# A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units

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# A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units

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*Abstract : A computer algorithm to calculate the USLE and RUSLE LS-factors over a two-dimensional landscape is presented. When compared to a manual method, both methods yield broadly similar results in terms of relative erosion risk mapping. However, there appear to be important differences in absolute values. Although both methods yield similar slope values, the use of the manual method leads to an underestimation of the erosion risk because the effect of flow convergence is not accounted for. The computer procedure has the obvious advantage that it can easily be linked to GIS software. If data on land use and soils are available, specific K, C and P-values can be assigned to each land unit so that predicted soil losses can then be calculated using a simple overlay procedure. The algorithm leaves the user the choice to consider land units as being hydrologically isolated or continuous. A comparison with soil data showed a reasonably good agreement between the predicted erosion risk and the intensity of soil truncation observed in the test area.*

Despite its shortcomings and limitations the Universal Soil Loss Equation (USLE) is still the most frequently used equation in (applied) erosion studies. This is mainly due to the simple, robust form of the equation as well as to its success in predicting the average, long-term erosion on uniform slopes or field units (Wischmeier 1976; Wischmeier and Smith 1965; 1978).

The USLE is primarily designed to predict erosion on straight slope sections. Foster and Wischmeier (1974) were the first to develop a procedure to calculate the average soil loss on complex slope profiles by dividing an irregular slope into a limited number of uniform segments. In this way, they were able to take the profile shape of the slope into account. This is important as slope shape influences erosion (D'Souza and Morgan 1976; Young and Mutchler 1969).

Using manual methods the USLE was already applied on a watershed scale (Griffin et al. 1988, Williams and Berndt 1972; 1977; Wilson 1986). Williams and Berndt (1972; 1977) represented a watershed by a limited number of points from which the average watershed slope was calculated. The watershed slope length was determined for the watershed as a whole, based on the catchment area and the total length of the drainage lines. Wilson (1986) represented a watershed by a limited number of profiles on which the methodology for irregular slopes was applied. Griffin et al. (1988) compared various manual methods and concluded that there was no obvious 'best' method. However, they observed that the uniform slope method consistently underestimated LS-values when compared to the irregular slope method or the point method. The point method, on the other hand, was more sensitive to the density of the sample grid than the irregular slope method.

Basically, all the methods described above calculate the LS-value for a sample of points or profiles in the area under study. The results are then considered to be representative for the whole area. The

**Interpretative summary**

**A comparison of manual calculation and a computer algorithm to calculate the USLE and RUSLE LS factors shows that the manual method leads to an underestimation of the erosion risk.**

*Keywords: complex topography, computer program, GIS, USLE.*

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number of data collected will necessarily be limited by the time-consuming nature of these methods. Furthermore, a fundamental problem may arise—although measuring the local slope from a contour map is relatively straightforward, measuring slope length at a given point is a greater problem. In a manual analysis, the distance from the point under consideration to the divide is measured and considered as the slope length for that point. A difficulty with this approach is that it is not always easy to define clearly the location of the divide. However, the major problem is that in a two-dimensional situation, slope length should be replaced by the unit contributing area, i.e. the upslope drainage area per unit of contour length (Kirkby and Chorley 1967). Indeed, in a real two-dimensional situation overland flow and the resulting soil loss does not really depend on the distance to the divide or upslope border of the field, but on the area per unit of contour length contributing runoff to that point (e.g. Ahnert 1976, Bork and Hensel 1988, Carson and Kirkby 1972 and Moore and Nieber 1989). The latter may differ considerably from the manually measured slope length, as it is strongly affected by flow convergence and/or divergence. Thus, although manual methods account for the effect of profile shape on erosion, they do not account for planform shape, i.e. the degree of convergence.

GIS-technology provides for relatively easy construction and handling of Digital Elevation Models (DEMs) which, in principle, allow for the calculation of the unit contributing area so that the complex nature of the topography may be fully accounted for. In order to do so, various routing algorithms have been proposed in the literature and some applications have already been made in erosion studies (e.g. Bork and Hensel 1988; Desmet 1993; Desmet and Govers 1995; Moore and Burch 1986; Moore and Nieber 1989; Moore et al. 1991).

The aim of this paper is to propose an algorithm that extends the Foster and Wischmeier (1974) approach for calculating the LS-factor to two-dimensional terrain using the concept of the unit contributing area. The results produced by the algorithm are compared to the manual point method described by Griffin et al. (1988). Finally, it is shown that the algorithm may increase the applicability of the USLE by incorporating the proposed procedure in a GIS-environment thereby allowing calculation of LS-values on a land unit basis.

