.29	0.41	0.44	0.43	0.18	0.14	0.53

Table 6 (continued)

Explanatory Variables	Spearman's ρ For_86	NonDev_06	RD_54	RD_100_84	RD_500_07	SR_95	WS_SD	WS_595	100_None	WS_None
TSL	-0.10	0.09	0.89	0.46	0.22	-0.11	0.65	-0.37	-0.11	0.26
2YrFSP	0.45	-0.55	0.17	0.14	-0.41	0.57	0.47	0.60	0.60	0.56
Slope	0.48	-0.54	-0.64	-0.27	-0.51	0.62	-0.16	0.87	0.61	0.29
BW	0.26	-0.27	0.53	0.38	-0.11	0.34	0.54	0.13	0.44	0.41
AMBW	0.28	-0.30	0.45	0.30	-0.11	0.30	0.48	0.16	0.44	0.44
d95	0.38	-0.58	0.04	-0.08	-0.40	0.46	0.24	0.58	0.59	0.43
SR_54_10m	0.51	-0.41	-0.26	0.01	-0.28	0.75	0.05	0.60	0.67	0.18
SR_07_10m	0.43	-0.40	-0.22	0.10	-0.34	0.66	0.03	0.61	0.69	0.14
WS_07_30m	0.56	-0.82	-0.26	-0.09	-0.67	0.45	0.08	0.80	0.81	0.53
For_86	1	-0.57	-0.22	-0.18	-0.46	0.36	0.13	0.59	0.60	0.34
NonDev_06	-0.57	1	0.25	0.23	0.61	-0.40	-0.08	-0.74	-0.67	-0.57
RD_54	-0.22	0.25	1	0.45	0.43	-0.18	0.65	-0.54	-0.37	0.12
RD_100_84	-0.18	0.23	0.45	1	0.20	0.04	0.29	-0.25	-0.10	0.05
RD_500_07	-0.46	0.61	0.43	0.20	1	-0.25	0.08	-0.60	-0.63	-0.42
SR_95	0.36	-0.40	-0.18	0.04	-0.25	1	0.14	0.55	0.55	0.29
WS_SD	0.13	-0.08	0.65	0.29	0.08	0.14	1	-0.14	-0.05	0.46
WS_595	0.59	-0.74	-0.54	-0.25	-0.60	0.55	-0.14	1	0.77	0.40
100_None	0.60	-0.67	-0.37	-0.10	-0.63	0.55	-0.05	0.77	1	0.42
WS_None	0.34	-0.57	0.12	0.05	-0.42	0.29	0.46	0.40	0.42	1

Table 7 – Spearman rank ρ correlations between forest cover at various buffer lengths for the 3 m, 10 m, and 30 m widths (horizontal axis) and response variables (vertical axis). Variables with a significant correlation ($p < 0.05$) have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30.}$

	Riparian Buffer Lengths at the 3 m Width									
	1954					2007				
	Reach	100 m	500 m	1,000 m	Watershed	Reach	100 m	500 m	1,000 m	Watershed
P/m	0.69	0.53	0.56	0.50	0.50	0.67	0.61	0.59	0.56	0.59
D/m	0.36	0.32	0.37	0.26	0.19	0.41	0.44	0.25	0.22	0.20
L/m	0.35	0.24	0.36	0.24	0.18	0.40	0.41	0.28	0.25	0.20
V/m	0.71	0.52	0.53	0.44	0.44	0.69	0.62	0.54	0.48	0.53
P/m²	0.61	0.50	0.53	0.48	0.44	0.56	0.63	0.56	0.55	0.50
D/m²	0.28	0.26	0.31	0.20	0.14	0.34	0.40	0.22	0.19	0.16
L/m²	0.27	0.22	0.30	0.20	0.13	0.33	0.38	0.24	0.20	0.16
V/m²	0.72	0.53	0.55	0.47	0.43	0.69	0.64	0.56	0.48	0.52
$P/L_{SR/30}$	0.65	0.46	0.49	0.40	0.43	0.65	0.51	0.51	0.45	0.53
$D/L_{SR/30}$	0.54	0.40	0.41	0.30	0.29	0.60	0.46	0.32	0.26	0.38
$L/L_{SR/30}$	0.50	0.21	0.33	0.21	0.25	0.59	0.39	0.34	0.26	0.37
$V/L_{SR/30}$	0.65	0.45	0.47	0.37	0.38	0.65	0.53	0.47	0.41	0.50

Table 7 (continued)

Riparian Buffer Lengths at the 10 m Width										
	1954					2007				
	Reach	100 m	500 m	1,000 m	Watershed	Reach	100 m	500 m	1,000 m	Watershed
P/m	0.73	0.63	0.59	0.50	0.57	0.72	0.62	0.59	0.60	0.61
D/m	0.35	0.40	0.34	0.22	0.25	0.38	0.37	0.25	0.19	0.14
L/m	0.36	0.31	0.33	0.22	0.22	0.40	0.32	0.28	0.23	0.16
V/m	0.73	0.60	0.55	0.42	0.51	0.73	0.63	0.54	0.51	0.55
P/m²	0.65	0.59	0.55	0.48	0.48	0.60	0.60	0.56	0.58	0.49
D/m²	0.30	0.32	0.28	0.19	0.19	0.31	0.32	0.22	0.17	0.10
L/m²	0.29	0.27	0.26	0.18	0.18	0.32	0.30	0.24	0.19	0.11
V/m²	0.74	0.64	0.56	0.45	0.50	0.74	0.65	0.56	0.52	0.53
$P/L_{SR/30}$	0.68	0.55	0.52	0.40	0.50	0.69	0.53	0.51	0.49	0.56
$D/L_{SR/30}$	0.53	0.50	0.41	0.26	0.39	0.60	0.47	0.32	0.24	0.38
$L/L_{SR/30}$	0.51	0.30	0.35	0.18	0.32	0.63	0.38	0.34	0.27	0.41
$V/L_{SR/30}$	0.67	0.53	0.49	0.36	0.46	0.69	0.55	0.47	0.43	0.52

Table 7 (continued)

	Riparian Buffer Lengths at the 30 m Width									
	1954					2007				
	Reach	100 m	500 m	1,000 m	Watershed	Reach	100 m	500 m	1,000 m	Watershed
P/m	0.72	0.72	0.59	0.56	0.57	0.67	0.66	0.53	0.59	0.62
D/m	0.28	0.31	0.31	0.29	0.25	0.41	0.31	0.21	0.21	0.13
L/m	0.24	0.24	0.31	0.28	0.22	0.39	0.30	0.21	0.25	0.13
V/m	0.73	0.68	0.54	0.49	0.51	0.66	0.64	0.48	0.52	0.56
P/m²	0.59	0.65	0.56	0.55	0.48	0.63	0.63	0.49	0.56	0.50
D/m²	0.19	0.24	0.26	0.25	0.19	0.35	0.26	0.17	0.18	0.07
L/m²	0.17	0.21	0.25	0.25	0.18	0.34	0.26	0.18	0.20	0.07
V/m²	0.73	0.70	0.54	0.51	0.50	0.69	0.66	0.49	0.52	0.53
$P/L_{SR/30}$	0.67	0.63	0.51	0.46	0.50	0.59	0.58	0.44	0.49	0.56
$D/L_{SR/30}$	0.57	0.50	0.36	0.32	0.39	0.51	0.43	0.29	0.27	0.38
$L/L_{SR/30}$	0.47	0.33	0.32	0.24	0.32	0.44	0.39	0.24	0.30	0.39
$V/L_{SR/30}$	0.68	0.61	0.48	0.42	0.46	0.59	0.57	0.41	0.44	0.53

was chosen out of the three options. However, using the 500 m or 1,000 m length would likely fail to alter the results dramatically.

Comparison of buffer widths for the selected lengths indicates that the 10 m width consistently has the best correlation with large wood at the scale of the study reach (Table 8). Correlation coefficients are significant at $p < 0.05$ for all wood measurements at the 10 m width around the reach and are generally higher than those for both the 3 and 30 m widths in all but a few exceptions that involve diameter and length. However, the difference in correlation values between the 3 m or 30 m and the 10 m widths is not great, with a maximum change of 0.05 in some cases. This difference is even less clear for the watershed-wide length, as many of the correlation coefficients are almost identical across all three widths. The 10 m width was selected for the 1954 and 2007 study reach buffers, and the 30 m width was chosen for the 2007 watershed-wide buffer due to slightly higher correlations with the wood measurements overall (SR_54_10m, SR_07_10m, and WS_07_30m in Table 5). As was the case for the buffer lengths, substantial collinearity between the width variables at all scales implies that using another width instead of those originally chosen for the final set of parameters would result in a similar model with perhaps only slightly less explanatory power.

The response variables were also redundant (Tables F1 and F2), and initial modeling revealed similar results among the different wood measurements and denominators of m length, m^2 area, and $length_{SR/30}$. The average diameter and length variables were excluded from analysis owing to aforementioned issues with anomalous values based on only one or two pieces of wood in some reaches. Correlations with the explanatory variables also tended to be lower overall for diameter and length (Tables 9 and 10). Wood frequency is one of the more common measures of large wood in the field of geomorphology, permitting comparison with other studies (Bilby and

Ward, 1989; Robison and Beschta, 1990; Martin, 2001; Jackson and Sturm, 2002), and volume integrates wood size and count to provide an idea of how much habitat is available. For these reasons, it was, not felt that examination of diameter and length was necessary. Wood count and volume were examined per m channel length and per m^2 area. Count and volume in terms of $length_{SR/30}$ had strong correlations (Tables 9 and 10), but it was decided to forego modeling with this expression because of its inherent incorporation of channel size and drainage area into both sides of the predictive equation.

Table 8 – Spearman rank ρ correlations between forest cover at various buffer widths for the selected study reach and watershed lengths (horizontal axis) and response variables (vertical axis). Variables with a significant correlation ($p < 0.05$) have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30.}$

	Riparian Buffer Widths at Selected Study Reach and Watershed Lengths								
	1954			2007			2007		
	Reach			Reach			Watershed		
	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
P/m	0.69	0.73	0.72	0.67	0.72	0.67	0.59	0.61	0.62
D/m	0.36	0.35	0.28	0.41	0.38	0.41	0.20	0.14	0.13
L/m	0.35	0.36	0.24	0.40	0.40	0.39	0.20	0.16	0.13
V/m	0.71	0.73	0.73	0.69	0.73	0.66	0.53	0.55	0.56
P/m^2	0.61	0.65	0.59	0.56	0.60	0.63	0.50	0.49	0.50
D/m^2	0.28	0.30	0.19	0.34	0.31	0.35	0.16	0.10	0.07
L/m^2	0.27	0.29	0.17	0.33	0.32	0.34	0.16	0.11	0.07
V/m^2	0.72	0.74	0.73	0.69	0.74	0.69	0.52	0.53	0.53
$P/L_{SR/30}$	0.65	0.68	0.67	0.65	0.69	0.59	0.53	0.56	0.56
$D/L_{SR/30}$	0.54	0.53	0.57	0.60	0.60	0.51	0.38	0.38	0.38
$L/L_{SR/30}$	0.50	0.51	0.47	0.59	0.63	0.44	0.37	0.41	0.39
$V/L_{SR/30}$	0.65	0.67	0.68	0.65	0.69	0.59	0.50	0.52	0.53

Table 9 – Spearman rank ρ correlations between explanatory and response variables. Variables with a significant correlation ($p < 0.05$) have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30}$ and the explanatory variable categories of influence: watershed geomorphology, reach geomorphology, riparian land cover, basin land cover, obstructions, side slope steepness and tax parcels.

	Spearman's ρ								
	TSL	2YrFSP	Slope	BW	AMBW	d95	SR_54_10m	SR_07_10m	WS_07_30m
P/m	-0.01	0.58	0.44	0.57	0.59	0.62	0.73	0.72	0.62
D/m	-0.47	-0.15	0.26	-0.14	-0.19	-0.01	0.35	0.38	0.13
L/m	-0.50	-0.14	0.27	-0.19	-0.25	-0.09	0.36	0.40	0.13
V/m	0.12	0.57	0.33	0.67	0.67	0.63	0.73	0.73	0.56
P/m^2	-0.36	0.28	0.48	0.18	0.23	0.39	0.65	0.60	0.50
D/m^2	-0.52	-0.22	0.23	-0.24	-0.28	-0.07	0.30	0.31	0.07
L/m^2	-0.53	-0.20	0.25	-0.27	-0.32	-0.10	0.29	0.32	0.07
V/m^2	-0.06	0.47	0.41	0.50	0.52	0.57	0.74	0.74	0.53
$P/L_{SR/30}$	0.25	0.65	0.29	0.78	0.76	0.67	0.68	0.69	0.56
$D/L_{SR/30}$	0.21	0.40	0.15	0.62	0.57	0.46	0.53	0.60	0.38
$L/L_{SR/30}$	0.36	0.51	0.05	0.71	0.61	0.37	0.51	0.63	0.39
$V/L_{SR/30}$	0.28	0.61	0.23	0.78	0.77	0.65	0.67	0.69	0.53

Table 9 (continued)

	Spearman's ρ									
	For_86	NonDev_06	RD_54	RD_100_84	RD_500_07	SR_95	WS_SD	WS_595	100_None	WS_None
P/m	0.42	-0.51	-0.15	0.07	-0.47	0.60	0.04	0.51	0.67	0.26
D/m	-0.04	0.07	-0.44	0.04	-0.12	0.14	-0.37	0.15	0.18	-0.28
L/m	-0.10	0.11	-0.43	0.13	-0.07	0.12	-0.37	0.18	0.12	-0.31
V/m	0.39	-0.45	-0.04	0.16	-0.34	0.58	0.12	0.43	0.65	0.26
P/m²	0.31	-0.38	-0.44	-0.10	-0.48	0.46	-0.25	0.49	0.56	0.05
D/m²	-0.08	0.11	-0.45	0.03	-0.09	0.10	-0.40	0.11	0.10	-0.33
L/m²	-0.12	0.14	-0.44	0.07	-0.07	0.09	-0.41	0.13	0.08	-0.35
V/m²	0.34	-0.41	-0.20	0.09	-0.37	0.56	-0.03	0.45	0.63	0.16
$P/L_{SR/30}$	0.39	-0.48	0.08	0.21	-0.37	0.56	0.21	0.40	0.63	0.32
$D/L_{SR/30}$	0.20	-0.24	0.08	0.30	-0.14	0.39	0.13	0.23	0.48	0.15
$L/L_{SR/30}$	0.12	-0.17	0.29	0.48	0.01	0.31	0.29	0.21	0.36	0.17
$V/L_{SR/30}$	0.37	-0.43	0.11	0.26	-0.29	0.54	0.21	0.36	0.61	0.29

Table 10 – Pearson's r correlations between the interval explanatory and response variables. Variables with a significant correlation ($p < 0.05$) have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30}$ and the explanatory variable categories of influence: watershed geomorphology, reach geomorphology, obstructions, and side slope steepness.

	Pearson's r										
	TSL	2YrFSP	Slope	BW	AMBW	d95	RD_54	RD_500_07	SR_95	WS_SD	WS_595
P/m	0.02	0.51	0.44	0.57	0.57	0.59	-0.18	-0.47	0.59	-0.01	0.50
D/m	-0.30	-0.07	0.21	0.04	-0.01	0.18	-0.34	-0.17	0.22	-0.23	0.16
L/m	-0.39	-0.18	0.19	-0.10	-0.19	0.04	-0.36	-0.10	0.10	-0.31	0.14
V/m	0.14	0.46	0.28	0.66	0.60	0.55	-0.05	-0.32	0.51	0.05	0.38
P/m^2	-0.28	0.26	0.48	0.25	0.28	0.42	-0.41	-0.49	0.50	-0.21	0.47
D/m^2	-0.43	-0.28	0.14	-0.21	-0.23	0.02	-0.41	-0.12	0.07	-0.32	0.04
L/m^2	-0.43	-0.26	0.17	-0.20	-0.25	0	-0.40	-0.12	0.06	-0.34	0.08
V/m^2	-0.09	0.40	0.44	0.43	0.49	0.56	-0.27	-0.42	0.55	-0.09	0.51
$P/L_{SR/30}$	0.25	0.60	0.31	0.76	0.72	0.59	0.04	-0.36	0.55	0.15	0.41
$D/L_{SR/30}$	0.16	0.27	0.09	0.54	0.46	0.42	0.02	-0.15	0.35	0.05	0.18
$L/L_{SR/30}$	0.27	0.39	0.10	0.67	0.53	0.40	0.14	-0.10	0.36	0.12	0.21
$V/L_{SR/30}$	0.26	0.53	0.23	0.75	0.69	0.57	0.06	-0.29	0.50	0.14	0.35

Models predicting wood frequency and volume per m length have considerable explanatory power with an R^2 of 0.71 and 0.73, respectively (Table 11). The models of wood per m^2 area share the same key model parameters as those per m length but with lower R^2 values of 0.55 for wood count and 0.52 for volume. Wood frequency and volume are highly correlated (Tables F1 and F2), so all four models have similar explanatory variables. Local riparian cover, reach geomorphology, and upstream obstructions comprise the model parameters. Forest cover in the 10 m buffer of the study reach is the single most important variable in all models, explaining between 46% and 62% of the variance in wood count and volume. The 1954 buffer was selected for both frequency models through backward elimination procedures, while riparian forest cover in 2007 was similarly chosen for both expressions of volume. Inclusion of the 1954 instead of the 2007 buffer may underline the importance of wood recruitment from mature forests that have existed since at least the 1950s. On the other hand, selection of the 2007 date may additionally indicate that even young forests, which do not yet contribute much wood to the stream, are critical for their protection of the channel from people removing snags and other woody debris. However, it is not possible to confidently make such an interpretation due to the great collinearity between these two variables (Table 6).

Substitution of 3 and 30 m widths into the models demonstrates that the 10 m buffer still has the greatest explanatory power, although using the 3 m width results in only slightly lower R^2 values (Table 12). The finding that the 10 m buffer performs best may suggest that this area of the riparian zone contributes most to wood recruitment, but further evidence is necessary to test this hypothesis, considering the high correlation between buffer width variables. Overall weaker models with the 30 m width implies a larger buffer is not as critical for large wood loads but could also simply reflect trees within 30 m of the channel that are not contiguous to the stream and, therefore, not technically part of the riparian forest.

Table 11 – Selected models for wood frequency and volume in terms of m length and m^2 area.

Response Variable	Intercept	Explanatory Variables	Coefficient Estimate	Partial R^2	Model R^2	Model Adjusted R^2	F-statistic
P/m	0.121*	SR_54_10m (Moderate)†	0.098*	0.54	0.71	0.68	27.36
		SR_54_10m (High)†	0.172***				
		AMBW	0.241***	0.09			
		RD_500_07	-0.055**	0.08			
V/m	-9.475***	SR_07_10m (Moderate)†	2.426***	0.62	0.73	0.71	41.32
		SR_07_10m (High)†	2.981***				
		BW	3.845***	0.11			
P/m^2	0.156***	SR_54_10m (Moderate)†	0.063*	0.46	0.55	0.52	18.66
		SR_54_10m (High)†	0.110***				
		RD_500_07	-0.032**	0.09			
V/m^2	0.013*	SR_07_10m (Moderate)†	0.030**	0.52	0.52	0.50	25.04
		SR_07_10m (High)†	0.053***				

* $p < 0.05$
** $p < 0.01$
*** $p < 0.001$
† Ordinal variables have different coefficients to express the level of forest cover as low, medium, or high.

Substituting the other four buffer lengths into the models in place of the study reach variables reveals that the reach is the most critical longitudinal scale for large wood (Table 13).

Exchanging the reach length with that just 100 m upstream causes a decrease of roughly 0.10 in the R^2 values of the selected models, even though these two parameters are highly collinear. As was expected from the buffer length and width correlations with the response variables (Table 7), either the 1,000 m or watershed-wide length results in the lowest explanatory power. These findings clearly demonstrate the importance of local riparian cover around the reach for wood loads. However, the R^2 values when using the other upstream lengths are significant, suggesting that more distant landscape factors can still impact wood in the reach. While watershed-wide influences cannot be entirely ignored, the far greater model response at the reach scale indicates that the immediate riparian condition has the most control over wood distributions.

Table 12 – Model performance with the substitution of different riparian buffer widths.

Response Variable	Buffer Width (m)	Model R^2	Model Adjusted R^2	F-statistic
P/m	3	0.68	0.65	23.56
	10	0.71	0.68	27.36
	30	0.64	0.61	19.96
V/m	3	0.72	0.70	39.72
	10	0.73	0.71	41.32
	30	0.65	0.63	29.08
P/m²	3	0.53	0.50	17.44
	10	0.55	0.52	18.66
	30	0.49	0.45	14.61
V/m²	3	0.47	0.44	20.61
	10	0.52	0.50	25.04
	30	0.47	0.45	21.14

Table 13 – Model performance with the substitution of different riparian buffer lengths.

Response Variable	Buffer Length	Model R^2	Model Adjusted R^2	F-statistic
P/m	Reach	0.71	0.68	27.36
	100 m Upstream	0.61	0.57	17.32
	500 m Upstream	0.61	0.57	17.24
	1,000 m Upstream	0.55	0.51	13.98
	Watershed	0.59	0.55	15.99
V/m	Reach	0.73	0.71	41.32
	100 m Upstream	0.64	0.62	27.43
	500 m Upstream	0.57	0.55	20.61
	1,000 m Upstream	0.57	0.54	20.04
	Watershed	0.52	0.50	25.54
P/m^2	Reach	0.55	0.52	18.66
	100 m Upstream	0.43	0.39	11.42
	500 m Upstream	0.40	0.36	10.01
	1,000 m Upstream	0.31	0.27	6.99
	Watershed	0.36	0.32	8.60
V/m^2	Reach	0.52	0.50	25.04
	100 m Upstream	0.44	0.42	18.50
	500 m Upstream	0.39	0.37	15.25
	1,000 m Upstream	0.37	0.34	13.53
	Watershed	0.30	0.28	20.08

Bankfull width and average meander belt width, which equals the width of the bankfull channel plus the floodplain on both sides, explain approximately an additional 10% of the variance in large wood volume and frequency, respectively, per m length (Table 11). These relationships are positive, indicating bigger channels that are more likely to receive wood fluvially transported from upstream and wider floodplains with the potential for considerable lateral migration have more wood. In addition, more of the wood piece is able to lie completely in the bankfull channel of larger streams, whereas sizeable logs in small reaches often get caught on the floodplain and only have a portion of the total length in the channel. This ability of wood to fit in the channel may partially explain why bankfull width impacts total volume and not frequency, although bankfull and average meander belt widths are also highly correlated with each other (Table 6).

Neither bankfull nor average meander belt width is included in the models of wood per m^2 area, possibly owing to the incorporation of channel width already into the denominator. However, average meander belt width was one of the variables selected for the volume per m^2 area model both from backward elimination procedures and based on the lowest BIC score. Fitting a model with average meander belt width as the only explanatory variable shows that this parameter alone accounts for 24% of the variance in volume and, as was the case of the models of wood per m length, demonstrates a positive trend of more wood with greater width. Despite these factors, the variable was not selected for the final model because of a non-significant intercept. Average meander belt width does appear to exhibit the same relationship with wood regardless of the response variable, although the correlation is weaker in terms of channel area (Tables 9 and 10).

Road obstructions 500 m upstream of the reach in 2007 are a parameter in the two wood frequency models (Table 11). As with the other variables, obstructions were correlated across the three dates, so selection of roads in 2007 versus 1984 or 1954 is likely somewhat arbitrary. The relationship between wood count and the number of roads is negative, lending support to the original hypothesis that obstructions prevent the transport of wood pieces. This association may suggest such obstructions are, indeed an impediment to wood movement downstream, but it is more probable that roads, instead, serve as a proxy for the overall level of watershed development. Regardless of the exact interpretation, inclusion of roads in the model demonstrates that upstream influences and watershed-wide development do impact wood loads.

The models ignore factors such as watershed geomorphology, basin land cover, side slope steepness, and tax parcel types that may still be important components in the large wood equation. The categories created for variable selection overlap to some degree, so, for example, slope steepness closely matches riparian forest cover in many cases, as steep areas near the channel were more likely to be excluded from development because of difficult access and were, thus, allowed to remain in forest. In this manner, the explanatory variables included in the models actually represent a combination of characteristics that are difficult to isolate into specific areas of influence.

3. Large Wood Variability at the Reach Scale

Comparison of large wood resurvey results from 2010 with those from September 2012 shows substantial differences in wood loads for some reaches but nearly identical amounts for others (Table 14). Non-forested reaches with no wood in 2010 still lack wood in 2012, and the non-forested Jones 6 reach maintains one piece of wood for both dates. Ball 2 also has the same number of wood pieces in 2010 and 2012, and Caler 5 and Crawford 5 differ by only one. Conversely, Cowee 2 and Rays 5 were found to have many more pieces in 2012; in the case of Cowee 2, the count nearly doubles. Jones 7 and Rays 1, however, have considerably fewer pieces of wood in 2012. The total count for all sample reaches increased by 25 from 130 to 155 pieces, which includes a net decrease of 11 among one-tree buffer reaches, 36 new pieces in forested reaches, and no change for non-forested reaches (Figure 18).

The occurrence that some reaches have the same wood counts for both dates while others have higher or lower counts suggests similar abilities to identify large wood in the bankfull channel, whereas a systematic trend of more or fewer pieces for one set would indicate a

Table 14 – Comparison of large wood measurements from 2010 with the results of the resurveys in September 2012 and October 2013. Divisions mark the riparian cover, and plus and minus signs indicate inputs or exports of wood from the reach, respectively.

		Number of Pieces			Total Volume (m³)		
Riparian	Reach	2010	September	January	2010	September	January
Forested	Ball 2	20	20	20	1.79	0.75 (-)	0.83 (+)
	Rays 1	26	22 (-)	15 (-)	3.29	1.43 (-)	1.47 (+)
	Rays 5	14	25 (+)	22 (-)	2.25	2.37 (+)	2.02 (-)
	Cowee 2	21	43 (+)	46 (+)	1.97	1.95 (-)	2.10 (+)
	Caler 5	2	3 (+)	3	0.08	0.04 (-)	0.08 (+)
	Watauga 6	7	12 (+)	11 (-)	0.37	0.36 (-)	0.34 (-)
	Crawford 5	3	4 (+)	3 (-)	0.15	0.22 (+)	0.22
One-tree Buffer	Jones 7	30	17 (-)	19 (+)	2.85	0.62 (-)	0.90 (+)
	Skeenah 1	5	3 (-)	3	0.16	0.23 (+)	0.21 (-)
	Crawford 2	1	5 (+)	3 (-)	0.43	0.44 (+)	0.42 (-)
Non-forested	Jones 6	1	1	1	0.02	0.01 (-)	0.01
	Bates 3	0	0	0	0	0	0
	Watauga 3	0	0	0	0	0	0
All	Total	130	155 (+)	146 (-)	13.36	8.44 (-)	8.59 (+)

		Average Diameter (m)			Average Length (m)		
Riparian	Reach	2010	September	January	2010	September	January
Forested	Ball 2	0.20	0.15 (-)	0.16 (+)	1.94	1.60 (-)	1.50 (-)
	Rays 1	0.22	0.18 (-)	0.23 (+)	2.35	1.89 (-)	1.93 (+)
	Rays 5	0.24	0.21 (-)	0.21	2.32	2.03 (-)	1.71 (-)
	Cowee 2	0.23	0.17 (-)	0.17	2.17	1.70 (-)	1.71 (+)
	Caler 5	0.18	0.10 (-)	0.15 (+)	1.23	1.73 (+)	1.73
	Watauga 6	0.18	0.15 (-)	0.14 (-)	2.13	1.64 (-)	1.70 (+)
	Crawford 5	0.15	0.21 (+)	0.25 (+)	2.32	1.33 (-)	1.43 (+)
One-tree Buffer	Jones 7	0.19	0.14 (-)	0.17 (+)	2.44	2.05 (-)	2.13 (+)
	Skeenah 1	0.16	0.21 (+)	0.17 (-)	1.56	1.72 (+)	1.93 (+)
	Crawford 2	0.55	0.21 (-)	0.28 (+)	1.83	1.32 (-)	1.27 (-)
Non-forested	Jones 6	0.13	0.13	0.13	1.15	1.20 (+)	1.20
	Bates 3	0	0	0	0	0	0
	Watauga 3	0	0	0	0	0	0
All	Average	0.19	0.14 (-)	0.16 (+)	1.65	1.40 (-)	1.40

difference in field methods. Therefore, the significant change in wood frequency noted in several reaches is likely a reflection of dynamic wood loads that vary through time, although mistakes in wood measurement cannot be excluded as a possible explanation. However, even with an allowance of 10% error between surveys, the total number of pieces across all reaches still exhibits a sizeable increase. The reaches that experience the greatest change in wood counts are also among the largest in the sample (Table 4), which may affect wood retention and transport.

