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EVALUATION OF THE WEPP HILLSLOPE MODEL ON STABLE AND ERODING SEMIARID WOODLANDS

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ABSTRACT

In this paper, we evaluate runoff and erosion prediction by the WEPP hillslope model for two pinyon-juniper sites in New Mexico: one has a low erosion rate (stable site) and the other (unstable site) is eroding at very rapid rates (as a result of landuse and climatic perturbations over the last century). Runoff and erosion measurements were made at plot and hillslope scales at both sites. WEPP was evaluated using both rainfall simulation and natural rainfall data. Rainfall simulation was performed on both vegetated and bare plots. Parameter values used were developed from rainfall simulation experiments and site characteristics.. In general, runoff and erosion were underpredicted at both sites but to a much larger degree at the unstable site. On the unstable site predictions were much improved when we used hydraulic conductivity (Ke) derived from the bare plot rainfall simulation. Also of importance, at the unstable site we observed a large increase in erosion as scale increased from the plot to the hillslope as a result of a well developed channel network. These results are preliminary, in that only a few storms

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were evaluated, however, they do suggest some important strategies for predicting the
impact of reduced vegetation cover to erosion in semiarid landscapes.

INTRODUCTION

Semiarid landscapes may be among the most sensitive to environmental change
(Schlesinger et al. 1990). This is especially true for “ecotonal” zones, in which a small
change in soil moisture can have a large impact on vegetation characteristics (Gosz and
Sharpe, 1989) – and these in turn, can have a large impact on soil erosion. Predicting the
magnitude of this impact, however, is much like trying to use a crystal ball: mathematical
models, the modern version of the crystal ball, are being and will continue to be used to
predict how environmental changes influence soil erosion, but our understanding of the
processes and feedbacks involved is incomplete, and there are many uncertainties. If the
use of such models is to have validity, we must not only improve our understanding in
both areas, but also exercise extensive field validation of these models as a means of
building the necessary confidence level.

In this paper, we report on a study to evaluate the hillslope version of the WEPP
soil erosion model (Flanagan and Nearing, 1995), in a semiarid (pinyon-juniper)
woodland in the southwestern United States. WEPP, a process-oriented model based on
fundamentals of hydrology and soil erosion mechanics, represents the state-of-the-art in
soil erosion modeling. It is capable of estimating both the spatial and temporal
distributions of soil erosion and deposition, for a hillslope or watershed. Such a process-
oriented model, developed to allow extrapolation to a broad range of conditions (field-
testing of which would be impractical) is ideally suited for predicting the impact of climate change on soil erosion.

The objective of this study is to evaluate WEPP's capability to predict runoff and erosion for two semiarid hillslopes: (1) a stable (low-erosion) hillslope and (2) an unstable (high-erosion) hillslope. This exercise represents an attempt to address key questions in evaluating the use of soil erosion models for predicting the impact of climate change: (1) How well does the model simulate current conditions? and (2) Can the model simulate the impact to soil erosion from changing surface conditions that may occur with changing climate and landuse?

In this comparison we use the stable site as an analog for current conditions and the unstable site as one for changing conditions (loss of surface vegetation cover). Both sites are similar with respect to tree cover, climate and soils, and prior to the last 50-100 years erosion rates, we believe, at both sites were similar. Landuse and climatic perturbations (Allen, 1989), however, have caused almost a complete loss of understory cover at the unstable site and erosion rates are now very high.

STUDY AREA

The data used for model validation were collected from pinyon-juniper hillslopes on the Pajarito Plateau in northern New Mexico (Figure 1). Pinyon-juniper woodlands represent an important vegetation type in the southwestern United States, covering some 24 million hectares. The range of these woodlands has been in almost continuous flux over the last 12,000 years, expanding and contracting with climatic change (Miller and,
Wigand, 1994); however, their expansion during the last century has been unprecedented and is almost certainly related to landuse patterns (and possibly climatic changes as well).