## Materials and methods

Foster and Wischmeier (1974) recognised the fact that a slope or even a field unit cannot be considered as totally uniform. Therefore, they subdivided the slope into a number of segments, which they assumed to be uniform in slope gradient and soil properties. The LS-factor for such a slope segment might then be calculated as:

$$LS_j = \frac{S_j \cdot (\lambda_j^{m+1} - \lambda_{j-1}^{m+1})}{(\lambda_j - \lambda_{j-1}) \cdot (22.13)^m} \quad (1)$$

where

- L = slope length factor for the j-th segment (-)
- $S_j$ = slope factor for j-th segment (-)
- $\lambda j$ = distance from the lower boundary of the j-th segment to the upslope field boundary (m)
- m = the length exponent of the USLE LS-factor (-)

In a grid-based DEM the surface is subdivided in square grid cells. If the LS-factor has to be calculated, the upslope contributing area of each cell as well as the grid cell slope have to be known. Various algorithms have been proposed in the literature to calculate the contributing area of each grid cell, i.e. the area upslope of the grid cell which drains into the cell. A basic distinction can be made between single flow algorithms, which transfer all matter from the source cell to a single cell downslope and multiple flow algorithms, which divide the matter flow out of a cell over several receiving cells. This distinction is not purely technical. Single flow algorithms allow only parallel and convergent flow, while multiple flow algorithms can accommodate divergent flow. Desmet and Govers (1996) reviewed the algorithms available and tested their performance. They concluded that the use of single flow algorithms to route water over a topographically complex surface is a problem because minor topographical accidents may result in the erratic location of main drainage lines. Multiple flow algorithms, which can accommodate for divergent flow, do not have this disadvantage.

In this study the multiple flow algorithm developed by Quinn et al. (1991) is used. In this algorithm the contributing area of the central cell in a 3x3 submatrix increased with the grid cell area is divided over all neighboring cells downslope of the central cell. The fraction received by each downslope cell is proportional to the product of the distance-weighted drop and a geometric weight factor, which depends on the direction:

$$A_i = A \frac{tg\,\beta_i \cdot W_i}{\sum_{j=1}^{k} tg\,\beta_j \cdot W_j} \quad (2)$$

where:

- $A_i$ = fraction draining through neighbor i ($m^2$)
- A = upslope area available for distribution ($m^2$)
- tg(βi) = tangent of the slope angle towards neighbor i (m/m)
- $W_i$ = weight factor (0.5 for a cardinal and 0.354 for a diagonal direction) towards neighbor i
- k = number of lower neighbors

In order to calculate the unit contributing area, the contributing area of a cell has to be divided by the effective contour length. This is the length of contour line within the grid cell over which flow can pass. The latter equals the length of the line through the grid cell center and perpendicular to the aspect direction and is calculated as:

$$D_{i,j} = D \cdot (\sin\alpha_{i,j} + \cos\alpha_{i,j}) = D \cdot x_{i,j} \quad (3)$$

where

- Di,j = the effective contour length (m)
- D = the grid cell size (m)
- $x_{i,j}$ = $(\sin\alpha_{i,j} + \cos\alpha_{i,j})$
- $\alpha_{i,j}$ = aspect direction for the grid cell with coordinates (i,j)

The unit contributing area at the inlet of a grid cell may then be calculated as:

$$A_{s_{i,j-n}} = \frac{A_{i,j-n}}{D_{i,j}} \quad (4)$$

where:

- $A_{i,j-in}$ = contributing area at the inlet of a grid cell with coordinates (i,j) ($m^2$)
- $A_{s_{i,j-in}}$ = unit contributing area at the inlet of grid cell with coordinates (i,j) ($m^2/m$)

At the cell outlet, the value at the inlet has to be increased by the grid cell area:

$$A_{i,j-out} = A_{i,j-in} + D^2 \quad (5)$$

with: $A_{i,j\text{-}out}$ = contributing area at the outlet of grid cell with coordinates (i,j) ($m^2$)

Equation (1) can now be adjusted for two-dimensional topography by substituting the unit contributing area for the slope length as each grid cell may be considered as a slope segment having a uniform slope. Replacing slope length by unit contributing area, the L-factor for the grid cell with coordinates (i,j) may then be written as:

$$L_{i,j} = \frac{A_{s_{i,j-out}}^{m+1} - A_{s_{i,j-in}}^{m+1}}{\left(A_{s_{i,j-out}} - A_{s_{i,j-in}}\right) \cdot (22.13)^m} \quad (6)$$

where:
$L_{i,j}$ = slope length factor for the grid cell with coordinates (i,j)

$$L_{i,j} = \frac{\left(\frac{A_{i,j-in} + D^2}{D \cdot x_{i,j}}\right)^{m+1} - \left(\frac{A_{i,j-in}}{D \cdot x_{i,j}}\right)^{m+1}}{\left(\frac{A_{i,j-in} + D^2}{D \cdot x_{i,j}} - \frac{A_{i,j-in}}{D \cdot x_{i,j}}\right) \cdot (22.13)^m} \quad (7)$$

or:

