Sediment delivery from hillslopes and the Universal Soil Loss Equation: Some perceptions and misconceptions

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ABSTRACT

The Universal Soil Loss Equation (USLE) or the Revised Universal Soil Loss Equation (RUSLE) are often used together with sediment delivery ratios in order to predict sediment delivery from hillslopes. In using sediment delivery ratios for this purpose, it is assumed that the sediment delivery ratio for a given hillslope does not vary with the amount of erosion occurring in the upslope area. This assumption is false. There is a perception that hillslope erosion is calculated on basis that hillslopes are, in effect, simply divided into 22.1 m long segments. This perception fails to recognize the fact the inclusion of 22.1 m length in the calculation has no physical significance but simply produces a value of 1.0 for the slope length factor when slopes have a length equal to that of the unit plot. There is a perception that the slope length factor is inappropriate because not all the dislodged sediment is discharged. This perception fails to recognize that the USLE and the RUSLE actually predict sediment yield from planar surfaces, not the total amount of soil material dislocated and removed some distance by erosion within an area. The application of the USLE/RUSLE to hillslopes also needs to take into account the fact that runoff may not be generated uniformly over that hillslope. This can be achieved by an equation for the slope length factor that takes account of spatial variations in upslope runoff on soil loss from a segment or grid cell. Several alternatives to the USLE event erosivity index have been proposed in order to predict event erosion better than can be achieved using the EI_{30} index. Most ignore the consequences of changing the event erosivity index on the values for the soil, crop and soil conservation protection factors because there is a misconception that these factors are independent of one another.

Keywords: USLE; soil erosion; sediment yield

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INTRODUCTION

At this time, sediment delivery to and from rivers and streams is a topic of interest with regard to the impact of land use on water quality. How much soil, nutrients and undesirable chemicals moves from hillslopes to these rivers and streams and then gets discharged in dams, lakes and sensitive marine environments is a matter of concern. The effects of current and alternative land uses needs to be investigated in order to determine appropriate land management strategies to maintain or obtain good water quality. Since measurement of erosion and sediment delivery to streams cannot be done on a wide scale, mathematical models are employed to do this task. Such models invariably depend on erosion measurements made at the small scale being extrapolated to the larger scale. A factor called the sediment delivery ratio, the ratio of the gross erosion upslope of a point to the sediment delivered, is often used to predict the amount of sediment delivered from the erosion estimated to occur on hillslopes as a result of this extrapolation.

As noted above, the estimates of erosion invariably depend on erosion measurements made at the small scale being extrapolated to the larger scale. Although not designed for this purpose, the Universal Soil Loss Equation (USLE: Wischmeier and Smith 1978), or the revised version of it (RUSLE: Renard et al, 1997), is commonly used to do this extrapolation. More process-based models such as WEPP (Laflen et al, 1991) and EUROSEM (Morgan et al., 1998) are too data and computationally intensive to use over large areas.

The USLE and the RUSLE are often given as

$$A = R\ K\ L\ S\ C\ P \qquad (1)$$

where A is average (mean) annual soil loss (mass/area) over the long term (eg 20 years), R is the rainfall-runoff “erosivity” factor, K is the soil “erodibility” factor, L and S are the topographic factors that depend on slope length and gradient, C is the crop and crop management factor, and P is the soil conservation practice factor. While Eq. 1 is commonly seen in the literature, the model actually works mathematically in two steps. The reason for this is that the USLE is based on the unit plot concept where the unit plot is defined as bare fallow area 22.1 m long on a 9 % slope with cultivation up and down the plot. Only R and K have units. L, S, C and P are reduced variables that are mathematically forced to take on values of 1.0 for the unit plot. As a consequence of this, the USLE and the RUSLE first predict erosion for the unit plot condition (A_1)

$$A_1 = R\ K \qquad (2)$$

and then multiply the result by appropriate values of L, S, C and P to account for the difference between the area of interest and the unit plot,

$$A = A_1\ L\ S\ C\ P \qquad (3)$$

The values of K, L, S, C, and P that can be used to do this are associated with more than 10,000 plot-years of experiments undertaken in the USA. The fact that L, S, C and P are reduced variables that are mathematically forced to take on values of 1.0 for the unit plot has no physical significance. For example, when appropriately parameterised, the model produces exactly the same value of A for a given non-unit plot situation no matter what value of slope length and gradient is chosen for the unit plot condition

