Validation of the USPED Erosion and Deposition Model at Schofield Barracks, O‘ahu, Hawai‘i

Authors: Warren, Steven D., and Ruzycki, Thomas S.

Source: Pacific Science, 76(1) : 43-51

Published By: University of Hawai'i Press

URL: https://doi.org/10.2984/76.1.4

Validation of the USPED Erosion and Deposition Model at Schofield Barracks, O'ahu, Hawai'i[1]

Steven D. Warren[2,4] *and Thomas S. Ruzycki*[3]

Abstract: Soil erosion has been recognized as a significant environmental issue in the United States for over 200 years. Numerous attempts have been made to predict and quantify the phenomenon, yet significant issues remain that hinder the accuracy and effectiveness of such models. This article describes the application of the new generation Unit Stream Power Erosion and Deposition (USPED) model that estimates soil erosion and concomitant sediment deposition at Schofield Barracks, Hawai'i, an active Army training installation. The model accurately placed modeled estimates of soil erosion and sediment deposition in the correct visually determined category 85% the time (51 of 60 randomly assigned points). While not perfect, the USPED model estimates exceeded a predetermined accuracy threshold of 80%, recognizing that model estimates represent long-term estimates while visual estimates are based primarily on relatively recent conditions.

Keywords: soil erosion, sediment deposition, model accuracy, military training area

For over two centuries, soil erosion has been recognized as a significant environmental problem in the United States (McDonald 1941). As early as the 1940s and 1950s, research scientists began to develop a quantitative procedure to estimate soil loss, and several factors including slope steepness and management practices that affect soil erosion were identified and quantified. Consequently, the Universal Soil Loss Equation (USLE) was developed (Wischmeier and Smith 1965) and later reissued (Wischmeier and Smith 1978). Given its success in predicting soil erosion in various locations worldwide, the USLE became a major conservation planning tool which is widely used in the United States and in multiple other countries. With additional research, experiments, data, and resources, the Revised Universal Soil Loss Equation (RUSLE) was issued (Renard et al. 1997). The RUSLE has the same formula as USLE, but has several improvements in determining contributing factors, including revised isoerodent maps, a time-varying approach for the soil erodibility factor, a subfactor approach for evaluating the cover-management factor, a new equation to reflect slope length and steepness, and new conservation-practice values. Despite the contributions of the RUSLE model, numerous deficiencies remain, and process-based alternatives have been developed, for example, the Water Erosion Prediction Project (Flanagan and Nearing 1995).

A major shortcoming of USLE-based and more complex process-based models is the one-dimensional approach used to account for the effects of topography. Landscapes have

[1]Manuscript accepted 12 August 2021.
[2]US Forest Service, Rocky Mountain Research Station, 735 N 500 E, Provo, UT 84606, USA.
[3]Center for Environmental Management of Military Lands, 1490 Campus Delivery, Colorado State University, Fort Collins, CO 80523-1490, USA.
[4]Corresponding author (e-mail: Steven.Warren@USDA.gov).

Pacific Science (2022), vol. 76, no. 1:43–51
doi:10.2984/76.1.4

generally been treated as homogeneous, planar features, and average erosion rates have been assigned to entire hillslopes and watersheds, thus providing no information regarding within-watershed sources and sinks of eroded materials. Alternatively, complex landscapes have been computationally divided into semi-homogeneous planes, and erosion has been calculated for each plane, thus giving some consideration to hillslope convexity and concavity (Foster and Wischmeier 1974). However, in both approaches, erosion is calculated only along straight flow lines without full consideration of the influence of flow convergence and divergence which can affect soil erosion greatly (Hallema et al. 2016, Meshkat et al. 2019). Neither approach provides adequate spatially distributed information on erosion necessary to effectively optimize erosion and sediment control efforts.

