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Modelling of Soil Loss using USLE, RUSLE and other models

1.1 INTRODUCTION:-

One of the principal reasons of low productivity in agriculture is the progressive deterioration of soil due to erosion. Soil erosion is the detachment and transportation of soil material from one place to another through the action of wind, water in motion, or by the beating action of the rain drops.

Soil is the upper most layer of the earth's crust and consists of weathered rocks and disintegrated minerals mixed with organic substances. Its depth is variable, in some places there is no soil, in others, the soil layer is many meters deep. However, it is little exaggeration to say that the top 30 cm of soil supports all human and animal; life. This thin layer is largely responsible for both the physical support and the nutrition for plant growth. The very existence of mankind depends on conserving this vital natural resource.

Land and water are essential for the primary production system as well as for meeting essential needs such as food, fodder, fiber, shelter, communication and other requirements. Serious consideration has to be given to the conservation and proper management of the land and water to support the likely increase in population, and provide better standard of living. In India out of the total geographical area of the 329 million ha about 173.64 million ha (53%) face degradation problems arising from water and wind erosion and through various problems off land degradation like water logging, salinity, alkalinity, ravines and shifting cultivation. The incidence of drought and flood is increasing, which in turn, is seriously affecting the productivity and production in problem areas.

Since independence, India has made considerable advance in terms of increased food production through scientific application of inputs and innovative approach to marketing and better credit flow. However, these inputs and innovation and could become effective only if the land is responsive and the available land is not allowed to get degraded. It is in this context that the soil and water conservation programmes assume great significance.

An equally important hazard is the sedimentation in rivers, streams, lakes, reservoirs, and finally in the sea, which occur when there is erosion in the catchment areas. The sediment load in the rivers, streams as well as the silt deposited in the reservoirs are indicators of soil erosion and land degradation in the catchments.

Soil erosion has been widespread in India. Various estimates shows that in India about 5500 million tonnes of soil is getting lost annually from the original site. It is estimated that the average loss of soil due to erosion amounts to about 16 tonnes of soil per hectare of land per year, which is double of the permissible limits.

Soil loss and soil degradation may be caused by the following principal factors:-

(i) The vicious cycle of deforestation
(ii) Shrinkage of natural pastures and overgrazing
(iii) Soil erosion
(iv) Adoption of improper agricultural practices in unsuitable areas
(v) Problem of waterlogging
(vi) Salt and alkali infestation of soils
(vii) Increasing flood proneness
(viii) Loss of soil productivity due to depletion of organic content and micronutrients
(ix) Excessive use of agricultural chemicals
(x) Continued monoculture farming
(xi) Improper water management

The above factors are interlinked and result from a gross disregard to nature and the capability of the soil and land units.

1.2 HISTORY OF SOIL EROSION:-

All over the world, whenever man has cultivated sloping land, there has been soil erosion to some degree. The history of soil erosion is an integral part of the history of agriculture. Exploitive agriculture, accompanied by the cutting of forests on the catchment of the river began at the dawn of history. Soil erosion has been responsible for the fall of various ancient civilizations. Mesopotamia, a land well developed in the time of Babylonians, Assyrians, Chaldeans and Persians is now virtually a desert. The removal of the forest increased the number and intensity of floods. As the water flow down the barren slopes, it carries with it the soil. Today treeless slopes, with bare rock exposures from one of the most characteristic features of the landscape in many regions. There are hundreds of dead cities in Syria, where 1 to 2m of top soil, has been washed off in many of the hill sides. The cities remain dead because of the soil of the adjacent areas cannot support agriculture to meet the needs of the city. The erosion of the high lands has been accompanied by rapid sedimentations along the lower river courses. With water channels blocked and gradient of drainage ways destroyed by sedimentation, low lands have been increasingly inundated. Formerly arable land has become waterlogged and swamps have developed.

In France, the Revolution of 1789 A.D. resulted in making the royal forests and game reserves free to access by the people. By 1803, it was necessary to limit the use of forests because of floods, as a result of forest denudation. The great flood of 1856 A.D. in the Rohne Valley made it necessary for the French Forestry Laws of 1860 and 1864 to lay down measures to revegetate mountain sides with either forest or grass. The success of these measures, costly through they have been, has led to their being copied by other European countries.

The humid areas of America have been subjected to the ravages of the civilization for fewer centuries than comparable areas in Europe and Asia. But, in some parts erosion has been disproportionately severe.

Old Chinese records tell of land destruction and abandonment in China in the past centuries. Many thousands of hectares of land in Shansi have either been completely eroded or buried and abandoned. Experimental records in Nekkiang, Sczechwan show that the average annual soil loss from land of 15 percent slope under different crops, with an annual rainfall of 970 mm, was about 207 tonnes per hectare. In South China, nearly all of the cleared hillsides have been stripped down to bedrock.

In India, the Mohenjodaro and Harappa civilizations became extinct because of neglect of their lands. Rivers like Saraswati have disappeared, as their watersheds and river basins were exploited. The Siwaliks is a range of hills fringing the Himalayas. Here, owing to the excessive grazing of cattle, the natural vegetation on the slopes has been gradually reduced. This has given rise to serious erosion of soil from hillside and silting of fields and river-beds in the plains below. In 1900 A.D., the Punjab Government attempted to check land denudation by passing the *Chos Act*, which prevented the closure of eroded areas to grazing and allowed grass cutting in its place.

Along most rivers in India, soil erosion has led to the formation of a vast network of fissures and gullies interfering the use of agricultural land. There are ravine lands adjoining most of the Indian rivers, but Chambal is the worst offender in this respect, where several thousand hectares of land have been destroyed. Even in the great alluvial plains in India where the land is comparatively flat, the damage by gullying is considerable.

Methods to control surface runoff and thereby prevent erosion have been practiced in India from time immemorial. Long lines of bunds made of stone or earth are a familiar feature in the rolling terrains below a long range of hills like the Eastern region of Western Ghats. In areas of low rainfall, farmers construct big bunds to form tanks in order to retain silt and water from the upper catchments. Similarly, individual farmers all over the country have constructed small bunds around their fields to retain water. But these measures are not sufficient to check effectively the serious problems of soil erosion.

1.3 HISTORY OF USLE (UNIVERSAL SOIL LOSS EQUATION):-

Conservation of soil and water requires both knowledge of the factors affecting these resources, and methods for controlling those factors to preserve those resources. Over the years, field, plot and small watershed studies have provided much valuable information regarding the complex factors and interactions involved in the environmental operations of land use farming. These studies are the basis of the Universal Soil Loss Equation (USLE), which is a conservation planning tool that has been demonstrated to do a reasonably good job of estimating erosion for many disturbed-land uses. Predicting soil losses associated with modern land use is based on guidelines developed from research information in combination with additional experience from many sources. Information from empirical experiments and physically-based-principles both assist in effective conservation planning.

The process of pulling together research results and experiences from agricultural practices began with Hugh Hammond Bennett (Helms, 2008), who was undoubtedly the most influential soil conservationist in the U.S. His early efforts led to his recognition as the 'father of soil conservation'. Bennett's early preaching against the menace of soil erosion led to Congressional action in 1929 establishing ten experimental stations, primarily in the cultivated agricultural areas of the US [Meyer and Moldenhauer, 1985; Renard 1985]. Later expansion of the research programmes included a large number of plots, crops, and management conditons that ultimately resulted in over 10,000 plot-years of data, collected over seven decades. Most of the plots involved the familiar dimensions 6.0 ft (1.8m) wide by 72.6 ft (22.1m) long, or a plot 35 ft(10.7 m) long used for some rainfall simulator studies. These plots simplified the computing of runoff and erosion on a per unit area basis (0.01 acre for the 6 × 72.6 ft or nominally 40 m^2 for the 1.8 × 22.1 m). Typical plot configurations were described in the Brakenseik et. al. (1979) and Laflen and Moldenhauer (2003).

In 1954, the National Runoff and Soil – Loss Data Center was established by the US Department of Agriculture – Agricultural Research Service (USDA – ARS) at Purdue University in West Lafayette, Indiana. The Center was established to provide a central location for compiling and analysing the soil erosion data collected from studies throughout the US. The Center, under the direction of W.H. Wischmeier, was responsible for summarizing and analysing the more than 10,000 plot-years of soil erosion and runoff data mentioned above, which resulted in the USLE [Wischmeier & Smith, 1965, 1978].

It has now been more than 50 years since the first releases of erosion production technology based on what have become widely known as the factors affecting sheet and rill erosion and, ultimately combining those in the USLE.

The USLE and its predecessors were meant as field-level conservation planning rather than research tools, and therefore were structured to be 'user friendly' for USDA programmes in the Soil Conservation Services (SCS) (now the Natural Resource Conservation Service – NRCS), and designed for tailoring erosion-control practices to the needs of specific fields and farms. The USLE was a 'paper-based' model where factors were found in printed tables and charts, and calculations were done by hand.

'Had digital computers been available in the 1940s when erosion became recognized as a national problem, current prediction methods might more closely mimic the theory contained in the Ellison's classic paper (1947) than the current empiricisms of the USLE. "[Renard, 1985:5]

1.4 BACKGROUND:-

Soil is created by weathering of rock and decomposition of organic materials. Soils are classified according to the amount of silt, sand or clay they contain. If the soil contains all three sediments, it is called loam and is modified by the word for the sediment of the highest concentration (e.g. silty loam: loam with equal amounts of sand and clay but with more silt). Soil forms very slowly and is necessary for sustaining life on earth. It is what our food is grown in! Erosion of this precious resources has been a problem since people first started farming during the Neolithic and continuous to be a problem for farmers today. Poor farming decisions have already caused erosion and desertification of 7.5 million square miles of land. This has directly affected the food supply of 250 million people. Once land cleared of trees and shrubs, it becomes more susceptible to erosion, even if crops are planted in it. The universal soil erosion equation can be used to determine how much erosion by water will occur in specific areas. Using erosion equation from Neolithic and Bronze age farming villages in Jordan, we can understand how scientists make sustainable farming decisions for the future. Beginning 10,000 years ago, during a period called the Neolithic, people started arming in Jordan. Large groups of people lived together in lowland and hillside landscapes that they had cleared of trees and shrubs to create farmland. Around 8,000 years ago the climate and more rain began to fall. People started living in much smaller groups (sometimes only 20 people) and farmed smaller areas because it was more sustainable. So, what happened that caused people to move to smaller villages? Later during the Bronze Age, people adopted more sustainable farming techniques and lived in larger villages.

We are going to use the universal soil erosion equation to see if soil erosion may have been a factor in the decisions made by early farmers about where to live. After we determine erosion rates we are going to use maps to locate the archaeological sites that these numbers correspond to.

1.5 ESTIMATION OF SOIL LOSS DUE TO WATER EROSION – UNIVERSAL SOIL LOSS EQUATION

Soil erosion is a potential threat to soil productivity. Most of the reduced crop yields from eroded soils is due to the decrease in nutrients and the moisture available to plants. On shallow soils and sloping terrain, erosion, may completely destroy productivity. Soil erosion has also important off site-effects. These are sedimentation and pollution. Estimation of soil losses, or relative erosion rates for different soil and crop management systems are valuable in assisting farmers and governmental agencies in evaluating existing farming systems or in planning to decrease soil losses. *Soil loss equation* are used to determine the amount of soil which will erode from a unit area of and in one year under varying conditions of rainfall, land slope and other factors.