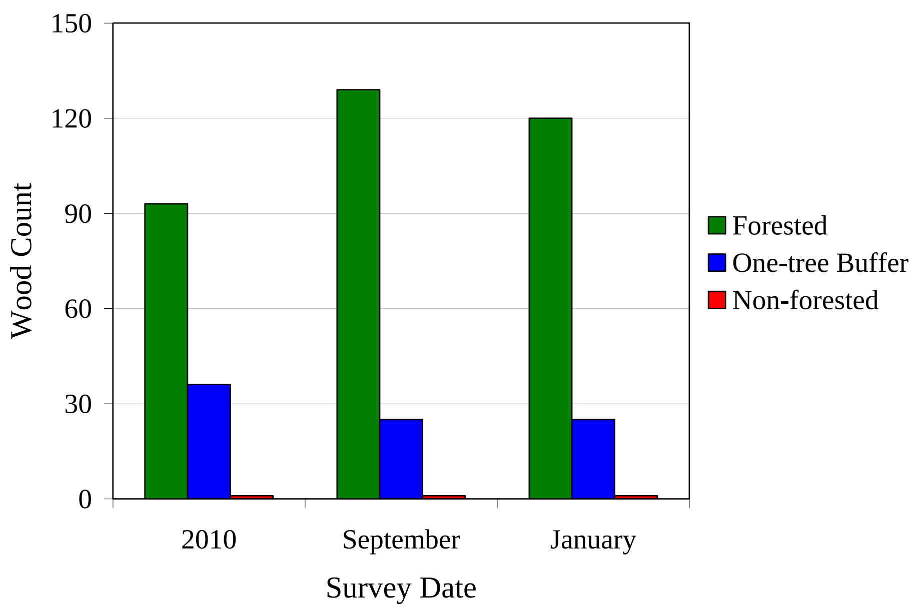


Figure 18 – Change in wood frequency between surveys.

Average diameter, average length, and total volume decrease from 2010 to 2012 (Table 14). In some cases, lower average diameters and lengths appear to result from the input of smaller pieces that shrink the overall value. Such small pieces may account for many of the new additions to Cowee 2 and Rays 5 in 2012; while wood counts increased greatly in these reaches, average diameters and lengths went down, and total volume remained nearly the same, since small pieces do not contribute much to the volume. For other reaches with only a few pieces of wood, which are usually the one-tree buffer and non-forested sites, the input or export of even a single piece can completely change the large wood statistics. In Crawford 2, the 2010 survey found only one piece of wood with a diameter of 0.55 m and a length of 1.83 m, which, therefore, became the average diameter and length values. By 2012, several small pieces had entered the reach, causing a considerable reduction in the average diameter and length.

Aside from these situations, several of the total volume values are drastically lower in 2012, even in reaches with the same or similar wood counts for both dates (Table 14). Ball 2, Rays 1, and Jones 7, which are some of the largest reaches in the sample, have less than half the volume in 2012 of that in 2010, although Rays 1 and Jones 7 do also have fewer pieces. It is unlikely that big pieces responsible for significant portions of the total volume would have moved downstream and out of the reach unless they were in a particularly precarious channel position. However, given the generally low wood loads of some streams in the study area, one or two large logs can comprise the majority of wood volume in reaches; therefore, the great disparity in volume and, to a lesser extent, average size may be due to the misclassification of a few large pieces as in or not in the bankfull channel. This issue seems to arise in wider reaches where the limits of the bankfull channel are perhaps less clear.

Differences in wood measurement techniques may also contribute to the disagreement between surveys. Large wood pieces are rarely cylindrical and are, more often than not, extremely irregularly-shaped. The goal of the surveys was to measure the average diameter and length of each piece, so the tendency to have smaller dimensions and, thus, volumes in 2012 may indicate a more conservative estimate of wood size. Due to the aforementioned issues, the count data is considered to be a more reliable indicator of the amount of wood in each survey.

The wood measurements from September 2012 and January 2013 are much more similar, likely owing to the short amount of time between resurveys—a few months as opposed to two years—and because the same individual collected the data. For this latter reason, more confidence is placed in the comparisons drawn between September and January than those between 2010 and 2012. As was the case with the 2010 and 2012 results, some reaches lost wood from September to January, others gained wood, and some have the same counts for both dates (Table 14). The biggest change is a reduction of 7 pieces in Rays 1, but most sites only differ by one or two pieces. Non-forested reaches with no wood in September continued to have counts of zero in January, and Jones 6 kept its one piece. The total count across all sample reaches decreased by 9 from 155 to 146 pieces, which is entirely attributed to a net loss of wood in forested reaches, as one-tree buffer and non-forested reaches showed no net change in wood frequency (Figure 18). The wood count in January is still 16 pieces greater than that of 2010.

Average length demonstrates no clear increase or decrease following the storm events (Table 14). However, forested and one-tree buffer reaches show slightly higher net average diameters in January, suggesting preferential retention of larger pieces during floods, although high winds and rainfall during storms can also introduce branches and other small pieces of wood (Figure 19). Average diameters do not change among non-forested reaches, as the low to nonexistent wood loads in these streams remain effectively the same from one survey to the next. Total volume barely increases by 0.15 m^3, which is not considered to be a meaningful change.

While the size and amount of wood did not vary greatly over the span of a few months, wood function did exhibit notable changes (Table 15). Most large wood in the sample reaches acts as bank protection, accounting for roughly 85% of the total pieces for both dates. Wood that retains organic matter and sediment increased from 54% to 67% and 34% to 52% of pieces, respectively. This occurrence may be the result of deposition of leaves, branches, and sediment during the falling limb of the last flood. The percentage of pieces forming pools also shows significant growth, although higher streamflows during field work in January may have filled pools that were dry in September. Wood with no function nearly doubled but remained a largely negligible component of the sample reaches. About half of the pieces in both September and January were positioned in jams. The amount of wood in jams increased, and wood protecting banks decreased, but these changes are slight and considered less informative than the other differences noted.

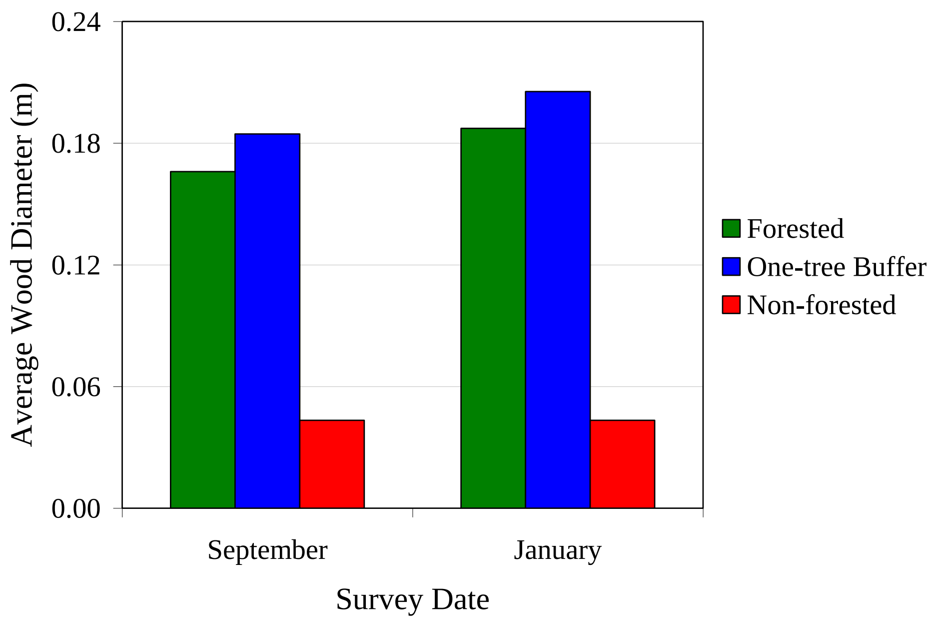


Figure 19 – Change in average wood diameter from September to January after flood events.

It is difficult to compare the midpoint distance of individual pieces, as many share similar dimensions, especially in large, forested reaches. Without flagging the wood or otherwise more thoroughly identifying specific pieces, it is almost impossible to know if pieces in September correspond to those in January, or if they are new inputs. Furthermore, extensive rhododendron and other vegetation in the forested reaches complicates measurement of the midpoint distance, making it unlikely that the survey tape will follow the exact same path twice. Therefore, different distances for a single piece may be due to fluvial transport but also may be a residual of measurement error. For this reason, midpoint distances were not considered in this analysis.

Table 15 – Comparison of wood function and whether or not the pieces are in a jam in September 2012 before the storm events and in January 2013 after the floods.

Function	Percent of Total Pieces Before Floods (%)	Percent of Total Pieces After Floods (%)
Bank Protection (B)	87.74	84.25
Organic Matter Retention (O)	54.19	67.12
Pool Formation (P)	15.48	26.71
Sediment Retention (S)	34.19	52.05
No Function (N)	2.58	4.11
In a Jam (Y)	52.90	56.16

CHAPTER 4

DISCUSSION

1. Riparian and Watershed Landscape Dynamics

Examination of the study area landscape through time demonstrates overall watershed and riparian land cover has remained predominantly forested over the past several decades (Tables C6 and C13). Forested area in the riparian buffer has slightly increased since 1954, possibly owing to agricultural abandonment as well as conservation efforts near streams (Table C7). However, the average trends are skewed by heavily forested watersheds such as Ball and Rays, as Crawford has forest cover in only one-third of its more urbanized watershed and roughly one-half of the riparian area (Tables C6 and C13). Although total forested area has not substantially changed in most watersheds, alteration of the landscape has primarily been in the form of expansion and intensification of development as well as a loss of pasture and increase in transitional shrub and grasslands (Table C12). A decrease in deciduous forest along with growth of evergreen and mixed forests may reflect forest clearing for residential and other development along with afforestation of early-successional pine stands in former agricultural lands.

The most telling indicator of development in the region is the number of road and other stream obstructions over the three time periods (Table C18). The notable increase in obstructions coincides with the findings of Kirk et al. (2012) of 361% more subdivision and private roads and driveways in Macon County between 1954 and 2009, which is a growth rate three times that of population. Roads now also comprise 11-12% of the 10 m watershed-wide buffer in Crawford and Watauga, according to the tax parcel data (Table C31). Though our results do not show large changes in total forested area, the rise in obstructions supports the conclusions of Kirk et al. (2012) that suggest a transformation in the nature of non-forested portions of the study area into a more spread-out suburban landscape.

2. Large Wood Distributions as a Function of the Landscape

Forest cover of the riparian buffer surrounding the reach is one of the most important determinants of wood loads, explaining roughly half the variation in wood frequency and volume. Graphical analysis, however, illustrates correlation between wood distributions and forest cover of not only the immediate riparian area, but also the riparian buffer further upstream. Completely forested reaches generally have greater amounts of wood than one-tree buffer and non-forested reaches, but of the forested channels, heavily forested upstream sites have more wood than those that are moderately forested (Figure 9). Likewise, modeling shows wood frequency tends to decrease with the number of roads upstream, possibly representing the level of development and, therefore, non-forested area. More importantly, this finding lends further support to the observation that factors in the larger watershed can affect wood variability (Finkenbine et al. 2000).

Less wood in moderately forested upstream reaches may be a residual of other riparian characteristics such as stand age, since heavily forested upstream reaches are usually in watersheds with less human influence and likely have more mature forests capable of providing greater wood recruitment to the channel (Hedman et al., 1996; Diez et al., 2001; Keeton et al., 2007). The difference in wood loads between riparian conditions may also imply factors such as water velocity or channel dimensions make heavily forested upstream reaches more retentive than their moderately forested counterparts—an idea that reflects the relationships additionally noted in this study between both local and upstream riparian cover and bankfull width (Figure 10). Whereas Hession et al. (2003) found that urbanization affects channel width regardless of riparian vegetation, our results indicate non-forested area in general can impact width, as total urban area in the watersheds is small (Table C11). Non-forested cover either upstream or around the reach tends to be associated with narrower channels, possibly suggesting a lag effect in which stream width does not fully recover downstream of a non-forested riparian buffer, even if the immediate riparian area is forested. The chemical properties (Golladay and Webster, 1988; Hassan et al., 2003) and velocity (Lepori et al., 2005) of streams have also been shown to impact the breakdown of organic matter, which could have implications for wood decay rates.

Heavily forested reaches, which generally have the most wood, are among the widest in the study. Modeling also reveals a strong, positive relationship between large wood and meander belt width in the case of wood frequency per m length and bankfull width for total volume per m length. The correlation with meander belt width may highlight the importance of lateral erosion of the channel for wood recruitment, but may also simply reflect the fact that forested reaches with wider channels and, therefore, meander belts have more wood. Average meander belt width and bankfull width are extremely collinear, so it is difficult to interpret which aspect of each variable impacts wood distributions. Leigh (2010) noted that the geomorphic floodplains in this region were likely younger than 100 years, reflecting a response and recovery to late 1800s and early 1900s timber harvest. Thus, it is reasonable to think that much of the lateral migration represented by the floodplain has occurred during the last several decades, undoubtedly recruiting wood to the stream in the process.

Pearson’s r correlations between meander belt width and the response variables exhibit weaker relationships among forested reaches than for all study sites (Table 16). Heavily forested upstream reaches have still lower r values than the forested subset, with even one negative coefficient. Volume per m length is an exception, having similar r values across all three reach groupings. Overall worse correlations for forested sites indicate that the significance of meander belt and bankfull width in the models is not simply capturing the fact that forested channels with more wood are wider. The mostly positive associations demonstrating an increase in wood with width may additionally correspond to the higher wood count and volume noted among one-tree buffer and non-forested reaches with distance downstream, which is attributed to the contribution of wood from fluvial transport and less frequent removal of snags by people. This explanation would account for why the correlation between meander belt width and wood is greater when considering all reaches rather than just those that are forested.

Table 16 – Pearson’s r correlations between average meander belt width (AMBW) and the four large wood response variables for all reaches, only the forested reaches, and only the heavily forested reaches. Variables with a significant correlation ($p < 0.05$) have a grey background. Divisions mark the denominators of m channel length and m^2 channel area.

	Pearson's r Correlations Between AMBW and Response Variables		
	All Reaches	Forested Reaches	Forested, Heavily Forested Upstream Reaches
P/m	0.57	0.44	0.31
V/m	0.60	0.54	0.59
P/m²	0.28	0.02	-0.14
V/m²	0.49	0.40	0.27

The link between riparian cover and large wood is clearer for low-order streams with small drainage areas. Extensive fluvial redistribution is unlikely in these portions of the stream network, as is also evidenced by the resurvey results, so there is substantial local control by the riparian buffer on wood loads. In this manner, a forested reach can still have a considerable amount of wood, even if a non-forested reach lies upstream. However, the relationship with riparian condition is less evident in bigger channels. Diez et al. (2001) also note the association between vegetation maturity and wood volume breaks down in larger streams. Moderately forested upstream, one-tree buffer, and non-forested reaches have more wood in terms of both count and volume at several sites (Figures 11-16). All cases occur at greater drainage areas at or near the watershed outlet, suggesting considerable movement of wood from upstream, as sometimes little to no recruitment from the immediate riparian area is possible.

The disconnect between local riparian cover and wood in large channels contrasts with findings of Wohl and Cadol (2011) that local-scale variability in channel and riparian characteristics is the most important determinant of wood distributions in basins less than 100 km^2. Though forest cover in the riparian buffer and geomorphology of the reach do account for substantially more of the variance in large wood than nearly all other landscape factors, our results indicate that, in this environment, immediate riparian condition can be insufficient to explain wood loads in streams with drainage areas less than 20 km^2 (Figures 11-16).

The observed relationships are also not consistent with the conclusions of Wing and Skaugset (2002) that call for more attention to big streams because of chronically low quantities of wood. Regardless of the metric used, some of the largest sites in the study area have wood totals that rival those further upstream, even without a forested riparian buffer. Contrary to the recommendations of Wing and Skaugset (2002), our findings show focusing on large wood in small streams through the maintenance of riparian forest cover and discouragement of wood removal is the best use of resources, as pieces in these upstream locations can supply channels downstream via fluvial transport.

A one-tree buffer roughly corresponding to the 3 m buffer around streams is generally not sufficient to provide wood to the channel, as reaches with this riparian condition often have little to no wood. Forest cover in the 3 m buffer width performs well in modeling wood distributions, especially for total volume, although high correlation with the 10 and 30 m widths suggests that true one-tree buffer reaches are rare in the study area and that this variable, instead, represents more continuous forest in a larger buffer area. Though one-tree buffers do not appear to add much wood to streams, they can be responsible for small, but undoubtedly important, increases in large wood along the longitudinal gradient downstream, if only for the reason that the line of trees blocks the channel from view. Access and visibility of the stream improve the likelihood that people will remove wood for aesthetic reasons and to keep water from pooling up around obstructions (Sakura Evans, personal correspondence, January 23, 2013). In this manner, one-tree buffers can deter human interference and, thus, help maintain greater overall wood totals than if reaches were completely non-forested.

Other studies recommend buffers of at least 20 m, although this value can vary with stand age and tree height (McDade et al., 1990; Reid and Hilton, 1998; Diez et al., 2001; Benda et al., 2002; May and Gresswell, 2003). Local riparian cover in the 10 m buffer had the highest correlation with wood count and volume in our study, which could reflect the average height of trees in the region or signify that this buffer size contributes most to large wood in the channel. However, similar model performance with riparian cover in the 3 and 30 m widths does not provide a good basis for asserting that the 10 m width is the most critical for wood.

3. Large Wood Transience in Streams

While more extensive data are needed to understand large wood transience at the reach scale over the course of months or years, resurvey results suggest wood frequency in larger streams with some forest cover is most likely to show significant variation. The greatest change in wood counts from 2010 to September 2012 and from September to January 2013 generally occurred among the widest forested and one-tree buffer reaches in the sample (Tables 4 and 14). Non-forested reaches, on the other hand, maintained the same, low wood loads throughout all surveys. Bigger reaches in our study were also more prone to survey and measurement error, based on some of the conflicting total volume values (Table 14). However, even with an allowance of 10% error between surveys for mistakes during the identification of pieces in the bankfull channel, the difference in counts is still considerable for some of the large reaches.

Increased variability in wood loads in these streams is likely a result of higher streamflows in bigger channels capable of moving wood downstream. Diez et al. (2001), Martin and Benda (2001), and Marcus et al. (2002) also found wood to be more unstable and subject to fluvial transport in streams with greater drainage areas, whereas mobility is much lower in headwater reaches. Some degree of forest cover in the riparian area can provide wood inputs to the channel but, additionally, obscures the stream from view and reduces access; landowners tend to remove wood that falls or washes into non-forested reaches that is noticeable to themselves or others, thus, eliminating any change in wood frequency that the reaches might otherwise demonstrate (Sakura Evans, personal correspondence, January 23, 2013). However, the non-forested reaches in our resurvey sample are all small, so wood counts may vary more at bigger non-forested sites further downstream, where more wood transport is possible, and people are less apt to take pieces out of the channel.

No definitive conclusions can be drawn concerning changes in wood size and volume from 2010 to 2012 because of potential sources of measurement error that exceed an allowance of 10% difference between surveys. Comparison of resurvey results from September and January does show a slight increase in average diameter (Figure 19), although average length remains the same. The decrease in overall wood count along with a greater average diameter suggests that winter floods washed out some of the smaller pieces that had accumulated over a dry fall by the end of September, with no rains to wash them out. The functions of wood also shifted after the storm events, with more pieces acting to store sediment and organic matter carried by floods, although most large wood in these streams still serves as channel bank protection (Table 15).

CHAPTER 5

CONCLUSION

Large wood in streams varies as a function of landscape factors both in the immediate riparian area and upstream. Forest cover of the riparian buffer at the scale of the reach is the single most important variable determining wood amounts, and sites with considerable non-forested area and development upstream tend to have less wood. The relationship between riparian cover and large wood breaks down at larger drainage areas of 10 to 20 km^2, at which point the riparian condition is no longer the primary influence on wood loads due to increased fluvial transport from upstream as well as a lack of human interference in big streams. The significance of meander belt and bankfull width in the models also likely corresponds to the greater potential for wood movement and less frequent snag removal downstream, although wood recruitment as a result of more lateral erosion appears to be another contributing factor. Fluvial redistribution was evident during the resurveys as well, as wood counts in wider reaches changed more drastically over time than at narrower sites. Our findings suggest substantial local control of wood distributions by riparian vegetation in small channels but much less of a connection in large, downstream reaches. Management efforts for large wood should, therefore focus on small streams ($< \sim 15 km^2$) that derive practically all of their wood from the nearby riparian area.

While one-tree riparian buffers generally supply minimal wood to channels, an optimal buffer width for the study area is not apparent from the statistical analysis. Buffers wider than 3 m are clearly necessary for adequate amounts of wood, but even narrow strips of forest cover decrease stream visibility and access. Although recruitment of wood into the stream is low for one-tree buffers, the pieces that do make their way into the channel are less likely to be removed by people. One-tree buffers can, therefore, be suggested as an option for landowners that do not want extensive forested area around streams because of the loss of agricultural acreage or for other reasons.

Large wood distributions are dynamic through time, with the greatest variation occurring in wide, forested reaches. Small, non-forested reaches did not demonstrate any change in wood loads, implying both a lack of recruitment from the riparian buffer as well as no fluvial transport from upstream or, conversely, persistent removal of wood by people. Floods can change the average size of wood in the channel by washing out small pieces that accumulate in the stream during relatively dry periods. Storm events additionally alter the functions of wood, with more pieces acting to store sediment and organic matter carried by the flood.

REFERENCES

Angradi, T.R., Schweiger, E.W., Bolgrien, D.W., Ismert, P., and Selle, T., 2004, Bank stabilization, riparian land use and the distribution of large woody debris in a regulated reach of the upper Missouri River, North Dakota, USA: River Research and Applications, v. 20, no. 7, p. 829-846.

Beechie, T.J., Pess, G., Kennard, P., Bilby, R.E., and Bolton, S., 2000, Modeling recovery rates and pathways for woody debris recruitment in northwestern Washington streams: North American Journal of Fisheries Management, v. 20, no. 2, p. 436-452.

Beechie, T.J., and Sibley T.H., 1997, Relationships between channel characteristics, woody debris, and fish habitat in northwestern Washington streams: Transactions of the American Fisheries Society, v. 126, no. 2, p. 217-229.

Benda, L.E., Bigelow, P., and Worsley, T.M., 2002, Recruitment of wood to streams in old-growth and second-growth redwood forests, northern California, U.S.A.: Canadian Journal of Forest Research, v. 32, no. 8, p. 1460-1477.

Bilby, R.E., and Likens, G.E., 1980, Importance of organic debris dams in the structure and function of stream ecosystems: Ecology, v. 61, no. 5, p. 1107-1113.

Bilby, R.E., and Ward, J.W., 1989, Changes in characteristics and function of woody debris with increasing size of streams in western Washington: Transactions of the American Fisheries Society, v. 118, no. 4, p. 368-378.

Bragg, D.C., 2000, Simulating catastrophic and individualistic large woody debris recruitment for a small riparian system: Ecology, v. 81, no. 5, p. 1383-1394.

Curran, J.H., and Wohl, E.E., 2003, Large woody debris and flow resistance in step-pool channels, Cascade Range, Washington: Geomorphology, v. 51, no. 1-3, p. 141-157.

Davies-Colley, R.J., 1997, Stream channels are narrower in pasture than in forest, New Zealand: Journal of Marine and Freshwater Research, v. 31, no. 5, p. 599-608.

Diez, J.R., Elosegi, A., and Pozo, J., 2001, Woody debris in north Iberian streams: influence of geomorphology, vegetation, and management: Environmental Management, v. 28, no. 5, p. 687-698.

Fetherston, K.L., Naiman, R.J., and Bilby, R.E., 1995, Large woody debris, physical process, and riparian forest development in montane river networks of the Pacific Northwest: Geomorphology, v 13, no. 1-4, p. 133-144.

Finkenbine, J.K., Atwater, J.W., and Mavinic, D.S., 2000, Stream health after urbanization: Journal of the American Water Resources Association, v. 36, no. 5, p. 1149-1160.

Gerhard, M., and Reich, M., 2000, Restoration of streams with large wood: effects of accumulated and built-in wood on channel morphology, habitat diversity, and aquatic fauna: International Review of Hydrobiology v. 85, no. 1, p. 123-137.

Golladay, S.W., and Webster, J.R., 1988, Effects of clear-cut logging on wood breakdown in Appalachian mountain streams: American Midland Naturalist, v. 119, no. 1, p. 143-155.

Gurnell, A.M., Piégay, H., Swanson, F.J., and Gregory, S.V., 2002, Large wood and fluvial processes: Freshwater Biology, v. 47, no. 4, p. 601-619.

Hassan, M.A., Hogan, D.L., Bird, S.A., May, C.L., Gomi, T., and Campbell, D., 2005, Spatial and temporal dynamics of wood in headwater streams of the Pacific Northwest: Journal of the American Water Resources Association, v. 41, no. 4, p. 899-919.

Hedman, C.W., Van Lear, D.H., and Swank, W.T., 1996, In-stream woody debris loading and riparian forest seral stage associations in the southern Appalachian Mountains: Canadian Journal of Forest Research, v. 26, no. 7, p. 1218-1227.

Hession, W.C., Pizzuto, J.E., Johnson, T.E., and Horwitz, R.J., 2003, Influence of bank vegetation on channel morphology in rural and urban watersheds: Geology, v. 31, no. 2, p. 147-150.

Hilderbrand, R.H., Lemly, A.D., Dollof, C.A., and Harpster, K.L., 1998, Design considerations for large woody debris placement in stream enhancement projects: North American Journal of Fisheries Management, v. 18, no. 1, p. 161-167.

Jackson, C.R., and Sturm, C.A., 2002, Woody debris and channel morphology in first- and second-order forested channels in Washington’s coast ranges: Water Resources Research, v. 38, no. 9, doi: 10.1029/2001WR001138.

Kang, R.S., and Marston. R.A., 2006, Geomorphic effects of rural-to-urban land use conversion on three streams in the Central Redbed Plains of Oklahoma: Geomorphology, v. 79, no. 3, p. 488-506.

Keeton, W.S., Kraft, C.E., and Warren, D.R., 2007, Mature and old-growth riparian forests: structure, dynamics, and effects on Adirondack stream habitats: Ecological Applications, v. 17, no. 3, p. 852-868.

Keller, E.A., and Swanson, F.J., 1979, Effects of large organic material on channel form and fluvial processes: Earth Surface Processes, v. 4, no. 4, p. 361-380.

Kirk, R.W., Bolstad, P.V., and Manson, S.M., 2012, Spatio-temporal trend analysis of long-term development patterns (1900-2030) in a southern Appalachian county: Landscape and Urban Planning, v. 104, p. 47-58.

Kirk, R.W., 2009, Land use and terrestrial carbon storage in western North Carolina from 1850-2030: a historical reconstruction and simulation study: University of Minnesota, 167 p.

Lautz, L.K., Siegel, D.I., and Bauer, R.L., 2006, Impact of debris dams on hyporheic interaction along a semi-arid stream: Hydrological Processes, v. 20, no. 1, p. 183-196.

Leigh, D.S., 2010, Morphology and channel evolution of small streams in the Southern Blue Ridge Mountains of western North Carolina: Southeastern Geographer, v. 50, no. 4, p. 397-421.

Lepori, F., Palm, D., and Malmqvist, B., 2005, Effects of stream restoration on ecosystem functioning: detritus retentiveness and decomposition: Journal of Applied Ecology, v. 42, no. 2, p. 228-238.

Marcus, W.A., Marston, R.A., Colvard Jr., C.R., and Gray, R.D., 2002, Mapping the spatial and temporal distributions of woody debris in streams of the Greater Yellowstone Ecosystem, USA: Geomorphology, v. 44, no. 3, p. 323-335.

Marston, R.A., 1982, The geomorphic significance of log steps in forest streams: Annals of the Association of American Geographers, v. 72, no. 1, p. 99-108.

Martin, D.J., 2001, The influence of geomorphic factors and geographic region on large woody debris loading and fish habitat in Alaska coastal streams: North American Journal of Fisheries Management, v. 21, no. 3, p. 429-440.