SOME PERCEPTIONS AND MISCONCEPTIONS

The USLE slope length factor

The slope length factor in the USLE and the RUSLE is calculated using the equation

$$L = (\lambda / 22.1)^m \qquad (4)$$

where λ is the slope length in metres and m is a factor that varies with slope gradient in the USLE and the ratio of rill to interrill erosion in the RUSLE. The USLE was designed to predict soil loss from planar surfaces that are uniform with respect to soil, vegetation and management. As a result of this, the length of slope upon which the calculation of L is based is defined as the distance from the onset of overland flow to the point where deposition begins or where overland flow enters a channel bigger than a rill. This definition of slope length is also used in the RUSLE (Renard et al, 1997) but, in the RUSLE, provisions exist to deal with more complex slopes where vegetation and slope gradient vary. For nonuniform one dimensional hillslopes, the slope is broken into a number of planar segments, and the L factor for each segment i calculated using

$$L_i = \frac{\lambda_i^{m+1} - \lambda_{i-1}^{m+1}}{\lambda_i - \lambda_{i-1} (22.1)^m} \qquad (5)$$

where λ_i is the slope length to the bottom of segment i, λ_{i-1} is the slope length to the bottom of the previous segment and m is determined by the slope gradient of segment i. Eq. 5 results from an equation for sediment yield for the ith segment developed by Foster and Wischmeier (1974) and adopted in the RUSLE (Renard et al., 1997). In reality, surface water flows converge and diverge in two dimensions on hillslopes because slopes usually have both a vertical and a lateral direction. Grid cell representations of landscapes in catchments provide a common vehicle for modelling spatial variations in soil loss given that each grid cell is considered to be uniform in terms of soil, slope length and gradient, and vegetation and management. In the L factor equation for grid cell i,j, contributing area (χ) divided by the width of the contour (w) over which the overflow flow from that area flows replaces λ. This approach gives

$$L_{i,j} = \frac{(\chi_{i,j.in} + D^2)^{m+1} - \chi_{i,j.in}^{m+1}}{D^{m+2}\, x_{i,j}^{m}\, (22.1)^m} \qquad (6)$$

where $\chi_{i,j.in}$ is the contributing area for overland flow into the cell, D is the size of the cell (length of the sides of the cell) and x is a factor which accounts for variations in flow width that depend on the direction of flow relative to cell orientation (Desmet and Govers, 1996). Eqs 5 and 6 account for not just segment length or grid cell size but also the position of the segment or cell in the landscape.

Parsons et al (2006) contend that the USLE and the RUSLE simply predict erosion on a 22.1 m long area so that, in effect, hillslopes are simply divided into 22.1 m long plots and the value of erosion allocated to each one of them added together to give erosion on the hillslope. That perception is false. The value of 22.1 m appears in Eq. 4, 5 and 6 not because it has great physical significance but simply so that the value of L = 1.0 when λ = 22.1 m. Experiments that provided the data upon which the USLE was based contained a wide range of plot lengths (Risse et al., 1993). The designers of the USLE could have chosen some value other than 22.1 m for a standard. If they had done that, L for a 22.1 m long slope would not be 1.0 but that would have not had any impact on the value of A predicted for any given slope length – gradient combination because the value of K (Eq. 2) would be different from that used when the unit plot is 22.1 m.

The USLE and sediment delivery from hillslopes

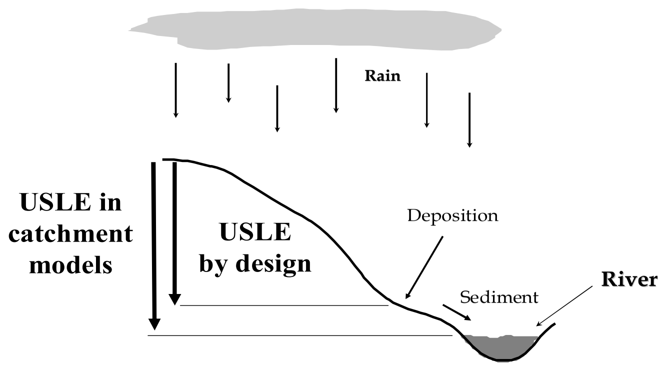

Figure 1. Schematic of the application of the USLE/RUSLE in catchments

Although Eqs. 5 and 6 exist to deal with complex hillslopes, neither the USLE nor the RUSLE deal with deposition that results from reductions in slope gradient such as occur on concave hillslopes. Because of this, it is common practice to predict gross soil loss from a hillslope (A_{gh}) using the USLE or the RUSLE ignoring the criteria for the slope length being limited to area where net deposition does not occur (Figure 1), and then multiply the result by the sediment delivery ratio to obtain the sediment yield (Y, mass/area) for the hillslope,

$$Y = A_{gh}\, DR_h \qquad (7)$$

where DR_h is the sediment delivery ratio for the hillslope involved. When sediment yield for a whole watershed is the issue,

$$Y = A_{gw}\, DR_w \qquad (8)$$

where A_{gw} is the gross soil loss over the whole area of the watershed and DR_w is the sediment delivery ratio for the watershed as a whole. As noted by Parsons et al (2006), the sediment discharged from a watershed may contain substantial quantities of material eroded from river banks. Consequently, Eq. 8 may not provide a reasonably estimate of the amount of sediment leaving the watershed unless it includes predictions of erosion in the large channels.