An additional significant shortcoming of the USLE and the RUSLE is that they predict soil erosion only; they do not predict sediment deposition (Alewell et al. 2019). Furthermore, both models predict erosion "universally," that is, even where sediment deposition occurs. Thus, at landscape or watershed scales, the spatial distribution of soil erosion as predicted by these models misrepresents actual conditions and tends to overestimate erosion on the entire watershed (e.g., Jensen 1983, Busacca et al. 1993, Spaeth et al. 2003). The only practical way to apply the models is to identify *a priori* those portions of the landscape subject to sediment deposition and exclude them from analysis (Mitasova et al. 1997). In addition, the models predict sheet and rill erosion only; they do not account for gully erosion or streambank erosion (Alewell et al. 2019).

The basic equation for the USLE and RUSLE models is $E = R \times K \times LS \times C \times P$, where E is the average annual soil erosion (metric tons ha^{-1} yr^{-1}), R (MJ mm ha^{-1} hr^{-1} yr^{-1}) represents the erosivity of local rainfall and runoff, K (metric tons ha hr ha^{-1} MJ^{-1} mm^{-1}) represents the inherent erodibility of the soil, LS is a dimensionless topographic factor based on slope length and steepness, C is a dimensionless factor representing vegetative cover, and P is a dimensionless conservation support practice factor (Wischmeier and Smith 1978, Foster et al. 1981). Values for these factors are determined from various maps, tables, and nomographs based on field measurements (Haan et al. 1994, Renard et al. 1997). An important modification of the USLE/RUSLE backbone used by the USPED was derived by Moore and Burch (1986) and applied by Desmet et al. (1995) and Mitasova et al. (1996). The modification involves replacement of the slope-length (LS) factor with the upslope contributing area, which allows the model to predict increased erosion due to concentrated flow without the need to define these areas as inputs for the model *a priori*. An LS analog is computed for each grid cell as $LS = A^m(\sin \beta)^n$, where A is the upslope contributing area per unit width, β is the slope angle, and m and n are constants that depend on the type of flow and the soil properties. Where rill erosion dominates, these parameters are usually set to $m = 1.6$ and $n = 1.3$; where sheet erosion prevails, they are set to $m = n = 1.0$ (Moore and Wilson 1992, Foster 1994). Moore and Burch (1986) further proposed that a modified USLE can be used as a proxy for sediment flow and sediment transport capacity. Using this concept, the USPED model computes both erosion and deposition (ED) as a change in sediment transport capacity across a geographic information system (GIS) grid cell. In complex topography, sediment flow is represented as a bivariate vector field with the magnitude given by E and the direction given by the water flow direction. Change in sediment flow is then derived as a divergence, leading to a computationally simple formulation for estimating the net erosion or deposition rates as $ED = ((E \cos a)/x) + ((E \sin a)/y)$, where a is the slope aspect (in degrees) equivalent to flow direction (Warren et al. 2000, Mitasova and Mitas 2001).

Geographic information systems (GIS) provide the capacity to more fully consider the effects of topographic complexity on soil erosion. Application of erosion models within a GIS has become increasingly popular as the technology has evolved (e.g., Fistikoglu and Harmancioglu 2002, Shi et al. 2004). Spatially distributed elevation data stored in a GIS can be analyzed to produce slope length and steepness (LS) values for any given point in a watershed (e.g. Warren et al. 2005, Zhang et al. 2017). More importantly, the effects of flow convergence and divergence can be more fully considered by determination of the upslope area that contributes to flow across each point in the watershed. When upslope contributing area is substituted for slope length, the resulting LS-factor is equivalent to the traditional LS-factor on planar surfaces, but has the added benefit of being applicable to complex hillslope geometries (Moore and Burch 1986, Moore and Wilson 1992). Equations for the computation of the LS-factor based on upslope contributing area have been developed by Desmet and Govers (1996) and Mitasova et al. (1996). These equations more fully account for topographic complexity by considering both the profile curvature (in the downhill direction) and the tangential curvature (perpendicular to the downhill direction) (Warren et al. 2000). Net erosion or deposition within a grid cell is calculated as the change in sediment transport capacity in the direction of flow. Collectively, the improvements to the traditional USLE/RUSLE that are based on the unit stream power theory (Moore and Burch 1986, Moore and Wilson 1992) have been named the Unit Stream Power Erosion and Deposition (USPED) model.