Martin, D.J., and Benda, L.E., 2001, Patterns of instream wood recruitment and transport at the watershed scale: Transactions of the American Fisheries Society, v. 130, no. 5, p. 940-958.

May, C.L., and Gresswell, R.E., 2003, Large wood recruitment and redistribution in headwater streams in the southern Oregon Coast Range, U.S.A.: Canadian Journal of Forest Research, v. 33, no. 8, p. 1352-1362.

McDade, M.H., Swanson, F.J., McKee, W.A., Franklin, J.F., and Van Sickle, J., 1990, Source distances for coarse woody debris entering small streams in western Oregon and Washington: Canadian Journal of Forest Research, v. 20, no. 3, p. 326-330.

Montgomery, D.R., Buffington, J.M., Smith, R.D., Schmidt, K.M., and Pess, G., 1995, Pool spacing in forest channels: Water Resources Research, v. 31, no. 4, p. 1097-1105.

Montgomery, D.R., Massong, T.M., and Hawley, S.C.S., 2003, Influence of debris flows and log jams on the location of pools and alluvial channel reaches, Oregon Coast Range: Geological Society of America Bulletin, v. 115, no. 1, p. 78-88.

Nakamura, F., and Swanson, F.J., 1993, Effects of coarse woody debris on morphology and sediment storage of a mountain stream system in western Oregon: Earth Surface Processes and Landforms, v. 18, no. 1, p. 43-61.

Nakamura, F., Swanson, F.J., and Wondzell, S.M., 2000, Disturbance regimes of stream and riparian systems—a disturbance-cascade perspective: Hydrological Processes, v. 14, p. 2849-2860.

Piégay, H., and Gurnell, A.M., 1997, Large woody debris and river geomorphological pattern: examples from S.E. France and S. England: Geomorphology, v 19, no. 1, p. 99-116.

Pittillo, J. D., Hatcher, R. D., Jr., and Buol, S. W., 1998, Introduction to the environment and vegetation of the Southern Blue Ridge Province: Castanea, v. 63, no. 3, p. 202-216.

Price, K., and Jackson, C.R., 2007, Effects of forest conversion on baseflows in the Southern Appalachians: a cross-landscape comparison of synoptic measurements: Proceedings of the 2007 Georgia Water Resources Conference, held March 27-29, 2007, at the University of Georgia.

Reid, L.M., and Hilton, S., 1998, Buffering the buffer: USDA Forest Service General Technical Report PSW-GTR-168-Web.

Robinson Jr., G.R., Lesure, F.G., Marlowe, II J.I., Foley, N.K., and Clark, S.H., 1992, Bedrock geology and mineral resources of the Knoxville 1 degree by 2 degrees quadrangle, Tennessee, North Carolina, and South Carolina: U.S. Geological Survey Bulletin 1979.

Robison, E.G., and Beschta, R.L., 1990, Characteristics of coarse woody debris for several coastal streams of southeast Alaska, USA: Canadian Journal of Fisheries and Aquatic Sciences, v. 47, no. 9, p. 1684-1693.

Roni, P., Beechie, T.J., Bilby, R.E., Leonetti, F.E., Pollock, M.M., and Pess, G.R., 2002, A review of stream restoration techniques and a hierarchical strategy for prioritizing restoration in Pacific Northwest watersheds: North American Journal of Fisheries Management, v. 22, no. 1, p. 1-20.

Roth, N.E., Allan, J.D., and Erickson, D.L., 1996, Landscape influences on stream biotic integrity assessed at multiple spatial scales: Landscape Ecology, v. 11, no. 3, p. 141-156.

Sawyer, A.H., Cardenas, M.B., and Buttles, J., 2011, Hyporheic exchange due to channel-spanning logs: Water Resources Research, v. 47, no. 8, W08502, doi: 10.1029/2011WR010484.

SERCC, 12/01/1942 to 04/30/2012, Climate data for Coweeta Exp Stn, North Carolina, <http://www.sercc.com/cgi-bin/sercc/cliMAIN.pl?nc2102> Accessed January 13, 2013.

Sobota, D.J., Gregory, S.V., and Sickle, J.V., 2006, Riparian tree fall directionality and modeling large wood recruitment to streams: Canadian Journal of Forest Research, v. 36, no. 5, p. 1243-1254.

Swanson, F.J., 2003, Wood in rivers: a landscape perspective: American Fisheries Society Symposium, v. 37, p. 299-213.

Trotter, E.H., 1990, Woody debris, forest-stream succession, and catchment geomorphology: Journal of the North American Benthological Society, v. 9, no. 2, p. 141-156.

Van Sickle, J., and Gregory, S.V., 1990, Modeling inputs of large woody debris to streams from falling trees: Canadian Journal of Forest Research, v. 20, no. 10, p. 1593-1601.

Vandermast, D.B., and Van Lear, D.H., 2002, Riparian vegetation in the southern Appalachian mountains (USA) following chestnut blight: Forest Ecology and Management, v. 155, no. 1, p. 97-106.

Wallace, J.B., Webster, J.R., Eggert, S.L., Meyer, J.L., and Siler, E.R., 2001, Large woody debris in a headwater stream: long-term legacies of forest disturbance: International Review of Hydrobiology, v. 86, no. 4-5, p. 501-513.

Walsh, C.J., Waller, K.A., Gehling, J., and MacNally, R., 2007, Riverine invertebrate assemblages are degraded more by catchment urbanisation than by riparian deforestation: Freshwater Biology, v. 52, no. 3, p. 574-587.

Walters, D.M., Roy A.H., and Leigh, D.S., 2009, Environmental indicators of macroinvertebrate and fish assemblage integrity in urbanizing watersheds: Ecological Indicators, v. 9, no. 6, p. 1222-1233.

Webster, J.R., Covich, A.P., Tank, J.L., and Crockett, T.V., 1994, Retention of coarse organic particles in streams in the southern Appalachian Mountains: Journal of the North American Benthological Society, v. 13, no. 2, p. 140-150.

Wing, M.G., and Skaugset, A., 2002, Relationships of channel characteristics, land ownership, and land use patterns to large woody debris in western Oregon streams: Canadian Journal of Fisheries and Aquatic Sciences, v. 59, no. 5, p. 796-807.

Wohl, E., and Cadol, D., 2011, Neighborhood matters: patterns and controls on wood distribution in old-growth forest streams of the Colorado Front Range, USA: Geomorphology, v. 125, no. 1, p. 132-146.

Wood-Smith, R.D., and Buffington, J.M., 1996, Multivariate geomorphic analysis of forest streams: implications for assessment of land use impacts on channel condition: Earth Surface Processes and Landforms, v. 21, no. 4, p. 277-393.

APPENDIX A

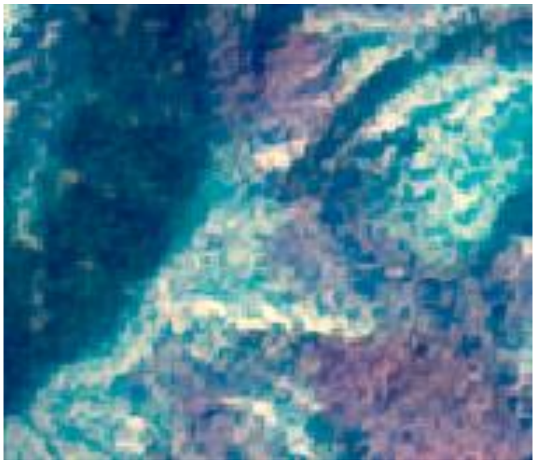
FOREST COVER CLASSIFICATION KEY FOR AERIAL PHOTOGRAPHS

A. The forested category includes deciduous and coniferous trees of any maturity.

B. The non-forested category includes grass, bare ground, buildings, and roads.

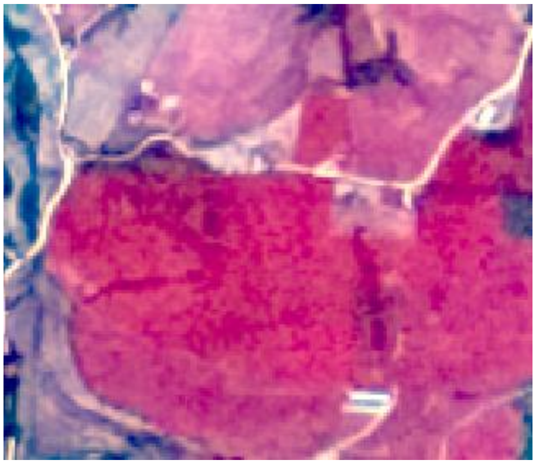
C. Transitional vegetation from grass and shrubs to trees remains in the non-forested category.

Figure A1. Forested (A) and non-forested (B and C) classification key for the 2007 aerial photographs.



A. Forested areas appear textured and range in color from purple to light and dark blue.

B. Developed areas and roads have a white reflectance.



C. Agricultural fields and grass appear smooth, ranging in color from light blue or pink to red.

Figure A2. Forested (A) and non-forested (B and C) classification key for the 1984 aerial photographs.

A. Forested areas appear textured and usually have a darker reflectance than non-forested areas.

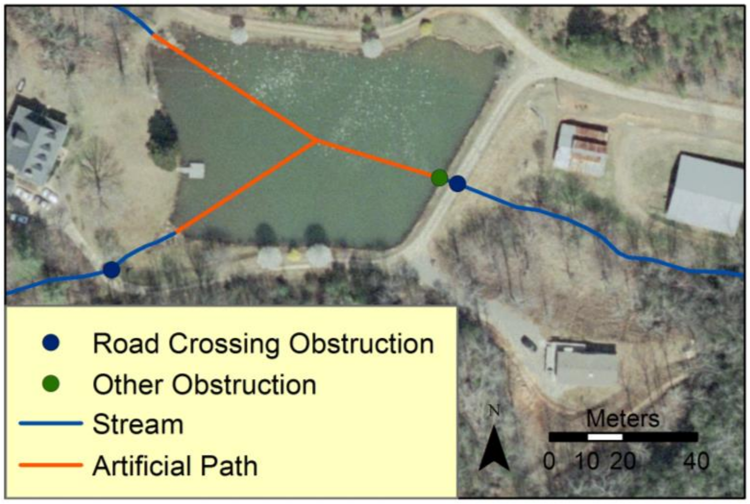
B. Grass and agricultural fields have a lighter reflectance than forests and appear smooth, while roads are white.

C. Building shapes are recognizable in urban areas.

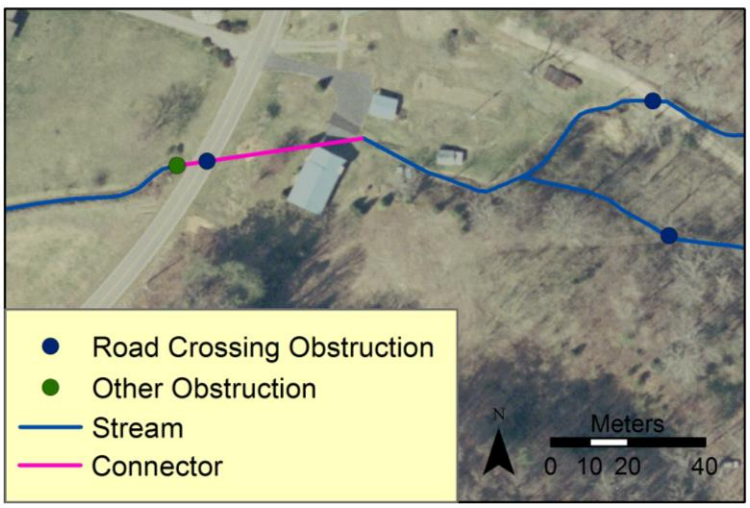
Figure A3. Forested (A) and non-forested (B and C) classification key for the 1954 aerial photographs.

APPENDIX B

OBSTRUCTION IDENTIFICATION KEY FOR AERIAL PHOTOGRAPHS

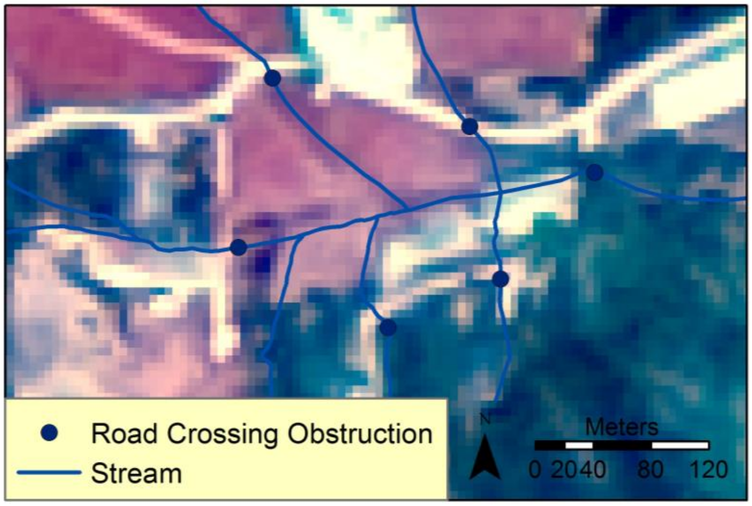


A. The NHD denotes some reservoirs as an Artificial Path.

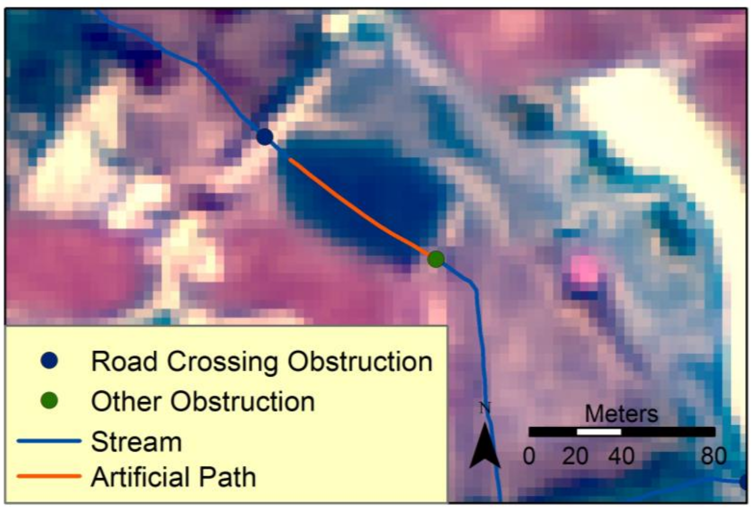


B. The NHD denotes pipelines and other water conveyance structures as a Connector.

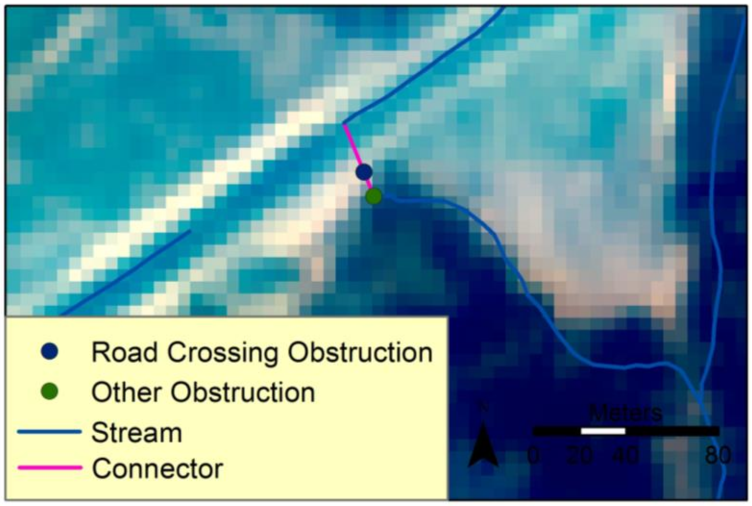
Figure B1. Identification of roads and other obstructions to wood transport in 2007 such as reservoirs (A) and underground pipelines (B) in the aerial photographs.



A. Roads appear white and are recognizable by their linear form and pattern.

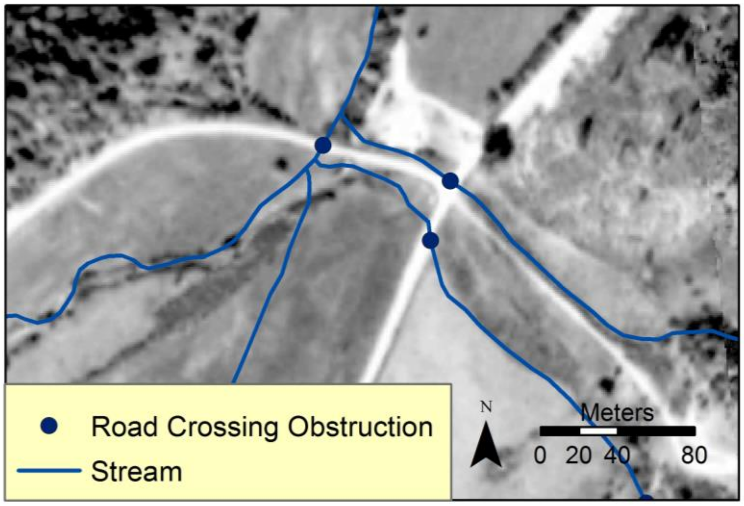


B. Reservoirs appear blue and often coincide with the Artificial Paths denoted in the NHD.

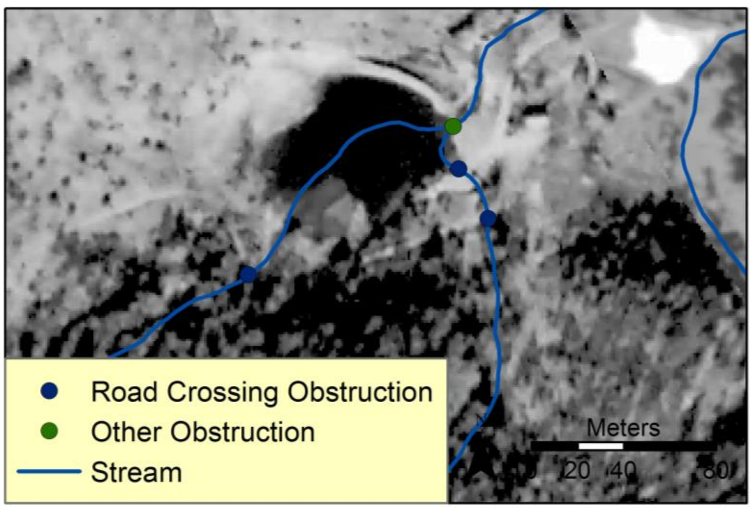


C. Many pipelines present in 2007 as Connectors in the NHD are also evident in 1984.

Figure B2. Identification of roads (A) and other obstructions to wood transport in 1984 such as reservoirs (B) and underground pipelines (C) in the aerial photographs.



A. Roads appear white and are recognizable by their linear form and pattern.



B. Reservoirs rarely coincide with the Artificial Paths denoted by the NHD.

Figure B3. Identification of roads (A) and other obstructions to wood transport in 1954 such as reservoirs (B) in the aerial photographs.

APPENDIX C

SPATIAL ANALYSIS DATA

Table C1. Percent forest cover of the study reach as determined by digitizing at 3, 10, and 30 m buffer widths from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Reach	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball 1	100	100	94.14	100	100	100	96.30	91.39	73.47
Ball 2	100	100	99.40	80.74	82.13	82.77	100	100	95.80
Ball 3	100	100	100	100	100	99.04	97.81	93.99	92.33
Ball 4	100	100	100	62.80	65.54	73.26	100	100	99.42
Ball 5	100	100	100	100	100	100	100	100	100
Bates 1	24.61	31.53	17.96	8.09	6.47	17.51	0	0	6.24
Bates 2	73.42	39.31	48.27	100	100	96.55	45.99	47.57	63.57
Bates 3	0	0	0	0	0	0	0	0	0
Bates 4	91.20	72.50	62.43	100	100	94.80	100	95.81	78.92
Bates 5	0	0	10.15	0	0.08	15.65	0	0	2.74
Bates 6	100	100	87.70	67.51	66.81	68.82	71.89	69.94	59.24
Caler 1	0	0	0.40	0	0	9.10	33.84	22.63	17.21
Caler 2	79.02	72.43	52.36	65.60	64.36	65.52	100	96.18	65.66
Caler 3	100	100	96.30	83.01	79.34	77.26	100	100	100
Caler 4	49.81	49.19	43.07	75.24	64.51	46.59	46.10	46.41	50.40
Caler 5	96.52	90.67	65.26	100	100	86.49	96.09	74.21	76.02
Cowee 1	98.60	95.72	83.94	60.80	63.13	83.94	100	99.11	83.20
Cowee 2	100	100	100	58.35	59.06	61.43	100	100	100
Cowee 3	5.76	29.30	52.27	0	0	5.68	30.16	28.84	31.28
Cowee 4	17.57	20.82	12.52	0	0	2.30	0	0	4.17
Cowee 5	34.63	31.69	15.15	0	0	5.27	60.25	52.76	30.09
Crawford 1	68.45	73.89	56	53.64	52.12	61.47	21.13	21.29	29.34
Crawford 2	10.30	27.04	41.34	100	100	82.56	51.63	54.57	54.63
Crawford 3	0	0	0	0	0	0	48.28	45.21	30.27
Crawford 4	100	93.50	83.88	100	100	97.77	100	100	100
Crawford 5	0	1.72	29.75	100	100	100	59.96	66.87	65.63
Crawford 6	31.40	39.96	35.39	100	100	96.91	99.60	85.08	57.65
Jones 1	100	100	87.31	50.33	51.02	53.08	66.54	66.84	60.36
Jones 2	84.54	77.77	68.44	83.15	82.87	86.06	100	100	100
Jones 3	100	100	100	100	100	100	100	100	100
Jones 4	100	100	100	91.95	83.61	81.16	100	100	100
Jones 5	100	90.15	44.74	36.42	36.71	29.72	63.28	61.93	36.42
Jones 6	0	0	0	0	0	0.40	0	0	1.61
Jones 7	13.51	8.09	4.41	0	0	0	90.02	66.06	22.43

Rays 1	100	100	100	100	100	100	100	100	94.29
Rays 2	100	100	100	100	100	100	100	100	100
Rays 3	100	100	100	100	100	100	89.03	91.05	93.35
Rays 4	67.79	69.67	79.88	60.57	59.80	49.58	66.18	68.03	76.04
Rays 5	100	100	100	100	100	98.65	100	100	100
Skeenah 1	47.30	36.61	13.62	0	0.00	1.04	49.66	41.20	16.63
Skeenah 2	60.70	64.24	67.70	100	100	100	100	100	100
Skeenah 3	0	5.37	7.96	0	0	0	0	0	2.99
Skeenah 4	0	21.40	13.36	0	3.50	10.33	27.55	11.90	7.75
Skeenah 5	100	100	100	100	100	100	100	100	100
Watauga 1	0	0	0	21.91	19.02	6.11	31.28	29.46	16.60
Watauga 2	0	0	0.28	0	0	0	0	0	21.28
Watauga 3	0	0	0	0	0	0	0	0	0
Watauga 4	100	100	99.81	100	100	100	100	99.84	90.03
Watauga 5	100	100	91.97	100	100	100	100	100	94.76
Watauga 6	100	100	100	100	100	100	100	100	93.91
Average	61.10	60.85	57.34	59.20	58.80	58.94	66.85	64.56	59.91

Table C2. Percent forest cover 100 m upstream of the study reach as determined by digitizing at 3, 10, and 30 m buffer widths from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Reach	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball 1	100	100	95.30	100	100	100	90.95	89.80	71.27
Ball 2	100	100	100	100	100	100	100	100	100
Ball 3	100	100	100	43.18	50.20	74.03	100	100	100
Ball 4	100	100	100	90.13	87.34	81.52	100	100	100
Ball 5	100	100	100	100	100	100	99.02	97.10	95.41
Bates 1	78.55	67.52	57.01	37.50	36.70	41.02	41.09	38.28	26.21
Bates 2	88.29	61.84	51.56	100	100	100	75.83	75.91	79.63
Bates 3	0	0	0.00	0	0	0	22.08	18.26	7.85
Bates 4	100	98.70	75.03	20.34	30.15	41.24	3.84	7.06	15.96
Bates 5	0	4	26.51	48.44	48.47	45.29	0	0	10.30
Bates 6	88.35	81.70	64.73	51.15	55.88	68.71	64.25	58.59	54.13
Caler 1	3.25	2.47	1.74	10.55	10.61	15.14	44.55	32.57	17.74
Caler 2	39.48	37.15	41.24	36.33	39.14	56.90	44.89	47.06	57.75
Caler 3	100	100	98.22	100	100	99.48	100	100	100
Caler 4	95.07	91.27	88.20	88.30	82.09	66.45	82.45	80.71	73.59
Caler 5	100	99.97	86.91	100	100	98.88	98.89	89.30	84.53
Cowee 1	48.98	50.99	54.26	67.43	67.68	67.52	87.64	86.35	74.86
Cowee 2	100	100	100	96.98	92.34	71.59	100	100	99.99
Cowee 3	97.20	88.84	75.49	24.53	24.73	33.23	62.14	58.81	54.07
Cowee 4	95.66	89.70	65.43	28.56	32.19	44.60	73.37	64.88	45.46
Cowee 5	30.81	30.19	25.30	26.31	27.62	27.56	61.33	58.05	35.32
Crawford 1	20.40	26	32.21	50.98	51.52	50.63	18.84	18.21	23.25
Crawford 2	20.98	26.43	32.56	66.05	76.29	61.32	99.23	96.28	71.23
Crawford 3	0	0.00	0	6.17	10.35	5.87	46.70	43.87	27.49
Crawford 4	100	100	96.48	100	100	100	100	100	100
Crawford 5	32.90	39.39	45.97	100	100	100	99.83	96.19	78.41
Crawford 6	100	90.51	65.50	100	100	100	48.52	43.76	37.84
Jones 1	90.63	89.81	89.58	88.68	86.23	74.76	80.99	78.24	75.90
Jones 2	100	97.76	78.53	100	99.38	86.76	100	100	100
Jones 3	100	100	100	100	100	100	100	100	100
Jones 4	100	100	100	99.15	95.35	79.31	100	100	97.15
Jones 5	51.59	49.89	32.21	0	0.89	7.72	62.21	48.44	28.31
Jones 6	49.50	47.14	35.36	40.61	40.72	27.01	51.94	48.10	26.29
Jones 7	25.50	26.27	25.32	9.80	12.01	11.91	47.10	33.62	24.25

Rays 1	100	100	100	100	100	100	100	100	100
Rays 2	100	100	100	100	100	100	100	100	100
Rays 3	100	100	100	100	100	100	100	100	98.49
Rays 4	80.64	78.64	83.22	69.80	71.69	73.60	78.44	76.37	76.26
Rays 5	100	100	100	100	99.99	99.13	100	100	100
Skeenah 1	26.25	24.94	12.93	8.40	10.19	11.36	25.43	22.10	17.71
Skeenah 2	74.55	73.73	80.12	100	100	100	100	100	100
Skeenah 3	59.90	46.30	31.09	24.09	20.03	28.10	0	0	11.78
Skeenah 4	23.30	22.99	12.80	2.45	6.44	15.07	14.22	7.89	5.83
Skeenah 5	100	100	100	100	100	100	100	100	100
Watauga 1	0	0	0	21.98	21.48	11.99	47.77	24.01	9.64
Watauga 2	0	0	0.67	0	0	0	21.82	19.45	23.36
Watauga 3	0	0	0	0	0	0	2.72	2.51	6.15
Watauga 4	100	100	100	100	100	100	100	95.63	93.31
Watauga 5	89.15	89.74	89.27	93.99	94.63	95.22	94.04	93.67	92.57
Watauga 6	100	100	100	100	100	100	100	93.96	84.32
Average	68.22	66.68	63.02	63.04	63.65	63.46	69.84	66.90	62.27

