1 **Historical erosion and sedimentation in two small watersheds of the southern Blue Ridge**
2 **Mountains, North Carolina, USA**

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Abstract

Sediment bodies produced during historical periods of human land use, sometimes referred to as legacy sediment, may be found in various locations within drainage basins, and potentially remobilized by hydrogeomorphic processes accompanying land use change. The amounts and locations of stored legacy sediment can be significant factors in modern drainage basin function and should be accounted for when possible. In this study, late nineteenth-century erosion and sediment storage were investigated and used to construct approximate sediment budgets for two small Blue Ridge Mountain drainage basins in North Carolina (USA). Erosion was quantified using a distributed implementation of the Universal Soil Loss Equation (USLE), and calibrated on the separate bases of soil profile truncation data and recent published rates for long-term erosion in the region. Sediment yield information was reconstructed from pond sediments trapped behind a mill dam. Alluvial sediment storage was quantified using field studies of streambank and floodplain sediment profiles and digital elevation data. Colluvial storage was calculated as a residual in the sediment budget, and further evaluated using soil profile studies of footslope deposits, and soil survey maps. The proportions of erosion accounted for by the different budget terms in the most reliable budget are: 28% sediment yield (i.e., a sediment delivery ratio of 0.28), 69% colluvial storage, and 3% alluvial storage. Blue Ridge basins with low levels of ground disturbance erode like Piedmont basins at high levels of ground disturbance, primarily due to higher slope angles. Sediment delivery ratio is high relative to those given for much larger basins in the adjacent and more frequently studied Piedmont province, and generally in accordance with published sediment delivery curves that reflect higher hydrogeomorphic connectivities within smaller basins. Low values for alluvial storage in Blue Ridge basins may be explained by high sediment transport within steep channels. Colluvial

46 storage values have high uncertainties because of the well known problem of error accumulation
47 in residual budget terms. Field data on colluvial deposits reported here are not sufficient to
48 correct for this problem, and in general, the acquisition of accurate field data on historical
49 colluviation remains an important methodological issue in historical sediment budgeting.

50 Keywords: drainage basin, historical sediment budget, legacy sediment storage, colluvium,
51 alluvium

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1.0 Introduction

Effective land management decisions require a thorough knowledge of how different land uses affect earth surface processes and landforms. However, earth surface responses to contemporaneous land use are not always easy to generalize. The geomorphological state of any location is variably conditioned by earlier environmental regimes or events whose current effects may be conspicuous or subtle, and dependent on original impact magnitudes, intrasystem connectivity, relaxation time, and other variables (Fryirs et al., 2007; Phillips, 2009, 2013; Brierley, 2010; James, 2013). In many places, historical land disturbance resulting from human activities represents a major or even dominant antecedent condition for modern landscape function (Wohl, 2015). One example is the profound effect that nineteenth-century Euro-American agricultural land use had on fluvial sedimentation and landforms across large areas of the eastern and midwestern U.S. (Trimble, 1974, 1983, 1999; Knox, 1977, 1987). That many of these past processes continue today to significantly influence modern fluvial systems indicates their status as “legacy effects” (Bain et al., 2012). Due to the discontinuous nature of sediment movement, reactivation of sediment storage bodies in particular represents an important means of extending the effects of prior land uses over substantial time intervals.

The future propagation of land use legacy effects on sediment dynamics in fluvial systems remains the subject of study and debate. Remobilization of stored legacy sediment could be accelerated by new land development that changes water flow amounts and/or pathways in watersheds. Thus, assessments of modern human impacts on stream erosion and sedimentation should ideally account for the prior history of upland erosion and sedimentation going back from

decades to a century or more (Jackson et al., 2005; Verstraeten et al, 2009; Bain et al., 2012; James and Lecce, 2013; Wohl, 2015).

Such information is unavailable in many instances, and may not always be confidently extrapolated from areas where it does exist. In the eastern U.S., it is unknown to what extent prior studies of the southern Piedmont may be applicable to adjacent areas of the Coastal Plain and southern Appalachian Mountains, where physiographic conditions are very different, and the state of knowledge regarding historical erosion and sedimentation is less advanced. Particularly within the mountains, few studies detailing sediment budgets and legacy sediment have been conducted, and most research has focused on sediment yields and not the delivery or storage of eroded soil at particular locations in watersheds (Taylor and Kite, 2006). Understanding the locations and sizes of these historical sediment bodies is of importance because these factor in to specifying the conditions under which legacy sediments are likely to be remobilized. Furthermore, previous sediment budgeting in the Appalachians has primarily focused on forested ecosystems, or those impacted only by forestry practices. Yet some areas in the southern Appalachians, along both gentle valley bottoms and on surprisingly steep valley walls, were planted in row crops after logging, without erosion controls. Such areas might be of particular importance to considerations of legacy sediment impacts in this now rapidly developing region.

In this study we analyze nineteenth-century erosion and sedimentation histories for two small watersheds in the Blue Ridge Mountains, part of the southern Appalachian chain, in North Carolina. Our goals are 1.) to determine how nineteenth-century land use affected contemporaneous sediment budgets and the production of persistent legacy sediment deposits, and 2.) to ascertain the differences between Blue Ridge historical sediment budgets and those from the adjacent Piedmont province, as well as other well-studied sites in the U.S. The broader

purpose is to provide an historical perspective on watershed change that will increase the likelihood of successful management of fluvial systems in the Appalachian Mountains and similar forested steep-land settings.

2.0 Background

Within the southern Piedmont physiographic province, late-19th and early 20th century agricultural erosion removed up to 0.25 m of soil across large expanses of the uplands (Trimble, 1974). A substantial proportion of this material moved into river channels producing one or more sediment waves and causing channel bed aggradation and extensive overbank sedimentation onto floodplains (Trimble, 1974; Jacobson and Coleman, 1986; James, 2006; James, 2013). On many smaller (~3rd-order) streams, much sediment was trapped behind mill dams which have since collapsed (Walter and Merritts, 2008). Fluvial erosion has been evacuating these legacy deposits, shifting sediment downstream, and leaving behind high channel banks as terraces capped with historical alluvium (James and Lecce, 2013; James, 2013; Royall, 2013). The sediment comprising these terraces is reworked into channels by incremental fluvial scour and mass wasting of banks, but may be stored in these often expansive landforms for long periods (Jackson et al., 2005; James, 2013). Legacy sediment inputs can elevate watershed sediment yields decades to centuries or longer, following their initial emplacement atop older floodplain surfaces (Phillips, 1991; Meals et al., 2010; Kennedy, 2013; Brierley, 2010).

The notion of the aggradation-degradation episode (James and Lecce, 2013), here described for the southern Piedmont, should be generally applicable to a wide range of humid-

climate environments, including the adjacent Blue Ridge Mountains, where locally, highly erosive historical land uses have given way to reestablishment of vegetation cover, limiting new sediment production. Indeed, Leigh (2010) and Rogers and Leigh (2013) have recently documented the occurrence of well-developed historical sediment terraces in parts of the southwestern Blue Ridge. The details of sediment dynamics including the pathways, types, and rates of sediment movement, as well as exact quantities and locations of sources and sinks are also important for effective and spatially explicit environmental management. A full knowledge of the conditions leading to the emplacement of legacy sediment bodies would include the spatial and temporal distribution and severity of erosion, the amounts of eroded material delivered to stream channels and various upland storage sites in watersheds, and the amount of sediment exported from the system. Linked together within the drainage basin process context, these phenomena collectively constitute a sediment budget (Dietrich and Dunne, 1978, Trimble, 1983, 1999; Taylor and Kite, 2006). For any given land surface area, the sediment budget can be expressed as: sediment input minus sediment output equals change in sediment storage.

