MODELING POTENTIAL EROSION DIFFERENCES OF SMALL TRIBUTARIES IN MANAGED STANDS IN THE BANKHEAD NATIONAL FOREST, ALABAMA

Allison Bohlman, Dawn Lemke, and Andy Scott

Abstract—In the William B. Bankhead National Forest, AL, the Sipsey Fork River Watershed's stream network is composed of many small tributaries that are short in length, ephemeral, and have low average discharges when wet. However, the potential to transport considerable amounts of sediment during significant storm events has not been thoroughly investigated. Sediment runoff was collected from small tributaries that drained recently burned, thinned, and control stands during heavy seasonal storms in early 2016. Water samples were analyzed for Total Suspended Solids. Results from between burned, thinned, and control stands were compared. Observational data were evaluated against predicted potential sediment loads modeled using WEPP (10.3), the geospatial interface program of the Water Erosion Prediction Project (WEPP) - a process-based hillslope and watershed model. The WEPP model performed poorly, and a second erosion potential model was developed to identify important variables that could improve modeling of erosion and sediment runoff from small tributaries. Using ArcMap's ModelBuilder, qualitative rankings of erosion potential were evaluated using the same runoff data. Erosion predictions were positively correlated with observational runoff of small tributaries from the second model.

INTRODUCTION

Forested watersheds in the Southeastern United States are generally well-protected areas that are good sources of clean water and aquatic fauna including fishes, freshwater mussels, and herpetofauna species (Gaines and Creed 2003, Grace 2005, U.S. Environmental Protection Agency 2002). Common management practices in southeastern forests that may contribute to lowered water quality and sedimentation include prescribed burning and timber harvesting (thinning) practices (Sheridan and others 1999, Sun and others 2001). Loss of ground cover, soil disturbance, stand size, and stream proximity are important factors contributing to topsoil erosion and increases in total suspended sediments, nutrients, and turbidity detected in local streams (Sanders and McBroom 2013). While the overall contribution of forest management activities to impairment of southern streams (approximately 8 percent of total continental streams) is low, the potential impact to critical instream habitats or water quality is crucial for conservation efforts in the region.

Best management practices (BMPs) have been implemented by the U.S. Department of Agriculture Forest Service to mitigate and prevent erosion in forests from prescribed burning and thinning activities. Intermittent streams in the conterminous United States account for about 60 percent of the total river length (Nadeau and Rains 2007). In Alabama, these streams may be a part of a complex hydrologic system that includes karst and cave systems that are poorly understood. Small streams link soil water storage, aquifers, and forest vegetation to the larger stream network within a watershed. Potential soil from disturbance and erosion caused by burning or thinning in forests may be quickly transported downstream, increasing sedimentation and siltation in larger rivers. Few studies have quantified the sediment contribution of intermittent streams in watersheds in Alabama or the greater United States. Additionally, BMPs in Alabama do not directly address how to protect these temporary and small-sized streams when burning or thinning a forest stand. It is unknown if forest management activities such as burning and thinning contribute excess sediment through these small stream channels. The research objective is to assess the impacts of burning and thinning management practices on small forested tributaries using a combination of field and remote sensing techniques.

Author information: A. Bohlman, Research Graduate Student, Alabama A&M University, Normal, AL 35762; D. Lemke, Assistant Professor, Alabama A&M University, Normal, AL 35762; Andy Scott, Research Soil Scientist, U.S. Department of Agriculture Forest Service, Southern Research Station, Normal, AL 35762.

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MATERIALS AND METHODS

Study Site and Design

The William B. Bankhead National Forest (BNF) is located within the dissected plateau of the Southern Cumberland Plateau in northwest Alabama (fig. 1). Approximately 730 km^2 in total area, it is a mesic, mixed hardwood-pine forest with highly erodible and well-drained soils. The Sipsey Fork River Watershed drains most of the BNF into Smith Lake, which is located on the southern edge of the BNF in Winston County, AL. Intermittent streams in the BNF are mostly diminutive in size (2m ± 0.5m width), flashy in nature, wet predominantly from December through June, and are dry stream beds in the later summer months of August and September through the fall. Twenty small intermittent streams that directly flow through and solely drain BNF forest stands were selected for water quality sampling at buried road culvert drains. Stream sites were grouped into three treatment types: prescribed burn (n = 7), thin (n = 5), and control (n = 8). Prescribed burns were performed by Forest Service BNF personnel in January through March 2016. Selective harvesting in thin stands occurred in the fall of 2015. Control stands received no management activities that changed the canopy or overall vegetative ground cover. Sites were mapped in ArcMap 10.1, with shapefile BNF boundaries, BNF 2015–2016 burn and thin stands, streams, and a LIDAR-based digital elevation model (DEM). Each sampling site's natural watershed was hand drawn in ArcMap to estimate the surface drainage area using a hill-shaded 10-m DEM overlaid with an ESRI topographic base map (USA Topo Maps 2013).