1.5.1 UNIVERSAL SOIL LOSS EQUATION:-

The universal soil loss equation (USLE) is a widely used empirical relationship developed from field plot obtained from small plots located in different states of the United States of America during the period 1945 -65. The basic equation is stated as follows (Wischmeier and Smith, 1978)

$$A = RK\,(LS)\,CP \qquad 1.1$$

Where,

A = average annual soil loss, tons/acre or tonnes/ha.

R = rainfall erosivity factor, usually expressed in terms of average erosion index, (EI) units,

K = soil erodibility for a specific soil horizon,

(LS) = topographic factor, a combined factor for length of slope L and steepness of slope S, dimensionless,

C = crop management factor, dimensionless.

P = erosion control factor, dimensionless.

Equation 1.1 provides an estimate of sheet and rill erosion in upland areas. It does not include erosion from stream banks, snowmelt or wind as eroded sediments at foot of the slope or other places where there is a reduction in the velocity of runoff. USLE was originally developed in F.P.S. units and it estimates the soil loss per unit area in a unit time. The commonly used unit of time is a year and the area in acres. As the factors L, S, C, and P are dimensionless, the units of A result from the multiplication of *R* and *K* in solving the USLE. The units may be chosen for *R* and *K* to given unit of *A* in tons per acre or metric tonnes per ha.

The term 'universal' was given to USLE to indicate that in contrast to the earlier equations to predict soil erosion which had application only to specific regions the USLE applied initially in 1965 to the area United States of America east of the Rocky Mountains, and with the revision of the equations in 1978 to all the areas of the USA. The original USLE of 1965 was based on the analysis of 10,000 plot years of source data collected mostly from agricultural plots under natural rainfall conditions. Subsequently, due to their high cost of collecting data from plots under natural rainfall conditions, rainfall simulators were used after 1965. The data used in the Revised USLE of 1978 was based on simulated rainfall data.

1.5.2 RAINFALL EROSIVITY FACTOR, R:-

The rainfall erosivity factor is an index that characterises the effect of raindrop and rate of runoff. It is the sum of the individual rainfall intensity values over a period, usually year or one season within a year. The erosivity of the rainfall can be calculated adopting the EI_{30} Index Method or the K.E. > 25 Method described as follows.

Water erosion is a function of the erosivity of the rain and the erodibility of the soil. Erosivity is defined as the potential ability of rain to induce the erosion process. Erosivity of rainfall is a function of its physical characteristics, namely, the rainfall intensity, raindrop size and drop size distribution, and the kinetic energy required to cause erosion. Thus, erosivity of rainfall is the input force required to detach the soil particles. Soil erodibility is the vulnerability or susceptibility of soil to erosion. Erodibility depends on the physical properties of the soil, the characteristics of the land and the crop improvement practices adopted. Soil erodibility varies with the texture of the soil, stability of the soil aggregates, shear strength, infiltration characteristics and organic matter content of the soil. Soil physical properties are the most important factors influencing the erodibility of soils. Bouyoucos (1935) suggested that the erodibility of a soil depends on the mechanical properties of the soil, expressed by the following ratio:

$$\text{Soil erodibility, } E = \frac{\%sand + \%silt}{\%clay} \tag{1.2}$$

The term *dispersion ratio*, based on the changes in silt and clay contents before and after dispersion in water, is also sometimes used to express the erodibility of a soil. Apart from the physical properties of soil, the other factors influencing soil erodibility, such as land management and crop management are difficult to quantify, as the number of variables involved are many.

The characteristics of raindrops influence the erosivity of a rainfall. Each rain is made up of drop many sizes. Low intensity rains have a high portion of smaller drops and high intensity rains have high proportion of large particles. A freely falling body under the force of gravity will accelerate until the frictional resistance of the air is equal to the gravitational force, and will then continue to fall at that velocity which is termed as the terminal velocity. The terminal velocity of raindrop ranges from 4 to 10 m/sec.

The kinetic energy gained by the rainfall of mass M can be determined from its terminal velocity, v by the relationship $\frac{1}{2} Mv^2$. For example, if the terminal velocity is 8m/sec, the kinetic energy is

$$\tfrac{1}{2} Mv^2 = 32\,M \qquad 1.3$$

The above equation with assumed figures which are only approximate, indicates the large amount of energy involved in splash erosion. The kinetic energy of rainfall can be computed if the size of the raindrops and the terminal velocities are known. As both these variables are functions of the intensity of rainfall, the kinetic energy is also a function of rainfall intensity. Wischmeier and Smith (1978) proposed the following relationship to determine the value of kinetic energy or rainfall:

$$\text{K.E.} = 0.119 - 0.873 \log_{10} I \text{ for } I \leq 76 \qquad 1.4$$

$$\text{K.E.} = 0.283 \qquad \text{for } I > 76 \qquad 1.5$$

In which K.E. = Kinetic energy, megajoules/ha – mm (Mj/ha – mm)

I = rainfall intensity, mm/hr

Equation 1.4 is a least square best fit of available data drop size distribution of raindrops.

Energy is required to break the soil aggregates, splashing them and then carrying them with runoff. The raindrops acquire kinetic energy while falling and on impact with the soil break down the soil aggregates and puddle the soil mass and seal the soil surface. The major impact of the impulses imparted on the soil surfaces by raindrops is the breakdown of the soil aggregates, splashing them and then carrying them with runoff. Subsequent splashing of fine soil particles tend to puddle the soil mass and seals the soil surface, thereby increasing surface runoff

Figure 1.1 illustrates the splash erosion due to the impact of rain on a bare soil surface. The kinetic energy released at the surface of a bare soil during a heavy storm is adequate to splash more than 200 tonnes if soil into the air in a hectare of bare and loose soil. Individual soil particles can be splashed to a height of about 60 cm and thrown a horizontal distance of 1.5 m.

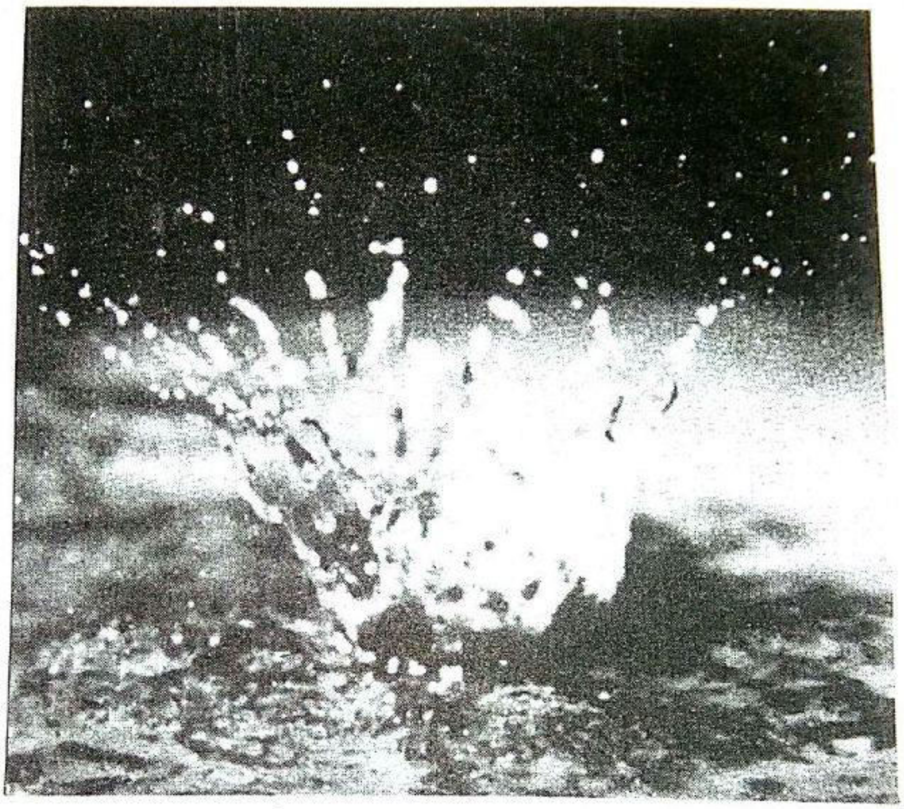


Figure 1.1 Impact of rain drop on bare soil surface. Soil particles are detached and splashed out; on falling back to the saturated soil surface these soil particles are carried away down the slope by fast flowing runoff water.

Surface runoff flowing down the land slope gains kinetic energy, which is used for the scouring action on the land surface. Surface runoff takes place when the rates of rainfall exceeds the infiltration rate of the soil on land slopes. Surface runoff is turbulent, formed by eddies in the flow. These eddies provide the impulses to dislodge and entrain soil particles.

1.5.3 ESTIMATING EROSIVITY FROM RAINFALL DATA:-

Erosivity of rainfall can be estimated using the information on rainfall as recorded in a recording rainguage chart. Using the data obtained from field experimental plots and assuming that rainfall erosivity is related to the kinetic energy of rainfall, the following two indices have been developed to quantify soil erodibility: *(i)* EI_{30} Index, and *(ii)* K.E. > 25 Index (Wischmeier, 1959, 1965 and Wischmeier and Smith 1958, 1978).

(i) **EI_{30} Index Method:** The method is based on the assumption that the product of the kinetic energy of a storm and the 30-minutes maximum rainfall intensity occurring during the storm provide a fair estimate of the soil loss. The greatest average intensity of rainfall recorded in any 30-minute period during the storm is computed from the recording rain gauge charts by locating the maximum amount of rain which occur in 30-minute period and converting the same into intensity in mm/hr. This conversion could be done by simply doubling the rainfall amount of 30 minutes. The kinetic energy can be computed by using the relationship expressed in equation 1.4. The maximum rainfall intensities or different durations are computed and rainfall hyetographs are drawn for the storm, adopting the procedures presented in Table 1.1 and illustrated in the given figure. The total energy of the storm is the sum of the energies of each of the incremental values of the total rainfall. The EI_{30} Index Method has the limitation that it was developed under American conditions and has not been found suitable for use in tropical and sub-tropical conditions.

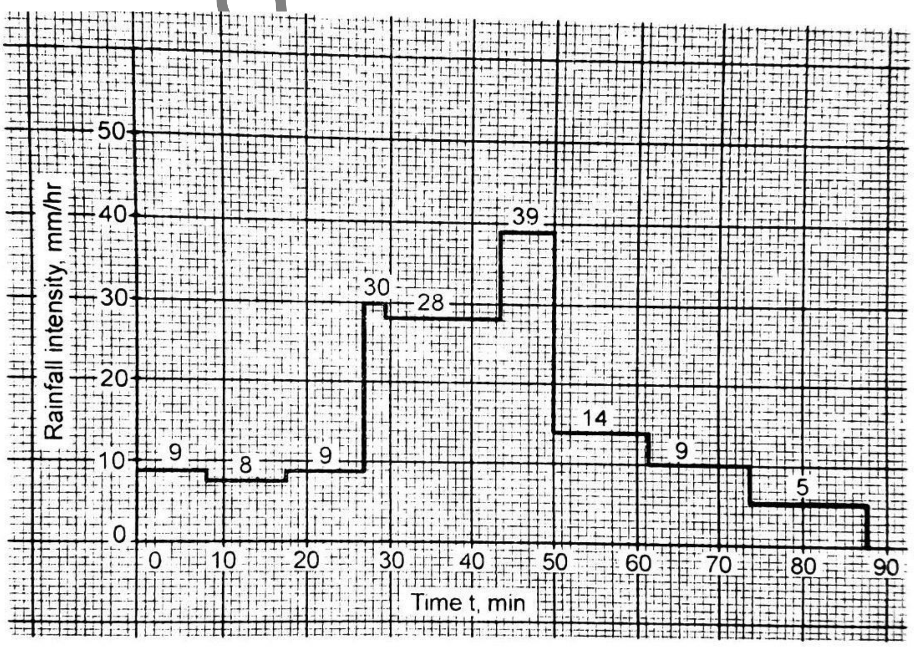


Figure 1.2 Hyetograph constructed from data in Table 1.1

Table:- 1.1

Classification of Gullies

S.No.	*Symbol*	*Description*	*Specifications*
1.	G_1	Very small gullies	Upto 3 m deep, bed width not greater than 18 m, side slope vary
2.	G_2	Small gullies	Up to 3 m deep, bed width greater than 18 m, sides uniformly sloping between 8 to 15 percent.
3.	G_3	Medium gullies	Depth between 3 to 9 m, bed width not less than 18 m. Sides uniformly sloping between 8 to 15 percent.
4.	G_4	Deep and narrow	(a) 3 to 9 m deep, bed width less than 18 m, side slope varies. (b) Depth greater than 9 m, bed width varies, side slopes vary, mostly steep or even vertical with intricate and active gullies.