Constructing a detailed sediment budget for even a small watershed is usually difficult and time-consuming, and thus also costly; as a result it is infrequently done. However, even a partial sediment budget can be informative and useful in land and water-resource management. Sediment budgeting is typically accomplished using direct observations and measurements often over a short period of time, as dictated by financial costs and the often immediate needs prompting the work. Reconstructing historical sediment budgets adds a further level of difficulty because it poses a different methodological problem: being unable to directly monitor historical processes (Bain et al, 2012). Fortunately, bodies of legacy sediment themselves preserve at least a partial record of past sediment budgets, and the method becomes one of characterizing the

deposits in time and space, and filling in the gaps using theory, modeling, and quasi-ergodic reasoning from prior studies in similar environments. Recent advances in erosion and sedimentation modeling, particularly in the incorporation of transport capacity submodels to determine the balance of erosion and deposition at a point, have enhanced the potential for reconstructing historical sediment budgets under some circumstances (VanRompae et al., 2001; Verstraeten et al., 2007; DeMoor and Verstraeten, 2008; Mitasova et al., 2013). Although the data requirements for calibrating and using such models may be high, more physically-based modeling potentially allows greater differentiation of internal dynamics and thus offers greater explanatory and predictive power.

Obtaining an account of the historical sediment dynamics and legacy sediment storage in Blue Ridge Mountain drainage basins is the subject of this research. The Blue Ridge adjoins the better-studied southern Piedmont province to the southeast, and has a parallel, if slightly lagged, history of European settlement, although at a lower population density. The province differs fundamentally from the Piedmont in having steeper average hillslope and stream gradients, often stonier soils with less clay, more limited terrain suitable for row-crop agriculture, and a more intact forest cover, both currently and historically. Over the last several decades, changing economies, construction of highways, and natural growth have combined to increase population in these mountain areas, and, along with redistribution of existing population closer to urban centers, continue to drive land development (Price and Leigh, 2006). Thus, new land uses and geomorphic processes are being applied to landscapes already altered by earlier and different nineteenth century land uses, to a largely unknown extent. These changes could influence the reworking of legacy sediments and have sedimentation effects out of proportion to what might be expected from new land use alone. Providing a basin-scale sediment budgeting context for these

sedimentation dynamics would allow the determination of process linkages critical to wise land use decisions.

Our analysis of historical erosion and sedimentation effects and approximate sediment budgets for two small Blue Ridge watersheds relies on existing historical sediment yield data, erosion modeling, the mapping and quantification of historical valley alluvium, and observations of soil profiles. Although the study watersheds are smaller than those for which most existing Piedmont data have been derived, small drainages represent the first line of impact by new development in these mountain areas where, outside of floodplains, gently sloping land is in limited supply.

3.0 Site Description

The study sites, Wolf Branch (2.38 km²) and Rocky Cove (1.76 km²), are sub-basins of the Bent Creek watershed (35.489862N, 82.611866W), part of the Bent Creek Experimental Forest and U.S. Department of Agriculture's Southeastern Forest Experiment Station in Pisgah National Forest near Asheville, NC (Fig. 1). The Bent Creek watershed was settled by Europeans beginning about 1800 CE, and for the first half of the nineteenth century was used primarily for subsistence agriculture and hunting. Forest clearance for small agricultural plots, selective logging for homestead construction and fuel were the most important forest disturbances. Following the U.S. Civil War (1861-1865 CE) and until about 1900 CE, external demand for the area's timber increased the rate of land clearance, including for the first time by commercial loggers and the land was further and more densely settled in small communities. Four mill dams

were constructed at various times on mainstem Bent Creek, and one was constructed on the Rocky Cove tributary (Nesbitt, 1941; Royall, 2003; Kennedy, 2013).

George Vanderbilt, son of railroad magnate and philanthropist William Vanderbilt, acquired the property in the early 1900s, and not long after his death in 1914 the land was sold to the U.S. Forest Service and became part of the first eastern national forest established following the Weeks Law, *Pisgah*. Afforestation of cleared land was promoted, and later the Civilian Conservation Corps conducted activities in parts of Bent Creek. Nesbitt (1941) documented the land use history and general physical state of the land, including estimates of the severity of erosion, and the locations and acreages of different land uses over time from ground surveys and anecdotal accounts from former residents. Currently, the area is fully forested with oak (*Quercus* sp.), hickory (*Carya* sp.), and many other hardwood tree types, plus evergreens including Virginia, shortleaf, and white pines (*Pinus virginiana*; *Pinus echinata*; *Pinus strobus*), holly (*Ilex*), and hemlock (*Tsuga canadensis*). Precipitation is around 120 cm annually, without strong seasonality. Fully forested Pre-Euro American watersheds in the southern Blue Ridge would have had very low sediment yields (around $3 \text{ Mg km}^{-2} \text{ y}^{-1}$), according to data for relatively undisturbed watersheds at nearby Coweeta Hydrological Laboratory (Velbel, 1985). Low sediment yields between 3 and $30 \text{ Mg km}^{-2} \text{ y}^{-1}$ have also been documented for some other present-day Blue Ridge watersheds under conditions of minimal disturbance (Simmons, 1993; Royall, 2000; Bolstad et al., 2006). Reusser et al. (2015) used ^{10}Be analyses to determine a long-term background erosion rate in the southern Blue Ridge Mountains of 14.6 m/m.y. , equivalent to between 19 and $23 \text{ Mg km}^{-2} \text{ y}^{-1}$ based on a soil bulk density value range from 1.3 and 1.57 g cm^{-3} representative of residual soils in our basins. Catastrophic mass wasting in the form of debris flows is common in some parts of the Appalachians (Wieczorek et al., 2009) and has been

reported in the highest elevations of Bent Creek during exceptional rainfall events (Neary and Swift, 1987), but not within the study basins.

Forty-three percent of the Wolf Branch watershed had been cleared for timber and farming by CE 1900, with more than half cleared in the three decades following the Civil War. (Table 1). Royall (2003) used lake sediments accumulated within Deer Lake (on Wolf Branch) to reconstruct 50 years of sediment yield, from CE 1927-1977, a period corresponding to one of continuing forest regrowth and watershed recovery after the major erosive land use phase from about CE 1865-1915. The average sediment yield during this recovery phase was $29.7 \text{ Mg km}^{-2} \text{ y}^{-1}$, between two and ten times greater than presettlement yields.

Thirty-five percent of the Rocky Cove watershed had been cleared for timber and farming by CE 1900, with 41% of that occurring after the Civil War in more gently sloping lowlands. Kennedy (2013) used pond sediments from Powell Mill (1880-1895 CE) in Rocky Cove to determine an average sediment yield for that period of $272 \text{ Mg km}^{-2} \text{ y}^{-1}$ (a value of $461 \text{ Mg km}^{-2} \text{ y}^{-1}$ without the 1.76 km^2 drainage area correction was erroneously reported in Kennedy, (2013)). This period falls within the major historical erosive phase associated with land clearance, logging, and agricultural activities at Bent Creek from about 1865 to 1915 CE. Assuming, as a first approximation, that peak nineteenth-century sediment yields at Wolf Branch were similar to those recorded in pond sediment from Rocky Cove (a quasi-ergodic space-for-time substitution) sediment yield would have dropped 89% between peak erosion and recovery phase periods. Although the space-for-time substitution may be erroneous, an order-of-magnitude difference in sediment yields between cultivated and forested land is a reasonable assertion supported by much previous research (Wolman, 1967; Simmons, 1993; Harden, 2013; Royall, 2013).

