RESEARCH REPORTS

# Estimating the topographic factor in the universal soil loss equation for watersheds

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*ABSTRACT: A new, objective approach for estimating slope gradient and slope length frequency distributions for watersheds using topographic maps and Grenville's spline function is described. Statistical analyses of slope segments and estimation of LS values for irregular slopes are used to analyze the computer-generated slope profiles and to produce the final LS values. The method was applied to 30 profiles in Ontario's Lovers Creek watershed. Slope gradients and lengths also were measured in the field. Results of estimated values were compared with measured values to show the accuracy of the new method and the significance of the scale and contour interval of topographic maps.*

THE universal soil loss equation uses six factors—rainfall-erosivity (R), soil erodibility (K), slope length (L), slope steepness (S), cover-management (C), and supporting practices (P)—to estimate average annual soil loss per unit area (*10*).

Although the effects of slope length and steepness were evaluated separately in the development of the USLE, the two factors usually are combined as a single topographic factor in field applications. The topographic factor, LS, is the ratio of soil loss per unit area from a field slope to that from a 22.1-m length of uniform 9% slope under otherwise identical conditions (*10*).

Values for slope length and steepness can be determined rapidly and easily by survey methods in small, field-sized areas with simple topography. A chart and table show LS values for combinations of field slope length and uniform steepness (*10*).

But estimating LS values on a watershed basis is a problem because the field surveys required to obtain the large number of profile measurements are time-consuming and costly, especially in large watersheds with complex topography. Reducing the number of samples may yield an inappropriate distribution of samples and inaccurate results (*8*).

In many watershed applications of the USLE the objective is to estimate an average soil loss for the watershed. Because of nonlinearity in several of the USLE terms and nonlinear distribution of factor values in the field, proper application of the USLE requires computing soil loss for individual profiles (*9*). The average soil loss for the watershed then is computed by taking a weighted average of the profile soil losses according to the area they represent.

Average watershed values for slope length and steepness cannot be used to estimate average soil loss in watersheds because the slope length and steepness factors are nonlinear. Moreover, slope steepness is not uniformly distributed about a mean value. Most slope steepness frequency distributions are positively skewed, such that the median exceeds the mean (*2*). Finally, K and C values may not be uniform over the watershed with respect to the L and S factors. For example, if all steep slopes are in nonerodible land uses, an average C value for the watershed will overestimate soil loss for the watershed. Also, K values can vary with steepness between profiles and along a given profile.

Despite these problems and the popularity of applying the USLE at the watershed scale, only one method has been proposed for generating slope frequency data. Williams and Berndt (*8*) proposed using the third-order natural spline function described by Grenville (*6*) to fit points defined by the horizontal distances and elevations of contours that cross grid lines on topographic maps. The grid lines were drawn at regular intervals from north to south and west to east. Slope in the direction of the grid lines was determined by differentiating the spline function at each grid intersection point. Mean slope at each point was taken as the average of the slopes in both directions. A shortcoming of this approach is that the slope at a grid intersection is not necessarily the slope of the line perpendicular to the contours at the intersection, which is the true slope, the direction of overland flow, and therefore the slope that should be used in the USLE.

A complementary procedure is also needed for producing slope length frequency distributions. Slope length in the USLE is defined as the "distance from the point of origin of overland flow to the point where either the slope gradient decreases enough that deposition occurs, or the runoff water enters a well-defined channel..." (*10*). Proper selection of slope length is difficult and depends on accurately identifying a well-defined channel or the point where deposition begins (*7*). Figure 1 shows several slope length examples. Associating a well-defined channel with an incised, although small, stream channel and the difficulty of identifying where deposition beings often causes extension of the slope downhill well beyond the end of the USLE slope length (*3, 7*).

A speedy, accurate method of estimating topographic factor values is needed to improve application of the USLE to watersheds. Herein, I describe one such method. The method is based on work using topographic map information as input data (*5, 6, 11*). It was field tested in the Lovers Creek watershed in Ontario.

## Description of new method

The new method uses topographic map input data and Greenville's spline function

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(6) to develop estimates of slope length, shape, and steepness. I used Young's (11) method for the statistical analysis of slope segments to divide computer-generated profiles into segments. Then I used Foster and Wischmeier's (5) method of estimating LS values for irregular slopes to calculate factor values. Finally, a cumulative frequency distribution of LS values for the watershed was computed by weighting the profile factor values according to the length that they represent. Overall, the method involved six steps.

