INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR/402 5

COLLEGE ON SOIL PHYSICS
9 - 27 October 1989

"Erosion Prevision"

G. CHISCI
Istituto Agronomia
Università di Palermo
Palermo
Italy

Please note: These are preliminary notes intended for internal distribution only.

Soil loss equation for upland erosion prediction

(Summary of the lecture by G. CHISCI)

1. Historical evolution

1.1 Proposed lecture: J. K. MITCHELL and G. BUBENZER, Soil loss estimation, chapter 2 in "Soil Erosion" ed. by M. J. KIRKBY and R. P. C. MORGAN, A Wiley Interscience pub., NY, 1980 (§§ 2.1 - Upland erosion prediction evolution)

1.2 The ZINGG's equation (1940):

$$A = C S^{m} L^{n-1} \qquad [1]$$

A = average soil loss per unit area from land slope of unit width

C = a constant of variation combining the effect of rainfall, soil, crop and management

S = degree of land slope

L = horizontal length of land slope

m = 1.4, n = 1.6 exponents of degree and horizontal length of land slope, respectively

1.3 The MUSGRAVE's equation (1947):

$$E = (0.00527)\, I R S^{1.35} L^{0.35} P_{30}^{1.75} \qquad [2]$$

E = the soil loss, mm . year

I = the inherent erodibility of a soil at 10 per cent slope and 22 m slope length, mm per year

R = a vegetal cover factor

S = degree of slope per cent

L = length of slope, metres

P_{30} = the maximum rainfall in 30', mm

1.4 The SMITH and WHITT's equation (1947, 1948)

$$A = C S L K P \qquad [3]$$

A = the average annual soil loss,

C = the average annual rotation soil loss from plot

S, L, K and P = multipliers to adjust the plot soil loss C for slope steepness, length, soil group and supporting conservation practices, respectively

1.5 The WISCHMEIER and SMITH's universal soil loss equation (USLE)(1958, 1965)

$$A = (0.224)\, R K S L C P \qquad [4]$$

A = the soil loss, Kg/m^2

R = the rainfall erosivity factor

K = the soil erodibility factor

L = the slope length factor

S = the slope gradient factor

C = the cropping management factor

P = the erosion control practice factor

1.6 The HUDSON's erosion equation (1961)(identical in concept to USLE)

$$E = T S L P M R \qquad [5]$$

E = the soil loss

T = the erodibility factor

S = the slope gradient factor

L = the slope length factor

P = agronomic or agricultural practice factor

M = mechanical protection factor

R = the erosivity factor

· The difference with USLE is mainly in the evaluation of factors for Sub-tropical Africa.

1.7 · The ELWELL's soil loss estimation system (Southern Africa) (1977)

$$Z = KCX \qquad [6]$$

Z = predicted mean annual soil loss

K = mean annual soil loss from a standard field plot 30m × 10m at 4.5 per cent slope for a soil of known erodibility under bare fallow

C = the ratio of soil lost from a cropped plot to that lost from the standard plot

X = the ratio o soil lost from a plot of length L and slope S to that lost from the standard plot.

The K factor is dependent on rainfall kinetic energy and soil erodibility. The soil erodibility index is defined by basic soil type and may be adjusted for permeability, structure and conservation practices. The crop cover factor C is a function of percentage of rainfall energy intercepted which is determined from a crop cover distribution curve for the assumed crop and the distribution of rainfall energy. The X factor is the same as SL in USLE

1.8 The FOSTER et al.'s modified USLE for soil loss prevision on a single event basis (1977a, 1977b)

$$A = \underbrace{x K_r (a S^c) F_r C_r P_r / \lambda_u}_{\text{rill erosion} = \overline{D_r}} + \underbrace{K_i (b S + c) R_r C_i P_i}_{\text{interrill erosion} = \overline{D_i}} \qquad [7]$$

A = soil loss from a slope of x length

x = length of the slope

F_r = runoff erosivity $= (1-y)\, 0.4\, G\, q_p^{1/3}$; where y is a coefficient ($0 \le y \le 1$) that represents the relative importance of rainfall erosivity to runoff erosivity (The AA here used a value y = 0.5), G is the runoff volume in mm; q_p is the peak runoff rate in mm/h.

R_r = rainfall erosivity = $y R_{st}$ or storm rainfall factor (EI_{30} units of the USLE)

K_r and K_i = erodibility of the soil by rill and interrill processes, respectively

a, b, c and e = coefficients

C_r and C_i = crop and management factors for rill and interrill erosion, respectively.

P_r and P_i = conservation practices factors for rill and interrill erosion, respectively

λ_u = length of the unit plot in the USLE (m 22.1)

1.9 · The CHISCI, SFALANGA and TORRI's soil loss equation on a single event basis for disturbed laboratory samples (1983)

$$A = \int_0^t (\alpha_0 + \alpha_1 + \alpha_2)\, \bar{F}\, dt \qquad [8]$$

A = soil loss, Kg/m^2

α_0 = availability of soil material at the beginning of the event. In the laboratory can be estimated as. $\alpha_0 = 0.118\, EXP\left[0.05\, \frac{\Psi(1-\mu)}{D_u}\right]$ expressed in $Kg\, N^{-1} s^{-1}$; where: Ψ is the material available as elementary particles and/or aggregated particles < 63μ per cent; μ = soil humidity at saturation (fraction); D_u = saturated bulk density (gr/cm^3);

α_1 = Splashed material. In the laboratory can be estimated as: $\alpha_1 = w\beta\left(\frac{\tan\gamma + \frac{4}{\pi}\tan\varphi}{1 + \tan\varphi}\right)\left(\frac{E}{E_0} - 1\right)$ expressed in $Kg\, N^{-1} S^{-1}$; where: w = width of the plot, metres; β = constant; E = Kinetic energy of rainfall in unit time; E_0 = dissipated kinetic energy = $18.8\, EXP\left[\frac{-3.74\, D_u}{1+\mu}\right]$; E and E_0 are expressed in $KJ\, m^{-2} h^{-1}$; γ = plot slope angle; $\tan\varphi$ = initial slope of ~~splashed partic~~ the trajectory of splashed particles estimated by. $\tan\varphi = 7030\, EXP\left[\frac{-8.58\, D_u}{1+\mu}\right]$

α_2 = a term for rillability not yet clarified. It was demonstrated that α_2 is related to shear stress estimated by.
$\tau = (\rho g)^{2/3} (3\nu)^{1/3} \sin^{2/3}\gamma\; q^{1/3}$; where: ρ = density of the fluid, g = acceleration of gravity; ν = kinematic viscosity of the fluid; γ = slope angle; q = runoff discharge rate per unit width

$\bar{F}$ = runoff transport capacity which in the laboratory was estimated as. $\bar{F} = \left(\frac{g}{3\nu}\right)^{1/3} \frac{w}{\rho^{1/3}}\, q^{5/3} \sin^{1/3}\gamma$

1.9 Chisci and Bazzoffi's empirical soil equation for estimating soil loss on a ~~sig~~ single event basis (1983) (Vertic autochtonous soil)

$$Y = -1{,}03 + 0.38 \ln X_1 - 0.002\, X_2 + 0.005 X_3 + 0.85\, \Sigma_i\, \alpha_i + 0.23\, \Sigma_j\, \beta_j + 0.063\, \Sigma_k\, \gamma_k + 0.015\, \Sigma_\ell\, \delta_\ell \qquad [9]$$

Y = Soil loss for a single storm, metric tons/ha
X_1 = Total rainfall for the event, mm
X_2 = maximum intensity of rainfall in the event, mm/h
X_3 = R value for the event (EI_{30} units of USLE)
$\alpha_1 = 0.86\, D_1$; $D_1 = 1$ for lucerne ley autumn-winter stand (15/10 - 31/3)
$\alpha_2 = 1.01\, D_2$; $D_2 = 1$ for lucerne ley summer stand (1/4 - 15/10)
$\alpha_3 = 0.73\, D_3$, $D_3 = 1$ for arable summer crops (mais and/or sugar beets) (1/5 - 30/8)
$\alpha_4 = -1{,}53\, D_4$; $D_4 = 1$ for wheat in the winter-spring period (15/12 - 31/5)
$\alpha_5 = 0.88\, D_5$; $D_5 = 1$ for ploughed fallow
$D_i = 0$ is the reference condition represented by "seed bed" in the autumn and spring periods (1/5 - 30/5; 1/10 - 25/12)
$\beta_1 = -0.45\, D_1 \ln X_1$
$\beta_2 = -1.23\, D_2 \ln X_1$
$\beta_3 = -0.77\, D_3 \ln X_1$
$\beta_4 = 1.15\, D_4 \ln X_1$
$\beta_5 = -0.90\, D_5 \ln X_1$
$D_j = 0$ is the reference condition as above

$\gamma_1 = 0.41\, D_3 X_3$
$\gamma_2 = 1.59\, D_4 X_3$
$D_k = 0$ is the reference condition as above. The condition is equal also for D_1, D_2, D_5
$\delta_1 = -1.16\, D_3 X_2$
$\delta_2 = 0.83\, D_4 X_2$
$\delta_\ell = 0$ is the reference condition as above. Such condition is equal also for D_1, D_2, D_5

The evaluation is standardize for a plot of 33 m length and 13% slope. The evaluation for slopes of different length and degree of slope can be made using SL corrections as in the USLE.