4.0 Methods

Sediment budgeting requires information on erosion, colluvial and alluvial sediment storage, and sediment yield. Sediment yield data for the high erosivity period are available for Rocky Cove (Kennedy, 2013), but not for Wolf Branch, and thus, sediment budgeting is only strictly possible for Rocky Cove. To facilitate comparison and discussion, we calculate the Wolf Branch sediment budget using an estimate of sediment yield equal to Wolf Branch USLE erosion multiplied by the directly quantifiable sediment delivery ratio for unadjusted USLE erosion at Rocky Cove. This is probably the best means of approximating Wolf Branch sediment yield available to us, given the likelihood that the delivery ratios for the two basins are more similar than their contemporaneous sediment yields, due to the larger cultivated area at Wolf Branch. Given the existing data on historical sediment yield, the quantification of watershed erosion and sediment storage are the principal requirements remaining for sediment budgeting.

4.1 Erosion

At both watersheds we conducted spatially distributed GIS-based analyses of erosion using the Universal Soil Loss Equation (Wischmeier and Smith; 1978; Renard et al., 1991). The cover (C) factor was based on historical land use conditions described and mapped by Nesbitt (1941) for these watersheds as they existed prior to the U.S. Forest Service afforestation program in 1920. We conducted the same assessment assuming fully forested conditions as a means of estimating background levels of erosion. Rainfall erosivity (R-factor) values were derived from published maps (Dunne and Leopold, 1978). Soil erodibility (K-factor) values were derived from

the Buncombe County Soil Survey (Hudson, 2009) for soil series whose digitized boundaries were obtained from the Web Soil Survey (Natural Resources Conservation Service, 2013). The combined length-slope (LS-factor) was derived using the unit stream power approach of Moore and Burch (1986), applied to a 6.1 m (20 ft.) resolution LiDAR-based digital elevation model (North Carolina Floodplain Mapping Program data, 2001-3; <http://www.ncfloodmaps.com/>). Vegetation cover (C-factor) values were derived from published tables (Dunne and Leopold, 1978) and spatially distributed into digitized polygons of Nesbitt's (1941) land use areas. The erosion control practice (P) factor was taken to be 1 because there is little evidence for the use of any control practice by Bent Creek farmers during the late nineteenth century. It is possible that contour plowing was used by some farmers, but this technique would have had limited effectiveness for slopes exceeding 2-7% (Trimble, 1974). The USLE factor value ranges used for each watershed are given in Table 1.

The Map Algebra functionality of ArcMap (ESRI, 2013) was used to compute USLE erosion to create a raster map of cell-point annual soil loss rate converted to metric tons (Mg) per cell, then accumulated to obtain total soil loss. Stream channels were defined using flow accumulation thresholds of 0.04 km² (Rocky Cove) and 0.09 km² (Wolf Branch), estimated from the combined bases of contour crenulations and field observation. The flow accumulations from stream channels were subtracted from the analysis so that only the total annual upland soil loss was summed. Potential erosional inputs from historical catastrophic mass wasting were not considered in the erosion assessment; nor was soil creep, considering that its proportion of historical sediment yield was probably minute compared to that of surface disturbance..

USLE-based soil loss estimates index soil detachment well, but are less capable of accounting for the downslope transport of soil to valley floors. Recent, more physically-based

erosion models like WATEM/SEDEM (Van Rompaey et al., 2001; Verstraeten et al., 2007) account for this shortcoming by incorporating sediment transport capacity equations. However, such equations must be calibrated, and our current data are insufficient for this. As a check on modeled soil loss rates, we conducted three cross-valley augering transects at Wolf Branch, and a single long transect at Rocky Cove crossing all three major tributaries. We studied soil profiles to evaluate soil loss depths and depths of colluviation at 61 locations. Erosion depth estimates were made for 32 sites representing a mix of nose, upper convexity and sideslope positions, based on apparent profile truncation depths. Sample sites were mostly from formerly cultivated uplands, but some areas outside these areas were also studied. Observations of profiles to maximum depths of 0.3 to 0.6 m were made using a 2.5-cm diameter open faced soil probe, or/and pit excavation by hand, when probe retrieval efficiency was impaired by wetness or other issue. Expected (uneroded) depth to Bt (argillic) horizon was determined from soil mapping data (Hudson, 2009; NRCS, 2013) and compared to actual depth to Bt observed in profiles; the difference was assumed to be total cumulative soil loss depth, and then compared to that predicted by the USLE model using bivariate regression. Although erosion would have occurred to some extent on cultivated footslope areas, the complex interplay of erosion and colluviation in such areas made interpretations of total erosional impacts difficult to unravel from the profiles we observed. We confined the regression analyses to soil units upslope of colluvial footslopes mapped on previous Buncombe County soil surveys (Hudson, 2009) to assess the USLE model. We recalculated erosion and the sediment budgets based on the slope of the regression line, and a second time based on the ratios of Reusser et al.'s (2015) long-term background erosion rates, to the USLE erosion values computed for fully forested conditions.

4.2. *Sediment storage*

4.2.1 Colluvium

Historical sediment storage compartments in the study watersheds consist of colluvial deposits (midslope drapes, sheetwash aprons, and fans; terminology from James, 2013), plus fluvial overbank flood alluvium. Houben et al. (2006) cite the need for improvements in accounting for land use impacts on sediment storage, with particular regard for colluvium, which can be difficult to measure. Colluvial deposits, and particularly drapes and aprons, may be difficult to recognize and separate out as anthropogenic, even when widespread, either because they are thin enough to become mixed within underlying topsoils, or because they may bury the original land surface to depths beyond easy observation. In the southern Piedmont of North Carolina, Phillips (1991) found that the boundary between colluvium and underlying residuum was frequently difficult to discern, and we have found this to be true at our sites as well. Because of such difficulties, we calculated colluvial deposition as a residual term in the sediment budgets, despite some important drawbacks to this method (Kondolf and Mathews, 1991; Parsons, 2012). To provide an independent field-based check on the resulting colluvial storage estimates, we studied 29 soil profiles on foot- and toeslope areas to determine the depth to Bt horizon, as we did for soil erosion analyses. In this case, a depth to Bt greater than predicted from soil survey mapping data was interpreted to indicate colluvial accumulation depth. These depths were compared to those that would have to occur on colluvial soil survey mapping units to accommodate the amount of colluvium calculated in the budgets.