*1. Selection of sample points.* The intersections of 1-km² grid lines drawn on 1:50,000-scale Canadian national topographic maps served as sample points. This provided a systematic sample. The choice of 1 km² was a matter of convenience. I did not use a smaller spacing because the Lovers Creek work described here was part of a larger project involving the 2,937-km² Lake Simcoe-Couchiching Basin. Halving the spacing would have increased the number of sample points four times and necessitated the selection of 11,760 as opposed to 2,940 sample points for the larger project. This would have increased the workload beyond the resources of the project.

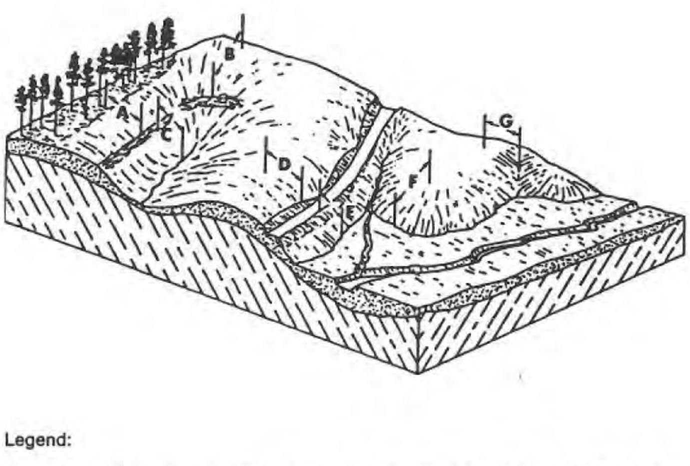
*2. Dividing the watershed into component slopes.* Young (12) proposed a system to divide the watershed into component slopes (Figure 2). First, I identified streams and other lines of concentrated drainage shown on topographic maps. Then I delimited nonslope areas, such as floodplains and marshy areas. Finally, I identified sloping areas and classified them as either valley-head, spur-end, or valley-side slopes. The first step, identifying drainage lines, is critical; this step is a function of map scale, which is discussed later.

Dividing the watershed into component slopes simplified the determination of the lines of true slope drawn perpendicular to the contours and through the sample points. The lines of true slope (Figure 2) assume that the contours run parallel to the streams and watershed boundaries. In large watersheds with complex topography these lines often change direction, crossing each contour at 90°. This approach minimized the tendency to include parts of the drainage divide and channel grades with the lines of true slope. Distinguishing these features is especially difficult close to the crests of convex interfluves and centers of concave valley floors.

*3. Collection of input data.* Lines of true slope, representing the pathways traveled by overland flow, were drawn from the drainage divides to the streams and other lines of concentrated drainage shown on the topographic map through the sample points and perpendicular to the contours. I measured ground distance horizontally from the drainage divides, recording the distances of the contours crossing the lines of true slope and their elevations. I estimated the elevations of the end points by assuming that interfluves and drainage channels had uniform gradients between pairs of contours.

These lines of true slope are not USLE slope lengths for the most part, especially with 1:50,000-scale maps. They include parts or segments that do constitute USLE slope lengths. The final three steps of the process identify and analyze these portions. The scale and contour interval of the topographic maps determine the level of accuracy of the input data and, hence, the slope gradients, lengths, and shapes that are generated.

I used 1:50,000-scale Canadian national topographic maps, based on a 7.6-m contour interval. Two other map series—the 1:25,000 Canadian national topographic series (3.1-m contours) and the 1:10,000 Ontario Ministry of Natural Resources base map series (5.0-m contours supplemented by numerous spot heights and occasionally 2.5-m contours)—would have offered more accurate contour placement, more spot heights for estimating elevations at the tops and bottoms of slope profiles,




Legend:

Slope A. If undisturbed forest soil above does not yield surface runoff, the top of slope starts with edge of undisturbed forest soil and extends down slope to windrow if runoff is concentrated by windrow.

Slope B. Point of origin of runoff to windrow if runoff is concentrated by windrow.

Slope C. From windrow to flow concentration point.

Slope D. Point of origin of runoff to road that concentrates runoff.