This article describes the application and testing of the USPED model at Schofield Barracks, an active Army training installation on the island of O'ahu, Hawai'i. As with most training installations, portions may be heavily disturbed, while other portions are scarcely impacted (Warren et al. 2007), primarily because some areas are conducive to military training doctrine while others are not (Warren and Herl 2005).

STUDY AREA

Schofield Barracks Military Reservation is a command within the US Army Garrison Hawai'i and the headquarters of the 25th Infantry Division, known as the Tropical Lightning Division. The area which was to become Schofield Barracks was ceded to the U.S. government on 26 July 1899, less than a year after the state of Hawai'i was annexed by the United States. The post was established in 1908 to provide mobile defense of Pearl Harbor and the entire island of O'ahu. Schofield Barracks saw considerable collateral damage and casualties during the Japanese attack on Pearl Harbor as it was located adjacent to Wheeler Airfield which was targeted in the initial phase of the Pearl Harbor attack designed to disable the air defense system of the island. It covers approximately 17,725 acres (7,173 ha) near the center of the island, at the foot of the Waianae mountain range, and near the city of Wahiawa.

Average annual temperature ranges from 20.6 °C (69 °F) in January and February to 25 °C (77 °F) in August. Prevailing winds are northeasterly from 4 to 12 mph in the warmer summer months, and lighter southeasterly winds prevail in the winter months. The elevation at Schofield Barracks ranges from 267 m (660 ft) in the cantonment area to >1,214 m (6,300 ft) in the Waianae mountain range. It is a large valley with a ridgeline along the north, west, and southwest boundaries. The valley faces primarily toward the east. The majority of the land is of moderate slope, increasing in steepness toward the east. Deeply dissected uplands of the leeward slopes make up the eastern portion. This portion of the installation, used primarily as a tactical training area for combat units, is typically rugged with steep terrain and dense vegetation. The western half of the training area is composed of gently sloping grass, brush, and tree-cover separated by steeply sloped watercourses. Exotic plants dominate. The high elevations are home to a wide variety of native, endemic plants and animals, some of which are officially listed by the U.S. Fish and Wildlife Service as threatened or endangered.

METHODS

To apply the USPED model at Schofield Barracks, it was necessary to first populate all parameters inside a GIS database. Because the *R*-factor typically varies minimally across an area the size of the training area, we consulted an isoerodent map available in Renard et al. (1997) and selected an appropriate *R*-factor of

350. The *R*-factor was considered to be generally constant across an area the size of Schofield Barracks, with only minimal extremes in elevation.

K-factors are generally published in Natural Resources Conservation Service (NRCS) soil maps and surveys. For Schofield Barracks, we selected the soil survey at https://gdg.sc.egov.usda.gov/GDGOrder.aspx, and assigned the appropriate *K*-factors for each soil series present to create a *K*-factor map. Where soil mapping units were listed as complexes of more than one component, *K*-factor data were calculated as the weighted average of *K*-factor values of the map unit components by percent of map unit composition, and this value was assigned to the entire mapping unit.

LS-factors were calculated from the upslope contributing area and slope steepness for each GIS grid cell in a map of Scofield Barracks using a digital elevation model (DEM). A digital elevation model produced by the US Geological Survey and found at the National Elevation Database (http://ned.usgs.gov) was used to derive these parameters for each raster pixel or grid cell. The grid cell resolution was 10 m. Based on visits to Schofield Barracks, it was determined that sheet erosion predominated. Therefore, both the *m* and *n* constants were set to 1.0 and the LS equation was solved for each grid cell in the DEM to produce a LS data layer.

