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PRELIMINARY RUNOFF SIMULATION SENSITIVITY TO VARIOUS MEASURES OF INITIAL SOIL WATER CONTENT

D.C. Goodrich[a], L.B. Bach[a], M.A. Weltz[a], T.J. Jackson[b], T.J. Schmugge[b],
T.O. Keefer[a], S.A. Amer[a], and C.L. Unkrich[a]

[a] U.S. Department of Agriculture (USDA),
Agricultural Research Service (ARS),
Aridland Watershed Management Research Unit, Tucson, AZ, 85716
[b] USDA-ARS, Hydrology Laboratory, Beltsville, MD

1. INTRODUCTION

Pre-storm initial soil water content is an important variable required for simulating runoff in an event based rainfall-runoff model employing a physically based infiltration algorithm. A variety of ground and remotely sensed water content measurements were obtained at, or adjacent to, a small (4.6 ha) semiarid, brush dominated watershed (Lucky Hills-104), by the USDA-ARS Aridland Watershed Management Research Unit and USDA-ARS Hydrology Lab as part of the multi-disciplinary MONSOON '90 experiment (Kustas et al., 1991). The experiment was conducted during the summer of 1990 in the USDA-ARS Walnut Gulch Watershed near Tombstone, Arizona. A general description of the Walnut Gulch Experimental Watershed is given by Renard (1970). The objective of this investigation is to assess the impact of using a limited set of initial water content estimates obtained from a variety of methods on rainfall-runoff computations. In addition, the variability of computed runoff quantities due to the different water content estimates will be compared to the variability induced by different estimates of measured storm rainfall.

2. THE RAINFALL-RUNOFF MODEL (KINEROS)

A research version of a physical, distributed, event based rainfall-runoff model (KINEROS) is used in this investigation (Woolhiser, et al., 1990). Because the model does not have an interstorm component, an estimate of the pre-storm initial water content is required. The infiltration component of the model is based on the Smith and Parlange (1978) simplification of the Richards equation. In this formulation the suction term of the infiltration component is explicitly dependent upon the initial, pre-storm water content. Significant sensitivity of the model runoff predictions to initial water content conditions was demonstrated by Goodrich (1990).

Goodrich (1990) also calibrated and verified the KINEROS model on the Lucky Hills-104 (LH-104) watershed using observed rainfall and runoff data from 1973-77 using two recording raingages. The same calibrated input files describing the watershed geometry, soils and hydraulic roughness are used in this investigation. However, it should be pointed out that since the calibration-verification time frame (1973-77), a raingage has been moved, the LH-104 runoff measuring structure has been changed (1978), and brush to grass management manipulations have occurred on a portion of the watershed (approximately 1.8 ha, 1981 and 1984). Recalibration has not been undertaken because management effects have induced a nonstationary period of watershed conditions. In addition, initial water content was computed from a simple daily water balance model to calibrate KINEROS during the 1973-77 time frame.

3. APPROACH

During the MONSOON '90 field campaign, water content, rainfall and runoff were intensively monitored on the LH-104 watershed from roughly July 23 to Aug. 15. As part of the investigation, the small scale spatial variability of rainfall in LH-104 was also monitored using five recording raingages and 50 non-recording raingages (Faures, 1990). Runoff was measured at the outlet of the watershed by a calibrated Smith supercritical flume.

Pre-storm initial water content was measured by three ground based methods and two remotely sensed methods. The ground based methods were: 1) gravimetric water content, converted to volumetric water content using bulk density measurements; 2) Time Domain Reflectometry (TDR) (Topp et al., 1980; Zegelin et al., 1989); and 3) porous electrical resistance sensors (ERS) (Coleman and Hendrix, 1949). The gravimetric data (surface 5 cm, 3 repetitions, roughly 0.3 m apart) was collected daily at approximately 9:30 a.m. adjacent to an automated meteorological (MET) station located approximately 190 m NNE of the centroid of watershed LH-104.

The TDR data was collected daily at approximately 9 a.m. at five locations adjacent to recording raingages within the LH-104 watershed separated by an average distance of 130 m. An average value of these five readings was used as a measure of pre-storm water content. The probes were 15 cm in length, and were installed vertically from the surface to provide integrated water content over the top 15 cm of soil. In-situ calibration was performed to develop a relationship between the TDR readings and volumetric water content.

The electrical resistance sensors were monitored every 20 minutes throughout the measurement period using a data-logger located at the automated MET station. The recorded resistance readings were converted to volumetric water content using laboratory calibration curves determined on soils obtained from the field site, along with in-situ bulk density measurements. Three sensors were placed at 2.5 cm, roughly 0.5 m apart, and two at 5 cm, roughly 0.5 m apart, and the average value of all five sensors was used for modeling pre-storm water content.