What has already happened in the pinyon-juniper woodlands is perhaps a good analog for future climate- and landuse-induced changes (both are components of global change) in semiarid landscapes. As these woodlands expand, vegetation patterns are greatly altered, and in many cases erosion is greatly accelerated — mainly as a result of diminishing understory cover. Both pinyon and juniper use water from intercanopy areas, and junipers, in particular, have extensive lateral root systems, which allow them to aggressively compete for water in intercanopy areas. The result is often a mosaic of tree canopy areas, under which the ground is well protected by a thick layer of litter, interspersed with patches that are mostly bare and are highly susceptible to erosion. The most xeric sites, generally those having shallow soils or south-facing slopes, seem to suffer the greatest loss of herbaceous cover as a result of pinyon-juniper expansion (Miller and Wigand, 1994). At the same time, there are many pinyon-juniper woodlands that exhibit both a healthy understory cover and low erosion rates.

We have been collecting data on runoff, erosion and weather conditions from pinyon-juniper areas of both types: one site is quite stable and has low erosion rates, and the other, by all appearances is eroding rapidly. The stable site (designated the LANL site, because it is within the borders of Los Alamos National Laboratory) has a well-established herbaceous component and shows little sign of accelerated erosion. The unstable site (designated the Bandelier site, because it lies within Bandelier National Monument) has a very different appearance. Understory vegetation cover is very low (<
there is abundant pedestalling and channeling, and the subsoil is exposed in many areas.

METHODS

LANL Site

Collection of data on runoff and erosion at this "stable" site began in 1987, with rainfall simulation studies that were part of the WEPP model-development effort (Simanton et al., 1991). Data collected from four 3- x 10-m plots were used to develop the default WEPP parameter values for pinyon-juniper woodlands. Two of the plots were completely denuded of all cover, including vegetation, litter and rocks, while the other two were left undisturbed. Rainfall simulation included a "dry run" during which water was applied at a rate of about 50 mm/hr for 45 minutes; a "wet run" 24 hours later again with rainfall intensities of around 50 mm/hr; and a "very wet run" 30 minutes later, during which rainfall was set and maintained at 50 mm/hr until runoff reached an equilibrium value, at which time rainfall was increased to 100 mm/hr. This rate was maintained also until runoff reached an equilibrium value, after which rainfall was returned to 50 mm/hr. This procedure was used for both the undisturbed and the bare plots (except towards the end of the very wet run, when additional water was applied to the bare plot only as overland flow). No overland flow was applied to the undisturbed plot.

We began to monitor naturally occurring runoff and erosion from all the plots in 1991 (Wilcox, 1994). The runoff was routed into steel tanks so that we could measure the volume of runoff and erosion. In 1994, we installed pressure transducers to record the
height of water in the tanks as well; this gave us information on peak flow and timing of
the event and provided a rough hydrograph. Fine-scale resolution of the hydrograph was
difficult because of turbulence created when water entered the tank. This was resolved in
1995, when the plots were fitted with small, fiberglass flumes. Sediment concentration
was determined from water samples collected from the steel tanks after each runoff event.
Because the “bare” plots had partially recovered by this time and were being filled in by
low successional grasses and forbs, we now refer to them as the “disturbed” plots.

In 1994 we also began monitoring runoff and erosion from a 400 m² hillslope
about 300 m east of the plots. Pinyon and juniper make up about 50% of the vegetation
cover. Understory vegetation is well established, and there are few signs of accelerated
erosion. Runoff is captured by a 12-m-long gutter placed perpendicular to the hillslope,
which routes it through a fiberglass flume. (A 4-in. flume was originally installed in
1994, but proved to be too small for larger events and was replaced with a 7-in flume.) If
personnel are on site during a storm, sediment concentrations are determined from hand
samples collected below the flume, otherwise we assume that sediment concentration is
the same as from the undisturbed plots.

**Bandelier Site**

At this “unstable” site, we are monitoring runoff and erosion from and within a 1-
ha catchment that exhibits all the signs of accelerated erosion (Figure 1). Pinyon and
juniper trees, spaced more or less evenly across the site, cover about half the catchment;
intercanopy patches are mostly bare ground or rock. In addition to the scant understory
vegetation and the extensive patches of bare ground, evidence of accelerated erosion includes numerous hillslope channels, soil pedestals, and exposed subsoil. Although channeling is extensive, the proximity of bedrock to the soil surface prevents the formation of gullies or deeply incised channels.

