Modeling Soil Erosion and Sediment Transport from Fires in Forested Watersheds of the South Carolina Piedmont

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Abstract

Forested watersheds in the Southeastern U.S. provide high quality water vital to ecosystem integrity and downstream aquatic resources. Excessive sedimentation from human activities in forest streams is of concern to responsible land managers. Prescribed fire is a common treatment applied to Southeastern piedmont forests and the risk of wildfire is becoming increasingly important under the threat of changing climate. Measuring and predicting the amount of runoff and erosion from fire induced forested watersheds is difficult and costly. Erosion simulation models assist in relieving the time and resources consumed predicting these effects. The process-based Water Erosion Prediction Project (GeoWEPP) is widely used in the Western U.S. to predict erosion from forest fires. The objective of this study was to evaluate the effectiveness of the GeoWEPP model in predicting sedimentation amounts from low, moderate and high intensity forest fires on pine stands of the Sumter National Forest in the piedmont region of South Carolina. Modeling results were compared to observed sediment production of 48 small-scale plots within the watersheds. Results from the simulations conclude that the GeoWEPP model satisfactorily predicted erosion amounts during unburned, low and moderate intensity forest fire conditions. We found that low intensity fires may not elevate sediment loading above tolerable rates, however, severe fires can cause soil erosion and sediment loading at levels of concern in water quality degradation. Land topography, fire intensity, storm intensity and soil type are key variables to predicting soil erosion and runoff. This study is the first to evaluate the effectiveness of the GeoWEPP model in predicting runoff and sedimentation in Southeastern piedmont watersheds.

Introduction

In the Southeastern U.S., forested watersheds provide high quality water important for ecosystem integrity and many downstream water uses (Sun et al., 2004). Maintaining the quality of these waters is important to natural resource and forest managers and is often required by law. There are however, threats to forested watersheds, such as pollutants. Pollutants can jeopardize the high quality of these waters. The number one pollutant of Southern waters from silvicultural activities is sediment (Riekerk et al., 1989). Sediment can carry nutrients that are vital to forest fertility and in excess, can become harmful to downstream water quality. A common forest operation of the Southeastern U.S. in pine cover types is the use of prescribed burns to decrease wildfire fuel loads, control unwanted species, improve wildlife habitat, and to prepare sites for regeneration (Ursic, 1986). Although the objective of forest managers is to minimize soil disturbance and surface runoff when managing forest stands, the severity of soil disturbance from prescribed and wildfires can ultimately be dictated by variability in surface conditions and forest hydrologic processes (Robichaud, 2000).

The measurement of erosion in forested systems is a difficult and costly endeavor due to the complex nature of erosion processes and the variability of forested conditions. Because these effects are so difficult and costly to measure in preparation of forest management and wildfire contingency plans, the use of erosion prediction models can assist with alleviating the expenses and time-consuming field work involved in accounting for the variables and effects associated with runoff and sediment production. Several models have been developed to estimate and predict runoff and sediment yields from a variety of land uses, such as: agriculture, forested roads, prescribed burns and wildfires. One of the most recently developed process-based models is the Geo-spatial interface for the Water Erosion Prediction Project (WEPP) named GeoWEPP, which is available at the website http://www.geog.buffalo.edu/~rensch/geowepp/. This model is a hybrid linkage of WEPP and Geographic Information Systems (GIS). This linkage allows users to geo-reference information using digital elevation models (DEM) and topographical maps to create site-specific, valid model input parameters for use in predicting runoff and soil erosion on different spatial scales (Renschler et al., 2002). The use of applied process-based models like GeoWEPP will be useful in predicting conditions and events when erosion from prescribed and wildfires will be of concern to forest managers in the Southeast.

Objective and Scope

The objective of this study is to evaluate the effectiveness of the GIS linked, process-based erosion model GeoWEPP in predicting sedimentation amounts from low, moderate and high intensity fire and precipitation events on pine stands in the piedmont of South Carolina. Analysis of the GeoWEPP model in the piedmont of South Carolina will provide an indication to Southeastern forest managers of the usefulness of this model in evaluating post-wildfire risks of runoff, soil erosion, and sedimentation to water quality. This initial assessment of the GeoWEPP model for predicting erosion and sedimentation required calibration and parameterization for local conditions as well as comparison to an observed sediment database in collaboration with the College of Charleston and the USDA Forest Service Southern Research Station, Charleston SC.