Remotely sensed estimates of water content were obtained from two instruments flown in fixed wing aircraft. For both instruments the soil brightness temperature was sensed and, after instrument verification, the surface water content was predicted using algorithms developed by the Institute of Radioengineering and Electronics (IRE) of the Academy of Sciences of the USSR, and USDA.

The first instrument was a multifrequency radiometer system (2.3, 21 and 27 cm wavelengths) provided by the IRE (Jackson et al., 1991; Mkrtchjan et al., 1988). At the altitude flown (~ 150 m), this instrument provided an estimate of water content over a spot which is approximately 105 meters in diameter. The water content estimate which was centered over the MET station adjacent to LH-104 was used for this study.

The second instrument was a pushbroom microwave radiometer (PBMR, 21 cm wavelengths) operated by NASA (Jackson et al., 1991). Multiple flight lines were flown with this instrument so areal estimates of water content on the LH-104 watershed were obtained. Thirty-four PBMR pixels were extracted from the overflight data covering LH-104. Since the majority of the methods used to measure water content were point measures, the thirty-four PBMR pixels were averaged to obtain a single value of water content for the LH-104 watershed. The effects of the spatial distribution of initial water content on runoff will be the subject of a future investigation. The frequency of remotely sensed measurements was dependent upon aircraft availability, therefore temporal coverage during the experiment was not as extensive as the ground based methods, which were obtained at least daily. Table 1 contains the acquisition dates, times and volumetric water content (VWC) estimates for both the IRE and PBMR instruments.

Three rainfall events, which caused runoff, were observed during the field campaign with nearly simultaneous soil-water content measurements. Table 2 contains the dates, times, average total rainfall depths based on the five recording raingages (PPT.), total observed runoff volume (V.) and observed peak runoff rate (Qp). Because of the stochastic nature of the storm arrival time, the infrequent gravimetric, TDR, PBMR, and IRE water content measurements must be adjusted to obtain values at the beginning of the storm. Since the electrical resistance sensor measurements were recorded every 20 minutes, the nearest point in time to storm onset was used, and no drying time adjustments were required. To perform the adjustment, daily TDR data at nine raingage locations were analyzed during periods of drying to obtain an exponential decay function (Faures, 1990). The procedure also accounted for any intervening rain between measurement time and storm onset. However, it should be noted that very little intervening rainfall occurred. For the August 1 storm approximately 1 mm of intervening precipitation occurred, resulting in an adjustment to the initial water content of roughly 0.55 to 0.87 percent. For the August 12 event 2.3 mm of intervening rainfall occurred between the last IRE measurement and the storm, resulting in a 1.4 percent increase in water content.

Table 1: Remotely Sensed Water Content and Acquisition Dates and Times

Date	IRE Time	IRE VWC(%)	PBMR Time	PBMR VWC(%)
July 30	--	--	1030	5.1
Aug. 1	--	--	--	--
Aug. 2	0830	13.7	0915	13.4
Aug. 3	0830	11.4	--	--
Aug. 4	0830	14.0	0830	14.0
Aug. 5	0830	10.6	1000	9.0
Aug. 6	--	--	--	--
Aug. 7	--	--	--	--
Aug. 8	--	--	0900	8.2
Aug. 9	--	--	0900	6.2

Table 2: Lucky Hills-104 Runoff Events During the MONSOON '90 Campaign.

Date	Time	PPT. (mm)	V. (mm)	Qp (mm/hr)
Aug. 1	1515	12.1	0.04	0.34
Aug. 3	2040	13.3	3.5	17.5
Aug. 12	0155	51.6	15.4	46.5

Although a single spatial average of initial relative water content (SI = volumetric water content divided by porosity) was used for model input, all of the methods except the IRE provided repetitive measurements or measurements at additional locations within LH-104. The range and average SI from all five methods for each storm event (if available) are plotted in Figure 1 at measurement acquisition time (prior to drying time adjustment). The range of variability of the SI measurements by each method are illustrated in this figure.

The variability is typically a function of the spatial separation of measurements and measurement error. For example the gravimetric and TDR measurements were separated by approximately 0.3 m and 130 m, respectively. In addition, the spot diameter of the IRE is approximately 105 m (roughly 8700 m^2). Similarly, the spot diameter of the PBMR at the flying altitude (~400 m) used is approximately 180 m. Due to the rapid data sampling rates of the PBMR, the plane does not move a full 180 m before acquiring the next set of data. A great deal of pixel overlap therefore exists. This is why 34 pixel samples are obtained in the relatively small LH-104 watershed. This contributes to the relatively small range of SI values for the PBMR data. In addition, these large-scale, remotely-sensed spot samples integrate and average the relative water content over the small scale heterogeneities caused by microtopography as well as textural and vegetation variation.

