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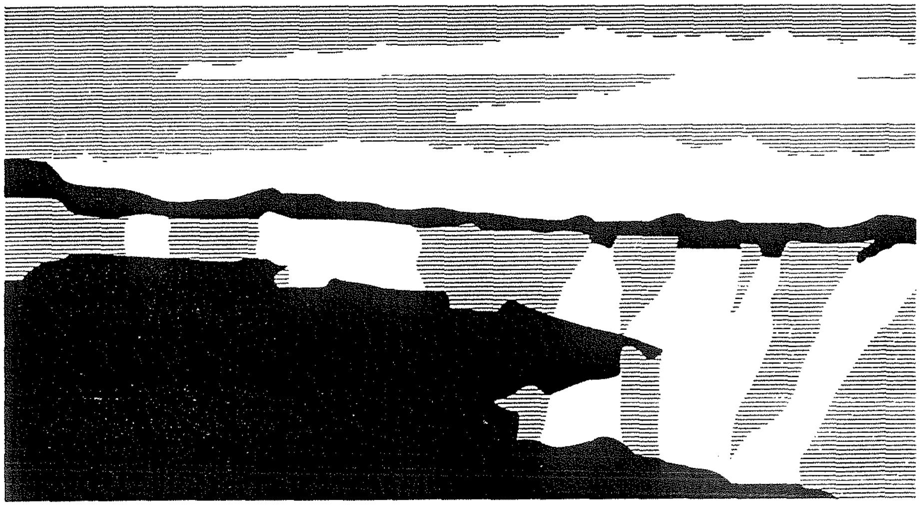

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PREDICTING RUNOFF IN SEMIARID WOODLANDS: EVALUATION OF THE WEPP MODEL

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Abstract

Dramatic environmental changes, either from changing climate or land use, or both, will strongly affect erosion processes in semiarid environments. Forecasting the extent and magnitude of these effects will require models: models in which we have some degree of confidence–or, at the very least, the limitations of which we fully understand. Validating these models, therefore, is critical. In this study, we evaluate the runoff prediction capabilities of the WEPP model, applied to a semiarid pinyon-juniper woodland of the southwestern United States. The model's parameters were drawn from detailed site characterization data, including data from rainfall simulation studies (the rainfall studies involved four 30-m^2 plots, two of which were disturbed, i.e., denuded of vegetation, and two were undisturbed; later, the four plots and a nearby 2000-m^2 hillslope were instrumented to gather data on naturally occurring runoff). WEPP was quite successful at simulating naturally occurring runoff from the disturbed plots, but underpredicted runoff from the undisturbed plots by nearly a factor of 3. This was a surprising result, given the quantity of detailed information from the plots used as input for the model. One possibility is that the hydraulic conductivity of the soil—which can vary over time depending on surface soil conditions and, perhaps, rainfall characteristics—was different during the studies of naturally occurring runoff than during the rainfall simulation experiments. With respect to runoff from the hillslope, WEPP's estimates were high; actual measured runoff was considerably lower than that from the plots, presumably because of the greater opportunity for storage and subsequent infiltration on the hillslope—a scale effect that the model's design does not take into account. These results point to the need for caution in applying models to scales significantly different from those for which their parameters were developed.

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 changes in vegetation, 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. Model validation studies are necessary to identify inherent model weaknesses and areas of uncertainty.

A new soil erosion model, WEPP (Water Erosion Prediction Project—Flanagan and Nearing, 1995) holds considerable promise as a tool for predicting the impact of environmental change on soil erosion. A process-oriented model based on fundamentals of hydrology and on soil erosion mechanics, WEPP was developed to allow extrapolation to a broad range of conditions. It is, therefore, ideally suited for predicting how climate change affects soil erosion. In this study, we evaluate one component of the WEPP model, the runoff component, for a semiarid woodland in the southwestern United States. Specifically, we evaluate runoff estimates by WEPP for a pinyon-juniper woodland at two scales: (1) the plot scale (30 m^2) and (2) the hillslope scale (2000 m^2).

Study Area and Methods

Pinyon-juniper woodlands represent an important vegetation type in the southwestern United States, where they cover 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; however, their expansion during the last century has been unprecedented and is almost certainly related to land-use 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 land-use-induced changes (both are components of global change) in semiarid landscapes (Miller and Wigand, 1994).

