An averaging procedure for applying the Revised Universal Soil Loss Equation (RUSLE) to disturbed mountain watersheds

Un procedimiento para aplicar la Ecuación Universal de Pérdida de Suelo Revisada (RUSLE) a cuencas hídricas de montaña

G. González Bonorino [(1)], W.R. Osterkamp [(2)] y F. Colombo [(3)]

[(1)] Inst. Geonorte, Univ. Salta-CONICET, Buenos Aires 177, (4400), Salta, Argentina (ggbnet3@netscape.net)
[(2)] Desert Lab., USGS, 1675 W Anklam Rd., Tucson AZ 85745
[(3)] Depto. Estratigrafia, Universitat de Barcelona, E-08028, Barcelona, Spain

ABSTRACT

*Disturbed lands in mountain watersheds may be a significant source of sediment. A systematic rating of their potential for erosion would be useful in soil conservation planning. RUSLE is a successful erosion-prediction technique, well tested on gentle slopes of agricultural lands. In view of its success, attempts have been made to apply RUSLE to areas of complex topography by substituting upstream contributing area for the linear-flow model embodied in the RUSLE L-factor. This substitution leads, however, to uncertain results. The L-factor represents, for a particular topographic profile, the length of overland flow from its inception to the point where it reaches a channel or a break in slope that causes deposition. Many separate profiles would sample the population of overland-flow lengths in a watershed. R.E. Horton's drainage density (D) offers a simple alternative to measuring numerous profiles. Because 1/(2*D) is a measure of average overland-flow length, it can be used to calculate the L-factor. The other RUSLE factors must be computed on an area-average basis. This procedure is applied to a forested watershed disturbed by wildfire, and the result is favorably compared to the value obtained from applying the traditional procedure.*

Key words: *mountain watersheds, surficial runoff, RUSLE.*

RESUMEN

*Los suelos disturbados situados en cuencas hídricas de montaña constituyen normalmente una importante fuente de detrito. Una evaluación sistemática del potencial de erosión en esas cuencas sería útil para una gestión adecuada del suelo. La Ecuación Universal de Pérdida de Suelo Revisada (RUSLE) corresponde a una técnica muy empleada para predecir la erosión, que ha sido exhaustivamente puesta a prueba en pendientes suaves de tierras agrícolas. En vista de su éxito, se han hecho intentos para aplicar la RUSLE en áreas de topografía compleja mediante la substitución del modelo de escorrentía lineal, propio del factor L en RUSLE, por otro basado en el área de contribución aguas arriba. Esta substitución conduce, sin embargo, a resultados inciertos. El factor L representa, para un perfil topográfico en particular, la longitud de la escorrentía superficial desde el punto de inicio hasta donde alcanza un canal o un quiebre de pendiente que condiciona una sedimentación. Muchos perfiles separados darían una muestra de la población de longitudes de escorrentía superficial en una cuenca hídrica. La densidad de drenaje (D) de R.E. Horton ofrece una alternativa sencilla a medir numerosos perfiles. Dado que 1/(2*D) es una medida de la longitud media de la escorrentía superficial, puede ser empleada para calcular el factor L. Los demás factores en la RUSLE deben ser calculados segun un promedio ponderado por área. Este procedimiento es aplicado a una cuenca perturbada por un incendio forestal, y el resultado se compara favorablemente con el valor obtenido mediante la aplicación del procedimiento tradicional.*

Palabras clave: *Cuencas hídricas de montaña, escorrentía superficial, RUSLE.*

Geogaceta, 33 (2003), 43-46
ISSN:0213683X

Introduction

The steep slopes of mountainous watersheds are prone to accelerated soil erosion following man-induced or natural disturbances. Gaging their contribution to instream suspended sediment and bedload is of interest to soil-conservation planners and water quality management. In the case of forested watersheds, the results could be compared to sediment movement from undisturbed forest lands (Fowler and Heady, 1981) to yield, for instance, a ranking of departures from normality. The Revised Universal Soil Loss Equation (RUSLE) (Renard et al., 1997) has been used successfully in this way for agricultural and reclaimed lands. RUSLE is designed to compute long-term average annual soil loss for ground slopes where flow convergence/divergence can be neglected, that is, planar slopes, common in agricultural lands. For reasons discussed below, application of