Slope E. From road to floodplain where deposition would occur.

Slope F. On nose of hill, from point of origin of runoff to floodplain where deposition would occur.

Slope G. Point of origin of runoff to slight depression where runoff would concentrate.

Figure 1. Slope examples (1).

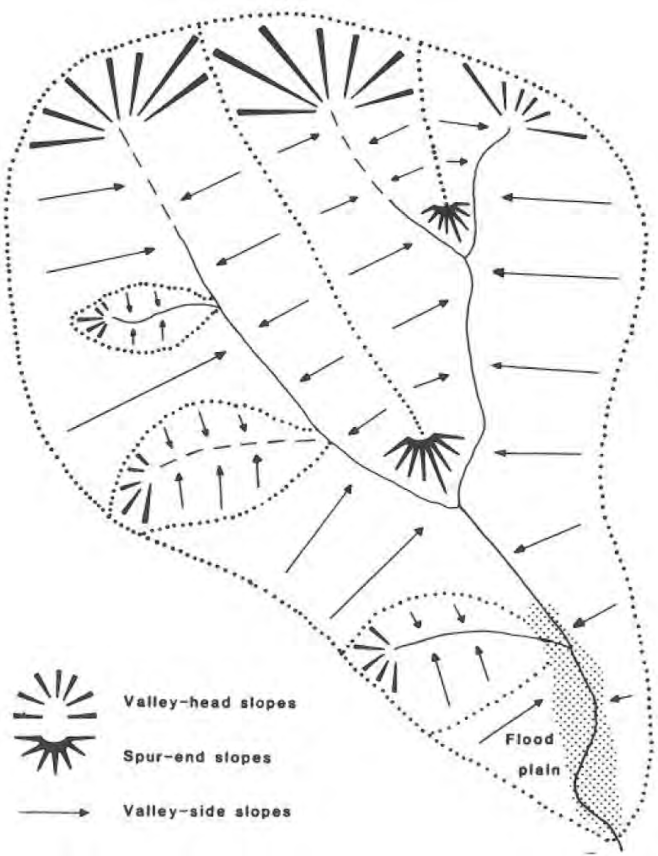



Figure 2. Division of a landscape into component slopes (12).

and better channel definition. Unfortunately, coverage in these map sets did not extend to the Lovers Creek watershed.

*4. Slope profile generation.* I used Grenville's (6, 8) spline function with the ground distance and elevation data described in the previous steps to draw slope profiles along the lines of true slope. I then calculated elevations and slope steepness at 10-m intervals along these profiles. The slope gradients were treated as the average slope of the measured lengths extending 5 m on either side. I delimited shorter lengths near the tops and bottoms of the profiles. The choice of interval length was not critical. I found no statistically significant differences for either the topographic factor values or the USLE slope lengths when using intervals of 5 m, 15 m, or 22 m. Nevertheless, the 10-m length produced marginally better results and was easier to work with.

The spline function was far superior to linear interpolation between contours, especially when using a broad contour interval, such as 7.6 m. Many slopes are concave or convex or consist of a series of concave, convex, and uniform segments. Estimates of average steepness produced by linear interpolation between contours do not accurately reflect the effects of these irregularities on soil loss. For example, a convex slope loses more soil and a concave slope less soil than an equivalent uniform slope (9, 13).

Foster and Wischmeier (5) divided appreciably irregular slopes into uniform segments to estimate LS values. With this method irregular slopes are divided into a series of segments such that a uniform slope steepness within a segment can be assumed. The error in the soil loss estimates for nonuniform slopes is reduced as the slope is divided into more segments. In practical applications Wischmeier and Smith (10) recommended dividing a slope into three to five equal length segments, which suggests combining adjacent 10-m lengths with similar gradients. However, further guidelines must be specified unless every USLE slope length is to be divided into some predetermined and arbitrary number of segments.

*5. Dividing slopes into segments.* I used Young's (11) system of "best segments" analysis to objectively select uniform slope segments. That method divides slopes into as many segments as needed to reduce the departure from exact rectilinearity within a segment to some given level. Once uniform slope segments are selected, LS values can be estimated using Foster and Wischmeier's method (5).