The data used for this model validation study were collected from a pinyon-juniper site on the Pajarito Plateau in northern New Mexico. It comprises four 30-m^2 plots and a 2000-m^2 hillslope having a well-established herbaceous component and showing little sign of accelerated erosion. This site is one of several in the western United States that were selected to provide data for developing baseline parameters for WEPP for U. S. rangelands (Simanton et al., 1991).

Data collection began in 1987, with detailed rainfall simulation studies on the plots; two of the plots were left undisturbed, whereas the other two were completely denuded of cover, including vegetation, litter, and rocks (the latter we now call the "disturbed" plots, because there has been regrowth of vegetation since 1987). 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 after the "wet run." For this last run, rainfall was maintained at 50 mm/hr until runoff reached an equilibrium value; rainfall was then increased to 100 mm/hr and again maintained until runoff reached an equilibrium value; at that point, rainfall was returned to 50 mm/hr. This procedure was used for both the disturbed and the undisturbed plots (except, towards the end of the very wet run, additional water was applied to the disturbed plots only, to simulate overland flow).In 1991, the four plots were instrumented for collection of naturally occurring runoff. At first, runoff was simply routed into steel tanks at the downslope end of the plots. In 1995, the collection system was upgraded with the addition of small fiberglass flumes that permit continual collection of runoff.

The hillslope experiment began in 1994, when we instrumented the 2000-m^2 pinyon-juniper hillslope for runoff collection. Because there are no permanent channel features on the hillslope, runoff is captured by a 12-m-long gutter installed perpendicular to the hillslope, which routes it through a fiberglass flume. Besides scale, the major difference between the hillslope and the plots is the vegetation cover. The plots are in an intercanopy area, whereas the hillslope encompasses both canopy and intercanopy areas. The canopy areas—pinyon and juniper—cover about 50 per cent of the hillslope; in the intercanopy areas, understory vegetation (mostly sod-forming grasses and semi-shrubs) is well established.

The hillslope version of WEPP (95.7) was used to estimate runoff from the plots and from the hillslope. For the plots, we modeled both the rainfall simulation events and a natural event; for the hillslope, we modeled a natural event. The key parameters used are listed in Table 1. The hydraulic conductivity parameter selected, which was derived from the rainfall simulation experiments conducted on the plots, was one-half the final infiltration rate of the very wet run.

Parameter	Undisturbed Plot	Disturbed Plot		Hillslope
		Natural event	Simulated event	
Ke* (mm/hr)	6.4	0.7	0.7	6.4
Antec. soil moisture (%)	60	60	60	60
Interrill basal cover (%)	22	13	0	53
Rill basal cover (%)	48	40	0	19
Canopy cover (%)	27	15	0	60
Random roughness (m)	0.01	0.007	0.005	0.01
Width (m)	3	3	3	12
Length (m)	10	10	10	40
Slope (%)	6	6	6	4
Sand (%)	50	50	50	50
Clay (%)	8	8	8	8
Organic matter (%)	1.4	1.4	1.4	1.4
CEC (meq/100 g)	7.2	7.2	7.2	7.2

* Ke = hydraulic conductivity

Table 1. Key parameter values by location.

Results

Phase I–Rainfall Simulation

Figure 1 shows the results of the WEPP runoff simulations for one of the undisturbed plots and one of the disturbed plots. The model was able to accurately mimic both the pattern of runoff and the volumes generated during the rainfall simulation experiments, with the exception of peak flow from the disturbed plot, which it overpredicted.

Phase II–Natural Rainfall at the Plot Scale

In a second phase, we evaluated WEPP's ability to estimate naturally occurring runoff. The event selected was a storm that occurred on September 8, 1995, and that produced 18 mm of rain in about 20 minutes. Antecedent soil moisture was high as a result of a smaller, more gentle rain (11 mm) the previous day. The parameters used for WEPP were the same as those used in the rainfall simulation model runs, except the vegetation cover parameter for the disturbed plots was modified to reflect the regrowth of vegetation that had taken place since the clearing of the plots 8 years earlier (Table 1).

The measured runoff for this event, for each of the four plots, is compared with the WEPP simulation in Figure 2. Runoff efficiency from all of the plots was quite high, ranging from 60 to 90 per cent; this is clearly because of the high antecedent soil moisture, as we have observed with other storms (Wilcox, 1994).

