

## The miscalculation of the USLE topographic factors in GIS

The Universal Soil Loss Equation (USLE; Wischmeier and Smith, 1978) or the revised version of it (RUSLE; Renard et al, 1997), is often used to predict rainfall erosion in landscapes using GIS. Using a grid cell representation of the landscape, and the assumption that each cell is internally uniform with respect to rainfall, soil, crop, aspect and slope gradient, enables the average annual soil erosion for any given cell (A) to be calculated from 6 factors:

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

where R is the longterm annual average of the product of event rainfall kinetic energy (E) and the maximum rainfall intensity in 30 minutes ( $I_{30}$ ), K is the soil erodibility factor, L is the slope length factor, S is the slope gradient factor, C is the crop and crop management factor and P is the conservation support practice factor. The topographic factors (L, S) are given by

$$L = (\lambda / 22.12)^m \quad (2)$$

where  $\lambda$  is the projected horizontal distance in metres between the onset of runoff and the point where runoff enters a channel larger than a rill or deposition occurs, and

$$S = 65.4 \sin^2 \theta + 4.56 \sin \theta + 0.0654 \quad (3)$$

where  $\theta$  is the angle to horizontal, in the USLE but

$$S = 10.0 \sin \theta + 0.03 \quad \text{slopes} < 9\% \quad (4a)$$

$$S = 16.8 \sin \theta - 0.50 \quad \text{slopes} \geq 9\% \quad (4b)$$

in the RUSLE. In the USLE, m varies from 0.6 for slopes  $> 10\%$  to 0.2 for slopes  $< 1\%$ . In the RUSLE,

$$m = \beta / (1+\beta) \quad (5)$$

where  $\beta$  = ratio rill to interrill erosion.

In modelling erosion in GIS, it is common to calculate the LS combination using a formula such as

$$LS = (\text{Flow Accumulation} * \text{Cell Size}/22.13)^{0.4} * (\sin \text{slope}/0.0896)^{1.3} \quad (6)$$

where Flow Accumulation is the number of cells contributing to flow into a given cell and Cell Size is the size of the cells being used in the grid based representation of the landscape. This formula is based on the suggestion by Moore and Burch (1986a,b) that there was a physical basis to the USLE L and S factor combination. However, approach often used does not produce appropriate values for the LS product for a grid cell.

Erosion, as calculated using the USLE/RUSLE has units of mass per unit area and it follows from Eqs. 1 and 2 that the value of A calculated using the GIS formula (Eq.6) is the average for the area contributing runoff to the cell being considered. However, erosion is not uniform over space. L for a hillslope area increases with  $\lambda$  (Eq. 2) so that the L factor values for a cell at the bottom of a

hillslope is greater than the average. This is illustrated in Table 1 for a rectangular hillslope one cell wide.

**Table 1. L values for cells in a hillslope 1 cell wide when m = 0.4 and the cell size is 50 metres**

Cell L for m = 0.4 and cell size 50 metres			
Cell	dist to bottom of cell	L for slope	L for cell
1	50	1.39	1.39
2	100	1.83	2.27
3	150	2.15	2.79
4	200	2.41	3.20
5	250	2.64	3.54

Table 1 is calculated using the equation for the slope length factor for segment i developed for the USLE and the RUSLE (Renard et al., 1997)

$$L_i = \frac{\lambda_i^{m+1} - \lambda_{i-1}^{m+1}}{(\lambda_i - \lambda_{i-1})(22.13)^m} \quad (7)$$

because, in the case of a rectangular hillslope one cell wide, each cell is equivalent to a segment 50 metres long. The LS value generated by the GIS formula (Eq. 6) when the slope gradient is 9 % will calculate the L factor value for the hillslope above any given cell assuming that m = 0.4, not the L factor for the cell.

Desmet and Govers (1996) extended Eq. 7 to the calculation of grid cell L for non rectangular hillslopes by replacing  $\lambda$  by the contributing area divided by the width of the cell, an approach consistent with Moore and Burch (1986a,b) in the context of L. The resulting equation is

$$L_{ij} = \frac{(A_{i,j-in} + D^2)^{m+1} - A_{i,j-in}^{m+1}}{D^{m+2} x_{i,j}^m (22.13)^m} \quad (8)$$

where  $A_{i,j-in}$  is the area (sq metres) contributing runoff to the cell with coordinates i,j and D is cell size (metres). x is a factor with accounts for variations in the width of flow resulting from the orientation of the cell with respect to the contour. In the case where flows exit the cell in one of 8 directions (D8), it has a value of 1.0 when the flow exits over a side and 1.41 when the flow exits over a corner.

Ignoring the x factor, Eq.8 simply replaces  $\lambda_{i-1}$  by  $A_{i,j-in} / D$  and the term  $\lambda_i - \lambda_{i-1}$  by D. Thus, the formulae for determining  $L_{ij}$  could be

UPlambda = Flow Accumulation \* Cell Size

SLOPElambda = UPlambda + Cell Size

L = (SLOPElambda ^1.4 – UPlambda \* ^1.4)/ Cell Size / 22.13 ^ 0.4

LS = L \* (sin slope/0.0896)^1.3

It should be noted that this approach will probably give LS values that are too high for steep slopes. The RUSLE approach to determining m (Eq.5) and S (Eq. 4) may be more appropriate.

Moore and Wilson (1992) observed that the product of L and S in the RUSLE could be approximated by

$$LS = (A_s / 22.13)^{0.6} (\sin \theta / 0.0896)^{1.3} \quad (9)$$

where  $A_s$  is the upslope contributing area divided by the width of the contour that that area contributes. The equation considers  $m = 0.6$  and  $n = 1.3$ . For erosion at a point, they recommend

$$LS = 1.6 (A_s / 22.13)^{0.6} (\sin \theta / 0.0896)^{1.3} \quad (10)$$

as recommended by Griffin et al. (1988). Table 2 shows that the approach adopted in Eq. 10 tends to overestimate cell LS values if  $A_s$  is based on the area contributing to the runoff from the cell, particularly when the contributing area is small.

**Table 2. RUSLE LS values for 50 metre cells on 9% gradient for  $m = 0.6$  and LS values calculated from Eq. 10.**

Cell LS for $m = 0.6$ and 50 metre cells on 9 % gradient				
segment	dist to bottom	LS for slope	LS for cell	LSslope*1.6
1	50	1.63	1.63	2.61
2	100	2.47	3.31	3.95
3	150	3.15	4.51	5.04
4	200	3.75	5.53	5.99
5	250	4.28	6.43	6.85

However, Eq. 10 does produce a more correct result if it directed at calculating the mid cell value of LS.

Cell LS for $m = 0.6$ and 50 metre cells on 9 % gradient					
segment	dist to bottom	LS for slope	LS for cell	LS for slope - 1/2 cell	(LS slope - 1/2 cell) * 1.6
1	25	1.63	1.63	1.08	1.72
2	75	2.47	3.31	2.08	3.33
3	125	3.15	4.51	2.83	4.52
4	175	3.75	5.53	3.46	5.53
5	225	4.28	6.43	4.02	6.43

Unfortunately, many approaches applying Eq.10 in GIS do not calculate the mid cell value of LS.

## References:

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