2. Detailed analysis of the USLE equation factors and modifications introduced in other environments for factor evaluation –

2.1 The rainfall erosivity factor, R

The rainfall erosion index presented by WISCHMEIR (1959) has been developed considering that storm soil losses from cultivated continuous fallow plot (22.1 m long and having a 9% degree of slope) is highly correlated to the cross product of the total kinetic energy and the maximum 30-minute rainfall intensity. This product, designed by EI, is a measure of the manner in which energy and intensity are combined in a storm and ~~defines~~ defines the combined effect of raindrop impact and turbolence of runoff to transport soil particles from a field.

WISCHMEIER has produced the following equation to estimate the kinetic energy of a rainstorm or a portion of a rainfall event

$$E = 1.213 + 0.890 \log_{10} I \qquad (10)$$

E = kinetic energy Kgm/m² mm
I = rainfall intensity, mm per hour

The kinetic energy for an intensity increment is obtained by multiplying the kinetic energy of equation (10) by the rainfall amount of that intensity increment. The ~~total~~ total energy, in Kgm/m² for a rainfall event can be computed by accumulating the kinetic energy for each ~~distinct~~ distinct intensity increments of the event. The overall computation of the R factor for an event can so be computed as follows:

$$R = \frac{\left[\sum_{j=1}^{m} (1.213 + 0.890 \log_{10} I_j)(I_j T_j)\right] I_{30}}{173.6} \qquad (11)$$

where:

R = the rainfall erosivity index, Kgm/m² × mm/hr
I_j = the rainfall intensity for a specific storm increment, mm/hr
T_j = the time period of the specific storm increment hr
I_{30} = the maximum 30-minute rainfall intensity for the storm, mm/hr
j = the specific storm increment
m = the numbers of storm increments

$\gamma_1 = 0.41\ D_3\ X_3$

$\gamma_2 = 1.59\ D_4\ X_3$

$D_K = 0$ is the reference condition as above. The condition is equal also for D_1, D_2, D_5

$\delta_1 = -1.16\ D_3\ X_2$

$\delta_2 = 0.83\ D_4\ X_2$

$\delta_l = 0$ is the reference condition as above. Such condition is equal also for D_1, D_2, D_5

The evaluation is standardize for a plot of 33 m length and 13% slope. The evaluation for slopes of different length and degree of slope can be made using SL corrections as in the USLE.

2. Detailed analysis of the USLE equation factors and modifications introduced in other environments for factor evaluation –

2.1 The rainfall erosivity factor, R

The rainfall erosion index presented by WISCHMEIR (1959) has been developed considering that storm soil losses from cultivated continuous fallow plot (22.1 m long and having a 9% degree of slope) is highly correlated to the cross product of the total kinetic energy and the maximum 30-minute rainfall intensity. This product, defined by EI, is a measure of the manner in which energy and intensity are combined in a storm and ~~define~~ defines the combined effect of raindrop impact and turbulence of runoff to transport

soil particles from a field.

WISCHMEIER has produced the following equation to estimate the kinetic energy of a rainstorm or a portion of a rainfall event

$$E = 1.213 + 0.890\ \log_{10} I \qquad (10)$$

E = kinetic energy Kgm/m² mm

I = rainfall intensity, mm per hour

The kinetic energy for ~~an~~ intensity increment is obtained by multiplying the kinetic energy of equation (10) by the rainfall amount of that intensity increment. The ~~total~~ total energy, in Kgm/m² for a rainfall event can be computed by accumulating the kinetic energy for each ~~distinct~~ distinct intensity increments of the event. The overall computation of the R factor for an event can so be computed as follows:

$$R = \frac{\left[\sum_{j=1}^{m} (1.213 + 0.890\ \log_{10} I_j)(I_j T_j)\right] I_{30}}{173.6} \qquad (11)$$

where:

R = the rainfall erosivity index, Kgm/m² x mm/hr

I_j = the rainfall intensity for a specific storm increment, mm/hr

T_j = the time period of the specific storm increment hr

I_{30} = the maximum 30-minute rainfall intensity for the storm, mm/hr

J = the specific storm increment

m = the numbers of storm increments

Example of calculation:

Time from start (min)	Rainfall mm	Intensity mm hr^{-1}	Kinetic energy kgm/m^2 mm	Total kinetic energy (col 2 × col 4) Kgm/m^2
0 - 14	1.52	6.08	1.91	2.90
15 - 29	14.22	56.88	2.77	39.39
30 - 44	26.16	104.64	3.01	78.74
45 - 59	31.50	126.00	3.08	97.02
60 - 74	8.38	33.52	2.57	-
75 - 89	0.25	1.00	-	

Total E = 218.05

maximum 30-min rainfall 26.16 + 31.50 = 57.66 mm

maximum 30-min intensity = 57.66 × 2 = 115.32 mm hr^{-1}

$$EI_{30} = 25145,52 \ Kgm/m^2 \cdot mm \ hr^{-1}$$

$$EI_{30} = \text{standard units} = \frac{25145,52}{173.6} = 144.85$$

This unit is in accord with the unit of K as it will be seen later so that the product R × K would give the soil loss A in Kg/m^2 -

The rainfall erosivity indexes can be summed for any time period to provide numerical measure of the erosivity of rainfall in that period(*).

For any hydrologic evaluation there is an associated annual distribution of the phenomena being investigated. The monthly and annual distribution for different area are normally different for some portion of the distribution curve.

* For the calculation of R, WISCHMEIER and SMITH (1965) have established a treshold value for a storm to be considered capable to give runoff and erosion of 12.7 mm of rain.

Typical distribution curves are shown in Figure 1 for the three areas. These distribution are used with obtained cropping management data to obtain seasonal cropping factors or to combine crop rotation information as will be discussed later.

The computation of R from long term precipitation records is cumbersome. Simplifying methods have been developed. For the mainland USA, the 2 yr probabilities of 6 hr rainfall (P) were best correlated with R:

$$R = EI_{30} = 27.38 \ P^{2.17} \qquad [12]$$

Based on this index, an isoerodent map was prepared for USA east of the Rocky Mountains.

Other simplifying methods have been developed especially for locations when rainfall records do not consent a storm to storm analysis but only day or months level observation rainfall data are available.

As a very simple example, average annual R values for the West Africa were calculated by ROOSE (1977) using a simple empirical relationship:

$$R_{an} / H_{an} = 0.50 \pm 0.05 \qquad [13]$$

Another very simple correlation equation was presented by ARNOLDUS (1980) to estimate annual average long term values of R from the average long term monthly and annual rainfall (p and P respectively)

FIGURE - 1

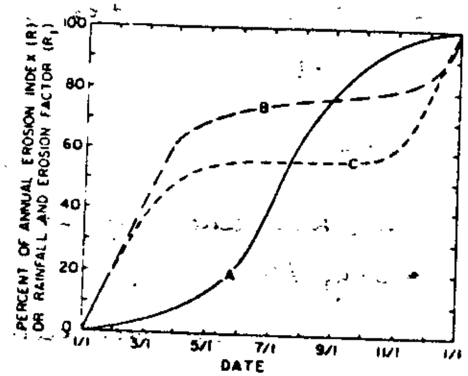


Figure 2.3 Distribution curves of erosion-index, *R*, for: (A) Central corn belt (northern Missouri and central Illinois, Indiana, and Ohio) (Wischmeier and Smith, 1965); (B) Dryland grain region of the Pacific Northwest, tentative (McCool *et al.*, 1977) (Reproduced by permission of SCSA); and (C) South Central part of Island of Molakai (USSCS, 1976)

$$\log R = b \log \sum_{1}^{12} \frac{p^2}{P} - a \qquad [14]$$

An example of application of such a regression equation was based on data of 178 stations of which 164 in USA and 14 in west Africa.

$$\log R = 1.93 \log \sum_{1}^{12} \frac{p^2}{P} - 1.52 \quad (R^2 = 0.81) \qquad [15]$$

Besides R other index of erosivity where proposed by different authors especially for tropical countries. HUDSON (1971) conducted extensive soil erosion studies in subtropical Africa. He ~~found that soil loss~~ found that the kinetic energy of rainstorms in tropical Africa were best calculated by the following equation:

$$E = 29.8 - \frac{127.5}{I} \qquad [16]$$

where

E = kinetic energy ($J m^{-2} mm^{-1}$)

I = rainfall intensity ($mm\ h^{-1}$)

HUDSON found that kinetic energy of individual storm > 25.4 mm of rain per hour was best correlated to soil loss that the R index of WISCHMEIER. He described this parameter as KE > 25 index.