C-factors were determined in a two-step process. First, the normalized difference vegetation index (NDVI) was calculated spatially from an unsupervised classification of a recently acquired growing season Landsat TM satellite image for Schofield Barracks. A 30-m resolution remotely-sensed image was available at https://earthexplorer.usgs.gov. The range of NDVI values was separated into 6 equally-sized categories across the represented range of values. Appropriate *C*-factors were derived using Landsat 8 imagery for Schofield Barracks. The image was collected on 20 June 2018 (LC08_HI_002000_20180620_2018119_C01_V01, path 65, row 45). The images were corrected for atmospheric effects by converting each scene, first for at-sensor radiance, and then for top of atmosphere (TOA) reflectance, using methods from Chandler et al. (2009). The normalized difference vegetation index (NDVI) was calculated (near infrared − red)/(near infrared + red) for each pixel or cell in the images. This NDVI raster dataset was then converted into a GIS polygon dataset to run a random point generator in ArcGIS. Ten points were randomly assigned into each category (10 points × 6 categories = 60 points total). These points were converted into a kml file and given to a soil erosion expert to overlay on aerial imagery in Google Earth. The erosion expert then assigned a *C*-factor to each of the NDVI categories based on visual inspection of the image and reference to a *C*-factor table published in Wischmeier and Smith (1978). The respective polygons of the NDVI GIS dataset were then populated with the estimated *C* values. This dataset was rasterized into a *C*-factor layer, which was then used as an input into the USPED calculations.

The *P*-factor is not used in the USPED model because conservation support practices typically affect plant cover (e.g., grassed waterways) and topography (e.g., terraces), and because such management effects are now accounted for in a spatially distributed manner by the *C* and LS values, respectively, of the USPED model using satellite imagery and digital elevation models (DEM), respectively. As a result, the *P*-factor has become largely irrelevant and is not used. Hence, it was assigned a value of 1.0 such that it had no effect on the erosion and sediment calculations.

After populating maps for each USPED parameter, the model was solved for each pixel or cell. The USPED erosion and deposition values were divided into six categories representing levels of erosion or deposition typically encountered (Table 1), and an erosion/deposition (ED) data layer was created. As the purpose of the study was to assess the modeled ED levels compared to the actual ED values, it was necessary to compare modeled ED values with observations of the same. To accomplish that goal, 10 random points were assigned within each of the six ED categories represented on the ED data layer (60 points total). The points were converted

TABLE 1

Erosion/Deposition Categories and Descriptions used for Field Validation of the USPED Erosion/Deposition Estimates (Modified from Warren et al. 2005)

CATEGORY 1 (High Erosion): >22.4 Mg ha^{-1} yr^{-1} (>10 tons ac^{-1} yr^{-1}). Signs of erosion clearly evident, including scouring, litter dams, and pedestaling of plants and surface stones. Often on sloped areas. Surface often rockier or more gravelly than noneroded areas due to removal of fine soil particles. Runoff patterns such as rills and gullies generally present. Plant density and vigor often less than in noneroded areas due to loss of soil fertility. Weedy species often present, subsoils exposed, and importation of seeds via overland flow of water. When erosion occurs through deposits in channels, often more than half of the deposits eroded away.

CATEGORY 2 (Medium Erosion): 11.2–22.4 Mg ha^{-1} yr^{-1} (5.01–10 tons ac^{-1} yr^{-1}). Marginal signs of erosion generally evident, including soil scouring, litter dams, and pedestaling of plant crowns and surface stones. Surface may appear marginally rockier or gravellier than in noneroded areas due to the loss of fine soil particles. Runoff patterns and small rills may be evident. Plant density and vigor may be lower than in noneroded areas due to loss of soil fertility.

CATEGORY 3 (Low Erosion): 0–11.2 Mg ha^{-1} yr^{-1} (0–5.0 tons ac^{-1} yr^{-1}). Few signs of water movement and erosion. Minimal evidence of scouring, litter dams, pedestaling of plant bases, and surface stones apparent. Slopes generally minor.

CATEGORY 4 (Low Deposition): 0–11.2 Mg ha^{-1} yr^{-1} (0–5.0 tons ac^{-1} yr^{-1}). Few signs of deposition. Generally located in flatter areas or below eroded areas. Surface soil texture may be marginally finer than surrounding areas. Minor sediment deposits may be present on the upslope sides of plants and rocks.

CATEGORY 5 (Medium Deposition): 11.2–22.4 Mg ha^{-1} yr^{-1} (5.01–10 tons ac^{-1} yr^{-1}). Signs of deposition evident. Generally located in flatter areas at the bottoms of slopes, in swales, or draws. Soil will generally be marginally deeper than surrounding areas as a result of deposition. Few rocks in the soil profile. Surface texture will tend to be silty, but sand and clay may be present depending on upslope soils. Vegetation may be marginally more robust than surrounding areas.