4.2.2. Alluvium

Historical overbank alluvium capping presettlement floodplains is identifiable in incised streambanks and auger holes overlying a dark buried A-horizon marking the original land surface (Fig. 2). It consists predominantly of silty and sandy sediments, usually light brown to tan, or sometimes light reddish-yellow in hue, and usually fining upwards. We mapped the thickness of this sediment moving upstream along all stream channels in each watershed until bottomland flats became absent along the smallest streams. We selected 17 typical stream locations (7 and 10 in Wolf Branch and Rocky Cove respectively) at a variety of drainage areas for cross-valley augering transects to delimit the lateral extents of historical alluvium deposits, and to analyze their shapes in cross-section. A regression equation was calculated relating the measured deposit width to drainage area. However, given the small number of points for each basin, we opted to measure apparent floodplain widths off of the DEM as described by Fuchs et al. (2011). Because low terraces not easily discriminated from digital elevation data, occur along some floodplain margins, we regressed the DEM floodplain widths against the measured deposit widths to obtain terrain-based estimates for every sediment depth sample point. Based on the augering data, we estimated alluvial deposit cross sectional areas for unmeasured points by assuming an ideal trapezoid having a top-width equal to the DEM-indexed deposit width (above), a bottom width equal to half that value, and a maximum depth equal to observed sediment depth in streambanks. Cross-sectional areas for these ideal trapezoids were then regressed against actual areas at the 17 sites to produce a transfer function accounting for an observed underestimation by the ideal trapezoid shape. The general procedures for translation of these values into alluvial sediment mass follows those outlined by Rommens et al. (2006) and DeMoor and Verstraeten (2008) in which cross-sectional areas for deposits are multiplied by

distances between alluvial depth measurement points and sediment bulk density values from sampled sediment profiles (1.2 mgm^{-3}).

4.3 Uncertainty estimation

Where possible, uncertainty in budget terms was estimated on the basis of field measurement uncertainty judgments and gaussian error propagation for those variables likely to have normally distributed error values. These include measurements of sediment deposit and pond dimensions, sediment bulk density measurements, and uncertainty introduced by the application of linear regression equations in sediment width and sediment cross-section shape estimations.

Uncertainty in erosion model output is difficult to assess. As described in section 4.1, we evaluated the USLE model results using regression analyses of field vs. modeling data, and comparisons of USLE output for fully forested (undisturbed) conditions to long term erosion rates given in Reusser et al. (2015) (14.6 m/m.y.), and adjusted for bulk density (Table 3).

Uncertainty in sediment yield estimation is discussed in general terms by Kennedy (2013) for pond-sediment-based reconstructions. Here we estimate uncertainty from pond sediment body dimensions based on a 5-cm sediment depth accuracy, 2-m sediment width accuracy, and 10-m sediment body length accuracy, the latter reflecting the more diffuse and potentially complex upstream mill pond boundary grading into floodplain. Pond sediment bulk density uncertainty is estimated from the standard deviation of bulk density measurements used to derive average values for mineral mass determination. Sediment trapping efficiency curve error cannot be directly assessed due to lack of original curve data. However, the inputs used in trap efficiency estimation are pond capacity and annual runoff. Pond capacity error has the same error terms (depth, width and length) as pond sediment, except that for water depth, an accuracy of 10

cm for water surface height (which cannot be directly observed in long-dry, century-old ponds) plus the sediment depth uncertainty (5 cm) were combined for a total water depth uncertainty estimate of 15 cm. Late 19th century water inflow was estimated from U.S. Geological Survey runoff maps derived from records extending back to the early 20th century, from which an average $\pm 7.4\%$ uncertainty for our field region was found. Despite such efforts, a rigorous accounting for trap efficiency remains complicated, requiring a high level of detailed data on such matters as particle-size characteristics of sediments in transport, the nature of flood events that move sediment into lakes, and other variables (Verstraeten and Poesen, 2000), many of which may be unobtainable, especially for historical circumstances

Uncertainty in alluvial storage mass was assessed based on a 5-cm measuring accuracy for sediment depth, 2-m accuracy for sediment width field measurement (from augering transects), a bulk density error estimated from the standard deviation of bulk density measurements, and two regression uncertainties, represented by the standard error of the estimate (Johnston, 1980). One of these is for the relation between DEM and field-based measurements of deposit width, and the second is for the relation between the ideal trapezoidal deposit cross-section and actual observed cross-section. Uncertainty in the residual term, colluvial storage, is estimated by propagation of error from the error in the other budget terms.

5.0 Results and Interpretations

The following quantifications of sediment budget terms are based on a 50-year time interval, representing the historical high land-use erosivity phase in this area between about 1865 and 1915. Our analysis requires the assumption that land use was homogeneous during this

period, and that neither erosion nor sediment storage were significant before and after. Land use records are insufficient for documenting within-tract heterogeneity in land use, and we believe that land use heterogeneity may have been larger for steeper portions of basins, particularly at Wolf Branch. Additions to and surficial erosion of overbank flood alluvium would probably have dropped to negligible values following the reestablishment of closed ground cover in the basin, as evidenced by low sediment yields under forest cover in this region (Velbel, 1985; Royall, 2003). In general, however, only rarely can historical impacts be considered homogeneous, and the assumptions we make for this idealized time period signify that our sediment budgeting must be considered similarly approximate.

5.1. Watershed erosion

USLE modeling results show spatial patterns closely aligned with the limits of cultivated area (Fig. 3), and give unadjusted values of soil loss (expressed here in sediment yield units) for Wolf Branch and Rocky Cove of 2,197 and 1,596 Mg km⁻² y⁻¹, respectively for the 50-year erosive land use period (Table 2). The same (USLE) values for fully forested conditions with continuous leaf litter (C-factor 0.001; Wischmeier and Smith, 1978; Dissmeyer and Foster, 1980) are 45 and 62 Mg km⁻² y⁻¹, respectively for the two basins.

Unadjusted USLE erosion results must be used cautiously in sediment budgeting, in all cases not conforming to the general conditions under which USLE erosion factor values were derived. The LS-factor values were based on plot experiments within a particular range of plot lengths (originally, 22.1 m) and slope angles, and for homogeneous conditions and simple topography (Mitasova et al., 2013). Watershed-scale USLE implementations may only match these conditions for the smallest drainage areas under conditions of low relief. Furthermore, the

USLE quantifies sheetwash and rill erosion only; yet in the topographically more complex upland terrain of many watersheds, gully erosion can also be important (Verstraeten et al. (2007). In particular, the USLE has been frequently observed to overestimate actual soil loss when applied at the watershed scale using terrain models (Bolstad et al., 2006). Because the USLE is a better predictor of soil detachment and not explicitly of sediment transport, it is always likely to overestimate watershed-scale soil loss (Mitasova et al., 2013). Overestimation appears highly likely at our sites, and especially at Wolf Branch.. Maximum unadjusted USLE erosion rates at Wolf Branch reach peaks in the range class 0.034- 0.099 Mg m^{-2} (about 8 cm y^{-1}) (Fig. 3A), although such values only occur in 0.03% of cells. Such values are conceivable given the topography, but probably unsustainable over a 50-year period without deep gullying or offsets from colluvial deposition.

We used two approaches to quantify and correct for USLE overestimation; one based on field observations, and a second based on recent long-term background erosion rates estimated by Reusser et al. (2015). Field observations of soil profile truncation depths are related to USLE point erosion values by a regression line slope of 0.61 (with near-zero y-intercept)(Fig. 4). Using the slope to adjust erosion values gives 1,340 and 973 $\text{Mg km}^{-2} \text{ y}^{-1}$ for Wolf Branch and Rocky Cove, respectively (Tables 2 and 3). Surface exposures of the Bt horizon at ground level, which are the norm on eroded midslope areas, give a minimum truncation depth because the total amount of Bt horizon potentially removed in excess of the thickness of the overlying horizons is indeterminate. Thus it is possible that actual erosion may have been greater than regression line slopes indicate.