Young (11) used the coefficient of variation of angle along a slope as the parameter for specifying variability. The mean angle, $\Theta_m$, in degrees and the coefficient of variation of angle, $V_a$, in percent are given by:

$$\Theta_m = \sum_{i=1}^{n} x_i \Theta_i \,/\, \sum_{i=1}^{n} x_i \qquad [1]$$

$$V_a = 100 \left[ \left(\sum_{i=1}^{n} x_i \Theta_i^2 \,/\, \sum_{i=1}^{n} x_i\right) - \Theta_m^2 \right]^{0.5} / \, \Theta_m \qquad [2]$$

where $x_i$ and $\Theta_i$ are the lengths (meters) and angle (degrees) of a succession of measured lengths, i, respectively.

In my analysis, I specified a segment quantitatively as a series of adjacent 10-m lengths within which the coefficient of variation of angle did not exceed a predetermined maximum value, $V_m$. The segment was described by its length, mean angle, and coefficient of variation of angle. Young (11) suggested that $V_m = 10\%$ gave segments with roughly uniform gradients. I examined several values to determine which $V_m$ value was best suited to USLE applications. Starting with $V_m = 0\%$, which meant that every 10-m length was treated as a segment, I increased the value of $V_m$ by 1% until the comparison of weighted LS values with $V_m = 0\%$ and the value being tested with a two-tail, matched-paired t test at the 0.05% level of significance produced statistically significant differences. The last value tried before this result was obtained, $V_m = 9\%$, was used for the remainder of the analysis. This minimized the number of segments into which the USLE slope lengths were divided without producing statistically significant changes in the final LS values. With this value, the 56 USLE slope lengths used to compute LS values were divided into an average of 5.4 segments.

Another difficulty that arises with this analysis is that of overlap, where a measured length may qualify for two or more segments. Young also recommended a procedure to deal with this problem. I assigned lengths to the longest segment or, if two segments were equal in length, to the segment with the lowest coefficient of variation. By itself, the second rule of allocating each measured length to the slope segment having the lowest coefficient of variation without any regard to segment length is unsatisfactory. Its effect is to divide the profile into numerous short lengths because, logically, each 10-m length becomes a segment with $V_a = 0\%$.

*6. Calculation of LS values.* I used the equation developed by Foster and Wischmeier (5) for irregular slopes to calculate LS values:

$$LS = \sum_{i=1}^{n} \left(S_i \lambda_i^{1+m} - S_i \lambda_{i-1}^{1+m}\right) / \left(\lambda_t \, 22.1^m\right) \qquad [3]$$

where n = number of segments; m = 0.5 if the slope is greater than or equal to 5%, 0.4 on slopes between 5% and 3%, 0.3 on slopes between 3% and 1%; and 0.2 on slopes less than 1%; $S_i$ = value of the slope gradient factor for segment i; $\lambda_i$ = distance in meters from the top of the slope to the end of any segment; $\lambda_{i-1}$ = the slope length above segment i; and $\lambda_T$ = the overall slope length.

The last problem was to determine those slope segments where the USLE applied, that is, where net detachment rather than net deposition was occurring. For example, the USLE does not apply to the lower portions of a concave slope where deposition occurs (Figure 3).

The transport capacity of the runoff where deposition occurs limits sediment load. Because runoff on a lower segment depends upon runoff produced on upper segments, successive segments of an irregular slope cannot be treated as independent slopes. Also sediment load on a downslope segment depends upon erosion on upslope segments. Foster and Meyer (4) found that the transport capacity of runoff from uniform slopes during moderate to intense rainstorms is usually sufficient to transport all available soil if the slope exceeds 2 or 3% and the soil is not so permeable that runoff is reduced greatly. Where deposition begins on an irregular slope depends on upslope conditions. If the upslope is steep, deposition may occur on a steeper slope than it will when the upslope is relatively flat.

These observations were used to justify the selection of slopes with average gradients at least 50% as steep as the steepest upslope segment as qualifying segments for soil loss prediction. Hence, I assumed deposition occurred when slope steepness decreased more than 50% on concave slopes, as in segment 2 of curve A in figure 3. The second curve (B) in figure 3 illustrates another possibility: a slope that steepens after flatening out. Although once again I assumed net deposition occurred on segment 2, segments 1 and 3 were treated as qualifying segments for soil loss prediction. Hence, I assumed net detachment occurred wherever slope steepness exceeded twice that encountered upslope on the few occasions this situation occurred.