CATEGORY 6 (High Deposition): >22.4 Mg ha^{-1} yr^{-1} (>10 tons ac^{-1} yr^{-1}). Significant signs of deposition evident. Generally located in flatter areas at the bottoms of slopes, in swales, or draws. Soil generally deeper than surrounding areas. Few rocks in the soil profile. Surface texture finer than surrounding soils. Vegetation more robust than surrounding areas due to greater water holding capacity and nutrient status of deposited fine soil particles. Gullies present in channels, but significantly less than half of the deposits should be gone.

into a kml file and given to the field soil erosion expert to overlay on aerial imagery in Google Earth. The erosion expert then observed the satellite imagery at each point and visually assigned the actual ED values to them. Table 1 was used to assist in the visual assignment of actual erosion and deposition.

RESULTS

Based on the six possible categories of soil erosion and sediment deposition (ED), we found that the USPED model produced calculated estimates of ED that agreed with visual estimates 85% of the time (51 of 60 sample points). As our predetermined threshold for acceptability was 80%, the accuracy of the USPED model (85% agreement) was more than acceptable. Figure 1 illustrates the spatial distribution of the calculated ED values at Schofield Barracks.

DISCUSSION

Evaluation of the accuracy of erosion models has been historically limited by the lack of long-term measured soil erosion (Nearing and Hairsine 2011). Furthermore, comparisons have been primarily made only with sediment yield data from watershed outlets, bringing into question the reliability of such comparisons as such data does not account for the spatial variability of erosional and depositional processes within the watersheds (Jetten et al. 2003). In an attempt to account for variability in watershed characteristics that affect the efficiency of sediment delivery to the watershed outlet, some researchers have attempted to employ a sediment delivery ratio (SDR) defined as the sediment yield from an area divided by the gross erosion of that same area (e.g., Lee and Kang 2013). The use of a sediment delivery ratio is a surrogate attempt