Considerable attention has been given to the factors that influence DR_w. The gross effect of watershed area ($Area_w$) has been considered using the equation

$$DR_w = (Area_w)^b \qquad (9)$$

with b having an value of less than 0 (Roehl, 1962; Renfro,1975; Walling, 1983). The decline in DR_w with watershed area is usually associated with an increase the amount of deposition that occurs on concave slopes and flat areas as watershed area increases. Other factors observed to affect DR_w are, for example, particle size (the finer the material the less likely it is to be deposited), runoff, and the average gradient of the watershed.

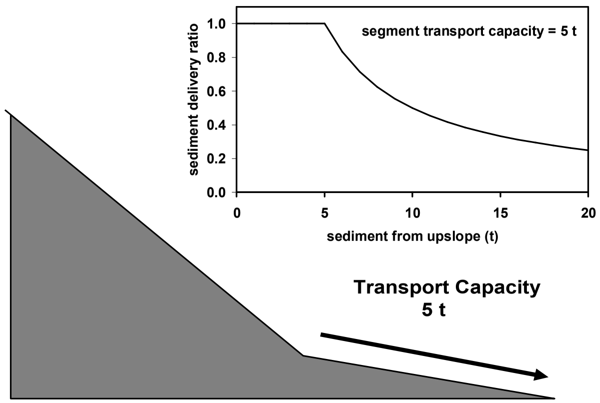

Figure 2. Schematic of a hillslope with overland flow in a lower segment having a transport capacity of 5 t over some arbitrary period of time and the effect of that transport capacity on sediment delivery ratios.

In terms of predicting sediment delivery from hillslopes, Eq. 7 depends on the assumption that DR_h does not vary with the amount of gross soil loss predicted to occur on the hillslope. This assumption is severely challenged by the fact that the deposition that results from a reduction of slope gradient results from the sediment entering that low gradient area being in excess of the capacity of the flow to transport sediment through the low gradient area. Consider the example shown in Figure 2 where, over some period of time, flow in the lowest segment has a capacity to transport only 5 tons of sediment through to its downslope boundary. If 20 tons of sediment enters the upslope boundary, 15 tons is deposited and so DR_h has a value of 5/20 = 0.25. If the supply of sediment drops so that 10 tons is delivered to the upslope boundary, 5 tons is deposited and so DR_h has a value of 5/10 = 0.5. The graph in Figure 2 shows how DR_h varies over other values of sediment input. The only time that DR_h is constant is when there is no deposition and DR_h = 1.0 (Kinnell, 2004). Arguably, Figure 2 illustrates a situation that may not occur much in practice because there are situations where both the sediment input and the transport capacity vary together. However, there is no guarantee that, when this does happen, the variation in the transport capacity will hold the sediment delivery ratio to a constant value.

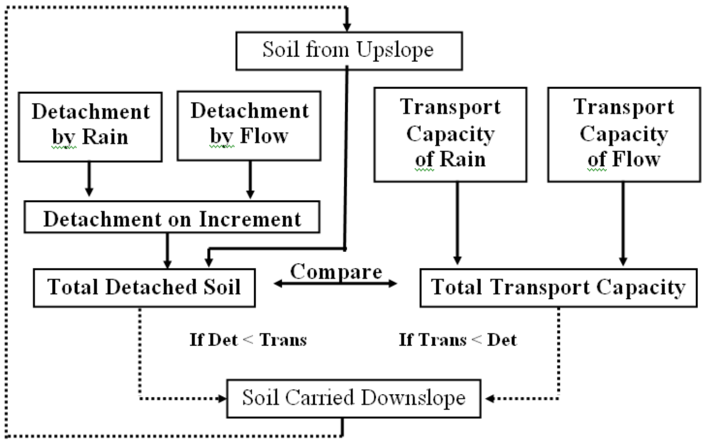

Figure 3: Approach used by Meyer and Wischmeier (1969) to simulate the processes of soil erosion by water

The need to consider sediment transport capacity with regard to the movement of soil material down a slope is not new. Figure 3 is reproduced from Meyer and Wischmeier (1969) and models like AGNPS 5.0 (Young et al., 1989) and ANSWERS (Beasley et al., 1980; Beasley and Huggins, 1991) use the USLE together with a sediment transport model to predict sediment delivery. In AGNPS 5.0, the USLE is directed to estimating detachment so that, in the context of Figure 2, the sediment transport capacity model controls not only sediment movement on the lower segment but also on the upper segment where there is no need to do so. A new version of the RUSLE, called RUSLE2 (Foster et al, 2003), also predicts sediment delivery using the sediment transport capacity approach. RUSLE2 also adjusts the composition of the sediment for the preferential deposition of coarse particles with respect to fine. However, AnnAGNPS (Bingner and Theurer, 2001), the replacement for AGNPS 5.0, uses the conventional approach where the RUSLE is used with sediment delivery ratios to predict sediment delivery.