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

and finally:

$$L_{i,j} = \frac{(A_{i,j-in}+D^2)^{m+1} - A_{i,j-in}^{m+1}}{D^{m+2} \cdot x_{i,j}^{m} \cdot (22.13)^m} \quad (9)$$

Different methods can be used to calculate the slope gradient on grid-based DEMs. For this study, the slope gradient for each point of the regular grid of the study area was computed according to the algorithm described by Zevenbergen and Thorne (1987):

$$G_{i,j} = \sqrt{G_x^2 + G_y^2} \quad (10)$$

where $G_x$ = gradient in the x-direction (m/m) and $G_y$ = gradient in the y-direction (m/m).

The LS-factor for a grid cell may then be obtained by inserting $G_{i,j}$ calculated by Equation (10) and $L_{i,j}$ calculated by Equation (9), in the equations of the chosen USLE approach. For this study, we employed the equations as proposed for the Revised Universal Soil Loss Equation - RUSLE (McCool et al. 1987, 1989, Renard et al. 1993).

The manual point method of Griffin et al. (1988) can also be used as the basis for an automated LS-algorithm. Erosion at a given point can be calculated as:

$$E = (m+1) \cdot R \cdot K \cdot \left(\frac{\lambda}{22.13}\right)^m S \cdot C \cdot P \quad (11)$$

where $\lambda$ = slope length (m)
m = slope length exponent (-)

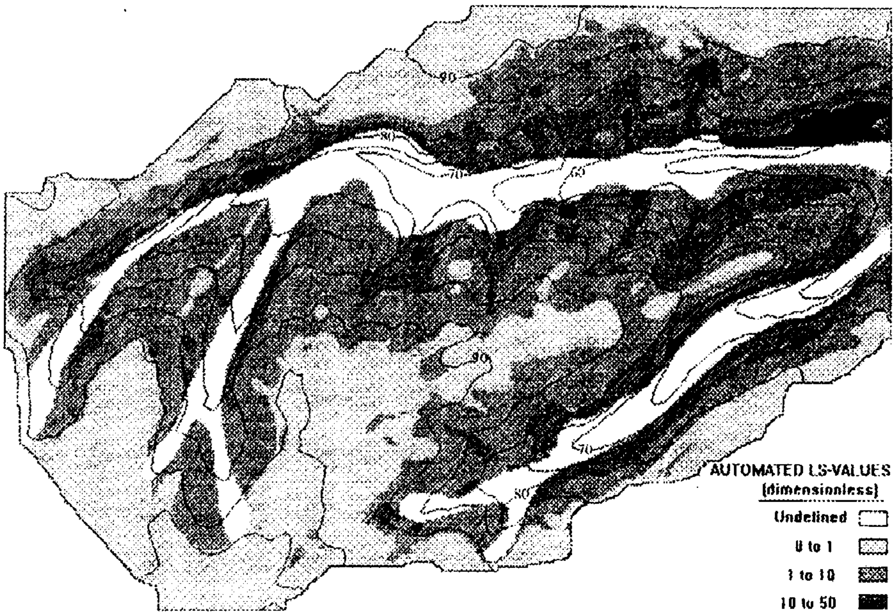


**Figure 1. Spatial pattern of the automated RUSLE LS-values (dimensionless) when the whole catchment is considered as a single land unit**
(Note: values are undefined for depositional areas identified on the Belgian soil map.)

