Design of geosynthetics for erosion control on slopes

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ABSTRACT: While the mechanisms of soil erosion is well known (consisting of detachment, transportation and deposition) its control is largely empirical. An engineering approach to the design of Geosynthetics for erosion control on slopes can be based on the well known Revised Universal Soil Loss Equation RUSLE, which can be adapted to the estimation of erosion on a single slope or a defined area comprising of multiple single slopes. The use of RUSLE for designing with Geosynthetics requires the definition of the performance of the various products by laboratory and full scale performance tests. The paper introduces the general procedure for using RUSLE for the design of Geosynthetics for erosion control on slopes and presents examples of practical interest. Conclusions and recommendations are finally exposed.

Keywords: erosion control, slopes, design, RUSLE

1 INTRODUCTION

Erosion is a natural process by which earth is loosened and removed, usually by wind and rain. Natural erosion occurs slowly, but in many places it is increased by human land use: poor land use practices include deforestation, overgrazing, unmanaged construction activity and road or trail building. The main natural factors influencing erosion include soil characteristics, surface cover, topography and climate. A certain amount of erosion is natural and, in fact, healthy for the ecosystem. Excessive erosion, however, does cause problems, such as producing water sedimentation, ecosystem damage and outright loss of soil.

The main forms of on site erosion are splash, sheet, rill and gully (Fig. 1). Offsite erosion includes stream and channel erosion.

Slopes present serious erosion control challenges which occur when rain and wind disturb civil grade soil and imported topsoil. Heavy precipitation may erode surface soils on slopes, especially with fine grained soils. Greater erosion and ruts can occur if the slope is poorly vegetated. Geosynthetic for erosion control are commonly used to address difficult erosion control problems on slopes. Geosynthetics for erosion control products give engineers ready solutions: Geosynthetics can provide immediate erosion protection and long-term site armoring, and assist in the establishment of vegetation while permanently reinforcing vegetation for applications where the forces exerted by water exceed the shear limits of unreinforced vegetation.

Biodegradable erosion control blankets provide soil erosion protection and assist in the establishment of vegetation on moderate slopes where loose mulches or bare-ground seeding are not effective; degradable products are used to enhance the establishment of vegetation, where vegetation alone will provide sufficient site protection once the erosion-control product has degraded; nondegradable products provide long-term reinforcement of vegetation: they are used in more challenging erosion control applications where immediate, high-performance erosion protection is required; these products are designed to extend the erosion resistance of soil, rock and other materials by permanently reinforcing the vegetative root structure.

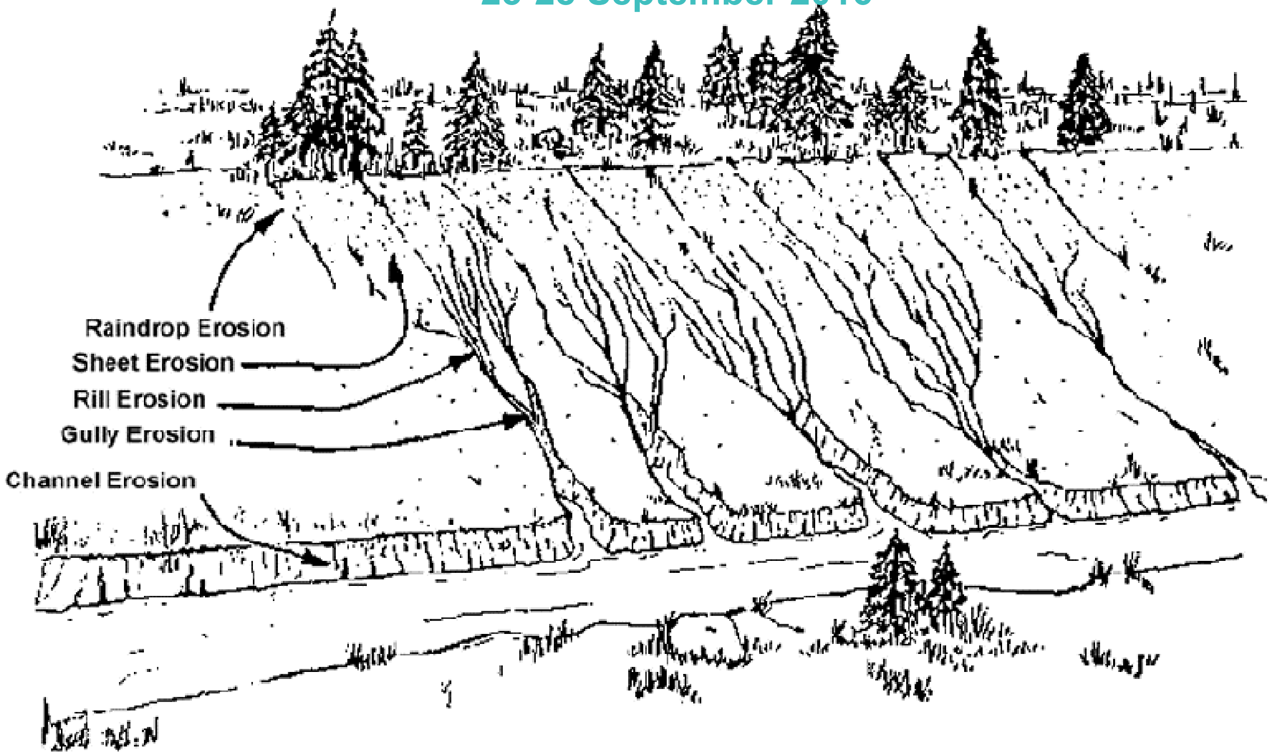


Fig. 1. Types of soil erosion

Knowledge of the potential erosion problems on a construction site enables the site planner to better manage site development and erosion control to minimize soil loss off the property. Prevention is much more effective than trying to improve water quality of the runoff. It is important to note that basic erosion mechanisms vary for different site conditions. Characteristics of construction site erosion material are highly dependent on site conditions and the local rainfall.
An engineering approach to the design of Geosynthetics for erosion control on slopes can be based on the well known Revised Universal Soil Loss Equation RUSLE, which can be adapted to the estimation of erosion on a single slope or a defined area comprising of multiple single slopes.The use of RUSLE for designing with Geosynthetics requires the definition of the performance of the various products by laboratory and full scale performance tests.

2 BASIC EROSION MECHANISMS

Soil erosion results when soil is exposed to the erosive powers of rainfall energy and flowing water (Barfield, et al. 1983). Rain (along with the shearing force of flowing water) acts to detach soil particles, while runoff transports the soil particles downslope. The most significant factor causing sheet erosion is raindrop impact, while the shearing force of flowing water is most important in rill and gully erosion.
Soil detachment has usually been related to raindrop parameters or soil parameters. The most important rain parameter is kinetic energy and the most important soil parameter is shear strength. Soil detachment occurs when rain energy overcomes the soil's shear strength. The use of Geosynthetics over bare soils can greatly decreases the transfer of energy to the soil, therefore lessening erosion losses.
During a rainfalls, drop impact on the soil surface dislodges soil particles, lifts them into the air and transports them away from the point of drop impact. On flat ground the soil particles splash uniformly in all directions and the net transport is zero. On a slope instead more soil is transported downhill by the splash, resulting in a net downslope transport, as shown in Fig. 2. This stage of the erosion process is termed “splash erosion”.
If the infiltration rate is less than the rainfall intensity, runoff flow occurs. Runoff flow increases soil erosion by transporting the particles dislodged by raindrops impact further downhill, before they settle back on the soil surface. Runoof dislodges soil particles as well, by exerting shear stresses on the soil surface. Once dislodged, soil particles are transported by runoff flow. This

wearing away and transportation of soil in a thin uniform laminar water flow is termed “sheet erosion”. Sheet erosion is a function of the thickness and velocity of the water.

Water always try to flow when it finds lower resistance; along these pattern of lower resistance the water removes soil particles and excavate a micro channel, where the water velocity increases compared to the uniform laminar flow; the increased velocity applies higher shear stresses, which removes soil particles even faster; then the micro channel deepens and widens and becomes a rill; in a rill the water flows as channelized transitional or turbulent flow, with increased erosion capacity. This stage is termed “rill erosion”. Rill erosion occurs at a faster rate than sheet erosion

If no erosion protection is applied at this stage, soil particles are continuously dislodges in the rills, leading to the development of larger and larger channels, which excavate deeply into the soil surface. This stage is termed “gully erosion”. A gully is a landform created by running water eroding sharply into soil, typically on a hillside. Gullies resemble large ditches or small valleys, but are meters to tens of meters in depth and width. When the gully formation is in process, the water flow rate can be substantial, which causes the significant deep cutting action into soil. Once established, large scale gullies are difficult to restore by normal cultivation and management practices. Restoration of areas subjected to gully erosion is costly and may require consistent works of earth moving and slope reshaping.

Hence the best management practice should be to avoid rill erosion, which will also avoid the formation of gullies: Geosynthetics for erosion control, laid on erosion prone slopes, when properly designed afford the minimization of sheet erosion and prevent the formation of rill erosion, and therefore also of gully erosion.