One further modification was needed for the curve-B situation. The correct USLE slope lengths for the profile shown in curve B (Figure 3) were not used in the initial run without the adjustments for small channels, built-up areas, and fences.

I assumed second and subsequent USLE slopes started at the top of each qualifying segment at points A and C in curve B. However, the slope length does not end at point B and begin again at C unless water is diverted between B and C. The upslope lengths should have been incorporated in the soil loss computations for segment 3 (7). I did not use this approach with the original topographic map data because it would have produced slope lengths much longer than those actually measured in the field and those for which the USLE was designed. The correct approach was used with the modified topographic map data because channels and built-up areas were eliminated and man-made features (roads, fences) were used to end USLE slope lengths where appropriate.

## Study area and field measurements

I field tested this method of constructing and segmenting profiles for computing soil loss with the USLE in the northern three-fifths of the Lovers Creek watershed. This small, 58.5-km² watershed is part of the Lake Simcoe-Couchiching Basin where I am using the USLE to estimate erosional changes since 1800. Lovers Creek and its tributaries drain north into Kempenfelt Bay and Lake Simcoe through a broad flat-bottomed U-shaped valley. The valley is flanked by uplands on either side. The uplands along the western and eastern margins of the watershed reach maximum elevations of 313 and 274 m, respectively. Lovers Creek enters Kempenfelt Bay at an elevation of approximately 220 m. The watershed includes both gently rolling and flat areas.

Slope and distance along slope profiles following 30 lines of true slope marked on a 1:50,000-scale topographic map were measured in the field in October and November 1983 using a Paragon geological survey alidade. I divided the profiles into slope segments using definite breaks in slope or 50-m intervals, whichever was shorter. Elevation was not determined in the field. I estimated the elevations of the tops of the field slopes from the topographic map contours. I analyzed the field profiles in the same way as the profiles generated from the spline function and topographic map input data. Hence, the equation developed by Foster and Wischmeier (5) for irregular slopes was used to calculate LS values for the USLE slope lengths.

## Results and discussion

The 30 lines of true slope (overland flow paths) drawn perpendicular to the contours identified on the 1:50,000 topographic map were easily located in the field, although their lengths varied slightly. The lines traversed in the field measured 25,314 m versus 25,575 m on the topographic maps, an average shortfall of 8.7 m (1.0%). The discrepancies resulted from the difficulty of accurately locating the tops of the slopes on 1:50,000-scale maps or the need to deviate from the flow paths identified on the maps to follow the paths travelled by overland flow in the field.

Parts of the lines of true slope traversed in the field were not analyzed further because of the presence of small, permanent or ephemeral channels and gullies or a variety of man-made structures, such as houses, railways, and roads. I eliminated lengths totaling 4,480 m because of recent signs of concentrated channel flow. I collected field data during a 6-week period in the autumn, punctuated by a series of moderately heavy rainstorms, which helped to identify ephemeral channels. Their frequency reflected the inability of 1:50,000-scale topographic maps to record many of the channels ending USLE slope lengths. Some of the man-made drainage ditches found in the field may have been constructed since the map was last revised.

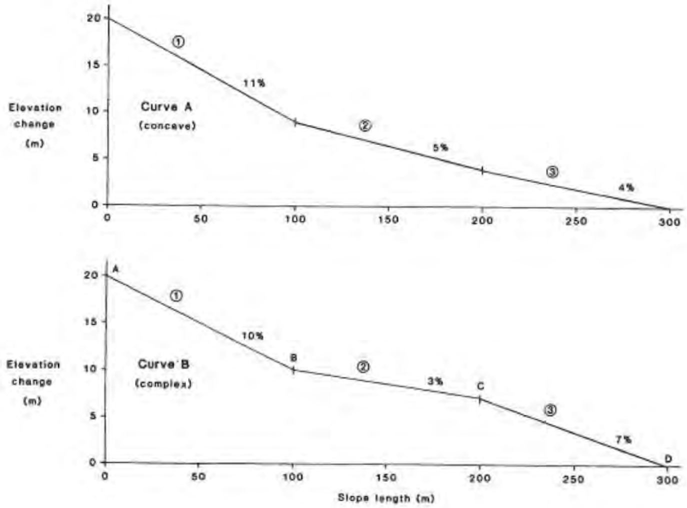
I rejected another 1,723 m (6.8%) because of the presence of houses, railways, and roads. These features often incorporated flat surfaces but, more importantly, they frequently include surface and subsurface drainage systems that completely interrupt natural patterns. They frequently terminated USLE slope lengths and seldom constituted parts of USLE slope lengths themselves. Of the remaining 19,111 m of flow paths traversed in the field, only 5,600 m (29.3%) were eliminated because net deposition was assumed to occur. After these considerations, the 30 initial profiles were divided into 118 separate USLE slope lengths ranging from 14 to 300 m, with an average of 114.5 m. The 30 original lines of true slope by comparison averaged 844 m. Seven of these lines included just two USLE slope lengths; nine included three slope lengths; eight included four slope lengths; and six included five or more such lengths.

