Runoff dependent erosivity and slope length factors suitable for modelling annual erosion using the Universal Soil Loss Equation

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Abstract

Despite revisions and refinements, RUSLE, the revised version of the Universal Soil Loss Equation, over predicts small annual soil losses and under predicts large annual soil losses. To some large extent, this results from the equation over estimating small event soil losses and under estimating large event soil losses. Replacing the USLE/RUSLE event erosivity index, EI_{30}, by the product of EI_{30} and the runoff ratio (Q_R) significantly reduces the errors in estimating event erosion when runoff is measured but the USLE-M, the USLE variant that uses the Q_REI_{30} index, requires crop and support practice factors that differ from those used in the RUSLE. The theory which enables the Q_REI_{30} index to be used in association with the RUSLE crop and support practice factors is presented. In addition, the USLE/RUSLE approach was developed for conditions where runoff is produced uniformly over a hillslope. A runoff dependent slope length factor that takes account of runoff variations over a hillslope is presented and demonstrated for the situation where runoff from a low runoff producing area passes onto an area where runoff is produced more readily.

Keywords: rainfall erosion, predicting soil loss, non uniform hillslopes.

INTRODUCTION

The Universal Soil Loss Equation (USLE, Wischmeir and Smith, 1965,1978), including the revised version of it (RUSLE, Renard et al., 1997),

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

where A is the long term annual average soil loss, R is the rainfall-runoff "erosivity" factor, K is the soil "erodibility" factor, L is the slope length factor, C is the crop and crop management factor, and P is the support practice factor, is the most widely used erosion prediction model in the world despite it having short comings, and other more process-based models like WEPP (Laflen et al., 1997) and EUROSEM (Morgan et al., 1998) being available. So called process-based models are often too data and computationally intensive to use in many circumstances, particularly in respect to modelling non point source pollution in medium and large watersheds or catchments. The USLE approach holds the advantage in such circumstances because of a perceived ease of parameterisation and use. While originally developed as an empirical model, revision of the USLE has led to a more conceptual model that provides a capacity to extend well beyond the conditions experienced in the associated data set. RUSLE2 (Yoder and Lowan, 1995; Foster et. al., 2003) is a computer program which predicts not just erosion on complex hillslopes, but also deposition, thus enabling sediment delivery from hillslopes to also be predicted.

Despite revisions and refinements, RUSLE, the revised version of the USLE, over predicts small average annual soil losses and under predicts large average annual soil losses (Risse et al., 1993). The RUSLE also over predicts small annual soil losses and under predicts large annual soil losses (Risse et al., 1993). The USLE/RUSLE model is based on the prediction of erosion for the unit plot condition (22.1m long slope, 9% gradient, bare fallow with cultivation up and down the slope) and the L, S, C and P factors are ratios with respect to the unit plot. For example, the

C factor is the ratio of the soil loss from a cropped area to that from a bare fallow area. Thus, the approach is in effect a two staged one; the prediction of erosion for the unit plot condition where

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

where A_1 is the annual average erosion on the unit plot, R is the annual average erosivity factor and K is the average annual soil erodibility, followed by

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

where A is the average annual erosion on an area that differs from the unit plot is some way. It follows from this that any error obtained in predicting erosion for the unit plot condition will be transmitted to the prediction of erosion on a cropped area.

In the USLE and RUSLE, R is the long term average annual value of the erosivity of individual rainfall events. Event erosivity is given by EI_{30}, the product of the total kinetic energy of the rainstorm (E) and the maximum 30-minute intensity (I_{30}). Consequently, for a bare fallow plot with cultivation up and down the slope,

$$A_{BUe} = k\ K\ EI_{30} \qquad (4)$$

where A_{BUe} is event soil loss (mass per unit area), k is an empirical factor that varies with slope length and gradient, and K is the soil erodibility factor which, in the context of Eq. 4, is assumed to remain constant with time as specified by Wischmeir and Smith (1965, 1978). Originally, K was determined from soil loss data obtained from runoff and soil loss plots in the USA by dividing the average annual soil loss observed for the unit plot condition (A_1) by R. A procedure for predicting K from soil properties was subsequently developed by Wischmeier et al. (1971)

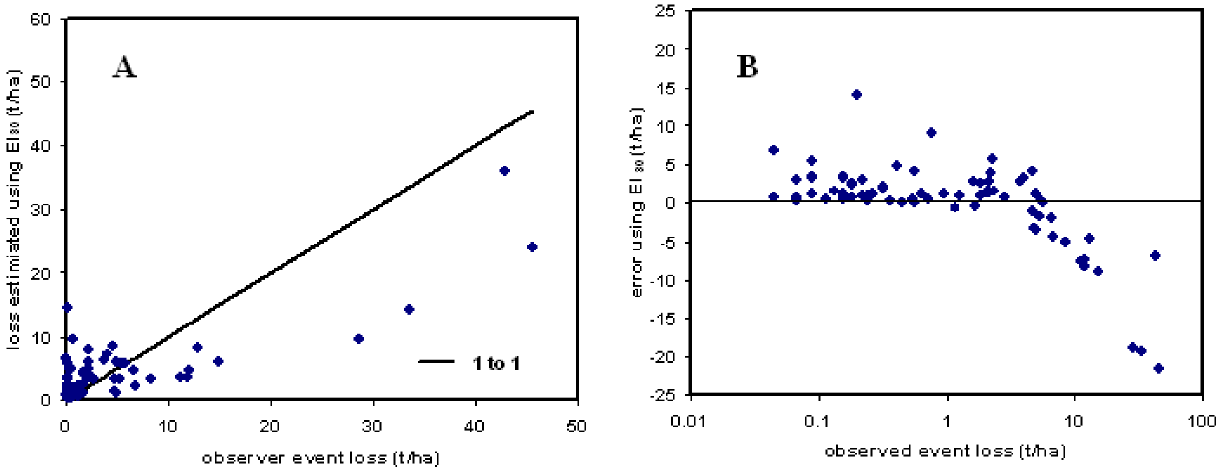

Figure 1. Relationships between event soil loss observed for plot 5 (bare fallow) in experiment 1 at Morris, MN between July 1961 and November 1971 and event soil loss estimated using the EI_{30} index (Eq. 4). NB. This analysis takes no account of short term variations in K

