

## Comment on "Physically based hydrologic modeling, 1, A terrain-based model for investigative purposes" by R. B. Grayson, I. D. Moore, and T. A. McMahon

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*Grayson et al.* [1992a] are to be commended for applying their model (THALES) to catchments with different dominant hydrologic responses. Only by careful testing with high-quality experimental data can we determine if something is seriously wrong with our models and thus can improve them.

First we wish to elaborate on the issue of heterogeneity and its impacts on runoff simulation. Results of several other studies conducted in the Lucky Hills (LH) watersheds indicate that spatial rainfall heterogeneity has a significant impact on runoff simulation. Other sources of watershed heterogeneity were discussed at length by *Grayson et al.* [1992a, b] (also see *Smith et al.* [this issue]), who specifically emphasize the importance of temporal rainfall model input resolution [*Grayson et al.*, 1992a, p. 2643]. However, they were unable to examine rainfall spatial variability, as only one rain gage was available for their analysis.

On the same watersheds, *Goodrich* [1990] found significant differences in rainfall amounts and intensities from an additional rain gage less than 300 m from the rain gage used by *Grayson et al.* In Figure 11 of *Grayson et al.* [1992a, p. 2647] and the accompanying discussion they point out that LH106 runoff rate is greater than the maximum observed rainfall intensity and note possible insufficient rain gage temporal resolution. The same storm sequence is plotted with the hyetograph from both rain gages used by *Goodrich* [1990] and the observed LH106 hydrograph (Figure 1). This figure illustrates that the maximum intensity of rain gage 384 is, in fact, greater than the maximum observed runoff rate at the LH106 outlet, indicating that spatial as well as temporal rainfall heterogeneity is a primary factor in runoff generation.

Typically, for length scales of the order of 300 m, rainfall is considered spatially uniform. However, the observations presented in Figure 1 indicate otherwise. This led *Goodrich* [1990] to develop a space-time rainfall interpolation scheme to utilize multiple rain gage information. This significantly improved model performance for Lucky Hills runoff simulations over the single-rain gage case. This might also explain why better simulation results by *Grayson et al.* [1992a] are obtained on LH102 (Figure 14, p. 2648), as this catchment is closest to the rain gage utilized in their analysis. *Goodrich et al.* [1993] also found that the impacts of rainfall

representation on runoff simulations far outweigh the effects of detailed versus simple topographic watershed representation. This indicates that watershed representation by a great number of model elements cannot overcome errors introduced by poor definition of the rainfall field.

These results led to a subsequent detailed small-scale rainfall-runoff study by *Faurès* [1990] which confirmed significant spatial variability of rainfall within the Lucky Hills watersheds, which in turn had a significant impact on runoff simulations. *Faurès* [1990] concluded that in order to obtain useful runoff simulation results at the scale of 4.4 ha it is necessary to define the rainfall variability on a comparable scale for thunderstorm-dominated rainfall environments. In other words, the single-rain gage, uniform spatial rainfall assumption was found to be invalid, even at this small scale in Lucky Hills. Therefore model performance expectations should reflect the uncertainty in the knowledge of input rainfall variability. The authors of this discussion are not familiar with the rainfall regime in the Wagga Wagga catchment, but *Grayson et al.* [1992a] stated that the rain gage used in their analyses was roughly 500 m north of the catchment. The assumption of rainfall uniformity should also be tested in this region.

*Grayson et al.* used initial values of soil hydraulic parameters based on those obtained by *Goodrich* [1990]. However, they failed to note that the mean saturated conductivity,  $K_s$ , shown in equation (2) was obtained by optimization over a set of 10 events and the model, KINEROSR (a research version of KINEROS [*Woolhiser et al.*, 1990]), accounts for small-scale spatial variability of  $K_s$  in a distribution sense that is not duplicated in THALES (but conceptually could be). The method assumes  $K_s$  is lognormally distributed within an overland flow element which requires the additional input of the coefficient of variation (CV) of  $K_s$  for each overland element [*Woolhiser and Goodrich*, 1988]. As the range of variation for CV is typically much smaller than in  $K_s$  [*Ahuja et al.*, 1984; *Nielsen et al.*, 1973], CV parameter selection is relatively straightforward. This conceptually allows the treatment of infiltration variability on the scale of meters that will never realistically be obtained by basin discretization. In *Goodrich's* [1990] study the event modeled by *Grayson et al.* was treated as two events; the first portion was in the verification set and the second was in the calibration set. The fact that THALES underestimated the volume and peak rates of runoff as shown in Figure 12 should be expected since it did not account for the small-scale variability of  $K_s$ . The authors characterize this fit as "poor." Considering that spatial variability of rainfall was not ac-

