

# COMMENTS & LETTERS TO THE EDITOR

## Letter to the Editor on “The Mathematical Integrity of Some Universal Soil Loss Equation Variants”

The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965, 1978) is reported to be the most widely used model for predicting rainfall erosion. As is well known, it is an empirical model based on a large number of plot studies in the USA, and it has been recently revised to produce the Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997).

The USLE was originally developed as a soil conservation planning tool. The need to predict erosion in watersheds has seen it used without modification in models like the Agricultural Non-Point Source Pollution (AGNPS) model (Young et al., 1987), albeit as a predictor of event erosion, a purpose for which it was not designed. However, in some approaches, the basis of the event erosivity factor has been changed (Williams et al., 1971, 1984; Williams, 1975; Williams and Arnold, 1997; Kinnell and Risse, 1998), and the change made without due regard to fundamental mathematical principles.

The form of the USLE/RUSLE model is

$$A = RKLSCP \quad [1]$$

where  $A$  is the average annual soil loss;  $R$  is the average annual sum of  $R_e$ , the event erosivity factor, when the value of  $R_e$  is given by the product of the storm rainfall kinetic energy ( $E$ ) and the maximum 30-min rainfall intensity ( $I_{30}$ );  $K$  is the soil (erodibility) factor;  $L$  and  $S$  are respectively the factors for slope length and gradient,  $C$  is the crop and crop management factor, and  $P$  is the soil conservation practice factor.

Runoff and soil loss plots are small watersheds or catchments. However, at a larger scale, areas of deposition within the catchment tend to reduce the sediment yield below that predicted from erosion models like the USLE. Under these circumstances, a delivery ratio is used to convert estimates of gross erosion to sediment yield (Williams et al., 1971). The sediment delivery ratio is the ratio of the sediment yield at a specific location in the watershed and the gross erosion upstream of that point. While a sediment delivery ratio is considered necessary to determine sediment delivery from erosion estimated using the USLE in catchments, Williams (1975) contended that the delivery ratio is not necessary if the rainfall energy factor in the USLE is replaced by a runoff rate factor because watershed characteristics such as drainage area, stream slope, and watershed shape influence runoff rates and delivery ratios in a similar manner. As a consequence of this, Williams proposed an equation that can be written as

$$SY_e = X_e K L S C_e P_e \quad [2]$$

where  $SY_e$  is the event sediment yield,

$$X_e = \alpha (Q_e q_p)^{0.56} \quad [3]$$

where  $\alpha$  is an empirical coefficient which is independent of climate, soil, vegetation, conservation practice, or management,  $Q_e$  is runoff amount and  $q_p$  is the peak runoff rate obtained during the erosion event, and  $K$ ,  $L$ , and  $S$  are as defined for the USLE with  $C_e$  and  $P_e$  being event  $C$  and  $P$  values. This model has become known as the Modified Universal Soil Loss Equation (MUSLE). The  $K$ ,  $L$ ,  $S$ ,  $C_e$ ,

and  $P_e$  actors are calculated using weighting factors that are dependent on the drainage area (Williams, 1975).

In the MUSLE,  $R_e$  in the USLE, the  $EI_{30}$  index, is replaced by  $\alpha (Q_e q_p)^{0.56}$  while all the other parameters remain as defined for the USLE. In the EPIC model (originally the Erosion/Productivity Impact Calculator but now Environmental Policy Integrated Climate), a continuous simulation model developed by Williams et al. (1984),

$$SY_e = X_e K L S C_e P_e ROKF \quad [4]$$

where  $ROKF$  is the coarse fragment factor as defined by Simanton et al. (1984), and  $X_e$  is selected from one of the following:

$$X_e = EI_{30} \quad [5a]$$

$$X_e = 1.586 (Q_e q_p)^{0.56} DA^{0.12} \quad [5b]$$

$$X_e = 0.65 EI_{30} + 0.45 (Q_e q_p)^{0.33} \quad [5c]$$

where  $DA$  is drainage area expressed in ha,  $Q_e$  is expressed in mm,  $q_p$  in mm h<sup>-1</sup>,  $EI_{30}$  in MJ mm ha<sup>-1</sup> h<sup>-1</sup>, and  $SY_e$  in Mg ha<sup>-1</sup> (Williams and Arnold, 1997). Values of  $K$ ,  $L$ ,  $S$ ,  $C_e$ ,  $P_e$ , and  $ROKF$  are determined independently of the index used for  $X_e$ .