Many experimental data and observations show that dense cover crops significantly reduce soil and water losses. Consequently, one way of reducing erosion is to establish and maintain a dense growth of vegetation on the land to be protected.

Geosynthetics for erosion control can provide temporary protection to a soil cover from raindrop impact and sheet erosion, until a dense, strong and erosion resistant vegetation can be established.

Some of these Geosynthetics are intended to be biodegradable or photodegradable in a relatively a short time after placement, when vegetation has already become established; other Geosynthetics remain in place for an extended period of time, or even permanently, and work in concert with the vegetation that grows up through them.

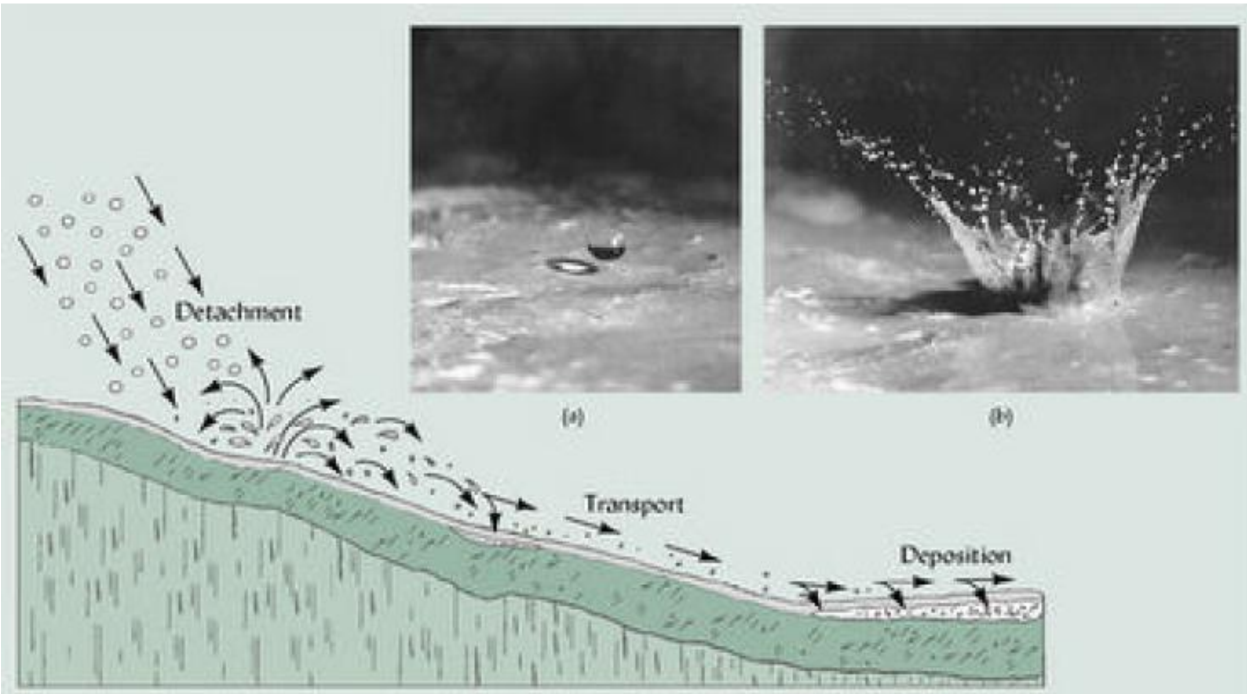


Fig. 2. Detachment and downslope soil transport by raindrops impact

Hence Geosynthetics for erosion control can afford two functions:

1) Provide erosion protection to the slope without vegetation, or before vegetation is established;
2) Increase the resistance of vegetation, once established, to raindrops impacts and shear stresses produced by runoff flow.

We can identify distinct and subsequent erosion phases:

- Detachment: produced by rain drop splash and shear stresses by a fluid stream
- Transport: produced by the runoff stream that occurs when the rain flow exceeds the infiltration capacity of soil
- Deposit: at the end of the capacity of transport of the stream

Factors affecting erosion are:

- rainfall characteristics
- morphological, pedological, topographical, hydraulic, biologic characteristics
- soil use and management

Splash erosion, which is the first phase of erosion, is the detachment and airborne movement of small soil particles caused by the impact of raindrops on soil. In general splash erosion is a function of the kinetic energy of raindrops E_{kdrops} and of the shear resistance of soil τ_{soil}:

$$f(E_{kdrops}, \tau_{soil}) = 0 \tag{1}$$

Erosion on slopes depends on two main factors:

- Erosivity = capacity of erosion (in general, erosive agents on slopes are: water and wind)

$$Ep = f(i, t, d, E_k) \tag{2}$$

where:
i = rainfall intensity;
t = rain duration;
d = raindrops diameter;
E_k = kinetic energy

- Erodibility = susceptibility to be eroded

$$Es = f(F, k, w, \tau, s, a) \tag{3}$$

where:
F = infiltration;
k = surficial permeability,
w = lamination capacity,
τ = shear resistance of soil
c = type of soil covering
s = resistance of soil to detachment
a = abrasion

Erosion occurs when the quantity of removed soil exceeds the quantity of newly formed soil.
Erosion is a natural phenomenon:

- in optimal conditions: 0.5 ton/hectare
- in well maintained wood or forest areas: 1.25 ton/hectare;
- in cultivated areas or in pasture areas: 3 - 50 ton/hectare;
- in degraded areas: 300 - 500 ton/hectare.
- Erosion phenomena which doesn’t produce particular problems: 2.5 - 10 ton/hectare/year.

2.1 Experimental observations

The depth h of a runoff stream varies from 1 mm to 10 mm; only in exceptional cases it can reach 20 mm – 30 mm (Horton, 1935)

The runoff velocity is of the order of 0.01 - 0.3 m/s (Cancelli et Al, 1990); only in exceptional cases it can reach 0.6 m/s (Bathurst, 1978).
Experiments with rainfall and slope simulators provided the following water velocities V of the sheet flow (with: Sand $d_{50} = 0.12 \div 0.15$ mm; rain intensity = 70 mm/hour; slope angle = 26.5°):

Soil protection	slope length L = 7.5 m
Bare soil	V = 0.31 m/s
Geocells	V = 0.19 m/s
Geomats	V = 0.13 m/s
Jute mesh	V = 0.19 m/s

Often, the physical nature of the soils means that they are non-cohesive, friable, and easily worked.
Soil texture is a term used to describe the percentages of sand, silt or clay that make up aspecific soil type. Eroded soil materials can be classified according to their grain sizes into clay, silt, and sand fractions. Different soil types have different proportions of these particles.
Clay particles are generally considered to be less than 0.002 mm in size, silt particles range from 0.002 to 0.063 mm, and sand particles are greater than 0.063 mm.
Soils dominated by sands are generally non-cohesive, and are more susceptible to erosion than silts and clays. However, sands settle out easily and can be controlled using simple management practices on site. Once they have been mobilized, clays and fine silts are more difficult to control as they can be held in suspension, and may require other methods (such as flocculation) to settle the particles out.
The soil more susceptible to erosion is sand, whose characteristic diameter d_s varies between 0.01 and 1 mm, hence its relative roughness, in a sheet flow where water flows with thickness h, is: $d_s/h = 1 \cdot 10^{-3} \div 1$.
Hence for erosion processes the Reynolds number of the sheet flow on sandy soil ($Re_d = V\, d_s/\nu$, where ν is the kinematic viscosity of water), typically varies between 20 and 500: this means that the water flow, even at the stage of sheet erosion, is typically a transitional flow, which implies higher erosivity than laminar flow.

2.2 Erosion modeling

Most of the present knowledge on erosion comes from works, started by the Soil Conservation Service (SCS) of the US, which in the years between 1920 and 1930 faced the serious erosion problems related to agricultural use of land in some areas of the country (the Dust Bowl States). The general outline and the first research was aimed at determining the practical methodologies that could be used for planning agricultural land use; the first proposals were essentially heuristic and strongly linked to local conditions: if the effect of some parameters, that come into play in the complex erosion phenomena, were locally not significant, then the proposed relationships did not take them into account.
But at the same time, researchers turned their attention to understanding the physical phenomena that influence erosion and on the identification of variables and parameters involved, and carried out a large number of measures, classifications and correlations, referring both to real cases and to situations recreated in the laboratory with rainfall simulators on the "standard plot", shown in Fig. 3 (Renard, 1985). Laboratory tests using the standard plot were, and still are, the bases for many erosion prediction models.
Many test researches on Geosynthetics for erosion control on slopes have been carried out with setups similar to the standard plot (Cancelli et Al, 1990; Weggell and Rustom, 1992; Cazzuffi et Al, 1994).
Much more research is still needed in order to be able to define reliable default parameters for the use of erosion prediction models with Geosynthetics.
There are dozens of erosion prediction models. Most have been developed for the agricultural areas and to compare the annual rates of soil loss expected on large areas with various techniques of land cultivation and pasture management. Some are purely statistical models, other are mechanistic models. Two of the most popular methods are the Revised Universal Soil Loss Equation (RUSLE) and the Water Erosion Prediction Project erosion model (WEPP).