Evaluation of the USLE for fully forested conditions at Wolf Branch and Rocky Cove gives erosion values (45 to 62 $\text{Mg km}^{-2} \text{ y}^{-1}$, respectively) that are approximately 2.14 and 2.95

times the long-term background erosion rates given by Reusser et al (2015) (19-23 Mg km⁻² y⁻¹; Table 3) on the basis of ¹⁰Be analyses. These values are equivalent to erosion adjustments for the two basins of 0.48 and 0.33 times the USLE values, and the resulting values for Wolf Branch and Rocky Cove are 1,055 and 527 Mg km⁻² y⁻¹, respectively (Tables 2 and 3).

5.2 Alluvial storage

Historical overbank sediment profiles were observed at 76 locations in Wolf Branch, but only 14 locations in Rocky Cove. The great disparity in observations might be best explained by the concentration of cultivated land in the lower third of Rocky Cove in contrast to the widely distributed land usage at Wolf Branch. The depths of historical sediment observed in channel banks and auger holes range up to 0.81 m at Wolf Branch, and to 0.55 m that at Rocky Cove (Fig. 5). The average of all historical bank sediment depths observed at Wolf Branch is 0.4 m; at Rocky Cove it is 0.35 m. Sediment depth is poorly correlated with drainage area at both sites (Fig. 6).

Estimates for sedimentation widths derived from DEMs are best related to field-measured sedimentation widths by a natural logarithmic curve ($R^2 = 0.67$; Fig. 7a). At Rocky Cove, two locations were represented by isolated pockets only (upper Walnut Cove and lower Rocky Cove mainstem), possibly due to floodplain interruptions by topographical constriction zones within which accumulation of sediment is less likely (limited accommodation space; James, 2013)). We calculated their widths (and ultimately, volumes and masses) independently before adding their contributions to the total. Augering data revealed that cross-sections of historical alluvium were roughly trapezoidal (Fig. 8), and could be modeled as ideal trapezoids (described in section 4.2.2). Cross-sectional areas estimated from the ideal trapezoids were compared to actual cross-

sectional areas derived in the field for the 17 transect locations using linear regression. The regression equation $(1.0567(\text{trapezoidal estimate}) + 0.4122; R^2=0.77; \text{ Fig. 7b})$ demonstrates the tendency for the ideal trapezoid model to underpredict actual cross-sectional area. We used this equation to correct for the original estimates in both basins.

The estimated cross-sectional area values were multiplied by stream segment lengths to quantify sediment volumes, which were then multiplied by alluvial bulk density and summed to get mass. Sediment bulk densities were measured from a number of historical sediment bank samples, and found to average 1.04 Mg m^{-3} ($\sigma = 0.12$; range $0.85 - 1.3$) for Wolf Branch and 1.13 ($\sigma = 0.11$; range $0.98 - 1.23$) for Rocky Cove. Total stored alluvial mass was $12,170 \text{ Mg}$ in Wolf Branch, and $2,979 \text{ Mg}$ in Rocky Cove. Expressed in units of sediment yield for the 50 year period of erosive land use, these values become 102 and $34 \text{ Mg km}^{-2} \text{ y}^{-1}$, for Wolf Branch and Rocky Cove respectively (Tables 2 and 3).

5.3 Sediment budgeting and the colluvial storage term

The sediment delivery ratio based on the unadjusted USLE erosion at Rocky Cove is 0.17 (17%). Applied to the unadjusted USLE erosion at Wolf Branch, ($2,197 \text{ Mg km}^{-2} \text{ y}^{-1}$), the resulting sediment yield estimate for that basin is $373 \text{ Mg km}^{-2} \text{ y}^{-1}$. Based on sediment budgets for the two USLE erosion adjustment approaches, sediment delivery ratios for Wolf Branch are 28% and 35% , and for Rocky Cove, 28% and 52% (Table 3), which are $10\text{-}20\%$ lower than curve-based estimates from Walling (1983) and Roehl (1962). Alluvial storage in both watersheds is the smallest budget term, accounting for, at most, 10% of erosion. Colluvial storage is $55\text{-}64\%$ of adjusted erosion at Wolf Branch, and $42\text{-}69\%$ at Rocky Cove, depending on the USLE erosion adjustment. Colluvial storage is about 2.35 times larger than sediment yield.

As a residual term, colluvial storage incorporates all error from USLE modeling, field measurements, and calculations of the other budget components, producing substantial uncertainty in its value (Kondolf and Mathews, 1991; Parsons, 2012). Uncertainty in USLE erosion is difficult to assess. We use the standard regression error (standard error of the estimate for the field observed vs. USLE erosion relation in Fig. 4) for the USLE adjustment scenarios based on those regressions (adjustments (a) in Table 2). The relative standard error about the erosion regression is high (52% of the mean). Combining this uncertainty with that for alluvial storage and sediment yield gives an uncertainty of $512 \text{ Mg km}^{-2} \text{ y}^{-1}$ (74%) for colluvial storage at Rocky Cove, and even greater at Wolf Branch. Erosion values and their uncertainty dominate other sources of uncertainty and several factors may be contributing, including undocumented within-tract land-use heterogeneity, inaccuracies in historical land use boundary maps, and error from interpretation of soil truncation depth. Furthermore, less divergence between observed and USLE model erosion rates might be expected in some areas (gentler uplands with simpler topography), and greater divergence in others (steep, complex topography). The differentiation of such influences will require better soil profile information and a larger data set; independent data for influences related to land use histories may be unavailable.

Most observed historical colluvium consisted of loam, sandy loam, and sandy clay loam, with Munsell hues of 7.5YR or 10YR, and moderate-to-high Munsell values and chromas, all of which are similar to soil survey mapping descriptions for both footslope and many upland soils. Of 29 footslope soil profiles examined, we could confidently interpret only 18. Average thickness of these colluvial deposits is 24.9 cm ($\sigma = 11$ cm; range 10-42; $n=13$) for Wolf Branch and 26.8 cm ($\sigma = 9.3$; range 17-40; $n=5$) in Rocky Cove. The small numbers of observations are limiting, but an initial indication of how such amounts might compare for the different erosion

adjustments can be determined by comparing them to calculations of colluvium depths necessary to accommodate the colluvial storage masses given in the sediment budgets.

U.S. Department of Agriculture soil surveys denote slope base colluvial deposits in our basins as belonging to the Tate and Toecane-Tusquitee soils, consisting of loams, clay loams, and some sandy clay loams (Hudson, 2009), with abundant cobbles in Toecane-Tusquitee. Areas of these units within and downslope of land use zones occupy 0.57 km² and 0.25 km² at Wolf Branch and Rocky Cove basins respectively. Assuming (hypothetically) that historical colluvium amounts calculated in the budgets, are distributed uniformly across these colluvial zones, the average depth of colluvium for Wolf Branch would be 15 cm and 10 cm for 0.61USLE and 0.48USLE adjustments respectively (Table 4). At Rocky Cove the values are 19.6 cm and 6.3 cm for 0.61USLE and 0.33USLE adjustments. The fact that observed values, though few, average greater depths than these, suggests that colluvium could be abundant, lending some support for the higher calculated colluvial storage values, and favoring the higher erosion adjustment scenario (0.61USLE).