LAL (1977) has found in the tropics a lower correlation coefficient between ~~EI_{30}~~ R and soil loss that was obtained for the [illegible] experiment in USA. LAL reported a better correlation with the product of total rainfall amount (A) and peak storm intensity (I_m) than either R and KE>25. The annual index AI_m is calculated according to the following equation:

$$AI_m = \left\{\sum_{1}^{12} \sum_{1}^{n} (a \, i_m)\right\} \quad (0.64 \cdot R^2) \quad [17]$$

where

- a = total rainfall in any storm in cm
- i_m = maximum storm intensity in cm/hr
- n = number of rainy days in the month

KOWAL and KASSAM (1977) have produced an equation for the tropics to calculate kinetic energy of rainstorms in $J m^{-2}$ from the rainfall amount (R_a)

$$E = 41.4 R_a - 120.0 \qquad [18]$$

The negative intercept of this equation suggest that rainstorms with total rainfall < 3.6 mm have zero kinetic energy in relation to soil loss

2.2- The soil erodibility factor, K

The soil erodibility factor, K, in the USLE is a quantitative description of the inherent erodibility of a particular soil. The factor reflects the fact that different soils erode at different rates when the other factors that affect erosion are the same. Soil properties that affect infiltration rate, permeability, total water capacity, dispersion, splash, abrasion and transporting forces also affect erodibility.

For a particular soil, the soil erodibility factor, K, is the rate of erosion in kg m^{-2} per unit of erosivity index from a standard plot. The standard plot used for USLE development is 22.13 m long on a uniform lengthwise slope of 9%. The plot is tilled up slope and maintained in continuous bare fallow for two years.

Direct measurement of K were made for 23 major soil of USA. Following these initial measurements, the K values were approximated for numerous other soils.

Indications of general magnitude of K is reported in table 1.

Direct measurement of the K factor require considerable time and equipment and is costly to perform.

Erodibility varies with soil texture, aggregate stability, shear strength, infiltration capacity and organic and chemical components.

In an effort to eliminate the empirical procedure, a study was conducted to describe K using different soil properties

TABLE - 1

Table 2.2 Indications of the general magnitude of the soil-erodibility factor, K*

Texture class	Organic matter content		
	< 0.5 per cent	2 per cent	4 per cent
	K	K	K
Sand	0.05	0.03	0.02
Find sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy fine sand	0.24	0.20	0.16
Loamy very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Fine sandy loam	0.35	0.30	0.24
Very fine sandy loam	0.47	0.41	0.33
Loam	0.38	0.34	0.29
Silt loam	0.48	0.42	0.33
Silt	0.60	0.52	0.42
Sandy clay loam	0.27	0.25	0.21
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Sandy clay	0.14	0.13	0.12
Silty clay	0.25	0.23	0.19
Clay		0.13–0.29	

* The values shown are estimated averages of broad ranges of specific-soil values. When a texture is near the borderline of two texture classes, use the average of the two K values. For specific soils, use of Figure 2.6 or Soil Conservation Service K-value tables will provide much greater accuracy. From ARS, 1975.

and their interactions.

A soil erodibility nomograph was developed for the estimation of K by WISCHMEIER et al. (1971) (figure 2). Five soil parameters are needed to use the nomograph: per cent silt (0.002–0.05 mm) plus very fine sand (0.05–0.10 mm), per cent sand (0.10–2 mm), organic matter content, structure and permeability. The ~~[illegible]~~ structure and permeability classes are shown in figure 2. Additional information on permeability classes given by WISCHMEIER et al. (1971) are: code fragipan soil as 6; code more permeable soil ~~[illegible]~~ underlain by massive clay or silty clay as 5; code moderately permeable surface soil underlain by by a silty clay or silty clay loam having a weak subangular or angular blocky structure as 4, and code as 3 if the subsoil structure grade is moderate or strong or the texture is coarser than silty clay loam.

The equation used to develop the nomograph is the following:

$$100\,K = 2.1\,M^{1.14}\left(10^{-4}\right)\left(12 - a\right) + 3.25\left(b - 2\right) + 2.5\left(c - 3\right) \quad [19]$$

where:

M = [(silt % + fine sand %) (0.002 – 0.1 mm)] × [(100 −) 100% clay (< 0.002 mm)]

a = organic matter per cent

b = index of soil structure: 1 = very fine granular; 2 = fine granular, 3 = med. or coarse granular, 4 = blocky, platy or massive.

FIGURE - 3

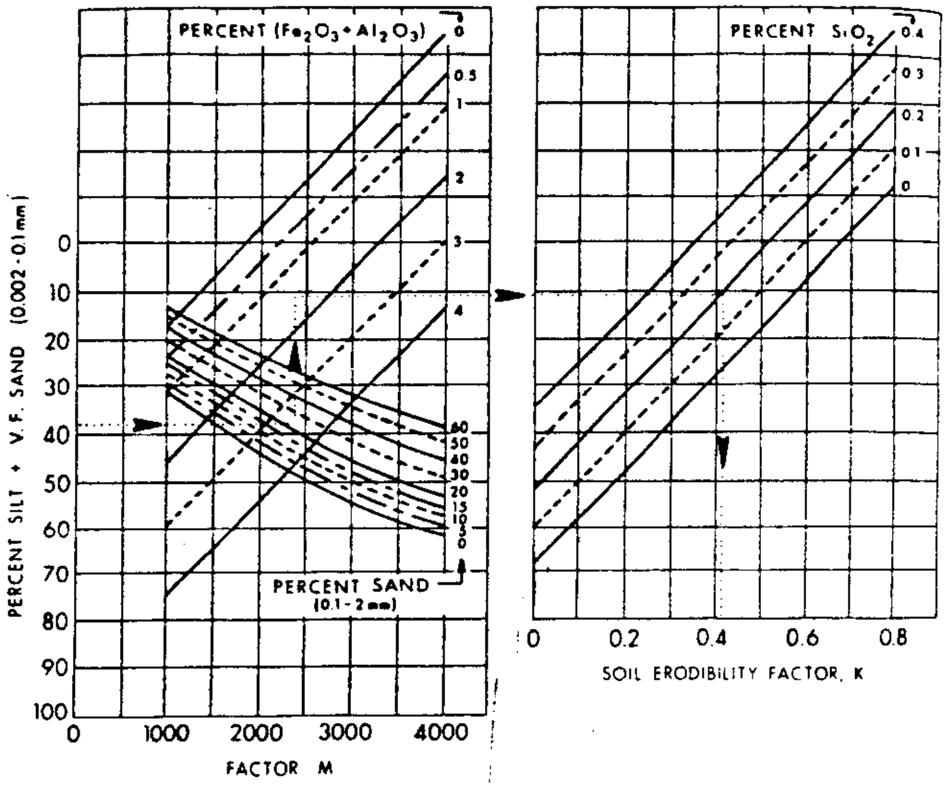


Figure 22. Roth, Nelson, and Romkens' (1974) nomograph for soil erodibility estimation

where.

L = slope length factor

x = Slope length metres

m = An exponent

Current recommendation (WISCHMEIER & SMITH, 1978) for the exponent m, are.

$m = 0.5$ if slope ≥ 5 per cent

$m = 0.4$ if slope < 5 per cent and > 3 per cent

$m = 0.3$ if slope ≤ 3 per cent and ≥ 1 per cent

$m = 0.2$ if slope < 1 per cent

These recommendation are reflected in the construction of the slope effect chart (figure 4).

~~Smith~~ SMITH and WISCHMEIER (1957) also determined that soil loss was correlated with a parabolic description of the effect of slope steepness gradient. Normalizing this equation to standard slope of 9 per cent resulted in a description of the slope-gradient factor

$$S = \frac{0.43 + 0.30\,s + 0.043\,s^2}{6.613} \quad [21]$$

where:

S = the slope gradient factor

s = the gradient per cent

Equation [21] is recommended for the slope gradient factor and used in the development of the slope effect chart (figure 4).