Fig. 3. The standard plot is an inclined plane with constant gradient of 9 %, with a down slope length of 22.13 m (72 feet) and a width of 1.83 m (6 feet)

Much of the research on erosion rates is directed towards support and development of these models. However much of the erosion literature is focused exclusively on RUSLE parameters. Apart from a couple of new specific and deterministic gully erosion models, the RUSLE and WEPP models do not consider gullies, mainly because of difficulties in modeling, and partly because the gullies are often stabilized in agricultural environments, forestry or mining.
These models can provide useful guidance for the designer if properly calibrated and verified for local conditions and if the design takes into account the uncertainty inherent in the calculation models.
The RUSLE model is probably the one with the largest use and applications in the world, and it will be presented hereinafter for the design of Geosynthetics for erosion control on slopes.

3 THE REVISED UNIVERSAL SOIL LOSS EQUATION RUSLE

Wischmeier and Smith (1958) presented the initial research on rainfall energy and its relationship to soil loss. The "Universal Soil Loss Equation (USLE)" was published in 1965 in the Agriculture Handbook No. 282 (USDA, 1965). The Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1965) was based on many years of data from about 10,000 standard plots from throughout the US. Each standard plot had about 22 m flow lengths (Fig. 3) and were all operated in a similar manner, allowing the soil loss measurements to be combined into a predictive tool. The USLE has been extensively used for conservation planning in agricultural operations for many years. Many of the features, and the original database, also allow it to be used to predict erosion losses, and the benefits of some erosion controls, at construction sites. USLE is still used for the estimation, on annual basis, of the quantity of eroded soil on large areas, particularly in USA.
During the following 20 years USLE has been revised and completed; it was finally published as RUSLE in 1978 in Agriculture Handbook No. 537 (USDA, 1978; Wischmeier and Smith, 1978).

The Revised Universal Soil Loss Equation (RUSLE) (Renard, et al. 1997) was developed to incorporate new research since the earlier USLE publication in 1978 (Wischmeier and Smith 1978). The basic form of the equation has remained the same, but modifications in several of the factors have been made.
The RUSLE only predicts sheet and rill erosion, it does not predict the effects of concentrated runoff.
RUSLE is a universal formula, hence it is applicable in any geographical region and socio-economic condition, but it requires a proper data base allowing the estimation of the various factors.
Such factors summarize the characteristics of the area under study and they are statistically defined.
In particular the various factors take into account climatic characteristics, soil properties, topography, cropping mode, land preparation, soil use and management, etc.
The most extended data base for the use of RUSLE is in USA: this is based on 11.000 data series related to 47 geographical areas in 24 different Countries.
Hence RUSLE, besides its universal formulation, is empirical in nature, and requires a vast and appropriate data base for the correct estimation of factors.
Results obtained from RUSLE have only statistical value, and can be considered valid only for large areas and sufficiently long periods (typically on annual base).
Extensions of RUSLE to slope scale shall be made with great care.
The present paper focuses on construction site erosion issues and is greatly simplified compared to the complete RUSLE that stresses agricultural operations.
The underlying assumption in the RUSLE is that detachment and deposition are controlled by the sediment content of the flow. The erosion material is not source limited, but the erosion is limited by the carrying capacity of the flow. When the sediment load reaches the carrying capacity of the flow, detachment can no longer occur. Sedimentation also occur during the receding portion of the hydrograph as the flow rate decreases (Novotny and Chesters 1981).
RUSLE is expressed by the following formula:

$$A = R \cdot K \cdot LS \cdot C \cdot P \tag{4}$$

where
A = estimated average soil loss (tons per acre per year)
R = rainfall - runoff erosivity factor (hundreds of foot·ton·inch / acre·hour·year)
K = soil erodibility factor (ton·acre·hours / hundred acre·foot·ton·inch)
L = slope length factor
S = slope steepness factor
C = cover - management factor
P = support practice factor
Another factor for soils is called "T value" which stands for "Tolerable Soil Loss." It is not directly used in RUSLE equation, but is often used along with RUSLE for conservation planning. Soil loss tolerance (T) is the maximum amount of soil loss in tons per acre per year, that can be tolerated and still permit a high level of crop productivity to be sustained economically and indefinitely.
RUSLE was developed in US customary units; table 1 provides conversion factors to SI units.
Hence RUSLE relates the rate of erosion per unit area (A) to the erosive power of the rain (R), the soil erodibility (K), the land slope and length (LS), the degree of soil cover (C), and the conservation practices (P):
The important aspect of this equation is the linear relationship between the equation parameters.
As any parameter is changed, the resulting erosion yield is similarly changed.
The basic values for LS, C, and P are all 1.0, and change according to specific site and management conditions change.
Many of these factors will change seasonally, especially corresponding to plant growth and according to changes in rain characteristics.
RUSLE equation can be used to predict the amount of soil that may be eroded from construction sites. Specifically, it enables the most critical source areas to be identified, and allows predictions of the benefits of basic mulching and seedbed controls. Also, the erodibility of different slopes and timing options can be compared for better design for prevention. In addition, RUSLE can be used to predict the amount of sediment that may enter a sediment pond.

Table 1. Conversion factors for RUSLE

To Convert From:	U.S. Customary Units	Multiply By:	To Obtain:	SI Units
Rainfall intensity, i or I	inch / hour	25.4	millimeter / hour	mm* / h
Rainfall energy per unit of rainfall, e	foot-tonf / acre-inch	2.638×10^{-4}	megajoule / hectare•millimeter	MJ† / ha•mm
Storm energy, E	foot-tonf / acre	0.006701	megajoule / hectare	MJ‡ / ha
Storm erosivity, EI	foot-tonf•inch / acre•hour	0.1702	megajoule•millimeter / hectare•hour	MJ•mm / ha•h
Storm erosivity, EI	hundreds of foot-tonf•inch§ / acre•hour	17.02	megajoule•millimeter / hectare•hour	MJ•mm / ha•h
Annual erosivity, R‖	hundreds of foot-tonf•inch / acre•hour•year	17.02	megajoule•millimeter / hectare•hour•year	MJ•mm / ha•h•y
Soil erodibility, K#	ton•acre•hour / hundreds of acre•foot-tonf•inch	0.1317	metric ton•hectare•hour / hectare•megajoule•millimeter	t•ha•h / ha•MJ•mm
Soil loss, A	ton / acre	2.242	metric ton / hectare	t / ha
Soil loss, A	ton / acre	0.2242	kilogram / meter²	kg / m²

*Hour and year are written in U.S. customary units as hr and yr and in SI units as h and y. The difference is helpful for distinguishing between U.S. customary and SI units.
†The prefix mega (M) has a multiplication factor of 1×10^6.
‡To convert ft-tonf to megajoule, multiply by 2.712×10^{-3}. To convert acre to hectare, multiply by 0.4071.
§This notation, "hundreds of," means numerical values should be multiplied by 100 to obtain true numerical values in given units. For example, R = 125 (hundreds of ft-ton•in/acre•hr) = 12,500 ft-tonf•in/acre•hr. The converse is true for "hundreds of" in the denominator of a fraction.
‖Erosivity, EI or R, can be converted from a value in U.S. customary units to a value in units of Newton/hour (N/h) by multiplying by 1.702.
#Soil erodibility, K, can be converted from a value in U.S. customary units to a value in units of metric ton•hectare/Newton•hour (t•h/ha•N) by multiplying by 1.317.

3.1 Rainfall - runoff erosivity factor (R)

The RUSLE implies that rain energy is directly related to erosion yield. Originally, the USLE was used with an annual R value to predict annual erosion yields, but Barfield et al. (1983) summarizes several procedures and studies that have shown relationships between individual storm energies and erosion yields. Therefore, the local rain energy can be used to directly relate the probabilities of individual rain events to approximate erosion yields.
Wischmeier (1959) found that the best predictor of the Rainfall - runoff erosivity factor R is:

$$R = \frac{1}{n}\sum_{j=1}^{n}\left[\sum_{k=1}^{m}(E)(I_{30})_k\right] \tag{5}$$

where
E = total storm kinetic energy (hundreds of ft tons per acre)
I_{30}= maximum 30-minute rainfall intensity (in/hour)
j = counter for each year used to produce the average
k = counter for the number of storms in a year
m = number of storms in each year
n =number of years used to obtain the average R.
The calculated erosion potential for an individual storm is usually designated EI.
The total annual R is therefore the sum of the individual EI values for each rain in the year.
Wischmeier also found that the rain kinetic energy (E) could be predicted by:

$$E = 916 + (331) \log10 (I) \tag{6}$$

where
I = average rain intensity (inches/hour)
E is given in ft-tons per acre per inch of rain, if intensities in inches per hour are used (for up to 3 in/hr).
The rain energy and R parameter are therefore only dependent on rain intensities alone.
As an example, a rain having an average intensity of 0.37 in/hr would have a calculated kinetic energy of 773 ft-tons per acre of land, per inch of rain.