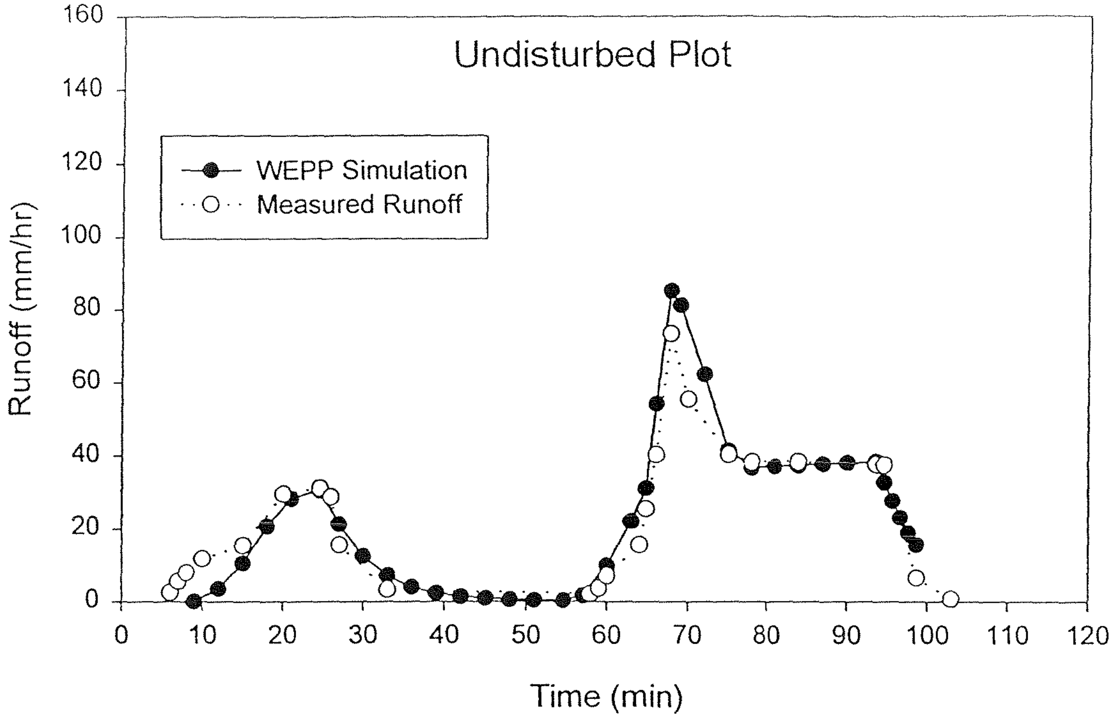
The results for the undisturbed plots were surprising: measured runoff volumes for the two plots were almost identical, but in both cases WEPP greatly underestimated the volumes (Figure 2a). In contrast, the two disturbed plots produced rather different volumes of runoff (we measured about 17 mm for one plot and about 11 mm for the other); in this case, the WEPP simulations were quite good, lying between the 17-mm and 11-mm hydrographs (Figure 2b).

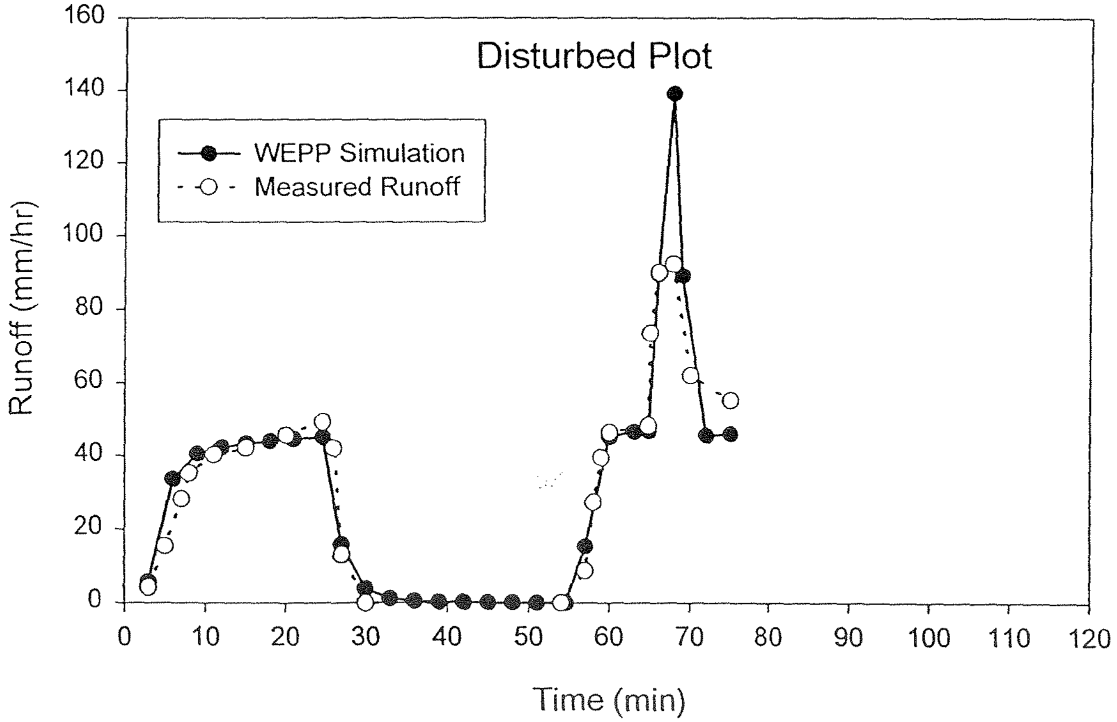
Phase III–Natural Rainfall at the Hillslope Scale