Particle travel distance, slope length and sediment delivery

One issue that raises concern about the use of the USLE and the RUSLE in predicting soil loss from hillslopes is the fact that detached particles are transported across the landscape at various rates. Parsons et al (2006) draw attention to the fact that, in experiments by a number of people, particles, particularly large ones, have been observed to travel limited distances downslope from their initial position over the duration of the experiments. In considering the experiments of Rejman et al (1999), Parsons et al indicate that the sediment yield would be 30 %, 12.9 % and 9 % of the total particles detached on areas with slopes of 30 m, 70 m and 100 m in length respectively over a period of 4 months used in the study. They then go on to suggest that the USLE slope length factor fails to take into account of the fact that a high proportion of detached material would not be discharged because the USLE has a time frame of one year (a misconception on their part) and so is invalid.

The concern about the USLE and the RUSLE L factor expressed by Parsons et al (2006) stems from the definition by Trimble (1975) that erosion measurement is “the total amount of soil material dislocated and removed some distance by erosion within an area”. According to Parsons et al, under this definition, soil particles dislodged and transported a few millimetres in rainsplash would be included in the amount of erosion occurring in an area, as would particles detached and transported several metres by rill flow. The proportions of detached material discharged quoted by Parsons et al (30, 12·9 and 9 per cent for areas with lengths of 30 m, 70 m and 100 m, respectively) assume that particles on all slope lengths move the same average distance, 9 m in 4 months. However, the data that was used to determine the L factor in the USLE included experiments on runoff and soil loss plots that had run for 10 or more years. Consequently, soil particles would have travelled much further and a much higher proportion of detached material would have been discharged than envisaged by Parsons et al. In addition, the particle travel distances associated with the sediment discharge would have varied between slopes of different lengths because, as a general rule, flow velocities tend to increase with slope length.

Although it is true that, no matter what the time frame, some detached particles will fail to cross the downslope boundary of erosion plots, the L factor used in the USLE and the RUSLE focuses on effect of slope length on the long term sediment yield not erosion per se. In reality, the USLE and the RUSLE predict sediment yield where transport limiting conditions do not cause significant deposition, and the term “sediment yield” not erosion is used when discussing the impact of topography on soil loss from hillslope segments in official documentation for the RUSLE (eg. Renard et al., 1997). The topographic factors in the USLE and the RUSLE have a physical basis (Moore and Burch, 1986) so that they do, in a gross sense, work correctly within the scheme shown in Figure 3 on planar and convex hillslopes. However, their ability to take account of the effect of transport capacity on sediment delivery does not extend to situations where the transport capacity decreases in the downslope direction such as in the case illustrated in Figure 2. The failure to predict sediment delivery from concave hillslopes has led to the misconception that, in the context of Figure 3, the USLE and the RUSLE predict only detachment. As a result, de Aruajo (2007) used the USLE together with sediment transport controlled by an approach based on entropy to deal with the effects of travel distance on sediment delivery. Also, as noted above, models like AGNPS 5.0 use a sediment transport model to control sediment movement on all parts of the hillslope, not just in areas where deposition results from changes in slope gradient. Such approaches ignore the fact that, given the time frame and purpose for which the USLE and the RUSLE were designed, Eq. 4 provides an appropriate means of dealing with the effect of slope length on A in Eq. 1. It should also be noted that while the soil loss is given in terms of mass per unit area, the value of A applies to a specific sized area at a specific geographic location. It cannot be extrapolated to other areas which differ in terms of climate, soil, topography or vegetation.

Predicting soil loss on nonuniform hillslopes

The RUSLE (Renard et al, 1997), while not dealing with deposition resulting from changes in slope gradient on hillslopes, does provide mechanisms to deal with deposition resulting from cross-slope strip cropping, buffer strips and filter strips through the P factor. Also, while it is common practice to apply Eqs. 5 and 6 to predicting soil loss on hillslopes where slope length, slope gradient, soil, vegetation and management vary spatially, Eqs. 5 and 6 can be perceived to work best when runoff is produced uniformly over the whole area because there is a physical basis to the product of L and S when this is the case (Moore and Burch, 1986; Moore and Wilson, 1992). Kinnell (in press) has proposed a modification of these equations to deal with the fact that, in many cases, runoff generation varies spatially. Conceptually, for a hillslope segment, Eq. 5 becomes