(ii) **K.E. > 25 Index Method:** The K.E.>25 Index Method was developed for computing the rainfall erosivity of tropical storms. The method is based on the concept that erosion takes place only at a threshold value of 25 mm/hr. Thus the method takes place into account only the rainfall intensities which are greater than 25 mm/hr. The estimation procedure is the same as in EI_{30} Index Method, except that the values of rainfall less than 25 mm are not taken into account.

The value of **Rainfall erosivity factor R** is computed as follows:

$$R = \sum_1^n(\mathrm{EI}) \qquad 1.6$$

Where, n = the number of storms in the series.

1.5.4 SOIL ERODIBILITY FACTOR, K:-

The soil erodibility factor indicates the susceptibility of the soil to erosion. It is expressed as the soil loss per unit of area per unit of *R* or *EI* for a specified soil, as measured in a unit plot. The unit plot is 72.6 ft (22.1 m) long with a uniform 9 % slope maintained in continuous fallow, with tillage when necessary to control weeds and break surface crusts.

(Continuous fallow was selected as a base to develop USLE as no single cropping system is common to all agriculture areas, and soil loss from any crop and management effect which vary from place to place). Edwards (1961) suggested that the following principles of soil loss are to be taken into account in estimating the value of *K* factor : *(i)* Soil erodibility decreases with the increase in grade and size of soil structure, *(ii)* Erodibility decreases with the coarseness of soil texture, *(iii)* Erodibility decrease with the increase in organic matter content, and *(iv)* Erodibility decreases with the increase in the ability of the underlying soil horizons to transmit water.

When the values of *K* are determined from measured field data, the units of *K* depend on the units chosen for soil loss and rainfall erosivity. The soil loss measured from plots, which do not confirm to the specifications of 9% slope and 22, 1 m width are to adjusted to estimate the soil loss of the standard unit plot. Olson (1961) proposed the following equation to calculate *K* values under such situations:

$$A = A_0/LSCP \qquad 1.7$$

Where,

A = Soil loss expected,

$A = A_0/S$

The estimated value of *K* will be

$$K = \frac{Total\ adjusted\ loss, A}{Total\ EI} \qquad 1.8$$

$$A = K\ (EI) \qquad 1.9$$

Thus, if in equation 1.9 the value of *A* has the units of tonnes/ha and EI has the units of tonnes – ha/ha – Mg. mm, the term ha appearing in the numerator and denominator will get cancelled. However, they are retained to emphasize that *K* is soil loss measured in mass per unit area per unit of *EI*. (Runoff plots were earlier made of 1/100 acre area, measuring 72.6 ft (22.1 m) in length and 6 ft (1.8 m) in width.

1.5.5 APPLICATION OF USLE:-

The USLE value of *R* is broadly

(i) To predict the annual soil loss from a field with specific land use practice,

(ii) To guide in the selection of appropriate crops and crop management and measurable farming practices,

(iii) To predict the change in soil which would result from a change in cropping or conservation farming practices, and

(iv) To provide soil loss estimate to plan the conservation needs of a specific area.

Soil erodibility factor *K* can be obtained from the nemographic solution given by *Foster et al* (1981) and also from the following regression equation:

$$K = 2.8 \times 10^{-7} M^{1.14} (12 - a) + 4.3 \times 10^{-3} (b - 2) + 3.3 \times 10^{-3} (c - 3) \qquad 1.10$$

Where,

M = particle size parameter (% silt + % fine sand) × (100 × % clay)

a = percent organic matter

b = soil structure code (very fine granular, 1; fine granular, 2; medium or coarse granular, 3; blocky, platy or massive)

c = profile permeability class (rapid, 1; moderate to rapid, 2; moderate, 3; slow to moderate, 4; slow, 5; very slow)

1.5.6 TOPOGRAPHIC FACTOR (LS):-

The topographic factor *LS* represents the influences of slope length *L* and slope steepness *S*, respectively in USLE. The length of slope refers to the distance from the point of origin of overland flow to the point where the runoff reaches a point where deposition of sediment begins or the runoff reaches a defined channel. Wischmeier and Smith (1965) defined the slope length factor as follows:

$$L = \left(\frac{X}{22.1}\right)^m$$

1.11

Where L = slope length factor

X = slope length, metres, and

m = an exponent

Wischmeier and Smith (1978) recommended the following values for *m*:

m = 0.5, if the slope is > = 5 %

m = 0.4, if the slope is > = 5% and > 3%

m = 0.3, if the slope is < = % and > 1%

m = 0.2, if the slope is < 1%

Equation 1.11 is used to calculate the values of slope length factor under conditions of uniform slope.

1.5.7 SLOPE STEEPNESS FACTOR, S:-

The slope steepness factor *S* has profound influence on soil loss. The velocity of runoff increases with the increase in the slope of the field, which allows more soil to detach and transport them along with the runoff. Surface detention of water is also reduced as the degree of the slope increases. Wischmeier and Smith (1978) proposed the following relationship to compute the value of *S* factor in the revised USLE

$$S = 65.41 \sin^2\theta + 4.58 \sin\theta + 0.065 \qquad 1.12$$

Where, S = percent land slope

θ = angle of the slope, given by the $\tan^{-1}$ (s/100), in which s is the field slope %.

The combined topographic factor (*LS)* can be expressed as follows:-

$$(LS) = (X/22.1)^m \; 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065 \qquad 1.13$$

1.5.8 CROP MANAGEMENT FACTOR, C:-

The crop management factor *C* expresses the effect of crop density, kind of crop cover, root growth, crop transpiration, crop sequence, productivity level and length of the growing season, tillage practices, residue management and the time of occurrence of erosive storm with reference to the stage of growth of crops. These conditions vary significantly during the crop growth period. Wischmeier and Smith(1978) identified the following five distinct growth stages of crop production with particular influence on the value of value of the factor *C* in USLE:

1. Period F : Rough fallow – Summer ploughing or seedbed preparation to sowing.
2. Period 1. Seedbed – Seeding to one month thereafter.
3. Period 2. Establishment - From one to two months after seeding.
4. Period 3. Growing period – From period 2 to harvest.
5. Period 4. Residue or stubble – From crop harvest to ploughing or new seedbed preparation works.

Within each crop stage period, there are a number of variable which influence soil loss. Adopting the above concept, *Tejwani et al (1975)* studied the derivation of the cropping management factor for maize – wheat rotation. The results for the maize crop under Dehradun conditions are presented in Table 1.2. The data for the wheat crop are not included in the table, as there was no rain or erosion during the growth of crop.

Table – 1.2

Period	***Month and date***	***EI, %***	***Soil loss ratio %***	***C – Value (EI, % x Soil loss ratio, %)***
F	May 15 – June 15	4	80	0.0320
1.	June 16 –July 15	0	85	0.0320
2.	July 16 – Aug 20	45	70	0.3150
3.	Aug 21 – Oct 1	11	35	0.0385
4.	Oct 1 – Oct 15	-	-	-
Total				0.7255

Source: *Tejwani t al (1975).*

The quantification of the factor *C* is most complex as there are numerous ways of growing crops. Several researchers based on their field investigations under specific situations, have proposed values of *C* to be used in the USLE under different agroclimatic and geographic conditions (Nema et al, 1978; Pratap Narain et al, 1980; Rao et al, 1981; Singh et al, 1990). Due to the variability in the value of C influenced by the numerous factors of the crop and their growth stages at different periods in a season or year, it is advisable to determine the *C* values for the crops and their combinations and growth stages by installing runoff plots and measure the soil losses in order to develop recommendations for the use in the USLE to a particular area.

1.5.9 EROSION CONTROL FACTOR:-

Erosion control factor *P* is defined as the ratio of the soil loss for a given soil conservation farming practice to the soil loss obtained from up-and-down slope cultivation. Conservation farming practices include contour farming, strip cropping, contour furrows, terracing, and contour trenching. Up-and-down the slope cultivation is the most hazardous and erosion inducing farming practice.

Tejwani et al (1975) reported the value of 1 for the up-and-down the slope cultivation practice. Contour farming resulted in the reduction of the P factor to 0.68. Corresponding values for strip cropping with maize and cowpea gave a *P* value of 0.51. A combination of channel terraces with contour farming reduced the value *P* to 0.38. Wischmeier and Smith (1978) observed that the value of *P* varied with the range in the slope of the field

Table:- 1.3

The values of the conservation practices *P* as influenced by the ranges in the degree of slope of the field

Value of P		
Slope %	***Contouring***	***Contouring and strip cropping***
1.1 – 2.0	0.60	0.30
2.1 – 7.0	0.50	0.25
7.1 – 12.0	0.60	0.30
12.1 – 18.0	0.80	0.40
18.1 – 24.0	0.90	0.52

Source: *Wischmeier and Smith (1978)*

By evaluating the different factors of USLE, the soil loss from a field under a given set of conditions can be estimated. Specifically USLE is used for the following purposes

(i) To predict the average annual average soil loss from a field having a particular land use pattern.

(ii) To guide in the selection of crops and their management in the selection of crops and their management along with appropriate conservation practices for specific land and soils and land slope situations.

(iii) To predict the change in soil loss which would result from a change of the crop or conservation practice in a particular field.

(iv) To estimate the soil loss from areas other than agricultural lands

(v) To provide the soil loss estimates under various land use and management systems to planning agencies.

Subsequent to the release of the USLE in 1965, efforts have been underway to revise the USLE to improve the equation with a view to adapt it to interrill and rill erosion as well as sediment transport and deposition associated with concentrated flow.

If it is observed that the soil loss is higher than that permissible for maintaining productivity. Suitable changes are to be made in the crop management and conservation farming practices to reduce the soil loss to the permissible level.

1.5.10 ESTIMATION OF SEDIMENT YIELD OF WATERSHEDS, USING USLE:-

USLE could be used as a first approximation for estimating the sediment yield of watersheds, adopting the following relationship:

$$Y = E\,(DR) \qquad 1.14$$

Where, Y = Sediment yield

E = Gross soil erosion, and

(DR) = Sediment delivery ratio.