FIGURE - 2

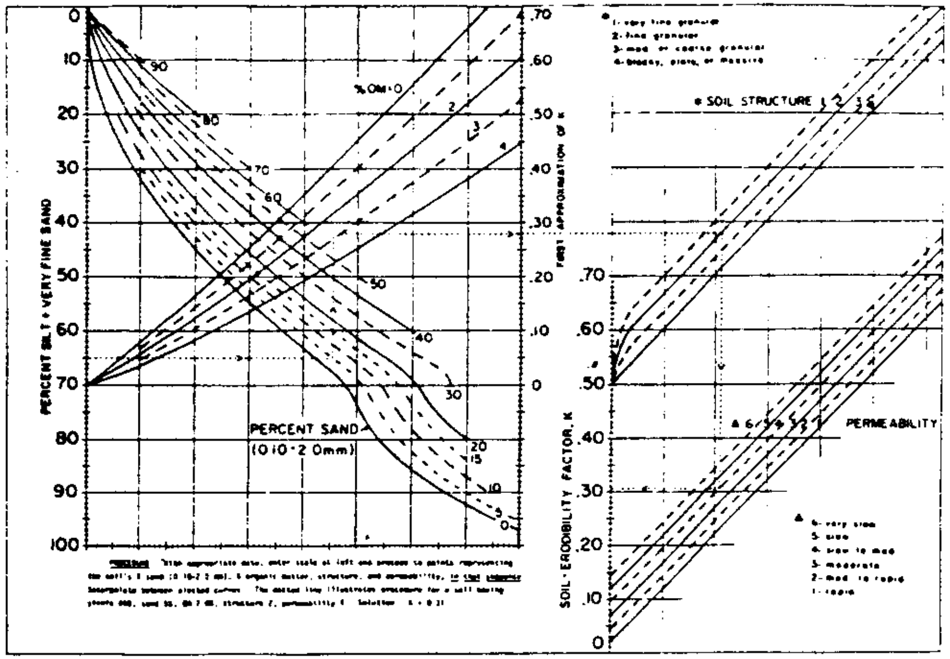


Figure 21. Wischmeier's nomograph for soil erodibility estimation. (Wischmeier et al. 1971)

C = index of permeability : 6 = very slow ; 5 = slow ; 4 slow to mod. ; 3 = moderate ; 2 = mod. to rapid ; 1 = rapid.

To obtain K values for subsoil condition ROTH et Al. (1974) developed another nomograph by taking in consideration mineralogical composition (figure 3).
A series of tables indicating erodibility of soils for several sites are reported by EL-SWAIFY et al. (1982).

2.3 - The slope length factor L, and the slope gradient factor S

The effects of slope length and gradient are represented in the USLE as L and S respectively; however, they are often evaluated as a single topographic factor LS. Slope length is defined as the distance from the point of origin of overland flow to the point where the slope decreases sufficiently for deposition to occur or to the point where runoff enters a defined channel. The channel may be part of a drainage network or a constructed channel. Slope gradient is the segment slope, usually expressed as percentage. The development of the USLE was based on a standard plot length of 22.13 metres; therefore, the slope-length factor was defined as.

$$L = \left(\frac{x}{22.13}\right)^m \qquad [20]$$

FIGURE - 4

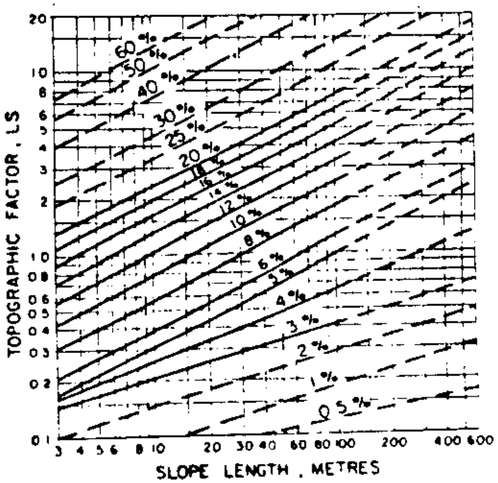


Figure 2.7. Slope length and gradient factor, *LS*, for use with the Universal Soil Loss Equation

Values of SL may be computed directly by the following equation:

$$SL = \left(\frac{x}{22.13}\right)^m \left(0.065 + 0.045\,s + 0.0065\,s^2\right) \quad [22]$$

where all the terms have been previously defined. Figure 4 was developed and should be used only for uniform slopes. The use of the topographic factor LS will usually overestimate soil loss from concave slopes and underestimate soil loss from convex slopes.

ONSTAD et al. (1967) and FOSTER and WISCHMEIER (1974) provided a method for estimating LS for irregular slopes. The irregular slope is divided into a series of uniform slope segments in relation to slope and soil type. The soil loss for the entire slope is then computed:

$$A = (0.224)\,\frac{RCP}{x_e}\sum_{j=1}^{n} K_j\left[\frac{S_j x_j^{m+1} - S_j x_{j-1}^{m+1}}{(22.13)^m}\right] \quad [23]$$

where

K_j = soil erodibility factor for the jth slope segment

x_j = the distance from the top of the slope to the lower end of the jth segment, metres

x_{j-1} = is the slope length from the top of the slope to upper end of the jth segment, metres

x_e = the overall slope length, metres

S_j = the value of the slope-gradient factor of the jth segment

A, R, C, P and m are as defined previously

If K is uniform on all the segment of the slope it become a constant and pass the sign of summation as the other constant factors.

Also a change of the factor C along the slope can be treated in the same manner as for K –

~~2.4 ...~~ It may be worthwile to define here some of the possibilities of the use of the SL factor for defining the maximum tolerable length and slope gradient in relation to a given tolerance limit for soil loss.

We will return to tolerance limits for soil losses but at the moment we can suppose that we would like to avail a maximum soil loss per ~~hect~~ yr T from a given slope. In such a situation SL can be calculated as it follows.

$$SL = \frac{T}{RKCP(0.224)}$$

given the specific slope gradient s the maximum length x can be calculated as follows.

$$x = 514.9 \left(\frac{SL}{0.43 + 0.30\,s + 0.043\,s^2} \right)^{\frac{5}{3}}$$

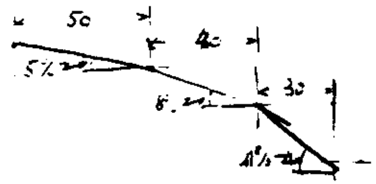
on the other hand being given the slope length x the maximum gradient s can be calculated as follows.

$$s = \frac{-0.30 + \sqrt{0.09 - 0.172\,c}}{0.086}$$

where :

Example of Calculation :

Assume a convex slope of the following segment



5% for 50 m   8% for 40 m   11% for 30 m

tabular solution is made expedient calculating

$$U_j = \frac{S_j\, x_j^{m+1}}{(22.13)^m} \qquad U_{j-1} = \frac{S_j\, x_{j-1}^{m+1}}{(22.13)^m}$$

Segment n°	slope %	S_j	length, m	x_j	x_{j-1}	U_j	U_{j-1}	$U_j - U_{j-1}$	Segment LS	% of total soil loss
1	5	0.454	50	50	0	34	0	34	0.68	13
2	8	0.844	40	90	50	153	63	90	2.25	35
3	11	1.351	30	120	90	378	245	133	4.43	52
			120					257		100

weighted average LS 2.14

2.4 - The cropping management factor, C -

The cropping management factor represents the ratio of soil loss from a specific cropping or cover condition to the soil loss from a tilled continuous fallow condition of the same soil and slope and for the same rainfall. This factor includes interrelated effects of cover, crop sequence, productivity level, growing season length, cultural practices, residue management and rainfall distribution. Crops can be grown continuously or can be rotated with other crops. The evaluation of C factor is often difficult because of the many cropping and management systems. Rotations are various in length and sequences. Residues can be removed or left on the field or incorporated in the soil. Each segment of the cropping and management sequence must be evaluated in combination with the rainfall erosivity distribution for the region, using the seasonal distribution curve (figure 1).

Several effect of cropping and management were presented by WISCHMEIER (1960) and WISCHMEIER and SMITH (1965) in the form of extensive tables of soil loss ratios. Greatly expanded tables of C factor values were presented by WISCHMEIER and SMITH (1978) -

We would consider here ~~at~~ only some example either for a rotational crop sequence or for the evaluation of C for undisturbed areas.

~~Table~~

Table 2 ~~as~~ illustrates for a series of crops, six crop-stage periods.

Table 2 - Soil-loss ratios for selected crops

Cover, sequence and management	Productivity kg/m^2	Soil loss ratios, percentage for crop-stage period (b) F	SB	1	2	3	4
First year corn after grain and legume hay, spring turn plough, conventional tillage, residue left	0.6+	8	22	19	17	10	14
Small grain in disked row-crop residue after one year corn, after meadow	–	–	12	12	11	7	2
Grass and legume meadow	0.7+	–	–	–	–	–	0.4

~~[illegible]~~
(b) crop-stage periods

F = rough fallow

SB = seed-bed to 10% canopy cover

1 = Establishment; 10-50 per cent canopy cover

2 = Development; 50-75 per cent canopy cover

3 = Maturing crop; 75 per cent canopy cover to crop harvest

4 = Residue or ~~stubble~~ stubble. Crop harvest to ~~[illegible]~~ ploughing or new seeding

An example of calculation of the ~~[illegible]~~ weighted average C value for a 3-year rotation follows in table 3.