$$L_i = \frac{(\lambda_{i-1.(eff)} + \lambda_{i.seg})^{m+1} - (\lambda_{i-1.(eff)})^{m+1}}{\lambda_{i.seg}\,(22.1)^m} \tag{10}$$

where $\lambda_{i-1.(eff)}$ is the effective length of the upslope are, and $\lambda_{i.seg}$ is the slope length of the segment (= $\lambda_i - \lambda_{i-1}$). $\lambda_{i-1.(eff)}$ will be less than λ_{i-1} when the runoff coefficient for the upslope area is less than that for the segment, equal to λ_{i-1} when the runoff coefficient for the upslope area is equal to that of the segment and greater than λ_{i-1} when the runoff coefficient for the upslope area is greater than that for the segment. Similarly, for a grid cell, Eq. 6 becomes

$$L_{i,j} = \frac{(\chi_{i,j.in.(eff)} + D^2)^{m+1} - (\chi_{i,j.in.(eff)})^{m+1}}{D^{m+2}\, x_{i,j}^{\;m}\; (22.1)^m} \tag{11}$$

where $\chi_{i,j.in.(eff)}$, the effective area of upslope area is less than $\chi_{i,j.in}$ when the runoff coefficient for the upslope area is less than that for the segment, equal to $\chi_{i,j.in}$ when the runoff coefficient for the upslope area is equal to that of the segment and greater than $\chi_{i,j.in}$ when the runoff coefficient for the upslope area is greater than that for the segment.

As noted above, the values of $\lambda_{i-1.(eff)}$ and $\chi_{i,j.in.(eff)}$ vary from λ_{i-1} and $\chi_{i,j.in}$ depending on the values of the runoff ratios in the upslope area ($Q_{C.up}$) and the segment ($Q_{C.seg}$) or cell ($Q_{C.cell}$). One possible approach to determining $\lambda_{i-1.(eff)}$ and $\chi_{i,j.in.(eff)}$ is to multiply λ_{i-1} and $\chi_{i,j.in}$ by the ratio of $Q_{C.up}$ to $Q_{C.seg}$ or $Q_{C.cell}$. However, that approach will cause $\lambda_{i-1.(eff)}$ and $\chi_{i,j.in.(eff)}$ to tend towards infinity as $Q_{C.seg}$ and $Q_{C.cell}$ tend towards zero. An alternative is to use the ratio of $Q_{C.up}$ to the runoff coefficient for the area that includes both the upslope area and either the cell or segment ($Q_{C.all}$):

$$\lambda_{i-1.(eff)} = \lambda_{i-1}\; Q_{C.up} / Q_{C.all} \tag{12}$$

$$\chi_{i,j.in.(eff)} = \chi_{i,j.in.}\; Q_{C.up} / Q_{C.all} \tag{13}$$

Figure 4 shows how the ratio of $Q_{C.up}$ to $Q_{C.all}$ varies as $Q_{C.up}$ varies from 0 to 1 when $Q_{C.all}$ is dependent on an upslope area that is 3 times that of the segment and $Q_{C.seg} = 0.5$. Since $Q_{c.all}$ can only take on a value of zero when both $Q_{C.up}$ and $Q_{C.seg}$ or $Q_{C.cell}$ are zero, the $Q_{C.up}$ to $Q_{C.all}$ ratio will not tend to infinity in the same way as the $Q_{C.up}$ to $Q_{C.seg}$ or $Q_{C.cell}$ ratio. Also, Eqs 12 and 13 are consistent with the concept that the adjustment has to deal with the fact that the upslope area is not producing runoff as it would if the whole area had the same runoff ratio, the condition that, as noted above, is central to operation of the USLE/RUSLE model as it was originally developed.

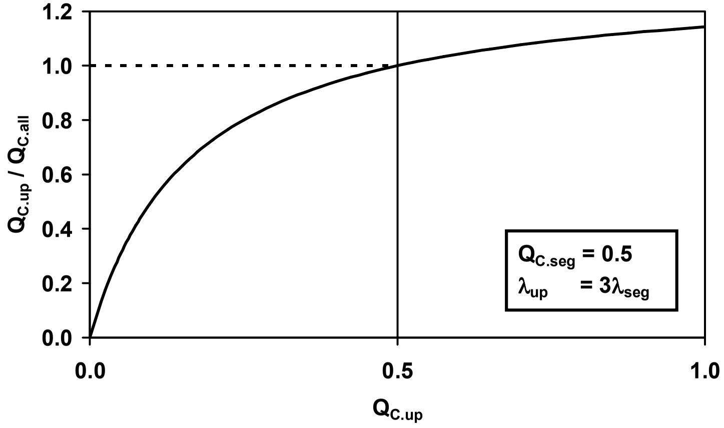

Figure 4: The effect of $Q_{C.up}$ on the ratio of $Q_{C.up}$ to $Q_{C.all}$ for the case where $Q_{C.seg}$ is 0.5 and the length of the upslope area is 3 times that of the segment being considered