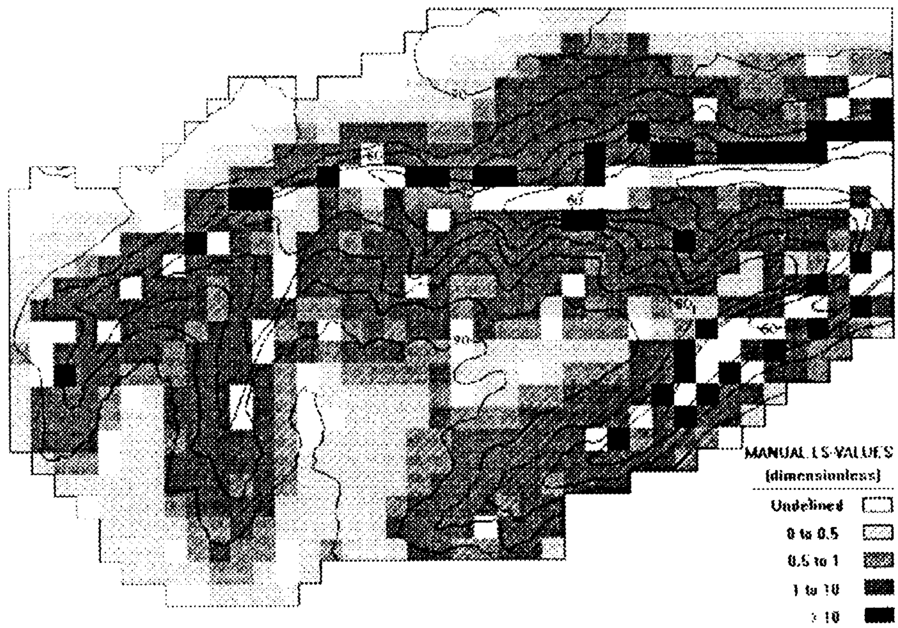


**Figure 2. Spatial pattern of the manual RUSLE LS-values (dimensionless) when the catchment is considered as one land unit**
(Note: values are undefined where slope steepness or slope length could not be reasonably determined, e.g. high benches.)

The L-factor may in this case be written as:

$$L = (m+1) \cdot \left(\frac{\lambda}{22.13}\right)^m \quad (12)$$

Which can be transformed to calculate the erosion rate in a grid cell with coordinates (i,j):

$$L_{i,j} = (m+1) \cdot \left(\frac{A_{s_{i,j-out}} + A_{s_{i,j-in}}}{2 \cdot (22.13)}\right)^m \quad (13)$$

As, from Equations (4) and (5):

$$A_{s_{i,j-out}} = \frac{A_{i,j-out}}{D \cdot x_{i,j}} = \frac{A_{i,j-in} + D^2}{D \cdot x_{i,j}} \quad (14)$$

where
$A_{si,j-out}$ = unit contributing area at the outlet of grid cell with coordinates (i,j) ($m^2/m$)

Equation (13) may then be rewritten:

$$L_{i,j} = (m+1) \cdot \left(\frac{2 \cdot A_{i,j-in} + D^2}{2 \cdot D \cdot x_{i,j} \cdot (22.13)}\right)^m \quad (15)$$

assuming that the center of the grid cell is representative for the whole grid cell.

Again, the LS factor for a grid cell may then be obtained by inserting $G_{i,j}$ calculated by Equation (6) and $L_{i,j}$ calculated by Equation (15), in the equations of the RUSLE.

The procedures described above were implemented in a Microsoft FORTRAN program. The program reads and writes information in the format of IDRISI, a raster-based GIS running under MS-DOS (Eastman 1992). The integration of the routine in an IDRISI-compatible program has several advantages, including the following:

- The combination of IDRISI with TOSCA (Jones 1991) permits the relatively easy construction of a DEM from a standard topographic map. This DEM can directly be used by the program to produce an information layer containing the LS-value for each grid cell.
- The study area can be subdivided into an arbitrary number of soil and land units. Using standard IDRISI procedures, it is then possible to assign to each of the land units C and P values and to each of the soil units a K value, so that predicted soil loss per unit area can be calculated for each grid cell by a simple overlay procedure. Furthermore, standard IDRISI procedures (EXTRACT) allow to sum and average predicted soil losses for each land or soil unit, so that total and average soil loss can be calculated on a land unit/soil unit basis.
- In a catchment with mixed land use, theoretical drainage areas are often irrelevant. Very often runoff will not be generated on the whole slope length at the same time, but only on land units with a specific land use. Following is an example of this: under Belgian conditions, mature grasslands or woodlands never generate significant amounts of runoff. Therefore, if there are parcels with this land use upslope of an area under cultivation, they should not be taken into account when calculating L-values for the cultivated part of the catchment. Also, land units may be separated by drainage systems diverting all the runoff from the upslope area. Therefore, the program allows the user to consider the land units as being hydrologically isolated. If this is done, only the area within the land unit under consideration will be taken into account when calculating L-values. Certainly, user experience is required to decide whether two parcels should be considered as being hydrologically isolated or hydrologically continuous.

**Table 1. Regression analysis between manually derived values and automatically derived values using various procedures**

| Regression equation | n | $r^2$ |
|---|---|---|
| $LS_{man} = 0.66\ LS_{avg} + 0.57$ | 635 | 0.66 |
| $LS_{man} = 0.49\ LS_{cent} + 1.06$ | 635 | 0.59 |
| $LS_{man} = 0.87\ LS_{50} + 0.45$ | 635 | 0.40 |
| $G_{man} = 1.03\ G_{avg} - 0.002$ | 635 | 0.79 |
| $G_{man} = 0.88\ G_{cent} + 0.0086$ | 635 | 0.76 |
| $G_{man} = 0.93\ G_{cent} + 0.0052$* | 633 | 0.77 |
| $G_{man} = 1.21\ G_{50} + 0.0053$ | 635 | 0.37 |
| $\lambda_{man} = 0.04\ A_{s,avg} + 118$ | 635 | 0.07 |
| $\lambda_{man} = 0.016\ A_{s,cent} + 123$ | 635 | 0.04 |
| $\lambda_{man} = 0.30\ A_{s,50} + 73$ | 635 | 0.30 |

*after the elimination of two extremely high automatically derived slope values (see text)
(Note: for explanation of the symbols see text.)