Table C3. Percent forest cover 500 m upstream of the study reach as determined by digitizing at 3, 10, and 30 m buffer widths from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Reach	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball 1	100	100	97.06	100	100	100	97.52	97.59	92.34
Ball 2	100	100	100	100	100	100	100	100	100
Ball 3	100	100	100	77.18	80.23	85.62	96.06	94.97	91.90
Ball 4	100	100	100	84.52	86.39	89.07	93.96	93.44	94.76
Ball 5	100	100	100	91.11	91.76	93.40	99.90	99.67	99.33
Bates 1	42.94	45.99	39.78	49.76	48.08	39.06	30.66	29.35	24.41
Bates 2	74.88	66.89	53.33	33.39	35.65	37.96	39.69	35.46	34.35
Bates 3	40.30	40.74	45.83	37.66	38.05	42.64	54.42	52.45	52.88
Bates 4	71.20	63.35	49.26	35.53	37.23	36.38	46.02	40.11	36.95
Bates 5	70.08	69.42	65.74	65.19	66.06	70.75	59.90	60.44	63.12
Bates 6	77.44	79.25	80.11	87.68	87.98	91.02	85.36	85.04	84.62
Caler 1	5.61	4.44	2.46	8.05	8.39	11.42	48.09	37.49	19.69
Caler 2	32.14	32.59	39.13	70.30	71.47	79.19	66.55	66.28	69.53
Caler 3	100	100	98.41	100	99.92	98.25	100	100	99.81
Caler 4	99	98.15	97.27	91.80	90.43	86.33	94.93	93.89	91.70
Caler 5	100	100	98.23	90.70	90.86	87.37	87.27	83.72	80.15
Cowee 1	38.82	37.34	38.78	48.60	49.52	51.82	55.68	52.80	49.09
Cowee 2	100	100	100	88.06	87.44	84.61	97.10	96.44	93.71
Cowee 3	79.82	79.37	71.93	42.81	46.18	52.37	59.22	61.41	68.28
Cowee 4	48.09	44.54	38.98	51.67	52.49	55.80	62.30	58.34	50.08
Cowee 5	48.54	47.15	42.56	42.55	44.15	51.38	60.96	59.82	54.05
Crawford 1	14.62	15.72	20.47	17.78	18.57	20.87	8.43	8.83	11.93
Crawford 2	16.24	16.88	21.16	35.29	36.77	33.74	49.68	47.05	33.73
Crawford 3	12.04	11.15	11.34	17.87	17.88	16.88	32.73	31.07	26.51
Crawford 4	69.63	70.33	66.12	76.22	75.77	76.24	87.08	87.63	83.96
Crawford 5	31.23	28.37	23.93	61.83	63.86	63.56	54.64	53.57	42.58
Crawford 6	92.16	88.17	84.91	92.98	92.49	91.59	62.85	62.80	56.55
Jones 1	74.78	74.31	70.59	80.22	79.65	75.25	68.52	65.04	63.31
Jones 2	100	99.51	95.89	99.14	98.44	95.90	98.51	98.34	97.47
Jones 3	100	99.83	99.04	98.30	97.97	97.16	98.49	98.51	98
Jones 4	100	100	100	91.19	90.17	91.45	93.39	93.08	93.85
Jones 5	84.72	83.41	72.05	84.59	85.58	86.25	77.36	73.39	64.23
Jones 6	84.64	82.63	67.98	71.26	72.45	71.43	73.80	68.53	51.64
Jones 7	48.82	46.38	40.91	57.08	56.63	57.04	48.01	46.66	48.55

Rays 1	100	100	100	100	100	100	100	100	100
Rays 2	100	100	100	100	100	100	100	99.93	99.68
Rays 3	100	100	100	100	100	100	100	100	99.71
Rays 4	92.45	92.40	95.32	88.80	89.45	89.12	88.51	88.01	88.88
Rays 5	100	100	100	100	100	99.79	100	100	100
Skeenah 1	33.81	29.93	22.33	45.34	45.43	43.01	38.26	35.82	34.24
Skeenah 2	95.42	95.00	95.72	98.15	98.48	98.09	100	100	100
Skeenah 3	39.20	38.10	42.90	88.93	88.25	87.50	71.88	74.18	78.67
Skeenah 4	48.32	43.94	44.78	52.18	54.21	60.39	42.95	44.26	45.71
Skeenah 5	100	100	100	100	100	100	100	100	100
Watauga 1	15.22	15.08	13.61	17.25	16.99	14.76	45.91	38.27	29.48
Watauga 2	39.10	40.69	49.10	30.69	32.24	37.87	44.74	45.37	51.28
Watauga 3	36.49	37.10	36.57	34.59	34.43	33.02	55.94	52.99	50.90
Watauga 4	100	100	100	100	100	100	98.86	96.88	95.74
Watauga 5	96.96	97.08	95.61	96.66	96.27	96.32	96.86	95.74	91.27
Watauga 6	96.12	95.65	92.65	86.18	85.66	84.27	88.66	86.19	85.36
Average	71.02	70.22	68.44	70.38	70.80	71.32	73.23	71.82	69.48

Table C4. Percent forest cover 1,000 m upstream of the study reach as determined by digitizing at 3, 10, and 30 m buffer widths from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Reach	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball 1	99.88	99.87	99.14	99.23	99.21	99.18	98.81	98.74	97.14
Ball 2	100	100	100	100	100	100	100	100	100
Ball 3	100	100	100	89.15	90.75	93.28	96.63	96.55	96.21
Ball 4	100	100	100	91.96	92.86	94.34	95.45	95.10	95.25
Ball 5	100	100	100	84.83	84.93	87.95	97.11	96.90	95.92
Bates 1	62.72	60.21	53.13	58.06	57.43	51.52	55.56	53.26	46.02
Bates 2	63.18	54.68	44.45	45.30	46.60	47.57	50.98	47.54	47.31
Bates 3	67.52	67.28	67.09	67.34	68.32	72.13	74.46	74.06	74.21
Bates 4	56.47	49.55	42.21	43.02	44.19	46.56	48.78	46.06	47.17
Bates 5	85.23	84.85	82.84	85.70	86.06	87.71	82.57	82.62	82.20
Bates 6	87.97	88.35	89.23	94.76	94.85	96	93.77	93.59	93.14
Caler 1	26.19	25.46	22.25	25.60	25.58	27.73	53.69	48.18	39.23
Caler 2	58.38	59.70	65.20	87.33	87.59	90.89	86.50	85.96	85.22
Caler 3	100	100	99.60	100	99.98	99.56	99.66	98.77	98.39
Caler 4	99.52	99.12	98.69	95.67	95.01	92.91	97.58	96.47	95.27
Caler 5	96.34	96.41	97.01	88.10	88.65	90.03	90.85	89.04	87.25
Cowee 1	45.34	45.42	49.10	67.38	67.53	67.65	69.99	68.53	65.67
Cowee 2	100	100	100	94.22	93.69	91.10	96.95	96.82	96.21
Cowee 3	90.78	90.63	87.97	69.95	71.81	76.76	86.72	86.67	86.58
Cowee 4	39.01	37.45	36.06	64.50	65.24	66.10	70.45	68.44	64.85
Cowee 5	57.49	57.57	58.56	64.60	65.68	69.85	73.65	72.04	69.02
Crawford 1	24.87	25.54	26.68	29.65	30.48	32.34	21.91	21.89	22.58
Crawford 2	20.24	20.43	21.91	35.15	35.11	32.33	43.45	41.20	33.05
Crawford 3	39.45	38.03	35.35	52.03	51.71	50.38	53.59	52.21	46.70
Crawford 4	68.17	69.17	67.88	81.62	81.49	82.29	86.47	86.72	84.34
Crawford 5	34.40	34.58	39.27	67.45	67.94	68.21	53.28	54.53	56.95
Crawford 6	97.56	96.27	94.98	85.02	85.52	87.25	65.74	66.40	67.97
Jones 1	80.29	80.78	79.02	87.84	87.70	84.34	79.96	77.19	74.82
Jones 2	100	99.85	98.64	98.20	97.99	97.20	98.58	98.59	98.42
Jones 3	100	99.93	99.57	98.21	98.05	97.65	98.23	98.21	98.06
Jones 4	100	100	100	95.35	94.86	95.29	95.99	95.84	95.83
Jones 5	88	86.28	78.63	90.99	91.57	91.99	82.49	78.93	73.91
Jones 6	86.92	85.09	76.45	87.09	87.61	87.10	81.64	78.14	70.80
Jones 7	63.34	62.01	58.56	78.29	77.91	76.12	74.21	73.26	71.42

Rays 1	100	100	100	100	99.97	99.56	98.38	98.23	97.49
Rays 2	100	100	100	100	100	100	100	99.97	99.85
Rays 3	100	100	100	100	100	100	100	100	99.85
Rays 4	89.05	88.69	88.83	80.80	82.05	84.30	87.18	86.59	85.46
Rays 5	100	100	100	100	100	99.91	99.58	99.58	99.37
Skeenah 1	32.73	30.56	30.42	44.03	45.67	47.89	42.08	40.47	41.98
Skeenah 2	97.63	97.35	97.83	99.21	99.34	99.16	99.56	99.55	99.55
Skeenah 3	67.19	66.94	68.23	84.16	84.62	87.20	77.46	77.87	81.54
Skeenah 4	60.35	58.13	55.02	81.15	81.36	82.43	64.58	66.02	69.07
Skeenah 5	100	100	100	100	100	100	98.18	98.01	98.25
Watauga 1	20.74	21.31	25.54	32.01	31.99	32.44	52.73	47.24	42.62
Watauga 2	70.70	72.13	75.36	64.11	65.91	69.32	71.62	72.15	74.26
Watauga 3	42.18	43.38	47.35	44.50	44.28	46.70	64.09	60.99	61.43
Watauga 4	100	100	100	100	100	100	97.04	96.69	97.03
Watauga 5	97.46	97.49	96.88	95.08	94.97	95.20	94.23	93.50	90.20
Watauga 6	88.47	88.46	86.50	80.59	80.23	78.94	84.08	82.25	78.74
Average	76.12	75.58	74.83	78.18	78.49	79.09	79.73	78.75	77.48

Table C5. Percent forest cover of the entire watershed upstream of the study reach as determined by digitizing at 3, 10, and 30 m buffer widths from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Reach	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball 1	97.93	98.04	97.97	95.72	95.96	96.63	97.97	97.75	97.32
Ball 2	100	100	100	92.35	92.63	94.17	98.16	97.95	97.85
Ball 3	100	100	100	88.92	90.61	93.34	96.78	96.70	96.39
Ball 4	100	99.99	99.96	93.42	94.12	94.80	96.81	96.33	95.94
Ball 5	100	100	100	90.57	90.75	92.36	97.12	96.78	96.57
Bates 1	68.32	65.33	62.21	65.73	66.48	67.77	68.86	67.60	67.06
Bates 2	70.14	66.95	64.47	67.39	68.23	70.51	71.61	70.40	70.86
Bates 3	78.05	77.90	78.19	78.60	79.29	81.85	82.93	82.67	82.53
Bates 4	70.09	67.07	64.52	67.16	68.02	70.34	71.79	70.56	70.95
Bates 5	90.19	89.94	89.70	91.04	91.36	93.00	89.19	89.34	89.71
Bates 6	92.77	92.99	93.50	96.55	96.82	97.59	95.95	95.95	95.81
Caler 1	79.89	80.02	80.18	83.34	83.56	85.01	85.96	84.77	83.35
Caler 2	85.89	86.40	88.50	95.12	95.13	96.30	91.30	90.49	88.91
Caler 3	100	100	99.78	99.76	99.77	99.55	99.81	99.31	99.10
Caler 4	98.63	98.47	98.27	95.18	94.47	92.76	96.07	95.19	94.62
Caler 5	96.60	96.62	96.96	89.27	89.77	90.86	91.65	89.76	88.41
Cowee 1	81.79	82.08	83.39	85.26	85.65	87.01	89.05	88.69	88.46
Cowee 2	100	100	100	95.69	95.70	95.62	98.19	98.08	97.96
Cowee 3	90.94	91.58	92.77	82.76	83.55	86.59	90.89	90.59	90.24
Cowee 4	80.89	81.07	81.96	81.70	82.06	82.95	85.24	84.66	84.42
Cowee 5	89.77	90.09	91.01	89.86	90.22	91.53	93.38	93.10	93.06
Crawford 1	45.33	45.06	44.92	55.30	55.37	54.73	52.95	51.94	48.74
Crawford 2	54.44	54.71	55.61	67.25	67.25	66.53	62.20	61.71	59.19
Crawford 3	60.07	60.14	60.81	70.82	70.85	71.24	64.48	64.41	63.57
Crawford 4	68.86	69.79	68.28	82.19	81.98	82.58	86.90	87.08	84.60
Crawford 5	53.38	54.47	58.11	79.69	79.91	80.18	67.14	67.56	68.43
Crawford 6	95.66	94.58	93.29	86.24	86.24	87.08	70.92	70.99	71.57
Jones 1	87.04	86.80	85.56	89.19	89.13	88.76	89.55	88.73	87.28
Jones 2	99.11	99.05	98.59	97.79	97.74	97.55	98.66	98.42	97.82
Jones 3	100	99.97	99.94	98.70	98.59	98.33	98.25	98.13	98.02
Jones 4	100	100	100	95.13	94.54	94.75	96.09	95.95	95.92
Jones 5	88.19	86.46	78.65	90.17	90.96	91.84	82.23	78.79	73.78
Jones 6	85.89	84.42	76.40	86.06	86.91	86.96	80.68	77.55	70.75
Jones 7	92.48	92.24	91.57	93.33	93.21	92.82	93.87	93.55	92.81

Rays 1	100	100	100	99.77	99.71	99.55	99.28	99.24	99.08
Rays 2	100	100	100	100	100	100	100	99.98	99.92
Rays 3	100	100	100	100	100	100	99.69	99.81	99.91
Rays 4	97.07	97	96.95	95.43	95.54	95.89	96.56	96.47	96.30
Rays 5	100	100	100	100	100	99.99	98.74	98.72	98.58
Skeenah 1	69.77	68.99	69.54	81.75	82.15	82.66	79.47	78.84	79.28
Skeenah 2	97.50	97.67	98.15	99.34	99.44	99.29	99.63	99.62	99.53
Skeenah 3	75.77	75.24	74.74	85.45	85.96	89.04	81.77	80.88	83.21
Skeenah 4	77.12	76.89	76.52	92.10	92.43	92.79	82.75	83.41	84.28
Skeenah 5	100	100	100	100	100	100	98.49	98.33	98.49
Watauga 1	66.96	67.31	69.64	68.76	69.04	70.88	76.42	74.37	73.53
Watauga 2	73.17	74.60	78.21	66.77	68.52	72.24	73.31	73.84	76.50
Watauga 3	76.56	76.85	78.06	74.46	74.66	76.18	81.20	80.04	79.27
Watauga 4	100	100	100	99.82	99.82	99.81	99	98.88	98.91
Watauga 5	97.79	97.81	97.32	95.12	94.97	94.82	94.57	93.84	90.50
Watauga 6	87.12	87.62	86.76	69.72	69.53	68.43	75.47	75.39	74.48
Average	86.42	86.24	86.02	86.91	87.17	87.91	87.38	86.86	86.28

Table C6. Percent forest cover of 3, 10, and 30 m riparian buffers in the nine study watersheds and in the total study area in from 1954 through 2007.

	Percent Forest Cover (%)								
	1954			1984			2007		
Watershed	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball	97.93	98.04	97.96	95.72	95.96	96.63	97.97	97.74	97.29
Bates	68.11	65.11	61.91	65.32	66.02	67.31	68.43	67.15	66.50
Caler	79.57	79.71	79.88	83.02	83.26	84.74	85.85	84.61	83.14
Cowee	81.79	82.08	83.39	85.26	85.65	87.01	89.05	88.69	88.46
Crawford	45.33	45.06	44.95	55.30	55.37	54.73	52.95	51.94	48.73
Jones	87.04	86.80	85.57	89.19	89.12	88.71	89.55	88.72	87.24
Rays	97.07	97.01	96.94	95.43	95.53	95.86	96.56	96.46	96.27
Skeenah	69.76	68.94	69.43	81.73	82.09	82.52	79.47	78.81	79.16
Watauga	66.96	67.30	69.60	68.76	69.03	70.85	76.42	74.37	73.50
Total	80.54	80.50	80.88	83.08	83.31	84.17	85.81	84.97	84.12

Table C7. Change in percent forest cover of 3, 10, and 30 m riparian buffers in the nine study watersheds and in the total study area from 1954 through 2007.

	Percent Change in Forest Cover (%)								
	1954-1984			1984-2007			1954-2007		
Watershed	3 m	10 m	30 m	3 m	10 m	30 m	3 m	10 m	30 m
Ball	-2.21	-2.07	-1.33	+2.25	+1.78	+0.66	+0.03	-0.29	-0.67
Bates	-2.79	+0.92	+5.40	+3.11	+1.13	-0.81	+0.32	+2.04	+4.58
Caler	+3.45	+3.55	+4.86	+2.84	+1.34	-1.60	+6.29	+4.89	+3.26
Cowee	+3.47	+3.57	+3.62	+3.79	+3.04	+1.45	+7.26	+6.61	+5.07
Crawford	+9.97	+10.31	+9.78	-2.36	-3.43	-6.00	+7.62	+6.88	+3.78
Jones	+2.15	+2.32	+3.15	+0.36	-0.40	-1.47	+2.51	+1.91	+1.67
Rays	-1.65	-1.47	-1.08	+1.13	+0.93	+0.41	-0.51	-0.54	-0.67
Skeenah	+11.98	+13.15	+13.09	-2.26	-3.28	-3.36	+9.72	+9.87	+9.73
Watauga	+1.80	+1.73	+1.24	+7.66	+5.34	+2.65	+9.46	+7.07	+3.89
Total	+2.54	+2.81	+3.29	+2.73	+1.66	-0.05	+5.28	+4.47	+3.24

Table C8. NLCD land cover of the watershed draining into each study reach in 1986.

	Percent of Watershed in 1986 (%)						
		Developed					
Reach	Open Water	Open Space	Low Intensity	Medium Intensity	High Intensity	Barren Land	Shrub/ Scrub
Ball 1	0	1.77	0	0	0	0	0
Ball 2	0	0.10	0	0	0	0	0
Ball 3	0	5.26	0	0	0	0	0
Ball 4	0	3.45	0	0	0	0	0
Ball 5	0	0.04	0	0	0	0	0
Bates 1	0.02	5.93	0	0	0	0	0.44
Bates 2	0	5.56	0	0	0	0	0.55
Bates 3	0	2.47	0	0	0	0	0
Bates 4	0	5.27	0	0	0	0	0.56
Bates 5	0	2.34	0	0	0	0	0
Bates 6	0	0.06	0	0	0	0	0
Caler 1	0	2.73	0	0	0	0	0.35
Caler 2	0	0.77	0	0	0	0	0.25
Caler 3	0	0	0	0	0	0	0
Caler 4	0	3.43	0	0	0	0	0
Caler 5	0	2.79	0	0	0	0	0
Cowee 1	0	2.11	0	0	0	0.04	0.65
Cowee 2	0	0.02	0	0	0	0	0.98
Cowee 3	0	1.86	0	0	0	0	0
Cowee 4	0	2.24	0	0	0	0	0.26
Cowee 5	0	1.59	0	0	0	0	0.90
Crawford 1	0.02	38.41	1.81	0.94	0.47	0	0.61
Crawford 2	0	28.12	0.10	0	0	0	0.66
Crawford 3	0	26.20	0	0	0	0	0.59
Crawford 4	0	7.37	0	0	0	0	0
Crawford 5	0	23.55	0	0	0	0	0.03
Crawford 6	0	25.49	0	0	0	0	1.43
Jones 1	0	2.10	0	0	0	0	0.14
Jones 2	0	0.79	0	0	0	0	0
Jones 3	0	0	0	0	0	0	0
Jones 4	0	1.69	0	0	0	0	0
Jones 5	0	0	0	0	0	0	0.52
Jones 6	0	0.13	0	0	0	0	0.48
Jones 7	0	1.21	0	0	0	0	0

Rays 1	0	0.12	0	0	0	1.10	0
Rays 2	0	0	0	0	0	0	0
Rays 3	0	0	0	0	0	0	0
Rays 4	0	0.67	0	0	0	0.41	0.45
Rays 5	0	0.60	0	0	0	0.19	0.12
Skeenah 1	0.03	3.29	0	0	0	0	0.75
Skeenah 2	0	0	0	0	0	0	0
Skeenah 3	0	3.30	0	0	0	0	0.81
Skeenah 4	0	2.26	0	0	0	0	0.47
Skeenah 5	0	0	0	0	0	0	1.32
Watauga 1	0.02	12.11	0.65	0	0	0.06	0.38
Watauga 2	0	2.04	0	0	0	0	0
Watauga 3	0.01	11.13	0.41	0	0	0	0.09
Watauga 4	0	0	0	0	0	0	0
Watauga 5	0	22.69	0	0	0	0	0
Watauga 6	0	25.77	2.10	0	0	0	0
Average	0	5.78	0.10	0.02	0.01	0.04	0.28

	Percent of Watershed in 1986 (%)						
	Forest						
Reach	Deciduous	Evergreen	Mixed	Grassland/ Herbaceous	Pasture/ Hay	Cultivated Crops	Woody Wetland
Ball 1	93.21	3.18	1.76	0	0.07	0	0
Ball 2	97.76	0.96	1.17	0	0	0	0
Ball 3	92.37	0.73	1.64	0	0	0	0
Ball 4	93.23	2.22	1.09	0	0	0	0
Ball 5	98.33	0.32	1.32	0	0	0	0
Bates 1	63.50	5.24	1.42	0	23.15	0.15	0.15
Bates 2	69.86	4.71	1.26	0	18.06	0	0
Bates 3	86.70	1.28	1.29	0	8.26	0	0
Bates 4	69.97	4.75	1.27	0	18.18	0	0
Bates 5	91	1.09	1.44	0	4.12	0	0
Bates 6	93.73	1.44	1.25	0	3.53	0	0
Caler 1	81.38	2.27	1.52	0.02	11.44	0.08	0.20
Caler 2	93.37	3.88	0.58	0	1.14	0	0
Caler 3	98.91	0.43	0.50	0	0.15	0	0
Caler 4	78.11	0.84	0	0	17.62	0	0
Caler 5	95.44	0	0.40	0	1.37	0	0
Cowee 1	81.60	4.15	1.61	0.07	9.73	0.05	0

Cowee 2	84.24	3.19	2.25	0	9.17	0.16	0
Cowee 3	94.37	1.51	0.92	0	1.34	0	0
Cowee 4	78.45	2.47	1.91	0	14.54	0.12	0
Cowee 5	86.01	3.59	1.56	0	6.31	0.05	0
Crawford 1	29.50	2.34	1.66	0.08	23.93	0.24	0
Crawford 2	46.66	3.57	2.46	0.14	18.03	0.27	0
Crawford 3	52.76	3.17	2.17	0.17	14.94	0	0
Crawford 4	73.88	4.38	4.81	0	9.57	0	0
Crawford 5	63.79	2.35	0.99	0	9.30	0	0
Crawford 6	51.23	4.49	3.38	0.59	13.38	0	0
Jones 1	88.51	0.48	1.38	0	7.37	0	0
Jones 2	93.47	0.67	2.23	0	2.83	0	0
Jones 3	96.85	0	1.08	0	2.07	0	0
Jones 4	97.11	0	0	0	1.19	0	0
Jones 5	93.03	0.98	0.56	0	4.91	0	0
Jones 6	88.51	0.92	0.52	0	9.44	0	0
Jones 7	92.20	0.43	1.63	0	4.54	0	0
Rays 1	89.62	0.23	3.03	0	5.89	0	0
Rays 2	90.45	0.03	2.15	0	7.38	0	0
Rays 3	98.50	0.35	0	0	1.15	0	0
Rays 4	90.03	0.52	1.84	0	5.93	0.11	0.04
Rays 5	92.21	0.39	0.83	0	5.19	0.47	0
Skeenah 1	76.78	2.42	1.02	0.06	15.58	0	0.07
Skeenah 2	81.90	0	0.91	0	17.19	0	0
Skeenah 3	88.97	0	1.40	0	5.51	0	0
Skeenah 4	92.03	0	0.41	0	4.83	0	0
Skeenah 5	94.57	0	1.23	0	2.88	0	0
Watauga 1	64.97	5.29	1.67	0.10	14.43	0.33	0
Watauga 2	83.59	0	6.10	0	8.27	0	0
Watauga 3	71.79	2.83	2.18	0.11	11.27	0.18	0
Watauga 4	90.32	3.56	1.35	0	4.77	0	0
Watauga 5	73.80	0.05	3.24	0	0.21	0	0
Watauga 6	64.04	0.64	0.83	0	5.54	1.08	0
Average	82.65	1.77	1.54	0.03	7.71	0.07	0.01

Table C9. NLCD land cover in 1986 of the nine study watersheds and the total study area.

	Percent of Watershed in 1986 (%)				
Land Cover	Ball	Bates	Caler	Cowee	Crawford
Open Water	0	0.02	0	0	0.02
Developed, Open Space	1.77	5.98	2.73	2.11	38.40
Developed, Low Intensity	0	0	0	0	1.81
Developed, Medium Intensity	0	0	0	0	0.94
Developed, High Intensity	0	0	0	0	0.47
Barren Land	0	0	0	0.04	0
Deciduous Forest	93.21	63.33	81.38	81.60	29.50
Evergreen Forest	3.18	5.23	2.27	4.15	2.34
Mixed Forest	1.76	1.41	1.52	1.61	1.66
Shrub/Scrub	0	0.44	0.35	0.65	0.61
Grassland/Herbaceous	0	0	0.02	0.07	0.08
Pasture/Hay	0.07	23.29	11.44	9.73	23.93
Cultivated Crops	0	0.15	0.08	0.05	0.24
Woody Wetlands	0	0.15	0.20	0	0

	Percent of Watershed in 1986 (%)				
Land Cover	Jones	Rays	Skeenah	Watauga	Total
Open Water	0	0	0.03	0.02	0.01
Developed, Open Space	2.10	0.67	3.29	12.12	5.26
Developed, Low Intensity	0	0	0	0.65	0.18
Developed, Medium Intensity	0	0	0	0	0.04
Developed, High Intensity	0	0	0	0	0.02
Barren Land	0	0.41	0	0.06	0.07
Deciduous Forest	88.52	90.03	76.77	64.96	78.69
Evergreen Forest	0.48	0.52	2.42	5.29	2.87
Mixed Forest	1.38	1.84	1.02	1.67	1.58
Shrub/Scrub	0.14	0.45	0.75	0.38	0.43
Grassland/Herbaceous	0	0	0.06	0.10	0.04
Pasture/Hay	7.37	5.93	15.59	14.43	10.66
Cultivated Crops	0	0.11	0	0.33	0.10
Woody Wetlands	0	0.04	0.07	0	0.05

Table C10. NLCD land cover of the watershed draining into each study reach in 2006.