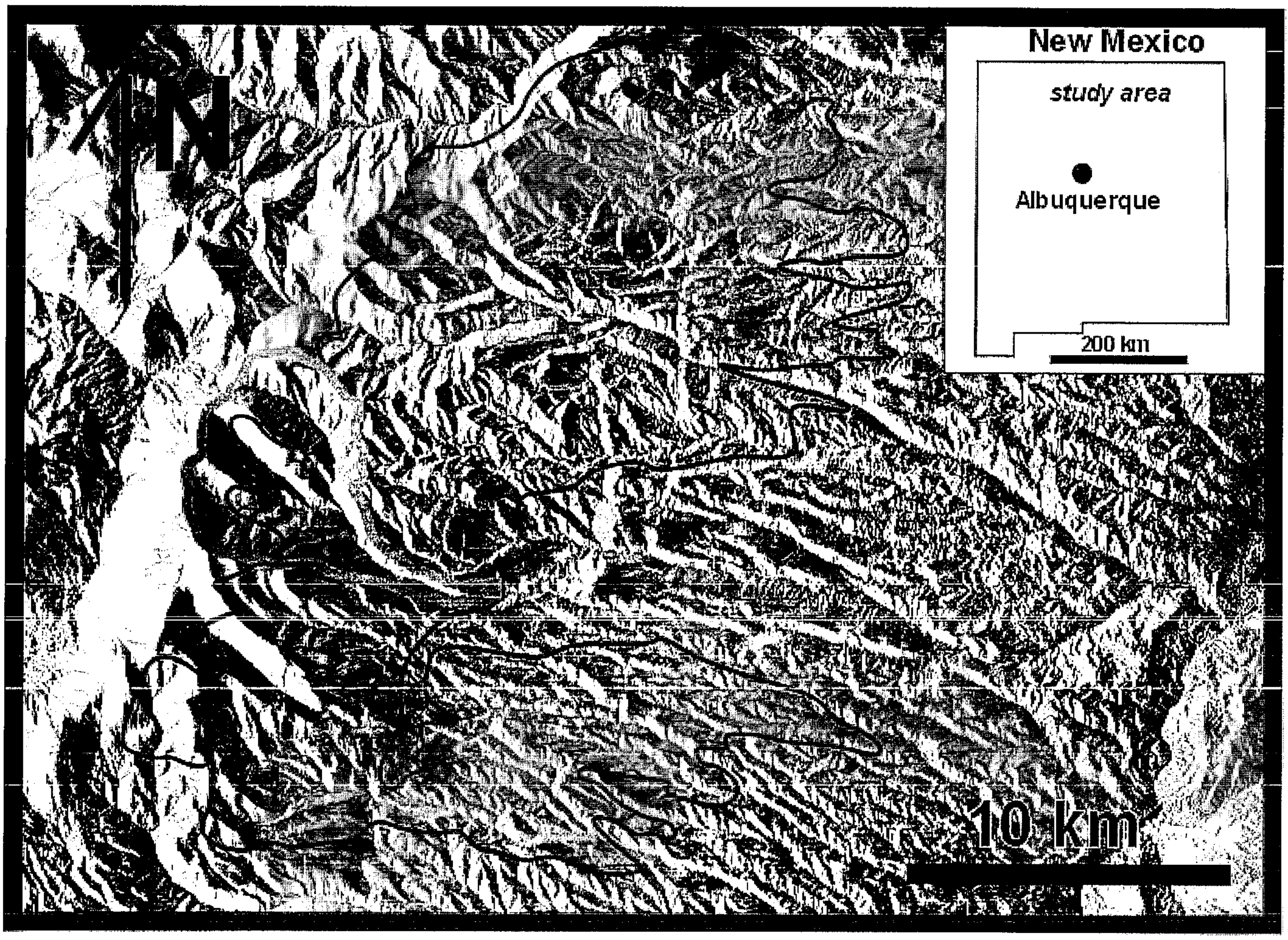

Fig. 1-. Digital elevation model of Cerro Grande Fire area, in New Mexico, with perimeter of maximum fire extent. Boundary of Los Alamos Creek drainage basin is shown in gray.

Fig. 1.- Modelo digital de elevación del área del incendio Cerro Grande, en New Mexico, con el perímetro de la máxima extensión del fuego. El contorno de la cuenca de drenaje del arroyo Los Alamos está indicada en gris.

RUSLE to mountain watersheds has been marred by difficulties in adapting the length-slope factor (L) to a complex topography. A procedure is presented herein that complies with the RUSLE rules and provides estimates of average soil loss from mountain watersheds.

