Plot-Scale Rainfall-Runoff Characteristics and Modeling at Six Sites in Australia and Southeast Asia

B. Yu, C. W. Rose, K. J. Coughlan, B. Fentie

Abstract. *During major runoff events when most soil loss occurs, runoff is likely to dominate the rainfall-driven erosion processes. Thus accurate estimation of the runoff rate is critical to soil loss predictions. At plot scale, the Green-Ampt infiltration model is commonly assumed to be able to describe the temporal variation of the infiltration rate over a storm event. Field measurements of both rainfall intensity and runoff rate at 1-min intervals at six sites in the tropical and sub-tropical regions of Australia and Southeast Asia, however, strongly suggest that the apparent infiltration rate is closely related to the rainfall intensity and it is essentially independent of the cumulative infiltration amount, features not accord with the Green-Ampt infiltration equation. Furthermore, the storage effect and runoff rate attenuation are not negligible at the plot scale. With an initial infiltration amount to determine when runoff begins, an exponential distribution to describe the spatial variation in the maximum infiltration rate and a linear storage formulation to model the lag between runoff and rainfall, we were able to develop a satisfactory three-parameter model for the runoff rate at 1-min intervals within a storm event.* **Keywords.** *Infiltration variability, Runoff, Erosion.*

Surface runoff plays a critical role in determining the rate of soil loss from agricultural lands. This is especially the case during large events with high streampower (Proffitt and Rose, 1991). In the USLE (Wischmeier and Smith, 1978), the effect of rainfall and runoff is encapsulated in a rainfall and runoff factor, known as the R-factor, to represent the climatic influence on soil erosion. As such, the R-factor cannot and should not be used to determine the soil loss on an event basis. In contrast, process-based water erosion models explicitly require the runoff rate in order to determine the rate of soil loss. For example, in WEPP (Water Erosion Prediction Project, Laflen et al., 19Ϛ•), which represents a new generation of process-based erosion models, the User Requirement (Foster and Lane, 1987) suggests that the maximum information required to represent a design storm consists of (1) storm amount, (2) storm duration, (3) ratio of peak intensity to average intensity, and (4) time to peak. With these standard inputs of storm characteristics, WEPP uses the Green-Ampt infiltration model to determine runoff amount, and a kinematic wave model to determine the peak runoff rate (WEPP User Manual, USDA, 1995). The peak runoff rate is then assumed to be the steady-state runoff rate for erosion computations. In GUEST (Rose, 1993; Ciesiolka et al., 1995), a theoretical expression is derived for sediment concentration at the transport limit by assuming a fraction of the stream power is used to raise sediment (against its immersed weight) at a rate corresponding to its deposition rate. This expression involves the instantaneous rate of runoff per unit area, Q. Rose (1993) and Ciesiolka et al. (1995) give the theoretical basis for computing a single effective runoff rate for any runoff event, Q_e, defined as:

$$Q_e = \left(\frac{\sum Q^{1.4}}{\sum Q} \right)^{2.5} \qquad (1)$$

where the summation is for the duration of the runoff event. In both cases, runoff rates are needed to determine the rate of soil loss using physically based methodology. It is important therefore to predict runoff rates for given rainfall intensity, soil and topographical characteristics.

As part of a project (No. 8551) funded by Australian Centre for International Agricultural Research (ACIAR), both rainfall intensity and runoff rate were measured at 1-min intervals at five sites in Australia and Southeast Asia. The major aim of the project was to provide a methodology to allow scientists to make rational decisions about the effectiveness of various land management options in reducing soil erosion in the tropics and sub-tropics. Research outcomes from the project were published in a spec.ıl issue of *Soil Technology* in 1995 (Vol. 8, No. 3). In a new project (No. 9201), new sites in Thailand and Australia were included, and additional rainfall and runoff data were collected with an explicit objective, among others, to develop hydrologic models to predict runoff rates from one-minute rainfall rates for a range of soil type, slope, slope length, and management practice in the tropical and sub-tropical regions of Australia and Southeast Asia. This article is one of the first attempts to meet these objectives.

In this article, plot-scale runoff processes are characterized and modeled in the context of soil erosion prediction using physically based methodology. We first

Article has been reviewed and approved for publication by the Soil & Water Div. of ASAE.

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describe the field sites and the nature of rainfall and runoff data collected for the project. A simple hydrologic model is developed for runoff rates at 1-min intervals taking into account the spatial variation in the infiltration rate and the lag between rainfall excess and observed runoff rate.

EXPERIMENTAL SITES, AND RAINFALL AND RUNOFF DATA

All six sites are in tropical and sub-tropical regions of Australia and Southeast Asia (fig. 1). Table 1 provides general information on the location, climate, soil, and plot dimensions. Summer rainfall predominated at the two Australian sites with about 70% of rain occurring between November and April. Annual rainfall at Kemaman is the highest of the six sites studied. Seasonal rainfall at the site show a bimodal distribution with peaks in March and November. Rainfall for the six months between June and November at Los Baños accounts for about 77% of annual total, while rainfall at VISCA (Visayas State College of Agriculture, Baybay, Leyte, the Philippines) has two peaks in January and July, respectively. Rainfall at Nan in Thailand is highly seasonal with up to 87% of rainfall in the six months from April to September.