Predicting annual soil loss and soil loss from individual events

Although the USLE and the RUSLE were not designed to do so (Wischmeier, 1976; Renard et al, 1997), they have been applied to predict year by year variations in soil loss and, as noted earlier, soil loss from individual rainfall events in the case of AGNPS 5.0. Risse et al (1993) observed that the USLE over predicted low soil losses and under predicted high soil losses when it was applied at both the long term average annual time scale (Figure 5) and the annual time scale. Kinnell and Risse (1998) observed that the event version of Eq. 2,

$$A_{1.e} = R_e K \tag{14}$$

where $A_{1.e}$ is the soil loss generated by a rainstorm on the unit plot and R_e is the product of the total storm kinetic energy (E) and the maximum 30-minute rainfall intensity (I_{30}), over predicted low erosion amounts and under predicted high erosion amounts at some locations (Figure 6)

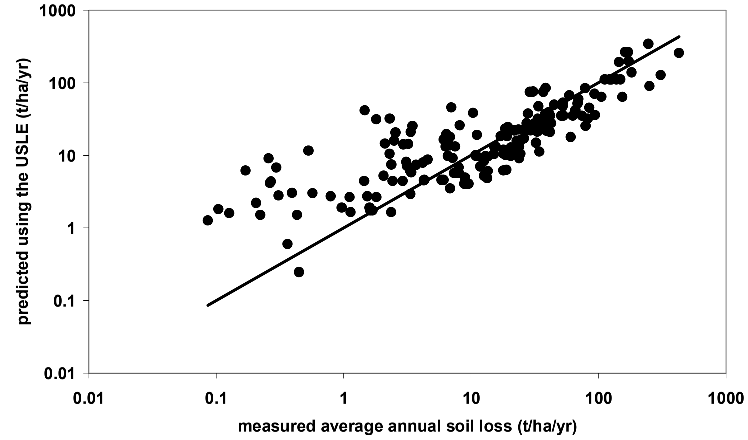

Figure 5. Measured average annual erosion in USLE runoff and soil loss plots in the USA and the values predicted by Risse et al (1993) using the USLE with best available parameter values for R, K, L, S, C and P. The line indicates the perfect fit.

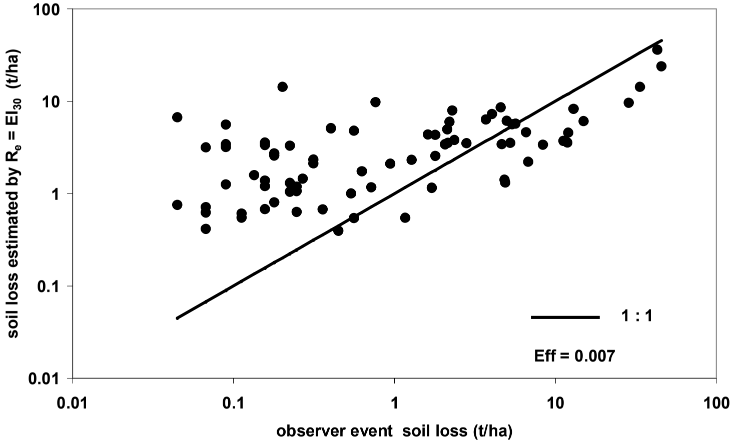

Figure 6. Relationships between observed event soil loss for plot 5 (bare fallow) in experiment 1 at Morris, MN and predicted event soil loss when R_e is EI_{30}. Eff is the Nash – Sutcliffe (1970) efficiency factor for logarithmic transforms of the data. A value zero indicates that the model is no better at predicting the observed data than using the mean.

They observed that replacing the EI_{30} index by the product of that index and the runoff ratio (Q_R) to give,

$$A_{1.e} = Q_{R1}\ E\ I_{30}\ K_{UM} \qquad (15)$$

where Q_{R1} is the runoff ratio for the unit plot and K_{UM} is a soil factor that has a value that differs from K in the USLE and the RUSLE, decreased the tendency to over predict low event soil losses and under predict high event soil losses substantially (Figure 7). In a gross sense, there is an empirical relationship between rainfall and runoff embedded in the USLE that works best when the eroding area is impervious. Consequently, it could be perceived that the runoff ratio provides a correction for situations where the eroding surface is pervious. However, in reality, the product of the runoff ratio and the EI_{30} index is based on the observation that the sediment concentration for an event is dependent on the kinetic energy per unit quantity of rain and a factor that is related to the peak rainfall intensity. Because of this, factors such as K_{UM}, C_{UMe} and P_{UMe} are directed at accounting for variations in event sediment concentration rather than both runoff and sediment concentration as is the case in the USLE.