(2 bis)

Table 3 - Example of cropping management (C) factor estimation (Corn - Oat - Meadow 3 yr rotation) (Central Corn Belt, USA, use curve A of figure 1 for R seasonal percentage amounts)

Crop stage period	Dates	Percent of R	Crop-stage soil loss C percentage	C factor
Meadow	1/1 - 4/5	10	0.4	0.0004
Rough ploughed sod (F)	4/15 - 5/5	5	8	0.0040
Dr seed and corn seeded (SB)	5/5 - 6/1	10	22	0.0220
10-50% canopy (1)	6/1 - 6/20	13	19	0.0247
50-75% canopy (2)	6/20 - 7/10	14	17	0.0238
75% canopy - harvest (3)	7/10 - 10/15	40	10	0.0400
Residue (4)	10/15 - 12/31	8	14	0.0112
Oat seedbed (SB)	4/1 - 4/15	2	12	0.0024
10-50% Canopy (1)	4/15 - 5/1	4	12	0.0048
50-75% canopy (2)	5/1 - 6/1	11	11	0.0121
75% - harvest	6/1 - 6/15	9	7	0.0063
New meadow in oat stubble	6/15 - 8/15	38	2	0.0076
Meadow (16.5 months)	8/15 - 1/1	128	0.4	0.0051
Total		300		0.1756
Average C Factor				0.0585

For the determination of the C value for undisturbed areas WISCHMEIER (1975) has developed a method based on the following equation

$$C = C_1 \, C_2 \, C_3 \qquad (24)$$

where:

- C = the vegetation and soil management factor
- C_1 = represent the effect of the canopy cover and depends on the surface of soil covered by the vegetation of different haight. (figure 5) (type effect I)
- C_2 = is the effect of mulch and close-growing vegetation (type II effect) (figure 6) and depends of the per cent of soil covered by mulch)
- C_3 = is the residual effect of land use (type III effect) and depend from the root network in topsoil relation to good rotation meadow (figure 7)

Some C values for permanent pastures, rangeland and idle land are reported from WISCHMEIER (1975) in table 4 - Other C values for WEST Africa obtained by ROOSE (1977) are included in table 4 bis

2.5 - The erosion control practice factor, P

The erosion control practice factor is the ratio of soil loss using the specific practice compared with the soil loss using up-and-down hill culture. The erosion control practices usually included in this factor are contouring, contour strip cropping and terracing. Conservation tillage, crop rotation, fertility treatments and the retention of residues are also

21bis

FIGURE-5

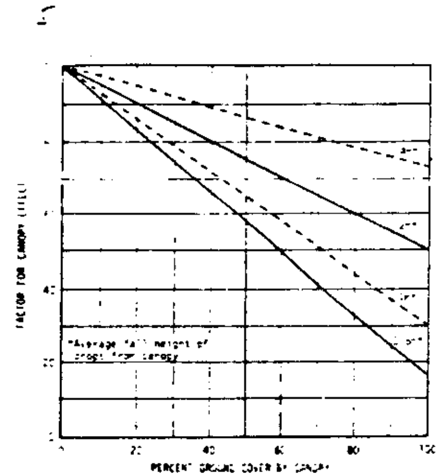


FIGURE 1.—Influence of vegetal canopy on effective *EI*, assuming bare soil beneath the canopy, and based on the velocities of free-falling waterdrops 2.5 mm in diameter

FIGURE-6

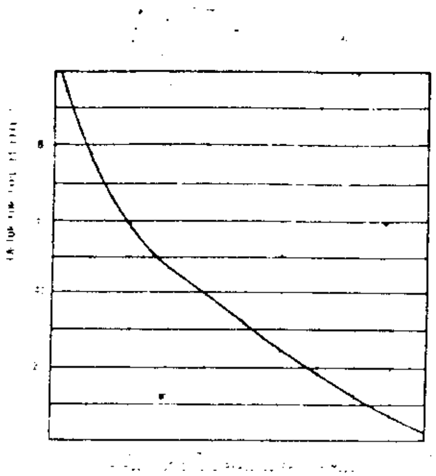


FIGURE 2.—Effect of plant residues or close-growing stems at the soil surface on C-factor (does not include subsurface root effects).

FIGURE - 7

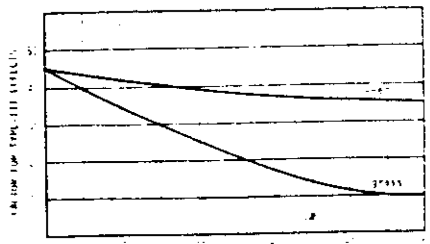


FIGURE 3.—Type III effects of undisturbed land areas on C-factor. These values do not apply to cropland and construction sites.

TABLE - 4

Table 2.7. C values, percentage for undisturbed land[a]

Vegetal canopy: Type and Height	Percentage Cover[c]	Mulch or vegetation at ground surface[b] Percentage cover: 0	20	40	60	80	95–100
None		45	24	15	9.1	4.3	1.1
Tall weeds or short brush, 0.5 m effective height	25	36	20	13	8.3	4.1	1.1
	75	17	12	9	6.8	3.8	1.1
Brush or bushes, 2 m effective height	25	40	22	14	8.7	4.2	1.1
	75	28	17	12	7.8	4.0	1.1
Trees, 4 m effective height	25	42	23	14	8.9	4.2	1.1
	75	36	20	13	8.4	4.1	1.1
Factor to obtain C values with grass or compacted duff ground cover[d]		1.0	0.53	0.67	0.46	0.30	0.27

[a] From Wischmeier, 1974. (Reproduced by permission of SCSA).
[b] C values in Table are for ground cover of weeds or undecayed residue.
[c] For canopy cover between 25–75 per cent, straight line interpolation is appropriate.
[d] To obtain C values for ground cover of grass or compacted duff, multiply the C value from the table by the factor.

TABLE-4 bis

Table 2.9 The vegetal cover factor and cultural techniques (C factor) in West Africa*

Practice		Annual Average C Factor
Bare soil		1
Forest or dense shrub, high mulch crops		0.001
Savannah, prairie in good condition		0.01
Over-grazed savannah or prairie		0.1
Crop cover of slow development or late planting: 1st year		0.3 to 0.8
Crop cover of rapid development or early planting: 1st year		0.01 to 0.1
Crop cover of slow development or late planting: 2nd year		0.01 to 0.1
Corn, sorghum, millet (as a function of yield)		0.4 to 0.9
Rice (intensive fertilization)		0.1 to 0.2
Cotton, tobacco (2nd cycle)		0.5 to 0.7
Peanuts (as a function of yield and the date of planting)		0.4 to 0.8
1st year cassava and yam (as a function of the date of planting)		0.2 to 0.8
Palm tree, coffee, cocoa with crop cover		0.1 to 0.3
Pineapple on contour (as a function of slope)	burned residue	0.2 to 0.5
	buried residue	0.1 to 0.3
	surface residue	0.01
Pineapple and tie-ridging (slope 7 per cent)		0.1

* From Roose, 1977 (Reproduced by permission of ORSTOM and SCSA)

such that erosion control practices. However, these ~~practices~~ are usually included in the cropping management C factor described ~~using~~ earlier.

The factor P ~~as~~ estimated by WISCHMEIER and SMITH (1978) for the three major mechanical conservation measures are reported in table 5. These values have been found ~~at~~ only ~~~~ for slope up to 25%. Within a practice type the P factor is most effective for the 3-8% slope range and values increase as the slope increases. As the slope decreases below 2 per cent the practice factor value increases due to the reduced effect of the practice when compared to up-and-down-hill cultivation. The factor for terracing in table 5 is for the prediction of the total off-the-field soil loss. If within-terrace interval soil loss is desired, the interval distance should be used for the slope length factor L and the contouring P value used for practice factor.

The P factor estimated for several erosion control practices in West Africa by ROOSE (1977) is illustrated in table 6 –

2.e – Soil loss tolerance

Soil loss tolerance is defined as the maximum rate of soil ~~loss~~ erosion that permits a high level of productivity to be sustained. Tolerances for specific soil in USA have been the subject of several workshops when soil scientists have extensively examined the soils and then recommended tolerance values. In general, deep, medium textured, moderately permeable soils

TABLE - 5

Table 2.10. Erosion control practice factor, P*

Land Slope, percentage	Contouring	Contour Strip cropping and Irrigated Furrows	Terracing†
1–2	0.60	0.30	0.12
3–8	0.50	0.25	0.10
9–12	0.60	0.30	0.12
13–16	0.70	0.35	0.14
17–20	0.80	0.40	0.16
21–25	0.90	0.45	0.18

* From Wischmeier and Smith, 1978.
† For prediction of contribution to off-field sediment load

TABLE - 6

Table 53. P factor for conservation practices in West Africa

Conservation practices	P factor
Tied-ridging	0.20-0.10
Antierosive buffer strips from 2 to 4 m width	0.30-0.10
Straw mulch	0.01
Curasol mulch (60 g/l/m^2)	0.50-0.20
2-3 years of temporary grassland	0.5-0.1
Reinforced ridges of earth or low dry stone walls	0.1

Source: Roose, 1977c.

that have subsoil characteristics favourable to plant growth when assigned maximum tolerances of 1.1 Kg/m²/yr. The actual range of tolerance limits given by the Soil Conservation Service in USA is between 0.2 - 1.1 Kg/m²/yr. However, LCCMAN (1979) feel that since most estimates of annual soil renewal are < 0.05 Kg/m²/yr one can assume that, in time, this limits will reduce progressively the topsoil. His specific recommendation in relation to a program for soil loss abatement were:

1) To maintain the present limits of 0.2-1.1 Kg/m²/yr at the soil series level which could be modified as knowledge of the effect of long-term erosion improves
2) To reduce the upper limit of 1.1 Kg/m²/yr for those soil geographical areas where lower level can be maintain with slight shifts in soil management
3) State and local technical people would modify T values based on local crop production needs and experiences —

GROSSMAN and BERDHNER (1979) proposed the use of a variable allowable soil loss tolerance (T-value) based on the depth of soil favourable to plant rooting.