In contrast to the large scale measurements, the ground based methods (gravimetric, ERS and TDR) sample a very small volume of soil (on the order of 100-300 cm^3). Even if the IRE instrument has an effective penetration depth of 0.5 mm the spot sample will effectively sample a volume of soil roughly equal to 4.3 x 10^6 cm^3. The ground based sampling methods are therefore much more likely to sample very small scale water content variations induced by the factors mentioned above.

The average pre-storm SI value for each method was input into KINEROS to assess the induced variability in computed runoff. To assess the relative magnitude of this induced variability, computer simulations were also conducted using different representations of the rainfall model input. Simulations were made using the average SI values for each water content method (corresponding to SI values plotted as circles in Figure 1) with the five recording raingages used by Faures (1990) and with a single raingage adjacent to LH-104. The research version of KINEROS used in this study employs a first order space-time rainfall interpolation scheme described by Goodrich (1990) to treat multiple raingages. If a single raingage is used, the rainfall field is considered uniform in space over the entire watershed.

4. RESULTS AND DISCUSSION

Results from the simulations described above are summarized in Table 3. It should be noted that the event on August 1 is very small and the total runoff volume on a per unit area basis is smaller than the measuring resolution of the recording raingages. In this situation, instrument, data reduction and observation errors are often a large part of the overall output signal and may dominate model response as measured by runoff quantities. Normally, an event whose runoff volume is smaller than the raingage measuring resolution is discarded for

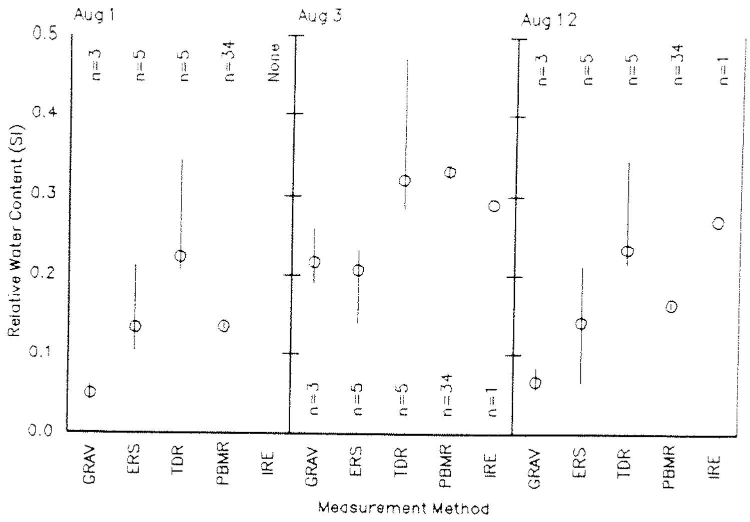

Figure 1. Average and range of SI by method for each storm event.

runoff simulation analysis, but is included here because of the small number of events occurring during the intensive field campaign.

From Table 3 it is apparent that the model has a tendency to under predict the small event on August 1 and over predict the large event of August 12. Previous comments regarding the model calibration and verification period and the subsequent watershed changes should be considered when comparing simulated to observed runoff data. In this investigation, the focus is on the variability induced in runoff simulations due to the variation in soil water content measuring method and changes in rainfall representation.

The variability in runoff volume and peak runoff rate induced by changes in relative soil water content measurement methods appear to be on the same order or smaller than those induced by changing the raingages from five to one. To separate the effects of SI measurement method and rainfall representation more clearly, additional simulations were done holding the water content measuring method constant (TDR) and varying the model rainfall input by using each of the five recording raingages individually for model input. This is contrasted with data from the simulation presented in Table 3 for the 5 raingage case in which the rainfall representation is held constant and the SI method changes. TDR measurements were selected for the case in which rainfall representation varied since the TDR sampling scheme provided the highest spatial and temporal sampling frequency within LH-104. Figure 2 graphically summarizes these simulations. In this figure, the two minute peak rainfall intensity is used as a surrogate measure of rainfall variability between raingages. This is an appropriate measure, as rainfall intensity largely controls runoff generation in the semi-arid environment of LH-104.

Table 3: Rainfall-Runoff Model Simulation Summary

Water Content Method		August 1, 1990			August 3, 1990			August 12, 1990		
		SI	V. (mm)	Qp (mm/hr)	SI	V. (mm)	Qp (mm/hr)	SI	V. (mm)	Qp (mm/hr)
GRAV	5 gages	.05	.01	.03	.22	2.2	10.8	.06	18.1	58.7
	1 gage		.02	.05		2.7	17.0		19.4	61.5
ERS	5 gages	.13	.02	.05	.21	2.2	10.4	.14	18.8	60.3
	1 gage		.03	.10		2.6	16.5		20.1	63.3
TDR	5 gages	.22	.04	.10	.31	2.6	12.8	.22	19.5	61.9
	1 gage		.05	.18		3.1	19.6		20.9	65.4
PBMR	5 gages	.12	.02	.05	.32	2.7	13.0	.13	18.7	60.0
	1 gage		.03	.09		3.2	20.0		20.0	63.1
IRE	5 gages	...	...	...	.29	2.5	12.3	.20	19.1	61.5
	1 gage		...	...		3.0	19.1		20.7	64.8