However, other issues must be taken into account. The Rocky Cove colluvial depths are from a much smaller sample size, and the average would be more sensitive to sample site position. If it is assumed that footslope colluvial deposits are wedge-shaped, thickening from zero depth at the upper end to reach maximum thickness at the lower end, then sampling away from the midpoint of a deposit would cause deviation from the average deposit depth. In several cases, sampling location was constrained by active spring sapping of soils or cultural features such as old roadbeds. The difficulty of interpreting colluviation depth from sometimes complex footslope soil profiles, and more generally, discriminating historical colluvium from other types of soil materials on the basis of field-observations, also add substantial uncertainty. Ultimately,

the colluvium field data are insufficient to make good projections. However, the available colluviation evidence suggest that, of the two USLE adjustment scenarios presented , higher erosion and colluvial storage estimates should be favored over lower ones. Furthermore, the 0.61USLE adjustment has the advantage of being derived from on-site observations, unlike that based on long-term erosion rates. Unless otherwise indicated, we refer to this adjustment for our sediment budget values in subsequent discussion. Given that an independent sediment yield value is unavailable for the high erosion period at Wolf Branch, we emphasize the importance of the sediment budget for Rocky Cove, at a USLE erosion adjustment factor of 0.61. This gives the following budget term allocations as proportions of erosion: 28% sediment yield, 3% alluvial storage, and 69% colluvial storage (Fig. 9).

6.0 Discussion

One of our basic goals is to compare our Blue Ridge erosion and sedimentation results with those from elsewhere in the region, and from other well known locations. We proceed with these comparisons, assuming that our budgeting values indicate the approximate magnitudes of terms, but cognizant of the uncertainties. Few budgeting data are available for the local Blue Ridge. Simmons (1993) reported erosion, sediment yield, and delivery for a number of North Carolina drainage basins, including four from the Blue Ridge (Table 3). Our results compare most favorably to those from the 1,129 km² Little Tennessee River drainage except for sediment yield and delivery, which were 2.8 times larger at Rocky Cove. For Simmons' (1993) basins, neither basin size nor generalized land cover are strongly related to sediment budget values,

suggesting that basin-specific variations in physiography and land use conditions may be more critical determinants of erosion and sedimentation.

The best available examples of complete sediment budgets for southern Piedmont drainage basins come from Phillips (1991) who studied four large basins in central North Carolina (Fig. 1)(Table 3). Further historical assessments of partial budgets in this region come from the work of Trimble (1977), also for large basins, and Simmons (1993) who includes recent data for two small basins (Table 3). Despite major differences in drainage area, both differences and commonalities in sediment budgets can be identified. The erosion rates for Rocky Cove and Wolf Branch are of similar magnitude to those of the peak-erosion Piedmont and the small, fully agricultural Piedmont basins of Simmons (1993) (Table 3). They are roughly twice those in the basins studied by Phillips (1991) which are similar in forest cover to historical conditions at our sites. Similarly, in the 194 km² Raven Fork drainage in the southern Blue Ridge, Leigh and Webb (2006) report historical period forest clearance-associated floodplain sedimentation rates that are similar in magnitude to those of much more disturbed Piedmont basins. The evidence indicates that Blue Ridge basins with low levels of ground disturbance erode like Piedmont basins at high levels of ground disturbance. Differences from the Piedmont are presumably driven mostly by higher LS-Factors in Blue Ridge steepplands. Some cultivated steepplands, such as those isolated along high ridge crests at Rocky Cove (Fig. 3B), may have been disconnected from valleys by intervening forests, and although such areas might have produced significant amounts of sediment, they would probably have contributed little to sediment yield. Compared to peak historical erosion at the well-known Coon Creek basin (62% cropland plus pasture; Trimble, 1983) in Wisconsin, our erosion values remain 30%-50% lower. We speculate that this

difference is a product of the highly erodible loessial soils (K-factor = 0.49, twice that at Rocky Cove) covering the uplands at Coon Creek.

In our small mountain basins, sediment yield is higher, alluvial storage is lower, and colluvial storage per unit drainage area is higher than in Phillips' (1991) Piedmont basins at similar land cover (although budget proportions are comparable), and similar to that at Coon Creek (Table 3). Large differences in drainage area, from one to three orders of magnitude, exist between our mountain sites and the Piedmont basins (Table 3). Higher sediment yields might be expected for small eroding mountain basins in which steep slopes are the norm, hillslope-channel coupling should be high, and sediment storage opportunities should be fewer (Walling, 1983; Walling and Webb, 1983; Richards, 1993). Although total storage in our basins is calculated to be large, its values are smaller than those for the peak erosion Piedmont and Coon Creek (Table 3). The proportion of erosion that is stored as colluvium (69% at Rocky Cove) is similar to that at Phillips' (1991) Piedmont watersheds, but more than the roughly 40% values found at Coon Creek (WI) and Indian Creek (MN) (Table 3), where easily eroded loessial soils may once again be accountable. Studies in two loess-covered European watersheds document colluvial storage proportions accounting for 50% and 39% of erosion for periods of Late Holocene deforestation, agriculture, and related impacts (Rommens et al., 2006; Notebaert et al., 2011). However, DeMoor and Verstraeten (2008) found a much higher value of 80% for colluvial storage in a 380km² loess covered basin in The Netherlands.

Notwithstanding the substantial uncertainties in sediment budget terms, their general magnitudes are likely to be such that: (colluvial storage > sediment yield > alluvial storage). This contrasts with the relative order given by Phillips (1991) for large Piedmont basins of similar land cover: (colluvial storage > alluvial storage > sediment yield), and Trimble's (1983) findings

at loess-mantled Coon Creek: (alluvial storage > colluvial storage > sediment yield). It does accord, however, with the findings of Beach (1994) at 17 km² Indian Creek (MN), a basin with gentle relief and glacial till substrate, and also with some European studies like that of Fuchs et al. (2011) in the 97 km² Aufsess River catchment in Germany, which is mantled by a diverse mixture of weathered carbonate rocks, residual clays, sands and loess, and where local relief along steep valley walls can be high. There are many possible physiographic, climatic, historical, and cultural controls on the allocation of eroded soil to sediment yield and to different storage locations. Much more data on sediment budgets under a variety of physiographies and land use histories, coupled with more sophisticated modeling of erosion and sedimentation are needed to fully understand these influences.

Perhaps the most conspicuous difference between our Blue Ridge basins and lower relief basins in the Piedmont is the small size of alluvial storage. The relatively minute contribution of alluvial storage to the budget, despite substantial sediment yield, suggests a strong capacity for sediment transport within the channel network (Taylor and Kite, 2006). The gradients at midpoints of main stream axes are steep, at 0.02 and 0.05 for Wolf Branch and Rocky Cove respectively, and this would have helped keep sediment moving to the outlet, even under conditions of general aggradation and overbank storage. For small watersheds, the proportion of remobilized stored channel sediment that is redeposited per unit time (the channel deposition parameter of Lu and Richards (2008)) should be lower than that of large watersheds. Lu and Richards (2008) show that the best fit curve through Roehl's (1962) sediment delivery ratio data, to which our data generally conform, indicates low-to-moderate values of the deposition parameter, indicating a greater ability to remove in-channel sediments.