The maximum calculated kinetic energy using this equation is 1074 ft-tons/acre/in, and is applied to rain intensities of 3.0 inches/hr, and greater.
This equation has been used to calculate the R values and the maps in RUSLE (Renard, et al. 1997). However, Renard, et al. (1997) recommend the following equation for all future R calculations:

$$E = 1099\,[1-0.72\,\exp(-1.27\,I)] \tag{7}$$

where E is still in ft-tons/acre per inch or rain.
Eq. (7) is the most used nowadays.
Wischmeier and Smith (1978) present an example for calculating the rainfall kinetic energy from a rain gage record, as illustrated in Table 2. In this example, the total kinetic energy of the storm is equal to 1284 ft-tons per acre, or 12.84 hundreds of ft-tons per acre. The maximum 30 minute rainfall during this 90-minute storm was 1.08 inches, occurring from 4:27 to 4:57. The corresponding I_{30} was therefore 2.16 inches per hour. If the storm duration is less than 30 minutes, the I_{30} used is twice the total rain depth, with a maximum used I_{30} value of 2.5 in/hr. The EI for this storm is therefore (2.16)(12.84) = 27.7.
Many other empirical formulas have been developed for calculating the factor R: the most commonly used are summarized in Table 3.
A common way of evaluating the factor R is to use several formulas, and to assume the average of the values obtained from each formula as the best estimate of R.
RUSLE (Renard, et al. 1997) provided maps of the R values (called isoerodent maps) for USA territory; since then many Countries and even Regions carried out local measurements of the R factors, and produced regional isoerodent map, as in the examples shown in Fig. 4; these maps can be used to evaluate the local value of the R factor, instead of using the above listed formulas.

Table 2. Procedure for Calculating Kinetic Energy using a Rain Gage Record (Wischmeier and Smith 1978)

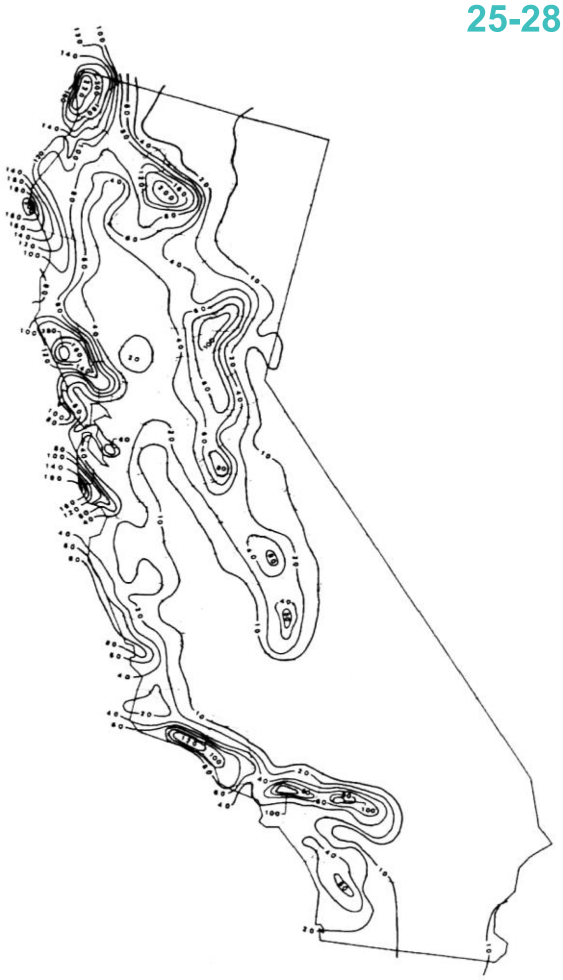
Rain Gage Chart Readings		**Storm Increments**			**Kinetic energy**	
Time	**Accumulative depth (inches)**	**Duration (minutes)**	**Amount (inches)**	**Intensity (in/hr)**	**Per inch (ft-tons per acre per inch of rain)**	**For increment (ft-tons per acre)**
4:00	0					
4:20	0.05	20	0.05	0.15	643	32
4:27	0.12	7	0.07	0.60	843	59
4:36	0.35	9	0.23	1.53	977	225
4:50	1.05	14	0.70	3.00	1074	752
4:57	1.20	7	0.15	1.29	953	143
5:05	1.25	8	0.05	0.38	777	39
5:15	1.25	10	0	0	0	0
5:30	1.30	15	0.05	0.20	685	34
Totals:	1.30	90	1.30			1284

Table 3. Empirical formulas for factor R (SI units)

	Author	*Model*
1	*Arnoldus (1980) - linear*	$R = ((4.17 \cdot F) - 152) * 17.02$
2	*Arnoldus (1977) - exponential*	$R = 0.302 \cdot F^{1.93}$
3	*Renard e Freimund (1994) - F*	$R = 0.739 \cdot F^{1.847}$
4	*Renard e Freimund (1994) - P*	$R = 0.0483 \cdot P^{1.61}$
5	*Lo et al. (1985)*	$R = 38.46 + 3.48 \cdot P$
6	*Yu & Rosewelt (1996)*	$R = 3.82 \cdot F^{1.41}$

P= average yearly rainfall mm; Pj=average monthly rainfall for the j^{th} month.

$$F = \sum_{1}^{12} \frac{P_j^2}{P}$$



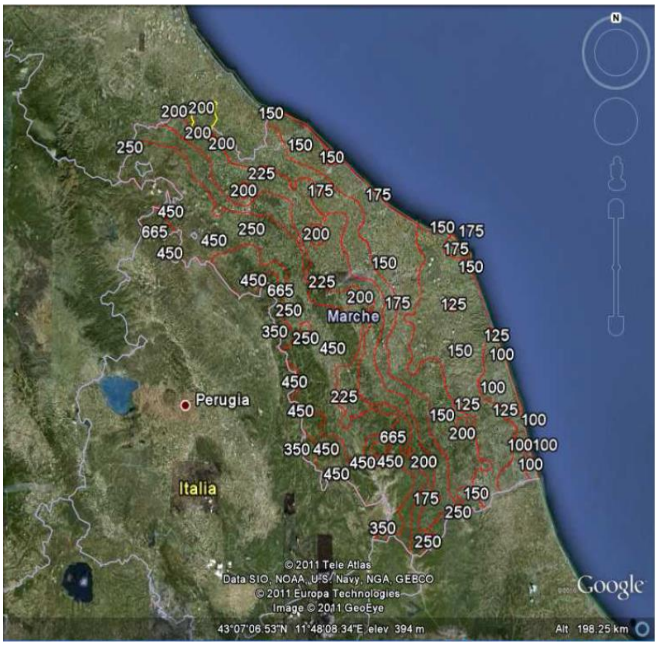


Figure 4. Left: isoerodent map of California, with R values in US customary units. Right: isoerodent map of Marche region in Central Italy, with R values in SI units.

3.2 Soil erodibility factor K

Soil erodibility is a complex property and is thought of as the ease with which soil is detached by splash during rainfall or by surface flow or both. From a fundamental standpoint, however, soil erodibility should be viewed as the change in the soil per unit of applied external force or energy. RUSLE uses a restrictive and applied definition of soil erodibility. Soil erodibility is related to the integrated effect of rainfall, runoff, and infiltration on soil loss and is commonly called the soil-erodibility factor (K), which in RUSLE accounts for the influence of soil properties on soil loss during storm events on upland areas.

In practical terms, the soil erodibility factor is the average long-term soil and soil profile response to the erosive powers of rainstorms; that is, the soil erodibility factor is a lumped parameter that represents an integrated average annual value of the total soil and soil profile reaction to a large number of erosion and hydrologic processes.

These processes consist of soil detachment and transport by raindrop impact and surface flow, localized deposition due to topography and tillage - induced roughness, and rain water infiltration into the soil profile.

The soil erodibility factor (K) is the rate of soil loss per rainfall erosion index on unit plot. The unit plot is 72.6 ft (22.1 m) long, has a 9% slope, and is continuously in a clean-tilled fallow condition with tillage performed upslope and downslope (Wischmeier and Smith 1978).

Soils high in clay have low K values, approx. from 0.05 to 0.15in US customary units, because they are resistant to detachment.

Coarse textured soils, such as sandy soils, have low K values, approx. from 0.05 to 0.2, because of low runoff even though these soils are easily detached.

