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EFFECTS OF GLOBAL CLIMATE CHANGE ON EROSION STABILITY IN ARID ENVIRONMENTS USING WEPP

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ABSTRACT

The notion of climate change requires accompanying weather changes. In most arid situations the regimen of rainstorm depth, intensity and duration govern erosion and runoff patterns. Using the 10 percent overall level of increased rainfalls suggested by General Circulation Model outputs, three alternative forms of achieving this increase are synthesized, and their effects on erosion patterns and intermittent runoff are modeled. Forms of rainfall increases are 1) more events (same intensity patterns and event durations); 2) longer events (same intensity patterns and number of events); 3) higher intensities (same durations and number of events). These are stochastically generated as a part of climate simulation for 20 100-year periods, and used as input to model erosion and event runoff with WEPP (Water Erosion Prediction Project), a recently developed U.S. Department of Agriculture erosion simulation model. An erosion scenario using Tombstone, Arizona climate and a nearby watershed is evaluated. Increases in both runoff and erosion occur in all cases, but especially so when event intensities are modified upwards. The ability (or inability) of such models to mimic the interrelationships between soil properties, hydrology, erosion, and plant cover and growth are discussed, as are implications for future modelling efforts.

INTRODUCTION

Background: Most literature on global change stresses the long term and wide area effects on water supply and vegetation communities. For example, General Circulation Model (GCM) output is on the order of 200 miles square, and water resource modeling derived from it is often on a monthly time step. However, in most arid lands, the processes over smaller areas and shorter durations are important. Weather, in the form of rainstorm events, is the entire water input to the landscape, and is the sole source of water for runoff, erosion, soil moisture, and ground water recharge. This occurs in short durations over small areas, and is sensitive to such rainstorm event details as amount, intensity, and duration. These internal storm characteristics will govern how erosion and runoff patterns will be altered. This matter is almost entirely absent in global climate change concerns, and will be examined here.

Strategy: The recently developed Water Erosion Prediction Project (WEPP) model will be applied to a semiarid hillslope watershed, and the inputs so adjusted to reflect the possible different forms of rainfall delivery to meet an increased overall rainfall depth of 10%, a figure often suggested from GCM studies. The differences in model output will be taken to be the effects of the altered rainfall.

METHODS

WEPP: The basic tool used in this work was the hillslope version (90.92) of the Water Erosion Prediction Project (WEPP) model. This model is the product of a five year interagency development effort by the U.S. Department of Agriculture and other agencies, and has been described in considerable detail elsewhere (Lane and Nearing, 1989). In the interests of space economy, only a minimum of the necessary background will be supplied here.

The WEPP model simulates daily climate (weather) to drive the model's hydrology, erosion, and plant growth components. The hillslope version contains an overland flow hydrology component and erosion model. The hydrology component is driven by rainfall excess using the Green and Ampt equation, with adjustments in parameters for soil and cover properties. The erosion model computes erosion in interrill areas, and detachment, transport, and deposition in rill areas. Interrill erosion is modeled as particle detachment by raindrop impact and delivery to rills. The interrill detachment is proportional to the square of the rainfall intensity, incorporating parameters to account for the effects of ground cover, canopy cover, and soil erodibility (Lane and others, 1987). Rill erosion is modeled as detachment, transport and deposition by concentrated flow, and is based upon the flow's capacity to detach and transport soil particles, including the sediment delivery from the interrill areas. Net detachment occurs when hydraulic shear exceeds critical shear and when sediment load is less than transport capacity. Net deposition occurs when sediment load is greater than transport capacity (Lopes and others, 1989).

Location: The location chosen is the semiarid landscape in the vicinity of Tombstone, Arizona, the site of the Walnut Gulch Experimental Watershed, a long-term research facility for the study of arid land hydrology and erosion (Renard, 1970), operated by U.S. Department of Agriculture, Agricultural Research Service. This area is at the northwestern extreme of the Chihuahuan desert, which is typified by low rainfalls (ca 5-15 in/yr, or 130-140 mm/yr) with a bimodal seasonal distribution and shrub dominated plant communities.

Land: The land characteristics were excerpted from those of a specific small watershed, "Lucky Hills #103", which is 9.1 acres (3.68 ha) in size, and is located about 2 miles (3 km) northeast of Tombstone, Arizona, at an elevation of about 4500 ft (1372 m). A 100 meter long hillslope 50 m wide and with an S-shaped slope configuration with successive slope gradients of five, ten, and five percent was used, with no channel component. The soils are in the Stronghold series, a gravelly-cobbly sandy loam surface texture with an erosion pavement. The vegetation is dominated by creosotebush, whitethorn acacia, and tarbush. The canopy cover is 39%, and the ground cover is 78%, of which 70% is rocks above 2mm in diameter. The area has not been grazed for the past 20 years, but had prior long-term continuous grazing since the late 1800s. All these attributes of land and climate are representative of the general area (with the exception of the recent grazing exclusion), and their parameter representations were used in the WEPP erosion simulations.