Statement of the problem

RUSLE computes average annual soil loss, A, as: A = R*K*L*S*C*P, in which R is the average annual rainfall-runoff erosivity factor, K is the soil erodibility factor, L is the slope-length factor, S is the slope-steepness factor, C is the cover factor, and P is the support-practice factor. The effect of topography on soil erosion is described in RUSLE by factors L and S. The S-factor represents the change in erosion potential with change in surface gradient, and L describes the increasing potential for erosion of surface runoff with distance along a slope and is computed from $L = f(\lambda)$, , where λ is the plan-view distance from the point of initiation of overland flow to the point where overland flow is collected in a channel or where deposition begins (Renard et al., 1997). To take advantage of digital elevation models (DEMs) and geographic information system (GIS) procedures, it has been proposed (e.g. Desmet and Govers, 1996) to replace λ by upslope contributing area (UCA), which is approximated easily by automated inspection of a DEM. For each cell in the DEM grid, a procedure determines the number of other cells from which it receives overland flow, and then multiplies the number of cells by the cell area to obtain the upstream contributing area for every cell.

A theoretical test was performed that showed agreement between the RUSLE L and the UCA-based L for surfaces of negligible tangential curvature, slope-lengths less than 100 m, and surface gradients lower than 14 degrees (Moore and Wilson, 1992). Most mountain watersheds, however, fall outside the test conditions. Yitayew et al. (1999) found that L*S values computed by the upstream contributing area appear to be systematically higher than those obtained by the RUSLE method.

Upstream contributing area methods infringe RUSLE rules in two significant aspects (Mitasova et al., 1997; Wilson and Lorang, 1994). One is that overland-flow lines extend from the upstream to the downstream margin of the DEM without consideration for intermediate derivation channels or areas of deposition such as roads; this omission may have caused large L*S values reported by Yitayew et al. (1999). The other problem is that upstream contributing area involves flow convergence and thus includes channels as part of the overland-flow system, which RUSLE excludes explicitly.

An alternative approach

Drainage density (D) is a morphometric factor relating cumulative stream length in a basin to the basin area (D = length of stream network/basin area) (Horton, 1932). Horton (1932, 1945) reasoned that the reciprocal of D describes the average distance between streams and that 1/2D approximates the average length of overland flow from the divides to the stream channels; thus, 1/2D is proportional to λ . The constant of proportionality approaches unity as the ratio of the stream-channel gradient to the valley side slope decreases (Horton, 1932). For ratios below about one third, departure from unity is not significant. A stream canyon with steep walls receives overland flow almost perpendicular to the canyon axis and no correction is needed. Introducing a corrective coefficient becomes important for gently sloping topography; if a correction is not applied, overland-flow length is underestimated. Conversely, inasmuch as some first-order streams may not be detected on the topographic map, there may be bias to measuring smaller-than-true values of D, thereby overestimating overland-flow length.

Measured as Horton (1932, 1945) suggested, average overland-flow length is consistent with RUSLE L in that it excludes stream channels. Average overland-flow length does not, however, distinguish areas of deposition on mid-slope positions that would terminate λ. With the relatively steep gradients of mountain watersheds, mid-slope sediment traps are likely rare. The drainage density and other needed values can be obtained from conventional paper maps, from DEMs queried by GIS procedures, or from combinations of both methodologies. In DEMs, the average slope is computed by number counts, but because cells have equal areas, the result is equivalent to an area-weighted average. Weighted average values for RUSLE K, C, and P factors should be similarly computed.

Example

The above-proposed procedure is tested on the small mountainous watershed of Los Alamos Creek, located in northern New Mexico, in southwestern

Total stream length	48.36 km
Basin area	1,329.20 ha
Drainage density	0.00364 m^{-1}
Average overland flow length	137 m
Average basin gradient	21 degrees
Average L factor	3.47
Average S factor	5.52
Average K factor	0.43 t h ha^{-1} N^{-1}
Average C factor	0.12
R factor	42.5 N/h
Average annual soil loss postfire	42 t/ha

Table I.- Morphometric parameters and RUSLE factors used to estimate soil loss from the Los Alamos drainage basin upstream from the confluence of Los Alamos and Quemazon canyons.