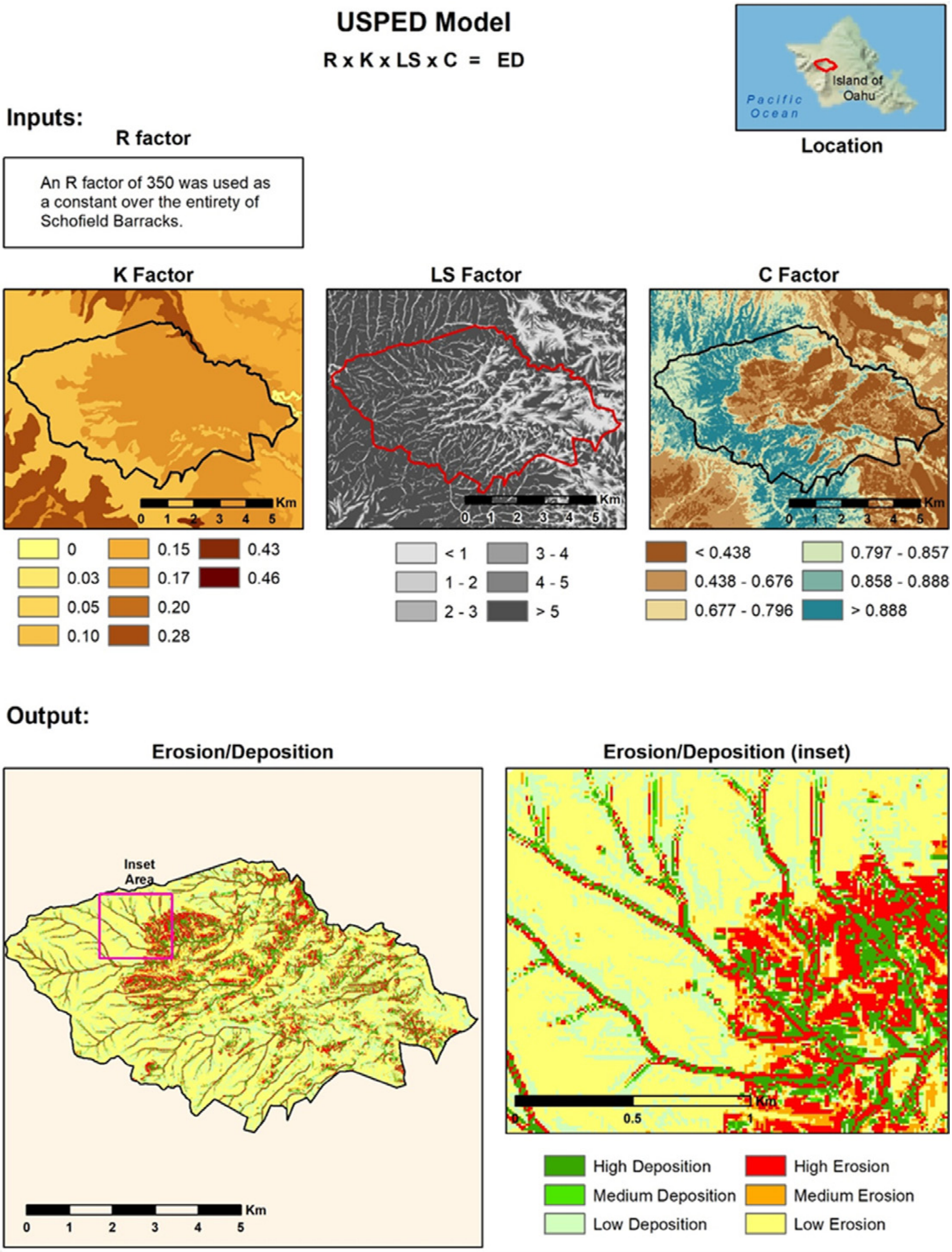

FIGURE 1. USPED model component factors and calculation results at Schofield Barracks, Hawai'i.

to account for processes occurring within a watershed that affect sediment transport, but suffers from both spatial and temporal variability (Walling 1983, Woznicki and Nejahashemi 2013). The use of an SDR is merely a performance factor that can vary seasonally and can produce erroneous results (Kinnell 2004).

The procedure we employed to determine the accuracy of the USPED model in this study is as revolutionary as the model itself. The USPED model predicts both soil erosion and sediment deposition spatially and quantitatively within watersheds. We compared the spatially distributed model results with spatially distributed observations of the same variables, something rarely, if ever, attempted in the past. The 85% agreement is particularly encouraging.

The fact that some discrepancies existed between model results and corresponding observations suggests that further effort may be required. While it is tempting to blame discrepancies on the model itself, other factors, particularly observer error may have contributed to the errors. We fully acknowledge that Table 1 may not fully account for all variability. Visual clues in the table correspond primarily to recent changes and may not be adequate to describe long-term variability as predicted by the USPED model. Furthermore, it is likely that the observer's opinion may have been swayed by focusing on visual clues at specific points rather than considering the entire polygon that it represented.

The level of accuracy of the USPED model was similar to comparisons of soil erosion produced by measuring levels of ^{137}Cesium in the soil (Warren et al. 2005), suggesting that erosion and/or deposition estimation, by whatever means, may not produce estimates with significantly greater accuracy. One must recall that the USPED model, as are all USLE-based models, is only a model. As a model, of naturally occurring processes in a natural environment where all variability cannot be controlled, it is unrealistic to expect accuracies beyond about 80%. While the USPED and USLE components are designed to be long-term average representations of the respective parameters, each parameter (*R*, *K*, LS, and *C*) may fluctuate greatly on both a spatial and temporal basis. Hence, estimates of average annual erosion and deposition will likewise fluctuate from year to year based on the parameters that feed their calculation.

In the quest to produce more accurate erosion prediction, predictive models have become more complex. However, there is minimal evidence that highly complex models significantly outperform simpler ones (Jakeman and Hornberger 1993, Merritt et al. 2003, Govers 2010). The USPED model is a relatively simple soil erosion and sediment deposition model that takes advantage of modern technologies such as remote sensing and digital elevation modeling to produce spatially distributed estimates that accurately approximate visual observations of the same parameters. Such distributed estimates replace the need to make meticulous spatially distributed measurements in order to adequately combat those processes.