Stormwater Sampling

Five storms were sampled from January through April 2016. A storm event was sampled if the predicted precipitation was >10 mm and the local meteorological stations forecasted that it would continue for at least 4 hours (The Weather Company 2016). Sites were sampled in mixed-treatment groups for each individual storm. One L of stormwater was collected from the upstream gully side of the culvert every 90 minutes during the storm for a total of three samples from each site. Sample runoff was tested immediately for pH (± 0.2), conductivity (µS, ± 1 percent), temperature (°C, ± 0.2), total dissolved solids (TDS) (ppm, calculated from conductivity and temperature readings), and dissolved oxygen (mg/L, ± 0.2 percent) using a portable multi-meter Pro Plus sonde (YSI Inc.). Turbidity (NTU, ± 0.2 percent) was measured using an Oakton turbidity meter. Each L of stormwater was subsampled a with well-mixed 100 mL subsample stored in a Nasco Whirl-pak®. Total suspended solids (TSS) (mg/L) were determined in the laboratory using three pooled 100-mL water samples collected at each site.

Erosion Modeling and Analysis

The online Water Erosion Prediction Project or WEPP GIS (WEPP) interface model was used to simulate the rate of erosion and sediment yields of the burn, thin, and control watersheds (Flanagan and Frankenberg 2002, National Soil Erosion Research Laboratory 2014). Watersheds were delineated using the allocated online WEPP tools using a preloaded elevation and land use and landcover (LULC). The final set up for the individual WEPP model included climate station selection, defaults for soil and LULC, simulation type, testing years, soil loss tolerance, and certain processing options. Soil and LULC processing were determined by individual grid cells' values. The simulation type selected was for representative hillslopes and channels, also known as the watershed method. The soil loss tolerance (T-value) was set to 3 tonne/ha/year. The model was set for a 10-year analysis estimation of average annual sediment yield (t/ha/year) for each watershed.

The raster files (30-m resolution) were extracted and spatial analyses were conducted within ArcMap (fig. 2). The total sediment loss raster files were extracted and reclassified into four broad erosion classifications. A simple scale of 1 to 4 was devised to estimate erosion potential within each watershed: 1. little to no erosion (modeled soil loss 0–2.5 t/ha/year), 2. slight erosion (modeled soil loss 2.5–5 t/ha/year), 3. moderate erosion (modeled soil loss 5–20 t/ha/year), and 4. heavy erosion (modeled soil loss 20–100 t/ha/year). To gauge the WEPP model's efficiency in modeling small forested streams, an iterative erosion model was proposed. An alternative erosion model (EM) was developed in ArcMap's ModelBuilder to estimate the potential erosion influenced by slope, road proximity, and aspect (fig. 3). Primary input parameters for the EM included the site's individual watershed polygon file, the LIDAR DEM for the BNF, and a Forest Service BNF roads vector line file.

The final EM produced individual delineated watersheds with ranked areas of potential erosion. Overall values for potential erosion rankings were classified on a scale of 1 to 4: (1) little to no erosion (estimated soil loss 0–2.5 t/ha/year), (2) slight erosion (estimated soil loss 2.5–5 t/ha/year), (3) moderate erosion (estimated soil loss 5–20 t/ha/year), and (4) heavy erosion (estimated soil loss 20–100 t/ha/year). This scale is qualitatively similar but cannot be quantitatively compared to the reclassified ranking scale derived from the WEPP model. Percent area for the ranked potential erosion areas was calculated.