Soil texture was classified using the U.S. system (Soil Survey Staff, 1975), the site at Imbil being particularly stony with 44% of particles larger than 5 mm.

Field experiments were carried out on hydrologically bounded plots with areas varying from 20 to 216 m^2 (see also table 1). Both rainfall intensity and runoff rate were measured using tipping bucket technology at one minute intervals. All of the tipping buckets were calibrated using a dynamic calibration method (Calder and Kidd, 1978; Ricchetti and Bailey, 1990) prior to the field trials. Details of recording equipment and measurements made were given elsewhere (Ciesiolka et al., 1995). Data management programs (Ciesiolka et al., 1995) were developed to convert data on tip rates into meaningful hydrologic data such as rainfall intensity (mm/h) and runoff rate (mm/h).

Data used in this article are from bare plots, kept virtually free from vegetation in order to provide reference data on soil and water loss to which the effectiveness of other management options are compared (Ciesiolka et al., 1995).

Data on rainfall and runoff rates at 1-min intervals were prepared for the 30 largest storm events in terms of total rainfall from bare plots at the six sites. Rainfall intensity and runoff rate are continuous processes while the tipping bucket technology is discrete in nature. As a result, there is a fixed absolute sampling error depending on such factors as the bucket size, catchment area, and sampling interval. For given plot size and sampling equipment, the shorter the sampling interval the higher the sampling error (Yu et al., 1997). Implications of this sampling error for runoff modeling are discussed later in the article.

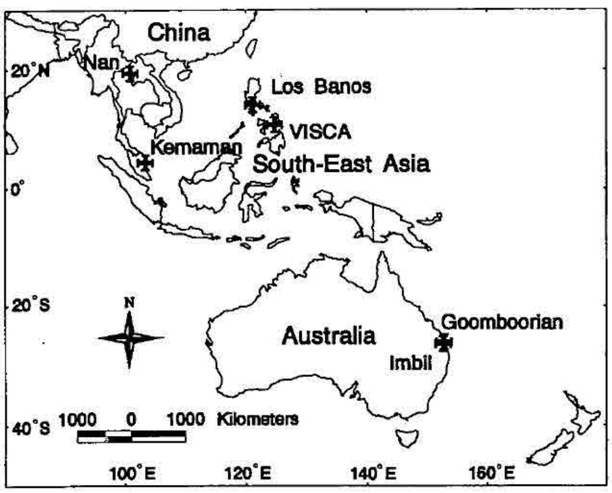

Figure 1–Locations of the six ACIAR sites from which data used in this article were gathered.

OBSERVATIONS OF RAINFALL-RUNOFF CHARACTERISTICS—PLOT SCALE

Of over 2000 events for which rainfall intensity and runoff were recorded at 1-min intervals, we prepared 30 events at each site for data analysis and modeling. While we have examined a large number of events for each of the six sites with respect to rainfall-runoff characteristics described below, we select only one such event to note and highlight those most important characteristics on which model development in the next section is based.

Figure 2 shows rainfall intensity and runoff rate during a thunder storm in the early summer of 1992-1993 at the Goomboorian site. The storm lasted a little over three hours. The total rainfall and runoff amounts for the event were 54.4 mm and 26.3 mm, respectively. Both rainfall intensity and runoff rate are highly variable at a 1-min time scale (fig. 2a). It is also clear that averaging over an interval of 10 min, for example, can result in considerable loss of detail with respect to the temporal variation in rainfall intensity and runoff rate. For example, the first peak of 83 mm/h in rainfall intensity (fig. 2a), which occurred 10 min after the event commenced, is completely averaged out (fig. 2b). There is a measurable lag between peak runoff rate and rainfall intensity in figure 2a of about

Table 1. Bare plot characteristics at the six sites in Australia and Southeast Asia

Site	Country	Location	Soil Type	Soil Texture	Mean Annual Rainfall (mm)	Length (m)	Width (m)	Slope* (%)
Goomboorian	Australia	26°04′S, 152°48′E	Typic Eutropept	Sand	1 200	36	3	5
Imbil	Australia	26°26′S, 152°41′E	Lithic Eutropept	Loam	1 200	12.2	3.2	33
Kemaman	Malaysia	4°18′N, 103°19′E	Orthoxic Tropudult	Sand loam	3 500	5	4	17
Los Baños	Philippines	14°6′N, 121°12′E	Typic Tropudalf	Clay	1 900	12	6	26
VISCA	Philippines	10°45′N, 124°49′E	Oxic Dystropept	Clay	2 200	11.9	6	50
Nan	Thailand	19°24′N, 100°45′E	Oxic Paleustult	Clay	1 200	36	6	Variable 12-50

* Each plot, though at different slope, was very approximately planar, but with unsurveyed natural irregularities in the 36 m length of plot.