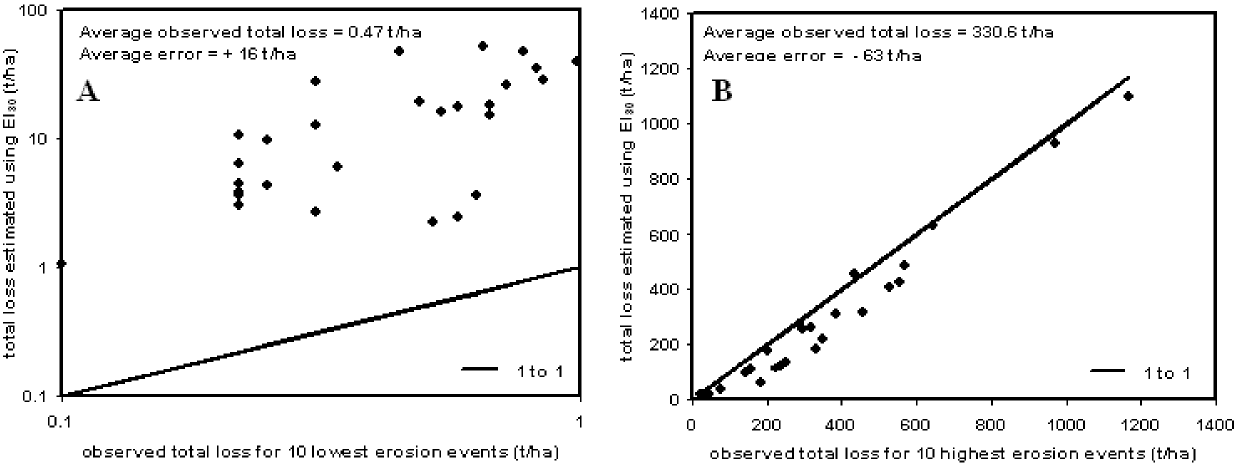

Figure 2. Relationships between observed and total losses estimated using the EI_{30} index (A) for 10 events producing the lowest erosion losses and (B) 10 events producing the highest erosion losses on each of 28 bare fallow runoff and soil loss plots spread over 15 locations in the USA constituting part of the USLE data base

Figure 1A shows the relationship between soil losses estimated using Eq. 4 and actual soil losses observed for rainfall events producing runoff on a bare fallow plot in experiment 1 at Morris, MN between July 1961 and November 1971. The data used for in this analysis came from the USA USLE data base. The total loss from the plot was 319 t ha^{-1} from 76 events over the 10 years. Figure 1B shows that, in general, Eq. 4 over predicts erosion losses for event producing losses less than 5 t/ha and under predicts erosion losses for events producing losses greater that 5 t/ha. The top 10 events produced 222 t ha^{-1}. The USLE approach (Eq. 4) estimated the loss to be 114 t ha^{-1} (-48 % error). The 10 events producing the lowest soil loss contributed 0.72 t ha^{-1}. The USLE approach estimated to loss to be 26 t ha^{-1} for these events, an error of + 3510 %. As indicted by Figure 2, the over estimation of low soil losses and under estimation of high soil losses is common when the EI_{30} index is used in estimating erosion on bare fallow areas. As with Figure 1, the data used for in this analysis came from the USA USLE data base. Although the USLE was not designed to predict event soil loss accurately, this inherent capacity to systematically over estimate and under estimate event soil losses from bare fallow surfaces at most geographic locations influences its capacity to predict annual soil loss.

Logically, using an approach that improves the accuracy of the estimation of event soil loss for the unit plot condition will improve the prediction of annual soil loss on the unit plot and hence the prediction of annual erosion for cropped areas. To do this, the EI_{30} index must be replaced by one that is better suited to predicting event erosion. The Q_REI_{30} index (Kinnell, 1997; Kinnell and Risse, 1998) has been shown to do this when runoff amounts are known accurately. It is possible to gain from the capacity of the Q_REI_{30} index to over come the over estimation – under estimation problem associated with the USLE in a way that enables values for C and P to be used. The theory associated with this approach is documented here. In addition, the USLE was originally designed to apply to a uniform slope containing one soil and cropping practice but, as noted above, has been subsequently applied to more complex situations. A runoff dependent slope length factor is described to account for the impact of variations in upslope runoff on erosion within a segment.

THEORY

Although the Q_REI_{30} index is an empirical index, it is based on the concept that the sediment discharged from an eroding area is given by the product of runoff and sediment concentration. Kinnell (1997) suggested that the sediment concentration for a rainfall event depended on the kinetic energy per unit quantity of rain during the storm and a measure of storm rainfall intensity. Kinnell suggested that I_{30} could be used as that measure of storm rainfall intensity so that event erosivity was given by the product of the runoff amount, I_{30}, and E and divided by rainfall amount. Since the runoff ratio (Q_R) is given by runoff amount by rainfall amount, the product of the runoff amount, I_{30}, and E and divided by rainfall amount simplifies to the $Q_R EI_{30}$ index .