Since both models produced separate watershed delineations of each study site, differences in total area (ha) and sub-catchment overlap (spatial agreement with the topography) were examined between the WEPP

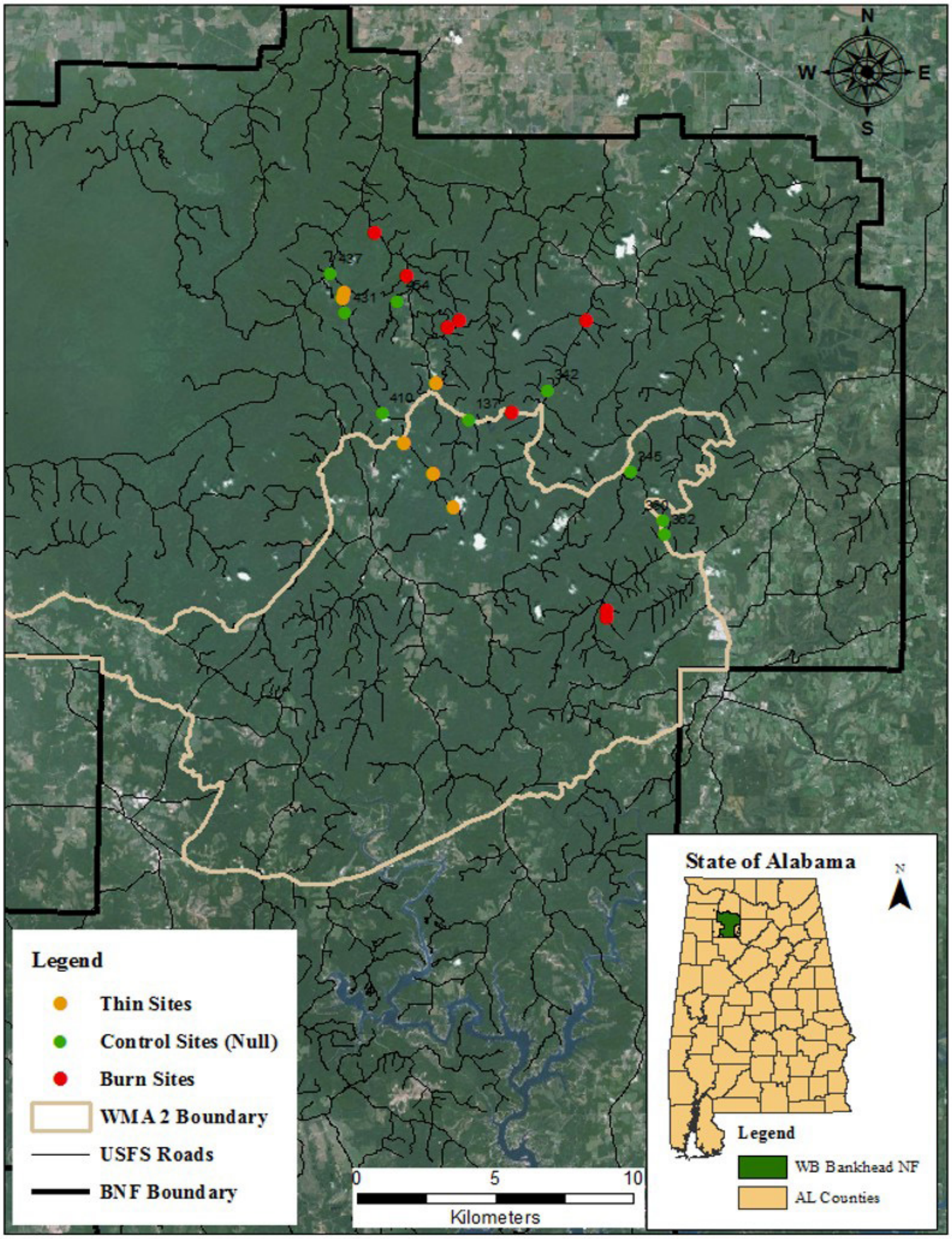

Figure 1—A map of the William B. Bankhead National Forest (BNF) with boundary, primary Forest Service roads, and Wildlife Management Area 2 (WMA 2) boundary, also known as the Black Warrior Wildlife Management Area (Alabama Department of Conservation and Natural Resources and U.S. Department of Agriculture Forest Service). Prescribed burn, thin, and control sites (n = 20) for the study are located in the north-central part of the BNF.