**Table 2. Analysis of Variance for the soil truncation classes**

| | No/slight Truncation mean | No/slight Truncation std.dev. | Moderate Truncation mean | Moderate Truncation std.dev. | Strong Truncation mean | Strong Truncation std.dev. |
|---|---|---|---|---|---|---|
| Manual LS-values* | 1.04 | 1.23 | 2.18 | 3.65 | 2.71 | 2.31 |
| LS-values† (one land unit) | 2.87 | 3.97 | 5.46 | 11.57 | 6.86 | 6.62 |
| LS-values† (parcels as land units) | 2.12 | 3.07 | 2.90 | 5.51 | 4.12 | 3.69 |
| LS-values† (land use as land units) | 2.20 | 3.12 | 3.94 | 6.89 | 5.99 | 6.24 |
| USLE-values† (land use as land units) | 2.74 | 5.63 | 34.86 | 70.28 | 74.85 | 84.73 |

* means in the same row are not significantly different from each other at the 0.05 probability level
† all means are significantly different from each other at the 0.05 probability level
[Note: Calculations were performed using the GLM-procedure (SAS Institute 1985).]

The procedure described above was applied to a study area named the Ganspoel catchment located in the hilly loam belt of Flanders, Belgium. The Ganspoel catchment occupies an area of 2.1 km² (5,189 ac) and has a rolling topography. Soils are mainly silty loamy luvisols. Main crops are winter cereals, sugar beets, and Belgian endives while limited parts are forested or under permanent pasture. The elevation data to construct the Digital Elevation Model were obtained by digitising the contour lines having a contour interval of 2.5 m (8.2 ft) from the Belgian topographical map (N.G.I.) on a 1/10,000 scale using the TOSCA program. This vector information was converted into a grid-based DEM by using the IDRISI procedures LINERAS and INTERCON (Eastman 1992). To produce a raster Digital Elevation Model, IDRISI uses linear interpolation between the digitised contours. A mean filter is recommended to remove some of the angularity of the linear interpolation and to produce a smooth terrain model (Eastman 1992). This filter calculates new values for each pixel by averaging the old values of the pixel and its eight immediate neighbors. In spite of some criticism (Carter 1988; Yoeli 1983) this technique yields a very adequate estimation of height with a mean error not significantly different from 0, although the digital model can never ameliorate the underlying accuracy of the contour representation (Eastman 1992). Accuracy on elevations of contour lines are in the order of 0.3-0.5 m (0.98-1.64 ft) (Depuydt 1969). For the Digital Elevation Model of the Ganspoel catchment a grid spacing of 5m (16.4 ft) was chosen giving an average slope of about 7.5% and a maximum slope of about 46%.

## Results

***Comparing manual and automated methods.*** The calculated LS-values based on the approach of Foster and Wischmeier (1974) (when the whole catchment is considered as a single land unit) are shown in Figure 1, excluding the major drainage lines where permanent deposition occurs based on soil map information.

It can be seen that, generally, the areas with the greatest slope gradients have the greatest LS-factors. This is simply because the slope gradient is the major control on