Literature Cited

Alewell, C., P. Borrelli, K. Meusburger, and P. Panagos. 2019. Using the USLE: chances, challenges and limitations of soil erosion modelling. Int. Soil Water Conserv. Res. 7:203–225.

Busacca, A. J., C. A. Cook, and D. J. Mulla. 1993. Comparing landscape-scale estimation of soil erosion in the Palouse using Cs-137 and RUSLE. J. Soil Water Conserv. 48:361–367.

Chandler, G., B. L. Markham, and D. L. Helder. 2009. Summary of current radiometric calibration coefficients for Landsat MSS, TM, ETM+, and EO-1 ALI sensors. Remote Sens. Environ. 113:893–903.

Desmet, P. J., and G. Govers. 1996. A GIS procedure for automatically calculating the USLE LS factor on topographically complex landscape units. J. Soil Water Conserv. 51:427–433.

Desmet, P. J., G. Govers, J. Poesen, and D. Goosens. 1995. GIS-based simulation of erosion and deposition patterns in an agricultural landscape: a comparison of

model results with soil map information. Catena 25:389–401.
Fistikoglu, O., and N. B. Harmancioglu. 2002. Integration of GIS with USLE in assessment of soil erosion. Water Resour. Manage. 16:447–467.
Flanagan, D. C., and M. A. Nearing, eds. 1995. USDA-Water Erosion Prediction Project. National Soil Erosion Research Laboratory Report No. 10. US Department of Agriculture, Agricultural Research Service, Lafayette, IN.
Foster, G. R. 1994. Comment on "Length-slope factors for the Revised Universal Soil Loss Equation: simplified method of estimation." J. Soil Water Conserv. 49:171–173.
Foster, G. R., and W. H. Wischmeier. 1974. Evaluating irregular slopes for soil loss prediction. Trans. Am. Soc. Agron. 17:305–309.
Foster, G. R., D. K. McCool, K. G. Renard, and W. C. Moldenhauer. 1981. Conversion of the universal soil loss equation to SI metric units. J. Soil Water Conserv. 36(6): 355–359.
Govers, G. 2010. Misapplications and misconceptions of erosion models. Pages 117–134 *in* R.P.C. Morgan, and M.A. Nearing, eds. Handbook of erosion modeling. Wiley-Blackwell Publishing, Chichester, UK.
Haan, C. T., B. J. Barfield, and J. C. Hayes. 1994. Design hydrology and sedimentology for small catchments, 2nd ed. Academic Press, San Diego, CA.
Hallema, D. W., R. Moussa, G. Sun, and S. G. McNulty. 2016. Surface storm flow prediction on hillslopes based on topography and hydrologic connectivity. Ecol. Proc. 5: #13
Jakeman, A. J., and G. M. Hornberger. 1993. How much complexity is warranted in a rainfall-runoff model? Water Resour. Res. 29:2637–2649.
Jensen, M. E. 1983. Applicability of the Universal Soil Loss Equation for southeastern Idaho wildlands. Great Basin Natur. 43:579–584.
Jetten, V., G. Govers, and R. Hessel. 2003. Erosion models: quality of spatial predictions. Hydrolog. Proc. 17:887–900.
Kinnell, P. I. A. 2004. Sediment delivery ratios: a misaligned approach to determining sediment delivery from hillslopes. Hydrolog. Proc. 18:3191–3194.
Lee, S. E., and S. H. Kang. 2013. Estimating the GIS-based soil loss and sediment delivery ratio to the sea for four major basins in South Korea. Water Sci. Technol. 68(1):124–133.
McDonald, A. H. 1941. Early American soil conservationists. U.S. Department of Agriculture Miscellaneous Publication 449. 109 pp.
Merritt, W. S., R. A. Letcher, and A. J. Jakeman. 2003. A review of erosion and sediment transport models. Environ. Model. Softw. 18:761–799.
Meshkat, M., N. Amanian, A. Talebi, M. Kiani-Harchegani, and J. Rodrigo-Comino. 2019. Effects of roughness coefficients and complex hillslope morphology on runoff variables under laboratory conditions. Water 11: #2550.
Mitasova, H., and L. Mitas. 2001. Multiscale soil erosion simulations for land use management. Pages 321–347 *in* R. Harmon and W. Doe, eds. Landscape erosion and landscape evolution modeling. Kluwer Academic/Plenum Publishers.
Mitasova, H., J. Hofierka, M. Zlocha, and L. R. Iverson. 1996. Modelling topographic potential for erosion and deposition using GIS. Int. J. Geog. Inf. Sys. 10:629–641.
———. 1997. Reply to comment by Desmet and Govers. Int. J. Geog. Inf. Sys. 11:611–618.
Moore, I. D., and G. Burch. 1986. Physical basis of the length-slope factor in the Universal Soil Loss Equation. Soil Sci. Soc. Am. J. 50:1294–1298.
Moore, I. D., and J. P. Wilson. 1992. Length-slope factors for the Revised Universal Soil Loss Equation: simplified method of estimation. J. Soil Wat. Conserv. 47:423–428.