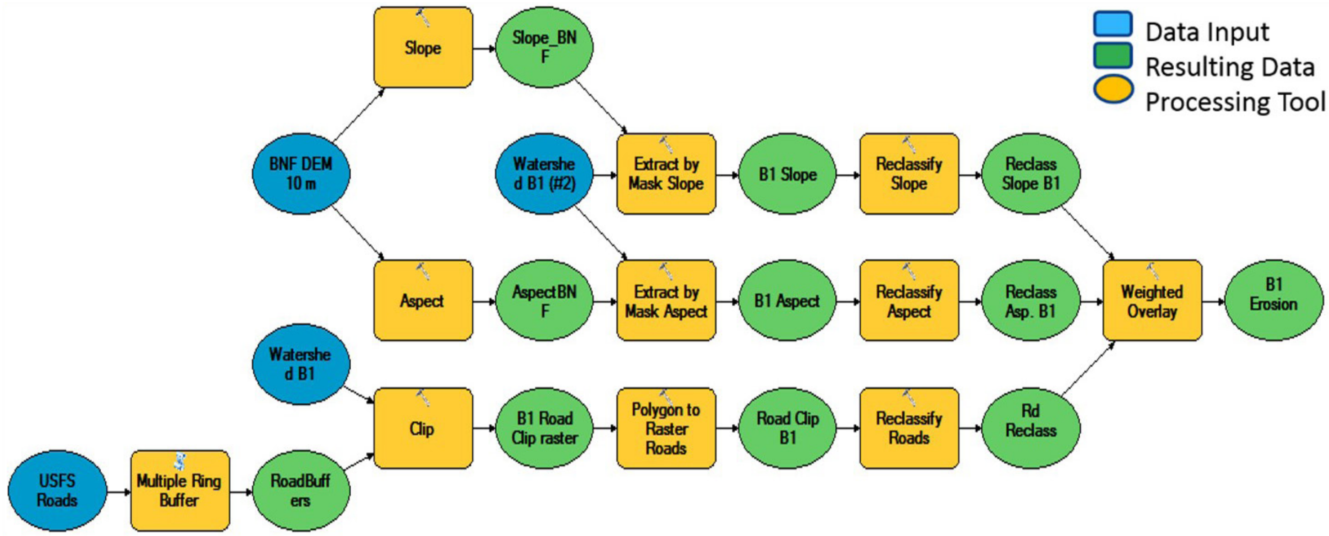

Figure 2—An online Water Erosion Prediction Project (WEPP)-delineated watershed from a thin stand in the William B. Bankhead National Forest (BNF) shapefile extracted and projected over a LIDAR 10-m digital elevation model in ArcMap 10.4. Areas of modeled soil loss (t/ha/year) ranging from 0–36 t/ha/year were modeled over a 10-year timeframe.

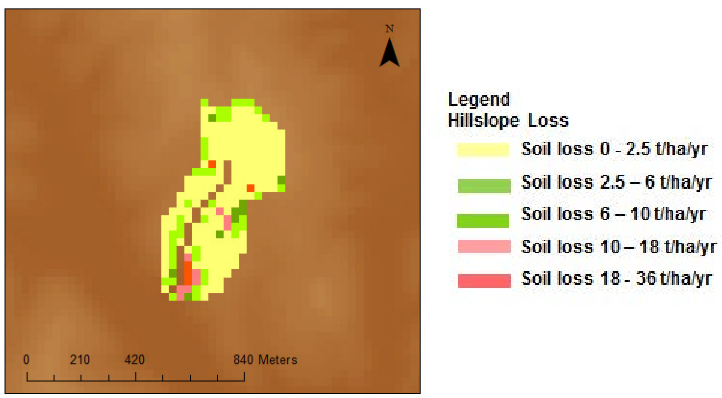

Figure 3—The work schematic for the erosion model built in ArcMap ModelBuilder to estimate the amount of potential erosion in delineated burn, thin, and control watersheds in the William B. Bankhead National Forest (BNF). Data inputs included shapefiles of each watershed, Forest Service roads, and a LIDAR-based 10-m digital elevation model.

and EM. The calculated areas for both models were compared to the topographically drawn watersheds' areas to gauge model accuracy for small intermittent streams. Summary statistics of select water quality parameters (TDS, TSS, and turbidity) and Pearson Correlation analyses were run using the program R Commander (v. 2.3-2), powered by open source statistical software R (v. 3.2.2) (Fox and Bouchet-Valat 2017, R Team 2008).