In applying Equation, the heterogeneous watersheds area is divided into sub-areas based on soil type, slope length, gradient, foliage cover, and erosion control practices. The USLE is then used for each sub-area. These values are multiplied with (DR) values obtained on the basis of previous studies for the region to obtain the approximate sediment yield, applying equation 1.14.

1.5.11 EXAMPLES BASED ON USLE AND MSLE:-

Example 1.1:- The following data were collected from an area subjected to soil erosion:

Rainfall erosivity index	-	*1400 MJ – m/ha – h – y*
Soil erodibility index	-	*0.25 t – ha – h/Mj. Mm*
Crop management factor	-	*0.65*
Conservation practice factor	-	*0.60*
Slope length factor	-	*0.10*

Estimate the annual soil loss.

Solution:- Applying equation of universal soil loss equation, the annual soil loss is computed as follows:

$$S = 1499 \times 0.65 \times 0.10$$

$$= 22.5 \text{ tonnes /ha/ year}$$

As the value of soil erosivity factor *(R)* is high, it may be necessary to change the cropping intensity in the area to obtain a higher density of foliage cover during the period of intensive rains, to obtain a lower value of *R*.

Example 1.2:- In a watershed of 8000 ha area of the following data were obtained from previous studies.

R = 350, K = 0.17, LS = 10, and VM = 0.15 based on 25% ground cover of grass. With 20% canopy of tail weeds. Estimate the rate of erosion from the watershed.

Solution:- Applying the Equation of Modified Soil Loss Equation:-

$$A = RK\,(LS)\,(VM)$$

$$= (350)\,(0.17)\,(10)\,(0.15)$$

$$= 89.25 \text{ tonnes/ha/year}$$

The estimated gross erosion from the watershed = 89.25 × 8000

= 714,000 tonnes/year

1.6 MODIFIED SOIL LOSS EQUATION (MSLE):-

Modified soil loss equation has been developed specifically for estimating the soil loss from large areas of open grazing lands (rangelands) and forest lands. In this approach, the Crop Management Factor, C and the Erosion Control Practice Factor, *P* used in the USLE is replaced by a vegetation Management Factor (*VM)* as follows:

$$A = RK\,(LS)\,(VM) \qquad 1.15$$

In which (*VM)* = Vegetation Management Factor, which is the ratio of soil loss from a land area managed under specific conditions of vegetative cover to that from fallow condition on which the factor is evaluated.

The other factors are the same as defined in the equation 1.15.

The *(VM)* factors account for vegetative cover and soil surface conditions. In the application of Equation 1.15, three different kinds of effects are considered as sub-factors:

(i) Canopy cover effects
(ii) Influence of the lower growing vegetative covers, mulch and litter, and
(iii) Bare ground with fine roots.

Wischmeier (1975) developed graphical relationships for each of the sub-factors (Fig 1.6.1). The three sub-factors are multiplied together to obtain the (*VM)* value.

Substantial work has been done in the determination of *C* values of USLE, as compared to the *(VM)* values for MSLE. Hence, published values of *C* can be used in place of *(VM)*, if they take into account for three effects presented in figure 1.2.

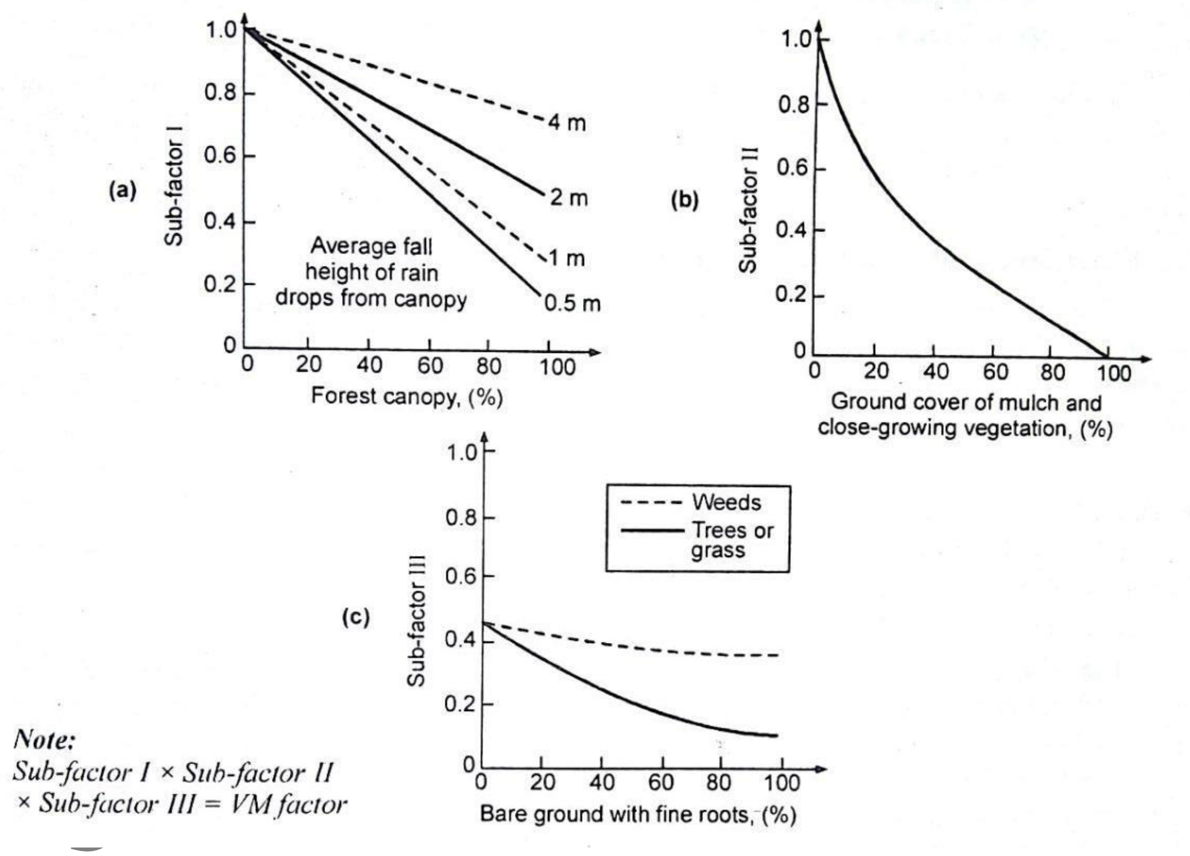


Figure 1.2 Relationships of forest canopy cover (a) ground cover, (b) and fine roots in the top soil, (c) used to determine *VM* factor. *(Adapted from Wischmeier, 1975)*

The relationship presented in Equation 1.15 (MSLE) can be used a guide for estimating the potential resulting from different land use and land management plans, only if the basic interactions on which the equation is based is clearly understood. If the underlying assumptions do not represent the actual processes in the forest environment, the actual values of soil erosion will be far different from the estimated value of erosion.

1.7 REVISED UNIVERSAL SOIL LOSS EQUATION (RUSLE):-

The original USLE released in 1965 (equation 1.15) was in widespread use in USA and selected other conditions. Subsequently, its use revealed significant weakness in terms of the conditions for which it was applicable and the results obtained. McCool and Rendard (1990) presented a revised soil loss equation, maintaining the basic structure of the USLE. *Morgan et al* (1990) have presented by the structure of soil erosion prediction model for the European community. For the application of USLE in developing countries substantial field data are to be generated and analysed to develop procedures to arrive at reasonable values of the various factors in the USLE to adopt to specific geographic locations.

In 1980s, the Agriculture Research Service of the USDA and its collaborators, initiated the development of improvements in USLE and proposed the Revised Universal Soil Loss Equation (RUSLE) to address the weakness in the original USLE. (Yoder and Lown, 1995). The RUSLE is largely based on USLE, but expanded data base and necessary corrections improved the accuracy and predicted litter biomass, plant height and canopy cover and ground cover. RUSLE is specifically applicable to predict soil erosion from watersheds comprising agricultural lands, grazing lands and forest areas. The RUSLE is a computer based, replacing the tables the graphs used in the USLE with keyboard entry. In general terms, RUSLE is a software version of a greatly improved USLE. *Renard et al* (1994) has provided detailed discussion on the improvements of the RUSLE over USLE. The following are the specific improvements in RUSLE in comparison to USLE:

(i) Use of more data from different locations, different crops and cropping systems, including forest and grazing lands have been incorporated into the RUSLE,
(ii) Corrections of errors and filling of gaps in data,
(iii) Provision of increased flexibility of RUSLE allows erosion prediction from a variety of ecosystems and crop and land management alternatives.

In April 2002, the *Agricultural Crop Rotation Act (ACRA)* was adopted to protect water and soil quality on Prince Edward Island. The basic concept of the act are that regulated crops cannot be grown in a field more frequently than once in three years or grown on land with a slope of 9% or greater unless the crop is under a management plan approved by the Prince

Edward Island Department of Agriculture and Forestry. Regulated crops may be grown on high sloped island (9 % or greater) if soil erosion is limited to a recognized tolerance of 3 tons/acre/year.

The potential for erosion can be calculated using the Revised Universal Soil Loss Equation (RUSLE). The equation is written as

$$\boldsymbol{A = R\ K\ L\ S\ C\ P}$$

Where ***A*** = predicted soil loss

R **=** rainfall and runoff

K **=** soil erodibility

LS = slope length and steepness

C = crop management

P **=** support practices (farming direction, strip cropping etc.)

Soil erosion is considered by many to be a serious environmental problem in Prince Edward Island. It depletes soil quality, decreases productivity and can affect surface water quality. 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 recognized tolerance level for Prince Edward Island soils is 3 tons/acre/year or less. If RUSLE indicates potential soil loss greater than this level, a field must have alternate management practices applied to it to sustain long term productivity. One cubic yard of soil weighs approximately one ton. The purpose of this document is to explain how to calculate soil loss using the RUSLE and to explain the factors that contribute to soil loss.

The RUSLE Factors

$$A = R \times K \times LS \times C \times P\ A$$

The potential long term average annual soil loss in tons per acre per year. This is the amount, which is compared to the "tolerable soil loss" limits. R- the rainfall and runoff factor. The greater the intensity and duration of the rain fall, the higher the erosion potential. The R factors for Prince Edward Island were calculated from the sum of the rainfall, the snow m elt and the winter runoff. K - the soil erodibility factor. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Texture is the principal factor affecting K, but structure, organic matter and permeability also contribute. LS - the slope length and steepness factor. The LS factor represents a ratio of soil loss under given conditions. The steeper and longer the slope, the higher the risk for erosion. This is a very important factor in the overall erosion rate. C - the crop 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 (Table 4) 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, which has a value of 1. The crop grown, type and timing of tillage, the use of winter cover and the application of solid manure will all impact on the C factor. P - the support practices factor. The P factor (Table 5) compares the soil losses from up and down slope farming to losses that result from practices such as cross slope cultivation, contour farming and strip cropping. Steps to Calculate the RUSLE:

1. Select the field on which the RUSLE is to be calculated.

2. Obtain a map showing field slopes and contours from the district agricultural office.

3. Select the R factor from Table by choosing the location closest to the field.

Location	R factor
Tignish	80
Summerside	84
Charlottetown	89
Montague	94
Souris	94

Table 1.4 Determining the Rainfall and Runoff factor (F)

4. Based on soil type, determine the K value from Table 2. If there is more than one soil type in the field, choose the type that represents the majority of the field. If no soil test analysis is available, select either 2.5% or 3.0% organic matter.