The USLE-M (Kinnell and Risse, 1998), a modification of the USLE which uses the $Q_R EI_{30}$ index, was designed to estimate event erosion on vegetated areas without using the two stepped approach used by the USLE/RUSLE. As a consequence, the USLE-M is described by

$$A_e = R_{UM.e}\ K_{UM.e}\ L\ S\ C_{UM.e}\ P_{UM.e} \qquad (5)$$

where $R_{UM.e} = Q_R EI_{30}$ with Q_R, the runoff ratio (runoff divided by rainfall), calculated using runoff from the cropped area, $K_{UM.e}$ is the soil erodibility for the event, and $C_{UM.e}$ and $P_{UM.e}$ are the crop and support practice factors for the event. Eq. 5 leads to long term erosion being given by

$$A = R_{UM}\ K_{UM}\ L\ S\ C_{UM}\ P_{UM} \qquad (6)$$

where R_{UM} is the average annual value of the $Q_R EI_{30}$ index determined using runoff from the cropped area, K_{UM} is the soil erodibilty factor that takes on values that differ from the USLE soil erodibility factor (K). Likewise, C_{UM} and P_{UM} are, respectively, crop and crop management and support practice factors that have values that differ from their USLE counterparts (C, P). As can be seen from comparing Eq. 6 with Eq. 1, only two (L, S) of the 6 factors used in the USLE-M and the USLE have common values. Kinnell and Risse (1998) presented values for K_{UM} for number of soils in the USA and C_{UM} for a number of cropping systems on those soils obtained by analysing data from the USLE data base. However, apart from the need to develop new procedures to determine values for rainfall erosivity and soil erodibility, the USLE-M requires a new set of procedures to be developed for determining the effects of crop and crop management and support practices before it can be used to predict erosion in the situations where the USLE/RUSLE approach can be used. A lack of such procedures is currently inhibiting the application of the USLE-M.

Using the $Q_R EI_{30}$ index together with USLE Factors

The equation for estimating event erosion for the bare fallow up and down the slope condition using the $Q_R EI_{30}$ index is given by

$$A_{eBU} = k\ K_{UM}\ Q_R EI_{30} \qquad (7)$$

where, as in Eq. 4, k is an empirical factor that varies with slope length and gradient, and K_{UM} is a soil dependent factor which, in the context of Eq. 7, is assumed to remain constant with time. Because the product of Q_R and EI_{30} is not numerically the same as EI_{30}, K_{UM} takes on values that differ from K (Kinnell and Risse, 1998). When compared with Figure 1, Figure 3 illustrates the gain in terms of removing the systematic errors associated with predicting event erosion obtained replacing the EI_{30} index with the $Q_R EI_{30}$ index when runoff amounts are known accurately. As noted earlier, the top 10 events on the bare fallow plot in experiment 1 at Morris, MN produced 222 t ha^{-1}. The USLE approach (Eq. 4) predicted 114 t ha^{-1} (-48% error) while using the $Q_R EI_{30}$ index (Eq. 7) predicted 213 t ha^{-1} (-4% error). The 10 events producing the lowest soil loss contributed 0.72 t ha^{-1}. The USLE approach predicted 26 t ha^{-1} for these events while using the $Q_R EI_{30}$ index index predicted 1.78 t ha^{-1}.

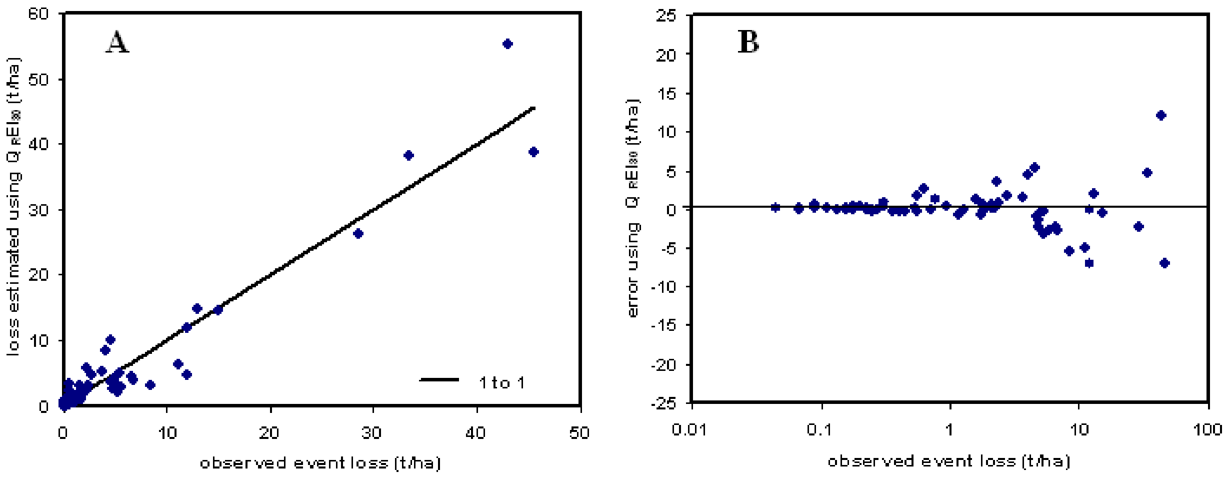

Figure 3. Relationships between event soil loss observed for plot 5 (bare fallow) in experiment 1 at Morris, MN between July 1961 and November 1971 and event soil loss estimated using the $Q_RE I_{30}$ index (Eq. 7) when runoff amounts are known accurately. NB. This analysis takes no account of short term variations in K_{UM}.

Conceptually, the EI_{30} index accounts for the effect of runoff on erosion best when the soil surface is impervious, and as observed in an analysis of data from 14 locations in the USA and one in Australia by Kinnell and Risse (1998), the gain in favour of the Q_REI_{30} index diminishes as the infiltration capacity of the soil between locations decreases. Morris, MN is one location where the Q_REI_{30} index is much more effective in accounting for event erosion on bare soil than the EI_{30} index. However, as illustrated by Figure 4, the Q_REI_{30} index estimated low erosion losses from 28 bare fallow plots in the USA better than the EI_{30} index and, except for events producing, on average, more than 50 t/ha of soil loss per event, produced little bias in estimating high soil loss while the EI_{30} index consistently under estimated high erosion losses.

