PREDICTING EROSION RATES ON CONSTRUCTION SITES USING THE UNIVERSAL SOIL LOSS EQUATION IN DANE COUNTY, WISCONSIN

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Abstract

The Universal Soil Loss Equation (USLE) was developed for estimating sheet and rill erosion from agricultural fields under specific conditions. Parameters used to estimate erosion include rainfall energy, soil erodibility, slope length, steepness, surface cover, and management practices. Traditionally, urban conservation planners have not used the USLE for estimating soil loss and evaluating conservation measures and have relied on intuition alone to locate erosion control practices on constructions sites. The results of this process are often subjective and may vary with the skill of the planner. A USLE-based equation would provide a valuable, objective method for all planners, regardless of skill, to tailor specific construction site practices to existing conditions. A method to predict soil loss from construction sites was developed by adapting existing data for USLE erosion calculations to construction site conditions. In addition, the construction site procedure was used to create a user-friendly computer-based program to assist planners in developing erosion control plans. The computer program was distributed to engineers responsible for erosion control planning in Dane County, Wisconsin. Implementation of the USLE-based equation has proven to be a valuable tool for assessing alternatives for site management and erosion control. Planners are able to uniformly implement the equation on construction sites throughout the county, decrease the time necessary to complete a USLE calculation, and reduce human error.

Keywords:
Universal Soil Loss Equation (USLE), urban erosion control.

Background
Soil erosion, detachment of soil particles from the soil surface, results when soil is exposed to the power of rainfall energy and flowing water. Soil erosion causes a loss of productivity in the land, delivers millions of tons of sediment into waterways, and provides a substrate for toxic chemicals which are carried into receiving waters. Construction site erosion has been identified as a significant source of suspended solids in runoff in many parts of the United States (Hagman, et al., 1974; Yorke and Herb, 1976; Becker, et al., 1974). In the State of Wisconsin, sediment is the largest pollutant by volume (Wisconsin Department of Natural Resources, 1994). When erosion is compared on a rate basis, construction site erosion generates more erosion in a short period of time than any other land disturbing activity (Johnson and Juengst, 1997). While it is not possible to urbanize a watershed without exposing soil to erosive forces, it is possible to plan construction to control the production of sediment through the use of erosion prevention and reduction practices.

The Universal Soil Loss Equation (USLE) (Equation 1) was developed by the United States Department of Agriculture (USDA) for estimating sheet and rill erosion from agricultural fields under specific conditions (Wischmeier and Smith, 1978). The USLE enables planners to predict the average annual rate of soil erosion for combinations of seeding and management practices in association with a specified soil type, rainfall pattern, and topography. The equation groups interrelated physical and management parameters influencing erosion rate into six major factors whose site-specific values can be expressed numerically. More than a half century of erosion research in many states has supplied information from which the USLE factors were determined.

The Universal Soil Loss Equation.

$$A = R \times K \times (LS) \times C \times P \qquad \text{(Equation 1)}$$

Where:
A = average annual soil loss
R = rainfall and runoff factor
K = soil erodibility factor
L = slope length
S = steepness factor
C = cover and management factor
P = support practice factor

A The computed soil loss in tons/acre/year.

R The rainfall and runoff factor is the number of erosion-index units in an average year's rain. The erosion index is the storm energy in hundreds of foot tons times the 30 minute storm intensity.

K The soil erodibility factor is the soil loss rate (tons per acre) of a specific soil type and horizon as measured on a standard plot of land.

L The slope/length factor is the ratio of soil loss from the actual land slope length to that from a standard plot (726 feet in length) of land. Slope length 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 begins or runoff water enters a well defined channel that may be part of a drainage network or a constructed structure.

S The slope/steepness factor is the ratio of soil loss from the actual land slope gradient to that from a standard plot of land (9%).

C The cover and management factor is the ratio of soil loss from an area with specified cover and management to the corresponding loss from a clean-tilled, continuously fallow condition.

P The ratio of soil loss with a support practice such as contouring, stripcropping, or implementing terraces compared to up and down the slope cultivation. The support practice factor does not usually apply to soil loss on construction sites.