Climate: Long term (20 year) data from Tombstone were used to estimate the parameters of the stochastic climate generator, "CLIGEN" (Nicks and Lane, 1989). Storm event characteristics are simulated through preservation of seasonal and monthly wet day - dry day characteristics, and - within a wet day - the duration, and intensity characteristics of the event. The long term average target rainfall was 294 mm/yr, or about 11.6 in/yr.

Climate Change: The study examined the effects of overall rainfall increases of 10 percent, a rough figure often suggested by GCM studies. This rainfall increase, assumed to be a manifestation of climate change, could occur in three separate forms in rainfall events: 1) 10 percent more storm events of the same duration and intensity patterns; 2) 10 percent longer storms, but of the same number and intensity, and 3) 10 percent more intense storms, but the same number and durations. It could also occur in combinations of the above, but these were not studied here.

Simulation of these three altered conditions was done by adjusting the descriptive statistical parameters in the WEPP climate generating routine. However, modeling the case of 10 percent more rainy days required changing the transition probabilities to produce 10 percent more wet days. This was done on both the dry-wet and wet-wet cases, and required multiplying them by the factor $(1+b)/[1-(Pr(W/D)-Pr(W/W)*b]$, where b is the fractional increase, here taken at 0.10. The transitions to dry days was merely subtracted in the transition matrix. Thus, the following overall procedure was used:

1. Generate the daily sequences with 10 percent more storms (wet days), using the above described adjustments to the transition probabilities. This is the "10 percent more storms case".

2. For the standard or base condition of NO climate change, delete the rainfall for every 11th wet day, thus leaving 100 percent of normal, or the "base" condition.

3. For the case of 10 percent higher intensities, use the data from condition 2 above, but merely multiply the simulated event depth by 1.10. The event duration is preserved, but the intensity is increased by 10 percent.

4. For the case of 10 percent longer storms, again use the data from condition 2 above, but multiply the simulated event depth *and* duration by 1.10. This preserves the intensity, and the storms are 10 percent longer in duration.

These specific procedures, which were chosen to preserve comparability between the data sets for each century, did create some compromises to reality. In the initial step (#1 above), the wet-dry day probabilities were adjusted uniformly throughout the year, thus ignoring any seasonal changes which might occur under a climate change, or differences for wet days or dry days. In step #2, making every 11th wet day a dry day fails to recapture the original population target transition probabilities. However, the total error is small, and was ignored here. Also, CLIGEN simulates only a single event per wet day, while in reality, multiple events do occur. In the Tombstone area the average is 1.75 events per wet day (Econopouly et al, 1990).

A total of 20 100-year sets were simulated for Case 1 (10 percent more storms). Conversion to Cases 2, 3, and 4 was done as described above within the WEPP model once individual data sets were read. The four cases were run in the WEPP model for the 20 sequences of 100 years each, a total of 80 scenarios.

RESULTS AND DISCUSSION

The results, greatly reduced, are given in summary form in the following table:

Table 1. Average annual values for the 20-100 year simulations.

Case	--------Rainfall---------		-------Runoff---------		Erosion
	Number of Events	Depth (mm)	Number of Events	Depth (mm)	(kg/ha)
Base	38.07	307.47	20.25	140.87	410.0
More	41.87	338.38	22.33	155.56	460.0
Longer	38.07	338.22	21.03	159.55	481.2
Intensity	38.07	338.22	21.69	165.42	529.4

According to the simulations, the increased rainfall did indeed increase the erosion rate. As shown in Table 1, the intensity case resulted in the greatest increases in erosion, amounting to an average of 29.1% over the base condition. Because the detachment portion of the erosion process (which makes the material available for transport by overland flow) is a function of the intensity squared, a potential increase on the order of 1.1^2-1.0 = 21% might be expected from this source process alone. The additional increase seen indicates the presence of other processes, specifically rill erosion, in this situation.

Figure 1 displays the general nature of the results, and shows the relationship with the base climatic conditions. The most benign form of rainfall increase is simply more storms (wet days), and this produces a basement effect of 10% increase in erosion as a minimum. Most impacts are non-linear with total rainfall depth.

This experience highlights some limitations of the WEPP model for this application. The model does not carry out a conservation-of-mass accounting on the soil profile, and thus does not mimic any hillslope evolution or soil armoring. The plant growth component does not carry over any long term changes: dynamics of cover and canopy apply only within a single year. Thus, it would not be possible to simulate the interacting effects of changing plant community on erosion with a climate of optimum erosion to verify the well-known

Langbein-Schumm (1958) relationship. As mentioned previously, the climate generating scheme produces only a single event per wet day.