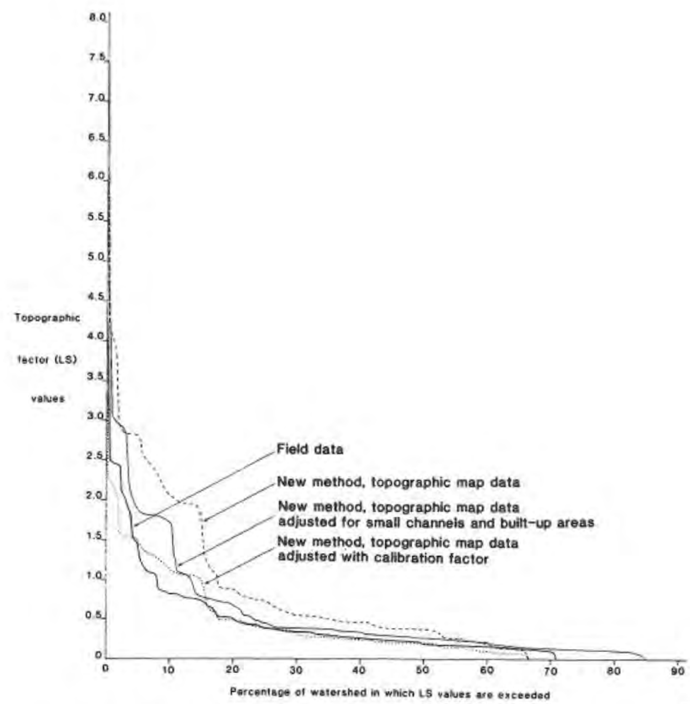
I calculated topographic factor values for the 118 USLE slopes. I then extrapolated these values to the watershed as a whole. One approach was to assign each line of true slope to represent 1 km² because a 1-km² grid was used to select the sample points. I rejected this approach because the length of the lines of true slope drawn through these points varied, as did the number and length of the USLE slopes associated with each of the grid intersection points and the lines of true slope drawn through them. Thus, I used the USLE slope lengths to apportion the LS values to areal units. For example, I attributed an LS value of 4.21 to 0.21% [40/19,111 (100)] of the watershed because one USLE slope measuring 40 m had a value of 4.21. Similarly, a value of 3.68 was computed for one 52-m slope, and attributed to 0.27% of the watershed. The cumulative frequency data confirm these results (Figure 4), showing 0.21% of the watershed with LS values greater than 3.68, the second largest value computed with the data collected in the field (solid line). This line (Figure 4) also indicates that LS values greater than zero were attributed to 70.7% of the watershed using the field data. In other words, 29.3% of the watershed consisted of slopes along which net deposition was assumed to occur.

The other three lines in figure 4 summarize the results of using the topographic map information as input data. Housing subdivisions and transportation routes shown on the 1:50,000-scale maps totaling 1,660 m were omitted from the outset. The topographic factor values, represented by the dashed line, indicate that net deposition was assumed to occur along 8,015 m of the remaining 23,915 m. Thus, 66.5% of the watershed had LS values greater than zero (Figure 4). The average LS value weighted by length determined with the map data was 0.67, compared with 0.36 for the field data. Four reasons account for this difference: the failure to identify all of the small, permanent, and ephemeral channels and gullies on the topographic map; the failure to use all of the houses, fences, and transport routes, where appropriate, to terminate USLE slope lengths; the difficulty of specifying elevations at the tops and bottoms of the profiles using a 1:50,000-scale map; and the inability to identify sharp discontinuities where the maximum range in elevation is less than the contour interval (7.6 m in this instance).