Soil losses computed with the USLE are best available estimates, not absolutes. The USLE will generally be most accurate for medium-textured soils, slope lengths of less than 400 feet, gradients of 3 to 18 percent, and consistent seeding and management systems represented in the USDA erosion studies. The USDA research shows that in comparing actual soil loss to computed soil loss, 84 percent of the differences in long-time average soil losses were less than 2 tons/acre/year (Wischmeier and Smith, 1978). The accuracy of a predicted soil loss depends on how accurately physical and management conditions on the particular site are described by the parameter values. Large-scale averaging of parameter values on mixed drainage areas reduces accuracy.

Traditionally, urban conservation planners have not widely used an equation similar to the USLE for estimating soil loss and evaluating conservation measures. They have relied on intuition alone to locate erosion control practices on construction sites. A USLE-based equation provides a valuable, objective method for all planners, regardless of skill, to tailor specific construction site practices to existing conditions. Erosion control is more efficient when it focuses erosion control practices in areas on the site identified by the USLE as being the most susceptible to erosion.

The objectives of this project were to: 1) develop a method to predict soil loss from construction sites by adapting existing data for USLE erosion estimation to construction site conditions and 2) create a user-friendly computer-based program to assist planners in developing construction site erosion control plans with the USLE.

Implementation Area

The project was conducted in Dane County, located in south-central Wisconsin. Dane County has extremely diverse and vast water resources with 475 miles of rivers and streams and 37 lakes, but these resources are threatened by rapid urban growth. Within the next twenty years, it is conservatively estimated that an additional 72,000 people will live in the county. Residents recognize how impacts to water quality effect their standard of living and are interested in protecting water resources.

Due to the value that the citizens of Dane County place on water quality, a very restrictive erosion control ordinance was adopted in 1995. Any land disturbance greater than 4000 square feet must comply with the Dane County Erosion Control Ordinance (Dane County, 1999). As part of this ordinance, applicants must prove that the erosion rate on their project will not exceed

15 tons per acre over the construction period for non-sensitive areas. In sensitive areas, including sites adjacent to or directly draining to lakes, streams, and wetlands, the soil loss is limited to 7.5 tons per acre over the construction period. In order to prove the soil loss rate is below the county standard, applicants need to calculate the USLE for their site from the start of construction until the site is stabilized. The Dane County Land Conservation Department reviews erosion control plans for accuracy of the plan and compliance with the ordinance.

Methods

Adapting USLE to construction site conditions

Our first objective was to develop a method of predicting soil loss from erosion on construction sites based on the guidelines given by the USDA for the USLE. In order to adapt the USLE to urban conditions, each variable in the equation was examined (see Equation 1).

The rainfall factor, R, is the first factor modified. Published R values represent erosivity during an average year. Most construction sites do not remain disturbed for exactly one year. In addition, the time of year that the site is open is critical in determining the amount of rainfall energy that will occur. In the Midwest, over half of this rainfall energy occurs during July, August, and September. Projects that take place in the summer will experience higher intensity storms than projects constructed in the winter. For these reasons, the R factor needs to adapted to the construction schedule of the project (Table 1).

Table 1. Percent of R occurring after January 1st for Dane County, Wisconsin.

	January	February	March	April	May	June
1st	0	0	2	4	9	20
15th	0	1	3	6	14	28

	July	August	September	October	November	December
1st	39	63	80	91	97	99
15th	59	72	87	94	98	100

Once the percent R is calculated for the interval of time that the land will be open, it is multiplied by the annual R factor for Dane County (150).

R = (% of R to date) x (Annual R factor)

The soil erodibility factor, K, represents a soil's ability to resist erosion. The factor is determined by documenting erosion of a soil in a bare condition on a unit test plot. The higher the erosion rate, the higher the K factor. On construction sites, the subsoil K factor is often used because the topsoil is usually stripped. Subsoil K factors can be found in USDA Soil Interpretation Records. The soil properties that effect erodibility include: soil structure, soil particle size distribution, permeability, organic matter content; and iron content.