	Percent of Watershed in 2006 (%)						
		Developed					
Reach	Open Water	Open Space	Low Intensity	Medium Intensity	High Intensity	Barren Land	Shrub/ Scrub
Ball 1	0	2.04	0	0	0	0.21	0.08
Ball 2	0	0.03	0	0	0	0	0.24
Ball 3	0	6.33	0	0	0	0	0
Ball 4	0	4.44	0	0	0	0.80	0
Ball 5	0	0.02	0	0	0	0	0
Bates 1	0	7.05	0	0	0	0	5.26
Bates 2	0	6.33	0	0	0	0	3.72
Bates 3	0	3.02	0	0	0	0	1.65
Bates 4	0	6.13	0	0	0	0	3.75
Bates 5	0	2.87	0	0	0	0	2.20
Bates 6	0	0.60	0	0	0	0	1.77
Caler 1	0	3.35	0.14	0	0	1.35	2.97
Caler 2	0	1.16	0.60	0	0	3.28	2.70
Caler 3	0	0	0	0	0	0	0
Caler 4	0	2.65	0	0	0	0	0.11
Caler 5	0	4.02	0	0	0	0	0.35
Cowee 1	0	2.41	0.02	0	0	0.10	1.09
Cowee 2	0	0.19	0	0	0	0	0
Cowee 3	0	1.97	0	0	0	0	0.60
Cowee 4	0	2.69	0	0	0	0.07	1.26
Cowee 5	0	1.74	0	0	0	0	0.52
Crawford 1	0	37.50	7.99	1.87	0.68	0.50	5.16
Crawford 2	0	29.57	3.06	0.45	0	0.60	5.99
Crawford 3	0	27.99	2.61	0	0	0	5.57
Crawford 4	0	10.39	0	0	0	0	6.39
Crawford 5	0	26.83	1.14	0	0	0	1.59
Crawford 6	0	27.50	0	0	0	0	8.94
Jones 1	0	2.23	0	0	0	0.64	1.12
Jones 2	0	0.67	0	0	0	0	0
Jones 3	0	0	0	0	0	0.85	0
Jones 4	0	1.70	0	0	0	0	0
Jones 5	0	0	0	0	0	0	4.65
Jones 6	0	0	0	0	0	0.27	6.03
Jones 7	0	1.14	0	0	0	0.31	0.36

Rays 1	0	0.55	0	0	0	0.47	0.16
Rays 2	0	0	0	0	0	0	0
Rays 3	0	0	0	0	0	0.46	0
Rays 4	0	1.08	0	0	0	1.23	0.29
Rays 5	0	1.09	0	0	0	4.45	0.01
Skeenah 1	0	4.55	0.09	0	0	0.49	4.08
Skeenah 2	0	0	0	0	0	0	1.39
Skeenah 3	0	2.97	0	0	0	0	1.76
Skeenah 4	0	3.58	0.10	0	0	0	3.88
Skeenah 5	0	0	0	0	0	0	0
Watauga 1	0	11.76	2.16	0.11	0	0.82	1.71
Watauga 2	0	2.49	0	0	0	0	0.69
Watauga 3	0	10.51	1.96	0	0	0.12	0.77
Watauga 4	0	0	0	0	0	0.09	0.56
Watauga 5	0	22.88	0	0	0	0	0
Watauga 6	0	20.57	6.79	0	0	0.45	0
Average	0	6.13	0.53	0.05	0.01	0.35	1.79

Percent of Watershed in 2006 (%)							
	Forest						
Reach	Deciduous	Evergreen	Mixed	Grassland/ Herbaceous	Pasture/ Hay	Cultivated Crops	Woody Wetland
Ball 1	85.86	3.97	7.85	0	0	0	0
Ball 2	89.06	2.60	8.07	0	0	0	0
Ball 3	93.07	0.47	0.13	0	0	0	0
Ball 4	83.11	3.23	8.42	0	0	0	0
Ball 5	96.66	0.12	3.20	0	0	0	0
Bates 1	61.98	3.73	6.76	1.56	13.55	0	0.11
Bates 2	68.24	3.88	6.40	0.80	10.49	0	0.14
Bates 3	84.20	1.92	2.68	0.81	5.71	0	0
Bates 4	68.21	3.92	6.46	0.80	10.58	0	0.15
Bates 5	89	2.38	1.09	1.22	1.25	0	0
Bates 6	92.69	3.09	1.43	0.42	0	0	0
Caler 1	77.18	2.04	4.05	3.13	5.55	0.02	0.22
Caler 2	81.13	0.99	1.32	5.25	3.57	0	0
Caler 3	94.55	0.66	4.79	0	0	0	0
Caler 4	78.94	1.36	16.03	0	0.91	0	0
Caler 5	81.66	0	6.61	7.35	0	0	0
Cowee 1	74.85	7.74	9.58	0.82	3.38	0	0

Cowee 2	71.07	15.22	13.52	0	0	0	0
Cowee 3	90.50	1.07	5.87	0	0	0	0
Cowee 4	81.13	2.76	5.35	1.46	5.27	0	0
Cowee 5	75.34	9.43	12.36	0.21	0.39	0	0
Crawford 1	26.72	0.58	2.37	2.78	13.85	0	0
Crawford 2	38.93	0.72	3.71	3.98	13	0	0
Crawford 3	44.30	0.86	3.27	4.54	10.87	0	0
Crawford 4	66.18	0	15.18	1.87	0	0	0
Crawford 5	51.56	2.10	1.58	2.55	12.64	0	0
Crawford 6	43.86	0	1.02	11.21	7.47	0	0
Jones 1	89.90	0.77	1.59	1.03	2.73	0	0
Jones 2	95.95	0.35	3.02	0	0	0	0
Jones 3	96.33	1.07	0.69	1.05	0	0	0
Jones 4	97.80	0	0.50	0	0	0	0
Jones 5	88.25	0	1.94	5.16	0	0	0
Jones 6	84.88	0	1.81	5.69	1.32	0	0
Jones 7	93.44	0.41	1.88	0.86	1.60	0	0
Rays 1	94.30	1.11	1.56	1.85	0	0	0
Rays 2	99.18	0.29	0.53	0	0	0	0
Rays 3	68.17	13.54	14.37	1.85	1.60	0	0
Rays 4	87.16	3.64	4.18	1.82	0.55	0	0.06
Rays 5	72.82	8.22	8.65	4.04	0.72	0	0
Skeenah 1	77.92	2.42	5.21	2.01	3.22	0	0
Skeenah 2	97.30	0.27	0.05	0.98	0	0	0
Skeenah 3	75.18	3.54	11.28	0.91	4.36	0	0
Skeenah 4	90.14	0	0.72	0.73	0.86	0	0
Skeenah 5	99.74	0.26	0	0	0	0	0
Watauga 1	65.55	2.09	6.13	3.63	6.04	0	0
Watauga 2	95.02	0.77	0.17	0	0.86	0	0
Watauga 3	71.90	2.69	3.29	4.58	4.18	0	0
Watauga 4	82.82	5.68	6.32	3.68	0.86	0	0
Watauga 5	71.63	0.84	0.61	2.43	1.61	0	0
Watauga 6	49.41	0	0.32	22.47	0	0	0
Average	78.70	2.46	4.68	2.31	2.98	0	0.01

Table C11. NLCD land cover in 2006 of the nine study watersheds and the total study area.

	Percent of Watershed in 2006 (%)				
Land Cover	Ball	Bates	Caler	Cowee	Crawford
Open Water	0	0	0	0	0
Developed, Open Space	2.04	7.08	3.35	2.41	37.49
Developed, Low Intensity	0	0	0.14	0.02	7.99
Developed, Medium Intensity	0	0	0	0	1.87
Developed, High Intensity	0	0	0	0	0.68
Barren Land	0.21	0	1.35	0.1	0.5
Deciduous Forest	85.87	61.83	77.18	74.86	26.72
Evergreen Forest	3.97	3.72	2.04	7.74	0.58
Mixed Forest	7.85	6.74	4.05	9.58	2.38
Shrub/Scrub	0.08	5.25	2.97	1.09	5.16
Grassland/Herbaceous	0	1.55	3.13	0.82	2.78
Pasture/Hay	0	13.73	5.55	3.38	13.85
Cultivated Crops	0	0	0.02	0	0
Woody Wetlands	0	0.11	0.22	0	0

	Percent of Watershed in 2006 (%)				
Land Cover	Jones	Rays	Skeenah	Watauga	Total
Open Water	0	0	0	0	0
Developed, Open Space	2.23	1.08	4.55	11.76	5.53
Developed, Low Intensity	0	0	0.09	2.16	0.70
Developed, Medium Intensity	0	0	0	0.11	0.10
Developed, High Intensity	0	0	0	0	0.03
Barren Land	0.64	1.23	0.49	0.82	0.66
Deciduous Forest	89.9	87.16	77.91	65.55	75.69
Evergreen Forest	0.77	3.64	2.42	2.09	3.62
Mixed Forest	1.59	4.18	5.21	6.13	5.71
Shrub/Scrub	1.11	0.29	4.09	1.71	1.79
Grassland/Herbaceous	1.03	1.82	2.01	3.63	1.87
Pasture/Hay	2.73	0.55	3.22	6.04	4.25
Cultivated Crops	0	0	0	0	0
Woody Wetlands	0	0.06	0	0	0.05

Table C12. Change in NLCD land cover of the nine study watersheds and the total study area from 1986 to 2006.

	Percent Change in Watershed Land Cover (%)				
Land Cover	Ball	Bates	Caler	Cowee	Crawford
Open Water	0	-0.02	0	0	-0.02
Developed, Open Space	+0.27	+1.10	+0.62	+0.30	-0.91
Developed, Low Intensity	0	0	+0.14	+0.02	+6.18
Developed, Medium Intensity	0	0	0	0	+0.93
Developed, High Intensity	0	0	0	0	+0.21
Barren Land	+0.21	0	+1.35	+0.06	+0.50
Deciduous Forest	-7.34	-1.50	-4.20	-6.74	-2.78
Evergreen Forest	+0.79	-1.51	-0.23	+3.59	-1.76
Mixed Forest	+6.09	+5.33	+2.53	+7.97	+0.72
Shrub/Scrub	+0.08	+4.81	+2.62	+0.44	+4.55
Grassland/Herbaceous	0	+1.55	+3.11	+0.75	+2.70
Pasture/Hay	-0.07	-9.56	-5.89	-6.35	-10.08
Cultivated Crops	0	-0.15	-0.06	-0.05	-0.24
Woody Wetlands	0	-0.04	+0.02	0	0

	Percent Change in Watershed Land Cover (%)				
Land Cover	Jones	Rays	Skeenah	Watauga	Total
Open Water	0	0	-0.03	-0.02	-0.01
Developed, Open Space	+0.13	+0.41	+1.26	-0.36	+0.27
Developed, Low Intensity	0	0	+0.09	+1.51	+0.53
Developed, Medium Intensity	0	0	0	+0.11	+0.06
Developed, High Intensity	0	0	0	0	+0.01
Barren Land	+0.64	+0.82	+0.49	+0.76	+0.59
Deciduous Forest	+1.38	-2.87	+1.14	+0.59	-3.01
Evergreen Forest	+0.29	+3.12	0	-3.2	+0.75
Mixed Forest	+0.21	+2.34	+4.19	+4.46	+4.13
Shrub/Scrub	+0.97	-0.16	+3.34	+1.33	+1.36
Grassland/Herbaceous	+1.03	+1.82	+1.95	+3.53	+1.83
Pasture/Hay	-4.64	-5.38	-12.37	-8.39	-6.41
Cultivated Crops	0	-0.11	0	-0.33	-0.10
Woody Wetlands	0	+0.02	-0.07	0	0.00

Table C13. Percent forest cover and change in forest cover of the nine study watersheds and the total study area as determined from the NLCD of 1986 and 2006. Forest cover refers to the sum of the Deciduous, Evergreen, and Mixed Forest NLCD categories.

Watershed	Percent Forest Cover in 1986 (%)	Percent Forest Cover in 2006 (%)	Percent Change in Forest Cover 1986-2006 (%)
Ball	98.15	97.68	-0.47
Bates	69.97	72.28	+2.31
Caler	85.18	83.28	-1.90
Cowee	87.36	92.17	+4.81
Crawford	33.50	29.68	-3.82
Jones	90.39	92.26	+1.87
Rays	92.39	94.98	+2.59
Skeenah	80.21	85.55	+5.34
Watauga	71.93	73.77	+1.84
Total	83.15	85.02	+1.88

Table C14. Correspondence between manual digitizing of 2007 aerial photographs and NLCD classification in 2006 of the 30 m riparian buffer.

	Percent Correspondence of 30 m Buffer (%)		
Watershed	No Difference	Digitized Forested, Classified Non-forested	Digitized Non-forested, Classified Forested
Ball	95.85	2.12	2.03
Bates	82.96	10.28	6.76
Caler	84.07	9.88	6.04
Cowee	90.42	4.81	4.77
Crawford	69.61	25.89	4.50
Jones	90.49	4.92	4.59
Rays	92.85	5.07	2.08
Skeenah	88.02	6.73	5.25
Watauga	78.51	14.62	6.87
Total	87.17	8.01	4.82

Table C15. Distance to the nearest obstruction in 1954 and number of each type of obstruction at 100, 500, and 1,000 m upstream and in the entire watershed upstream of the study reaches.

		Number of Obstructions at Distances Upstream of the Study Reach in 1954				
		100 m	500 m	1,000 m	Watershed	
Reach	Distance to Nearest Obstruction (m)	Roads*	Roads*	Roads*	Roads	Other
Ball 1	98.95	1	3	12	61	0
Ball 2	237.25	0	3	4	25	0
Ball 3	463.52	0	1	4	4	0
Ball 4	187.36	0	6	10	17	0
Ball 5	516.63	0	0	9	16	0
Bates 1	51.39	1	3	4	30	0
Bates 2	249.18	0	3	9	24	0
Bates 3	386.13	0	1	8	8	0
Bates 4	122.97	0	4	11	24	0
Bates 5	106.12	0	4	6	6	0
Bates 6	210.42	0	1	1	1	0
Caler 1	2.55	2	4	12	176	0
Caler 2	32.05	2	5	16	38	0
Caler 3	903.87	0	0	1	1	0
Caler 4	NA**	0	0	0	0	0
Caler 5	359.62	0	1	7	7	0
Cowee 1	88.43	1	7	10	262	0
Cowee 2	179.90	0	3	8	21	0
Cowee 3	369.60	0	4	6	32	0
Cowee 4	199.99	0	7	13	67	0
Cowee 5	64.89	1	3	7	117	0
Crawford 1	33.76	2	12	21	60	1
Crawford 2	219.09	0	5	15	27	1
Crawford 3	230.43	0	4	10	16	1
Crawford 4	270.42	0	3	3	3	0
Crawford 5	160.03	0	2	5	8	1
Crawford 6	15.64	1	1	1	1	0
Jones 1	33.81	1	6	12	156	0
Jones 2	104.50	0	2	7	18	0
Jones 3	143.66	0	3	7	17	0
Jones 4	874.40	0	0	2	2	0
Jones 5	196.89	0	4	6	6	0
Jones 6	337.05	0	3	6	6	0

Jones 7	269.80	0	6	21	105	0
Rays 1	241.24	0	3	6	10	0
Rays 2	NA**	0	0	0	0	0
Rays 3	NA**	0	0	0	0	0
Rays 4	24.62	1	2	10	52	1
Rays 5	5.50	1	4	8	10	0
Skeenah 1	111.40	0	6	14	67	0
Skeenah 2	19.40	1	1	5	5	0
Skeenah 3	155.33	0	6	6	8	0
Skeenah 4	253.09	0	2	13	17	0
Skeenah 5	791.99	0	0	2	2	0
Watauga 1	44.75	1	10	16	221	0
Watauga 2	139.26	0	3	5	5	0
Watauga 3	365.58	0	2	11	134	0
Watauga 4	119.50	0	3	5	8	0
Watauga 5	64.09	1	9	30	32	0
Watauga 6	213.61	0	8	17	27	0
Average	218.50	0.34	3.46	8.44	39.20	0.10

* There were no other obstructions at 100, 500, and 1,000 m upstream of any study reach. For this reason, only roads are shown at these distances upstream.

** These reaches have no obstructions upstream and, therefore, have no value for the distance to the nearest obstruction.

Table C16. Distance to the nearest obstruction in 1984 and number of each type of obstruction at 100, 500, and 1,000 m upstream and in the entire watershed upstream of the study reaches.

		Number of Obstructions at Distances Upstream of the Study Reach in 1984							
		100 m		500 m		1,000 m		Watershed	
Reach	Distance to Nearest Obstruction (m)	Roads	Other	Roads	Other	Roads	Other	Roads	Other
Ball 1	98.95	1	0	3	0	12	0	87	0
Ball 2	237.25	0	0	3	0	4	0	52	0
Ball 3	478.26	0	0	1	0	4	0	4	0
Ball 4	187.36	0	0	6	0	10	0	17	0
Ball 5	92.11	1	0	4	0	28	0	37	0
Bates 1	51.39	1	0	3	1	4	1	42	4
Bates 2	133.72	0	0	6	0	15	1	36	3
Bates 3	387.85	0	0	2	0	9	1	12	1
Bates 4	7.51	1	0	7	0	19	2	36	3
Bates 5	107.84	0	0	5	0	8	1	12	1
Bates 6	210.42	0	0	1	0	3	0	3	0
Caler 1	2.55	2	0	4	0	12	1	190	2
Caler 2	35.02	2	0	5	0	16	0	38	0
Caler 3	581.34	0	0	0	0	10	0	15	0
Caler 4	360.01	0	0	1	0	3	0	3	0
Caler 5	218.89	0	0	4	0	7	0	7	0
Cowee 1	88.43	1	0	7	1	10	1	274	3
Cowee 2	179.90	0	0	3	0	8	0	40	0
Cowee 3	370.27	0	0	4	0	6	0	32	0
Cowee 4	207.75	0	0	7	0	13	1	86	1
Cowee 5	51.35	1	0	3	0	7	0	131	1
Crawford 1	5.81	3	2	14	5	24	5	100	8
Crawford 2	218.97	0	0	7	0	22	0	59	2
Crawford 3	107.93	0	0	12	0	17	1	49	2
Crawford 4	270.42	0	0	3	1	3	1	3	1
Crawford 5	160.03	0	0	3	0	10	0	12	0
Crawford 6	15.64	1	0	1	1	15	1	21	1
Jones 1	33.81	1	0	6	0	12	0	160	1
Jones 2	104.50	0	0	3	0	10	0	27	0
Jones 3	127.75	0	0	5	0	13	0	27	0
Jones 4	133.56	0	0	6	0	8	0	10	0
Jones 5	204.23	0	0	8	0	15	0	15	0

Jones 6	344.40	0	0	3	0	15	0	15	0
Jones 7	269.80	0	0	6	0	21	0	110	0
Rays 1	169.83	0	0	4	0	10	0	17	0
Rays 2	NA*	0	0	0	0	0	0	0	0
Rays 3	NA*	0	0	0	0	0	0	0	0
Rays 4	28.46	1	0	5	0	10	0	125	0
Rays 5	5.50	1	0	4	0	9	0	19	0
Skeenah 1	114.78	0	0	8	0	16	0	90	0
Skeenah 2	19.40	2	0	4	0	7	0	7	0
Skeenah 3	161.74	0	0	6	0	12	0	15	0
Skeenah 4	253.09	0	0	2	0	13	0	22	0
Skeenah 5	520.22	0	0	0	0	5	0	6	0
Watauga 1	39.39	1	0	10	4	18	4	265	19
Watauga 2	141.17	0	0	3	0	5	0	5	0
Watauga 3	232.68	0	0	5	0	12	0	145	11
Watauga 4	119.50	0	0	3	0	5	0	9	0
Watauga 5	63.34	2	0	12	0	37	0	40	0
Watauga 6	213.61	0	0	9	1	23	3	32	4
Average	170.16	0.44	0.04	4.62	0.28	11.50	0.48	51.18	1.36

** These reaches have no obstructions upstream and, therefore, have no value for the distance to the nearest obstruction.

Table C17. Distance to the nearest obstruction in 2007 and number of each type of obstruction at 100, 500, and 1,000 m upstream and in the entire watershed upstream of the study reaches.

		Number of Obstructions at Distances Upstream of the Study Reach in 2007							
		100 m		500 m		1,000 m		Watershed	
Reach	Distance to Nearest Obstruction (m)	Roads	Other	Roads	Other	Roads	Other	Roads	Other
Ball 1	91.26	1	0	3	0	12	0	91	0
Ball 2	237.25	0	0	3	0	4	0	52	0
Ball 3	459.29	0	0	2	0	12	0	12	0
Ball 4	187.36	0	0	6	0	12	0	26	0
Ball 5	87.68	1	0	4	0	28	0	37	0
Bates 1	48.64	1	0	3	1	7	1	47	5
Bates 2	20.09	1	0	8	0	15	2	37	4
Bates 3	313.91	0	0	6	0	12	1	15	1
Bates 4	6.38	1	0	8	1	19	3	36	4
Bates 5	111.25	0	0	6	1	8	1	10	1
Bates 6	195.43	0	0	1	0	3	0	3	0
Caler 1	2.55	2	0	4	0	12	1	337	7
Caler 2	35.02	2	0	9	0	23	0	85	0
Caler 3	589.74	0	0	0	0	10	0	15	0
Caler 4	360.91	0	0	1	0	3	0	5	0
Caler 5	101.51	0	0	8	0	18	0	18	0
Cowee 1	88.43	1	0	7	1	10	1	307	7
Cowee 2	179.90	0	0	3	0	8	0	41	0
Cowee 3	370.27	0	0	4	0	6	0	32	1
Cowee 4	207.75	0	0	7	0	13	1	92	3
Cowee 5	51.35	2	0	4	0	8	0	146	1
Crawford 1	5.81	3	2	17	4	36	5	146	10
Crawford 2	216.74	0	0	7	1	22	1	89	4
Crawford 3	107.93	0	0	12	0	32	0	81	3
Crawford 4	269.99	0	0	3	1	5	1	5	1
Crawford 5	154.21	0	0	7	0	20	1	28	1
Crawford 6	15.64	2	0	6	1	20	1	29	1
Jones 1	34.78	1	0	7	1	13	2	203	5
Jones 2	104.50	0	0	3	0	10	0	29	0
Jones 3	127.75	0	0	5	0	13	0	29	0
Jones 4	131.73	0	0	6	0	12	0	12	0

Jones 5	199.21	0	0	11	1	21	1	21	1
Jones 6	339.37	0	0	5	1	21	1	21	1
Jones 7	248.36	0	0	4	0	21	0	141	0
Rays 1	169.83	0	0	4	0	10	0	17	0
Rays 2	NA*	0	0	0	0	0	0	0	0
Rays 3	NA*	0	0	0	0	0	0	0	0
Rays 4	28.46	1	0	5	0	11	0	125	1
Rays 5	5.50	1	0	4	0	10	0	33	0
Skeenah 1	114.78	0	0	11	0	20	1	90	1
Skeenah 2	19.40	2	0	4	0	7	0	7	0
Skeenah 3	153.61	0	0	6	0	15	0	20	0
Skeenah 4	253.09	1	0	4	0	13	0	22	0
Skeenah 5	520.22	0	0	0	0	5	0	7	0
Watauga 1	39.24	1	0	10	4	20	4	369	29
Watauga 2	142.26	0	0	6	0	14	0	17	0
Watauga 3	237.40	0	0	5	0	16	0	205	15
Watauga 4	121.46	0	0	2	0	5	0	21	0
Watauga 5	55.10	2	0	12	0	39	1	44	1
Watauga 6	213.61	0	0	9	1	26	3	38	4
Average	162	0.52	0.04	5.44	0.38	14	0.66	65.86	2.24

** These reaches have no obstructions upstream and, therefore, have no value for the distance to the nearest obstruction.

Table C18. The number of road and other obstructions in the nine study watersheds and the total study area from 1954 through 2007.

	Number of Obstructions					
	1954		1984		2007	
Watershed	Roads	Other	Roads	Other	Roads	Other
Ball	61	0	87	0	91	0
Bates	30	0	42	4	47	5
Caler	176	0	190	2	337	7
Cowee	262	0	274	3	307	7
Crawford	60	1	100	8	146	10
Jones	156	0	160	1	203	5
Rays	52	1	125	0	125	1
Skeenah	67	0	90	2	93	3
Watauga	221	0	265	19	369	29
Total	1085	2	1333	39	1718	67

Table C19. Density of obstructions in the nine study watersheds and the total study area from 1954 through 2007. Obstruction density was found by dividing the number of obstructions in the watershed by the watershed area.

	Obstruction Density (count/km²)					
	1954		1984		2007	
Watershed	Roads	Other	Roads	Other	Roads	Other
Ball	8.51	0	12.14	0	12.70	0
Bates	8.19	0	11.46	1.09	12.83	1.36
Caler	9.40	0	10.15	0.11	18.00	0.37
Cowee	8.99	0	9.40	0.10	10.54	0.24
Crawford	11.32	0.19	18.87	1.51	27.55	1.89
Jones	10.01	0	10.27	0.06	13.03	0.32
Rays	3.54	0.07	8.51	0	8.51	0.07
Skeenah	11.12	0	14.94	0.33	15.43	0.50
Watauga	13.20	0	15.83	1.13	22.04	1.73
Total	9.27	0.02	11.39	0.33	14.68	0.57

Table C20. Standard statistics of slope steepness in the 30 m buffer of the study reach in degrees.

	Slope Steepness in the 30 m Buffer of the Study Reach (°)				
Reach	Mean	Standard Deviation	Kurtosis	Skewness	Coefficient of Variation
Ball 1	7.06	8.41	4.37	2.28	1.19
Ball 2	9.45	5.36	-0.49	0.74	0.57
Ball 3	9.32	2.91	-0.08	-0.16	0.31
Ball 4	15.05	10.38	-0.66	0.85	0.69
Ball 5	14.12	10.32	-0.26	0.95	0.73
Bates 1	3.23	4.14	4.21	2.15	1.28
Bates 2	4.71	4.75	6.69	2.54	1.01
Bates 3	2.66	0.77	0.84	-0.32	0.29
Bates 4	2.90	2.09	1.26	1.03	0.72
Bates 5	7.93	5.50	-0.97	0.64	0.69
Bates 6	8.81	4.48	-0.39	0.62	0.51
Caler 1	1.35	1.24	0.47	0.99	0.92
Caler 2	6.64	6.91	0.57	1.42	1.04
Caler 3	9.48	7.15	1.48	1.66	0.75
Caler 4	8.56	4.12	-0.37	0.84	0.48
Caler 5	19.21	8.83	-0.98	-0.18	0.46
Cowee 1	19.17	8.14	-0.68	-0.44	0.42
Cowee 2	21.52	9.75	-1.26	-0.25	0.45
Cowee 3	5.22	2.82	4.95	1.89	0.54
Cowee 4	9.76	7	-0.36	0.82	0.72
Cowee 5	3.76	3.68	10.41	2.94	0.98
Crawford 1	6.51	4.89	0.21	1.02	0.75
Crawford 2	5.67	6.13	-0.45	0.98	1.08
Crawford 3	2.07	1.07	-0.19	0.24	0.52
Crawford 4	16.28	6.45	-0.56	-0.17	0.40
Crawford 5	1.38	0.79	0.01	0.32	0.57
Crawford 6	5.40	4.24	2.31	1.71	0.79
Jones 1	12.07	10.42	-1.15	0.44	0.86
Jones 2	4.80	4.46	12.85	3.47	0.93
Jones 3	13.67	7.21	-1.29	-0.01	0.53
Jones 4	15.36	9.55	-1.04	0.40	0.62
Jones 5	4.56	2.60	0.76	1.21	0.57
Jones 6	2.01	0.96	0.05	0.41	0.48
Jones 7	2.49	1.92	22.46	3.82	0.77
Rays 1	13.56	12.39	-0.42	0.99	0.91
Rays 2	25.36	8.06	-0.61	-0.36	0.32

Rays 3	16.03	5.53	-1.01	0.35	0.35
Rays 4	6.83	6.90	4.39	2.23	1.01
Rays 5	18.53	10.10	-1.38	0.13	0.54
Skeenah 1	2.72	1.60	0.33	0.81	0.59
Skeenah 2	10.46	5.88	-0.27	0.88	0.56
Skeenah 3	5.86	2.27	-0.86	0.14	0.39
Skeenah 4	6.80	5.29	0.07	1.17	0.78
Skeenah 5	24.46	7.75	-0.84	-0.35	0.32
Watauga 1	2.91	2.63	2.48	1.35	0.90
Watauga 2	11.08	6.35	-0.83	0.51	0.57
Watauga 3	4.65	3.96	3.01	1.53	0.85
Watauga 4	24.72	8.24	-0.40	-0.64	0.33
Watauga 5	17.44	10.49	-1.04	0.49	0.60
Watauga 6	17.22	8.42	-0.09	0.95	0.49
Average	9.82	5.71	1.30	0.90	0.66

	Slope Steepness in the 30 m Buffer of the Study Reach (°)					
	Percentiles					
Reach	5th	25th	50th	75th	95th	5th/95th
Ball 1	1	2.53	4.17	6.65	29.63	0.03
Ball 2	2.89	5.64	7.57	13.05	19.23	0.15
Ball 3	3.93	7.55	9.47	11.41	13.98	0.28
Ball 4	3.76	7.13	10.75	23.52	34.96	0.11
Ball 5	3.21	6.57	10.22	20.58	34.81	0.09
Bates 1	0	0.72	1.60	3.58	14.10	0
Bates 2	1.01	1.83	3.58	4.98	16.45	0.06
Bates 3	1.43	2.15	2.73	3.08	3.85	0.37
Bates 4	0.51	1.43	2.53	4.29	6.43	0.08
Bates 5	2.26	2.86	6.01	12.41	18.04	0.13
Bates 6	3.05	5.27	7.88	12.56	16.50	0.18
Caler 1	0	0.51	1.13	1.83	3.95	0
Caler 2	1.13	2.26	3.39	6.73	22	0.05
Caler 3	3.64	5.37	6.76	9.05	27.56	0.13
Caler 4	4.08	5.37	6.52	11.56	16.28	0.25
Caler 5	4.70	11.20	20.44	25.58	32.86	0.14
Cowee 1	4.01	13.59	20.69	25.08	30.47	0.13
Cowee 2	5.82	13.04	24.03	30.17	34.39	0.17
Cowee 3	2.19	3.54	4.52	6.57	10.47	0.21

Cowee 4	1.83	4.17	7.67	14.30	23.84	0.08
Cowee 5	1.01	1.60	2.58	4.32	10.85	0.09
Crawford 1	1.13	2.86	4.77	9.62	15.90	0.07
Crawford 2	0	1.07	2.53	10.61	17.11	0
Crawford 3	0.51	1.28	2.02	2.73	3.86	0.13
Crawford 4	5.66	12.61	16.65	20.51	26.40	0.21
Crawford 5	0	0.72	1.43	1.83	2.88	0
Crawford 6	1.60	2.62	3.68	6.24	15.38	0.10
Jones 1	0.51	1.83	11.53	20.99	30.17	0.02
Jones 2	1.60	2.86	3.58	4.77	13.30	0.12
Jones 3	3.30	7	14.28	19.85	24	0.14
Jones 4	3.53	6.36	14.08	23.11	31.43	0.11
Jones 5	1.83	2.73	3.68	5.64	10.33	0.18
Jones 6	0.51	1.43	2.02	2.53	3.67	0.14
Jones 7	0.72	1.52	2.06	2.95	5.26	0.14
Rays 1	2.09	4.01	7.13	20.11	38.80	0.05
Rays 2	10.71	20.69	26.16	31.47	37.13	0.29
Rays 3	8.86	11.18	14.78	20.70	24.99	0.35
Rays 4	1.52	3.08	4.35	7.06	25.12	0.06
Rays 5	4.42	9.26	17.35	28.04	33.33	0.13
Skeenah 1	0.72	1.43	2.53	3.68	5.85	0.12
Skeenah 2	4.17	5.71	8.19	14.41	21.64	0.19
Skeenah 3	2.26	4.29	5.82	7.50	9.69	0.23
Skeenah 4	1.79	2.86	4.32	10.09	18.21	0.10
Skeenah 5	10.89	18.18	24.95	31.25	35.08	0.31
Watauga 1	0	1.07	2.09	4.62	7.86	0
Watauga 2	3.20	5.44	10.01	15.84	22.71	0.14
Watauga 3	0	1.60	3.68	6.48	12.04	0
Watauga 4	9.52	18.62	26.34	31.51	34.91	0.27
Watauga 5	4.66	8.19	14.80	26.42	34.96	0.13
Watauga 6	8.55	10.65	14.77	21.83	34.74	0.25
Average	2.91	5.51	8.68	13.27	20.35	0.13

Table C21. Standard statistics of slope steepness in the 30 m buffer 100 m upstream of the study reach in degrees.