Figure 5 illustrates the third and fourth inconsistencies. The two slope profiles, drawn from field and topographic map input data, differ in terms of the total change in elevation recorded. The steep portion measured in the field between 359 and 384 m involved a difference of only 4.9 m. Hence, this feature was not marked on the topographic map; as a result, it was not incorporated into the profile generated with the computer from the input data.

The effect of the first two inconsistencies can be quantified from either field reconnaisance or aerial photogaphy. The latter offers a quick and accurate method in most environments. However, I used field evi-



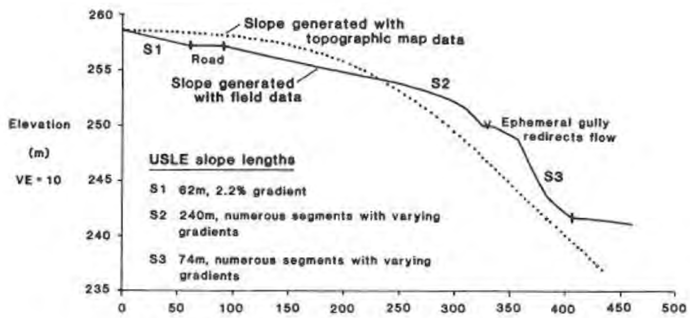




Figure 3 (top left). Slope dimensions used to illustrate choice of qualifying segments for irregular slopes.

Figure 4 (above). LS factor exceedance frequencies for field and topographic map data in the northern part of the Lovers Creek watershed.

Figure 5 (left). Comparison of profiles generated from field and topographic map data.

dence because such data had already been collected. As a result, I reworked the new method by eliminating the parts of the ori ginal flow paths consisting of small permanent and ephemeral channels and gullies as well as houses and transportation routes. Fences known in the field to end USLE slope lengths were also used where appropriate. These adjustments narrowed the gap between the topographic factor exceedance frequencies obtained with the field data and from the topographic maps (Figure 4). The weighted average LS value was reduced from 0.67 to 0.51.

These results suggest that the remainder of the difference—a weighted average LS value of 0.51 versus the 0.36 value calculated with the field data—was due to the third and fourth problems (Figure 5). They are also a function of the scale of the topographic maps. Although these effects are much more difficult to quantify, maps with a larger scale or shorter contour interval should produce smaller discrepancies.

The profiles generated with the modified topographic map data produced both too many USLE slopes (126 versus 118 with the field data) and slopes that were too long (128.3 m versus 114.5 m for the field data). The discrepancies between the two weighted averages and the frequency distributions resulted from the tendency for the topographic map data to predict too many slopes on which net detachment was assumed to occur and too many combinations of slope gradient and length that produced LS values between 1.0 and 4.0 (Figure 4).

The easiest way to reduce the discrepancies between the distributions obtained from the topographic map and field data is to multiply the LS values by 0.54 before they are transformed into areal equivalents. This adjustment represents the difference in the weighted averages obtained with the two sets of data (Figure 4). I verified this calibration factor with further field-testing and applied it to all of the watershed topographic factor frequency distributions used in the larger Lake Simcoe-Couchiching Basin study.

With this new method the location of the worst areas, from the point of view of the topographic factor and its influence on soil loss, are not known with certainty. For example, the exact location of the 0.21% of the watershed determined to have an LS value of 4.21 is not known. Similarly, the location of the worst areas from the point of view of the cover-management factor and its influence on soil loss is not known. A complementary procedure for combining the values of all six USLE factors has been developed. The LS, C, and P factors are tied to soil types and corresponding soil erodibility (K) factors by way of the qualitative information about the topography and suitability of different soil types for agriculture reported in county soils reports. Using this approach, the best possible input data can be used to estimate USLE factor values. Most watershed applications have had to make do with second best or worse data for one or more of the USLE factors because of the need to use the same areal units for all six factors.