Medium textured soils, such as silt loam soils, have a moderate K values, approx. from 0.25 to 0.4, because they are moderately susceptible to detachment and they produce moderate runoff.
Soils having a high silt content are most erodible of all soils. They are easily detached; tend to crust and produce high rates of runoff. Values of K for these soils tend to be greater than 0.4.
Organic matter reduces erodibility because it reduces the susceptibility of the soil to detachment, and it increases infiltration, which reduce runoff and thus erosion. Addition or accumulation of increased organic matter through management such as incorporation of manure is represented in the C factor rather than the K Factor. Extrapolation of the K factor values beyond an organic matter of 4% is not recommended or allowed in RUSLE.
Soil structures affects both susceptibility to detachment and infiltration. Permeability of the soil profile affects K because it affects runoff.
Although a K factor was selected to represent a soil in its natural condition, past management or misuse of a soil by intensive cropping can increase a soil's erodibility. Hence the K factor may need to be increased if the subsoil is exposed or where the organic matter has been depleted, the soil's structure destroyed or soil compaction has reduced permeability.
Originally the K evaluation was performed with a simple nomogram (Wischmeier& Smith, 1978), as shown in Fig. 5.
RENARD et al. (1997), authors of the RUSLE Manual, have made changes to the original formula for estimating K. The formulations have been obtained through experimental measurements of erodibility on a set of 225 soil, divided in textural classes andsubjected to both natural and artificial rainfall events.
K is expressed in U.S. customary units of $[(\text{ton} \cdot \text{acre} \cdot \text{h}) \cdot (\text{hundreds of acre} \cdot \text{foot-ton}_f \cdot \text{in})^{-1}]$, where foot–$\text{ton}_f$ is a unit of energy equal to the work done in raising one ton_f against standard gravity through the height of one foot
RENARD et al. (1997) formula, in US customary units is:

$$K = [2.1*10^{-4} (12 - OM) \cdot M^{1.14} + 3.25 (s - 2) + 2.5 (p - 3)] / 100 \qquad (8)$$

with:

$$M = g \cdot (100 – ag) \qquad (9)$$

where:
OM = percentage of organic substance in the surface soil layer;
M = texture parameter of the soil
s = structure code (see Table 4)
p = permeability class (see Table 4)
M = g · (100 - ag)
g = percentage of silty material (ie, with particles diameter = 0.002 ÷ 0.1 mm)
ag = percentage of clay (iewith particles diameter <0.002 mm)

In the international system K is expressed in $[(\text{Mg} \cdot \text{ha} \cdot \text{h}) \cdot (\text{MJ} \cdot \text{ha} \cdot \text{mm})^{-1})]$.

K values expressed in SI units is given by:

$$K\ (SI) = 0.1317 \times K\ (USA) \qquad (10)$$

The K factor can be calculated according to the pedological function of Renard et al., 1997, which was calibrated on global data, and which takes into account only the soil texture values:

$$K = 7.594 [0.0034 + 0.0405 \exp [-0.5 ((\log (D_g) +1,659) /0.7101)^{2}]] \qquad (11)$$

where
D_g = geometric mean diameter of particles (mm)

D_g shall be calculated as follows (Shirazi and Boersma, 1984):

$$D_g = \exp\left[0.01\Sigma\, f_i \ln(d_i)\right] \tag{12}$$

with
f_i = percentage of i-th sieve fraction
d_i = the respective average diameter.

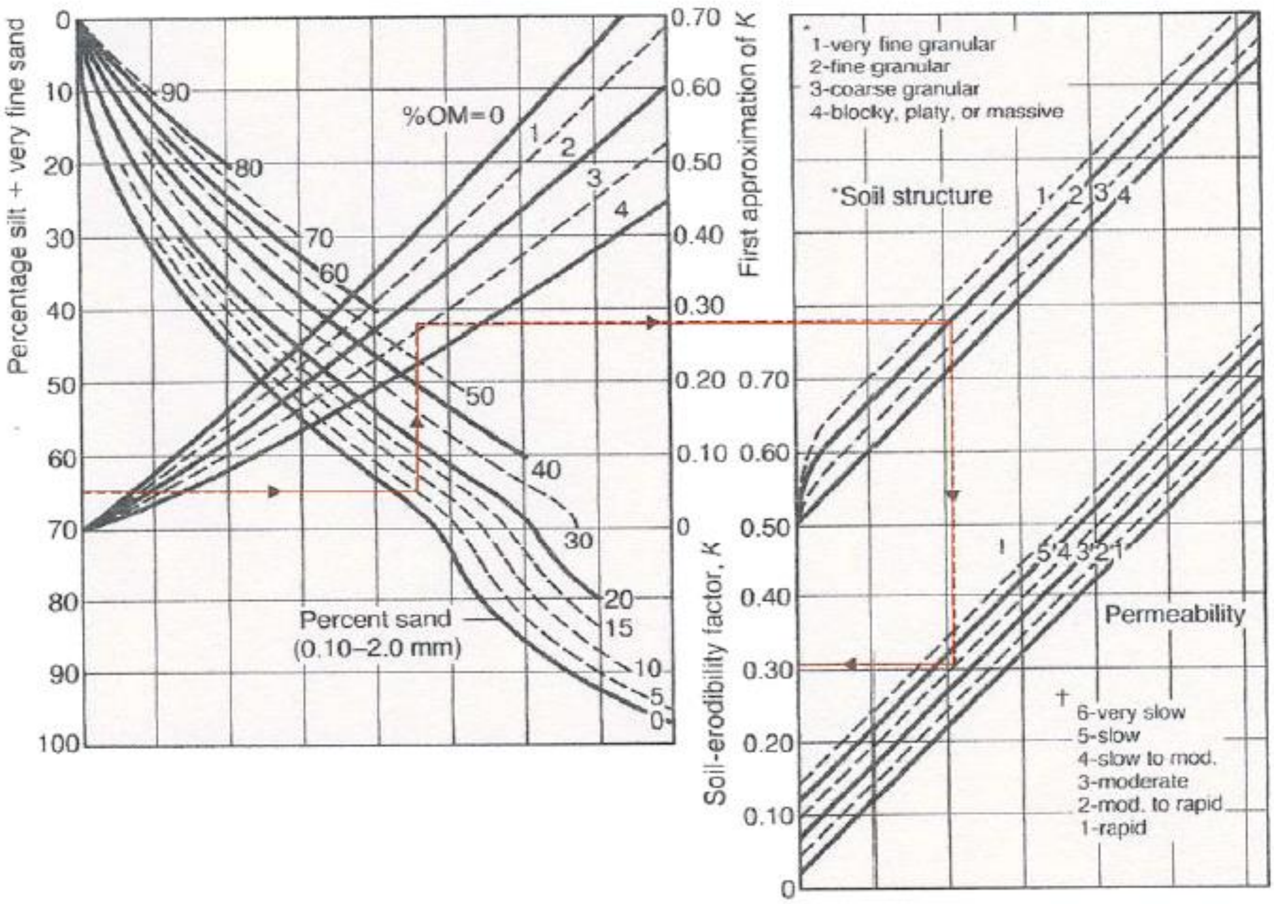


Fig. 5. USDA nomogram used to calculate soil erodibility factor K (Wischmeier& Smith, 1978)

Table 4. Structure code and permeability class for evaluating the K factor

Structure code	permeability
1 = very fine granular	1 = rapid
2 = fine granular	2 = moderate to rapid
3 = medium coarse granular	3 = moderate
4 = blocky, platy, massive	4 = slow to moderate
	5 = slow
	6 = very slow

Many Countries and even Regions carried out local measurements of the K factors, and produced large scale, regional and local erodibility maps, which are available in literature or at local Agencies. Fig. 6 show the map of K factor values, in SI units, for all western Europe.
These maps can be used to evaluate the local value of the K factor, instead of using the above listed formulas.

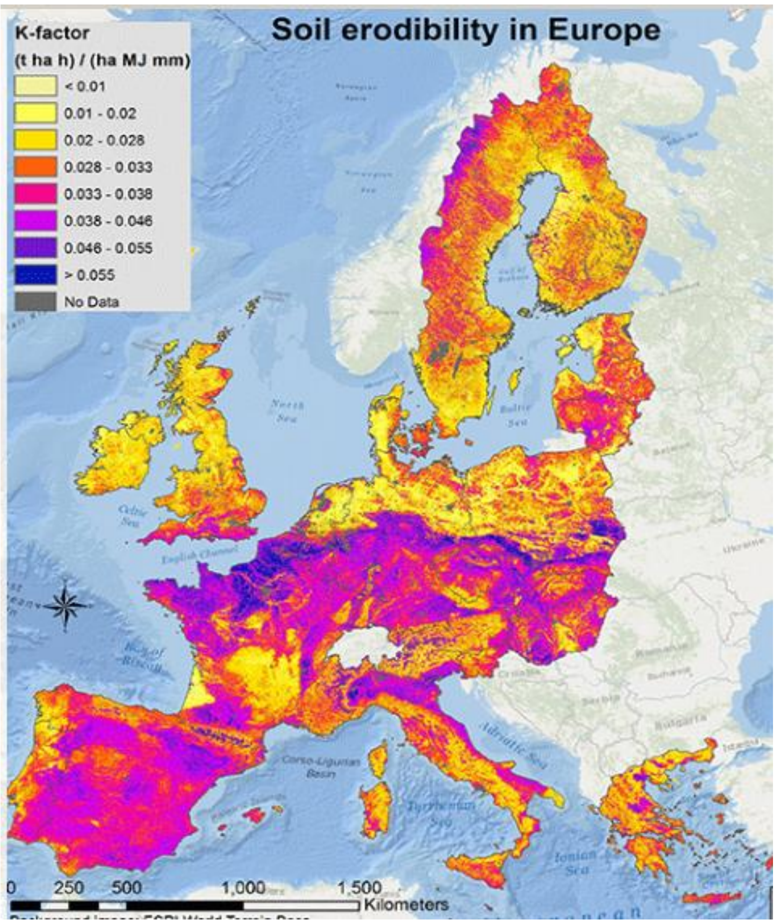


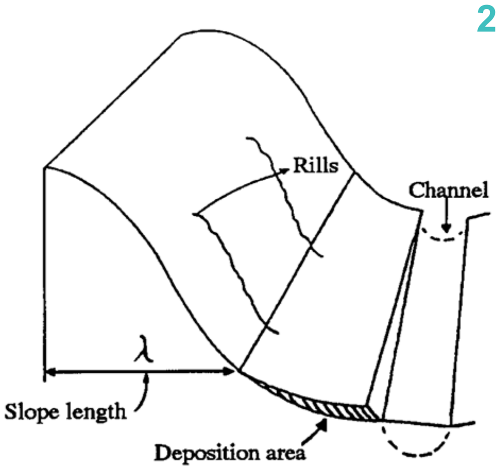
Figure 6. Map of K factor in Europe

3.3 Slope length and steepness factor LS

L is the slope length factor, representing the effect of slope length on erosion. It is the ratio of soil loss from the actual field slope length to that from the standard plot of 72.6 ft (22.1 m) length at 9 % slope on the same soil type and gradient. Slope length is the distance from the origin of overland flow along its flow path to the location of either concentrated flow or deposition, as shown in Fig. 7 (Renard, et al. 1997). Fortunately, computed soil loss values are not especially sensitive to slope length and differences in slope length of + or – 10% are not important on most slopes, especially flat landscapes.