Because the USLE is based on the unit plot concept where  $L = S = C = P = 1.0$  for a bare fallow plot 22.1 m in length on a 9% slope with cultivation up and down the slope,  $L$ ,  $S$ ,  $C$ , and  $P$  are dimensionless, while  $R$  and  $K$  have units. For the unit plot

$$A = KR \quad [6]$$

where  $R$  is the primary independent variable. As a result,  $K$  is an empirical parameter whose units are determined by the units of both  $A$  and  $R$ . Thus, if the basis of  $R_e$  is changed from  $EI_{30}$ , then USLE  $K$  values no longer apply. For EPIC,  $K$  should be determined for each different  $X_e$  factor using the equation

$$K(X_e) = \frac{\sum_{n=1}^N (A_{e1})_n}{\sum_{n=1}^N (X_e)_n} \quad [7]$$

where  $N$  is the number of rainfall events and  $A_{e1}$  is the soil loss from the unit plot during the rainfall event. As noted above, in EPIC  $K$  remains the same irrespective of the basis of  $X_e$  and, as a result, the model violates fundamental mathematical rules.

Both the MUSLE and EPIC use event erosivity factors that include runoff as a parameter. For the USLE/RUSLE

$$C = \frac{\sum_{n=1}^N (A_{ec})_n}{\sum_{n=1}^N (A_{e1})_n} = \frac{\sum_{n=1}^N (A_{ec})_n}{K \sum_{n=1}^N (EI_{30})_n} \quad [8]$$

where  $A_{ec}$  is the event soil loss from the vegetated plot when  $L = S = P = 1.0$ . In the USLE/RUSLE, the  $C$  factor accounts

**Abbreviations:** MUSLE, Modified Universal Soil Loss Equation; RUSLE, Revised Universal Soil Loss Equation; USLE, Universal Soil Loss Equation.

for the effect of crop and crop management on both runoff and sediment concentration. Moving runoff to the event erosivity term means that  $C$  must be re-evaluated if the runoff from the cropped condition is used to determine event erosivity. The USLE  $C$  factor can only be used when the event erosivity factor includes runoff as a parameter and is calculated for the unit plot condition. Otherwise, runoff is considered twice, once in the erosivity term and again in the  $C$  factor.

As indicated by Kinnell and Risse (1998), there is no doubt that including runoff as a factor in the erosivity term improves the capacity of the USLE/RUSLE type of approach to predict event erosion when  $C = 1$ , but the consequences of including runoff as an independent term in accounting for event soil loss on other terms in the model must be respected. If this is not done, then the model is not mathematically sound and should not be used. In effect, the approach used by the USLE to predict erosion is a two-stepped one, the prediction of erosion on the unit plot,

$$A_1 = RK \quad [9]$$

followed by the prediction of erosion on a vegetated plot, or a plot of different slope length or gradient as a departure from the erosion on the unit plot,

$$A = A_1 LSCP \quad [10]$$

Because of this, factors like  $C$  and  $P$  must be redetermined whenever runoff from a vegetated situation is used as the basis for the event erosivity factor. Since slope length and gradient are not regarded as influencing runoff per unit area (Renard et al., 1997), USLE/RUSLE  $L$  and  $S$  values can be applied when  $R_c$  is based on runoff (Kinnell and Risse, 1998).

It should be noted that the primary issue discussed here is the mathematical integrity of the modeling approach. Users of models assume them to be mathematically sound and we,

as scientists, need to ensure that they are. The scientific nature of the various erosivity indices mentioned is a separate issue.

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