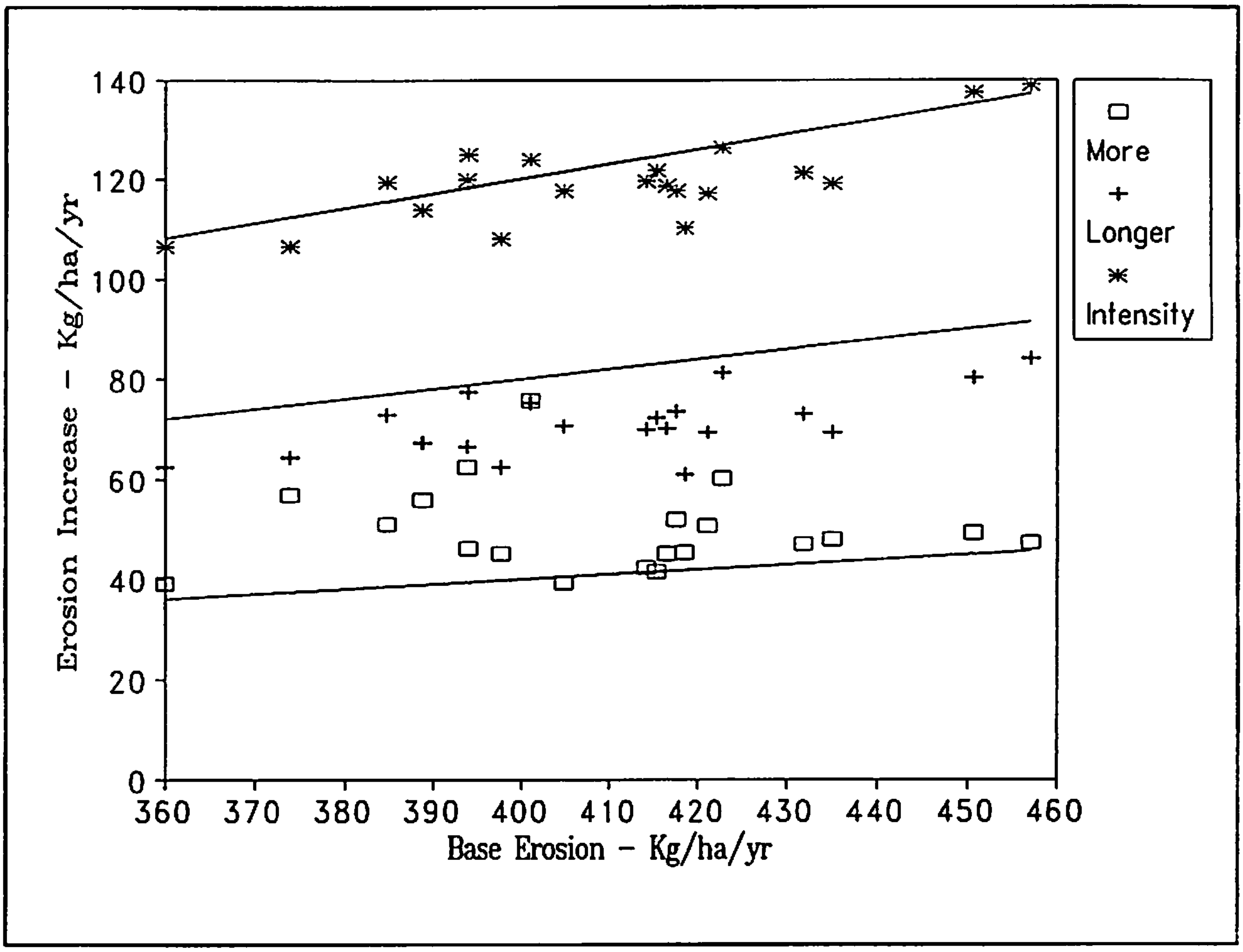

Figure 1. Simulated average erosion rates increases in Kg/ha/yr for centuries for three different scenarios of a 10 percent increase in rainfall at Tombstone, Arizona as a function of the base erosion rate. The three lines shown are, from bottom to top, 10, 20 and 30 percent erosion increases from the base condition.

The simulations for the Walnut Gulch case presented some specific difficulties. The simulated runoff is much higher than that actually experienced at similar sites in the Walnut Gulch area. Analyses of on-site gage records indicates about 25 mm/yr might be expected for these conditions, with an accompanying erosion of about 0.61 Tons/acre/yr, or 1365 Kilograms/hectare/year (Simanton et al, 1980). As shown in Table 1, the model gave about 141 mm/yr and 410 Kg/ha/yr respectively. Post-simulation analysis suggests that a source of these aberrations might be in the accounting for the effects of soil surface and profile rock content on infiltration properties, and in specific limitations in the weather generating routines. These experiences give a basis for enhancing future versions of WEPP.

The work here suggests several possible variations. The effects of seasonal distribution of additional rainfalls might be an avenue of fruitful inquiry, insofar as the summer storms are the more intense and productive of erosion episodes. Assessing the climate change effects on larger drainages which include more substantial channel processes would be an obvious extension of the work here. Also, an important consideration in this area is the regional groundwater recharge, which occurs almost entirely from these intermittent events, but which occurs almost entirely the larger downstream channels not considered here.

A general conclusion from this study is that these simulation techniques are useful within the acknowledged limits of the model. Erosion variation can be expected to be non-linear with increased rainfall in any form. Simply having more storms of the same characteristics will create the minimum effect. More intense storms will create the maximum effect, and longer storms will produce an intermediate effect. From this experience, it might also be expected that rainfall decreases would produce similar negative responses.

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