The fact that a substantial quantity of eroded soil never reaches channels demonstrates the importance of natural buffers (*sensu* Fryirs et al., 2007) such as gentle footslopes and floodplains between uplands and channels that serve to disconnect the two. Such buffers, while typically increasing with basin size, may also be effective in small Blue Ridge basins, perhaps especially for conditions of mild or short-duration erosion periods. However, abundant colluvial storage does not necessarily indicate low transmission to streams, as the substantial sediment yields in our study area indicate. The capacity to transport sediment that does reach a channel may make low-order streams more resilient, but implies the rapid passage of sediment from headwater streams to higher-order channels. Land use changes resulting in greater clearwater runoff and streamflow would likely enlarge headwater channels via bank erosion, increasing excess fine sediment loads in amounts proportional to the relative thickness of historical overbank deposits. Appropriate land use management would minimize impervious surface area, and maximize runoff dispersion in time and space, without increasing the risk of landsliding, a risk that frequently accompanies road construction in steep lands (Harden, 2013; Royall, 2013).

7.0 Conclusions

Unlike the southern Piedmont physiographic province of the Appalachian Highlands, few data on sediment budgets are available from higher elevation and higher relief settings in the adjacent Blue Ridge Mountains. Short-term sediment yield, and sediment delivery ratios have been derived largely via modeling and limited field measurements for some locations in the Blue Ridge (Simmons, 1993; Bolstad et al., 2006), but few studies have been spatially explicit in their treatment of sediment storage. Where and in what quantities storage occurs is critical knowledge

for managing land use changes that affect hydrological systems with the capacity to reactivate stored sediment.

Historical sediment budgeting can provide important information for land management and assessment of increasingly sophisticated erosion models; yet it presents many challenges. In this study, we reconstruct approximate historical budgets that include basin-wide mapping of alluvial storage, and present some evidence that colluviation has been substantial in footslope areas. We also demonstrate the large uncertainties in budget terms that can arise with limitations of land use history data, difficulties with interpreting soil profiles in a dynamic and heterogeneous environment, and requiring closure terms to complete sediment budgets, as we did for colluvial storage. Colluvial storage, by virtue of its large abundance in many drainage basins, and the frequently inadequate means for its assessment, has been noted as a major problem in sediment budgeting (Houben et al., 2006). At our Blue Ridge Mountain sites, projected colluvial depths are small, colluvium is often physically similar to residuum, and gently sloping (and usually cultivated) footslope areas were probably both recipients of colluvial deposition and potential sediment sources for nearby streams. These circumstances make soil profile interpretations particularly difficult. The need for research that helps solve the colluvium problem, including the unambiguous distinguishing of colluvium from residual soil, cited by Phillips (1991), remains, as does the need cited by Houben et al (2006), for continued refinement of sediment storage estimation techniques in general .

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840

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Table 1

TABLE 1. Physical attributes of Wolf Branch and Rocky Cove.

ATTRIBUTE	WOLF BRANCH	ROCKY COVE
Drainage Area (km ²)	2.38	1.76
Elevation (Min/Max; m)	648/988	641/944
Relief (m)	340	303
Relief Ratio	0.14	0.18
Channel Gradient (midpoint/outlet)	0.02/0.016	0.05/0.027
Channel Width (m; outlet)	3.3	2.65
Channel Depth (m; outlet)	0.76	0.65
Bankfull Discharge ¹ (m ³ s ⁻¹ ; outlet)	6	3.96
Area Cultivated ² (km ² ; total/%)	1.03/43%	0.6/35%
USLE Value Ranges		
R-Factor	225	225
K-factor	0.02-0.20	0.02-0.24
LS-Factor ³	0-50	0-76
C-Factor	0.011-0.115	0.011-0.115
P-Factor ⁴	1	1

1 - Manning equation-based estimate.

2 - Area cultivated during the major erosive period of the late 19th century.

3- Derived from digital elevation model; Burch and Moore (1986).

4 - assumes no erosion control practices; both down-slope (P=1), and across-slope (P=0.75) plowing may have been used at these sites.

Table 2

Table 2. Sediment budgets for Wolf Branch and Rocky Cove for three scenarios of erosion correction.

	EROSION (Mgkm ⁻² y ⁻¹)	SEDIMENT YIELD (Mgkm ⁻² y ⁻¹) (% uncert.)	ALLUVIAL STORAGE (Mgkm ⁻² y ⁻¹) (% uncert.)	COLLUVIAL STORAGE (Mgkm ⁻² y ⁻¹) (% uncert.)
Wolf Branch (2.38 km ²) (Unadjusted USLE Erosion)	2,197 indet. ²	373 ¹ indet.	102 ± 51	1,722 ± (>>52)
Adjustment (a) ³ : 0.61(USLE Erosion)	1,340 ± 697	373 indet.	102 ± 51	865 ± (>699)
Adjustment (b) ³ : 0.48(USLE Erosion)	1,055 indet.	373 indet.	102 ± 51	580 ± (>>51)
Rocky Cove (1.76 km ²) (Unadjusted USLE Erosion)	1,596 indet.	272 ⁴ ± 79.7	34 ± 16.4	1,290 ± (>83)
Adjustment (a): 0.61(USLE Erosion)	973 ± 506	272 ± 79.7	34 ± 16.4	667 ± 512
Adjustment (b): 0.33(USLE Erosion)	527 indet.	272 ± 79.7	34 ± 16.4	221 ± (>83)

1 - calculated by applying the sediment delivery ratio for Rocky Cove to the unadjusted USLE erosion at Wolf Branch.

2 - indeterminate; the uncertainty cannot be evaluated.

3 - adjustments assuming that the USLE values are overestimated by factors derived from two methods:

a.) slope of the regression line relating USLE cumulative 50-year soil and field observation of soil loss, and

b.) the ratio of the long-term ¹⁰Be-based erosion rate from Reusser et al. (2015) to the USLE model rate under fully forested conditions.

4 - Sediment yield value corrected from Kennedy (2013); the value was mistakenly reported as 461 without the basin area adjustment.

Table 3

Table 3. Sediment budget information for various eastern U.S. drainage basins. (All values rounded to nearest whole number).