	Slope Steepness in the 30 m Buffer 100 m Upstream of the Study Reach (º)				
Reach	Mean	Standard Deviation	Kurtosis	Skewness	Coefficient of Variation
Ball 1	3.10	2.27	8.42	2.40	0.73
Ball 2	14.79	5.43	-0.31	0.17	0.37
Ball 3	12.49	6.59	4.14	1.87	0.53
Ball 4	12.92	9.07	0.90	1.31	0.70
Ball 5	19.09	12.94	-0.99	0.47	0.68
Bates 1	7.54	7.22	-0.57	0.85	0.96
Bates 2	2.52	1.56	-0.90	0.38	0.62
Bates 3	4.24	2.85	2.59	1.76	0.67
Bates 4	3.89	2.54	-0.02	0.84	0.65
Bates 5	8.72	6.43	0.18	1.14	0.74
Bates 6	11.66	5.81	-0.66	0.35	0.50
Caler 1	1.62	2.30	17.19	3.71	1.42
Caler 2	8.07	6.16	0.49	1.11	0.76
Caler 3	11.82	6.58	-0.76	0.54	0.56
Caler 4	11.10	5.65	0.16	0.85	0.51
Caler 5	20.56	11.94	-1.53	-0.09	0.58
Cowee 1	11.20	8.80	-0.90	0.59	0.79
Cowee 2	26.03	8.15	0.70	-1.14	0.31
Cowee 3	13.60	9.29	-1.09	0.45	0.68
Cowee 4	14.96	7.98	-0.90	0.15	0.53
Cowee 5	6.54	6.22	0.11	1.18	0.95
Crawford 1	6.40	4.76	-0.38	0.86	0.74
Crawford 2	5.96	6.12	-0.43	1.01	1.03
Crawford 3	2.96	1.70	0.03	0.59	0.57
Crawford 4	17.15	5.88	-0.16	-0.50	0.34
Crawford 5	2.96	2.56	4.31	2	0.86
Crawford 6	5.99	4.29	0.33	1.18	0.72
Jones 1	14.38	8.16	-0.58	0.17	0.57
Jones 2	6.52	6.19	1.40	1.68	0.95
Jones 3	14.95	6.51	-0.99	-0.07	0.44
Jones 4	10.91	4.24	0.16	0.36	0.39
Jones 5	6.40	3.91	7.51	2.35	0.61
Jones 6	4.52	3.25	1.50	1.41	0.72
Jones 7	4.52	4.48	5.09	2.29	0.99
Rays 1	20.58	12.28	-1.42	-0.10	0.60

Rays 2	26.96	8.60	-0.98	-0.14	0.32
Rays 3	18.75	5.34	0.21	0.25	0.28
Rays 4	6.77	5.89	2.30	1.62	0.87
Rays 5	21.48	8.84	-0.89	-0.26	0.41
Skeenah 1	4.44	4.71	12.03	3.22	1.06
Skeenah 2	13.47	5.86	-1.18	0.06	0.43
Skeenah 3	8.71	6.34	2.28	1.68	0.73
Skeenah 4	6.39	4.78	0.86	1.38	0.75
Skeenah 5	26.01	9.14	-1.13	-0.05	0.35
Watauga 1	3.63	3.41	1.33	1.30	0.94
Watauga 2	9.77	6	-0.10	0.89	0.61
Watauga 3	6.39	4.54	-0.70	0.57	0.71
Watauga 4	25.45	8.33	-0.82	-0.50	0.33
Watauga 5	19.47	10.72	-1.42	0.11	0.55
Watauga 6	20.71	8.31	-0.99	0.18	0.40
Average	11.38	6.22	1.07	0.85	0.65

	Slope Steepness in the 30 m Buffer 100 m Upstream of the Study Reach (º)					
	Percentiles					
Reach	5th	25th	50th	75th	95th	5th/95th
Ball 1	0.70	1.60	2.58	3.95	7.21	0.10
Ball 2	6.39	10.77	15.13	18.52	23.49	0.27
Ball 3	5.70	8.55	10.93	13.87	26.42	0.22
Ball 4	3.65	6.56	10.33	15.81	34.23	0.11
Ball 5	3.68	7.47	17.64	29.08	41.02	0.09
Bates 1	0	1.52	4.52	13.56	21.09	0
Bates 2	0.51	1.43	2.09	3.85	5.27	0.10
Bates 3	1.60	2.53	3.24	4.66	11.08	0.14
Bates 4	0.66	1.83	3.24	5.37	8.97	0.07
Bates 5	2.73	3.95	5.64	11.93	21.83	0.12
Bates 6	3.08	7.44	11.18	15.51	22.05	0.14
Caler 1	0	0.51	1.13	1.60	4.69	0
Caler 2	1.83	3.20	5.75	11.02	20.41	0.09
Caler 3	3.68	5.91	10.32	17.25	22.43	0.16
Caler 4	4.52	6.41	9.99	14.25	22.16	0.20
Caler 5	3.85	8.57	20.86	32.32	36.54	0.11
Cowee 1	1.52	3.08	8.94	18.06	27.14	0.06
Cowee 2	7.41	22.36	28.30	31.71	35.16	0.21

Cowee 3	2.58	4.69	11.95	21.53	29.71	0.09
Cowee 4	3.04	8.33	14.39	21.10	28.49	0.11
Cowee 5	1.13	2.02	3.68	10.22	19.16	0.06
Crawford 1	1.13	2.58	4.66	9.89	15.51	0.07
Crawford 2	0	1.43	3.06	9.59	17.70	0
Crawford 3	0.51	1.60	2.58	4.08	5.92	0.09
Crawford 4	5.44	13.50	18.06	20.57	25.93	0.21
Crawford 5	0.51	1.43	2.09	3.58	8.32	0.06
Crawford 6	1.60	2.86	4.52	7.49	15.29	0.10
Jones 1	1.43	8.29	14.28	19.96	27.15	0.05
Jones 2	1.60	2.95	4.08	6.08	20.98	0.08
Jones 3	4.32	9.61	15.55	20.38	24.86	0.17
Jones 4	4.04	7.98	10.75	13.20	18.34	0.22
Jones 5	2.58	4.08	5.20	7.57	13.41	0.19
Jones 6	1.43	2.15	3.24	5.72	10.72	0.13
Jones 7	1.13	2.02	2.95	4.66	15.32	0.07
Rays 1	3.20	7.05	21.93	31.25	38.53	0.08
Rays 2	13.03	19.68	27.81	34.40	38.97	0.33
Rays 3	10.14	14.64	19.15	22.49	27.10	0.37
Rays 4	1.12	2.58	5.05	8.60	20.49	0.05
Rays 5	6.57	14.11	22.36	28.74	33.85	0.19
Skeenah 1	1.01	1.83	3.20	4.58	13.70	0.07
Skeenah 2	5.37	7.28	14.30	18.06	22.57	0.24
Skeenah 3	2.89	4.52	6.24	10.65	24.49	0.12
Skeenah 4	1.83	3.24	4.30	8.13	17.37	0.11
Skeenah 5	11.59	18.58	25.12	34.41	39.29	0.29
Watauga 1	0	1.13	2.58	5.32	10.93	0
Watauga 2	3.20	4.79	8.13	13.09	22.22	0.14
Watauga 3	0.51	2.53	5.64	9.58	15.02	0.03
Watauga 4	10.49	18.97	27.76	32.48	36.18	0.29
Watauga 5	4.98	8.98	19.91	29.16	36.23	0.14
Watauga 6	8.92	13.06	20.37	27.57	35.62	0.25
Average	3.38	6.44	10.53	15.33	22.41	0.13

Table C22. Standard statistics of slope steepness in the 30 m buffer 500 m upstream of the study reach in degrees.

	Slope Steepness in the 30 m Buffer 500 m Upstream of the Study Reach (º)				
Reach	Mean	Standard Deviation	Kurtosis	Skewness	Coefficient of Variation
Ball 1	26.61	10.22	-0.87	0.31	0.38
Ball 2	24.41	9.22	-0.67	0.08	0.38
Ball 3	16.48	6.54	0.30	0.80	0.40
Ball 4	15.09	9.39	0.28	1.10	0.62
Ball 5	18.46	8.97	0.13	0.63	0.49
Bates 1	6.02	6.44	1.36	1.45	1.07
Bates 2	5.63	1.60	1.66	1.51	0.28
Bates 3	10.89	6.70	-0.88	0.45	0.61
Bates 4	6.38	5.27	2.24	1.50	0.83
Bates 5	14.28	7.52	-0.92	0.30	0.53
Bates 6	20.33	8.84	0.04	0.27	0.43
Caler 1	2.81	3.78	6.44	2.37	1.34
Caler 2	11	7.31	0.09	0.81	0.66
Caler 3	13.34	5.39	-0.23	0.31	0.40
Caler 4	18.35	7.94	-1.01	0.07	0.43
Caler 5	13.07	7.65	0.62	1.08	0.59
Cowee 1	11.73	7.68	-0.85	0.37	0.65
Cowee 2	28.42	8.49	0.51	-0.87	0.30
Cowee 3	18.91	10.66	-1.28	-0.07	0.56
Cowee 4	9.98	7.64	0.06	0.92	0.77
Cowee 5	14.19	11.11	-1.22	0.40	0.78
Crawford 1	5.36	4.51	0.45	1.12	0.84
Crawford 2	6.03	4.56	0.64	0.98	0.76
Crawford 3	5.89	4.66	2.28	1.49	0.79
Crawford 4	13.74	6.75	-0.78	0.10	0.49
Crawford 5	5.32	3.34	1.91	1.21	0.63
Crawford 6	8.30	5.53	-0.03	0.67	0.67
Jones 1	13.03	8.22	-0.57	0.41	0.63
Jones 2	13	6.32	-0.82	0.17	0.49
Jones 3	15.45	7.33	-0.04	0.71	0.47
Jones 4	19.02	8.30	-0.83	0.07	0.44
Jones 5	11.69	5.94	0.27	0.73	0.51
Jones 6	9.65	5.82	0.92	1.08	0.60
Jones 7	9.18	7.90	0.45	1.17	0.86

Rays 1	16.60	9	-0.62	0.53	0.54
Rays 2	27.75	8.95	-0.40	-0.11	0.32
Rays 3	30.58	9.89	-0.68	-0.24	0.32
Rays 4	17.46	11.26	-1.29	0.00	0.65
Rays 5	23.84	9.33	-0.64	-0.15	0.39
Skeenah 1	8.56	6.85	0.69	1.13	0.80
Skeenah 2	15.58	5.68	0.36	0.44	0.36
Skeenah 3	11.43	6.21	-0.16	0.73	0.54
Skeenah 4	9.84	6.50	-0.47	0.77	0.66
Skeenah 5	21.59	9.35	-0.71	0	0.43
Watauga 1	8.06	8	0.03	1.06	0.99
Watauga 2	16.83	8.96	-0.93	0.41	0.53
Watauga 3	12.75	8.64	-0.53	0.60	0.68
Watauga 4	24.66	9.39	-0.39	-0.76	0.38
Watauga 5	18.65	8.86	-0.66	0.40	0.48
Watauga 6	24.09	8.15	-0.14	-0.28	0.34
Average	14.61	7.45	0.06	0.56	0.58

	Slope Steepness in the 30 m Buffer 500 m Upstream of the Study Reach (º)					
	Percentiles					
Reach	5th	25th	50th	75th	95th	5th/95th
Ball 1	1.83	4.66	24.68	25.11	35.32	0.05
Ball 2	9.33	17.57	23.63	31.80	38.78	0.24
Ball 3	7.87	11.87	15.05	20.42	29.14	0.27
Ball 4	5.05	8.19	11.62	20.00	35.30	0.14
Ball 5	5.75	11.66	17.35	23.54	35.42	0.16
Bates 1	0.51	1.52	2.95	9.38	19.78	0.03
Bates 2	1.13	2.53	4.04	7.02	16.39	0.07
Bates 3	2.53	4.66	9.85	16.32	22.55	0.11
Bates 4	1.43	2.58	4.35	8.79	17.35	0.08
Bates 5	3.54	7.88	13.46	20.02	27.24	0.13
Bates 6	5.91	14.45	20.32	25.93	35.80	0.16
Caler 1	0	0.51	1.43	3.24	11.23	0
Caler 2	2.09	4.77	9.64	15.80	24.18	0.09
Caler 3	5	9.64	13.03	16.79	22.54	0.22
Caler 4	5.75	11.66	18.41	24.88	31.15	0.18
Caler 5	4.52	7.33	10.33	17.70	28.31	0.16
Cowee 1	1.43	4.79	11.07	17.35	25.17	0.06

Cowee 2	10.28	24.07	30.35	34.02	39.74	0.26
Cowee 3	2.95	9.07	19.61	28.47	34.52	0.09
Cowee 4	1.43	3.65	8.11	14.45	25.78	0.06
Cowee 5	1.43	3.20	12.47	23.88	32.77	0.04
Crawford 1	0.51	1.83	3.85	7.57	14.92	0.03
Crawford 2	0.72	2.26	5	8.68	14.86	0.05
Crawford 3	1.01	2.53	4.58	7.62	16.17	0.06
Crawford 4	3.24	8.19	13.56	18.99	24.65	0.13
Crawford 5	1.13	2.95	4.66	7	11.74	0.10
Crawford 6	1.01	3.68	7.30	12.27	17.69	0.06
Jones 1	1.60	5.20	12.70	18.62	27.73	0.06
Jones 2	3.22	8.13	12.60	17.83	23.44	0.14
Jones 3	5.75	10.02	13.85	20.19	29.23	0.20
Jones 4	6.10	11.90	19.31	25.58	32.51	0.19
Jones 5	3.85	7.02	10.97	15.36	23.28	0.17
Jones 6	2.53	5.44	8.37	12.50	21.81	0.12
Jones 7	1.43	3.08	6.10	13.06	25.76	0.06
Rays 1	4.68	9.23	14.98	23.11	32.99	0.14
Rays 2	12.71	20.70	28.62	34.36	41.02	0.31
Rays 3	12.94	22.94	31.92	38.16	45	0.29
Rays 4	1.60	5.57	18.18	27.06	34.38	0.05
Rays 5	7.86	16.40	25.12	31.02	37.21	0.21
Skeenah 1	1.43	3.20	6.57	12.31	22.73	0.06
Skeenah 2	6.46	11.66	15.33	19.05	25.34	0.25
Skeenah 3	3.58	6.38	10.13	15.50	23.46	0.15
Skeenah 4	2.58	4.32	7.82	14.57	22.75	0.11
Skeenah 5	6.08	15.42	21.30	27.91	37.27	0.16
Watauga 1	0.51	1.60	4.66	12.77	25.10	0.02
Watauga 2	4.79	9.09	15.17	24.67	32.35	0.15
Watauga 3	1.43	5.64	11.18	18.57	30.17	0.05
Watauga 4	5.36	18.71	27.27	31.96	35.88	0.15
Watauga 5	6.38	11.07	18	25.14	34.52	0.18
Watauga 6	9.05	18.70	25.19	29.65	35.94	0.25
Average	3.99	8.38	13.72	19.52	27.77	0.13

Table C23. Standard statistics of slope steepness in the 30 m buffer 1,000 m upstream of the study reach in degrees.

	Slope Steepness in the 30 m Buffer 1,000 m Upstream of the Study Reach (º)				
Reach	Mean	Standard Deviation	Kurtosis	Skewness	Coefficient of Variation
Ball 1	21.28	10.58	-0.99	-0.26	0.50
Ball 2	26.17	9.22	-0.65	-0.20	0.35
Ball 3	22.95	8.60	-0.98	-0.01	0.37
Ball 4	19.95	9.49	-0.81	0.34	0.48
Ball 5	19.66	8.14	-0.31	0.42	0.41
Bates 1	7.53	6.06	0.24	0.98	0.80
Bates 2	7.99	6.23	0.21	0.99	0.78
Bates 3	16.42	8.61	-0.45	0.27	0.52
Bates 4	8.95	6.65	0.11	0.91	0.74
Bates 5	18.66	8.53	-0.38	0.17	0.46
Bates 6	18.46	8.57	-0.26	0.30	0.46
Caler 1	6.07	6.11	1.78	1.42	1.01
Caler 2	14.70	8.19	-0.44	0.47	0.56
Caler 3	18.12	8.16	-0.55	0.46	0.45
Caler 4	21.93	8.16	-0.75	-0.30	0.37
Caler 5	22.69	10.65	-1.22	-0.20	0.47
Cowee 1	13.68	9.07	-1.13	0.24	0.66
Cowee 2	25.55	9.13	-0.58	-0.54	0.36
Cowee 3	20.49	9.71	-0.89	-0.26	0.47
Cowee 4	10.44	8.54	0.42	1.11	0.82
Cowee 5	16.41	10.47	-1.29	0.07	0.64
Crawford 1	6.02	4.61	0.58	1	0.77
Crawford 2	6.74	5.08	1.28	1.19	0.75
Crawford 3	7.83	6.03	0.52	1.08	0.77
Crawford 4	15.50	7.77	-0.81	0.12	0.50
Crawford 5	10.29	6.66	-0.38	0.72	0.65
Crawford 6	14.45	8.24	-0.95	0.08	0.57
Jones 1	16.27	8.59	-0.93	0.05	0.53
Jones 2	16.33	8.37	-0.51	0.51	0.51
Jones 3	18.47	8.76	-0.75	0.34	0.47
Jones 4	21.54	7.09	-0.38	-0.27	0.33
Jones 5	14.35	6.77	-0.48	0.40	0.47
Jones 6	13.75	6.92	-0.46	0.41	0.50
Jones 7	14.09	8.48	-0.92	0.22	0.60
Rays 1	20.52	9.18	-0.95	0.10	0.45

Rays 2	27.83	8.33	-0.12	-0.24	0.30
Rays 3	31.95	8.51	0.25	-0.27	0.27
Rays 4	13.93	11.07	-1.03	0.51	0.79
Rays 5	22.81	8.40	-0.63	-0.02	0.37
Skeenah 1	10.27	7.85	-0.09	0.89	0.76
Skeenah 2	17.60	6.09	-0.13	0.28	0.35
Skeenah 3	15.10	7.66	-0.29	0.52	0.51
Skeenah 4	14.40	7.83	-0.02	0.52	0.54
Skeenah 5	18.23	7.68	0.01	0.43	0.42
Watauga 1	10.98	8.58	-0.70	0.59	0.78
Watauga 2	21.37	8.75	-0.90	-0.21	0.41
Watauga 3	14.69	9.36	-0.97	0.31	0.64
Watauga 4	22.05	9.40	-1.08	-0.26	0.43
Watauga 5	21.02	9.26	-0.93	0.17	0.44
Watauga 6	21.37	8.73	-0.53	-0.24	0.41
Average	16.76	8.18	-0.42	0.31	0.54

	Slope Steepness in the 30 m Buffer 1,000 m Upstream of the Study Reach (º)					
	Percentiles					
Reach	5th	25th	50th	75th	95th	5th/95th
Ball 1	3.39	12.61	23.21	29.65	35.97	0.09
Ball 2	10.14	19.04	27.42	33.30	39.73	0.26
Ball 3	9.70	15.33	23.63	30.18	35.65	0.27
Ball 4	6.57	12.08	18.83	27.36	35.95	0.18
Ball 5	7.86	13.39	18.70	25.20	34.16	0.23
Bates 1	0.72	2.73	5.64	11.50	19.71	0.04
Bates 2	1.43	3.04	5.75	12.07	20.10	0.07
Bates 3	3.24	9.65	16.21	22.63	30.52	0.11
Bates 4	1.52	3.54	7	13.27	22.12	0.07
Bates 5	4.98	12.14	18.76	24.78	32.39	0.15
Bates 6	5.64	11.40	18.60	24.43	32.23	0.18
Caler 1	0	1.43	4.29	9.05	19.94	0
Caler 2	3.08	7.96	13.91	20.58	29.34	0.10
Caler 3	6.63	11.40	17.05	23.98	32.54	0.20
Caler 4	7.49	15.69	22.83	28.33	33.60	0.22
Caler 5	5.75	12.92	24.26	32.01	37.11	0.16
Cowee 1	1.52	5.08	13.17	21.26	28.79	0.05
Cowee 2	8.63	18.71	27.81	32.64	37.46	0.23

Cowee 3	3.58	13.09	22.04	27.93	34.77	0.10
Cowee 4	1.53	3.68	7.92	14.72	28.83	0.05
Cowee 5	1.83	5.75	16.79	25.45	32.32	0.06
Crawford 1	0.72	2.26	4.66	8.94	14.96	0.05
Crawford 2	1.01	2.86	5.55	9.16	17.18	0.06
Crawford 3	1.13	3.20	5.89	11.33	20.01	0.06
Crawford 4	3.58	9.23	15.26	21.49	28.18	0.13
Crawford 5	1.83	5	8.65	14.72	22.89	0.08
Crawford 6	1.75	7.49	14.51	21.01	27.81	0.06
Jones 1	2.73	9.58	16.05	23.19	29.88	0.09
Jones 2	4.52	9.85	14.85	22.17	31.69	0.14
Jones 3	6.06	11.23	17.25	25.42	33.30	0.18
Jones 4	9.23	16.82	22.23	26.60	32.63	0.28
Jones 5	4.52	9.09	13.74	19	26.29	0.17
Jones 6	3.62	8.53	13.09	18.40	25.95	0.14
Jones 7	1.60	6.76	13.56	20.82	28.01	0.06
Rays 1	6.42	13.06	20.10	27.92	35.29	0.18
Rays 2	13.03	22.15	28.83	33.55	40.36	0.32
Rays 3	15.90	27.27	32.27	37.69	45.05	0.35
Rays 4	1.52	3.24	11.75	23.15	33.80	0.04
Rays 5	9.05	16.29	23.15	29.34	35.47	0.26
Skeenah 1	1.52	3.68	7.88	15.51	26.02	0.06
Skeenah 2	7.83	13.39	17.22	21.69	28.20	0.28
Skeenah 3	4.52	9.05	13.99	20.45	28.73	0.16
Skeenah 4	3.39	7.88	14.01	19.59	28.10	0.12
Skeenah 5	6.55	12.50	18.02	23.03	32.81	0.20
Watauga 1	0.72	3.08	9.38	17.35	26.68	0.03
Watauga 2	6.55	14.05	22.56	28.23	34.58	0.19
Watauga 3	1.52	6.38	13.70	22.20	30.79	0.05
Watauga 4	6.38	14.28	23.13	30.27	35.00	0.18
Watauga 5	7.26	13.35	20.50	28.38	36.34	0.20
Watauga 6	5.07	15.38	22.35	27.97	34.19	0.15
Average	4.69	10.15	16.36	22.78	30.47	0.14

Table C24. Standard statistics of slope steepness in the 30 m buffer of the entire watershed upstream of the study reach in degrees.

	Slope Steepness in the 30 m Buffer of the Study Reach Watershed (º)				
Reach	Mean	Standard Deviation	Kurtosis	Skewness	Coefficient of Variation
Ball 1	23.52	9.34	-0.61	-0.23	0.40
Ball 2	22.75	9.48	-0.66	0.11	0.42
Ball 3	22.93	8.72	-0.98	0.01	0.38
Ball 4	23.87	9.24	-0.76	-0.19	0.39
Ball 5	22.82	9.25	-0.61	0.23	0.41
Bates 1	13.42	8.77	-0.61	0.48	0.65
Bates 2	14.70	8.81	-0.71	0.34	0.60
Bates 3	17.73	8.46	-0.66	0.06	0.48
Bates 4	14.77	8.79	-0.71	0.33	0.60
Bates 5	19.38	8.14	-0.52	-0.02	0.42
Bates 6	19.93	8.02	-0.40	-0.04	0.40
Caler 1	18.91	10.03	-0.96	0.02	0.53
Caler 2	21.36	8.96	-0.78	-0.25	0.42
Caler 3	22.00	9.15	-0.77	0.16	0.42
Caler 4	22.36	8.29	-0.77	-0.36	0.37
Caler 5	23.40	10.55	-1.15	-0.32	0.45
Cowee 1	21.45	10.15	-0.91	-0.16	0.47
Cowee 2	26.72	8.78	-0.61	-0.54	0.33
Cowee 3	20.84	9.17	-0.76	0.09	0.44
Cowee 4	21.23	10.93	-1.03	-0.13	0.51
Cowee 5	23.27	9.47	-0.77	-0.26	0.41
Crawford 1	10.29	7.38	-0.11	0.81	0.72
Crawford 2	12.08	7.99	-0.70	0.50	0.66
Crawford 3	12.96	8.11	-0.84	0.36	0.63
Crawford 4	15.46	7.70	-0.78	0.12	0.50
Crawford 5	13.90	7.87	-0.77	0.33	0.57
Crawford 6	15.26	7.82	-0.81	-0.03	0.51
Jones 1	19.73	9.93	-0.77	0.03	0.50
Jones 2	24.58	9.36	-0.53	-0.23	0.38
Jones 3	21.64	8.68	-0.85	-0.03	0.40
Jones 4	21.47	7.23	-0.33	-0.31	0.34
Jones 5	14.32	6.81	-0.48	0.40	0.48
Jones 6	13.78	6.97	-0.48	0.40	0.51
Jones 7	21.48	9.76	-0.68	-0.09	0.45
Rays 1	25.08	8.98	-0.55	-0.27	0.36

Rays 2	28.90	7.56	0.18	-0.42	0.26
Rays 3	32.14	8.44	0.34	-0.28	0.26
Rays 4	22.53	9.98	-0.68	-0.17	0.44
Rays 5	24.80	9.56	-0.83	0.05	0.39
Skeenah 1	16.16	8.37	-0.58	0.24	0.52
Skeenah 2	17.98	5.86	-0.06	0.22	0.33
Skeenah 3	16.45	7.96	-0.56	0.38	0.48
Skeenah 4	19.41	8.34	-0.68	-0.01	0.43
Skeenah 5	18.40	7.52	0.09	0.45	0.41
Watauga 1	19.04	10.07	-1.04	-0.07	0.53
Watauga 2	22.25	8.87	-0.84	-0.28	0.40
Watauga 3	20.11	9.74	-0.93	-0.13	0.48
Watauga 4	23.74	8.34	-0.59	-0.50	0.35
Watauga 5	21.54	9.13	-0.90	0.11	0.42
Watauga 6	21.37	9.50	-0.50	-0.06	0.44
Average	20.08	8.73	-0.64	0.02	0.45

	Slope Steepness in the 30 m Buffer of the Study Reach Watershed (º)					
	Percentiles					
Reach	5th	25th	50th	75th	95th	5th/95th
Ball 1	7.05	16.55	24.54	30.65	37.21	0.19
Ball 2	7.68	15.27	22.59	29.98	38.19	0.20
Ball 3	9.55	15.08	23.59	30.25	35.78	0.27
Ball 4	8.06	16.55	24.95	31.01	37.39	0.22
Ball 5	9.05	15.35	22.34	29.68	38.44	0.24
Bates 1	1.60	5.64	12.46	19.84	29.12	0.05
Bates 2	2.26	7.07	14.10	21.30	29.83	0.08
Bates 3	4.04	11.07	18.06	24.05	30.77	0.13
Bates 4	2.26	7.13	14.20	21.37	29.84	0.08
Bates 5	5.89	13.22	19.97	25.52	31.51	0.19
Bates 6	6.55	14.05	20.62	25.85	31.53	0.21
Caler 1	2.73	10.64	19.07	27.02	34.66	0.08
Caler 2	5.64	14.67	22.36	28.35	34.54	0.16
Caler 3	8.19	14.57	21.74	29.10	37.06	0.22
Caler 4	7.21	16.15	23.42	29.02	33.92	0.21
Caler 5	5.89	13.92	25.77	32.35	37.27	0.16
Cowee 1	4.04	13.39	22.30	29.67	36.48	0.11
Cowee 2	10.56	20.20	28.95	33.33	38.21	0.28

Cowee 3	6.08	13.64	20.57	27.98	35.74	0.17
Cowee 4	3.20	12	22.41	30.23	37.21	0.09
Cowee 5	6.73	15.98	24.26	30.91	36.98	0.18
Crawford 1	1.43	4.32	8.56	14.98	24.83	0.06
Crawford 2	1.60	5.20	10.80	18.01	26.66	0.06
Crawford 3	1.83	5.75	12.15	19.16	27.27	0.07
Crawford 4	3.58	9.26	15.33	21.30	28.03	0.13
Crawford 5	2.53	7.21	13.14	19.69	27.74	0.09
Crawford 6	2.26	9.26	15.50	21.32	27.77	0.08
Jones 1	3.20	12.02	19.93	27.36	35.65	0.09
Jones 2	8.11	17.68	25.53	31.48	38.69	0.21
Jones 3	7.68	14.51	21.97	28.60	34.95	0.22
Jones 4	8.68	16.73	22.27	26.64	32.60	0.27
Jones 5	4.35	9.09	13.70	18.97	26.37	0.16
Jones 6	3.58	8.55	13.14	18.56	26.07	0.14
Jones 7	4.35	14.10	22.07	28.84	36.77	0.12
Rays 1	9.05	18.54	26.34	31.89	38.15	0.24
Rays 2	14.89	24.53	29.88	34.08	39.96	0.37
Rays 3	16.20	27.57	32.36	37.81	45.23	0.36
Rays 4	4.66	15.02	23.43	30.20	37.42	0.12
Rays 5	10.22	16.37	25.38	32.26	39.61	0.26
Skeenah 1	3.20	9.65	15.94	22.11	30.52	0.10
Skeenah 2	8.37	14.04	17.68	21.84	28.02	0.30
Skeenah 3	4.77	10.52	15.62	22.24	30.50	0.16
Skeenah 4	5.27	13.34	19.45	25.76	32.52	0.16
Skeenah 5	6.76	13.06	17.96	23.03	32.86	0.21
Watauga 1	2.86	10.46	19.71	27.42	34.08	0.08
Watauga 2	6.86	15.26	23.59	29.14	35.14	0.20
Watauga 3	3.85	12.15	20.98	27.97	34.59	0.11
Watauga 4	8.11	17.83	25.45	30.23	34.85	0.23
Watauga 5	7.57	14.05	21.26	28.79	36.45	0.21
Watauga 6	4.66	14.70	22.08	28.30	36.42	0.13
Average	5.89	13.26	20.39	26.71	33.83	0.17

Table C25. Slope steepness of the 30 m buffer of the nine study watersheds and the total study area in degrees.

