**Calculating Slope Length Factor (LS) in the Revised Universal Soil Loss Equation (RUSLE)**

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The Universal Soil Loss Equation (USLE) computes the average soil loss per unit area. Many sources in the literature we surveyed give Wischmeier, et. al. (1965) the credit for the development of the USLE. However, Wischmeier’s paper mentions the National Runoff and Soil Loss Data Center and Purdue University for developing it in 1954. A later revision called the RUSLE was prompted by limitations in the older USLE.

Both the USLE and RUSLE are defined as:

The and factors represent the effects of slope length () and slope steepness () on the erosion of a slope. The combination of the two factors is commonly called the “topgraphic factor.” The L factor is the ratio of the actual horizontal slope length to the experimentally measured slope length of 22.1-m. The S factor is the ratio of the actual slope to an experimental slope of 9%. The L and S factors are designed such that they are one when the actual slope length is 22.1 and the actual slope is 9%.

Accurately calculating the LS factor turns out to be something of an art. It requires that the user pay close attention to gathering good empirical data about the landscape and choosing an appropriate method of calculating LS (of which there are many). Readers might be interested in reading [1] which provides a very high level overview of the common problem of miscalculating the topographic factor from DEMs in GIS software.

The original USLE is limited in that it is only effective at predicting soil loss for mild slopes (cropland) sensitive to rill and inter-rill erosion [2]. Additionally, the USLE is very sensitive to the choice of slope steepness values chosen during the LS factor calculation. For example, McCool et al. (1987) note that errors of 10% in the in the slope steepness values, can give an overall error in the soil loss equation of near 20%. They further note the importance of choosing accurate slope values that match the actual terrain of the study area as the soil loss estimates from the USLE are overly sensitive to slope steepness values.

These limitations led to the development of the Revised Universal Soil Loss Equation (RUSLE) which attempts to correct for some of the limitations imposed by the USLE [3]. Additionally, the RUSLE imposes better guidelines for using RUSLE in varying terrains.

Following is a description of LS factor calculations for the USLE and RUSLE. Then we introduce the method we used to calculate the LS factor in ArcMap, called the Unit Stream Power Erosion and Deposition (USPED) method. Finally, we provide instructions on the generation of a depressionless DEM, and then give the step-by-step instructions on performing the calculations in ArcMAP. We used ArcMap 10.1 when performing the steps ourselves.

## LS In The Original USLE

The LS calculation from the original USLE is provided in Equation (1).

|  |  |  |
| --- | --- | --- |
|  |  | () |

Where is the horizontally measured plot length,

is the slope angle, and

is a variable plot exponent adjustable to match terrain and soil variants. varies between 0.5 (slopes of or more) and 0.2 (slopes of) [4].

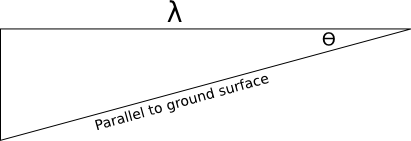


Figure 1 Illustration of the values used in the calculations of LS

## The Revised USLE (RUSLE)

The topographic calculations calculations for the RUSLE are shown separately in Equations (2) and (*4*) [5] [6].

|  |  |  |
| --- | --- | --- |
|  |  | () |

Where,

L is the slope length factor,

is the horizontal plot length (as in Figure 1), and

is a variable exponent calculated from the ratio of rill-to-interrill erosion, as described in [3].

|  |  |  |
| --- | --- | --- |
|  |  | (3) |

Where,

is the slope factor, and

is the slope angle.

Depending on the measured slope gradient, a different equation for must be used. Choosing allows the RUSLE to be more finely tuned for different terrains. This is important because the topographic factor (and the RUSLE entirely) is very sensitive to the slope factor .

The RUSLE method of calculating L and S terms are not directly applicable to the out-of-box functionality of ArcMap. However, there are programmatic methods for calculating the L and S factors from the empirical models in Equations (2) and (*3*). One method compatible with an old version of ArcInfo is described in [2]. It uses the old AML scripting language to trace out transections of steepest slope and calculate the slope length ().

## Unit Stream Power Erosion and Deposition (USPED) Model for LS

We chose to use the USPED method for calculating the LS factor because it was obvious that it could be done with the tools included in a normal ArcMap installation. The specific topographic factor calculation we use in this section is provided in [6]. Additionally, [7] provides detailed information on deriving the LS topographic factor for USPED.