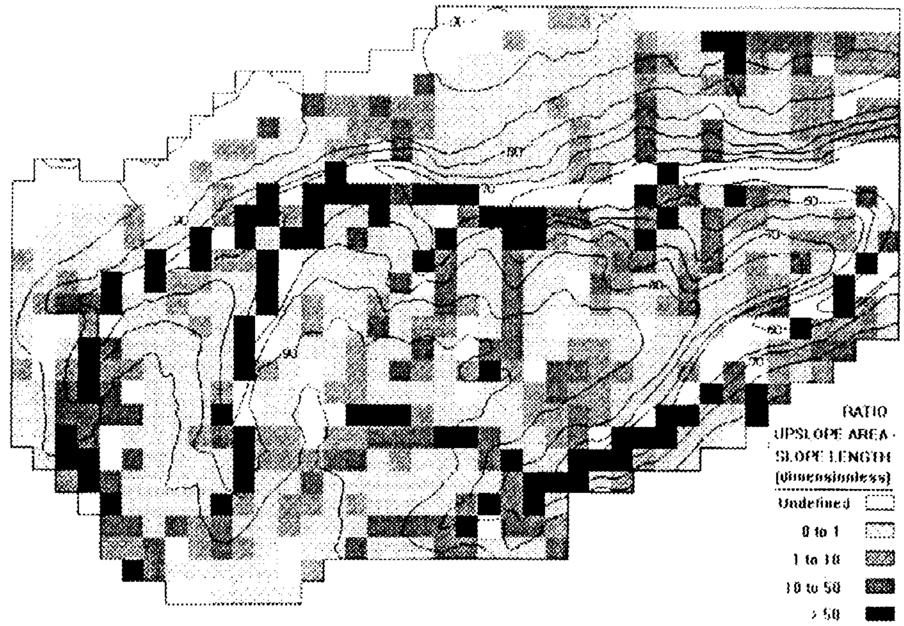


**Figure 3. Ratios (dimensionless) between automated unit upslope area $A_{s,avg}$ and the manual slope length $L_{man}$ (Note: values are undefined where slope steepness or slope length could not be reasonably determined, e.g. high benches.)**

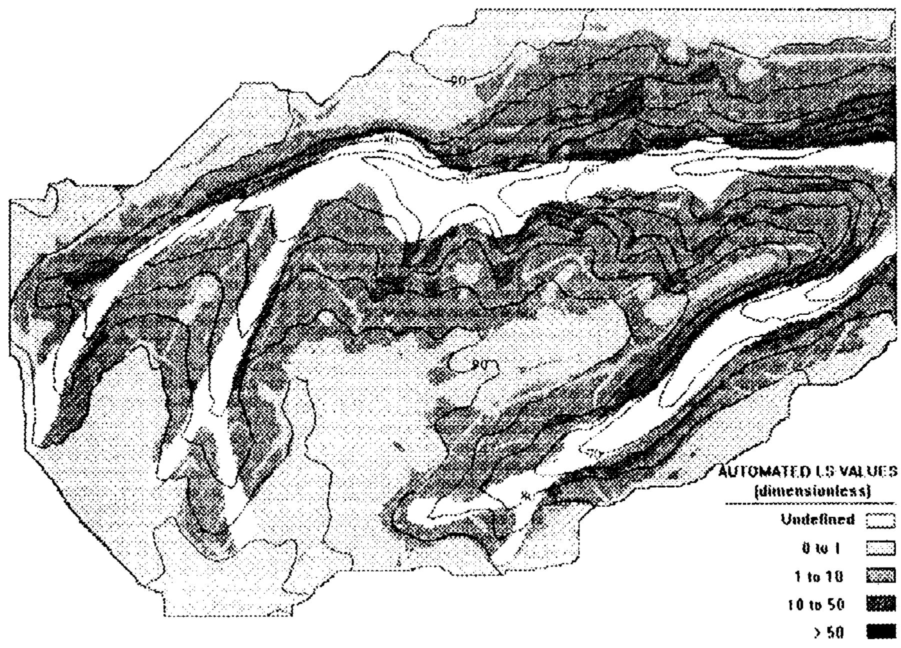


**Figure 4. Spatial pattern of the automated RUSLE LS-values (dimensionless) when the catchment is subdivided in land units as could be observed in 1990 (Note: values are undefined for depositional areas identified on the Belgian soil map.)**

the LS value. However, plan-concave areas (i.e. zones of flow concentration) do have significantly greater LS-values than plan-convex areas. This is because overland flow tends to concentrate in the concavities. It may therefore be expected that both rill density and rill volumes are higher in these areas, as it is well known that rill erosion rates increase with runoff discharge (e.g. Govers and Loch 1993). The fact that these areas are also prone to ephemeral gully formation is not considered here, as the (R)USLE was not designed to account for this erosion form. If Equation (15) is used, results are virtually identical. A regression between the Foster and Wischmeier approach (Equation 9) and the approach of Griffin et al. (Equation 15) yields the following result:

$$RUSLE_{Griffin\ et\ al.} = 0.0000685 + 0.9999978\ RUSLE_{Foster\ \&\ Wischmeier}$$
$(R^2 = 1.00;\ n = 82791)$

The manual point method, proposed by Griffin et al. (1988), was applied to the study area using a 50 m (164 ft) grid and estimating LS at the center of the grid cell. A visual comparison of the two maps suggests that both the manual and automated method yield broadly similar results in terms of the spatial pattern of predicted erosion intensities (Figures 1, 2). However, the manual method produces a far less homogeneous output, which is more difficult to interpret. Furthermore, the average LS-value obtained is less than half of the LS-value obtained using the automated method (2.20 versus 6.99). A more quantitative comparison of the manual and the automated method was also carried out. The manually obtained values were compared with automatically derived values using various procedures, including the following:

- the average of all automatically derived values [on a 5 m (16.4 ft) grid basis] over the 50 m (164 ft) grid cell with the manual observation point in the center ($LS_{avg}$)
- the automatically calculated value extracted at the center of the 50 m grid cell ($LS_{cent}$)
- the automatically calculated value obtained from a Digital Elevation Model with a 50 m grid cell size instead of a 5 m grid cell size. ($LS_{50}$)