	% Organic Matter				
Soil Classification	2 .0	2.5	3.0	3.5	4.0
Charlottetown	0.34	0.32	0.30	0.27	0.25
Alberry	0.34	0.32	0.30	0.27	0.25
Culloden	0.33	0.32	0.31	0.28	0.26
Tignish	0.40	0.37	0.34	0.32	0.29
O'Leary	0.40	0.37	0.34	0.32	0.29

Table 1.4 Determining the Soil erodibility factor (K)

5. Determine the slope length and grade for the longest slope and the steepest slope on the property. Compute the LS factor using the formula below.

Equation for Calculating Slope Length-Gradient Factor (LS). A calculator with an exponent feature is required to complete the calculation.

$$LS = [0.065 + 0.0456\ (slope) + 0.006541\ (slope)]^2\ [slope\ length]^{NN}$$

Where: slope = slope steepness (%)

slope length = length of slope (ft.)

For the value of NN the following table is generally used.

Slope steepness	less than 1%	equal to or greater than 1% but less than 3%	equal to or greater than 3% but less than 5%	5% or greater
NN	.2	.3	.4	.5

Table 1.5 Determining the value of NN for the value of LS

6. Using Table 1.6, determine the C factor by adding together the C factors for each year of the rotation and then dividing the total by the number of years in the rotation.

Table 1.6 Determining the Crop Management Factor (C)

POTATOES	**C Factor**
Potatoes following small grains with spring plowing	0.31
Potatoes following small grains with fall plowing	0.35
Potatoes following small grains with 10% residue on surface after planting	0.28
Potatoes following small grains with 30% residue on surface after planting	0.20
Potatoes with a winter cover following small grains with spring plowing	0.29
Potatoes with a winter cover following small grains with fall plowing	0.30
Potatoes with a winter cover following small grains with 30% residue on surface after	0.16
Potatoes following row crops with spring plowing	0.41
Potatoes following row crops with fall plowing	0.48
Potatoes following row crops with 10% residue on surface after planting	0.36
Potatoes following row crops with 30% residue on surface after planting	0.30
Potatoes with a winter cover following row crops with spring plowing	0.39
Potatoes following hay with spring plowing or conservation tillage with 30% residue on	0.16
Potatoes following hay with fall plowing	0.26
Potatoes with a winter cover following hay with spring plowing or or conservation tillage	0.13
Potatoes with a winter cover following hay with fall plowing	0.20
Potatoes following ryegrass with spring plowing and winter cover	0.16
Potatoes following ryegrass with spring plowing	0.19
Potatoes following ryegrass with fall plowing and no winter cover	0.26
Potatoes with spring plowing and a winter cover following grain underseeded with	0.16
SMALL GRAIN (cereals & soybeans)	
Small grain following a high residue crop (grain corn, cereal crop) with the straw removed	0.13
Small grain following a high residue crop (grain corn, cereal crop)	0.09
Small grain under seeded following a high residue crop (grain corn, cereal crop)	0.04
Small grain following a low residue crop (corn silage, potatoes) with the straw removed	0.18
Small grain following a low residue crop (corn silage, potatoes)	0.15
Small grain under seeded following a low residue crop (corn silage, potatoes)	0.10

SILAGE CORN	
Silage corn following small grains with spring plowing	0.30
Silage corn following small grains with fall plowing	0.33
Silage corn following small grains with 10% residue on surface after planting	0.23
Silage corn following small grains with 30% residue on surface after planting	0.12
Silage corn following row crops with spring plowing	0.30
Silage corn following row crops with fall plowing	0.34
Silage corn following row crops with 10% residue on surface after planting	0.21
Silage corn following row crops with 30% residue on surface after planting	0.17
Silage corn following row crops with manure* applied	0.24
Silage corn following hay with spring plowing	0.18
Silage corn following hay with fall plowing	0.20
Silage corn with winter cover following small grains and spring plowing	0.26
Silage corn with winter cover following row crops with spring plowing	0.24
Silage corn with winter cover following row crops with 10% residue on surface after	0.17
Silage corn with winter cover following row crops with manure* applied	0.16
Silage corn with winter cover following hay and spring plowed	0.14
Silage corn intercropped with ryegrass following corn silage or potatoes	0.19
Silage corn intercropped with ryegrass following corn silage intercropped with ryegrass	0.12
Silage corn intercropped with ryegrass following small grain	0.17
Silage corn intercropped with ryegrass following silage corn intercropped with ryegrass	0.09
Silage corn no-till planted into winter cover	0.11
Silage corn no-till planted into a well established sod	0.05
Silage corn no-till planted second year after sod	0.15
Silage corn no-till planted third year or more after sod	0.18
GRAIN CORN	
Grain corn following small grains with spring plowing	0.21
Grain corn following small grains with fall plowing	0.28
Grain corn following small grains with 10% residue on surface after planting	0.15

Grain corn following small grains with 30% residue on surface after planting	0.08
Grain corn following row crops with spring plowing	0.18
Grain corn following row crops with fall plowing	0.24
Grain corn following row crops with 10% residue on surface after planting	0.10
Grain corn following row crops with 30% residue on surface after planting	0.07
Grain corn following row crops with manure* applied	0.13
Grain corn following hay with spring plowing	0.11
Grain corn following hay with spring plowing	0.18
VEGETABLES	
Mixed vegetables after mixed vegetables	0.50
Mixed vegetables with winter cover	0.42
Cole crop following a row crop	0.29
Cole crop with winter cover following a row crop	0.25
Cole crop with spring plowing or residue management after hay	0.16
Cole crop with spring plowing or residue management and winter crop after hay	0.13
Cole crop after hay with fall plowing	0.24
Cole crop with winter crop after hay with fall plowing	0.18
Rutabagas following potatoes	0.30
Rutabagas with winter cover following potatoes	0.26
Vine crop following hay with fall plowing	0.20
Vine crop with spring plowing or winter cover following hay	0.16
Vine crop following vine crop with winter cover	0.24
Vine crop with 10% residue following mulched vine crop	0.17
Sequential planting of lettuce with spring plowing following a ryegrass cover crop	0.16
Carrots after hay with fall plowing	0.30
Carrots with a winter cover following hay with fall plowing	0.24
Carrots following grain with fall plowing	0.50
Carrots, spring plowed following grain	0.46
Onions with spring plowing and winter cover, following under seeded grain	0.40
Onions with 30% residue and winter cover, following under seeded grain	0.26

HAY - ESTABLISHMENT YEAR	
Direct seeding in spring following high residue crop	0.14
Direct seeding in summer following high residue crop	0.14
Direct seeding in spring following low residue crop	0.15
Direct seeding in summer following low residue crop	0.15
Direct seeding ryegrass with fertility management	0.10
HAY - SEASON AFTER ESTABLISHMENT	
Legume hay (not plowed or killed)	0.01
Hay land killed with glyphosate no fall tillage	0.02
Fall plowed hay land	0.03
ESTABLISHED GRASSLAND	
Grass	0.005
Legume	0.005
Permanent Pasture	0.005
FALLOW LAND	1.00

*manure assumes 2-3 tons of dry matter/acre applied in spring

7. Select the P factor from Table 1.7 based on the support practice used.

Table 1.7 Determining the Support Practice Factor (P)

Support Practice	P Factor
Up & Down Slope	1.00
Cross Slope	0.75
Strip cropping, 2 year rotation	0.50
Strip cropping, 3 year rotation	0.30

8. Multiply the five factors together to determine the soil loss.

1.7.1 MANAGEMENT STRATEGIES THAT CAN BE USED TO REDUCE SOIL LOSS:-

It may be necessary to modify management practices in a field if the RUSLE indicates that the soil loss is greater than the tolerable level of 3 ton/acre/year. For example:

(i) Increasing the organic matter level will decrease the K factor.

(ii) Constructing terraces or farmable berms to reduce slope length will decrease the LS factor.

(iii) Selecting crop types, tillage practices, winter cover crops and the application of solid manure can decrease the C factor.

(iv) Selecting a support practice with a lower P factor.

1.7.2 DETERMINING ACCEPTABLE EROSION RATES:-

If regulated crops are grown on land with less than 9 per cent slope, but more frequently than once in three years, there are two options:

(i) To develop a rotation with a C factor of 013 or less

(ii) To match the management to the topography to achieve an acceptable erosion rate of 3 tons/acre/year or less, using the factors in the RUSLE equation.

If regulated crops are to be grown on land with 9 per cent or greater slope, the RUSLE must be used to determine if the erosion rate is acceptable.

1.7.3 CALCULATING RUSLE USING A FARMING EXAMPLE:-

A field in western PEI has traditionally been farmed with two regulated crops in a five year rotation — potatoes/grain/potatoes/grain/hay. No winter cover was established after the first crop of potatoes was harvested. Fall mould-board ploughing occurred before the potato crops and grain crops. The grain crops were under-seeded. The field has a slope length of 1000 feet and a 3% grade. The field is cropped up and down the slope. The soil type is O'Leary and has 2.5 % organic matter.

Although the slope is less than 9%, a management plan will be required for this field since the rotation has regulated crops grown more frequently than once in three years. When developing a plan for the field there are two options:

1. Determine if the rotation has a C factor of 0.13 or less.

C factor for 1st potato crop	0.26
C factor for 1st grain crop (under seeded)	0.10
C factor for 2nd potato crop	0.35
C factor for 2nd grain crop (under seeded)	0.10
C factor for hay	0.03
Total	0.84

Table 1.7 Calculating the C factor

C factor for this five year rotation is 0.168 (0.84/5). Since the C Factor is greater than .13 the rotation is not acceptable.

2. Using RUSLE

R - Rainfall and Runoff Factor

Using above Table, select the location closest to the field. This field is closest to Tignish, therefore, the R factor is 80.

K - Soil Erodibility Factor

Using Table, select the soil type and organic matter level. The soil type is O'Leary and the organic matter level is 2.5%; therefore, the K factor is 0.37.

LS - Slope Length-Steepness Factor

This field is 1000 feet long. Above table indicates that a 3% slope has a NN value of 0.4. Solving the equation below results in a LS factor of .74.

$$LS = [0.065 + 0.0456\ (3) + 0.006541\ (3)^2]\ [1000/72.5]^4$$

C - Crop Management Factor (from above tables)

C factor for 1st potato crop	0.26
C factor for 1st grain crop (under seeded)	0.10
C factor for 2nd potato crop	0.35
C factor for 2nd grain crop (under seeded)	0.10
C factor for hay	0.03
Total	0.84

The C factor is (0.84/5) = .168.

P - Support Practice Factor:-

The P factor in Table described above for up and down slope is 1.0.

Use the numerical values for each of the factors to solve the RUSLE equation:

$$A = R \times K \times LS \times C \times P$$

$$= 80 \text{ X } .37 \text{ X } .74 \text{ X } .168 \text{ X } 1.0$$

$$= 3.68 \text{ tons/acre/year.}$$

The soil loss of 3.68 tons/acre/year exceeds the acceptable level of 3 tons/acre/year. This rotation is not acceptable. Management practices must be adjusted to meet the Agricultural Crop Rotation Act requirements.