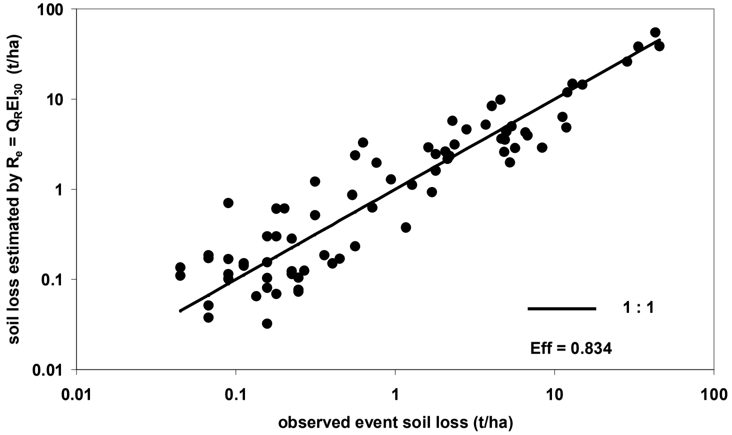

Figure 7. Relationships between observed event soil loss for plot 5 (bare fallow) in experiment 1 at Morris, MN and predicted event soil loss when R_e is Q_REI_{30}

Kinnell (2005) drew attention to the fact that, because runoff is not always generated on both vegetated and bare fallow areas during any given event, the event version of Eq. 3,

$$A_e = A_{1.e}\ L\ S\ C_e\ P_e \qquad (16)$$

tended to predict soil loss to occur on vegetated areas when, on many occasions, none actually occurred. To avoid this problem, the USLE-M (Kinnell and Risse, 1998) used runoff from vegetated areas in the determination of the Q_REI_{30} index with the consequence that

$$A_e = Q_R\ EI_{30}\ K_{UM}\ L\ S\ C_{UMe}\ P_{UMe} \qquad (17)$$

where Q_R is the runoff ratio for the vegetated area, and C_{UMe} and P_{UMe} differ in value from C and P because of that.

A number of other rainfall-runoff factors have been proposed. For example, in EPIC, a model designed to assess the effect of soil erosion on productivity (Williams et al., 1984), event sediment yield is predicted by

$$SY_e = X_e\ K\ L\ S\ C_e P_e\ [ROKF] \qquad (18)$$

where ROKF is the coarse fragment factor as defined by Simanton et al (1984), K, L and S are the normal USLE factors for the soil and topographic effects, C_e and P_e are event values for the USLE C and P factors, and X_e, the rainfall-runoff “erosivity” factor, is selected from

$$X_e = E\ I_{30} \qquad (19a)$$

$$X_e = 1.586\ (Q_e\ q_{pe})^{0.56}\ DA^{0.12} \qquad (19b)$$

$$X_e = 0.65\ E\ I_{30} + 0.45\ (Q_e\ q_{pe})^{0.33} \qquad (19c)$$

where DA is drainage area expressed in ha, Q_e is runoff expressed in mm, q_{pe} is peak runoff rate expressed in mm/h, $E\ I_{30}$ in MJ.mm/ha.h and SY_e is the sediment yield for the event in t/ha (Williams and Arnold, 1997). However, given that K is the sum of event soil loss from the unit plot divided by the sum of event values of the EI_{30} index, K can only be used when $X_e = E\ I_{30}$. Also, as with the USLE-M, if, as is the case with EPIC, runoff from the area of interest and not the unit plot is used for Q_e, then C_e and P_e cannot be used when X_e is given by either Eq. 19b or 19c. Thus the combination of Eq.18 and either Eq.19b or Eq.19c is not valid.

Williams et al (1984) indicated that Onstad and Foster (1975) was the source of Eq. 15c. However, the approach used by Onstad and Foster gave an equation that had the form

$$R_e = a\ E\ I_{30} + b\ Q\ (q_p)^{0.333} \qquad (20)$$

rather than

$$R_e = a\ E\ I_{30} + b\ (Qq_p)^{0.333} \qquad (21)$$

In addition, Foster et al. (1977) used a = 0.5 and b = 0.5 α where α was a factor that caused the average annual value of R_e produced by Eq. 20 using Q and q_p values obtained for the unit plot to equal the average annual value of R_e when $R_e = E\ I_{30}$. Because of this, Eq. 20 can be used with USLE K, C and P values while Eq. 19c cannot. In applying Eq. 20 to the data of Piest et al (1975), Foster et al (1977) were fortunate that the crop in the Treynor watersheds was corn and corn has little impact on runoff generation when compared to bare fallow (Kinnell and Risse, 1998).