Individual runoff events from the catchment are measured by means of a flume installed in a bedrock-floored segment of the main channel. Following the design of Replogle et al. (1990), the flume is constructed from a 2-m-long piece of 38-cm PVC pipe. Concurrent with installation of the flume, a pit with a capacity of 0.4 m$^3$ was excavated immediately upstream of the flume to capture sediment being transported in the channel. We have found that this pit is sufficient only for small and moderate events; but because trying to trap all the sediment from the catchment is impractical, in 1994, we added four 1-m$^3$ sediment traps within the catchment; contributing area for each of which varies from about 300 to 1000 m$^2$ (Figure 1). On a smaller scale, we are also measuring runoff and erosion from a network of twelve 1-m$^2$ plots, having a range of cover conditions representative of the major cover types within the catchment. The plot network was completed in 1995.

Model simulations were performed for (1) the LANL plots (2) the LANL hillslope, and (3) the Bandelier hillslope, each of which is characterized by a particular set of conditions (parameter values for each condition are listed in Table 1). The soil and hydraulic parameters for all three were derived from rainfall simulation experiments conducted on the LANL plots. Other parameters such as slope, slope length, and
vegetation cover, were based upon site characteristics. The model was run using the single-storm option and breakpoint precipitation data.

RESULTS

LANL Plots - Rainfall Simulation Data

Measured data were compared with model simulations for an undisturbed plot and a bare plot for the wet and very wet runs of the experiment. With the exception of Ke, vegetation cover, and random roughness, parameter values were identical for the two plots (Table 1).

Modeled runoff closely matched measured runoff for both bare and undisturbed conditions, (Figure 2). Peak flow was, however, over predicted for the very wet run on the bare plot. With respect to erosion, the match between measured and modeled values was very good for bare conditions. For undisturbed conditions, however, modeled erosion was about ten times smaller than measured (Figure 2). This underprediction, in practice may not be important, given the low rates of natural erosion at this site. These results represent a “best fit”, since parameter values were derived from the data.

LANL Plots - Natural Rainfall Event

The model was next evaluated for how well it simulates erosion and runoff from the same plots in the wake of a natural rainstorm, some seven years later. The selected rainstorm occurred in August of 1994 and was typical of the high-intensity summer thunderstorms in the area (such storms are by far the most important agents of erosion in
these regions (Wilcox 1994). Precipitation from the storm totaled 26 mm, 20 of which
came in about 20 minutes (Figure 3). Peak rainfall intensity was close to 2 mm/min.

Measured and modeled runoff and erosion for the disturbed and undisturbed plots
are shown in Figure 3. Hydrographs for the storm were reconstructed from the water
heights, recorded by pressure transducers in the tanks (the potential problems with these
hydrographs, mentioned earlier, may account for their “spiked” appearance). But the fact
that the spikes in the two measured hydrographs generally match, and both follow the
pattern of rainfall, suggests that the hydrographs are roughly correct and are adequate for
evaluating how well WEPP predicted the timing and peak flow of runoff.

The models runoff predictions were better for the disturbed plot (timing and
volume of runoff correlated well with measured data, although peak flows were
underestimated) than for the undisturbed plot (the timing of runoff correlated well but
both volumes and peak flows were underestimated).

Erosion was underpredicted for both undisturbed and disturbed conditions,
especially the undisturbed. Again, given the low rates of erosion this underprediction
may not be important.

**LANL Hillslope - Natural Rainfall**

The model was next evaluated at a larger scale, using runoff data from the 400 m²
hillslope for the same rainstorm in August 1994 as evaluated above. The model was
parameterized using the same soil and hydraulic parameters (derived from the
undisturbed plot), but different vegetation and slope parameters, to reflect the differences
in vegetation and slope characteristics between the hillslope and the plot. The major
difference is that of tree cover: about 50% of the hillslope is covered by trees, whereas no
trees are present on the plot.

Results are presented in Figure 4. At the hillslope scale, the volume of runoff was
lower, per unit area, than at the plot scale (Figure 3)—reflecting both the increased
opportunity for storage with increasing slope length and, probably, the effect of tree
cover. Similarly, sediment loss was lower at the hillslope scale than at the plot scale.