Tabla I.- Parámetros morfométricos y factores de RUSLE empleados para estimar la pérdida de suelo en la cuenca alta de Los Alamos, aguas arriba de la confluencia de los cañadones Los Alamos y Quemazón.

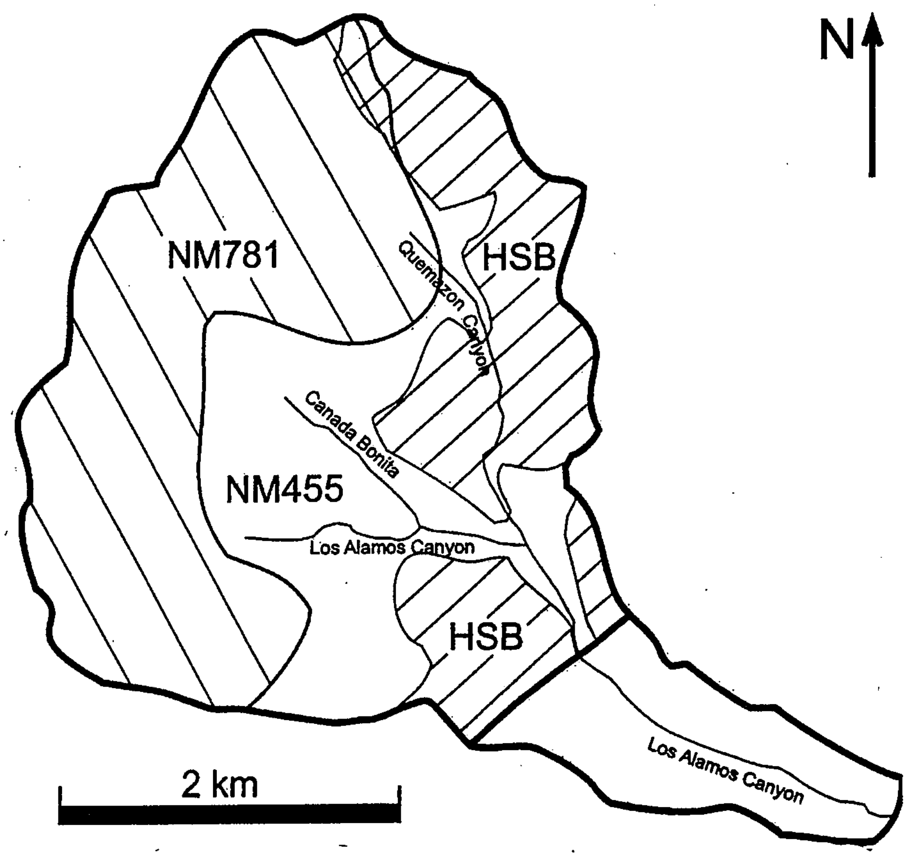

Fig. 2.- Los Alamos Creek drainage basin, emphasizing upper reaches for which soil loss is computed. Soil map units are NM781, grayed, and NM455, remainder of basin. Superimposed is high-severity burn (HSB) area.

Fig. 2.- Cuenca de drenaje de Los Alamos, enfatizando los tramos superiores para los cuales se ha calculado la pérdida de suelo. Unidades edáficas NM781, en gris, y NM455, resto del área. Se sobreimpone el área de alta severidad de incendio.

United States (Fig. 1). The Los Alamos watershed drains the eastern flank of the Jemez Mountains at elevations of about 2400 to 3000 m a.s.l., and narrows downstream into the steep-walled Los Alamos Canyon, which crosses the gently sloping Pajarito Plateau, and debouches into the Rio Grande. The watershed is underlain by a sandy loam of volcanic origin, and is mantled by pinyon-juniper and ponderosa pine forests. Precipitation averages about 600 mm/yr and is largely concentrated in the boreal summer months. This watershed was severely disturbed by the Cerro Grande Fire of May, 2000. The Los Alamos drainage basin contains three major water courses, Quemazon Canyon, Cañada Bonita, and Los Alamos Canyon (Fig. 2). Los Alamos Canyon and Quemazon Canyon join at an elevation of about 2400 m a.s.l., near the base of the Jemez Mountains. The portion of the basin upstream from this confluence is approximately identical to subwatershed LA1 in the subdivision implemented by the Burned Area Emergency Rehabilitation (BAER) team for the Cerro Grande fire area (BAER, 2000). The averaging procedure described above was applied to the upper Los Alamos drainage basin.