Study Sites

The Long Cane and Enoree study sites are located in the piedmont region of South Carolina. The Sumter National Forest districts are part of a historically rich landscape. Hundreds of years of agriculture had degraded the soils and depleted nutrients until afforestation efforts began in the early 1960s (Richter, 2001). Since then, these sites have been managed within the Forest Plan Prescriptions of the USDA Forest Service. The prescribed burnings of the Enoree Ranger District study sites were conducted in March of 2002 and again in April of 2005. The burning of the study compartments in the Long Cane Ranger District occurred in May of 2005. Both sites were burned in the growing season with vegetation surveys, forest floor analyses, and erosion measurements conducted pre- and post-burn. The erosion database was compiled from biannual sediment movement estimates collected on erosion fences for pre and post-burn sampling of randomly selected plots within the study sites (Henrick, 2006).

Methods

The modeling method applied to this project was to create predictive assessments of erosion strictly as a "user" and apply inputs from easily accessible data sources without significant manipulations to the program scripts or input files. The input data files were downloaded from several commonly available websites. The required input data for running GeoWEPP are: Digital Elevation Models (DEMs) and climate input files. The optional input data include: spatial and tabular soil information, land use/land cover, and topographic images for reference of the study sites. The NRCS Geospatial Data Gateway (www.datagateway.nrcs.usda.gov/) was used to download DEM and land-use/land cover data for both study sites. The available data from the NRCS website allows the user to choose from two resolutions of DEMs, 30m and 10m. The spatial and tabular soil data were downloaded from the NRCS SSurgo Data tables and Coverages (www.ncgc.nrcs.usda.gov/products/datasets/ssurgo/). The appropriate DEMs, soil, and land-use files were then clipped to the boundaries of the study sites and converted to ASCII format in accordance with the "What About my Data?" and "Advanced GeoWEPP Tools" publications (Minkowski, 2005; Minkowski, 2005). Due to a lack of observed climate parameters specific to the study sites, the climate files were created using the Climate Generator program (CLIGEN), which is attached to the WEPP program. The weather stations used to represent the Enoree and Long Cane study sites were Santuck 4 SE and the Johnston 2 SSW, respectively. These weather stations were both in close proximity to their respective study site.

The results produced by the WEPP program most comparable to the observed estimates of erosion were obtained through the use of WEPP representative hillslopes (V.2006). The spatial output of the GeoWEPP version was also used to create comparisons to a tolerable soil loss value (T-value) of 0.41 t/ac/yr. These comparisons were made on the catchment and subcatchment scale of the input DEM using color-coded ratio values within the ArcView/GeoWEPP legend. The main WEPP output creates an average value of sediment yield from the entire hillslope in kilograms per meter of width (kg/m) for each representative hillslope. The GPS point location of each silt fence was overlaid upon the subwatershed layers of the spatial GeoWEPP output in order to select the appropriate representative hillslope. The appropriate GeoWEPP management and soil files were then used to most accurately represent the field treatments and erosion measurement methods. The tabular main WEPP output and the spatial GeoWEPP outputs were then created to compare to the observed erosion data.

To evaluate model predictions based upon fire intensity and precipitation intensity, the GeoWEPP library files of management and climate used in the simulations were changed to reflect the prescribed burning, moderated intensity, and high-intensity wildfire as well as extreme storm precipitations based upon return periods of 2, 5, 10, and 20 year probabilities in order to hypothetically simulate the risks posed by such events and the reaction of the model under those circumstances. Since slope is a predetermined influence on erosion processes, one representative hillslope was used for the simulations of high-intensity fire and precipitation events.

Results

The two resolutions of DEMs downloaded from the NRCS Spatial Data Gateway (30m and 10m) were used to produce spatially different views of catchment and stream delineation, but the predicted soil erosion amounts were not significantly different (alpha = 0.05). The observed erosion data averages were nearly zero and resulted in no significant differences in average soil loss values between treatments (White et al, 2003; Henrick, 2006). The direct comparisons of the WEPP on a Hillslope model produced average results two orders of magnitude greater than the observed amounts on a kg per width basis. The comparative model runs did however produce satisfactory results of T-values. Table 1 compares the differences between measured erosion amounts and modeled results. Figure 1 shows an example of the spatial capabilities of the GeoWEPP model in delineating potential "hotspots" for fire-induced erosion. The 50-year model simulations of high-intensity fire and precipitation events are shown in Figure 2.