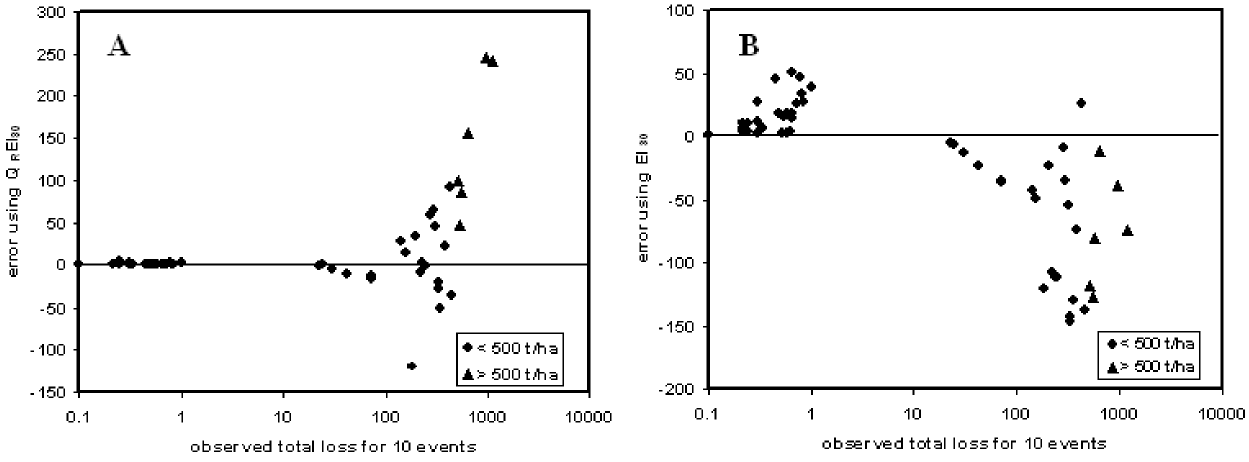

Figure 4. Relationships between observed and total losses estimated using (A) the Q_REI_{30} index and (B) the EI_{30} index for 10 events producing the lowest erosion losses and 10 events producing the highest erosion losses on each of 28 bare fallow runoff and soil loss plots spread over 15 locations in the USA constituting part of the USLE data base.

With the USLE and RUSLE, the long term annual erosion for the unit plot condition is predicted in terms of R and K (Eq. 2) given

$$R = \sum_{e=1}^{N} (EI_{30})_e / Y \tag{8}$$

where N is the number of valid rainstorms and Y is the number of years. It follows that, in the case of the Q_REI_{30} index, the long term annual erosion for the unit plot condition is given by

$$A_1 = R_{UM.1}\ K_{UM} \tag{9}$$

where R_{UM} for the bare fallow up and down the slope condition ($R_{UM.1}$) is given by

$$R_{UM.1} = \sum_{e=1}^{N} (Q_{R1}EI_{30})_e / Y \tag{10}$$

where Q_{R1} is the runoff ratio based on the runoff that occurs from the bare fallow, cultivation up and down the slope condition. Combining Eqs. 3 and 9 gives

$$A = R_{UM.1}\ K_{UM}\ L\ S\ C\ P \tag{11}$$

Eq.11 differs from Eq. 6 simply because the erosivity factor is based on runoff from the bare fallow, up and down the slope condition rather than runoff from the cropped area. The reason why the USLE-M uses runoff from the cropped area is because it is directed at prediction event erosion and runoff from the cropped plot may not necessarily occur when runoff occurs on the bare fallow up and down the slope condition producing a result such as illustrated in Figure 5. To distinguish between the two approaches, the approach that allows the USLE C and P to be used with the Q_REI_{30} index will be referred to as the USLE-M "lite".

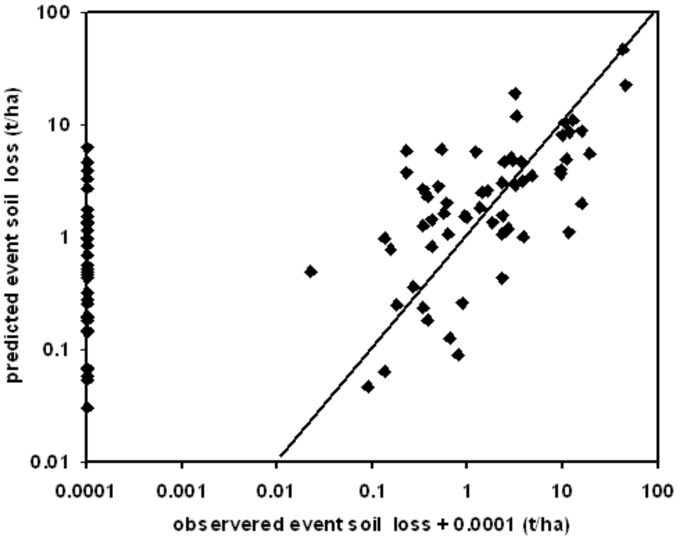

Figure 5. Relationship between event soil losses predicted by multiplying event soil losses from a nearby bare fallow plot by RUSLE period Soil Loss Ratios (fortnightly C factor values) and event soil losses observed for conventional corn at Clarinda, Iowa plus 0.0001 t ha^{-1} to enable predicted losses to be displayed when observed losses are zero.

Runoff dependent slope length factor

The slope length factor (L) for the Universal Soil Loss Equation (USLE) is given by

$$L = (\lambda/\lambda_1)^m \qquad (12)$$

where λ is the length of the slope being considered and λ_1 is the slope length of the unit plot (Wischmeier and Smith, 1965, 1978). Eq. 12 also applies to the Revised Universal Soil Loss Equation (RUSLE). m is a factor that varies with slope gradient in the USLE (Wischmeier and Smith,1965, 1978) or with the rill to interrill ratio in the RUSLE (Renard et al., 1997). In both the USLE and the RUSLE, slope length is defined as the horizantal distance from the origin of overland flow to the point where deposition begins or runoff becomes concentrated into a channel that is not a rill. λ_1 is 72.6 feet or 22.13 metres.