In comparison to the USLE and RUSLE, the USPED is a physically based model that incorporates a spatial component. In the USLE and RUSLE, is dependent on linear distance, which is the horizontal length from the start of sediment transport to point on the slope. Thus, they are inherently a single dimensional function. The USPED instead uses the area of upland contributing flow at distance .

In the USPED model, the area is substituted in place of the former slope length.

The L calculation for point on a slope is shown in Equation (*4*).

|  |  |  |
| --- | --- | --- |
|  |  | (4) |

Where,

is the slope length factor at some point on the landscape,

is the area of upland flow,

is an adjustable value depending on the soil’s susceptibility to erosion,

is the unit plot length.

The comes from the fact that, in order to get a value for that is considerate of the area of contributing upland flow on the slope up to point , we must integrate over the interval .

But, the extra changes the property of that it achieves unity when slope length (in this case slope area) is 22.1. Provisioning L with the extra term removes the equal term from the denominator.

The S calculation is shown in Equation (*5*).

|  |  |  |
| --- | --- | --- |
|  |  | (5) |

Where

is the slope in degrees,

is the slope gradient constant, and

is an adjustable value depending on the soil’s susceptibility to erosion [6].

Designations for exponents and values can be found in the literature. We omit a detailed discussion here, but readers should consult [6] and [7] for case studies and examples. It appears that using *m=0.4* and *n=1.4* is typical of farm and rangeland with low susceptibility to rill erosion.

If the slope values are in degrees (as with the ArcMap slope tool output), they need to be converted back to radians for the sin calculation. There are 0.01745 radians in one degree so the slope is multiplied by this constant.[[1]](#footnote-1)

# Creating a Depressionless DEM

A depressionless DEM is required to perform the subsequent steps in finding the LS factor. A depressionless DEM is one in which there are no sinks present. Simply using the Fill tool (described below) does not always produce a sink-free DEM, so the following steps should be followed in order to ensure the DEM is depressionless.

Delineate a Watershed <http://gis4geomorphology.com/watershed/> with the following modifications to Step 3:

1) Fill DEM using Fill Tool. Name the output file *filled\_dem*.

2) Run the Sink Tool using *filled\_dem*. Name the output file *sink\_dem*.

3) Inspect *sink\_dem*, specifically examining the maximum value shown on the color ramp in the layer pane. If the maximum value is displayed as NoData or 0, then a depressionless DEM has been created and you can continue on to Step 4 of the Watershed Tutorial.

**However, if any other maximum value is present, you will need to recreate another filled DEM using the Fill Tool with modification of the Z Factor. To calculate the modified Z factor, follow the steps below:**

1. Create a raster of sinks with values that identify their depth by running the Sink tool to locate sinks in the raster.
2. Use the [Watershed](http://help.arcgis.com/en/arcgisdesktop/10.0/help/009z/009z00000059000000.htm) tool to create a raster of the contributing area for each sink using the flow direction from the elevation raster and the output from the Sink tool as input for pour points.
3. With [Map Algebra](http://help.arcgis.com/en/arcgisdesktop/10.0/help/00p6/00p600000002000000.htm) in Python, use the [Zonal Statistics](http://help.arcgis.com/en/arcgisdesktop/10.0/help/009z/009z000000w7000000.htm) tool with the Minimum option to create a raster of the minimum elevation in the watershed of each sink:

**sink\_min = ZonalStatistics(sink\_areas, "Value", elev\_ras, "Minimum")**

Note: The sink\_areas input is the output from the Watershed tool.