The prediction (assignment) of favourable rooting start with depth of common plant rooting. An increment of variable thickness is added, determined by the shallowest depth of any of four root-limiting conditions. (1) presence of taxonomic features that include root limitations as part of the definitions, (2) other horizons with high strength

and weak structure that probably restrict roots nearly totally, (3) horizons that permit roots but restrict them strongly to planes > 5 mm apart; (4) horizon relatively high in extractable aluminium and or low in calcium. Finally, a standard increment is added to the favourable rooting depth on the assumption that the upper part of the root-limiting zone could be made favourable by tillage and amendments.

For illustrative purpose, the relationship could be as follows:

Potential favourable rooting Depth cm.	T-rate ~~T-rate~~ Kg/m²/yr
0-25	NA
25-50	0.4
50-100	0.8
100-150	1.2
150-200	1.6
> 200	2.0

SKIDMORE (1979) described a function he developed for defining soil-loss tolerances for permanent preservation of the soil resource. The relationship is expressed by

$$T_{(x,y,z)} = T_1 + (T_2 - T_1)/2 + [(T_2 - T_1)/2] \cos\{\pi + [(Z - Z_1)/(Z_2 - Z_1)]\pi\} \quad [25]$$

where

$T_{(x,y,z)}$ = the tolerable soil loss rate at point (x,y) mm/yr

T_1 and T_2 = ~~soil~~ are lower and upper ~~soil renewal rate~~ limits of allowable soil loss rate, respectively; T_1 corresponds to soil renewal rate - (in mm/yr)

Z_1 and Z_2 = are minimum allowable and optimum soil depths

Z = is the present soil depth

Tolerable soil loss function between the points $(T_1 Z_1)$ and $(T_2 Z_2)$ is sinusoidal and dependent upon soil depth and $(T_2-T_1)/2$ is the amplitude. The period is represented by the cosine argument and goes from zero to 180 degrees for values of Z between the limits of Z_1 and Z_2.

2.7 Sediment yield prediction

Generally, specific modifications of the USLE have been developed especially for sediment yield prediction from small watersheds.

We shall deal here with an example of modification which was used by WILLIAMS (1975):

$$Y = 11800\,(Q\,q_p)^{0.56}\,KCPLS \qquad [26]$$

where:

Y = Sediment yield from an individual storm, Kg

Q = storm runoff volume, m^3

q_p = peak runoff rate m^3/sec

$KCPLS$ are as defined in the USLE

A sediment delivery ratio was considered not necessary when the rainfall term R of the usle was replaced by the

Example of application of SKIDMORE's equation for the evaluation of T-tolerance limit for soil erosion:

A soil in the position (x, y) is 1.4 m deep (Z). The [illegible] of such a soil is estimated to be [illegible] to 2.0 m (Z_2) and that a depth of 0.5 m (Z_1) would be the minimum allowable. The soil renewal rate is estimated to be 0.2 mm/yr (T_1) while the maximum soil loss that should be never exceed is established in 2.0 mm/yr (T_2).

Than the following formula is applied:

$$T(x,y) = T_1 + \frac{(T_2-T_1)}{2} + \left\{ \frac{(T_2-T_1)}{2} \cos\left[\pi + \frac{(Z-Z_1)}{(Z_2-Z_1)}\pi\right]\right\}$$

$$T(x,y) = 0.2 + \frac{(2.0-0.2)}{2} + \left\{\frac{(2.0-0.2)}{2} \cos\left[3.14159 + \frac{(1.4-0.5)}{(2.0-0.5)} 3.14159\right]\right\}$$

$$T(x,y) = 0.2 + 0.9 + \{0.9 \cos 5.0265\} = 0.2 + 0.9 + 0.278 = 1.38 \text{ mm}$$

runoff term as shown in equation (26)

The application of equation (26) required estimation of K CP and LS terms in a different way to integrate watershed variable situations. The K, LS, C and P factors are weighted according to drainage area so that the source erosion can be computed for the entire watershed in one solution of the equation. The general form of the weighting function is:

$$x = \frac{\sum_{i=1}^{m} X_i DA_i}{DA} \qquad [27]$$

where.

x = weighted factor

X_i = value of the factor covering drainage area DA_i

DA = total drainage area of the watershed

Only the cultivated area of a watershed is considered in computing the P factor.

Another modification of USLE (FOSTER et al 1973) was used by ONSTAD et al. (1976) as the major component in a sediment yield model for small watersheds.

$$A = (0.224)\, W K C P S L \qquad [28]$$

where:

W = a R_{st} + (1-a) 0.40 $Q q_p^{1/3}$ is an energy factor based either on rainfall storm erosivity R_{st} and runoff erosivity based on runoff volume Q in mm and peak runoff rate

q_p is in mm/hr, a is a coefficient $(0 \le a \le 1)$ which represents the relative importance of rainfall energy compared with runoff energy for detaching soil. The other terms are as defined in the USLE

FOSTER et al. (1975) developed a system to evaluate erosion as a continuous process of detachment and transport in several segments downslope having uniform factor characteristics.

The detached soil capacity is for segment j:

$$A_{dj} = \frac{W_j K_j C_j P_j S_j}{31} \left(x_{i+1}^{1.5} - x_i^{1.5} \right) \qquad (28)$$

where:

A_{dj} = detached soil capacity of segment j (Kg/m)

K_j, C_j, P_j, S_j = the USLE factors for segment j

W_j = the energy factor for segment j

x_i = the higher limit of segment j m

x_{i+1} = the lower limit of segment j m

31 = a conversion factor

The total unslope sediment yield for unit width is $A_t = \Sigma_j A_{dj}$

The transport capacity at x point is

$$A_{cx_{i+1}} = \frac{W_j C_j \bar{K} P_j S_j}{31} x_{i+1}^{1.5} \qquad (29)$$

where:

$A_{cx_{i+1}}$ = the transport capacity at the lower end of segment j (Kg/m)

W_j = the energy factor for segment j

K_j, C_j, P_j, S_j = the USLE factors for segment j

$\bar{K}$ = effective value of K which is the average value for upslope segments

x_{j+1} = lower limit of segment j ...

There are two cases possible for slope segment j

case 1

if $A_t \le A_{c x_{j+1}}$ erosion occurs on slope segment j because the transport capacity exceeds the total detached soil. Therefore the sediment yield is equal $G = \sum_1^j A_d$, while the deposition $M = 0$

case 2

if $A_t \ge A_{c x_{j+1}}$ deposition occurs on slope segment j because total detachment exceed the transport capacity. Therefore sediment yield $G = A_{c x_{j+1}}$ and the deposition $M = A_t - A_{c x_{j+1}}$.

The gross erosion and sediment delivery ratio technique of estimating sediment yield is a two step procedure. First, the gross erosion in a drainage area is computed. The gross erosion includes interrill, rill, gully and stream erosion. The USLE and its modification can be used to estimate the sediment yield and the sheet and rill erosion that is usually but not always the major portion of a watershed's gross erosion. Sediment from gully, streambank and streambed erosion and from uncontrolled roadsides must be added to the USLE estimates. Methods

for estimating sediment yield from these sources are discussed in Section 3 of the SCS National Engineering Handbook (1971) and would be above the scope here.

Sediment delivery ratio equations have been developed from studies of watersheds in particular region. As with predictive equations, most sediment delivery ratios equations have limited regional applicability. The method of estimating sediment yield by gross erosion/sediment delivery can be summarized as follows:

$$Y = \frac{E(DR)}{W_s} \qquad [30]$$

where:

Y = sediment yield per unit area

E = gross erosion

DR = sediment delivery ratio

W_s = the area of the watershed

The sediment delivery ratio is dependent upon drainage area size and from other watershed characteristics as relief, stream length, bifurcation ratio (STRAHLER, 1964). The sediment delivery ratio is also influenced by the sediment source and its proximity to the stream, the transport system and the texture of the eroded material (RENFRO, 1975).