Eq. 12 was developed on uniform slopes. For non-uniform slopes, the slope length factor for segement i (L_i) is given by (Renard el al., 1997)

$$L_i = \frac{\lambda_i^{m+1} - \lambda_{i-1}^{m+1}}{(\lambda_i - \lambda_{i-1})\ \lambda_1^m} \qquad (13)$$

where λ_i is the length of the slope including the cell and λ_{i-1} is the length of slope upslope of the segment. Desment and Govers (1996) extended Eq. 13 to the calculation of slope length for a grid cell with co-ordinates i,j by replacing λ by the contributing area (A) divided by the width of the contour (w) over which the overflow flow from that area flows. This approach gives

$$L_{i,j} = \frac{(A_{i,j.in} + D^2)^{m+1} - A_{i,j.in}^{m+1}}{D^{m+2}\ x_{i,j}^m\ \lambda_1^m} \qquad (14)$$

where $A_{i,j.in}$ 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 variations in flow width that depend on the direction of flow relative to cell orientation.

For a rectangular area, the numerical values of A/w and λ are exactly the same. The argument for using A/w rather than the length of longest flow path in a non rectangular area is that, in a segment or grid cell, the effect of the upslope area is more to do with the flow of water into the cell than the length of the flow path and that, with a uniform area, that inflow is directly related to the size of the contributing area. However, there are many examples where Eqs. 13 and 14 have been applied to areas which are not uniform with respect to soil and/or crop. Under these conditions, the relationship between inflow to a segment or grid cell is not necessarily related to upslope contributing area alone. An extreme example is the case when a rain falls on a newly cultivated upslope area that consequently produces no runoff yet runoff is produced in the segment or cell.

Obviously, if the upslope area is completely previous, then following the definition of slope length for the USLE, λ_{i-1} must be set to zero when calculating the slope length factor for a segment via Eq. 13. Likewise, $A_{i,j.in}$ must be set to zero when calculating the slope length factor for a cell via Eq. 14. However, there will be situations when the upslope area contributes little runoff and produces situations where the slope length factors lie close to the zero inflow case. In addition, the slope length factors will tend towards those calculated via Eqs. 13 and 14 as the inflow increases towards that produced if the whole area were uniform. Under these circumstances, the effective values of λ_{i-1} and $A_{i,j.in}$ vary with the ability of the upslope area to produce runoff relative to its ability to produce runoff when the crop and soil conditions in the upslope area are the same as in the segment or cell. Conceptually,

$$L_i = \frac{(\lambda_{i-1.(eff)} + \lambda_{i.seg})^{m+1} - (\lambda_{i-1.(eff)})^{m+1}}{\lambda_{i.seg}\, \lambda_1^{m}} \qquad (15)$$

where $\lambda_{i-1.(eff)}$ is the effective length of the upslope area, $\lambda_{i.seg}$ is the slope length of the segment (= $\lambda_i - \lambda_{i-1}$), and $\lambda_{i-1.(eff)}$ 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,

$$L_{i,j} = \frac{(A_{i,j.in.(eff)} + D^2)^{m+1} - (A_{i,j.in.(eff)})^{m+1}}{D^{m+2}\, x_{i,j}^{m}\, \lambda_1^{m}} \qquad (16)$$

where $A_{i,j.in.(eff)}$, the effective area of upslope area is less than $A_{i,j.in}$ when the runoff coefficient for the upslope area is less than that for the segment, equal to $\lambda\ A_{i,j.in}$ when the runoff coefficient for the upslope area is equal to that of the segment and greater than $A_{i,j.in}$ 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 $A_{i,j.in.(eff)}$ vary from λ_{i-1} and $A_{i,j.in}$ 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 $A_{i,j.in.(eff)}$ is to multiply λ_{i-1} and $A_{i,j.in}$ 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 $A_{i,j.in.(eff)}$ 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 ($Q_{C.all}$):

$$\lambda_{i-1.(eff)} = \lambda_{i-1}\ Q_{C.up} / Q_{C.all} \qquad (17)$$

$$A_{i,j.in.(eff)} = A_{i,j.in.}\ Q_{C.up} / Q_{C.all} \qquad (18)$$

Figure 6 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. Figure 7 shows the effect on L_i of $Q_{C.up}$ varying 0 to 1 when the segment runoff coefficient is 0.6, the segment length is 25 m and the length of the hillslope above the segment is 175 m when L_i is calculated from Eqs. 15 and 17. The values of L_i for a 25 m slope and a 200 m slope are provided for comparison. $L_{i,j}$ calculated from Eqs.16 and 18 for a 25 m grid cell will show the same variation given an upslope area of 4375 m^2.

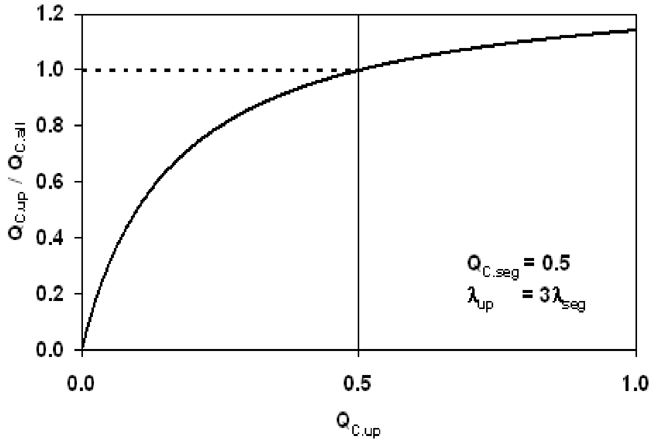

Figure 6: The effect of $Q_{C.up}$ on the ratio of $Q_{C.up}$ to $Q_{C.all}$ for the case where $Q_{C.seg}$ is 0.5 and the length of the upslope area is 3 times that of the segment being considered