Slope lengths are best determined by visiting the site, pacing out flow paths, and making measurements directly on the ground: L should be obtained by measuring perpendicular to the contour from the point of origin of overland flow to where deposition begins or runoff enters a well defined channel. Slope lengths usually do not exceed 100 m. Slope lengths longer than 300 m should not be used in RUSLE because the reliability of RUSLE at these long slope lengths is questionable, and flow becomes concentrated on most landscapes before such long slope lengths.

The main areas of deposition that end RUSLE slope length are at the base of concave slopes. If no signs of deposition are present, the user will have to visualize where deposition occurs. The slope-ending depositional area on a concave slope is usually below where the slope begins to flatten.



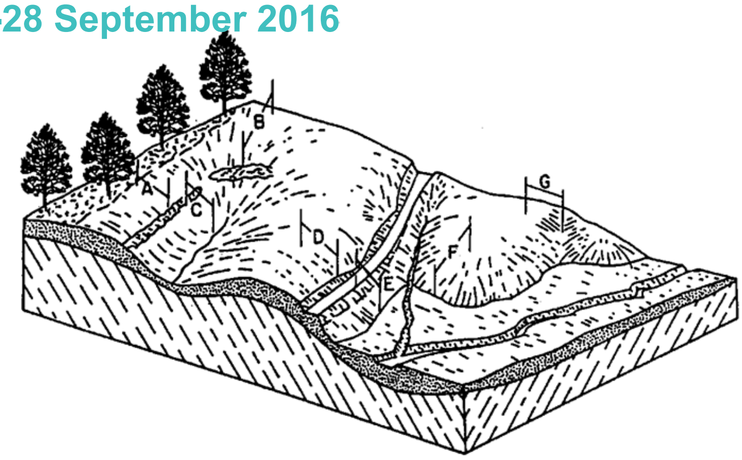


Figure 7. Examples of different slope length measurements (Renard, et al. 1997).

As a rule of thumb, if no signs of deposition are present on a concave slope, assume that deposition begins at the location where the steepness is 1/2 of the average steepness of the concave area.
Another difficulty is determining if a channel is a concentrated flow channel that ends a RUSLE slope length. Channels that collect the flow from numerous rills are generally considered to be slope ending concentrated flow channels.
S is the slope steepness factor, which represents the effect of slope steepness on erosion. Soil loss increases more rapidly with slope steepness than it does with slope length. S is the ratio of soil loss from the actual field gradient to that from the standard plot having 9 percent slope under otherwise identical conditions. The relation of soil loss to gradient is influenced by density of vegetative cover and soil particle size.
L factor and S factor are usually considered together as LS factors: the slope length factor L computes the effect of slope length on erosion and the slope steepness factor S computes the effect of slope steepness on erosion. Values of both L and S equal 1 for the standard plot conditions of 22.1 m length and 9 % steepness. Values of L and S are relative and represent how erodible the particular slope length and steepness is relative to the 22.1 m long, 9 % steep standard plot. Thus some values of L and S are less than 1 and some values are greater than 1. Stripcropping or contouring does not affect the LS value.The erosion of soil from a slope increases as the slope increases and lengthens.
In RUSLE if the length of the slope is 90 m, or less, the LS factor would be less than 0.10 for all slopes of 0.5 % or less.
Roadway side cuts of 1V:2H (50% gradient) would have LS factors greater than 1.0 for all slope lengths of about 2 m, or longer.
Long and steep slopes, frequently occurring along roadway cuts in hilly terrain, can have extremely large LS factors.
The RUSLE LS factors have been significantly changed compared to the original USLE LS values. RUSLE contains four separate LS tables (Renard et al., 1997), although the one reported in Table 5 is the only one appropriate for construction sites (freshly prepared sites that are highly disturbed).
L and S factors can be computed using the following formulas, obtained from tests performed on the standard plot:

$$L = \left(\frac{x}{22.13}\right)^m \qquad \begin{array}{ll} m=0.5 & s \leq 5\ \% \\ m=0.4 & 3\ \% \leq s < 5\ \% \\ m=0.3 & 1\ \% \leq s < 3\ \% \\ m=0.2 & s < 1\ \% \end{array} \tag{13}$$

$$S = \frac{0.43 + 0.3\ s + 0.04\ s^2}{6.613} \tag{14}$$

Table 5. LS factors for construction sites (freshly prepared sites that are highly disturbed)

Slope (%)	Slope Length (ft.)																
	<3	6	9	12	15	25	50	75	100	150	200	250	300	400	600	800	1000
0.2	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.06	0.06	0.06	0.06	0.06	0.06	0.06
0.5	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.08	0.09	0.09	0.10	0.10	0.10	0.11	0.12	0.12	0.13
1.0	0.09	0.09	0.09	0.09	0.09	0.10	0.13	0.14	0.15	0.17	0.18	0.19	0.20	0.22	0.24	0.26	0.27
2.0	0.13	0.13	0.13	0.13	0.13	0.16	0.21	0.25	0.28	0.33	0.37	0.40	0.43	0.48	0.56	0.63	0.69
3.0	0.17	0.17	0.17	0.17	0.17	0.21	0.30	0.36	0.41	0.50	0.57	0.64	0.69	0.80	0.96	1.10	1.23
4.0	0.20	0.20	0.20	0.20	0.20	0.26	0.38	0.47	0.55	0.68	0.79	0.89	0.98	1.14	1.42	1.65	1.86
5.0	0.23	0.23	0.23	0.23	0.23	0.31	0.46	0.58	0.68	0.86	1.02	1.16	1.28	1.51	1.91	2.25	2.55
6.0	0.26	0.26	0.26	0.26	0.26	0.36	0.54	0.69	0.82	1.05	1.25	1.43	1.60	1.90	2.43	2.89	3.30
8.0	0.32	0.32	0.32	0.32	0.32	0.45	0.70	0.91	1.10	1.43	1.72	1.99	2.24	2.70	3.52	4.24	4.91
10.0	0.35	0.37	0.38	0.39	0.40	0.57	0.91	1.20	1.46	1.92	2.34	2.72	3.09	3.75	4.95	6.03	7.02
12.0	0.36	0.41	0.45	0.47	0.49	0.71	1.15	1.54	1.88	2.51	3.07	3.60	4.09	5.01	6.67	8.17	9.57
14.0	0.38	0.45	0.51	0.55	0.58	0.85	1.40	1.87	2.31	3.09	3.81	4.48	5.11	6.30	8.45	10.40	12.23
16.0	0.39	0.49	0.56	0.62	0.67	0.98	1.64	2.21	2.73	3.68	4.56	5.37	6.15	7.60	10.26	12.69	14.96
20.0	0.41	0.56	0.67	0.76	0.84	1.24	2.10	2.86	3.57	4.85	6.04	7.16	8.23	10.24	13.94	17.35	20.57
25.0	0.45	0.64	0.80	0.93	1.04	1.56	2.67	3.67	4.59	6.30	7.88	9.38	10.81	13.53	18.57	23.24	27.66
30.0	0.48	0.72	0.91	1.08	1.24	1.86	3.22	4.44	5.58	7.70	9.67	11.55	13.35	16.77	23.14	29.07	34.71
40.0	0.53	0.85	1.13	1.37	1.59	2.41	4.24	5.89	7.44	10.35	13.07	15.67	18.17	22.95	31.89	40.29	48.29
50.0	0.58	0.97	1.31	1.62	1.91	2.91	5.16	7.20	9.13	12.75	16.16	19.42	22.57	28.60	39.95	50.63	60.84
60.0	0.63	1.07	1.47	1.84	2.19	3.36	5.97	8.37	10.63	14.89	18.92	22.78	26.51	33.67	47.18	59.93	72.15

(From: USDA Agricultural Handbook No. 703).