The SCS, USDA (1971) has developed a general delivery ratio versus drainage area relationship from data of earlier studies. It is understood that this relationship can be used only if local or regional relationships are not established and time is not available to develop a sediment yield relationship for the project area. The relationship shows that the sediment delivery ratio varies approximately inversely as the 0.2 power of the drainage area. The wide scatter of data used in the development of this relationship indicates that ~~additional~~ additional variables affects the relationship. Estimates of the delivery ratio may be obtained from table 7. The use of these estimates should be tempered with a consideration of other factors that may affect the sediment delivery ratio of a particular site. A higher delivery ratio should be used when the eroding soil is very high in silt or clay and lower if the eroding soil is coarse textured. The conditions of the channels and delivery system should also be evaluated to alter the general relationship of table 7 if ~~desi~~ desirable.

The gross erosion and sediment delivery ratio computation method of sediment estimation is in some respect similar to the use of empirical predictive equations which are based on watershed parameters and normally have only regional applicability. These equations are usually statistical equations developed from measured watershed parameters. The watershed variables often used are amount and intensity of rainfall, amount or peak rate of runoff, temperature, drainage area size, slope or relief parameters, soil dispersion and land use descriptions. Additionally several geological and time

TABLE - 7

Table 2.13 General sediment delivery-ratio estimates*

Drainage area, square kilometres	Sediment delivery-ratio
0.05	0.58
0.1	0.52
0.5	0.39
1	0.35
5	0.25
10	0.22
50	0.153
100	0.127
500	0.079
1000	0.059

* From United States Soil Conservation Service (1971). Reference points taken from logarithmic plot.

parametres are found in some equations. The number of equations available for estimating sediment yield is quite large and we shall report only some example.

The simplest equation relating sediment loss to either rainfall and runoff is the following:

$$Q_s = a\, Q_w^{\,b} \qquad [31]$$

Where:

Q_s is sediment discharge and

Q_w is water discharge

JOVANOVIĆ and VUKČEVIĆ (1958) using data for sexteen gauging station in Yugoslavia established that b = 2.25 whilst according to LEOPOLD et al. (1964) b ranges in value from 2 to 3. The value of a is an index of erosion severity and in the Yugoslav example a > 0.007 indicates excessive soil loss and a < 0.003 indicate a low erosion rate.

~~Probably, the nearest approach to an equation of use~~

~~Fourni~~ FOURNIER (1960) has developed an equation relating mean annual sediment yield to rainfall, altitude and slope:

$$\log Q_s = 2.65 \log \frac{p^2}{P} + 0.46 (\log H)(\tan S) - 1.56 \qquad [32]$$

where:

Q_s = mean annual ~~de~~ sediment yield (gr m²)

p = highest mean monthly precipitation, (mm)

P = mean annual precipitation (mm)

H = mean altitude of the watershed (m)

S = mean slope of the watershed

Another predictive equation was developed by GAVRILOVIĆ (1965) taking in consideration more specifically the ~~a~~ characteristics of land use and management of the several section of a watershed. The equation of ~~gav~~ GAVRILOVIĆ for the watersheds of Slovenia is the following:

$$W = T h \pi \sqrt{Z^3}\; F \qquad [33]$$

where:

W = mean annual sediment yield (m³/yr)

T = temperature coefficient $T = \sqrt{\frac{t^\circ}{10} + 0.1}$ where t° isotherme mean annual on the watershed

h = precipitation mean annual ~~[illegible]~~ in the watershed (mm),

π = 3,14159

F = Watershed area, (km²)

Z = relative erosion coefficient: $Z = XY(\varphi + \sqrt{I})$, where:

X = coefficient of the ~~s~~ soil protection in relation to erosion due to the vegetative cover which range from 0.05 to 1.0 (see table 8); Y = soil erodibility index

~~Y~~ = depending on lithological and soil characteristics of the watershed ranging from 0.2 to 2.0 (see table 9);

φ = Coefficient expressing the type and degree of erosion process (see table 10); I = mean slope degree of the watershed.

32 bis

TABLE - 8

Conditions qui influencent les valeurs du coefficient	Valeur moyen X
I BASSIN-VERSANT OU LA SURFACE TRAITÉE AVANT DE TRAVAUX CONTRE l'ÉROSION:	
Terrain entièrement dénudé, incultivable	1,00
Champs, labourés suivant la pente	0,90
Vergers et vignobles sans végétation au sol	0,70
Alpages, forêts dégradées et broussailles avec le sol érodé	0,60
Prairies, champs de trèfle et d'autres cultures semblables	0,40
Forêts ou broussailles denses et de bonne structure	0,05
II BASSIN-VERSANT OU LA SURFACE TRAITÉE APRÈS LES TRAVAUX CONTRE l'ÉROSION:	
Aménagement des lits, barrages, corrections	0,70
Champs, labourés suivant les isohypses	0,63
Champs bien cultivés, fertilisés par le mulch	0,54
Champs, labourés en bandes horizontales (strip-cropping) et assolés	0,45
Champs en terrasses, banquettes ou gradonis	0,36
Vergers et vignobles suivant les isohypses	0,32
Gazonnement de terres dénudées, améliorations des alpages et des prés	0,30
Canaux de retardation, micro-retenues d'eau	0,27
Réseau des canaux suivant les isohypses, de densité moyenne	0,24
Reboisement, accompagné par gradonis	0,10

SEMPLIFIED CLASSES

Type de la couverture végétale	X
Forêts mixtes et broussailles denses, forêts claires avec sous-bois	0,05 — 0,20
Forêts résineuses avec sous-bois faible, broussailles claires, prés bocagères	0,20 — 0,40
Forêts et broussailles dégradées, pâturages	0,40 — 0,60
Pâturages et terres cultivées dégradés	0,60 — 0,80
Surfaces sans couverture végétale	0,80 — 1,00

32 bis

TABLE - 9

Valeurs du facteur d'erodibilite du sol „Y"

Type de la roche — sous-sol	Y
Roches dures, résistantes à l'érosion	0,2—0,6
Roches mi-résistantes à l'érosion	0,6—1,0
Roches friables, stabilisées (éboulis, schistes, argiles compactes, etc.)	1,0—1,3
Sédiments, moraines, argiles et autres roches peu résistantes	1,3—1,8
Sédiments fins et terres, non résistantes à l'érosion	1,8—2,0

(32 pendrs)

TABLE - 10

Valeurs du facteur „ φ ", exprimant les processus d'erosion visibles

Type et degré d'érosion dans le bassin-versant	φ
Erosion faible dans le bassin	0,1—0,2
Erosion en nappes sur 20—50 % du bassin	0,3—0,5
Erosion en nappes, éboulis et dépôts ravinés, l'érosion karstique	0,6—0,7
50—80 % du bassin érodés par affouillements et éboulements	0,8—0,9
Bassin entièrement érodé par affouillements et eboulements	1,0

The transport capacity of the streams system, especially in the talwegs, is not generally enough to transport the sediments produced on the slopes. A ~~cd~~ certain amount is deposited already in the talwegs upstream to their exit, while the enlargement and long sections of slope accumulation of the streambeds favorise the deposition, too. In relation to the sediment yield on the slopes, the discharge of sediments is usually reduced. In relation to this fact, GAVRILOVIĆ introduce a form of delivery ratio in the following form.

$$G = W \cdot R \qquad [34]$$

where:

$$R = \frac{\sqrt{O \cdot D}}{0.25\ (L + 10{,}0)} \qquad [35]$$

where.

G = discharge of sediment in the reservoir (m^3/hr)
R = reduction factor
O = perimeter of the watershed (Km)
D = Mean altitude of the watershed, defined by the use of the hypsographic curve (Km)
L = ~~Length~~ Length of the watershed along the main talweg (Km)

Probably the nearest approach to an equation with worldwide general applicability on a very large scale is that developed by DOUGLAS (1976) relating mean ~~annual~~ annual suspended sediment yield (m^3/Km^2) to effective precipitation (PE)

$$Q_s = \frac{1.631\,(0.03937\,PE)^{2.3}}{1 + 0.007\,(0.03937\,PE)^{3.3}} \qquad [36]$$

The numerator of this equation represents the direct erosive effect of rainfall whilst the denominator attempts to take account of the protective effect of plant cover.

All the predictive equations discussed here refer to drainage basins and do not provide suitable techniques for assessing soil loss from smaller areas such as ~~hilly sts~~ hillslopes and field as we have seen was the scope of the USLE which remain the only operative available tool for such purpose at the moment.