The upper Los Alamos basin is of order 4, in Strahler's (1957) scheme, and shows an almost circular plan shape (form factor = 0.8; area/length square). In calculating the basin area, the stream channels were buffered 20 m to each side of the axis to eliminate from the calculation probable areas of in-channel deposition. Stream length was measured on USGS 1:24,000 topographic maps. Table 1 summarizes the results. The mean overland-flow length is about 140 m. Ratios of stream-axis to canyon-wall slopes measured in the upper reaches of Cañada Bonita and Quemazon Canyon yielded 0.32 and 0.30, respectively; consequently, no correction was applied. The value for the R-factor was taken from the isoerodent map in Renard et al. (1997). The erodibility, K, factor was obtained from STATSGO tables for New Mexico. The STATSGO database compiles information from detailed soil surveys to produce soil map units mappable at a scale of 1:250,000, approximately ; the minimum area for STATSGO map unit is about 625 hectares. STATSGO (State Soil Geographic Database) soil map units NM781 and NM455 underlie 52% and 48% of the area of interest, with K-factor values of 0.26 and 0.49 $t\ h\ ha^{-1}\ N^{-1}$, respectively. The cover factor, C, was categorized in terms of burn severity, with a C value of 0.27 given to high-severity burn areas (22% of the upper Los Alamos basin) and a value of 0.07 given to the remaining area, which includes a small proportion of unburned land. Average values for C and K are weighted by area. The P factor was taken as 1, which assumes no postfire stabilization or remediation treatments. The average annual soil loss from the upper Los Alamos basin is in the order of 42 t/ha. The BAER team, employing USLE (BAER, 2000), estimated postfire soil loss for subwatershed LA1 to be approximately 36 t/ha.

Conclusions

Many past applications of RUSLE to steep watersheds gave unreliable results due to the use of procedures that do not comply with RUSLE rules for computing the L-factor. The averaging procedure presented in this paper is based on an approximation of overland-flow length from the measurement of drainage density. Input parameter values may be computed using conventional map-analysis techniques or modern GIS tools and DEMs. The results obtained by the presented procedure should be more reliable in steep drainage basins, where areas of deposition outside the stream channels cover a minor area. RUSLE has proven a valuable tool in soil conservation planning in gently-sloping agricultural lands, and should provide a similar service to soil conservation and water quality management in disturbed mountain watersheds.

Acknowledgments

The senior author thanks the Fulbright Senior Scholar Program and the Argentine Consejo Nacional de Investigaciones Científicas y Técnicas (CONICET) for financial support, and the U.S. Geological Survey for kindly hosting his stay in the United States.

Partially founded by the Generalitat de Catalunya, Comissionat per Universitats i Recerca, Grup de Qualitat 2001-SGR-00074.

References

BAER, (2000): Cerro Grande Fire Burned Area Emergency Rehabilitation (BAER) Plan. Interagency BAER Team, Los Alamos, New Mexico, 403p.

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

Fowler, J.M., and Heady E.O. (1981): *Suspended sediment production potential on undisturbed forest land.* Journal of Soil and Water Conservation, 1, 47-50.

Horton, R.E. (1932): *Drainage-basin characteristics. Trans. Am. Geophys. Union*, p. 350-361.

Horton, R.E. (1945): *Erosional development of streams and their drainage basins; hydrophysical approach to quantitative morphology.* Geological Society of America Bulletin, 56, 275-370.

Mitasova, H., Hofierka J., Zlocha M., and Iverson L. (1997): *Reply to Comment by Desmet and Govers.* International Journal of Geographical Information Sciences, 11, 611-618.

Moore, I.D., and Wilson J.P., (1992): *Length-slope factors for the Revised Universal Soil Loss Equation: simplified method of estimation.* Journal of Soil and Water Conservation, 47, 423-428.

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). USDA Agricultural Handbook No. 703.

Strahler, A.N., (1957): Quantitative analysis of watershe geomorphology. Transactions of the American Geophysical Union, 387, 913-920.

Wilson, J.P., and Lorang M.S. (1994): Spatial models of soil erosion and GIS. *In* Fotheringham, A.S. and Rogerson, P. (eds.) Spatial analysis and GIS. Technical issues in geographical information systems. Taylor & Francis, London. p. 83-108

Yitayew, M., Pokrzywka S.J. and Renard K.G. (1999): Using GIS for facilitating erosion estimation. Applied Engineering Agriculture, 15, 295-301.