The variability of SI and rainfall intensity should not be compared directly (incompatible measures), but can be interpreted via the variability of model outputs. In the middle two regions of Figure 2, the variability in runoff volume and peak rate in response to changes in the SI method and changes in the rainfall representation, are plotted side by side for each of the three runoff events. This figure more clearly illustrates that the spatial variation in rainfall induces larger variations in runoff characteristics than the different SI measurement methods.

5. CONCLUSIONS

Conclusions regarding the analysis described in this investigation must be considered in the context of the small number of events considered and the scale of the watershed in relation to the relative water content measurement method. When using an average value of SI for input into LH-104 simulations, there appears to be little difference among the SI measurement methods as indicated by the variation in computed runoff volume and peak rate, when contrasted to the variations due to rainfall variability. If an average SI value is desired for runoff modeling it could be reasonably obtained by any of the methods used in the study, however, adequate resources should be devoted

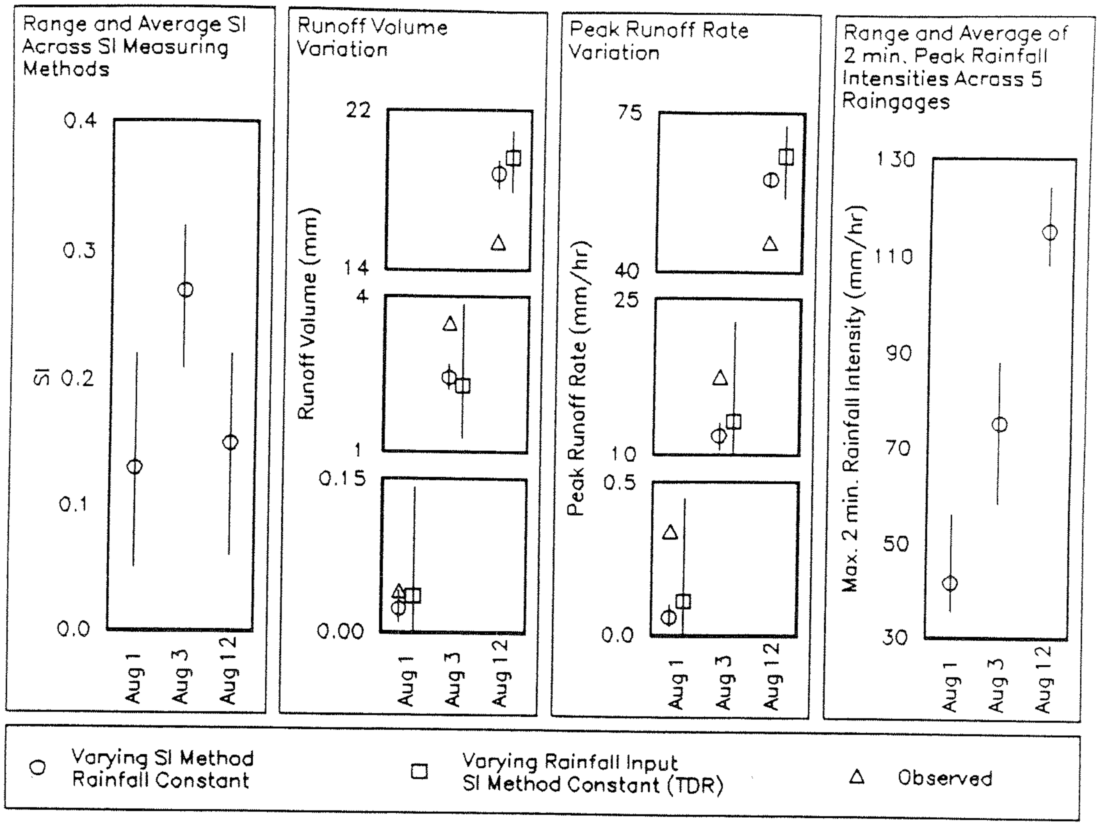

Figure 2. Variation in runoff volume and peak rate due to SI variability and rainfall variability.

for runoff modeling it could be reasonably obtained by any of the methods used in the study, however, adequate resources should be devoted to definition of spatial rainfall variability. This does not imply that a superior SI method will not be deduced if small scale spatial variability of SI, practically obtainable only by distributed ground based methods at the scale of LH-104, is used for runoff modeling input. This issue is the subject of ongoing research.

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