The slope length/steepness factor, LS, relates the length and steepness of the slope (Equation 2). The rate of erosion increases exponentially as the length of the slope becomes longer. Erosion rates rise even more drastically as the steepness of the slope increases. The percent slope is a representative portion of the disturbed area, representing overland flow, not channel flow. The slope length is measured along the flow path from the top to the bottom of the slope of the disturbed area.

Formula used to calculate the LS factor.

$$LS = (L/76.6)^M(65.41\sin^2\theta+4.56\sin\theta+0.065) \qquad \text{(Equation 2)}$$

Where: L = slope length in feet
θ = angle of slope (in degrees)
M = 0.2 for slopes < 1%
M = 0.3 for slopes 1.0 to 3.0%
M = 0.4 for slopes 3.0 to 4.5%
M = 0.5 for slopes > 4.5%

The cover and management factor, C, is based on the type and condition of the cover on the soil surface. In construction site erosion control, the cover is extremely important. The vegetative cover provides protection from rainfall impact and runoff water. If the condition of the cover is poor, the C factor will be high. Conversely, when the vegetation is well established, the erosion and C factor will be reduced. C factors for construction sites can be found in *Predicting Rainfall Erosion Losses* (Wischmeier and Smith, 1978). The C factors for seeding, seeding and mulching, and sod represent the average cover over the establishment period. Once the site is seeded or sod is installed, a period of sixty days during the growing season is automatically assumed for cover establishment. If the end of the sixty day cover establishment period falls after the recommended seeding dates, the calculation must be carried out to the following spring to allow for adequate growth.

Commonly Used C Factors:	Bare ground	1.00
	Seeding	0.40
	Seeding and Mulching	0.12
	Sod	0.01

The support practice factor, P, is not used to calculate soil loss on construction sites.

The product of the R, K, LS, and C factors equals the computed soil loss per acre over the construction period. In Dane County, if this number is greater than the required standard, the project must reduce erosion below the standard by using erosion control practices or by changing the management schedule. Assuming that 100 percent of soil loss is transported and deposited off-site for relatively small areas of less than 40 acres with no intervening obstructions or flattening of the land slope.

Developing the Spreadsheet to Calculate the USLE

Implementation of the USLE in erosion control plans was required for all land disturbing activities greater than 20,000 square feet in Dane County after January of 1995. The calculation of soil loss was difficult for the consulting engineers responsible for submitting plans. In addition, the USLE calculations were often done incorrectly or the wrong data were used as inputs. For these reasons, a user-friendly computer-based program was developed to assist erosion control planners with the USLE calculation. The program uses Microsoft Excel 97 *, a spreadsheet program that is commonly used among the engineering community.

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*Use of the commercial product name is for the convenience of the reader and does not imply endorsement of the product by either the Dane County Land Conservation Department or the University of Wisconsin.