In the third phase of our evaluation, we consider runoff from the same storm at a larger scale: that of the 2000-m^2 hillslope adjacent to the plots. (We retained the hillslope version of the model for this phase, rather than use the watershed version, because no permanent channel features are evident on the hillslope.) Parameters for the model were based on site characteristics and data from the rainfall simulation experiments (Table 1): hydraulic conductivity was set at 6.4 mm/hr—the same as for the undisturbed plot—but vegetation-cover parameters were set higher, to reflect the presence of tree canopies over about half the hillslope.

Runoff from the hillslope, on a unit-area basis, was markedly lower than that from the plots. We estimate that less than 2 mm of runoff was produced from the hillslope, in contrast to the 11 - 17 mm from the plots. In other words, as scale increased from 30 to 2000 m^2, runoff

Figure 1. Measured vs. modeled runoff for rainfall simulation experiments conducted on the plots in 1987.





efficiency decreased from 60 per cent to less than 10 per cent. Two factors come into play as scale increases from plot to hillslope: (1) The presence of tree canopy areas, from which runoff is lower, reduces overall runoff volumes; and (2) as slope length increases, opportunities for storage and subsequent infiltration of water increase. At the same time, the overall dynamics of runoff from the hillslope were similar to those of the plots, even showing similar bimodal peaks (reflecting rainfall patterns) in the hydrograph. As would be expected, runoff from the hillslope was more prolonged than that from the plots.

In this case, the hydrograph produced by WEPP was very close to measured data only for peak flow. For both timing and volume of runoff, the match was poor; for runoff volume, the model's estimation was similar to that for the undisturbed plots (Figure 3). These poor results suggest that even for this relatively small hillslope, channel routing procedures—which are incorporated into the watershed version of WEPP—are needed to adequately allow for water movement on the hillslope.

Discussion and Conclusions

This validation study, although limited in scope, has been enlightening. The most surprising result was the model's inability to accurately estimate runoff for the undisturbed plots. Given the detailed characterization of the hydraulic characteristics of the soil using rainfall simulation, and the fact that these same plots provided base data for the development of the WEPP default parameters for pinyon-juniper woodlands, one would expect model simulations to have been better.

A possible explanation for the discrepancy between the results for the undisturbed plots and those for the disturbed plots is that hydraulic conductivity may have changed in the case of the former. Hydraulic conductivity is the key parameter for runoff prediction by WEPP, and our findings suggest that the hydraulic conductivity of the undisturbed plot was lower during the natural event than during the simulated event. The surface soils at the site are alternately loosened with the freezing/thawing cycles of spring and then recompacted by summer rains. It is possible that at the time of the rainfall simulation experiments, in the early summer, the soil was more permeable than during the natural runoff event, at the end of the summer. Another possibility is that soil hydraulic conductivity is affected by rainfall characteristics. This explanation is not completely satisfying, however, given that rainfall intensities during the natural event were well within the range of intensities applied during the rainfall simulation.