RESULTS AND DISCUSSION

Measured water quality parameters among the three treatments did not significantly differ (p = 0.01). Turbidity and TSS had the highest variance (coefficient of variance = 1.08 and 1.69). TSS had statistically high measurements (100 percent quartile) of 535.33 mg/L and turbidity of 417.67 NTU, both originating from a control site. The mean areas were 1.53 ha for the natural watersheds, 7.65 ha for the WEPP-delineated watersheds, and 1.65 ha for the EM watersheds. A paired t-test found no significant difference in watershed areas that were hand-drawn and those delineated by the EM [95 percent confidence interval (CI), -3.129 to 0.923, t (19) = -1.139, p = 0.268]. A significant difference between the WEPP-delineated watershed areas and the hand-drawn watershed areas [95 percent CI, -12.449 to -3.983, t (19) = -0.062, p = 0.0006] was found. Forty percent of the WEPP watersheds were spatially dissimilar in total area or location than the EM-delineated areas. Half of all WEPP delineations were projected with opposite flow directions of the natural watershed from the sampling site.

A Pearson correlation analysis (p = 0.01) showed a negative relationship between the WEPP model's sediment yield results for each watershed and water quality variables of turbidity (-0.27), TDS (-0.11), and TSS (-0.39). Using the same water quality variables, a positive correlation (r >0.8; p = 0.01) was found with the EM model's rankings (standardized by area): turbidity (0.21), TDS (0.29), and TSS (0.33) (table 1). The erosion potential-scaled rankings tabulated for the WEPP and EM models did not show agreement among the predicted burned, thinned, or control treatments. A Spearman rank correlation between the WEPP and EM models' rankings did not find a strong correlation (r >0.8) between the predicted rank values and the three selected water quality variables of turbidity, TDS, and TSS. WEPP predicted very low amounts of erosion in the treatments. The EM ranks were mixed with higher estimates for slight (2) or moderate (3) erosion potential in the treatments (table 2).

Table 1—Pearson correlation analyses (*p* = 0.01) between two erosion prediction models with observed water quality variables

Water quality parameter	**EM model ranking/∑ area**	**WEPP model sediment yield**
TDS	0.29	-0.11
TSS	0.33	-0.39
Turbidity	0.21	-0.27

Table 2—Calculated mean rankings by treatment type (burn, control, or thin) and standard deviations from each model

Treatment type	**Mean erosion ranking (1–4)**	**Standard deviation**
EM model ranking/∑ area		
Burn	2.52	0.42
Control	2.64	0.43
Thin	2.30	0.37
WEPP model sediment yield		
Burn	1.41	0.93
Control	1.73	0.84
Thin	2.00	0.64

The WEPP model is considered a reliable model for small forested watersheds under 10 ha with permanently flowing streams, but it can overestimate sediment yield and other variables such as discharge (Covert and others 2005, Dun and others 2009). The online WEPP model's preset inputs were a contributing factor for oversized delineations, flow path direction, and spatial positioning of sites. The lower base map resolution (10 m) used in the EM to create smaller stream channels likely increased its delineation accuracy compared to the larger 30-m resolution used by the WEPP. Counter to other popular erosion and hydrological models, the EM model did not include LULC inputs while the WEPP model included both LULC and treatment type (burn, thin, or control stand) for computation. The overall better performance by the EM model through positive correlation with the available observational data suggests that regional landscape characteristics of slope and soil type are more important.

CONCLUSIONS

This research's conclusions are limited for the BNF region during a typical winter and early spring season with average monthly precipitation. Total sites (n = 20) and low treatment replication currently do not support interpretations for other southeastern forest ecosystems or similar management activities. The BNF management activities of burning and thinning appear to maintain current State and Federal water quality standards. The higher values for turbidity, TSS, and TDS found during storm events in the BNF originated from control stands where there were no human-based stand disturbances recorded.

Improvements in model efficiency for the WEPP should include a 10-m resolution DEM to improve hillslope estimations surrounding smaller intermittent channels. Parameter refinement of the EM's five inputs and calibration is needed to provide further useful information regarding potential erosion. More information is needed to accurately model the connectivity and sediment loading from intermittent streams and their downstream channels. There is an abundance of hydrological data within the Sipsey Fork River Watershed and the greater BNF to supplement future modeling and BMP assessments.

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