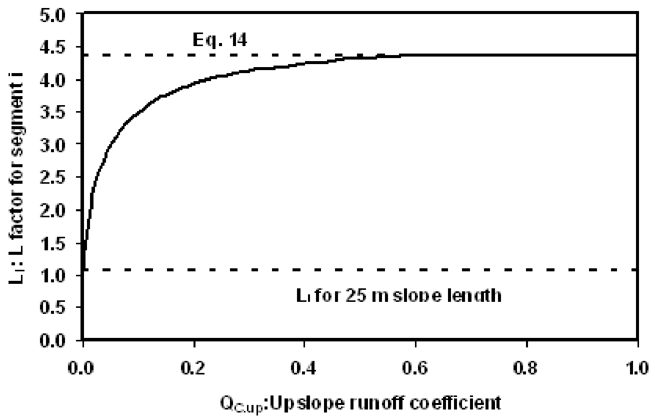

Figure 7. Variation in the runoff based L factor value determined from Eqs. 16 and 18 for a 25 m long segment in relation to variations in the runoff coefficient in a 175 m long area upslope of the segment. L factor values for the segment receiving no runoff from upslope and the equation used in the RUSLE (Eq. 14) are shown as dotted lines

DISCUSSION

Foster et al. (1982) evaluated a number of rainfall-runoff erosivity factors for individual storms but did not consider the Q_REI_{30} index. They concluded that erosivity factors that include terms for volume and rate of rainfall and runoff are better than the EI_{30} index, and that the major advantage of an erosivity factor that includes runoff terms is the reduction of large over estimates of soil loss when runoff is negligible and rainfall amounts and rates are great. They also concluded that conversely, the amount of under estimation is reduced when runoff is great relative to rainfall. The data presented here, and in Kinnell and Risse (1998), shows that the Q_REI_{30} index operates in a manner that is consistent with these conclusions. Nearing et al. (1999) suggested that a replicate of an experiment provided the best possible prediction model and analysed predictions based on applying that approach to data from field experiments in the USLE database. Figure 8 shows the comparison between observed event losses for plot 5 in experiment 1 at Morris, MN and those estimated using the Q_REI_{30} index together with the curves representing 95% confidence that results from analysis of replicates in the USLE database by Nearing et al. When runoff is known accurately, the Q_REI_{30} index produces estimates of event erosion that are, in many cases, as accurate as can be estimated using a replicate. Foster et al. (1982) suggested that erosivity factors should take account of the separate contribution of rill and interrill erosion to the total soil loss for an event. However, they noted that the relative importance of interrill and rill erosion could not be identified in the experiments they analysed, and this is also the case for the data presented here, and by Kinnell and Risse (1998). Part of the "random" variation observed between events is likely to be caused by variation in the relative importance of sheet, interrill and rill erosion over time.

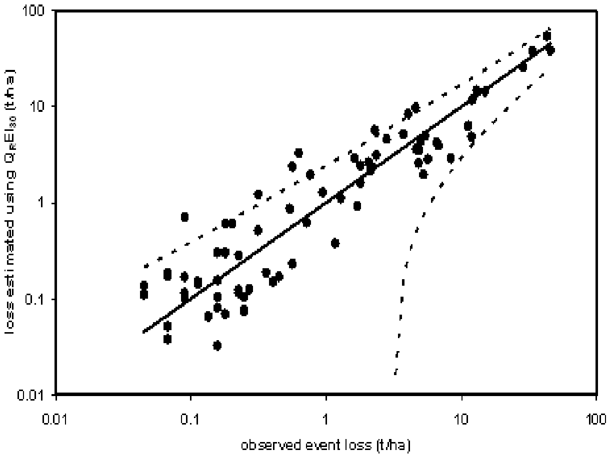

Figure 8. Relationships between event soil loss observed for plot 5 (bare fallow) in experiment 1 at Morris, MN between July 1961 and November 1971 and event soil loss estimated using the $Q_R EI_{30}$ index (Eq. 7) when runoff amounts are known accurately. The dotted lines represent the 95% confidence limits based on the analysis of Nearing et al. (1999) of data from the USLE database. NB. This analysis takes no account of short term variations in K_{UM}

There are other variants of the USLE than include runoff as a term in the event erosivity index. For example, Williams (1975) proposed a variant of the USLE which uses an event erosivity index given by the product of runoff and peak runoff rate to a power less than 1.0.This variant has subsequently become known as the Modified Universal Soil Loss Equation (MUSLE) but the model is flawed because of inappropriate use of USLE parameter values (Kinnell, 2003, 2004). The approach adopted in Eq. 11 avoids this problem. Also, Kinnell (2003) has shown the $Q_R EI_{30}$ index is better at predicting event erosion from cropped plots than the index proposed by Williams.

Currently, the application of the USLE-M is limited because of the need to re-evaluate the factors associated with the soil, the crop and conservation practices. Given that procedures exist to convert annual K to annual K_{UM} (Kinnell and Risse, 1998), and values for the other USLE/RUSLE factors can be used without modification provided that the $Q_R EI_{30}$ index is used to predict erosion for the bare fallow with cultivation up and down the slope condition, the USLE-M lite provides an approach that can be used to predict long term erosion using the existing USLE/RUSLE procedures for determining the effects of crops and crop management on erosion. The USLE-M lite is not a direct replacement for the USLE-M in predicting event erosion because using it in that manner one assumes that erosion occurs when $C \neq 1$ and $P \neq 1$ under the same rainfall conditions as when erosion occurs when $C = 1$ and $P = 1$, an assumption that is not supported by Figure 5. However, the USLE-M lite approach does have a role predicting erosion over a longer time frame.

As noted above, the L factor for the USLE and RUSLE was originally developed for areas that are uniform with respect to both soil and cropping practice. The equation for the slope length factor for a segment (Eq. 14) presented by Renard et al (1997) was also directed at areas that are uniform with respect to both soil and cropping practice. However, models like RUSLE2 apply it to hillslopes that are not uniform with respect to both soil and cropping practice, a situation where runoff is not generated uniformly over the hillslope. Such circumstances warrant the application of a different equation such as Eq. 15 presented above. Eqs. 15 and 16 can be used at the event, annual, and long term average annual timescales.

