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Discussion

Comment on "SCS-CN based time-distributed sediment yield model" by Tyagi et al. Journal of Hydrology 352 (2008) 388–403

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Tyagi et al. (2008) claim that there is an interdependence between the Universal Soil Loss Equation (USLE, Wischmeier and Smith, 1965, 1978) and the SCS Curve Number (SCS, 1956) parameter S. As noted by Tyagi et al. the SCS Curve Number method for predicting runoff amount (Q) from rainfall amount (P) is based on

$$Q = \frac{(P - I_a)^2}{P - I_a + S} \tag{1}$$

where I_a is the initial abstraction and S, the potential maximum retention, is given by

$$S = \frac{25400}{\mathrm{CN}} - 254 \tag{2}$$

where CN is the curve number and Q and P are expressed in millimetres. Tyagi et al. claim that, for any initial moisture condition, this interdependence is expressed by

$$RKLSCP = \frac{S(1-n)}{n}\rho_s \tag{3}$$

where R is the rainfall erosivity factor, K is the soil erodibility factor, LS is the topographic factor dependent on slope length and gradient, C is the crop management factor, P is the support practice factor, n is soil porosity and ρ_s is the density of solids. Not withstanding the fact that the right side of Eq. (3) does not match the left side in terms of dealing with many of the factors that affect water erosion, it indicates that the soil loss predicted by the USLE for a rainfall event decreases as S decreases. However, (a) the product of R, K, LS, C and P does not vary with the initial moisture content of the soil and (b) Q increases as S decreases (Eq. (1)) and it is well known that the soil loss for any given event increases as Q increases when all other factors remain constant.

Eq. (3) results from the observation that, since A is the potential mass of soil loss per unit watershed area predicted by the Universal Soil Loss Equation, A can be expressed in terms of the density of solids (ρ_s) and the volume of solids (V_s) per unit surface area,

$$A = V_s\rho_s \tag{4}$$

This then leads to

$$A = (V - V_v)\rho_s = \frac{V_v(1-n)}{n}\rho_s \tag{5}$$

where V is the total volume of the soil column of unit area and V_v is the volume of the voids so that $V = V_v + V_s$. The replacement of V_v by S in Eq. (5) to produce Eq. (3) follows from the observation that the term A in Eq. (5) correlates with S for a completely dry soil and that value of S is given approximately by the value of S at AMC 1. Further equations then follow to indicate that

$$\frac{A}{S} = \frac{1-n}{n}\rho_s \tag{6}$$

applies irrespective of the initial moisture conditions in the soil.

Although the mathematics employed by Tygai et al. in developing Eq. (3) may initially seem to be sound to many, and their calibration data generated A/S ratios that, for individual events in seven different watersheds, tend to support their approach, the application of Eq. (6) to any initial moisture condition differs from Mishra et al. (2006) where it was observed that the ratio of A to S could only be constant when AMC 1 occurred. It also ignores physical realities. $S = 0$ means that there is no pore space available for rainwater to enter so that all the rainwater runs off. AMC III, which is basically associated with saturated soil, produces low values of S and relatively high values of Q for a given rainfall event, and it is well known that rainfall erosion increases with runoff. However, Eqs. (3) and (6) indicate otherwise. Also, they indicate that as S tends towards 0 as the initial moisture content varies, A tends towards 0 where, as noted above, the product of R, K, LS, C and P does not vary with the initial moisture content of the soil.

The effect of the failure of Eq. (6) to deal with the fact the product of R, K, LS, C and P does not vary with the initial moisture content of the soil can be demonstrated using the example depicted in Fig. 1. In this example, the amount of space not occupied by solid material is 50% so that the porosity is 0.5. The mass of soil that is eroded per unit area during the event is directly related to the depth eroded (D_{Er}) and the dry density of the soil which, for example, can be considered to be about 1.2 t/m^3. Consequently,

$$A_1 = 1.2D_{Er}\ (\mathrm{t/m^2}) \tag{7}$$

where D_{Er} is in m. If the situation depicted in Fig. 1 shows the volume of water in the soil when the soil is at AMC 1, water can enter the soil until the volume initially occupied by air ($V_{a.S}$) is filled with water. Thus, following the concepts presented by Tyagi et al. (2008),