- References -
(in order of quotation in the script)

ZINGG, A.W (1940) Degree and length of land slope as it affects soil loss in runoff. Agr. Eng., 21, 59-64

MUSGRAVE, G.W. (1947) The quantitative evaluation of factors in water erosion - a first approximation - J. Soil and Water Conserv., 2, 133-138

SMITH, D.D., and WHITT, D.M (1947) Estimating soil losses from field area of claypan soil. Proc. Soil Sci. Soc. Am. 12, 485-490

SMITH, D.D. and WHITT, D.M (1948) Evaluating soil losses from field areas - Agr. Eng. 29, 394-396

WISCHMEIER, W.H. and SMITH, D.D. (1958) Rainfall energy and its relationships to soil loss. Trans. Am. Geoph. Union, 39, 285-291

WISCHMEIER, W.H., SMITH, D.D., and UHLAND, R.E. (1958) Evaluation of factors in the soil-loss equation. Agr. Eng., 39, 458-462

WISCHMEIER, W.H., and SMITH, D.D (1965) Predicting Rainfall - erosion losses from Cropland East of the Rocky Mountains. Agr. Hand. n. 537. USDA, Washington, D.C.

HUDSON, N.W. (1961) An introduction to the mechanics of soil erosion under conditions of subtropical rainfall. Rhodesia Sci. Assoc. Proc., 49, 14-25

HUDSON, N. W. - (1961) Soil Conservation, Cornell Univ Press, Ithaca, N.Y., 32 p

ELWELL, H. A. (1977) Soil loss estimation system for Southern Africa. Dept of Conservation and Extension Res Bull n° 22, Salisbury - Rhodesia

FOSTER, G. R., MEYER, L. D., and ONSTAD, C. A. (1977a) - En erosion equation derived from basic erosion principles Trans Am Soc Agr. Engrs 20, 678-682

FOSTER, G R, MEYER, L D., and ONSTAD, C A. (1977 b) A runoff erosivity factor and variable slope length exponents for soil loss estimates. Trans Am Soc. Agr. Engrs, 20, 683-687

CHISCI, G., SFALANGA, M, TORRI, D, (1983) An approach to soil erosion evaluation on a single rainstorm basis - Int. Conf. on Soil Erosion and Conservation - January 16 22, Honolulu, Hawaii -

CHISCI, G and BOSCHI, V. (1984) Misure e previsione dell'erosione superficiale sui terreni della collina argillosa centro-settentrionale (in preparazione)

CHISCI, G., GIORDANO, A., INDELICATO, S., LIDESTRI NICOSIA, C., SFALANGA, M., TORRI, D. (1982) Acquisizioni per la previsione dell'erosione idrica sui versanti. Convegno Finale del Progetto Finalizzato 'Conservazione del Suolo' del CNR, Roma (in stampa)

WISCHMEIER, W. H. (1959) A rainfall erosion index for a universal soil-loss equation - Proc Soil Sci Soc Am 23 246-249

ROOSE, E (1977) Use of the universal soil loss equation to predict erosion in West Africa in Soil Erosion Prediction and Control, Proceeding of the National Conference on Soil Erosion, Soil Conservation Society of America, Ankeny, Iowa, pp 143-151

ARNOLDUS, H. M. J (1980) An Approximation of the rainfall factor in the universal soil loss equation. in Assessment of Erosion, ed. by M. De Boodt and D. Gabriels, Wiley Intersc Pub

HUDSON, N. W. (1971) Soil Conservation, Batsford, England

LAL, R. (1977) Analysis of factors affecting rainfall erosivity and soil erodibility. in Soil Conservation and management in the humid tropics, ed. by D. J Greenland and R. Lal, Wiley Intersc. Pub

KOWAL, J M and KASSAM, A. H. (1977) Energy load and instantaneous intensity of rainstorms at Samaru, Northern Nigeria in Soil Conservation and management in the humid tropics ed by D J Greenland and R Lal, Wiley Intersc. Pub

WISCHMEIER, W. H., JOHNSON, C. B, and CROSS, B V (1971) A soil erodibility nomograph for farmland and construction sites J. of Soil and Water Cons., 26(5), 189-193

ROTH, C. B, NELSON, D W, and RÖMKENS, M J M (1974) Prediction of subsoil erodibility using chemical, mineralogical and physical parameters. EPA 660/2-74-043 Washington DC US Environmental Protection

Agency, Office of Research and Development

ELLSWORTH [illegible] A, DANGLER E.W. and [illegible]
[illegible]
[illegible]

WISCHMEIER W.H., and SMITH D.D (1978) Predicting rainfall erosion losses. A guide to conservation planning. USDA Agr. Hand. n 537

SMITH D.D., and WISCHMEIER W.H. (1957) Factors affecting sheet and rill erosion. Trans. Am. Geophys. Union. 38. 889-896

ONSTAD, C.A., LARSON, C.L., HERMSMEIER, L.F., and YOUNG, R.A. (1967) A method of computing soil movement throughout a field. Trans. Am. Soc. Agr. Engrs, 10, 742-745

FOSTER, G.R., and WISCHMEIER, W.H. (1974) Evaluating irregular slopes for soil loss prediction. Trans. Am. Soc. Agr. Engrs, 17, 305-309

WISCHMEIER, W.H. (1960) Cropping-management factor evaluations for a universal soil loss equation. Proc. Soil Sci. Soc. Am, 24 322-326

WISCHMEIER, W.H. (1975) Estimating the soil loss equation's cover and management factor for undisturbed areas. in Present and prospective technology for predicting sediment yield and sources. [illegible] USDA, ARS-S-40

[illegible] E.J (1977) [illegible] [illegible] [illegible], WEST [illegible]

[illegible] to predict erosion [illegible] in SCS A, p 52-74

[illegible] T.J (1979) Improved criteria for developing soil loss tolerance levels for cropland. Symp. on Determinants of Soil Loss Tolerance. Soil Sci. Soc. Am. Ann. Mtg., Ft Collins, Co.

GROSSMANN, R.B., and BERDANIER, C.R (1979) Variable rate for cropland: prediction of depth favorable to rooting from the soil survey data base. Symp. on Determinants of Soil Loss Tolerance. Soil Sci. Soc. Am. Ann. Mtg., Ft Collins, Co.

[illegible] E.L (1979) Soil loss Tolerance. Symp. on Determinants of Soil Loss Tolerance. Soil Sci. Soc. Am. Ann. Mtg., Ft Collins, Co.

WILLIAMS, J.R (1975) Sediment yield prediction with universal equation using runoff energy factor. in Present and prospective technology for predicting sediment yield and sources, USDA, ARS-S-40, 244-252

FOSTER, G.R., MEYER, L.D. and ONSTAD C.A (1977) Erosion equation derived from erosion principles -

Trans. Am. Soc. Agr. Engrs. ~~paper~~ unpublished pap. n. 75-2550, St Joseph ~~[illegible]~~ Michigan

ONSTAD, C.A., PIEST, R.F., SAXTON, K.E. (1976) Watershed erosion model validation for southwest Iowa. Proc. of the Third Federal Inter-Agency Sedimentation Conf., PB-245-100, Water Resources Council, Washington, D.C., pp 1-22 - 1-34

FRERE, M.H., ONSTAD, C.A., and HOLTAN, H.N. (1975) ACTMO ~~An~~ An Agricultural Chemical Transport Model, USDA, ARS-H-3

US Department of Agriculture (1971) Sediment Sources, Yields and Delivery Ratios - National Engineering Handbook, section 3, Sedimentation, USDA, ARS

~~STRAHLER~~
STRAHLER, A.N. (1964) Geology, Part II. Quantitative geomorphology of drainage basins and channel networks. in: Handbook of Applied Hydrogeology (V.T. Chow, ed) Mc Graw-Hill, N.Y.

RENFRO, G.W. (1975) Use of erosion equations and sediment delivery ratios for predicting sediment yield. In: Present and Prospective technology for predicting sediment yield and sources, USDA, ARS report ARS-S-40, 33-45

JOVANOVIĆ, S. and VUKČEVIĆ, M. (1958) Suspended sediment regimen on some watercourses in Yugoslavia and analysis of erosion processes. Int. Ass. Scient. Hydrol. pub. 42, 337-359

LEOPOLD, L.B., WOLMAN, M.G., and MILLER, J.P. (1964) Fluvial processes in geomorphology, Freeman, San Francisco

FOURNIER, F. (1960) Climat et érosion: la relation entre l'érosion du sol par l'eau et les précipitations atmosphériques. Presses Universitaires de France, Paris

~~G~~GAVRILOVIĆ S. (1965) Proračun srednje godišnje količine nanosa prema potencijalu erozije Beograd DGA-750
(Calcul de la fraction annuelle moyenne des alluvions d'après la potentialité d'érosion)

GAVRILOVIĆ, S. (1965) Određivanje režima nanosa bujičnog područja i izrada karata erozije, Beograd, DGA-750

DOUGLAS, I. (1976) Erosion rate and climate: geomorphological implications, in Derbyshire, E. (ed.) Geomorphology and Climate, Wiley, London, 269-287