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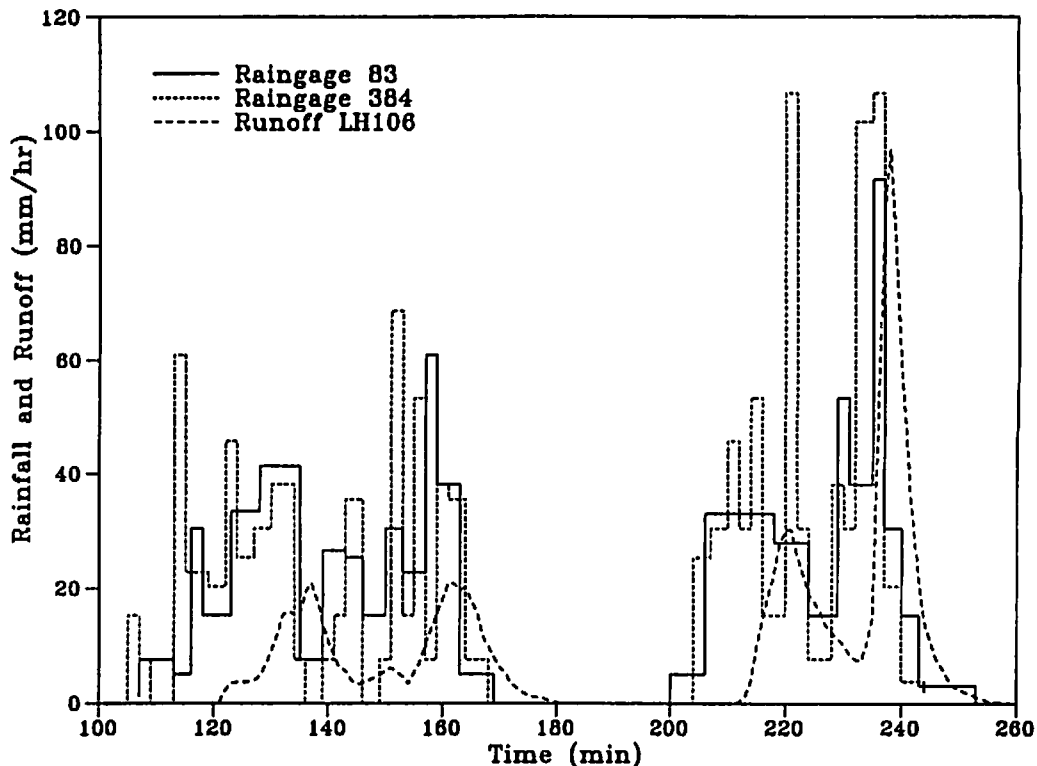


Figure 1. Hyetographs from rain gages roughly 300 m apart and observed runoff from LH106 for event of September 26, 1977.

counted for and that there are structural differences between the models we would characterize this as a rather good fit.

There is also a danger in drawing too many conclusions from detailed analysis of a very limited set of runoff events used by Grayson *et al.* [1992a]. They stated that testing two catchments does not attest to universal applicability (p. 2661). We would also add that model testing using a very small number of events in a catchment results in a very limited evaluation and does not confirm the applicability of the model to that catchment. To insure model robustness, model performance over a range of runoff events must be examined. This is alluded to by the authors on page 2648.

Grayson *et al.*, and others before them, have emphasized that models such as THALES should use parameters measured in the field or should use published values. It is well known that infiltration parameters estimated from soil texture contain a great deal of uncertainty. In our studies we treat them only as starting values. We, and others, have also found that field measurements of infiltration are also often unreliable because of instrument limitations as well as spatial variability of soils and cover.

We are puzzled by the results of changing the channel network for LH106 as shown in Figure 20 (p. 2652). Although it is difficult to tell from Figure 9 (p. 2646), it appears that the original channel area was approximately 10% of the area of LH106 and the extended channel area may be about 20%. A visual estimate from Figure 20 suggests that the runoff volume is nearly doubled by extending the channel area. It is difficult to rationalize this result given the rainfall rates and the fact that the ratio of  $K_s$  in the channel to that on the uplands is 0.7.

We appreciate the authors' concern regarding the use and

interpretation of flow depths and velocities from the hydrologic model to calculate erosion, deposition, and sediment transport. They stated that surface flow in nonchannel areas could be represented as either sheet or rill flow but neither would be physically correct. We agree, but offer as a third alternative that the depth be considered as having a probability distribution with a positive mass on zero to account for surface microtopography and variation in infiltration rates. In this approach the routed quantity is still the mean depth. This approach is supported by some field measurements in a rangeland environment [Abrahams *et al.*, 1989], but fitted parameters are likely to be dependent on the ratio of computational scale to watershed scale.

Finally, we wish to clarify several minor points regarding the Walnut Gulch subwatersheds discussed by Grayson *et al.* [1992a]. The Lucky Hills watersheds are located in the north central portion rather than in the western end of the Walnut Gulch experimental watershed, and the bedrock in this area is not at a shallow depth as stated in the paper.

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