		Slope in Degrees (º)				
Watershed	Mean	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Ball	23.52	7.05	16.55	24.54	30.65	37.21
Bates	13.42	1.60	5.64	12.46	19.84	29.12
Caler	18.91	2.73	10.64	19.07	27.02	34.66
Cowee	21.45	4.04	13.39	22.30	29.67	36.48
Crawford	10.29	1.43	4.32	8.56	14.98	24.83
Jones	19.73	3.20	12.02	19.93	27.36	35.65
Rays	22.53	4.66	15.02	23.43	30.20	37.42
Skeenah	16.16	3.20	9.65	15.94	22.11	30.52
Watauga	19.04	2.86	10.46	19.71	27.42	34.08
Total	18.34	3.42	10.85	18.44	25.47	33.33

Table C26. Percent of the 10 m buffer of the study reach pertaining to each tax parcel type.

	Percent of the 10 m Buffer of the Study Reach (%)					
Reach	None	Agriculture	Residential	Commercial	Exempt	Road*
Ball 1	100	0	0	0	0	0
Ball 2	100	0	0	0	0	0
Ball 3	100	0	0	0	0	0
Ball 4	100	0	0	0	0	0
Ball 5	100	0	0	0	0	0
Bates 1	0	100	0	0	0	0
Bates 2	0	0	100	0	0	0
Bates 3	0	0	100	0	0	0
Bates 4	0	0	100	0	0	0
Bates 5	0	0	100	0	0	0
Bates 6	39.07	0	60.93	0	0	0
Caler 1	0	100	0	0	0	0
Caler 2	0	0	100	0	0	0
Caler 3	100	0	0	0	0	0
Caler 4	0	0.32	99.68	0	0	0
Caler 5	0	0	100	0	0	0
Cowee 1	0	0	99.74	0	0	0.26
Cowee 2	100	0	0	0	0	0
Cowee 3	0	0	48.44	0	0	51.56
Cowee 4	0	98.57	0	0	0	1.43
Cowee 5	0	100	0	0	0	0
Crawford 1	0	0	0	86.88	12.45	0.67
Crawford 2	0	0	30.51	69.44	0	0.04
Crawford 3	0	0	100	0	0	0
Crawford 4	0	0	100	0	0	0
Crawford 5	0	0	100	0	0	0
Crawford 6	0	0	97.23	0	0	2.77
Jones 1	0	7.93	64.96	0	27.08	0.03
Jones 2	100	0	0	0	0	0
Jones 3	100	0	0	0	0	0
Jones 4	100	0	0	0	0	0
Jones 5	0	100	0	0	0	0
Jones 6	0	100	0	0	0	0
Jones 7	0	100	0	0	0	0
Rays 1	0	0	100	0	0	0
Rays 2	100	0	0	0	0	0
Rays 3	100	0	0	0	0	0

Rays 4	60.51	0	22.16	0	0	17.33
Rays 5	100	0	0	0	0	0
Skeenah 1	0	0	89.26	0	0	10.74
Skeenah 2	100	0	0	0	0	0
Skeenah 3	0	0	100	0	0	0
Skeenah 4	0	0	43.89	0	55.65	0.46
Skeenah 5	100	0	0	0	0	0
Watauga 1	0	100	0	0	0	0
Watauga 2	0	0	100	0	0	0
Watauga 3	0	0	100	0	0	0
Watauga 4	0.86	0	99.14	0	0	0
Watauga 5	0	10.62	89.38	0	0	0
Watauga 6	0	100	0	0	0	0
Average	32.01	18.35	42.91	3.13	1.90	1.71

* The transportation network does not receive a tax parcel type designation, so the percent road cover of the buffer equals the difference between the total buffer area and the area of the other parcels.

Table C27. Percent of the 10 m buffer 100 m upstream of the reach pertaining to each tax parcel type.

	Percent of the 10 m Buffer 100 m Upstream of the Study Reach (%)					
Reach	None	Agriculture	Residential	Commercial	Exempt	Road*
Ball 1	100	0	0	0	0	0
Ball 2	100	0	0	0	0	0
Ball 3	100	0	0	0	0	0
Ball 4	100	0	0	0	0	0
Ball 5	100	0	0	0	0	0
Bates 1	0	66.48	15.60	0	0	17.92
Bates 2	0	0	100	0	0	0
Bates 3	0	0	100	0	0	0
Bates 4	0	0	99.53	0	0	0.47
Bates 5	0	0	79.19	0	0	20.81
Bates 6	50.98	0	49.02	0	0	0
Caler 1	0	71.60	28.40	0	0	0
Caler 2	0	21.66	64.28	0	0	14.06
Caler 3	100	0	0	0	0	0
Caler 4	0	0	100	0	0	0
Caler 5	0	0	100	0	0	0
Cowee 1	0	1.19	98.81	0	0	0
Cowee 2	100	0	0	0	0	0
Cowee 3	0	0	67.59	0	0	32.41
Cowee 4	0	77	0	0	0	23
Cowee 5	0	73.49	17.46	0	0	9.05
Crawford 1	0	0	2.84	87.77	2.33	7.06
Crawford 2	0	0	39.95	60.05	0	0
Crawford 3	0	0	95.38	0	0	4.62
Crawford 4	0	0	100	0	0	0
Crawford 5	0	0	100	0	0	0
Crawford 6	0	0	77.07	0	0	22.93
Jones 1	0	33.38	22.43	0	36.25	7.94
Jones 2	100	0	0	0	0	0
Jones 3	100	0	0	0	0	0
Jones 4	100	0	0	0	0	0
Jones 5	0	100	0	0	0	0
Jones 6	0	100	0	0	0	0
Jones 7	0	71.59	28.41	0	0	0
Rays 1	0.84	0	99.16	0	0	0

Rays 2	100	0	0	0	0	0
Rays 3	100	0	0	0	0	0
Rays 4	83.52	0	4.63	0	0	11.85
Rays 5	100	0	0	0	0	0
Skeenah 1	0	0	99.35	0	0	0.65
Skeenah 2	100	0	0	0	0	0
Skeenah 3	0	0	75.52	0	0	24.48
Skeenah 4	0	0	76.85	0	23.15	0
Skeenah 5	100	0	0	0	0	0
Watauga 1	0	27.26	57.60	0	0	15.14
Watauga 2	0	61.01	38.99	0	0	0
Watauga 3	0	0	100	0	0	0
Watauga 4	92.28	0	7.72	0	0	0
Watauga 5	0	0.52	87.91	0	0	11.57
Watauga 6	0	96.95	3.05	0	0	0
Average	34.55	16.04	40.73	2.96	1.23	4.48

* The transportation network does not receive a tax parcel type designation, so the percent road cover of the buffer equals the difference between the total buffer area and the area of the other parcels.

Table C28. Percent of the 10 m buffer 500 m upstream of the reach pertaining to each tax parcel type.

	Percent of the 10 m Buffer 500 m Upstream of the Study Reach (%)					
Reach	None	Agriculture	Residential	Commercial	Exempt	Road*
Ball 1	100	0	0	0	0	0
Ball 2	100	0	0	0	0	0
Ball 3	100	0	0	0	0	0
Ball 4	100	0	0	0	0	0
Ball 5	100	0	0	0	0	0
Bates 1	0	11	86.17	0	0	2.83
Bates 2	2.76	0	90.37	3.52	0	3.35
Bates 3	2.19	0	95.93	0	0	1.88
Bates 4	4.11	0	89.41	2.83	0	3.65
Bates 5	23.34	0	71.64	0	0	5.02
Bates 6	68.95	0	31.05	0	0	0
Caler 1	0	49.57	49.40	0	0	1.03
Caler 2	0	32.76	63.81	0	0	3.43
Caler 3	100	0	0	0	0	0
Caler 4	41.16	0	58.84	0	0	0
Caler 5	0	0	100	0	0	0
Cowee 1	0	44.38	50.71	0	0	4.91
Cowee 2	100	0	0	0	0	0
Cowee 3	0	76.95	15.49	0	0	7.56
Cowee 4	0	33.53	44.12	0	5.14	17.21
Cowee 5	0	61.33	33.83	0	0	4.84
Crawford 1	0	0	10.86	63.61	15.05	10.48
Crawford 2	0	0	72.17	8.59	13.94	5.30
Crawford 3	0	0	80.37	0	0	19.63
Crawford 4	0	0	94.11	0	0	5.89
Crawford 5	0	0	93.92	0	0	6.08
Crawford 6	0	0	86.61	0	0	13.39
Jones 1	22.31	24.27	35.29	0	13.38	4.75
Jones 2	100	0	0	0	0	0
Jones 3	100	0	0	0	0	0
Jones 4	100	0	0	0	0	0
Jones 5	0	77.75	22.25	0	0	0
Jones 6	0	89.67	10.33	0	0	0
Jones 7	0	47.77	49.09	0	0	3.14
Rays 1	83.83	0	16.17	0	0	0

Rays 2	100	0	0	0	0	0
Rays 3	100	0	0	0	0	0
Rays 4	73.42	0	21.63	0	0	4.95
Rays 5	100	0	0	0	0	0
Skeenah 1	0	0	97.27	0	0	2.73
Skeenah 2	100	0	0	0	0	0
Skeenah 3	0	0	96.49	0	0	3.51
Skeenah 4	0	0	94.35	0	5.65	0
Skeenah 5	100	0	0	0	0	0
Watauga 1	0	2.66	58.85	0	0	38.49
Watauga 2	0	51.51	48.49	0	0	0
Watauga 3	0	0	85.72	0	0	14.28
Watauga 4	98.80	0	1.20	0	0	0
Watauga 5	0	0.06	92.20	0	0	7.74
Watauga 6	0	56.91	9.64	0	0	33.45
Average	38.42	13.20	41.16	1.57	1.06	4.59

* The transportation network does not receive a tax parcel type designation, so the percent road cover of the buffer equals the difference between the total buffer area and the area of the other parcels.

Table C29. Percent of the 10 m buffer 1,000 m upstream of the reach pertaining to each tax parcel type.

	Percent of the 10 m Buffer 1,000 m Upstream of the Study Reach (%)					
Reach	None	Agriculture	Residential	Commercial	Exempt	Road*
Ball 1	100	0	0	0	0	0
Ball 2	100	0	0	0	0	0
Ball 3	100	0	0	0	0	0
Ball 4	100	0	0	0	0	0
Ball 5	100	0	0	0	0	0
Bates 1	0	7.26	91.90	0	0	0.84
Bates 2	2.03	0	92.85	1.40	0	3.72
Bates 3	13.86	0	84.86	0	0	1.28
Bates 4	1.64	0	92.33	1.13	0	4.90
Bates 5	37.88	0	60.05	0	0	2.07
Bates 6	86.30	0	13.70	0	0	0
Caler 1	0	42.61	55.29	0	0	2.10
Caler 2	0	9.94	88.67	0	0	1.39
Caler 3	100	0	0	0	0	0
Caler 4	56.68	0	43.32	0	0	0
Caler 5	24.59	0	75.41	0	0	0
Cowee 1	0	51.49	46.54	0	0	1.97
Cowee 2	100	0	0	0	0	0
Cowee 3	25.01	49.87	19.95	0	0	5.17
Cowee 4	0	12.12	77.79	0	1.86	8.23
Cowee 5	4.86	41.35	48.20	0	0	5.59
Crawford 1	0	0	28.32	48.13	12.47	11.08
Crawford 2	0	0	75.27	3.34	8	13.39
Crawford 3	0	0	85.21	0	0	14.79
Crawford 4	0	0	93.91	0	0	6.09
Crawford 5	0	0	91.33	0	0	8.67
Crawford 6	0	0	79.05	0	0	20.95
Jones 1	21.30	11.30	58.85	0	6.35	2.20
Jones 2	100	0	0	0	0	0
Jones 3	100	0	0	0	0	0
Jones 4	100	0	0	0	0	0
Jones 5	0	52.01	47.99	0	0	0
Jones 6	0	55.70	44.30	0	0	0
Jones 7	1.43	45.45	50.74	0	0	2.38
Rays 1	94.94	0	5.06	0	0	0

Rays 2	100	0	0	0	0	0
Rays 3	100	0	0	0	0	0
Rays 4	59.61	0	37.75	0	0	2.64
Rays 5	100	0	0	0	0	0
Skeenah 1	0	0	91.62	0	4.77	3.61
Skeenah 2	100	0	0	0	0	0
Skeenah 3	0	0	98.61	0	0	1.39
Skeenah 4	0	0	97.98	0	2.02	0
Skeenah 5	100	0	0	0	0	0
Watauga 1	0	1.09	51.93	12.14	0	34.84
Watauga 2	0	21.30	78	0	0	0.70
Watauga 3	0	21.39	63.57	0	0	15.04
Watauga 4	89.89	0	10.11	0	0	0
Watauga 5	0	0.02	90.41	0	0	9.57
Watauga 6	0	17.30	44.28	0	0	38.42
Average	40.40	8.80	44.30	1.32	0.71	4.46

* The transportation network does not receive a tax parcel type designation, so the percent road cover of the buffer equals the difference between the total buffer area and the area of the other parcels.

Table C30. Percent of the 10 m buffer of the watershed upstream of the reach pertaining to each tax parcel type.

	Percent of the 10 m Buffer of the Study Reach Watershed (%)					
Reach	None	Agriculture	Residential	Commercial	Exempt	Road*
Ball 1	100	0	0	0	0	0
Ball 2	100	0	0	0	0	0
Ball 3	100	0	0	0	0	0
Ball 4	100	0	0	0	0	0
Ball 5	100	0	0	0	0	0
Bates 1	18.88	0.90	77.69	0.30	0	2.23
Bates 2	23.17	0	74.11	0.36	0	2.36
Bates 3	40.88	0	58.29	0	0	0.83
Bates 4	23.32	0	73.94	0.37	0	2.37
Bates 5	62.98	0	35.81	0	0	1.21
Bates 6	91.25	0	8.75	0	0	0
Caler 1	17.43	5.81	75.72	0.02	0.04	0.98
Caler 2	0.15	2.95	95.86	0	0	1.04
Caler 3	100	0	0	0	0	0
Caler 4	54.39	0	45.61	0	0	0
Caler 5	30.69	0	69.31	0	0	0
Cowee 1	45.15	11.24	42.31	0.01	0.04	1.25
Cowee 2	100	0	0	0	0	0
Cowee 3	44.51	10.49	43.84	0	0	1.16
Cowee 4	35.51	13.48	48.68	0.06	0.20	2.07
Cowee 5	62.86	5.08	31.27	0	0	0.79
Crawford 1	0	0	73.39	10.57	4.56	11.48
Crawford 2	0	0	84.34	1.32	2.42	11.92
Crawford 3	0	0	87.40	0	0	12.60
Crawford 4	0	0	94.07	0	0	5.93
Crawford 5	0	0	94.53	0	0	5.47
Crawford 6	0	0	80.36	0	0	19.64
Jones 1	65.80	11.78	21	0	0.43	0.99
Jones 2	100	0	0	0	0	0
Jones 3	100	0	0	0	0	0
Jones 4	100	0	0	0	0	0
Jones 5	0	52.68	47.32	0	0	0
Jones 6	0	55.89	44.11	0	0	0
Jones 7	82.47	6.20	10.91	0	0	0.42
Rays 1	96.51	0	3.49	0	0	0

Rays 2	100	0	0	0	0	0
Rays 3	100	0	0	0	0	0
Rays 4	87.44	0.01	10.26	0	1.79	0.50
Rays 5	100	0	0	0	0	0
Skeenah 1	31.75	4.22	62.16	0	0.79	1.08
Skeenah 2	100	0	0	0	0	0
Skeenah 3	0	0	99.07	0	0	0.93
Skeenah 4	6.52	0	92.20	0	1.28	0
Skeenah 5	100	0	0	0	0	0
Watauga 1	11.48	5.77	68.59	1.92	0.15	12.09
Watauga 2	4.81	18.83	75.45	0	0	0.91
Watauga 3	20.34	8.12	58.94	1.16	0	11.44
Watauga 4	94.26	0	5.59	0	0	0.15
Watauga 5	0.72	0.07	89.96	0	0	9.25
Watauga 6	0	13.77	47.60	9.33	0	29.30
Average	51.07	4.55	40.64	0.51	0.23	3.01

* The transportation network does not receive a tax parcel type designation, so the percent road cover of the buffer equals the difference between the total buffer area and the area of the other parcels.

Table C31. Percent of the 10 m buffer of the nine study watersheds and the total study area pertaining to each tax parcel type.

	Percent Parcel Type (%)					
Watershed	None	Agriculture	Residential	Commercial	Exempt	Road
Ball	100	0	0	0	0	0
Bates	18.88	0.90	77.69	0.30	0	2.23
Caler	17.43	5.81	75.72	0.02	0.04	0.98
Cowee	45.15	11.24	42.31	0.01	0.04	1.25
Crawford	0	0	73.39	10.57	4.56	11.48
Jones	65.80	11.78	21	0	0.43	0.99
Rays	87.44	0.01	10.26	0	1.79	0.50
Skeenah	31.75	4.22	62.16	0	0.79	1.08
Watauga	11.48	5.77	68.59	1.92	0.15	12.09
Total	41.99	4.41	47.90	1.42	0.87	3.40

APPENDIX D

LARGE WOOD MEASUREMENTS FROM 2010 FOR STATISTICAL ANALYSIS

Table D1. Raw channel dimensions and large wood measurements by study reach from surveys in 2010.

Reach	Stream Length Surveyed (m)	Bankfull Channel Width (m)	Large Wood Measurements of the Study Reach: Number of Pieces	Average Diameter (m)	Average Length (m)	Total Volume (m³)
Ball 1	150	6.14	17	0.23	2.64	2.42
Ball 2	135	4.76	20	0.20	1.94	1.79
Ball 3	75	2.57	7	0.30	2.01	1.30
Ball 4	135	4.32	27	0.24	2.26	3.90
Ball 5	105	3.43	27	0.27	2.15	4.37
Bates 1	90	2.35	11	0.16	1.79	0.38
Bates 2	60	2.53	0	0	0	0
Bates 3	30	1.50	0	0	0	0
Bates 4	90	3.62	4	0.31	2.43	0.91
Bates 5	30	1.13	0	0	0	0
Bates 6	45	2.10	3	0.14	1.55	0.07
Caler 1	150	5.28	4	0.18	1.88	0.22
Caler 2	90	2.71	3	0.14	2.09	0.10
Caler 3	75	2.42	12	0.23	1.90	1.49
Caler 4	45	1.78	3	0.14	1.70	0.07
Caler 5	45	1.67	2	0.18	1.23	0.08
Cowee 1	195	6.29	30	0.21	2.95	3.75
Cowee 2	120	4.52	21	0.23	2.17	1.97
Cowee 3	45	1.97	0	0	0	0
Cowee 4	75	2.43	1	0.10	1.08	0.01
Cowee 5	135	3.73	11	0.25	2.17	1.38
Crawford 1	90	2.84	7	0.26	1.98	0.97
Crawford 2	75	2.25	1	0.55	1.83	0.43
Crawford 3	60	2.16	0	0	0	0
Crawford 4	45	1.46	6	0.16	1.71	0.23
Crawford 5	45	1.43	3	0.15	2.32	0.15
Crawford 6	45	1.58	1	0.20	1.56	0.05
Jones 1	240	7.64	34	0.21	2.40	5.48
Jones 2	180	5.82	11	0.17	2.29	0.89
Jones 3	105	4.06	18	0.27	2.55	3.22
Jones 4	90	2.76	22	0.27	1.97	4.08
Jones 5	60	2.08	4	0.15	2.28	0.17
Jones 6	30	1.09	1	0.13	1.15	0.02

Jones 7	165	5.81	30	0.19	2.44	2.85
Rays 1	150	4.59	26	0.22	2.35	3.29
Rays 2	105	4.29	39	0.29	1.97	6.22
Rays 3	75	2.43	13	0.16	2.25	1.07
Rays 4	180	6.05	27	0.21	2.60	2.96
Rays 5	120	4.48	14	0.24	2.32	2.25
Skeenah 1	120	3.55	5	0.16	1.56	0.16
Skeenah 2	75	2.38	4	0.12	2.25	0.10
Skeenah 3	45	1.52	0	0	0	0
Skeenah 4	45	1.63	0	0	0	0
Skeenah 5	75	2.63	19	0.21	1.94	1.53
Watauga 1	105	4.29	2	0.23	2.80	0.25
Watauga 2	30	1	0	0	0	0
Watauga 3	60	2.09	0	0	0	0
Watauga 4	120	3.75	14	0.19	2.19	0.89
Watauga 5	60	2.48	3	0.16	2.69	0.15
Watauga 6	90	3.22	7	0.18	2.13	0.37
Average	92.10	3.17	10.28	0.17	1.71	1.24

Table D2. Large wood measurements per m channel length from surveys in 2010.

	Large Wood Measurements Per m Channel Length*			
Reach	Pieces/m	Average Diameter (m)/m	Average Length (m)/m	Total Volume (m^3)/m
Ball 1	0.11	0.0015	0.018	0.0161
Ball 2	0.15	0.0015	0.014	0.0132
Ball 3	0.09	0.0041	0.027	0.0174
Ball 4	0.20	0.0018	0.017	0.0289
Ball 5	0.26	0.0026	0.020	0.0416
Bates 1	0.12	0.0017	0.020	0.0042
Bates 2	0	0	0	0
Bates 3	0	0	0	0
Bates 4	0.04	0.0034	0.027	0.0102
Bates 5	0	0	0	0
Bates 6	0.07	0.0032	0.035	0.0016
Caler 1	0.03	0.0012	0.013	0.0014
Caler 2	0.03	0.0016	0.023	0.0011
Caler 3	0.16	0.0030	0.025	0.0198
Caler 4	0.07	0.0031	0.038	0.0016
Caler 5	0.04	0.0040	0.027	0.0017
Cowee 1	0.15	0.0011	0.015	0.0192
Cowee 2	0.18	0.0019	0.018	0.0164
Cowee 3	0	0	0	0
Cowee 4	0.01	0.0013	0.014	0.0001
Cowee 5	0.08	0.0018	0.016	0.0102
Crawford 1	0.08	0.0028	0.022	0.0108
Crawford 2	0.01	0.0073	0.024	0.0058
Crawford 3	0	0	0	0
Crawford 4	0.13	0.0035	0.038	0.0052
Crawford 5	0.07	0.0033	0.052	0.0032
Crawford 6	0.02	0.0044	0.035	0.0011
Jones 1	0.14	0.0009	0.010	0.0229
Jones 2	0.06	0.0009	0.013	0.0049
Jones 3	0.17	0.0026	0.024	0.0307
Jones 4	0.24	0.0031	0.022	0.0454
Jones 5	0.07	0.0025	0.038	0.0028
Jones 6	0.03	0.0043	0.038	0.0005
Jones 7	0.18	0.0012	0.015	0.0173
Rays 1	0.17	0.0014	0.016	0.0219

Rays 2	0.37	0.0027	0.019	0.0593
Rays 3	0.17	0.0022	0.030	0.0143
Rays 4	0.15	0.0012	0.014	0.0165
Rays 5	0.12	0.0020	0.019	0.0187
Skeenah 1	0.04	0.0014	0.013	0.0013
Skeenah 2	0.05	0.0016	0.030	0.0014
Skeenah 3	0	0	0	0
Skeenah 4	0	0	0	0
Skeenah 5	0.25	0.0028	0.026	0.0204
Watauga 1	0.02	0.0021	0.027	0.0023
Watauga 2	0	0	0	0
Watauga 3	0	0	0	0
Watauga 4	0.12	0.0016	0.018	0.0074
Watauga 5	0.05	0.0027	0.045	0.0025
Watauga 6	0.08	0.0020	0.024	0.0042
Average	0.09	0.0020	0.020	0.0105

* Measurements per m channel length are found by dividing the variables by the stream length surveyed.

Table D3. Large wood measurements per m² channel area from surveys in 2010.