$$S_1 = 0.4D_{So} \tag{8}$$

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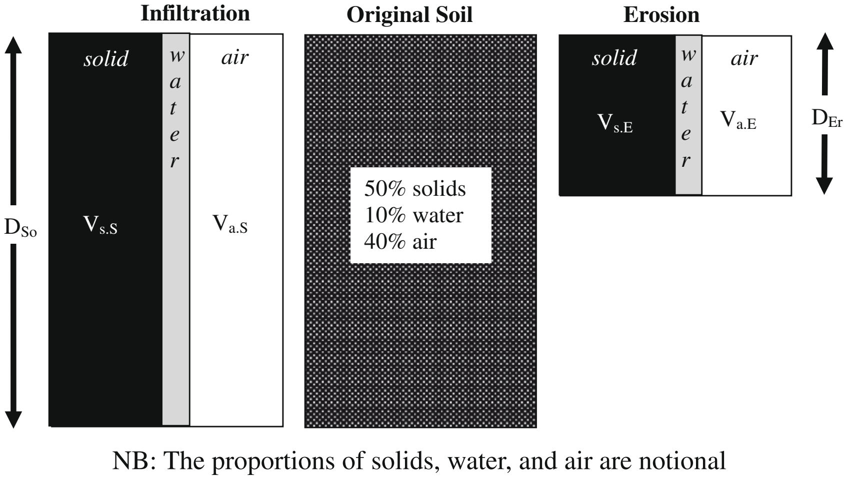

Fig. 1. Schematic of the relative volumes of solids, water and air in the soil in which water infiltrates and the soil eroded when the AMC I condition exist. NB: proportions of the solids, water and air in the soil are notional and are not relevant to any existing soil. D_{So} = depth of soil into which water infiltrates, D_{Er} is the depth of soil eroded so that the depth remaining after erosion = $D_{So} - D_{Er}$. In most erosion events, D_{Er} is very small compared with D_{So} so that the vertical scale of the element eroded is exaggerated.

and

$$\frac{A_1}{S_1} = 3.0\frac{D_{Er}}{D_{So}} \tag{9}$$

Consider that, for argument's sake, the same soil loss occurred at AMC 3 rather than AMC 1 and that the proportion of water in the soil at AMC 3 was 30%. In this case,

$$S_3 = 0.2D_{So} \tag{10}$$

and

$$\frac{A_3}{S_3} = 6.0\frac{D_{Er}}{D_{So}} \tag{11}$$

The ratio of D_{Er} to D_{So} has not changed but, contrary to the model presented by Tyagi et al. the value of A/S has because the ratio of the volume of solids in the depth of soil predicted to be lost ($V_{s.E}$) and the volume of air in the original soil ($V_{a.S}$) does not remain constant as the initial moisture content of the soil varies. That ratio also varies when the initial moisture content remains constant when the product of R, K, LS, C and P varies.

As noted above, it is well known that runoff and erosion are linked but the USLE model does not include any direct consideration of runoff in predicting A. However, crude relationships between runoff amount and storm kinetic energy (E) and between peak runoff rate and the maximum 30 min intensity (I_{30}) upon which the R factor is based provide an indirect approach to accounting for the impact of runoff on erosion in the model and, as a result, changes in the initial moisture status of the soil do not influence the prediction of A by the USLE. As observed by Kinnell and Risse (1998), adding direct consideration of runoff by multiplying the USLE EI_{30} index by the runoff ratio (Q_R) overcomes the tendency for the EI_{30} index to overpredict small soil losses and underpredict large soil losses from individual events. Although the Q_REI_{30} index was developed through considering the fact that soil loss is directly related to the product of water discharge and sediment concentration, the results obtained using the Q_REI_{30} index indicate that the approach to accounting for the impact of runoff on erosion in the USLE model works best when erosion occurs on impervious ($Q_R = 1$) or close to impervious surfaces. It works worst on surfaces which have low runoff coefficients. Logically, the linkage between soil loss and the SCS-CN parameter S should be through the effect of S in predicting runoff ratios rather than through attempts to link S and A.

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