Nearing, M. A., and P. B. Hairsine. 2011. The future of soil erosion modelling. Pages 389–397 *in* R. P. C. Morgan and M. A. Nearing, eds. Handbook of erosion modelling. Wiley-Blackwell Publishing. 416 pp.

Renard, K. G., G. R. Foster, G. A. Weesies, D. K. McCool, and D. C. Yoder, coords. 1997. Predicting soil erosion by water: a guide to conservation planning with the Revised Universal Soil Loss Equation. U.S. Department of Agriculture, Agriculture Handbook 703.

Shi, Z.-H., C. F. Cai, S. W. Ding, T.-W. Wang, and T. L Chow. 2004. Soil conservation planning at the small watershed level using RUSLE with GIS: a case study in the Three Gorge Area of China. Catena 55(1):33–48.

Spaeth, K. E., F. B. Pierson, M. A. Weltz, and W. H. Blackburn. 2003. Evaluation of USLE and RUSLE estimated soil loss on rangeland. J. Range Manage. 56:234–246.

Walling, D. E. 1983. The sediment delivery problem. J. Hydrol. 65:209–237.

Warren, S. D., and B. K. Herl. 2005. Use of military training doctrine to predict patterns of maneuver disturbance on the landscape. II. Validation. J. Terramech. 42(3–4):373–384.

Warren, S. D., H. Mitasova, M. R. Jourdan, W. M. Brown, B. R. Johnson, D. M. Johnston, P. Y. Julien, L. Mitas, D. K. Molnar, and C. C. Watson. 2000. Final report: digital terrain modeling and distributed soil erosion simulation/measurement for minimizing environmental impacts of military training. Center for Ecological Management of Military Lands TPS 00-02.

Warren, S. D., H. Mitasova, M. G. Hohmann, S. Landsberger, Y. Iskander, T. S. Rusycki, and G. M. Senseman. 2005. Validation of a 3-D enhancement of the Universal Soil Loss Equation for prediction of soil erosion and sediment deposition. Catena 64:281–296.

Warren, S. D., S. W. Holbrook, D. A. Dale, N. L. Whelan, M. Elyn, W. Grimm, and A. Jentsch. 2007. Biodiversity and the heterogeneous disturbance regime on military training lands. Restor. Ecol. 15(4):606–612.

Wischmeier, W. H., and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains: a guide selection of practices for soil and water conservation. U.S. Department of Agriculture. Agricultural Handbook No. 282.

———. 1978. Predicting rainfall erosion losses – a guide to conservation planning. U.S. Department of Agriculture. Agriculture Handbook No. 537.

Woznicki, S. A., and A. P. Nejahashemi. 2013. Spatial and temporal variabilities of sediment delivery ratio. Water Resour. Manage. 27(7):2483–2499.

Zhang, H., J. Wei, Q. Yang, J. Baartman, L. Gai, X. Yang, S. Li, J. Yu, C. Ritsema, and Y. Geissen. 2017. An improved method for calculating slope length (λ) and the LS parameters of the Revised Universal Soil Loss Equation for large watersheds. Geoderma 308:36–45.