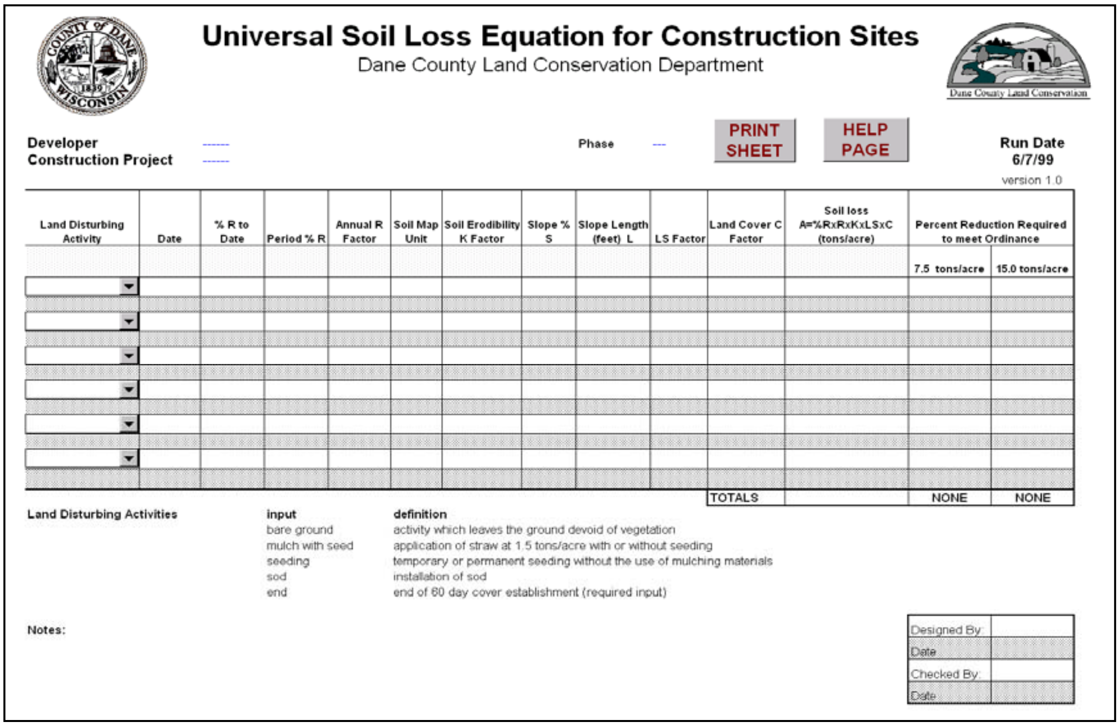

Figure 1. Screen-capture of spreadsheet.

The worksheet uses the following variables and inputs which are either entered by the user or automatically calculated in the non-shaded rows.

Table 3. Variables used in the spreadsheet.

Column #	Variable	Type
1	Land Disturbing Activity	entered by user
2	Date	entered by user
3	% R to Date	automatically calculated
4	Period % R	automatically calculated
5	Annual R Factor	automatically calculated
6	Soil Map Unit	entered by user
7	Soil Erodibility K Factor	automatically determined
8	Slope % S	entered by user
9	Slope Length L	entered by user
10	LS Factor	automatically calculated
11	Land Cover C Factor	automatically determined
12	Soil Loss	automatically calculated
13	Percent Reduction to Meet Ordinance	automatically calculated

Variable/Input Descriptions:

Land Disturbing Activity
The land disturbing activity relates to the type of disturbance that is occurring on the ground and must be selected by using a pull down menu.

Activity Inputs:

bare ground	Usually the initial disturbance and occurs when the ground is left bare due to stripping vegetation, grading, or other actions that leave the ground devoid of vegetation.
seeding	The application of permanent or temporary seeding without the use of mulch. Seeding requires that the user allows 60 days during the growing season for cover establishment.
mulch with seed	The application of a minimum of 1.5 tons/acre straw or other comparable mulching. This input is entered if the seeding and mulching are done at the same time. It is not necessary to also enter *seeding* if this input is used. This input also requires a 60 day cover establishment period during the growing season.
sod	The installation of sod for cover establishment.
end	*End* is a required input at the end of the 60 day cover establishment period. If the site is stabilized by a method other then vegetative cover, *end* should also be entered.

Date
The date the planned land disturbing activity begins, e.g. 5/15/99. The activity is assumed to continue until the next activity is entered. When seeding dates are later than the dates recommended for permanent cover establishment, the *end* date must be carried out to the next spring, rather than 60 days.

% R to Date
The percentage of the annual R factor from January 1st to the entered date.

Period % R
The percentage of the annual R factor calculated for the period from one land disturbing activity to the next.

Annual R factor
The rainfall factor, R, is the number of erosion-index units in a normal year's rain. The erosion index is a measure of the erosive force of a specific rainfall. In Dane County, Wisconsin the rainfall factor is 150.

Soil Map Unit
The soil map unit for the predominant soil type in the area of the land disturbing activity.

Soil Erodibility K Factor
The erosiveness factor of the subsoil for the specified soil map unit.

Slope % S
The percentage slope for the representative portion of the disturbed area, representing overland flow and not channel flow.

Slope Length L
Slope length (in feet) is measured along the overland flow path from the top to the bottom of the slope of the representative disturbed area.

LS Factor
The LS factor is calculated using the equation for LS described previously (see Equation 2).