The volume of runoff predicted by the model (7 mm) was quite close to that
measured (9 mm), but peak flow was underestimated, probably even more so than
indicated in Figure 4. The 4-in. flume that was in place at the time was undersized for
this event, and caused water to back up, so that measurements of flow were lower than
they otherwise would have been. With respect to erosion, WEPP predicted essentially
none, correlating rather well with the very low measured sediment loss (0.006 kg/m²).

Bandelier Hillslope - Natural Events

In predicting erosion from the entire 1-ha catchment, which has a well developed
channel network, the WEPP watershed version would be the appropriate model; but
because the scope of our investigation is limited to the WEPP hillslope model we use
erosion data from the small plots for evaluating the model erosion predictions. Modeled
runoff, however, is compared to runoff measured from the outlet, but only on a volume
basis.
Runoff prediction by WEPP was evaluated using nine events, that occurred from 1993 to 1995. Breakpoint precipitation data was used for each event, and the model was parameterized as shown in Table 1. We initially used a value of 6.4 mm/hr, derived from the rainfall simulation runs on the undisturbed plots, as a baseline hydraulic conductivity (Ke), but found that runoff was generally underpredicted. We then used a Ke value of 0.7 mm/hr, derived from the bare plot; runoff predictions were improved but slightly overpredicted (Figure 5a). We made no further attempt to optimize Ke.

The model’s erosion-prediction capability was evaluated using those five of the nine events for which plot-scale erosion data were available. (An average plot scale erosion was calculated as a weighted average using three categories: (1) canopy (50%) (2) intercanopy - tuff parent material (35%) and (3) intercanopy - pumice parent material (15 %)). The results are presented, again using two Ke values, in Figure 5b. As would be expected, plot-scale erosion was underpredicted for the “undisturbed” Ke value (6.4 mm/hr); the predictions yielded from the use of the “disturbed” Ke value were much closer to the measured plot-scale results. Erosion rates were, however, much higher for the subcatchments as shown in Figure 6, most assuredly because of channel erosion on the subcatchments. For the three storms in 1995 for which data are available, erosion was about 5 times higher from the subcatchments than from the small plots.

DISCUSSION AND CONCLUSIONS

These results are preliminary in that the model was evaluated for only a few storms at two locations. Several more years of data collection will be required to develop
a comprehensive data set on runoff and erosion from these two sites. Also the test represents a “best case”, at least for the stable hillslope, given that the stable hillslope site was the exact location from which the parameter values were developed. The limited evaluation here indicates that runoff and erosion on the stable site are somewhat underpredicted, but more detailed evaluations will be required to confirm this.

A more extensive evaluation of WEPP was accomplished on the unstable site. Runoff was greatly underpredicted when the default Ke was used. In WEPP, the Ke parameter input into the model represents a “baseline” value that is modified according to cover conditions. Even with the low cover input for the site, small amounts of runoff were predicted. We are assuming that prior to the current period of accelerated erosion, infiltration characteristics of the Bandelier soil were similar to that of the LANL site. Soils are quite similar at both sites. Runoff and erosion predictions at the plot scale were quite good when we used the Ke value developed from the “bare” plot simulations. However, when compared to erosion rates from the subcatchments, model predictions were low. The well-developed channel network apparently contributes greatly to total erosion.

These results are helpful in developing strategies for evaluating the impact of climate change to soil erosion. For example, a likely scenario to be evaluated is that of a dryer climate with much lower surface cover. One modeling strategy would be to keep all parameters the same as current conditions with the exception of surface cover. After all, WEPP internally modifies parameter values on the basis of cover conditions. Our results, however, suggest that under degraded conditions the baseline Ke should be
considerably lowered. Secondly, and perhaps most importantly, one should anticipate the
development of channels. The model will not automatically do so. Incorporation of
channels requires the use of the watershed version of WEPP. Our observations at
Bandelier suggest that the channel network that develops may be so dense that it may not
be feasible to model.

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Table 1. Key parameter values according to location.

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Figure 1. Location of study area including details of Bandelier Site.
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