1.7.4 EXAMPLES OF MANAGEMENT PRACTICES THAT COULD DECREASE SOIL LOSS:-

1. Constructing a farmable berm at mid-slope will change the slope length from 1000 to 500 feet and result in the factor being decreased to 0.56.

$$LS = [0.065 + 0.0456\ (3) + 0.006541\ (3)^2]\ [500 / 72.5]^{0.4}$$

$$A = R \times K \times LS \times C \times P$$

$$= 80 \times .37 \times .56 \times .168 \times 1.0$$

$$= 2.78 \text{ tons/acre/year.}$$

As a result of this change the soil loss is decreased from 3.68 tons/acre/year to 2.78 tons/acre/year. This is within the acceptable limit of 3.0 tons.

2. Another option is to reduce the C factor by changing agronomic practices; for example, using conservation tillage after the first grain crop and establishing winter cover after the second potato crop.

C factor for 1st potato crop	0.26
C factor for 1st grain crop (under seeded)	0.10
C factor for 2nd potato crop with winter cover & 30% residue	0.16
C factor for 2nd grain crop (under seeded)	0.10
C factor for hay	0.03
Total	0.65

The C factor is 0.13 (0.65/5) and meets the requirements of the Agricultural Crop Rotation Act.

1.8 SOIL LOSS EQUATION MODEL FOR SOUTH AFRICA (SLEMSA):-

SLEMSA was developed by Elwell (1978) for the southern region of Africa and is a modification over USLE. This model has been designed to predict mean annual soil loss, raising from sheet erosion on area of arable land. Framework of SLEMSA is presented in Figure 1.3. **Bhargav (1999)** has modified the SLEMSA model for indian conditions for conservation practices in use by incorporating conservation practice factor (P). The modified model is:-

$$Z = K . C . X . P. \quad 1.16$$

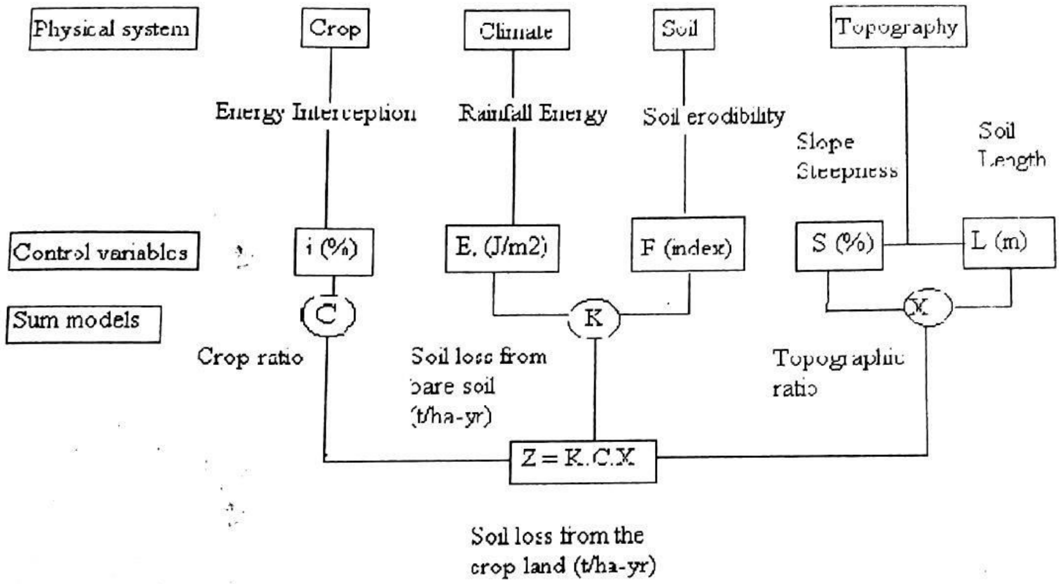
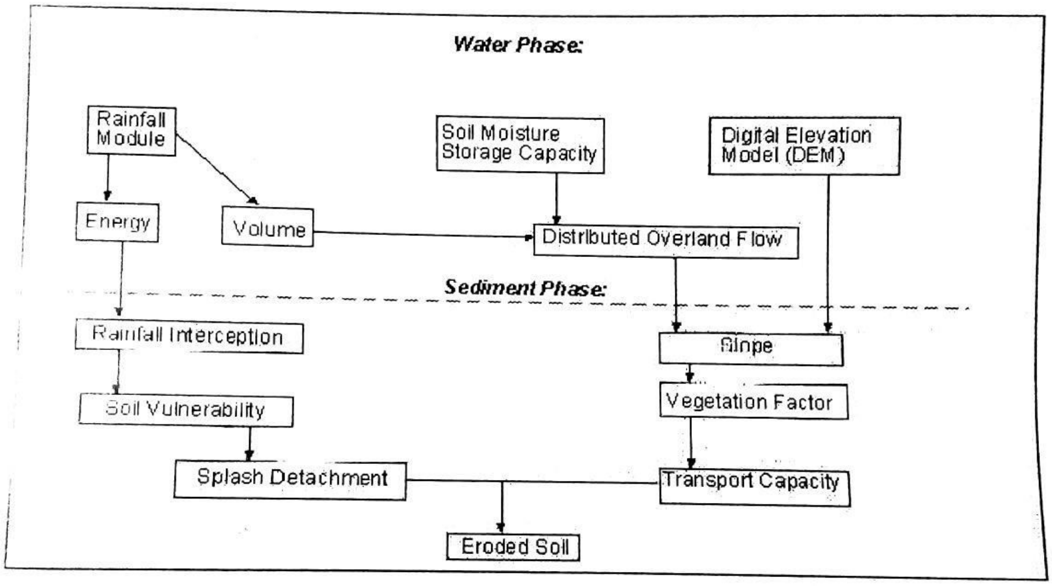


Figure 1.3 Framework of SLEMSA model. (Elwell, 1982)

1.9 SOIL EROSION MODEL FOR MEDITERRANEAN REGION (SEMMED):-

A soil erosion model SEMMED (Soil Erosion Model for Mediterranean regions) was developed for the test site Ardeche, France **(De Jong, 1997).** SEMMED comprises several modules, each of which describes a part of the erosion process such as soil particle detachment, moisture storage in the top soil and transport of soil particles by overland flow. SEMMED uses (multi-temporal) Landset TM images to account for vegetation properties and it uses a digital terrain model in a GIS to account for topographical properties. Spectral vegetation indices allow a pixel-by-pixel assessment of vegetation properties and the multi-temporal approach enables the assessment of the change of vegetative cover in one growing period. Figure 1.4 shows flow chart of the model.



Source: De Jong (1997)

Figure 1.4 SEMMED Model

1.10 MORGAN, MORGAN AND FINNEY MODEL:-

Morgan et al. (1984) developed a model for estimating annual soil loss from field size area on hill slopes. Inputs and flow charts of the model is illustrated in figure 1.5. For determination of annual rate of soil loss, the model compares the prediction of splash detachment and transport capacity of the overland flow. The lower of these two is considered as annual rate of soil loss. Some of the limitations of the model are:

- The model is more sensitive to change in the annual rainfall and soil parameters, when erosion is transport limited and also sensitive to changes in rainfall interception and annual rainfall, when erosion is detachment sensitive.
- It requires precise information on rainfall and other associated parameters, for having accurate prediction.
- This model cannot be employed for predicting the sediment yield from the drainage basin.
- Like USLE, it is also not suitable for predicting the soil loss, resulting from an individual storm.

Figure 1.5 Morgan et al. model for soil erosion.

1.11 WEPP MODEL:-

Water erosion Prediction Project (WEPP) model (Nearing et al., 1989) has capability of predicting spatial and temporal distribution of the net soil loss/gain for the entire hill slope for any period of time. It contains its own process based hydrology, water balance plant growth, residue decomposition and soil consolidation models as a climate generator and many other components that broadens its range of usefulness. The basic equation used for estimation of erosion from land is represented as:-

$$\frac{dG}{dx} = D_f + D_i \qquad 1.17$$

Where, G = sediment concentration;

X = distance down slope,

D_i = Inter-rill erosion,

D_f = Rill erosion.

$$D_i = K_i . I_e \sigma_{ir} . SDR_{rr} . F_{nozzle} . (R_s/W) \qquad 1.18$$

Where, K_i = inter-rill erodibility,

I_e = effective rainfall intensity,

σ_{ir} = inter-rill runoff rate,

SDR_{rr} = sediment delivery ratio,

F_{nozzle} = adjustment factor to account for sprinkler irrigation nozzle impact variation,

R_s = rill spacing,

W = width of the rill.

$$D_f = D_c (1 - G/T_c) \qquad 1.19$$

Where, D_c = rill detachment capacity = $K_r (\tau_f - \tau_c)$

T_c = transport capacity of flow in rill,

K_r = rill erodibility of soil,

τ_f = flow shear stress,

τ_c = critical shear stress.

Tiwari et el. (2000) compared the WEPP model predictions with the measured natural runoff plot data and found that the model efficiency is 0.71% in terms of annual soil loss with average magnitude of error 2.01 kg m – 2. It was concluded that WEPP is comparable with USLE and MUSLE.

1.12 QUASI THREE-DIMENSIONAL RUNOFF MODEL FOR SOIL EROSION:-

Victor Demidov (2001), used quasi three-dimensional runoff model for soil erosion modelling. The developed soil erosion model allows to simulate the temporal and spatial variations in erosion by raindrop impact and overland flow, sediment transport and deposition.

Structure of the Model:-

Quasi Three Dimensional Model Rainfall Runoff Formation – A physically based model of rainfall runoff formation is based on using differential equations which describe the process of overland, groundwater, subsurface, channel flow as well as vertical moisture transfer in soil. The catchment is represented in the horizontal plane by rectangular grid squares. The main channel and the tributaries of different orders are represented by the boundaries of grid squares.

The model describes the following processes:-

1. Vertical moisture transport in the unsaturated zone (the one-dimensional Richard's equation is used; the calculation is carried out at for each grid square of hill slope).
2. Groundwater flow and the interaction of the surface and ground water on the hill slope and in the river channel (the two-dimensional Boussineq equations are used);
3. Overland flow (the two dimensional kinematic wave equations are applied);
4. Unsteady flow in the river network (the one-dimensional kinematic wave equations are used).

The organization of the interaction between components of the hydrological modelling system allows taking feedback into account. Coupling of the calculations of the vertical moisture transport with the overland and groundwater flow is accomplished by means of a special procedure.

Modelling Soil Erosion and Sediment Transport in the River Basin:-

A soil erosion and sediment transport model was developed as a separate block of the hydrological modelling system. The soil erosion model describes the temporal and spatial variations of the soil erosion and the sediment transport in the river basins during flood events (erosion by raindrop impact and overland flow, sediment transportation and deposition)

The erosion rate by raindrop impact, D_r $(kgm^{-2}s^{-1})$, is expressed by the following equation

$$D_r = K_r \quad K_s \quad i \quad F_r \quad R^{\beta}$$

1.20

Where, K_r = soil erodibility factor for erosion by raindrop impact,

K_s = fraction of bare soil,

i = ground surface slope,

R = rainfall intensity (cm/s),

β = and exponent, and

F_r = is the factor reflecting influence of the water depth on erosion by raindrop impact that is expressed as

$$F_r = exp\ (1 - h\ D^{-1})\ if\ h > D$$

$$= 1 \qquad if\ h \leq D$$

Where, h is the flow depth (m); D is the median diameter of the raindrops that is determined from $D = 0.0193\ R^{0.182}$

The erosion rate by overland flow impact, D_e $(kg\ m^{-2}s^{-1})$, is calculated as :

$$D_e = K_e\ (\tau/\tau_c - 1)\ \ if\ \tau > \tau_c$$

$$= 0 \quad if\ \tau \leq \tau_c$$

Where K_e is the overland soil erodibility coefficient; τ is the shear stress $(kg\ m^{-2}\ s^{-1})$ and τ_c is the critical shear stress, which is taken to be:

$$\tau_c = \rho\ g\ i\ (ni^{-.05}V_p)^{-1.5}$$

Where ρ is the water density *(kg/m³)*, g is the acceleration due to gravity (ms^{-2}); n is the Manning roughness coefficient; V_p is the pickup velocity (m/s) that is determined by the equation

$$V_p = 1.14\ (g\ a\ d\ )^{0.5}$$

Where $a\ (= P_T\ \rho^{-1}\ -1)$ and P_T is the sediment density *(kf/m³);* d is the grain diameter (m). The sediment transport capacity , $G_T\ (kg\ m^{-1}\ s^{-1})$, is calculated by means of the Engelund - Hansen's equation

$$G_T = 0.04\ (VV^{*2}P_T)\ (\varphi\ a\ g)$$

Where V is the flow velocity *(m/s)*; V^* is the shear velocity *(m/s)*; φ is the criterion which is equal $\varphi = a\ d\ h^{-1}\ i^{-1}$.