	Large Wood Measurements Per m² Channel Area*			
Reach	Pieces/m²	Average Diameter (m)/m²	Average Length (m)/m²	Total Volume (m³)/m²
Ball 1	0.018	0.0002	0.003	0.0026
Ball 2	0.031	0.0003	0.003	0.0028
Ball 3	0.036	0.0016	0.010	0.0068
Ball 4	0.046	0.0004	0.004	0.0067
Ball 5	0.075	0.0008	0.006	0.0121
Bates 1	0.052	0.0007	0.008	0.0018
Bates 2	0	0	0	0
Bates 3	0	0	0	0
Bates 4	0.012	0.0009	0.007	0.0028
Bates 5	0	0	0	0
Bates 6	0.032	0.0015	0.016	0.0008
Caler 1	0.005	0.0002	0.002	0.0003
Caler 2	0.012	0.0006	0.009	0.0004
Caler 3	0.066	0.0012	0.010	0.0082
Caler 4	0.037	0.0017	0.021	0.0009
Caler 5	0.027	0.0024	0.016	0.0010
Cowee 1	0.024	0.0002	0.002	0.0031
Cowee 2	0.039	0.0004	0.004	0.0036
Cowee 3	0	0	0	0
Cowee 4	0.005	0.0005	0.006	0.0000
Cowee 5	0.022	0.0005	0.004	0.0027
Crawford 1	0.027	0.0010	0.008	0.0038
Crawford 2	0.006	0.0033	0.011	0.0026
Crawford 3	0	0	0	0
Crawford 4	0.091	0.0024	0.026	0.0035
Crawford 5	0.047	0.0023	0.036	0.0023
Crawford 6	0.014	0.0028	0.022	0.0007
Jones 1	0.019	0.0001	0.001	0.0030
Jones 2	0.011	0.0002	0.002	0.0009
Jones 3	0.042	0.0006	0.006	0.0076
Jones 4	0.089	0.0011	0.008	0.0164
Jones 5	0.032	0.0012	0.018	0.0013
Jones 6	0.031	0.0040	0.035	0.0005
Jones 7	0.031	0.0002	0.003	0.0030
Rays 1	0.038	0.0003	0.003	0.0048

Rays 2	0.087	0.0006	0.004	0.0138
Rays 3	0.071	0.0009	0.012	0.0059
Rays 4	0.025	0.0002	0.002	0.0027
Rays 5	0.026	0.0005	0.004	0.0042
Skeenah 1	0.012	0.0004	0.004	0.0004
Skeenah 2	0.022	0.0007	0.013	0.0006
Skeenah 3	0	0	0	0
Skeenah 4	0	0	0	0
Skeenah 5	0.096	0.0011	0.010	0.0078
Watauga 1	0.004	0.0005	0.006	0.0005
Watauga 2	0	0	0	0
Watauga 3	0	0	0	0
Watauga 4	0.031	0.0004	0.005	0.0020
Watauga 5	0.020	0.0011	0.018	0.0010
Watauga 6	0.024	0.0006	0.007	0.0013
Average	0.029	0.0008	0.008	0.0029

* Measurements per m^2 channel area are found by dividing the variables by the product of the bankfull width and the stream length surveyed.

Table D4. Large wood measurements per channel length in units of channel width ($length_{SR/30}$) from surveys in 2010.

	Large Wood Measurements Per $Length_{SR/30}$*			
Reach	Pieces/$Length_{SR/30}$	Average Diameter (m)/$Length_{SR/30}$	Average Length (m)/$Length_{SR/30}$	Total Volume (m^3)/$Length_{SR/30}$
Ball 1	0.57	0.0075	0.088	0.081
Ball 2	0.67	0.0068	0.065	0.060
Ball 3	0.23	0.0101	0.067	0.043
Ball 4	0.90	0.0079	0.075	0.130
Ball 5	0.90	0.0092	0.072	0.146
Bates 1	0.37	0.0052	0.060	0.013
Bates 2	0	0	0.000	0.000
Bates 3	0	0	0	0
Bates 4	0.13	0.0102	0.081	0.030
Bates 5	0	0	0	0
Bates 6	0.10	0.0048	0.052	0.002
Caler 1	0.13	0.0059	0.063	0.007
Caler 2	0.10	0.0047	0.070	0.003
Caler 3	0.40	0.0076	0.063	0.050
Caler 4	0.10	0.0047	0.057	0.002
Caler 5	0.07	0.0060	0.041	0.003
Cowee 1	1.00	0.0070	0.098	0.125
Cowee 2	0.70	0.0076	0.072	0.066
Cowee 3	0	0	0	0
Cowee 4	0.03	0.0033	0.036	0.000
Cowee 5	0.37	0.0083	0.072	0.046
Crawford 1	0.23	0.0085	0.066	0.032
Crawford 2	0.03	0.0183	0.061	0.014
Crawford 3	0	0	0	0
Crawford 4	0.20	0.0052	0.057	0.008
Crawford 5	0.10	0.0050	0.077	0.005
Crawford 6	0.03	0.0067	0.052	0.002
Jones 1	1.13	0.0071	0.080	0.183
Jones 2	0.37	0.0056	0.076	0.030
Jones 3	0.60	0.0091	0.085	0.107
Jones 4	0.73	0.0092	0.066	0.136
Jones 5	0.13	0.0051	0.076	0.006
Jones 6	0.03	0.0043	0.038	0.001
Jones 7	1.00	0.0064	0.081	0.095

Rays 1	0.87	0.0072	0.078	0.110
Rays 2	1.30	0.0096	0.066	0.207
Rays 3	0.43	0.0054	0.075	0.036
Rays 4	0.90	0.0070	0.087	0.099
Rays 5	0.47	0.0081	0.077	0.075
Skeenah 1	0.17	0.0055	0.052	0.005
Skeenah 2	0.13	0.0041	0.075	0.003
Skeenah 3	0	0	0	0
Skeenah 4	0	0	0	0
Skeenah 5	0.63	0.0070	0.065	0.051
Watauga 1	0.07	0.0075	0.093	0.008
Watauga 2	0	0	0	0
Watauga 3	0	0	0	0
Watauga 4	0.47	0.0063	0.073	0.030
Watauga 5	0.10	0.0054	0.090	0.005
Watauga 6	0.23	0.0060	0.071	0.012
Average	0.34	0.0057	0.057	0.041

* Measurements are found by dividing the variables by 30, because the reach length equals 30 times the bankfull width.

APPENDIX E

LARGE WOOD RESURVEY DATA FROM SEPTEMBER 2012 AND JANUARY 2013

* Functions: B—bank protection, O—organic matter retention, P—pool formation, S—sediment retention, N—no function

Table E1. Ball 2

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.12	1.50	0.02	Y	B,O,S	10.1
2	0.12	1.00	0.01	Y	B,O	29.2
3	0.10	1.50	0.01	Y	B,O	29.2
4	0.11	3.00	0.03	Y	B	30.1
5	0.13	1.20	0.02	Y	B	30.1
6	0.11	1.40	0.01	Y	B	35
7	0.10	1.20	0.01	N	B	41.8
8	0.17	2.20	0.05	N	B,O	42.5
9	0.25	1.50	0.07	N	B,O	52.7
10	0.13	1.20	0.02	N	B	63.6
11	0.27	1.40	0.08	Y	B,O	68.5
12	0.12	1.10	0.01	Y	B,O	68.5
13	0.12	1.30	0.01	Y	B	71.6
14	0.12	1.00	0.01	N	B,O,S	72.3
15	0.10	2.50	0.02	N	B,O,P,S	73.6
16	0.11	1.40	0.01	Y	B,O	89.2
17	0.15	1.50	0.03	Y	B,O	89.2
18	0.13	1.30	0.02	N	B	106.3
19	0.20	2.30	0.07	N	B	107.4
20	0.35	2.50	0.24	N	B,O	124.9

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.21	1.20	0.04	Y	O,P,S	10.6
2	0.13	1.20	0.02	Y	B	30.7
3	0.10	1.00	0.01	Y	B,O	36.2
4	0.10	1.20	0.01	N	B	43
5	0.17	2.20	0.05	N	B,O,P,S	43.5
6	0.25	1.50	0.07	N	B,O,S	55.2
7	0.13	1.20	0.02	N	B,O,S	62.6
8	0.10	2.00	0.02	N	B	66.6

9	0.27	1.40	0.08	Y	B,O,P,S	72.3
10	0.12	1.00	0.01	Y	B,O,P,S	72.3
11	0.14	1.50	0.02	N	O,P,S	75.2
12	0.10	1.00	0.01	N	B	76.2
13	0.10	2.50	0.02	N	B,O,S	77.5
14	0.11	1.40	0.01	Y	B,O,P	91.8
15	0.13	1.00	0.01	Y	B,O,P	91.8
16	0.15	1.50	0.03	Y	B,O,P	91.8
17	0.13	1.30	0.02	N	B	107.2
18	0.20	2.30	0.07	N	B,O,S	107.7
19	0.30	1.10	0.08	N	B,O,S	113.9
20	0.35	2.50	0.24	N	B,O,S	124.8

Table E2. Bates 3

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
0	0	0	0	NA	NA	NA

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
0	0	0	0	NA	NA	NA

Table E3. Caler 5

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	1.00	0.01	Y	B,O,S	5.5
2	0.10	3.00	0.02	N	N	15.4
3	0.10	1.20	0.01	N	B,O,P,S	45

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	3.00	0.02	N	O,S	13.8
2	0.25	1.00	0.05	N	B,O,P,S	25.6
3	0.10	1.20	0.01	N	B,O,P,S	45

Table E4. Cowee 2

			September			
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.19	1.70	0.05	N	B,O,P,S	2.6
2	0.25	2.00	0.10	N	B,O	10.3
3	0.30	2.50	0.18	Y	B,O	13.3
4	0.17	2.50	0.06	Y	B,O	13.4
5	0.13	1.30	0.02	Y	B	15
6	0.17	2.00	0.05	Y	B	15.4
7	0.30	2.30	0.16	N	B,O,S	23.8
8	0.30	1.50	0.11	N	B	24
9	0.20	1.00	0.03	Y	B,O,S	25.8
10	0.13	2.00	0.03	Y	B,O,P,S	31.5
11	0.22	1.20	0.05	Y	B,O,P,S	31.5
12	0.20	1.10	0.03	N	O	31.8
13	0.12	1.00	0.01	Y	B,O	32.9
14	0.12	1.80	0.02	N	B	35.7
15	0.27	1.50	0.09	N	O,P,S	36.3
16	0.15	2.20	0.04	Y	B	57.3
17	0.10	1.00	0.01	Y	B	58
18	0.11	1.70	0.02	N	B,O,S	61.4
19	0.11	2.50	0.02	N	B	71.1
20	0.14	1.90	0.03	N	N	74.6
21	0.17	2.50	0.06	N	B,O,S	75.9
22	0.10	1.30	0.01	N	B	80.3
23	0.21	1.50	0.05	N	B,S	86.7
24	0.20	1.80	0.06	N	B	90.7
25	0.22	1.60	0.06	N	B,S	100.4
26	0.10	1.00	0.01	Y	B,O,P,S	101.4
27	0.10	1.20	0.01	Y	B,O,P,S	101.9
28	0.12	1.00	0.01	Y	B,O,P,S	101.9
29	0.13	1.10	0.01	N	B,S	107.8
30	0.25	1.50	0.07	Y	B,O,P,S	111.2
31	0.20	1.70	0.05	Y	B,O,S	115.1
32	0.10	1.50	0.01	Y	B	115.1
33	0.11	1.10	0.01	Y	B	115.1
34	0.16	6.00	0.12	Y	B,S	117.3

35	0.15	1.50	0.03	Y	O,P,S	117.4
36	0.22	2.30	0.09	Y	B,O,P,S	117.4
37	0.15	1.20	0.02	Y	O,S	117.5
38	0.12	1.50	0.02	Y	B,O,S	117.5
39	0.13	1.20	0.02	N	O,P,S	119.6
40	0.21	1.00	0.03	Y	B,O,S	119.8
41	0.22	2.20	0.08	Y	B,O,S	119.8
42	0.12	1.20	0.01	Y	B,O,P,S	120
43	0.13	1.50	0.02	Y	B,O,P,S	120

January

Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.18	2.30	0.06	Y	B,O	0
2	0.19	1.70	0.05	N	B,S	2.6
3	0.25	2.00	0.10	N	B,S	3.6
4	0.21	1.80	0.06	N	B,O,S	9.7
5	0.25	2.20	0.11	N	B,O,S	15
6	0.13	1.30	0.02	Y	B,O,S	16.6
7	0.17	2.00	0.05	Y	B,O,S	17.8
8	0.16	2.00	0.04	N	B	20.5
9	0.15	1.10	0.02	Y	B,O	20.5
10	0.20	1.20	0.04	N	B,S	21.5
11	0.13	1.80	0.02	Y	O	25.8
12	0.18	1.40	0.04	Y	O	25.8
13	0.16	1.00	0.02	Y	B,P	29.5
14	0.12	1.80	0.02	Y	P,O,S	34.2
15	0.16	1.40	0.03	Y	P,O,S	34.2
16	0.10	1.20	0.01	Y	P,O	37
17	0.10	1.50	0.01	N	B,S	39.2
18	0.11	1.70	0.02	Y	B,O	60.4
19	0.13	1.00	0.01	Y	B,O	63
20	0.10	1.60	0.01	Y	B,O,P,S	67
21	0.25	1.30	0.06	Y	B,O,S	67
22	0.14	1.90	0.03	N	B,O,S	75.6
23	0.17	1.10	0.02	N	B,O,S	83.2
24	0.21	1.50	0.05	Y	B,O,P,S	90.3
25	0.20	1.80	0.06	N	B,O,S	94.5
26	0.22	1.60	0.06	N	B,O	99
27	0.10	2.00	0.02	Y	B,O,P,S	100.1
28	0.13	1.10	0.01	Y	B,O,P,S	100.1

29	0.10	1.20	0.01	Y	B,O,P,S	100.4
30	0.25	1.50	0.07	Y	B	102.8
31	0.20	1.70	0.05	Y	B,O,P,S	104.1
32	0.20	1.00	0.03	Y	B,O,P,S	104.1
33	0.10	1.50	0.01	Y	B,O,P,S	105.6
34	0.15	1.80	0.03	Y	B,O	105.8
35	0.10	1.00	0.01	Y	B,O	106
36	0.35	4.00	0.38	Y	B,O,P,S	110.3
37	0.16	6.00	0.12	Y	B,O,P,S	113.2
38	0.22	2.30	0.09	Y	B,O,P,S	114.3
39	0.22	2.20	0.08	Y	B,O,P,S	115
40	0.10	1.00	0.01	Y	B,O,P,S	115.3
41	0.15	1.50	0.03	Y	B,O,P,S	115.4
42	0.14	1.90	0.03	Y	B,O,P,S	115.5
43	0.21	1.10	0.04	Y	B,O,P,S	115.5
44	0.10	1.00	0.01	Y	B,O,P,S	115.6
45	0.15	2.00	0.04	Y	B,O	118.2
46	0.13	1.50	0.02	Y	B,O	118.3

Table E5. Crawford 2

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	1.00	0.01	Y	O,P	26.1
2	0.11	1.30	0.01	Y	B	28.2
3	0.10	1.50	0.01	N	B	35.6
4	0.20	1.10	0.03	N	N	66.6
5	0.53	1.70	0.38	Y	B	67

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	1.00	0.01	Y	B,O,P	25.8
2	0.20	1.10	0.03	Y	N	67
3	0.53	1.70	0.38	Y	B,O,S	67.3

Table E6. Crawford 5

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.27	1.90	0.11	N	B	3.7
2	0.10	1.00	0.01	N	B	4.5
3	0.30	1.10	0.08	N	B	21
4	0.17	1.30	0.03	N	B,S	24.3

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.27	1.90	0.11	N	B	3.8
2	0.30	1.10	0.08	N	B	20.8
3	0.17	1.30	0.03	N	B,S	24.2

Table E7. Jones 6

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.13	0.12	0.00	N	B	25.2

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.13	0.12	0.00	N	B	25.1

Table E8. Jones 7

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	1.20	0.01	Y	B,O	19.3
2	0.10	1.00	0.01	N	B	30.9
3	0.11	2.20	0.02	Y	B,O	35.4
4	0.13	1.70	0.02	Y	B,O	45.4
5	0.14	2.00	0.03	Y	B,O	54.7
6	0.10	2.50	0.02	N	B	64
7	0.11	1.00	0.01	Y	B,S	77.5
8	0.22	3.00	0.11	Y	B,O	85.2
9	0.17	3.50	0.08	Y	B,O	85.2
10	0.15	1.00	0.02	Y	B,O	85.2
11	0.11	1.80	0.02	Y	B,O	85.8
12	0.13	2.50	0.03	N	B	88.8
13	0.14	3.50	0.05	Y	B,O	90.4
14	0.25	2.00	0.10	Y	B,O,P	94.8
15	0.13	2.20	0.03	Y	B,O	154.1
16	0.12	2.00	0.02	N	B	154.5
17	0.15	1.80	0.03	Y	N	157.8

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.12	3.00	0.03	Y	B	28.7
2	0.11	2.20	0.02	Y	B	39.4
3	0.13	1.70	0.02	Y	B,O,P	49.1
4	0.14	2.00	0.03	Y	B	57.5
5	0.22	3.00	0.11	Y	B,O,S	88
6	0.17	3.50	0.08	Y	B	88
7	0.25	1.00	0.05	Y	B,O	90.1
8	0.11	1.80	0.02	N	B	94.8
9	0.13	2.50	0.03	Y	N	98.5
10	0.14	3.50	0.05	Y	B,O	98.5
11	0.25	2.00	0.10	Y	B	102
12	0.15	1.80	0.03	N	B,S	106.1
13	0.15	3.50	0.06	Y	B,O,S	106.5
14	0.22	2.00	0.08	Y	P	107.2

15	0.20	1.00	0.03	Y	P	107.2
16	0.25	1.50	0.07	Y	P	107.2
17	0.15	1.30	0.02	Y	B,O,S	110.9
18	0.14	1.00	0.02	Y	B,O,S	110.9
19	0.13	2.20	0.03	Y	B	142.8

Table E9. Rays 1

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	2.00	0.02	N	B,O	4.6
2	0.10	2.00	0.02	Y	B,O	11.5
3	0.13	1.10	0.01	Y	B,O	11.8
4	0.11	4.00	0.04	Y	B,O,P,S	15.2
5	0.55	1.70	0.40	N	B,O	16.3
6	0.10	1.00	0.01	N	B	21.7
7	0.10	4.00	0.03	Y	B,O,S	22.4
8	0.55	1.50	0.36	Y	B,O,P,S	23.3
9	0.40	1.30	0.16	N	B,O,P,S	41.6
10	0.12	1.10	0.01	N	B,O,S	45.5
11	0.14	2.00	0.03	Y	B,O,S	57.5
12	0.10	1.50	0.01	N	B	70.4
13	0.13	2.20	0.03	Y	B	110.1
14	0.10	1.00	0.01	N	B	112
15	0.13	2.50	0.03	N	B	112.2
16	0.10	3.00	0.02	N	B	113.8
17	0.16	2.50	0.05	Y	B	115.1
18	0.25	1.50	0.07	Y	B	115.1
19	0.22	1.60	0.06	N	B	121.7
20	0.12	1.10	0.01	N	B	129.8
21	0.13	1.00	0.01	Y	B,O,S	143.2
22	0.11	2.00	0.02	N	B,O	150

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	2.00	0.02	Y	N	10.9
2	0.55	1.70	0.40	N	B,O,S	15.4
3	0.10	4.00	0.03	Y	N	21.1
4	0.55	1.50	0.36	Y	B,O,P,S	23.1
5	0.10	3.00	0.02	N	N	35
6	0.40	1.30	0.16	Y	B,O,P,S	39.5
7	0.12	1.10	0.01	Y	O,S	48.9
8	0.30	2.00	0.14	Y	B,O,P,S	48.9
9	0.27	1.40	0.08	Y	B,O,S	57.3

10	0.14	2.00	0.03	Y	B,O,S	57.4
11	0.13	2.20	0.03	Y	B,O	111.3
12	0.13	2.50	0.03	Y	B,O	111.3
13	0.25	1.50	0.07	Y	B,O,S	111.4
14	0.22	1.60	0.06	N	B	116.6
15	0.12	1.10	0.01	Y	B,O	128.9

Table E10. Rays 5

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.15	2.50	0.04	N	B	1
2	0.60	1.20	0.34	N	B	1
3	0.20	2.00	0.06	Y	B,O,P,S	10.4
4	0.26	4.00	0.21	Y	B,O,P,S	14.3
5	0.11	1.50	0.01	Y	B,O	14.5
6	0.13	1.10	0.01	Y	B,O	14.5
7	0.55	2.70	0.64	N	B,O	22
8	0.13	1.10	0.01	N	B	49.3
9	0.32	2.40	0.19	N	O,S	53.1
10	0.10	2.50	0.02	N	B,O,S	55.3
11	0.15	2.00	0.04	N	O,S	57.1
12	0.20	1.30	0.04	N	B	58.7
13	0.45	2.00	0.32	Y	B	60
14	0.23	1.30	0.05	Y	B,O	61.7
15	0.10	1.00	0.01	N	B	66.8
16	0.25	1.40	0.07	N	B	67.9
17	0.10	3.00	0.02	N	B	87.8
18	0.20	1.50	0.05	Y	B,O,P,S	91.8
19	0.12	3.00	0.03	N	B,O,S	104.8
20	0.12	2.00	0.02	N	B,O	105.5
21	0.14	2.50	0.04	N	B	107.1
22	0.13	3.00	0.04	N	N	112
23	0.10	2.50	0.02	Y	B	113.1
24	0.20	1.20	0.04	Y	B	113.9
25	0.14	2.00	0.03	N	B	119.4

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.12	1.20	0.01	N	B,S	0.5
2	0.60	1.20	0.34	N	B,O,P,S	1
3	0.15	1.00	0.02	Y	N	5.1
4	0.11	1.20	0.01	Y	B	5.1
5	0.26	4.00	0.21	Y	B,O,P,S	14

6	0.18	1.40	0.04	Y	B,S	15.1
7	0.13	1.10	0.01	Y	B	15.6
8	0.13	1.20	0.02	N	B,O,S	18.5
9	0.55	2.70	0.64	N	B,O,S	22.1
10	0.32	2.40	0.19	Y	O,S	56.5
11	0.24	2.20	0.10	Y	B,O,S	63.2
12	0.23	1.30	0.05	Y	B,O,S	63.9
13	0.40	1.30	0.16	N	B,O,S	72.6
14	0.11	1.50	0.01	N	B,O,S	80
15	0.15	1.00	0.02	N	B,S	95.2
16	0.12	2.00	0.02	N	N	101.2
17	0.10	1.00	0.01	Y	B,O,P,S	108.7
18	0.10	2.50	0.02	Y	B,S	108.9
19	0.13	3.00	0.04	Y	B,O	114.6
20	0.20	1.20	0.04	Y	B,O,S	115
21	0.14	2.00	0.03	Y	B,O,S	116.3
22	0.13	1.30	0.02	N	B	119.8

Table E11. Skeenah 1

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.20	1.35	0.04	Y	B,O	89.2
2	0.30	2.50	0.18	Y	B,O	90.3
3	0.12	1.30	0.01	N	B,S	115

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.10	2.00	0.02	N	B	83.5
2	0.30	2.50	0.18	Y	B,O	91.9
3	0.12	1.30	0.01	N	B,S	115

Table E12. Watauga 3

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
0	0	0	0	NA	NA	NA

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
0	0	0	0	NA	NA	NA

Table E13. Watauga 6

September						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.14	1.20	0.02	Y	B,O	1.7
2	0.12	1.50	0.02	Y	B,O	1.7
3	0.13	3.00	0.04	N	B	6
4	0.10	2.50	0.02	Y	B,O	13
5	0.20	1.70	0.05	Y	B,O,P,S	52.9
6	0.14	1.10	0.02	Y	B,O,S	54.1
7	0.17	1.00	0.02	N	B,S	56
8	0.10	1.10	0.01	N	B	57.4
9	0.10	1.70	0.01	N	O	57.7
10	0.10	1.50	0.01	N	B	69.5
11	0.11	2.00	0.02	Y	B,O	80.5
12	0.33	1.40	0.12	Y	B,O	80.5

January						
Count	Diameter (m)	Length (m)	Volume (m^3)	Jam (Y/N)	Function*	Midpoint Distance (m)
1	0.14	1.20	0.02	Y	B,O	3.4
2	0.12	1.50	0.02	Y	B,O	3.4
3	0.13	3.00	0.04	N	B	7.3
4	0.10	2.50	0.02	Y	B,O	13.8
5	0.20	1.70	0.05	Y	B,O,P,S	54
6	0.14	1.10	0.02	Y	B,O,S	54.4
7	0.10	1.70	0.01	N	B,O,S	59.3
8	0.10	1.10	0.01	N	B	59.3
9	0.10	1.50	0.01	N	B	72.3
10	0.11	2.00	0.02	N	B,O	83
11	0.33	1.40	0.12	N	B	83.3

APPENDIX F

STATISTICAL MODELING

Table F1. Pearson's r correlations between response variables. Highly correlated variables with r > 0.7 have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30}$.

	Pearson's r							
Response Variables*	P/m	D/m	L/m	V/m	P/m²	D/m²	L/m²	V/m²
P/m	1	0.55	0.42	0.94	0.92	0.36	0.38	0.91
D/m	0.55	1	0.87	0.65	0.72	0.94	0.88	0.60
L/m	0.42	0.87	1	0.47	0.65	0.88	0.97	0.38
V/m	0.94	0.65	0.47	1	0.83	0.43	0.40	0.90
P/m²	0.92	0.72	0.65	0.83	1	0.61	0.64	0.86
D/m²	0.36	0.94	0.88	0.43	0.61	1	0.95	0.40
L/m²	0.38	0.88	0.97	0.40	0.64	0.95	1	0.34
V/m²	0.91	0.60	0.38	0.90	0.86	0.40	0.34	1
$P/L_{SR/30}$	0.95	0.40	0.27	0.94	0.78	0.18	0.21	0.82
$D/L_{SR/30}$	0.71	0.79	0.50	0.88	0.64	0.58	0.46	0.78
$L/L_{SR/30}$	0.76	0.64	0.62	0.88	0.67	0.45	0.52	0.64
$V/L_{SR/30}$	0.92	0.54	0.35	0.99	0.76	0.30	0.27	0.86

	Pearson's r			
Response Variables*	$P/L_{SR/30}$	$D/L_{SR/30}$	$L/L_{SR/30}$	$V/L_{SR/30}$
P/m	0.95	0.71	0.76	0.92
D/m	0.40	0.79	0.64	0.54
L/m	0.27	0.50	0.62	0.35
V/m	0.94	0.88	0.88	0.99
P/m²	0.78	0.64	0.67	0.76
D/m²	0.18	0.58	0.45	0.30
L/m²	0.21	0.46	0.52	0.27
V/m²	0.82	0.78	0.64	0.86
$P/L_{SR/30}$	1	0.70	0.81	0.96
$D/L_{SR/30}$	0.70	1	0.80	0.86
$L/L_{SR/30}$	0.81	0.80	1	0.87
$V/L_{SR/30}$	0.96	0.86	0.87	1

Table F2. Spearman rank ρ correlations between response variables. Highly correlated variables with ρ > 0.7 have a grey background. Divisions mark the three denominators of m channel length, m^2 channel area, and $length_{SR/30}$.

	Spearman's ρ							
Response Variables*	P/m	D/m	L/m	V/m	P/m²	D/m²	L/m²	V/m²
P/m	1	0.36	0.31	0.93	0.88	0.30	0.27	0.92
D/m	0.36	1	0.90	0.39	0.63	0.97	0.90	0.54
L/m	0.31	0.90	1	0.27	0.60	0.93	0.97	0.41
V/m	0.93	0.39	0.27	1	0.75	0.28	0.21	0.97
P/m²	0.88	0.63	0.60	0.75	1	0.62	0.60	0.84
D/m²	0.30	0.97	0.93	0.28	0.62	1	0.97	0.44
L/m²	0.27	0.90	0.97	0.21	0.60	0.97	1	0.36
V/m²	0.92	0.54	0.41	0.97	0.84	0.44	0.36	1
$P/L_{SR/30}$	0.94	0.18	0.13	0.93	0.70	0.11	0.08	0.85
$D/L_{SR/30}$	0.68	0.53	0.31	0.86	0.51	0.38	0.25	0.84
$L/L_{SR/30}$	0.60	0.21	0.35	0.68	0.38	0.16	0.22	0.59
$V/L_{SR/30}$	0.90	0.27	0.16	0.98	0.65	0.16	0.10	0.90

	Spearman's ρ			
Response Variables*	$P/L_{SR/30}$	$D/L_{SR/30}$	$L/L_{SR/30}$	$V/L_{SR/30}$
P/m	0.94	0.68	0.60	0.90
D/m	0.18	0.53	0.21	0.27
L/m	0.13	0.31	0.35	0.16
V/m	0.93	0.86	0.68	0.98
P/m²	0.70	0.51	0.38	0.65
D/m²	0.11	0.38	0.16	0.16
L/m²	0.08	0.25	0.22	0.10
V/m²	0.85	0.84	0.59	0.90
$P/L_{SR/30}$	1	0.71	0.70	0.96
$D/L_{SR/30}$	0.71	1	0.61	0.85
$L/L_{SR/30}$	0.70	0.61	1	0.73
$V/L_{SR/30}$	0.96	0.85	0.73	1