Combining the two previous equations we get:

$$LS = \left[0.065 + 0.0456\,(slope) + 0.006541\,(slope)^2\right] \left(\frac{slope\ \ length}{constant}\right)^{NN} \tag{15}$$

where:
slope = slope steepness in %
slope length = length of slope in m (ft)
constant = 22.1 metric (72.5 ft)
NN = see Table 6

Table 6. Exponent for LS formula

S	< 1	1 ≤ Slope < 3	3 ≤ Slope < 5	≥ 5
NN	0.2	0.3	0.4	0.5

The topographic factor LS, in the case of non-flat side, consisting of a succession of slopes with variable length and slope, is estimated as a weighted average of the individual values of length and slope:

$$LS = \left[\frac{\sum_{j=1}^{n}\left(S_j \lambda_j^{m+1} - S_i \lambda_{j-1}^{m+1}\right)}{22.13\lambda_t}\right] \tag{16}$$

where:
S_j = slope of j-th slope
λ_j = distance of the end of the horizontal projection of the j-th slope valley from the top of the slope
λ_{j-1} = distance of the horizontal projection of the upstream end of the (j-1)-th slope from the top of the slope
λ_t = total length of the horizontal projection of the entire slope
n = total number of segments constituting the slope
m = NN = see Table 6

3.4 Cover - management factor C

C is the crop / vegetation and cover / management factor.
It is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss.
The C factor is a ratio comparing the soil loss from land under a specific crop and management system to the corresponding loss from continuously fallow and tilled land, like in the standard plot.
When RUSLE is used to evaluate erosion in agricultural sloping land, the C Factor can be determined by selecting the crop type and tillage method (Table 7A and Table 7B, respectively) that corresponds to the field and then multiplying these factors together (Wischmeier, 1960).
The C factor resulting from this calculation is a generalized C factor value for a specific crop that does not account for crop rotations or climate and annual rainfall distribution for the different agricultural regions. This generalized C factor, however, provides relative numbers for the different cropping and tillage systems.

Table 7A. Crop Type Factor

Crop Type	Factor
Grain corn	0.40
Silage corn, beans & canola	0.50
Cereals (spring & winter)	0.35
Seasonal horticultural crops	0.50
Fruit trees	0.10
Hay and pasture	0.02

Table 7B. Tillage Method Factor

Tillage Method	Factor
Fall plow	1.0
Spring plow	0.90
Mulch tillage	0.60
Ridge tillage	0.35
Zone tillage	0.25
No-till	0.25

The C factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The C factor indicates how the conservation plan will affect the average annual soil loss and how that soil-loss potential will be distributed in time during construction activities, crop rotations or other management schemes.
In general C represents the effects of plants, soil cover, soil biomass, and soil disturbing activities on erosion. RUSLE uses a subfactor method to compute soil loss ratios, which are the ratios at any given time in a cover management sequence to soil loss from the standard plot (Renard et al., 1997). Soil loss ratios vary with time as canopy, ground cover, roughness, soil biomass and consolidation change. The subfactors used to compute a soil loss ratio values are canopy, surface cover, surface roughness, prior land use and antecedent soil moisture:

$$SLR = PLU \cdot CC \cdot SC \cdot SR \cdot SM \qquad (17)$$

where:
SLR = soil loss ratio defined by the factor C (Soil Loss Ratio)
PLU = sub-factor reflecting the previous use of the slope (Prior Land Use)
DC = sub-factor, for the air cover of vegetation (Crop Canopy)

SC = sub-factor for the ground cover (surface cover)
SR = sub-factor for the roughness of the soil surface (Surface Roughness)
SM = sub-factor for soil moisture (Soil Moisture)
The SLR value is determined for biweekly time intervals: in each time interval each sub-factor is assumed constant; the annual C factor is the weighted average of the SLR values to the periodic rain erosivity factors R.
Surface cover is material in contact with the soil surface that intercepts raindrops and slows surface runoff. The total percent of the surface covered is the characteristic used by RUSLE to compute how surface cover affects erosion. Surface cover includes all cover that is present, including rock fragments, live vegetation, cryptograms, and plant residue. The only minimum size requirement for material to be counted as surface residue is that it either be of sufficient size or attached to the surface such that is not removed by runoff.
RUSLE accounts for surface roughness in the C value calculation. Surface roughness ponds water in depressions and reduces erosivity of raindrop impact and water flow. If the deposition are sufficiently deep, much deposition occurs in them. Over time, roughness disappears as the depressions fill with sediment. and one soil subsides after the tillage operations that formed the depressions.
Roughness is reduced in RUSLE as a function of cumulative rainfall after the last tillage operation. Roughness also indicates the degree of clodiness and the likelihood that the surface will seal, producing increased runoff and soil erodibility. Accounting for roughness, such as with the plow plant tillage system, is one reason some C values are quite low with RUSLE.
If a C factor of 0.15 represents the specified cropping management system, it signifies that the erosion will be reduced to 15 percent of the amount that would have occured under continuous fallow conditions.

Table 8. Typical effect of surficial roughness for the same type of soil

Type of surface	runoff (%)	eroded soil (t/acre/year)
smooth	59.0	13.5
middle	32.0	6.0
rough	14.0	1.5

In civil engineering projects the C factor represents the cover and management system; in details the type and density of vegetation on the given slope, and the type of management system in terms of erosion control techniques that are applied, which may consist in Geosynthetics for erosion control.
For a given slope (as example: a road cut with sandy silt surface soil layer) the correct evaluation of the C factor for different Geosynthetics is fundamental for the design of the erosion control system.
The C factor for a specific Geosynthetic product should be obtained by extensive test on real slopes under natural rainfall, and/or laboratory tests with a rain simulator and a standard plot.
Cancelli et Al (1990) and Weggell and Rustom (1992) provides valuable information about the laboratory testing methods and erosion data for several specific Geosynthetics.
It has to be mentioned that much more research is still needed for getting a reliable data base of C factor values for the many types of erosion control Geosynthetics available on the market.
For preliminary design, the C factor values in Tables 9 and 10 can be used.

3.5 Supporting Practices Factor P

P is the support practice factor. The RUSLE P factor reflects the impact of support practices on the average annual erosion rate. It is the ratio of soil loss with contouring and/or stripcropping to that with straight row farming up-and-down slope.
As with the other factors, the P factor differentiates between cropland and rangeland or permanent pasture. For the purpose of this factor, the rangeland / permanent pasture option is based on the support operation being performed infrequently, whereas in the cropland option the support operation is part of the annual management practice.

Table 9. Cover Index Factor C for different ground cover conditions

Cover Index factor (C) for Different Ground Cover Conditions

Type of Cover		Factor C	Percent Effectiveness
None (fallow ground)		1.0	0.0
Temporary seedings (90% stand)			
Ryegrass (perennial type)		0.05	95
Ryegrass (annuals)		0.10	90
Small grain		0.05	95
Millet or sudan grass		0.05	95
Field bromegrass		0.03	97
Permanent seedings (90% stand)		0.01	99
Sod (laid immediately)		0.01	99
Mulch			
Hay, rate of application, tons/ac:			
	0.5	0.25	75
	1.0	0.13	87
	2.0	0.02	98
Small grain straw	2.0	0.02	98
Wood chips	6.0	0.06	94
Wood cellulose	1.5	0.10	90
Fiberglas	1.5	0.05	95

Source: primarily HEC-15 (1988)
percent soil loss reduction as compared with fallow ground

Table 10. Proposed C factors for erosion control Geosynthetics

RECP Category	Approximate Proposed Mass/Unit Area g/m^2 (oz/ yd^2)		Reported Range of C-factors	C-factors
ECN	34 to 100	100% Woven	0.02	0.01
	(1 to 3)	Polypropylene		
	400 to 880	100% Woven	0.002 to 0.003	0.01 to 0.1
	(12 to 26)	Coir/Jute		
ECB	270 to 340	100% Straw	0.002 to 0.30	0.01
	(8 to 10)			
	270 to 370	Straw/Coconut	0.002 to 0.11	0.01
	(8 to 11)			
	270 to 400	100% Coconut/	0.003 to 0.09	0.01
	(8 to 12)	Excelsior		
TRM	270 to 490	100% Synthetic	0.003 to 0.11	

“ECN” indicates temporary degradable erosion control net. Values assumes slope is flatter than 2H:1V.
“ECB” indicates temporary degradable erosion control blanket. Values assumes slope is flatter than 2H:1V.
“TRM” indicate permanent nondegradable turf reinforcement mat. Values assumes slope is flatter than 1H:1V.

The method of tillage and crop rotations all affect the soil erosion rate for an agricultural operation, as shown by the P factor values reported in Table 11.
This factor is rarely applicable for construction sites and is therefore given a value of 1.0 for this application.

Table 11. P factor values for different support practices and slope gradients

Support Practice	P Factor
Up & down slope	1.0
Cross slope	0.75
Contour farming	0.50
Strip cropping, cross slope	0.37
Strip cropping, contour	0.25

% Slope	Contouring	Contour Strip Cropping	Terracing and Contouring
1 to 2	0.6	0.30	-
2 to 7	0.5	0.25	0.10
7 to 12	0.6	0.30	0.12
12 to 18	0.8	0.40	0.16
18 to 24	0.9	0.45	-
Level bench terrace			0.14
Reverse slope bench terrace			0.05
Outward sloping bench terrace			0.35

3.6 *Soil loss tolerance rates - T value*

T is the soil loss tolerance expressed in tons per hectare (or acre) per year (Renard et Al, 1997).
A tolerable soil loss is the maximum annual amount of soil, which can be removed before the long-term natural soil productivity is adversely affected.
The impact of erosion on a given soil type, and hence the tolerance level, varies, depending on the type and depth of soil. Generally, soils with deep, uniform, stone-free topsoil materials and/or not previously eroded have been assumed to have a higher tolerance limit than soils that are shallow or previously eroded.
Soil loss tolerance rates are included in Table 12.
The T value is not directly used in RUSLE. However, it is important in the use of the soil loss equation for conservation planning.
T values are not applicable to construction sites or other non-farm uses of the erosion equation.