The sediment transport by the overland flow is described by the two-dimensional sediment continuity equation

$$\frac{\partial\ (hC)}{\partial t} + \frac{\partial\ (Gx)}{\partial x} + \frac{\partial\ (Gy)}{\partial y} = E$$

$$E = -(1 - \varepsilon)\ P_T \frac{\partial (z)}{\partial t}$$

Where C is the sediment concentration ($kg\ m^{-3}$); Gx and Gy are the sediment transport rate in the x and y direction respectively; ε is the soil surface porosity; z is the soil surface elevation (m); E is the erosion or deposition rate on surface slope *($kg\ m^{-2}s^{-1}$)*.

Sediment routing in channels is described by the one-dimensional sediment continuity equation. Numerical integration of these equations is carried out an implicit finite difference scheme.

1.13 LISEM MODEL:-

The LISEM model (De Roo et al. 2001) is one of the first examples of a physically based model that is completely incorporated in a raster Geographical Information System. Incorporation means that there are no conversion routines necessary; the model is completely expressed in terms of the GIS command structure. Furthermore, the incorporation facilities easy application in larger catchments, improves the user friendliness, and allows remotely sensed data from airplanes or satellites to be used. If required, the model can be linked easily with other GIS's. Process incorporated in the model are rainfall, interception, surface storage in micro depression, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall, detachment by overland flow, and transport capacity of the flow. Also, the influence of tractor wheeling, small paved roads (smaller than pixel size) and surface sealing on the hydrological and soil erosion processes is taken into account.

Any rainfall begins, some is intercepted by the vegetation canopy until such time as the maximum interception storage capacity is met. Besides interception, direct through fall and leaf drainage occur, which, together with overland flow from upslope areas, contribute to the amount of water available for infiltration. The amount of water remaining after infiltration begins to accumulate on the surface in micro-depressions.

When a predefined amount of depressions are filled, overland flow begins. Overland flow rates are calculated using Manning's n and slope gradient, with a direction according to the aspect of the slope. When rainfall ceases, infiltration continues until depression storage water is no longer available. Soil detachment and transport can both be caused by either raindrop impact or overland flow. Whether or not a detached soil profile moves, depe nds upon the sediment load in the flow and its capacity for sediment transport. When water and sediment reach an element with a channel, they are transported to the catchment outlet. Sedimentation within a channel appears when the transport capacity has been exceeded.

When there are no sufficient field measurements available, the distribution of a desired input variable can be derived from digitized soil or land use maps. A raster-based GIS is the ideal tool to serve needs and fulfil requirements associated with the DEM and the geostatistical interpolation techniques. Further advantages of using a GIS are:-

1. The possibilities of rapidly producing modified input-maps with different land use patterns or conservation measures to stimulate alternative scenarios.
2. The ability to use very large catchments with many pixels, so the catchment can be simulated with more detail, and
3. The facility to display the results as maps.

A series of maps can be produced with showing the variation with the time of spatial patterns of soil erosion, sedimentation and runoff over the catchment. These maps can be compared by subtraction to yield maps indicating how erosion or sedimentation might be affected by certain control measures within the catchment or they can be viewed successively to create a video of the modelled process. Runoff can also be displayed as an overlay on the landform surface.

The main advantage of incorporating models in GIS is that the 'source code' of the model then resides on the comprehensible abstraction level of one or two lines of source code, a GIS command, per process (e.g. interception, infiltration and sediment routing). Such a high level of abstraction simplifies model modification, maintenance and reusability of parts of the model in other models. The current implementation of LISEM is less than 200 lines
(exclusive comments)

INPUT

LISEM needs a number of input files and maps to run. These inputs are described below.

Rainfall file: Data from multiple raingauges can be entered in an input data file. A map is used as input to define for each pixel which raingauge must be used. For every time increment during the simulation of a storm, the model generates a map with the spatial distribution of the rainfall intensity. Thus, the model allows for spatial and temporal variability of rainfall. In the future, this approach allows for the input of e.g. radar data indicating rainfall intensity patterns changing in space and time: e.g. to simulate a thunder storm which moves a catchment.

Tables for soil water model: Within the catchment, soil profile are defined. The vertical soil water movement is simulated by subdividing a soil profile in a user defined number of layers (e.g. 12). For each characteristic soil horizon, the measured K-t3-h relations are read from the horizontal specific tables.

Maps of relevant topographical, soil and land use variables: To run LISEM, a number of maps are needed in the PcRaster format-

- A group of map which describe the catchment morphology:
  - An 'area.map', in which the main catchment is defined;
  - An 'id.map', which defines the spatial rainfall pattern.
  - A map with the locations of the main outlet and subcatchment outlets;
  - A map with the 'Local Drain Direction', which refers to aspect;
  - A map with slope gradient;
  - A map with the Manning's n for overland flow;
  - A map with the slope gradient of the main channels;

    - A map with Manning's n for channel flow,
    - Two maps which describe the channel morphology;
    - A map with the location and width of roads;
  - A map with the location and width of wheel tracks from tractors;
  - A group of maps needed for the soil-water sub-model;
    - A map with the soil profile types, referring to the conductivity tables;
    - A similar map, but then for profiles under wheel tracks;
    - Maps with the initial soil metric suction for each soil layer;
- A group of maps with soil and land use variables;
    - A map of the Leaf area Index;
    - A map with the soil coverage by vegetation;
    - A map with the crop height;
    - A map with the Random roughness of the soil surface;
    - A map with the aggregate stability of the soil;
    - A map with the soil cohesion;
    - A map with the soil cohesion of channels;

Command file: When the model is run, the user is prompted for the selection of the catchment, the rainfall event, a few tuning parameters and the desired output. Alternatively the user can specify this information in a command file. The interface empowers the user to:

- Select the catchment area by specifying the directory of the topographical, soil and land use map database;
- Select the soil water model parameters by specifying the directory of the soil water tables. Separating the map database and the soil water tables permits optional sharing of the soil water tables between different catchments.
- Select the rainfall event by specifying the rainfall file; Select the starting and end time of the simulation;
- Select the overall simulation time step, and the minimum time step for the soil-water sub-model;
- Select a precision factor of the soil-water sub-model;
- Select a number of parameters and coefficients used in the detachment and transport formulas, such as settling velocity of the soil particles could be used for celebrating the sediment part of the model;

- Select names of the output files: e.g. hydrograph files (main outlet and outlets of predefined sub-catchments), runoff maps at several times, soil erosion map and the 'results' file with totals.

OUTPUT

The results of the LISEM model consist of:

- A text-file with totals (total rainfall, total discharge, peak discharge, total soil loss etc.);
- An ASCII data file which can be used to plot hydrographs and sedigraphs.
- Pc-Raster maps of soil erosion and deposition, as caused by the event;
- Pc-Raster maps of overland flow at desired time intervals during the event.

VALIDATION OF LISEM

The model results are compared with observed data (validation). Statistical criteria determine the 'goodness of fit'. The model user has to decide whether the results are satisfactory. If so, the simulations end and the 'final results' are produced. If the validation is not satisfactory, there are several options:

- Modify the model;
- Re-calibrate the model;
- Change the resolution (pixel-size or simulation type step);
- Collect more data;
- Collect better data; (measurement errors);
- Collect different data (other variable);

This feature is repeated until satisfactory results are obtained.

There are various erosion process model available and use depends upon the data required in the model and the data available.

1.14 MATHEMATICAL MODELS FOR SOIL EROSION PROCESSES AND SEDIMENT YIELD:-

In analysing sediment yield from watersheds different erosion processes are described using mathematical approaches and they are put together to obtain the sediment yield from a particular watershed. Several approaches have been developed and some of them have been outlined by *Haan et. al.* (1982).

A major step in the prediction of water erosion from watersheds have been the development of process-based models through evaluation of cause-and-effect relationship. One major example of such a process-based, computer-driven model is the Water Erosion Prediction Project (WEPP) of the USDA Agricultural Research Service *(Savadi et. al. 1995)*. The WEPP model is designed to operate on a daily time-step of temporal changes in soil erodibility, management practice, and biomass above and below ground level, litter biomass, plant height, canopy cover and ground cover into the prediction of water erosion from agricultural lands, range lands and forest areas. The WEPP model is also used to estimate sediment yield from watersheds, sediment transport over hill slopes, and detachment, transport and deposition of sediment in channels within a watershed.

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Sediment Yield measurement

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2020

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Sediment measurement

Sediment concentration in runoff water is measured by collecting samples of the runoff water and analysing them for sediment concentration, which is generally in the units of parts per million (ppm). It is not possible to directly measure the sediment outflow with runoff from a stream by any mechanical equipment. All the methods employed collect only the samples of the runoff water. The following are the three popular methods by which the samples are collected, depending upon the runoff amount to be handled:

1. Multislot divisor
2. Coshocton wheel sampler
3. Depth integrating samplers (bottle samplers)

The first two samplers are mostly used for small research plots. These are installed in the field and automatically collect a part of the runoff flow, which is also called aliquot collection, in a storage tank. An aliquot collection is a small sample of the material (water in the present case) assayed to determine the properties of the total material (total runoff). The third type of sampler is used for large flows, where samples have to be collected manually.

Multislot Divisor:

The multislot divisor was developed by R.V. Geib for collection of the runoff water from small plots of sizes from 1/125 to 1/250 ha. The divisor is provided with a number of slots of equal dimensions. It is fitted at the end of a rectangular box through which the runoff water from a stilling tank passes with a uniform horizontal velocity. The flow gets divided into equal parts on passing through the slots. Only the flow passing through the central slot is considered, which is let into a collecting tank, and the rest of the flow is allowed to drain away.

The runoff from the plot is at first collected in a structure, called the collector, from where it is guided to a stilling tank to dissipate the energy of the runoff water. A relatively tranquil water now enters the multislot divisor, and then from the central slot of the divisor to a storage tank. The water from the storage tank is collected and analysed for sediment concentration.