Discussion and Conclusions

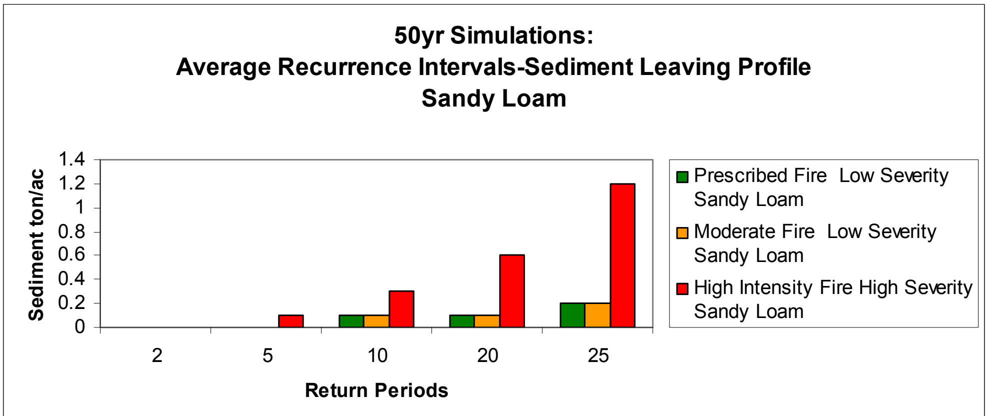
Under prescribed fire conditions, both actual observations and model predictions show very little erosion (<0.41t/ac/yr). The model predicted erosion amounts that were 1-2 orders of magnitude higher than the observed erosion amounts. This over prediction could be attributed to several factors. The model may

Table 1. Comparison of Five-Year Simulations and Observed Erosion Amounts

Site	Number of plots	Observed average erosion (kg/m width)	10m DEM average erosion predicted (kg/m width)	Observed average T-values (t/ac/yr)	GeoWEPP average T-values predicted (t/ac/yr)
Enoree	24	0.007	0.19	0	0.025
Long Cane	24	0.011	0.44	0	0

Figure 1. Example of GeoWEPP Spatial Application Long Cane RD 50 Year Simulations on Single Watershed (1. Low-intensity fire, sandy loam, 2. Medium-intensity fire, sandy loam, 3. High-intensity fire, sandy-loam)

Figure 2. Average Sediment Yield from Analysis of Return Period Events (50-year simulations on representative hillslope using a sandy loam texture with fire occurring in first year. Note: Comparative model runs and observed data only incorporated 2-year return periods.)



over predict erosion amounts after high intensity fire due to the assumption of soil hydrophobicity largely unseen in forests of the Southeast. The model also may not accurately account for the movement of subsurface lateral flow inherent in Southeastern forested systems, although this error is being corrected in more recent WEPP versions (Covert et al., 2005). There was no accurate estimate of contributing area to the field erosion measurements, thereby necessitating the use of "entire" hillslope averages, rather than "partial" hillslope estimates on the exact portion of the hillslope profile. Conversely, the field measurement erosion database may have underestimated the actual erosion amounts (White et al., 2003). The fifty-year simulations performed to include higher-intensity return period storms produced results that exceeded the forested T-value of soil loss only after storms with a return probability of 25 years. The storm of lower intensities predicted in the 50yr simulations (20 year return period or less) produced erosion estimates well within the forested T-value of 0.41 t/ha/yr.

There were also limitations to this study in the amount of available data. The measurements conducted by the College of Charleston and the USDA Forest Service of Charleston, only measured after controlled burns and therefore erosion amounts from high-intensity, uncontrolled wildfire were not available to compare with model predictions. This study was also lacking any hydrologic verification for the predictions of runoff and sediment loading at the watershed outlets. Comparisons of WEPP model predictions and measured streamflow at the watershed outlets will prove useful in future studies.

The GeoWEPP model was developed for use in the Western U.S. Many variables of the soil erosion processes differ in the Southeast from Western conditions (Bill Elliot, pers. comm., E-mail, 8 Jan 2007). This study is the first in-depth analysis of the GeoWEPP model for use in fire erosion prediction in the Southeast. From this initial usage of GeoWEPP in the piedmont setting, it appears that topography, fire intensity, storm intensity, and soil type are the driving forces behind the model.

Southeastern forest managers and decision makers may be able to use GeoWEPP as a tool for assessment of management effects and to designate "hotspots" for increased erosion protection from wildfire. The spatial capabilities of the GeoWEPP model may provide the most benefit for this specified use by allowing the user to quickly designate problem areas over larger spatial scales. GeoWEPP is still presently a research tool and much calibration and parameterization is still needed to validate its uses in the piedmont of the Southeastern U.S. This study highlights the need for further work toward accurately modeling fire-induced erosion and its effects on water quality in the piedmont forests of the Southeastern U.S.

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