1. Create a raster containing the lowest elevation along the boundary of each watershed with the [Zonal Fill](http://help.arcgis.com/en/arcgisdesktop/10.0/help/009z/009z000000w3000000.htm) tool (this corresponds to the elevation at which flow would leave the basin after filling to the rim):

**sink\_max = ZonalFill(sink\_areas, elev\_ras)**

1. Use the [Minus](http://help.arcgis.com/en/arcgisdesktop/10.0/help/009z/009z00000093000000.htm) tool to subtract the minimum value from the maximum value to find the depth again:

**sink\_depth = Minus(sink\_max, sink\_min)**

**Reference: Esri Site**

[**http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?id=3914&pid=3910&topicname=Creating\_a\_depressionless\_DEM**](http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?id=3914&pid=3910&topicname=Creating_a_depressionless_DEM)

# Calculating the LS Factor in ArcMAP 10.1

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| --- | --- |
| **Step 1**  Calculate Flow Direction from clipped Watershed DEM layer Using Flow Direction Tool, name this *fd\_ws\_dem.* |  |

|  |  |
| --- | --- |
| **Step 2**  Calculate Flow Accumulation with Flow Accumulation Tool using *fd\_ws\_dem* as your input raster. Name the output file *fa\_ws\_dem.* |  |

|  |  |
| --- | --- |
| **Step 3**  Calculate slope of watershed **in degrees** using Slope Tool using clipped watershed DEM as the input layer. Make sure that *Output Measurement* dropdown menu is set to DEGREES. Name this output file, *slope\_ws.* |  |

**Step 4:**

**Copy and paste the LS-factor formula below into Raster Calculator:**

Power(“flowacc”\*[cell resolution]/22.1,0.4)\*Power(Sin(“sloperasterdeg”\*0.01745))/0.09, 1.4)\*1.4

|  |  |
| --- | --- |
| **Step 5:**  **Replace the following variables in the formula with information below:**  **“flowacc”** = Flow accumulation raster (*fa\_ws\_dem*) from Step 2  **[cell resolution]** = Resolution of DEM in meters  (Look in *Properties* of layer)  **“sloprasterdeg”** = Slope Raster in Degrees (*slope\_ws)* from Step 3  Name output file: *LS\_ws* |  |

# References

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| [1] | P. Kinnell, "The miscalculation of the USLE topographic factors in GIS," [Online]. Available: http://members.ozemail.com.au/~pkinnell/Bits&Pieces/L-miscalc.pdf. [Accessed 12 4 14]. |
| [2] | R. Van Remortel, M. Hamilton and R. Hickey, "Estimating the LS Factor for RUSLE through Iterative Slope Length PRocessing of Digital Elecation Data within ArcInfo Grid," *Cartography,* vol. 30, no. 1, pp. 27-35, 2001. |
| [3] | K. G. Renard, G. R. Foster, G. A. Weesies, D. K. McCool and D. C. Yoder, "Predicting Soil Erosion by Water: A Guide to Conservation Planning With the Revised Universal Soil Loss Equation," U.S Government Printing Office, Washington DC, 1997. |
| [4] | W. H. Wischmeier and D. Smith, *Predicting rainfal erosion losses-a guide to conservation planning,* S. a. E. Administration, Ed., U.S. Department of Agriculture, 1978. |
| [5] | H. S. Kim and P. Y. Julien, "Soil Erosion Modeling Using RUSLE and GIS on the IMHA Watershed," *Water Engineering Research,* vol. 7, no. 1, pp. 29-41, 2006. |
| [6] | A. H. Oliveira, M. Aparecida da Silva, M. L. N. Silva, N. Curi, G. K. Neta and D. A. França de Freitas, "Development of Topographic Factor Modeling for Application in Soil Erosion Models," in *Soil Processes and Current Trends in Quality Assessment*, M. C. H. Soriano, Ed., InTech, 2013, pp. 111-138. |
| [7] | H. Mitasova, J. Hofierka, M. Zlocha and L. R. Iverson, "Modeling topographic potential for erosion and deposition using GIS," *International Journal of GIS,* vol. 10, no. 5, pp. 629-641, 1996. |
| [8] | ESRI, "Creating a Depressionless DEM," ESRI, [Online]. Available: http://webhelp.esri.com/arcgisdesktop/9.2/index.cfm?id=3914&pid=3910&topicname=Creating\_a\_depressionless\_DEM. |
| [9] | D. Ouyang and J. Bartholic, "Proceedings of An International Symposium - Soil Erosion Research for the 21st Century," 2001. [Online]. Available: http://www.iwr.msu.edu/rusle/papers/rusle.htm. [Accessed 4 04 2012]. |

1. <http://www.ias.ac.in/resonance/Volumes/12/07/0086-0091.pdf> [↑](#footnote-ref-1)