Table 12. Soil loss tolerance rates T

Soil Erosion Class	Potential Soil Loss tonnes/hectare/year (tons/acre/year)
Very low (tolerable)	<6.7 (3)
Low	6.7 (3)–11.2 (5)
Moderate	11.2 (5)–22.4 (10)
High	22.4 (10)–33.6 (15)
Severe	>33.6 (15)

4 DESIGN OF GEOSYNTHETICS FOR EROSION CONTROL

In civil and environmental engineering projects erosion control systems may be required both during construction, for limiting the soil loss and the sediments flowing out of the construction site for a limited time, and in long term, for allowing the establishment and maintenance of a dense vegetation coverage which will finally protect slopes from splash and sheet erosion, preventing the formation of rill erosion.

The design of erosion control systems with Geosynthetics, both for temporary and long term applications, can be carried out using the RUSLE.

The procedure for using the RUSLE is the following:

1. Collect rain an soil data for the project area.
2. Determine the R Factor: usually civil and environmental engineering projects cover a relatively small area, hence in general one only R value is applicable.
3. Based on the soil texture, determine the K value. If there is more than one soil type in the project area and the soil textures are not very different, use the soil type that represents the majority of the field. Otherwise repeat for other soil types as necessary.
3. Divide the project area into sections of uniform slope gradient and length. Assign an LS value to each section.
4. Select several options for the erosion control measures to be implemented (as example: no soil coverage during construction; biodegradable Geosynthetics for temporary protection during construction; nondegradable Geosynthetics for long term protection; etc.); for each option select the C Factor from Tables or evaluate it from specific tests.
5. Select the P factor based on the support practice used (in general P = 1.0 for civil and environmental engineering projects).
6. According to Eq. (4), multiply the 5 factors together to obtain the soil loss per hectare (acre).
7. Multiply by the total area (in hectares) to obtain the total soil loss in 1 year.

4.1 Example: design the erosion control system for a agricultural slope in Canada

The slope to be protected is situated in Middlesex County, Ontario, Canada.
The slope is 244 m (800 ft) long with a 6 % slope.
The surface soil layer consists of fine sandy loam soil with an average organic matter content.
The slope was plowed in the spring and grain corn was planted. Cross-slope farming is used.
Soil loss tolerance rate is very low.

- The R Factor is obtained from data available at the London (Ontario) weather station.
  Finally it is determined that: R = 100 (US units) = 1702 (SI units)
- The Soil Erodibility Factor K is obtained from Equations (8) and (9):

percent clay	0
percent silt (0.1 - 0.002 mm)	40
percent fine sand	60
percent coarse sand	0
percent O.M.	1
structure code	2
permeability class	5

  Hence: K = 0.345 (US units) = 0.04545 (SI units)
- The LS Factor is calculated with Equation (15):
  From Table 6: NN = 0.5
  Hence: LS = 1.91
- The C Factor is evaluated from Tables 7A and 7B:
  Crop Type Factor for grain corn = 0.4
  Tillage Method Factor for spring plow = 0.9
  Hence: C Factor = 0.4 x 0.9 = 0.36
- The Support Practice Factor P is evaluated from table 11
  For cross-slope farming: P = 0.75
- Therefore the annual soil loss is:

A = R x K x LS x C x P = 100 x 0.345 x 1.91 x 0.36 x 0.75 = 17.79 tonnes/hectar/year

Referring to Table 12, this soil loss rate of 17.79 tonnes/hectare/year is in the moderate range and considerably higher than the very low tolerable loss level of 6.7 tonnes/hectare/ year.

To reduce the soil losses for this slope below 6.7 tonnes/hectare/year, one possibility is to implement the following changes:

- Change tillage method from spring plow (tillage factor = 0.9) to no-till (tillage factor = 0.25)

Therefore: C Factor (revised) = 0.4 x 0.25 = 0.10

The adjusted annual soil loss value is:

A = R x K x LS x C x P = 100 x 0.345 x 1.91 x 0.10 x 0.75 = 4.94 tonnes/hectare/year

Thus by changing the tillage practice, the average annual predicted soil loss for this slope is below the tolerable soil loss T of 6.7 tonnes/hectare/year.

4.2 Example: design the erosion control system for a construction site final grading

A construction site is comprised of different zones (embankment, road cut, parking, etc.), each one with different area, slope, length, surface soil, vegetation cover.

The construction period is anticipated to be from 1 March to 31 July.

The calculation of the soil loss for the construction period is shown in Table 13, where the following notes apply:

1. Annual R = 350 (US units). From 5 March to 31 July: R_{period} = 56 % of annual R; so construction phase partial R = 0.56 · 350 = 196
2. K values are obtained from county soil map and anticipated surface soils during the construction phase
3. C factors based on: native good cover for undisturbed areas, temporary erosion control mats for road cuts, planted vegetation or tacked mulches on embankments, and gravel pads for parking, building, and road areas. The vegetation C factor is calculated based on plant growth stages during this construction phase.

It is noted that the total soil loss in the construction period is equal to almost 50 tons.

If a sedimentation pond is required to block this amount of sediments, considering a 100 g/liter concentration in the water flowing out the construction site, the pond shall be designed for 500 m^3 of flowing water.

Table 13. Soil loss during the construction period

Site area designation	Area description	Land area (acres)	R for construction period[1]	K soil factor[2]	LS slope length factor	C cover factor[3]	Unit area soil loss (tons/acre/ period)	Total area soil loss (tons/period)
1a	Undisturbed area	1.51	196.00	0.15	0.30	0.001	0.01	0.01
1b	Undisturbed area	3.72	196.00	0.17	0.68	0.005	0.11	0.42
2	Road cut	0.54	196.00	0.28	2.67	0.020	2.93	1.58
3	Road cut	1.37	196.00	0.37	4.59	0.020	6.66	9.12
4a	Main embankment	0.84	196.00	0.28	0.40	0.550	12.07	10.14
4b	Main embankment	0.33	196.00	0.37	4.56	0.170	56.22	18.55
4c	Main embankment	1.15	196.00	0.17	3.09	0.070	7.21	8.29
5	Parking area	10.50	196.00	0.28	0.06	0.020	0.07	0.69
6	Building areas	5.53	196.00	0.35	0.06	0.020	0.08	0.46
7a	Road segment	0.26	196.00	0.17	0.57	0.020	0.38	0.10
7b	Road segment	0.95	196.00	0.28	0.22	0.020	0.24	0.23
7c	Road segment	0.37	196.00	0.28	0.10	0.020	0.11	0.04
Total site		27.07						49.64

For designing the final erosion control system, it is noted that the largest soil loss occurs on road cuts and main embankment.

It is possible to reduce the long term soil loss by acting on the C Factor.

Let's lay polypropylene geomats on road cut and embankment slopes: let's assume that, from Table 10, the C Factor for this type of erosion control Geosynthetic is C = 0.003.
The calculation of soil loss becomes as shown in Table 14, where the annual value of R has been considered: the total annual soil loss is reduced to 7.67 tons/year, that is 1/7 of the soil loss during the 5 months construction period.
This example clearly shows the impressive effects of Geosynthetics for erosion control on slopes.

Table 14. Annual soil loss with geomats for erosion control on road cuts and embankment

Site area designation	Area description	Land area (acres)	Annual R	K soil factor[2]	LS slope length factor	C cover factor[3]	Unit area soil loss (tons/acre/ period)	Total area soil loss (tons/period)
1a	Undisturbed area	1.51	350.00	0.15	0.30	0.001	0.02	0.02
1b	Undisturbed area	3.72	350.00	0.17	0.68	0.005	0.20	0.75
2	Road cut	0.54	350.00	0.28	2.67	0.003	0.78	0.42
3	Road cut	1.37	350.00	0.37	4.59	0.003	1.78	2.44
4a	Main embankment	0.84	350.00	0.28	0.40	0.003	0.12	0.10
4b	Main embankment	0.33	350.00	0.37	4.56	0.003	1.77	0.58
4c	Main embankment	1.15	350.00	0.17	3.09	0.003	0.55	0.63
5	Parking area	10.50	350.00	0.28	0.06	0.020	0.12	1.23
6	Building areas	5.53	350.00	0.35	0.06	0.020	0.15	0.81
7a	Road segment	0.26	350.00	0.17	0.57	0.020	0.68	0.18
7b	Road segment	0.95	350.00	0.28	0.22	0.020	0.43	0.41
7c	Road segment	0.37	350.00	0.28	0.10	0.020	0.20	0.07

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