To illustrate the effect the runoff dependent slope length factor on the how erosion varies spatially, consider the situation depicted in Figure 9, a 1.5 ha area where runoff from an area of Bermuda grass passes into an area cropped with a wheat-clover-cotton rotation. The soil is a fine sandy loam. The runoff coefficients for bare soil, the wheat-clover-cotton rotation and Bermuda grass are 0.47, 0.18 and 0.01 respectively. These runoff coefficients relate to the USLE plots at Guthrie, Oklahoma, analysed by Kinnell and Risse (1998) in relation to determining values for K_{UM} and C_{UM}. Table 1 shows the L factor values calculated for the 25 m grid cells using the Desmet and Govers equation (Eq. 14) and the runoff dependent approach (Eqs. 16 and 18). The two approaches produce identical L factor values in the area containing Bermuda grass but the values are not identical in the area cropped with the wheat-clover-cotton rotation. The discrepancy is greatest in the cells adjacent to the divide between the two cropping systems. The results imply that the Desmet and Govers approach over predicts erosion in these cells.

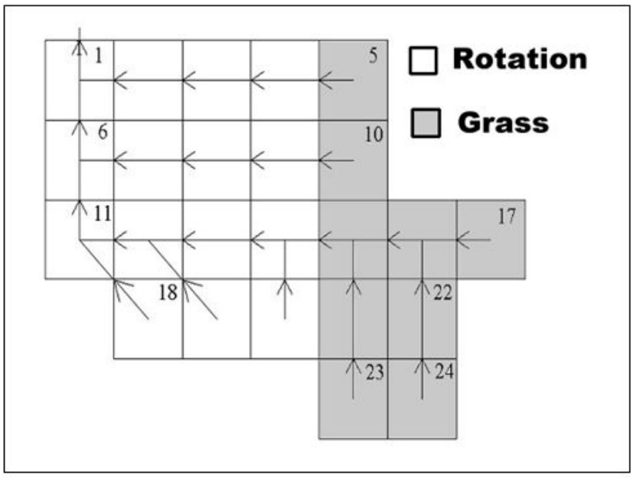

Figure 9. Grid cell map of a 1.5 ha area where runoff from an area of Bermuda grass passes onto an area subjected to a wheat-clover-cotton rotation. Each cell is 25 m by 25 m (0.625 ha). The arrows indicate the direction of flow

Table 1. L factor values for grid cells shown in Figure 9.

cell	**1**	**2**	**3**	**4**	**5**		
runoff coefficient	0.18	0.18	0.18	0.18	0.01		
slope gradient (%)	3	3	3	4	4		
L Desmet and Govers (Eq. 14)	5.20	2.43	2.12	1.72	1.05		
L Eq. 16	5.15	2.34	1.95	1.16	1.05		
ratio Eq. 16 : Eq. 14	0.99	0.96	0.92	0.68	1.00		
cell	**6**	**7**	**8**	**9**	**10**		
runoff coefficient	0.18	0.18	0.3	0.18	0.01		
slope gradient (%)	2	3	4	4	4		
L Desmet and Govers (Eq. 14)	3.24	2.43	2.12	1.72	1.05		
L Eq. 16	3.20	2.34	1.95	1.16	1.05		
ratio Eq. 16 : Eq. 14	0.99	0.96	0.92	0.68	1.00		
cell	**11**	**12**	**13**	**14**	**15**	**16**	**17**
runoff coefficient	0.18	0.18	0.18	0.18	0.01	0.01	0.01
slope gradient (%)	2	3	4	5	4	3	3
L Desmet and Govers (Eq. 14)	2.95	3.91	3.62	3.46	3.11	2.43	1.05
L Eq. 16	2.88	3.73	3.30	2.95	3.11	2.42	1.05
ratio Eq. 16 : Eq. 14	0.98	0.96	0.91	0.85	1.00	1.00	1.00
cell		**18**	**19**	**29**	**21**	**22**	
runoff coefficient		0.18	0.18	0.18	0.01	0.01	
slope gradient (%)		2	6	7	7	4	
L Desmet and Govers (Eq. 14)		1.04	1.06	1.06	1.94	1.72	
L Eq. 16		1.04	1.06	1.06	1.94	1.72	
ratio Eq. 16 : Eq. 14		1.00	1.00	1.00	1.00	1.00	
cell					**23**	**24**	
runoff coefficient					0.01	0.01	
slope gradient (%)					6	4	
L Desmet and Govers (Eq. 14)					1.06	1.05	
L Eq. 16					1.06	1.05	
ratio Eq. 16 : Eq. 14					1.00	1.00	

The analyses undertaken in this paper are based on runoff amounts that have been measured rather than predicted. As with so called process-based models, the ability of the USLE-M lite to predict soil loss well depends on the capacity to predict runoff. The capacity of any particular model to predict a good result depends to a great extent on the accuracy of the values used for the model's input parameters. Just like errors associated with the prediction of E and I_{30}, errors in the prediction of event runoff will have a direct impact on the accuracy of the prediction of event erosion. Likewise, Eqs. 17 and 18 also require runoff to be predicted before they can be applied in Eqs. 15 and 16. Methods exist to predict runoff with varying degrees of accuracy. It is not uncommon for runoff to be predicted using the Curve Number method (U.S. Department of Agriculture, Soil Conservation Service, 1972) in non-point source pollution models directed at determining the impact of land management on water quality. In some cases, runoff is predicted by models that rely on infiltration equations such as those developed by Richards (1931), Holtan (1961), Phillip (1957) and Green and Ampt (1911). Given data on K_{UM}, the USLE-M lite can replace the USLE or the RUSLE in models where event runoff is already predicted. Otherwise, it is entirely up to the user of the USLE-M lite to determine how runoff should be predicted.

CONCLUSION

The Universal Soil Loss Equation (USLE) has been revised (RUSLE) but, despite this, it over predicts small average annual erosion and under predicts high average annual erosion. The over prediction – under prediction problem also occurs at shorter timescales but can be reduced by replacing the USLE/RUSLE event erosivity index (EI_{30}) with the Q_REI_{30} index originally presented by Kinnell (1997). Because the USLE model uses a two stepped approach, the prediction of erosion on the unit plot (A_1), a bare fallow plot 22.13 m long on a 9 % slope with cultivation up and down the slope, followed by the use of coefficients to account for differences between the unit plot condition and the cropped area, the Q_REI_{30} index can be used with the USLE C and P to predict erosion on a cropped area provided that the runoff ratio (Q_R) for the bare fallow cultivated up and down condition is used to determine the index. The model (Eq. 11) is referred to here as the USLE-M lite to distinguish it from the USLE-M, a USLE variant that uses the Q_REI_{30} index in such a way that it cannot be used to predict erosion using USLE C and P factor values.