A comparison was made not only for the final LS-values, but also for computed slope gradient (G) and slope length ($\lambda$) or unit contributing area ($A_s$) values. A summary of the results is presented in Table 1. Although there is a strong, positive relationship between manually and automatically calculated LS values, agreement is far from perfect. In all cases there is a positive intercept and a slope significantly smaller than 1. The regression results for the slope gradient are far better than those for the slope length. With respect to slope gradient, the best results are obtained for $G_{avg}$. However, the results for $G_{cent}$ are strongly influenced by two high automatically derived slope values. If these are eliminated, the results are similar to those obtained for $G_{avg}$ (Table 1). When a 50 m (164 ft) DEM is used for slope calculation, maximum slope values will be lower as height differences are considered over a larger area. Therefore, this method will lead to lower slope values than the manual point method. Nevertheless, it may be concluded that the automated and manual slope calculation methods yield very similar results.

With respect to slope length, the results

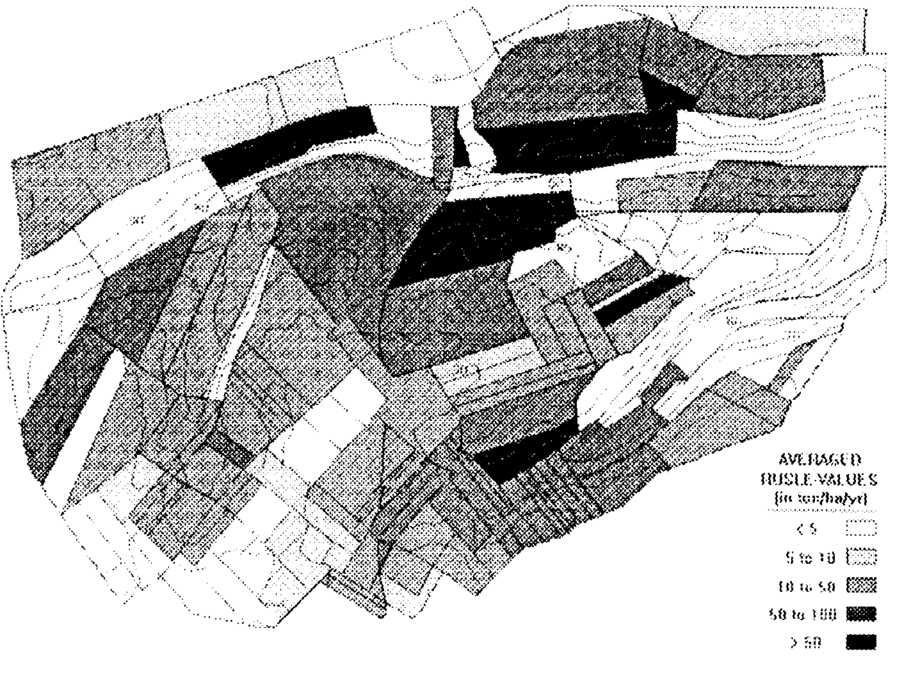


**Figure 5. Spatial pattern of the automated RUSLE soil loss values (in tons/ha/year) when land units are based on the division of land use in arable land, pasture, forest and built-up areas (Note: values in depositional areas identified on the Belgian soil map, were set to zero before calculating the parcel average.)**

are far less satisfying: there is a reasonable agreement with the manually determined slope length values for $A_{s,50}$ only. The reason for the poor correlation is that, in manual slope length determination, flow convergence and/or divergence are not taken into account. Therefore, slope length is significantly lower than $A_s$ on a number of places in the landscape, especially those located in or near hollows

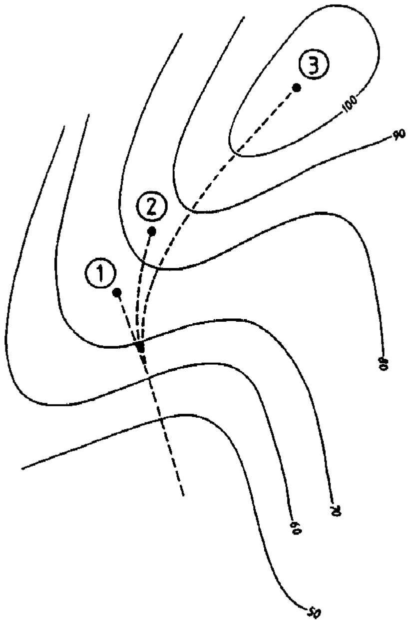


**Figure 6. Typical configuration of contour lines showing the lack of objectivity in the manual determination of slope length**

(Figure 3). This effect will be stronger when the resolution of the DEM used for the calculation of $A_s$ is increased, as this will lead to concentration of the flow over a narrower area. This phenomenon explains the poor agreement between the point method on the one hand, and $A_{s,cent}$ or $A_{s,avg}$ on the other hand.