Eq. 19b is based on the so called Modified Universal Soil Loss Equation (MUSLE) proposed by Williams (1975). In the Soil and Water Assessment Tool (SWAT) (Arnold et al, 1995), a model which, like AGNPS 5.0 is designed to determine the impact of land use on water quality, the MUSLE is used to predict event sediment yield from hillslopes. As with EPIC, the MUSLE uses the USLE factors to account for variations in soil erodibility and the effects of crops and soil conservation practices,

$$SY_e = 11.8\,(Q_e\, q_{pe})^{0.56}\, K\, L\, S\, C_e\, P_e \qquad (21)$$

where SY_e is in tonnes, Q is volume of runoff in m^3, q_p is peak flow rate in m^3/s (Williams and Berndt, 1977). Consequently, the MUSLE is technically an invalid variant of the USLE. Only the USLE-M takes account of the impact of changing the event erosivity factor from the EI_{30} index but, as with the USLE or the RUSLE, the USLE-M does not take account of the effect of deposition on concave hillslopes. To do so, the USLE-M must operate in conjunction with an approach that deals appropriately with deposition when the sediment supply to a segment or cell exceeds the transport capacity of that segment or cell.

CONCLUSION

The USLE was originally designed to predict the long term average annual soil loss from uniform planar areas and values for the K, L, S, C and P factors were determined from more than 10,000 plot years of data collected from runoff and soil loss plots in the USA. The Revised USLE (RUSLE) retained the fundamental mathematical structure of the USLE as described by Eqs. 1, 2, and 3, but the technology for factor evaluation was altered and new data introduced with which terms for specific conditions are evaluated. These changes moved the USLE from an empirically based model to a more conceptual one that enabled predictions to be made for conditions not experienced in the original experiments. Included in the RUSLE is a provision to predict soil loss from irregular and segmented slopes. However, while provision was made in the RUSLE to deal with deposition resulting from cross-slope strip cropping, buffer strips and filter strips, no provision was made to deal with deposition that results from reductions in slope gradient. Consequently, it has been common practice in catchment scale models to ignore the fact that the USLE and the RUSLE slope length factor is, by definition, dependent on the distance from the onset of runoff to the point were deposition begins on concave slopes, and use sediment delivery ratios to correct for the overestimation of the amount of sediment delivered from hillslopes to rivers and streams. This approach is flawed because deposition on concave slopes results from the amount of sediment entering the deposition zone exceeding the capacity of surface water flow to transport sediment through that zone and, as a result, sediment delivery ratios vary with the amount of sediment delivered from upslope. Because they are potentially less flawed in terms of the way they deal with deposition of concave slopes, models that deal with deposition by considering sediment transport capacity explicitly are to be preferred to models that deal with deposition using sediment delivery ratios.

Given Trimble's (1975) definition that erosion measurement is "the total amount of soil material dislocated and removed some distance by erosion within an area", and the observation that, in experiments by a number of people, particles, particularly large ones, have been observed to travel limited distances downslope from their initial position over the duration of the experiments, concern has been raised about the ability of the USLE and the RUSLE to predict erosion. The problem here is not that the USLE and the RUSLE do not do what they are intended to do, predict the long term average annual soil loss from a given area, but what the word "erosion" means to different people. To some people, soil loss from an area is erosion but, given Trimble's definition, and the definition of sediment yield as the amount of sediment discharged per unit area, soil loss from an area is sediment yield. Given that the objective of the USLE and the RUSLE is to predict the long term average annual soil loss, the distinction is academic but the fact that the USLE and the RUSLE do not account for deposition resulting from reductions in slope gradient is not.

Although neither the USLE nor the RUSLE were designed to do so, they have been used to predict soil loss on the annual or event time frames. Foster et al. (1982) observed that including runoff as a factor in the event erosivity index increased the ability of the event erosivity factor to account for variations in event soil loss. However, simply replacing the EI_{30} index by another which includes direct consideration of runoff without considering the impact this has in terms of using K, C and P, as is done in EPIC and the MUSLE, produces an invalid modification of the USLE and the RUSLE. The USLE-M equation, which uses the product of the runoff ratio and the EI_{30} index, does recognize that values for the soil, crop and soil conservation protection factors used in the model differ from those used in the USLE and the RUSLE. Also, modifications of the equations for effect of slope length on soil loss in segments and cells provide a capacity to account for the spatial variation in the generation of runoff.

It should also be noted that while the soil loss is given in terms of mass per unit area, the soil loss predicted by the USLE or the RUSLE applies to a specific sized area at a specific geographic location. It cannot be extrapolated to other areas which differ in terms of climate, soil, topography or vegetation.

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