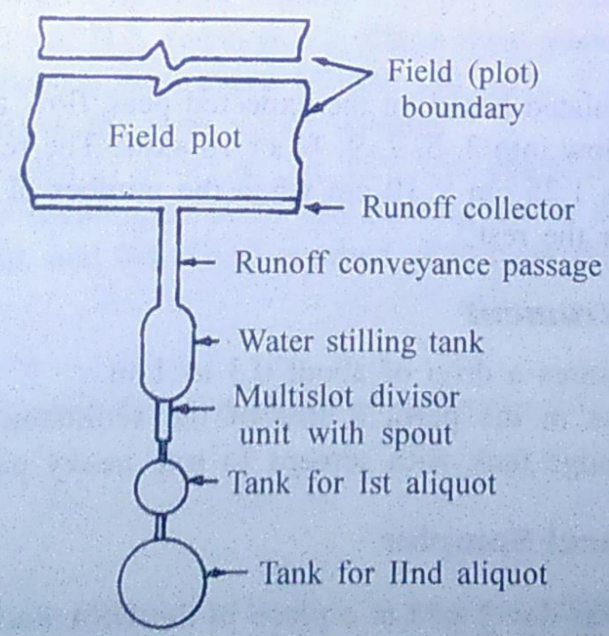

Fig. 15.6 Layout plan of a multislot divisor unit on a field plot.

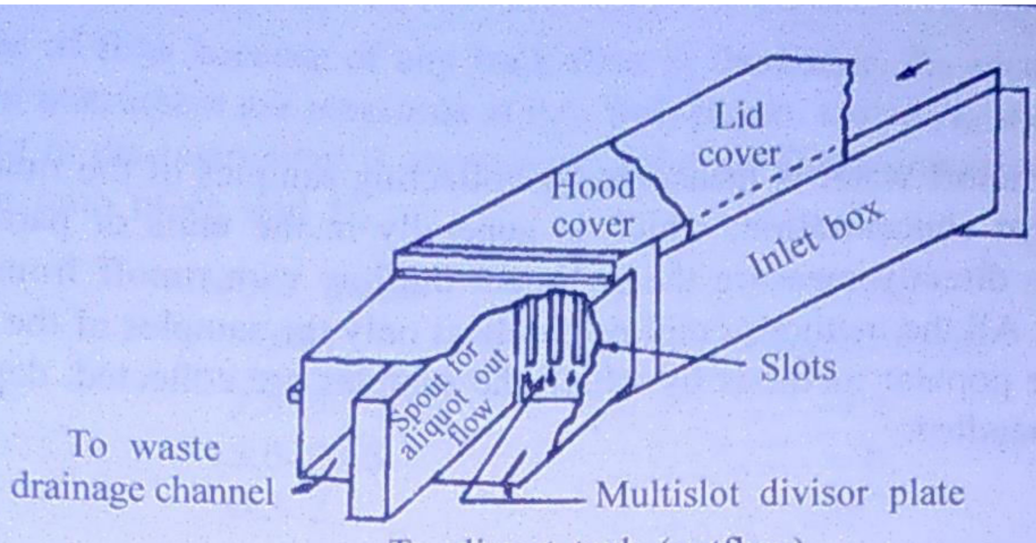

Fig. 15.7 Multislot divisor—cut-section view.

Capacity of the divisor:

This equipment is used for runoff rates falling in the range of 0.03 m'is to 1.2 m3/s.

Number of slots in a divisor:

The number of slots required in a divisor for a plot of a given size is calculated by the following, formula:

F x A x P

C.

where

N = number of slots, or the divisor ratio

F = maximum expected runoff percentage (decimal fraction)

A = area of the plot, m-

P = precipitation depth, m

C = volume of the storage tank, m3.

Size of slots:

The size of the slots is calculated based on the expected peak flow and the number of slots. The equipment may divide the flow into 3, 5, 7, 9, 11 or 13 slots. The relationship between the width and the height of- the slot is 1.25 cm x 10 cm. When the number of slots is in the range of 3 to 11, and 2.5 cm x 15 cm for the rest.

Limitation of instrument:

1. 'The instrument requires a drop of about 0.3 to 1 m.

2. Owing to variations in the particle size of the sediment, the instrument requires the installation of at sludge tank with screens to trap heavy particles.

Coshocton Wheel Sampler:

Coshocton wheel sampler was developed ait at place in the USA known as Coshocton. The runoff discharge through a H-flume. or a. triangular notch is allowed to fall upon a water wheel which has a sampling head, with a slot along its top, mounted on it. During each revolution of the wheel, the slot cuts across the jet of water falling from the flume. collects a portion of it and passes this runoff water vertically downwards into a collection pan, from where the water sample is carried to a storage tank through a conduit.

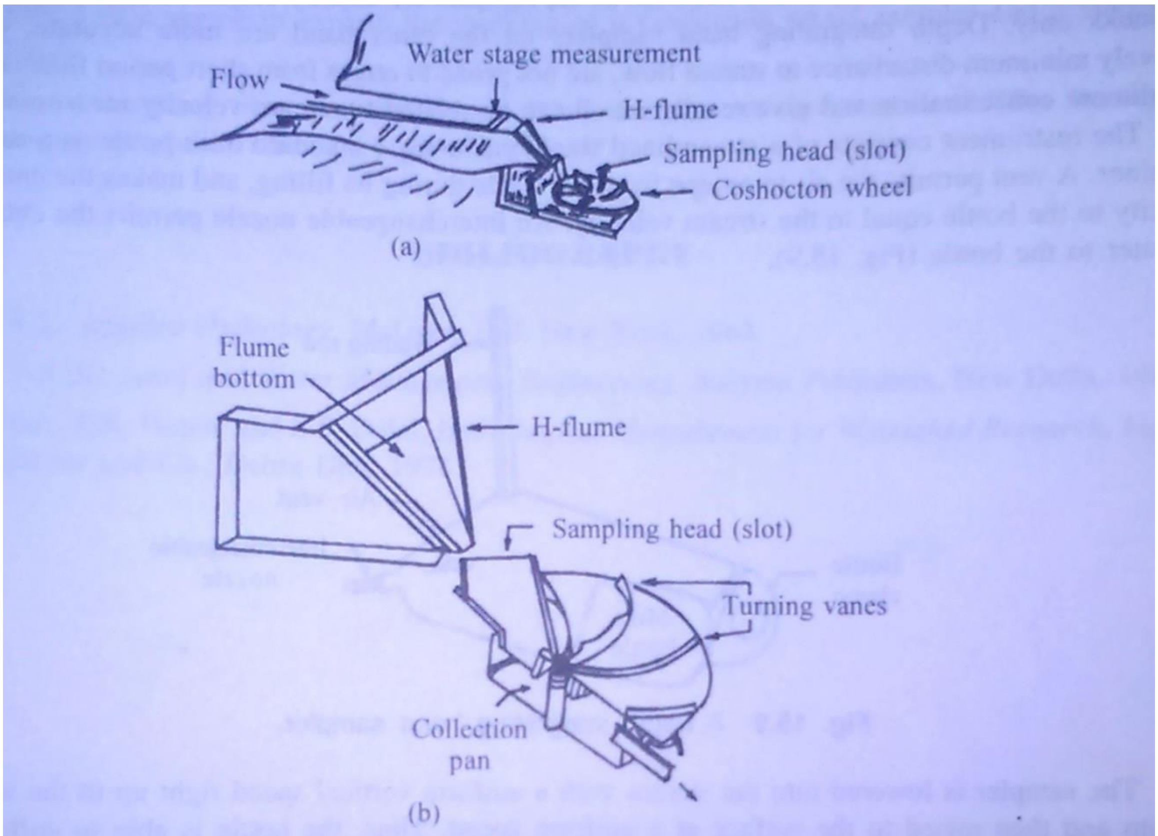

Fig. 15.8 Coshocton wheel: (a) Installation in field, (b) Isometric cut-section view.

Coshocton wheels are available in dimensions of FPS units. There are three most common sties which are based on wheel diameters, namely 0.3 m (1 ft), 0.6 in (2 ft), and 1 m (3 ft), and ;ire designated as N-1, N-2, and N-3, respectively. These three ss heels are fitted with H-flumes of 15 cm (1/2 1i) and respectively collect about I/100th (30 cm = 1 ft), 1/200th (45 cm 1.5 ft), and I/300th (60 cm =2 ft) of the total runoff volume. The instrument is installed as shown in Fig. 15.8. The centre of the wheel is kept at an offset from the centre line Of the 11-flume to avoid any stalling action by the wheel. The slot is also provided with UMW overlap, and the wheel is tilted slightly in the direction of the flow.

Range of operation:

The instrument is recommended for a peak flow rate falling in the range of approximately 0.15 m^3/s.

Limitations:

The bearing of the sampler are required to be kept in a proper running condition to obtain correct measurements. Otherwise the instrument is liable to give a large errors.

Depth Integrating Sampler (Bottle Sampler):

The computation of sediment transported in large streams is done by discrete field measurements. Generally, samples of stream water are collected in 1 litre open bottles. This process at times is difficult to operate and also not very accurate as the samples are usually collected from places near the banks only. Depth integrating hand samplers on the other hand are more accurate, cause relatively minimum disturbance to stream flow, are not prone to errors from short period fluctuations in sediment concentration and give results which can be related to stream velocity measurements.

The instrument consists of a streamlined shield enclosing a standard milk bottle as a sample container. A vent permits the air to escape from the bottle during its filling, and makes the entrance velocity to the bottle equal to the stream velocity. An interchangeable nozzle permits the entrance of water to the bottle.

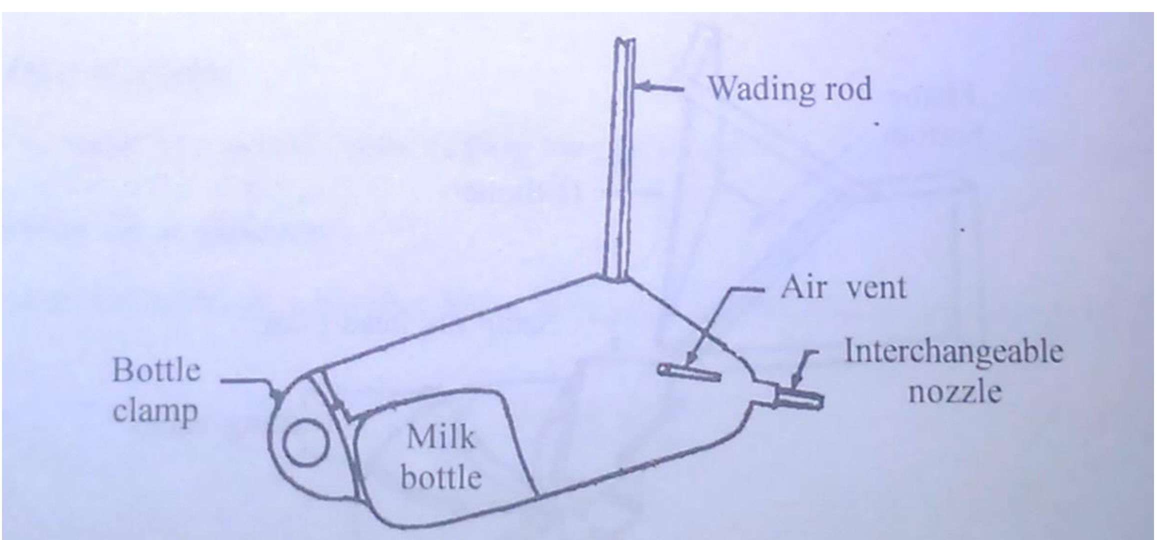

Fig. 15.9 A depth integrating hand sampler.

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