The result of the LS-calculation when the study area is subdivided in land units as they could be observed in 1990 is shown in Figure 4. The general spatial pattern is preserved; however, the average LS-value decreased from 7.144 (when only one land unit is considered) to 3.906. The regression between both approaches has a slope distinctly lower than '1':

$$LS_{\text{multiple land units}} = 0.977 + 0.398 \cdot LS_{\text{one land unit}}$$
$(R^2 = 0.647;\ n = 82791)$

***A comparison with soil map information.*** Three levels of erosion classes can be identified from the Belgian soil map for most of the catchment. These classes are based on the degree of truncation and are, therefore, long-term averages comparable to USLE estimates. Areas of strong truncation are located on the lower slopes close to the thalwegs; areas of no or slight truncation can be found on plateaus and upper slopes, while areas of moderate truncation take an intermediate position. The mean LS-values for the three truncation classes appear in the right sequence with all means significantly different from each other. This is also the case when considering all parcels as separate land units or compiling land units based on the division of land use in arable land, built-up areas, pasture, and forest (Table 2).

## Discussion

Considering the discrepancy in results between the automated and the manual method, the question may be raised which method is best both from a practical and from a theoretical viewpoint. From a practical viewpoint, it is clear that an automated method which can be integrated in a GIS-environment, has several advantages as all factors can be stored, manipulated, and displayed within the GIS. Digitising land units, soil maps, and other plane geometric information, and the availability of digital soil information databases enable easy storage, updating, and manipulation of the soil erodibility factor K, the cover-management factor C, and the support practice factor P for each soil and unit. Some information for the rainfall-runoff factor R can be achieved and improved by using GIS techniques (e.g. interpolation, Thiessen polygons). The automated LS-approach is, therefore, the missing link for a full two-dimensional, GIS-based approach for the USLE. The ease of manipulating the data within a GIS also enables a quick evaluation of divergent land-use scenarios or erosion control strategies. Furthermore, the automated method is much less tedious and less time-consuming.

The ease of working with multiple land units is illustrated in Figure 5 where predicted soil loss values are shown, using the following values for the other (R)USLE-factors: R=67.4; K=0.43; P=1 and C=0.47 for arable land, 0.02 for pasture, 0.01 for woodland and 0 for built-up areas (Bollinne 1985). Furthermore, it was assumed that both meadow and forest parcels do not generate any runoff and are therefore considered to be hydrologically isolated, while the arable land areas were considered as being hydrologically continuous.

From a theoretical viewpoint, the manual determination of slope length from a map is very subjective, so different operators will obtain different results (Figure 6). Another point is the degree of detail with which average soil losses may be calculated. While the manual approach is restricted to a limited number of grid points, the automated approach allows in principle an infinite number of grid cells. However, the increased resolution may lead to a false impression of accuracy. The final precision that can be achieved, will be determined by the accuracy of the DEM and the routing algorithm. Most importantly, the manual method fails for topographically complex areas because it is unable to capture the convergence and/or divergence of the real topography. Indeed, the manual calculation of slope length is only an approximation of the unit contributing area, which can only efficiently be calculated using an automated procedure.

It may therefore be concluded that the automated method offers considerable practical and theoretical advantages. Possible future developments may include the introduction of sediment routing with the incorporation of a deposition criterion, the calculation of the catchment sediment yield and the determination of the sediment budget. An automatic delineation of ephemeral gullies from Digital Elevation Models (e.g. Moore et al. 1988; Thorne et al. 1986) combined with this USLE approach may improve the predictions of the most critical areas within a catchment. Further work is also needed to investigate if, and if so, in which way land units must be hydrologically connected. This may give the topographical L-factor a genuine hydrological meaning.

## Conclusion

An automated two-dimensional formulation of the concept of Foster and Wischmeier (1974) to calculate the topographic factor LS for topographically complex terrain was presented and compared to an existing manual method. The use of the manual method leads to significantly lower LS-values for plan-concave areas, because the effect of flow concentration on rill development cannot be accounted for. Both the manual and the automated method yield results in agreement with soil map information. However, the automated method has advantages in terms of speed of execution and objectivity. The ease of linking this topographical module with a GIS facilitates the application of the (Revised) Universal Soil Loss Equation to complex land units, thereby extending the applicability and flexibility of the USLE in land resources management. The applicability of the proposed algorithm may be significantly improved in the future by including procedures to predict the location and intensity of ephemeral gully erosion which is not accounted for by the USLE.

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