The USLE/RUSLE approach was originally developed to predict erosion on hillslopes that are uniform with respect to soil and crop conditions. However, the approach has been extrapolated to hillslopes that are not uniform with respect to soil and crop conditions. As a consequence, variations in upslope runoff on erosion have not been taken into account appropriately. A runoff dependent L factor has been presented here to as a means of overcoming this problem. Eqs. 15 and 16 determine L factor values for segments and cells by considering that the effective slope length or contributing area of the area upslope of a segment or cell differs from the physical slope length or area if the runoff ratio of the segment or cell differs from that for the area upslope of the segment or cell. The approach produces lower L factor values than currently used method in areas where runoff from a low runoff producing area enters an area which has a higher capacity to produce runoff.

REFERENCES

Desmet, P.J.J., and Govers, G. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. *Journal Soil and Water Conservation* **51**, 427-433

Foster, G.R., Lombardi, F. and Moldenhauer, W.C. 1982. Evaluation of rainfall-runoff erosivity factors for individual storms. *Transactions of the American Society of Agricultural Engineers* **25**, 124-129.

Foster, G.R., Toy,T.E. and Renard, K.G. 2003. Comparison of the USLE, RUSLE1.06 and RUSLE2 for application to highly disturbed lands. In Renard, K.G, Mc. Ilroy,S.A., Gburek, W.J., Cranfield,. H.E. and Scott, R.L. (eds). *First Interagency Conference on Research in Watersheds, October 27-30, 2003*. US Department of Agriculture, Agricultural Research Service, Washington. DC.

Green, W. H. and G.A. Ampt. 1911. Studies on soil physics. 1. The flow of air and water through soils. *Journal of Agricultural Science* **4**: 11-24.

Holtan, H.N. 1961. A concept for infiltration estimates in watershed engineering. *USDA-ARS Bulletin* **41-51**. US Department of Agriculture, Agricultural Research Service, Washington. DC.

Kinnell, P.I.A. 1997. Runoff ratio as a factor in the empirical modelling of soil erosion by individual rainstorms. *Australian Journal of Soil Research* **35**: 1-13

Kinnell, P.I.A. 2003. Event erosivity factor and errors in erosion predictions by some empirical models. *Australian Journal of Soil Research* **41**: 991-1003.

Kinnell, P.I.A. 2004. Letter to the Editor on "The Mathematical Integrity of Some Universal Soil Loss Equation Variants". *Soil Science Society America Journal* **68**: 336-337

Kinnell, P.I.A., and Risse, L.M. 1998. USLE-M: Empirical modelling rainfall erosion through runoff and sediment concentration. *Soil Science Society America Journal* **62**: 1667-1672.

Laflen, J.J., Elliott, W.J., Flanagan, D.C., Meyer, C.R., and Nearing, M.A. 1997. WEPP-Predicting water erosion using a process-based model. *Journal Soil and Water Conservation* **52**; 96-102.

Morgan, R.P.C., Quinton, J.N., Smith, R.E., Govers, G., Poesen, J.W.A., Auerswald, K., Chisci, G., Torri, D., and Styczen, M.E. 1998. The European Soil Erosion Model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms* **23**: 527-544.

Nash, J.E., and J.E. Sutcliffe, 1970. River flow forecasting through conceptual models. Part 1 - A discussion of principles. *Journal of Hydrology* **10**: 282-290

Nearing, M.A., Govers, G.A., and Norton, D. 1999. Variability in soil erosion data from replicated plots. *Soil Science Society America Journal* **63**: 1829-1835.

Philip, J.R. 1957. The theory of infiltration: 1. The infiltration equation and its solution. *Soil Science* **83**: 435-448**.**

Renard, K.G., Foster, G.R., Weesies, G.A., McCool, D.K., and Yoder, D.C. 1997. Predicting soil erosion by water: A guide to conservation planning with the Revised Universal Soil Loss Equation (RUSLE). *U.S. Department of Agriculture Agricultural Handbook*. **No. 703**. US Department of Agriculture, Washington, DC.

Richards, L.A. 1931. Capillary conduction through porous mediums. *Physics* **1**: 313-318**.**

Risse, L.M., M.A. Nearing, A.D. Nicks, and J.M. Laflen. 1993. Error assessment in the Universal Soil Loss Equation. *Soil Science Society of America Journal*. **57**: 825-833

U.S. Department of Agriculture, Soil Conservation Service. 1972. *National Engineering Handbook, Section 4, HYDROLOGY*. U.S. Govt. Printing Office, Washington, DC 544 pp.

Williams, J.R. 1975. Sediment-yield prediction with universal equation using runoff energy factor. In *Present and Prospective Technology for Predicting Sediment Yield and Sources*. **ARS.S-40,** US Government Print Office, Washington, D.C.: 244-252

Wischmeier,W.C., Johnson, C.B., and Cross, B.V. A soil erodibility nomograph for farmland and construction sites. *Journal of Soil and Water Conservation* **26**: 189-193.

Wischmeier, W.H., and D.D. Smith. 1965. Perdicting rainfall erosion losses from Cropland east of the Rocky Mountains. *Agricultural Handbook No.* 282. US Depertment of Agriculture, Washington, DC.

Wischmeier,W.C., and Smith, D.D. 1978. Predicting rainfall erosion losses – a guide to conservation planning. *Agriciultural. Hanbook*. **No. 537**. US Department of Agriculture, Washington, DC.

Yoder, D. C., and Lown, J. B. 1995. The future of RUSLE: Inside the new Revised Universal Soil Loss Equation**.** *Journal of Soil and Water Conservation* **50**: 484-489.