A second important result was the dramatic difference in per-unit-area runoff with scale: much less runoff was generated from the hillslope than from the plots, presumably because of increased opportunity for surface storage and subsequent infiltration. Because the surface conditions on the hillslope are similar to those on the undisturbed plots, the same hydraulic conductivity value was used in the model for both sites. The volume of runoff predicted for the hillslope, therefore, was about the same as that predicted for the undisturbed plot—which in this case constituted an overprediction. Perhaps it is because scale relationships are really poorly understood, particularly for semiarid environments, that the hillslope version of WEPP does not explicitly consider the effect of scale. This result, then, highlights the need for caution in applying a model to scales other than the scale to which it was calibrated, and the importance of understanding the general scale relationships in the environment to be modeled.

Figure 2. Measured vs modeled runoff from the undisturbed and disturbed plots for the storm on September 8, 1995.

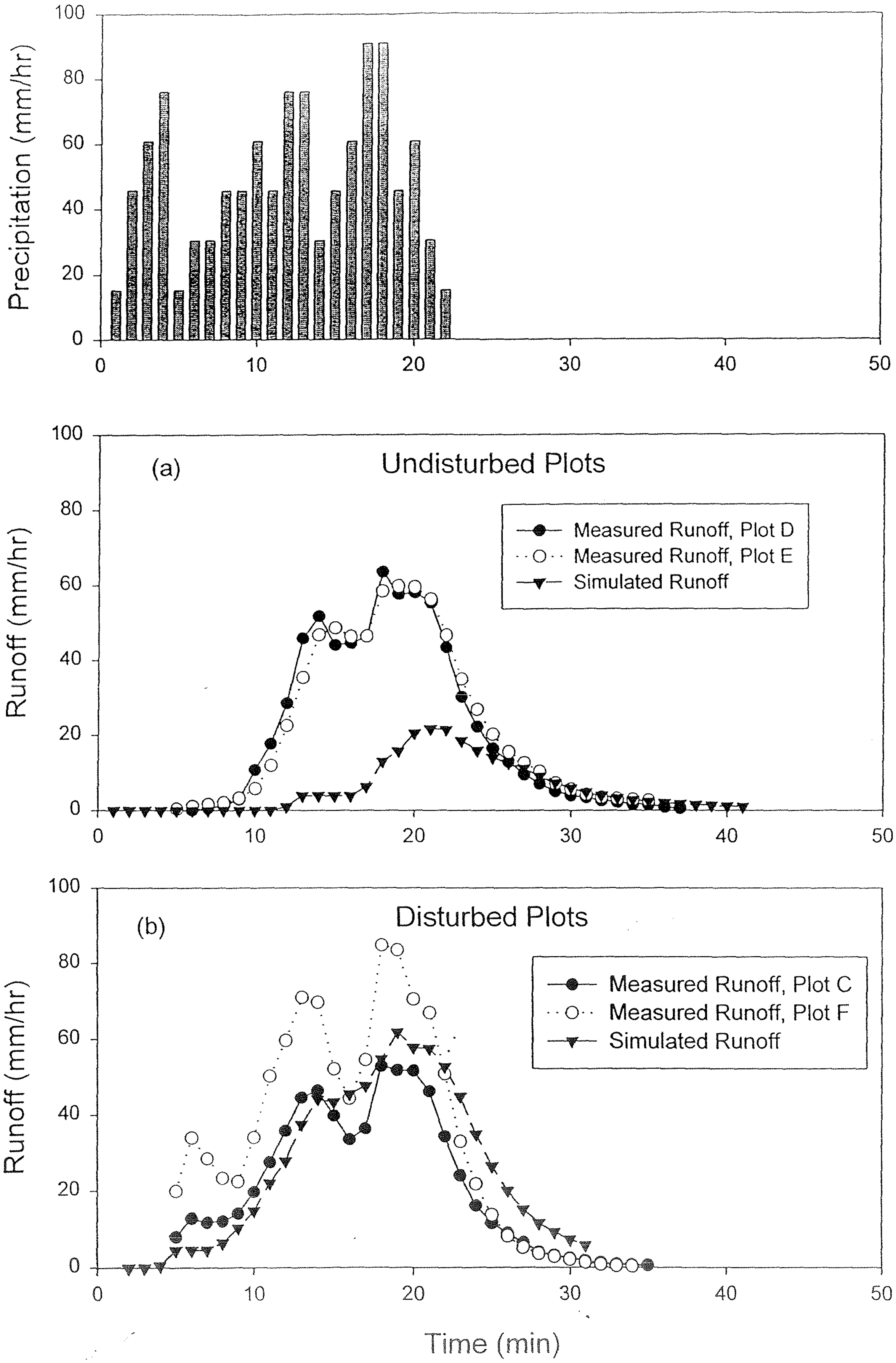
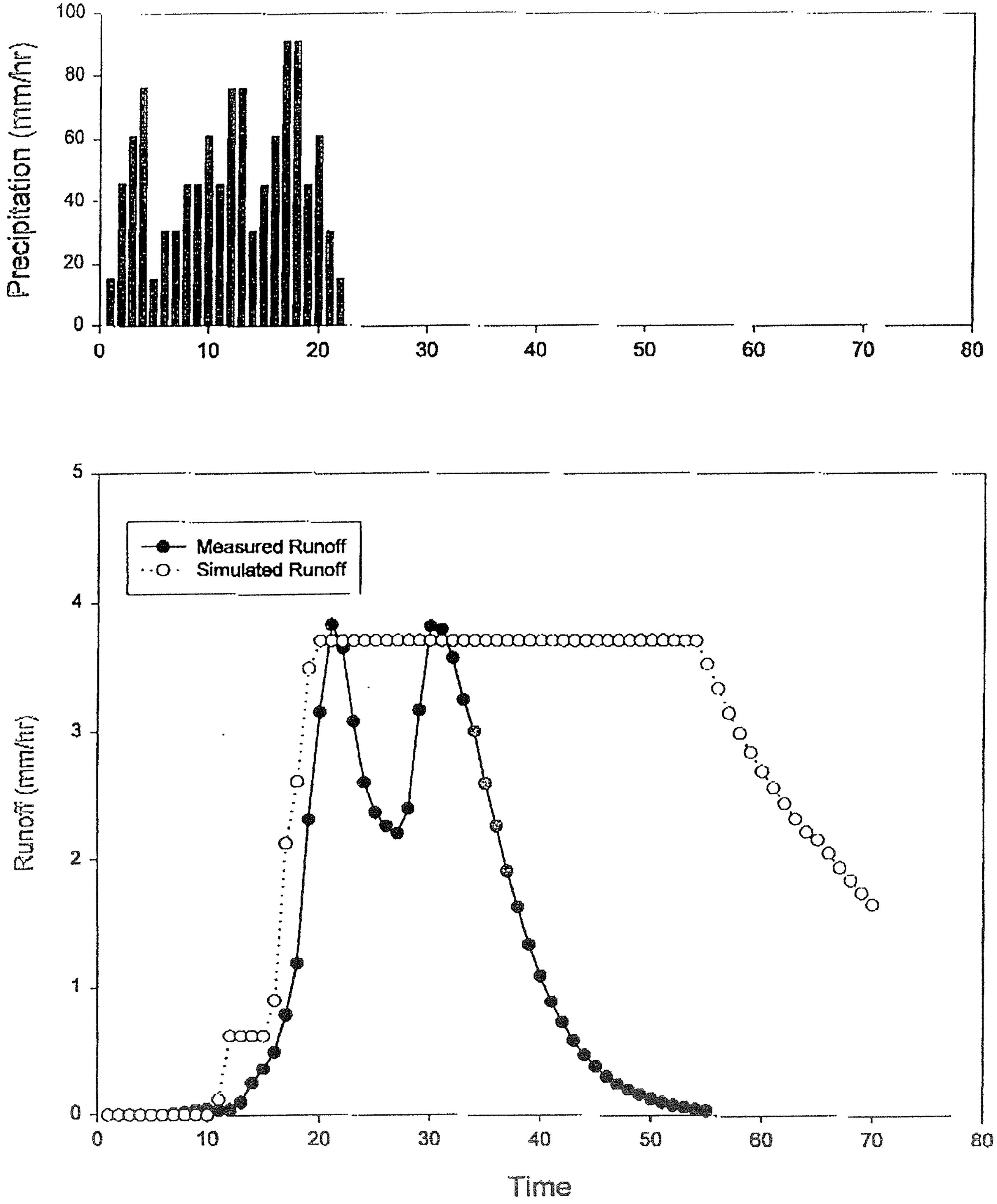


Figure 3. Measured vs modeled runoff from the hillslope for the storm on September 8, 1995.



The WEPP model, which incorporates significant advances over more mature, less flexible modeling technologies, represents the state-of-the-art in modeling the effects of changes in surface characteristics on soil erosion. Used with caution and a little skepticism, it can be a powerful tool—but as our study has shown, verification through field observations is critical.

Acknowledgments

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