## Conclusions

The proposed method for quickly and accurately estimating LS values for watershed applications of the USLE is promising. The lines of true slope used for the collection of field data matched the lines of true slope drawn on the topographic maps as closely as possible to enhance their comparison. Field reconnaisance and aerial photography eliminated some of these effects. Also, a final calibration factor minimized the differences between the LS values obtained from the field and topographic map input data. These discrepancies and the size of the calibration factor could be reduced with alternative map series drawn at larger scales or with smaller contour intervals.

The present application, using 1:50,000-scale topographic maps, demonstrates that the basic approach has several strengths. It is objective, the analysis can be carried out quickly and inexpensively by computer, and the output is consistent with the original USLE definitions for the slope parameters. Most important, the method produces frequency distributions of slope gradients, slope lengths, and LS values.

Further work is required to assess what grid density should be used to select the sample points, what critical slope gradients should be used to decide which slope segments qualify for soil loss estimation, and the effects of the map scale and contour intervals. All of these attributes relate to the choice of input data as opposed to the structure of the method. Improvements could be incorporated into future applications of this method.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# Soil water conditions and yield of tall fescue, switchgrass, and Caucasian bluestem in the Appalachian Northeast


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*ABSTRACT: Soil conditions on beef cattle pastures in the Appalachian Northeast limit the amount of precipitation that is stored and used for forage production. To determine the effect of soil water availability on the yield of cool- and warm-season forage grasses, four subplots each of tall fescue (*Festuca arundinacea *Schreb.), switchgrass (*Panicum virgatum *L.), and Caucasian bluestem [*Bothriochloa caucasica *(Trin.) C.E. Hubb] were established on each of two soil types (Edom silt loam—Typic Hapludalf, fine, illitic, mesic—and Weikert channery silt loam—Lithic Dystrochrept, loamy-skeletal, mixed, mesic). Water storage capacity of the Edom profile was 16.6 cm; that of the Weikert profile was 6.25 cm. Soil water, mid-day plant water potential, and canopy temperature data were taken at two-week intervals starting at the initiation of growth in the spring and ending as each species was harvested. Productivity of switchgrass and tall fescue was significantly higher on the Edom soil than on the Weikert soil. Switchgrass produced the most dry matter and used water more efficiently than the other species. Both the cool-and warm-season grasses growing on the Weikert soil experienced moisture stress at mid-day during July. Grasses growing on the Edom soil did not. Moreover, moisture stress generally was greater for the cool-season grasses than for the warm-season grasses.*


BEEF cattle pastures in the Appalachian Northeast generally are located on hill land with soils that have severe limitations for row-crop production. These soils often are shallow, contain a large percentage of coarse fragments, have acid subsoils, or have root-restricting layers in the subsoil. These limitations affect the amount of precipitation that can be stored and used for forage production. Soil erosion also has reduced the water storage capacity of many of these soils.

Although the Appalachian Northeast is considered a humid region, the low water-holding capacity of pasture soils limits forage production on these soils (*4*).

Recent work has shown that warm-season grass species are well adapted to the Northeast (*7*). Because these grasses use water and nutrients efficiently (*2*), they offer the potential of increasing production on droughty pastures, especially during mid-summer when cool-season grass production declines (*7*).

We sought to determine the effect of soil water on the production of a cool-season and two warm-season grasses on pasture soils common to the Appalachian Northeast.

## Study area and methods

Our study took place at West Virginia University's Reymann Memorial Farm near Wardensville. The farm is in the Northern Appalachian Ridge and Valley Land Resource Area (*1*). Soils at the site were derived from the Marcellus (upper Devonian) formation of gray acid shale interbedded with thin layers of limestone. Typically, the Marcellus shale weathers into the droughty Berks and Weikert soils. Where limestone occurs, it weathers into the Edom soil, which has a moderate to high moisture-holding capacity. Our study plots were on Edom silt loam (Typic Hapludalf, fine, illitic, mesic) and Weikert shaly silt loam (Lithic Dystrochrept, loamy-skeletal, mixed mesic). These and similar shale soils are common in Maryland, Pennsylvania, Virginia, and West Virginia.

Precipitation at the site averages 91.8 cm/year and is favorably distributed throughout the year; 46.2 cm occur from April through August. Average yearly temperature is 11.8°C; maximum and minimum averages for July are 31.1°C and 16.7°C, respectively (5). Yet hill-land pas-


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