	DRAINAGE AREA (Km ²)	TIME INTERVAL (CE years)	EROSION (Mgkm ⁻² y ⁻¹)	SEDIMENT YIELD (Mgkm ⁻² y ⁻¹) / (% of erosion)	ALLUVIAL STORAGE (Mgkm ⁻² y ⁻¹) / (% of erosion)	COLLUVIAL STORAGE (Mgkm ⁻² y ⁻¹) / (% of erosion)	TOTAL STORAGE (Mgkm ⁻² y ⁻¹) / (% of erosion)
Wolf Branch (Unadjusted)	2.38	1865-1915	2,197	373 ² / 17%	102 / 5%	1,722 / 78%	1,824 / 84%
Adjustment (a) ¹ : 0.61(USLE Erosion)			1,340	373 / 28%	102 / 8%	865 / 64%	967 / 72%
Adjustment (b) ¹ : 0.48(USLE Erosion)			1,055	373 / 35%	102 / 10%	580 / 55%	682 / 65%
Rocky Cove (Unadjusted)	1.76	1865-1915	1,596	272 / 17%	34 / 2%	1,290 / 81%	1,324 / 83%
Adjustment (a) ¹ : 0.61(Erosion)			973	272 / 28%	34 / 3%	667 / 69%	701 / 72%
Adjustment (b) ¹ : 0.33(Erosion)			527	272 / 52%	34 / 6%	221 / 42%	255 / 48%
Blue Ridge (background) ³	unspecified	Long-term	19-23	na	na	na	na
Coweeta (NC) subbasins ⁴ (forested Blue Ridge)	2	recent	na	<5	na	na	na
Thompson Lake (VA) ⁵ (forested Blue Ridge)	3.8	1966-1995	na	8	na	na	na
<i>Sites from Simmons (1993):</i>							
Nantahala R. (NC Blue Ridge - forested)	134	1970-1979	345	22 / 6%	na	na	323 / 94%
French Broad R. (NC Blue Ridge – rural/agric.)	766	1970-1979	331	102 / 31%	na	na	229 / 69%
Little Tennessee R. (NC Blue Ridge – rural/mixed)	1,129	1970-1979	992	97 / 10%	na	na	895 / 90%
French Broad R.at Marshall (NC Blue Ridge – rural/mixed)	3,449	1970-1979	539	194 / 36%	na	na	345 / 64%
Leonard Creek (NC Piedmont - agric.)	13.4	1970-1979	914	135 / 15%	na	na	779 / 85%
Lanes Creek (NC Piedmont - agric.)	12.7	1970-1979	1,600	79 / 5%	na	na	1,521 / 95%
S. Piedmont ⁶ (Avg. of Tar R. and Neuse R.; 60% forested); Phillips (1991)	1,119-1,997	1970-1979	519	56 / 11%	93 / 18%	368 / 71%	461 / 89%
S. Piedmont ⁷ ; (peak erosion; Trimble, 1977)	2,652-19,446	1750-1950	1,370	72 / 5%	na	na	1,298 / 95%
S. Piedmont (background) ³	unspecified	Long-term	11-14	na	na	na	na
Coon Creek (WI) ⁸ ; hist. peak erosion	360	1853-1938	1,586	na	na	678 / 43%	na
Coon Creek (WI) ⁹ ; hist. peak erosion	360	1853-1938	1,906	106 / 6%	1,125 / 59%	678 / 36%	1,803 / 95%

Indian Creek (MN) ¹⁰ ; hist. peak erosion to CE 1988	17	1856-1993	730	258 / 35%	131 / 18%	343 / 47%	474 / 65%
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- 1 - adjustments assuming that the USLE values are overestimated by factors derived from two methods:
a.) slope of the regression line relating USLE cumulative 50-year soil and field observation of soil loss, and
b.) the ratio of the long-term ¹⁰Be-based erosion rate from Reusser et al. (2015) to the USLE model rate under fully forested conditions.
- 2 - calculated by applying the sediment delivery ratio for Rocky Cove to the unadjusted USLE erosion at Wolf Branch
- 3 - Calculated from ¹⁰Be estimates made by Reusser et al. (2015) for the watersheds of Trimble (1977), plus bulk density data for upland soils mapped at our sites (Hudson, 2009) and Piedmont sites in Trimble's watersheds.
- 4 - Velbel (1985); Coweeta Hydrological Laboratory, NC Blue Ridge.
- 5 - Royall (2000); Northern Blue Ridge.
- 6 - Phillips (1991); two smallest basins in study; 60% forest, 12-20% cropland, 7% pasture or hay.
- 7 - A composite of Trimble (1974) and (1977); peak erosive period was 1860-1920.
- 8 - Trimble (1983); upland sheet and rill erosion only.
- 9 - Trimble (1983); includes upland sheet and rill erosion, plus gully and tributary inputs.
- 10 - Beach, (1994)

Table 4

Table 4. Average colluvium depths across combined footslope and toeslope soil mapping units, that are required to account for colluvial masses predicted for unadjusted USLE values and by two scenarios of erosion overestimation. Averages, standard deviations, and ranges of colluvial depth observations at footslope sites interpreted as historically colluviated, are below each site name. Four augered footslope locations at Wolf Branch were interpreted as having no historical colluvium, and are omitted from the sample statistics.

Site	Unadj. USLE (cm)	0.61 USLE ¹ (cm)	0.48 USLE ² (cm)	0.61 USLE ¹ (cm)	0.33 USLE ² (cm)
Wolf Branch (obs. avg. = 24.9 cm) (n = 13; σ = 11 cm) (range: 10-42 cm)	44	15	10		
Rocky Cove (obs. avg. = 26.8 cm) (n=5; σ = 9.3 cm) (range: 17-40 cm)	38			19.6	6.3

1 - USLE erosion adjustments based on slope of regression line relating USLE model cumulative soil loss and spatially correspondent field estimates of soil profile truncation depth.

2 - USLE erosion adjustments based on ratios of the long-term erosion rate for the southern Blue Ridge Mountains given by Reusser et al. (2015) on the basis of ¹⁰Be data to the USLE cumulative 50-year erosion under fully forested conditions.

FIGURE 1

FIGURE 2

FIGURE 2 COLOR

FIGURE 3A

(A)

FIGURE 3B

(B)

FIGURE 4

FIGURE 5

FIGURE 6

FIGURE 7

FIGURE 8

FIGURE 9

Approximate Sediment Budget

Rocky Cove
CE 1865-1915 ($\text{Mgkm}^{-2}\text{y}^{-1}/\%$)
Condition: 0.61(USLE Erosion)

Figure Captions

Figure 1. Site location maps. Cross-points show approximate centers of Trimble's (1977) Piedmont study basins, which are the same as those analyzed by Reusser et al. (2015). Triangles show the approximate centers of Phillips' (1991) Piedmont study basins. Filled boxes represent small basins in Simmons (1993). Sub-basin DEM: Sub-basins shown in the Rocky Cove drainage basin are Rocky Cove main drainage (RC); Walnut Cove tributary drainage (WC); and Poplar Cove tributary drainage (PC).

Figure 2. Historical alluvium in streambank sediment profiles.

Figure 3. Late nineteenth century USLE C-factors, and USLE annual erosion maps. Topographic contour interval is 12.2 m (40 ft). (A) Wolf Branch, minimum contour line elevation: 658 m (2160 ft.); (B) Rocky Cove; minimum contour line elevation: 646 m (2120 ft.).

Figure 4. Plot of observed erosion depth from profile truncation studies vs. cumulative 50-year soil loss estimated from corresponding locations in the distributed USLE model. Standard error of the estimate is 0.035, 52% of the mean.

Figure 5. Spatial patterns of historical alluvium depth and volume. Squares on volume maps show the locations of cross-valley alluvium transects, with box size proportional to sediment width (the total floodplain width over which historical overbank sediments were traceable).

Figure 6. Scatter and regression plots for sediment depth and volumes vs. drainage areas.

Figure 7. Relationships between (a.) measured alluvial sediment widths and widths derived from digital elevation models (standard error of the estimate is 2.93, 26.7% of the mean), and (b.) measured alluvial cross-sectional area (CSA) and trapezoidal model cross-sectional area (standard error of the estimate is 1.25, 25.6% of the mean).

Figure 8. Examples of historical alluvial deposit cross-sectional shape.

Figure 9. Graphical representation of the Rocky Cove historical sediment budget (CE 1865-1915), for the USLE calibration factor 0.61.