Land Cover C factor
The cover and management factor is the ratio of soil loss from an area with a specified cover and management practice to that of a unit plot of bare land. The input for the land disturbing activity corresponds to this factor.

Soil Loss
The predicted value of soil loss (tons/acre) which corresponds to the time period of each land disturbing activity. This value is calculated using the equation:
$A = \%R \times R \times K \times (LS) \times C$

Percent Reduction Required to Meet Ordinance
The percentage value in the total row corresponds to the reduction of soil loss necessary to comply with the Dane County Erosion Control Ordinance. It is required that the cumulative soil loss rate not exceed 15 tons/acre for non-sensitive areas and 7.5 tons/acre for sites that are located adjacent to or directly drain to sensitive areas.

Typical Spreadsheet Example for Dane County, Wisconsin
Figure 2 shows a sample USLE calculation using the spreadsheet. The assumptions are that construction will begin on July 17, 1999 and the site will be seeded and mulched on October 31, 1999. The representative pre-existing slope is 10% over 100 feet and the slope after grading will be 5% over 250 feet. The soil type is Dresden Silt loam (DsC2). The estimated soil loss rate for this site is 15.9 tons/acre. If this site is located near a sensitive area, the soil loss must be reduced by 53% to comply with the 7.5 tons/acre standard; on the other hand, if the site was not located near a sensitive area, the soil loss only needs to be reduced by 6% (15 tons/acre standard).

Universal Soil Loss Equation for Construction Sites

Dane County Land Conservation Department

Developer Example Calculation
Construction Project -------

Phase ---

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Run Date 7/7/99
version 1.0

Land Disturbing Activity	Date	% R to Date	Period % R	Annual R Factor	Soil Map Unit	Soil Erodibility K Factor	Slope % S	Slope Length (feet) L	LS Factor	Land Cover C Factor	Soil loss A=%RxRxKxLSxC (tons/acre)	Percent Reduction Required to meet Ordinance 7.5 tons/acre	15.0 tons/acre
bare ground	7/17/99	53.3%	26.2%	150	DsC2	0.28	10.0%	100	1.38	1.00	15.2		
	To												
mulch with seed	8/31/99	79.5%	17.3%	150	DsC2	0.28	5.0%	250	0.85	0.12	0.7		
	To												
end	10/31/99	96.8%	3.2%	150	DsC2	0.28	5.0%	250	0.85				
										TOTALS	15.9	53%	6%

Land Disturbing Activities

input	definition
bare ground	activity which leaves the ground devoid of vegetation
mulch with seed	application of straw at 1.5 tons/acre with or without seeding
seeding	temporary or permanent seeding without the use of mulching materials
sod	installation of sod
end	end of 60 day cover establishment (required input)

Notes:

Designed By:	
Date	
Checked By:	
Date	

Figure 2. Sample USLE calculation.

Results and Discussion

There are several advantages to using the adapted USLE for erosion control planning on construction sites. One advantage is being able to locate areas with the highest erosion rates, which results in more effective erosion control. If one portion of a construction site is predicted to have a higher erosion rate, more or larger erosion control practices may be targeted in that area, while less intensive practices may be required elsewhere on the site. The adapted USLE also facilitates the design of sediment ponds and other erosion control practices. The predicted amount of soil loss exceeding the standard can be used to calculate the percent reduction necessary to comply with the ordinance.

Another advantage is that the adapted USLE brings in the important element of time. In Wisconsin, the majority of the year's rainfall erosivity occurs during the summer months. Summer is also the time of year that most construction is occurring. The USLE accounts for the date and duration the development project occurs and predicts the soil's vulnerability to erosion at that time. The USLE may show that staging the construction project will help to reduce the soil loss on the site.

The spreadsheet program has proven to be a valuable tool for calculating the soil loss. The program has been distributed for more than a year, free of charge, to the planners and consultants in Dane County. The County's review of the calculation in the erosion control plans has become easier and quicker by having a printout that summarizes the variables used. An advantage of having tables and formulas included in the spreadsheet, is the consistency that is achieved by everyone using the same parameters. Not only have the calculations of soil loss been more precise and time schedules more realistic, but planners and consultants have stated that it has saved them time and simplified the calculation process.

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