SIMULATION OF THE EFFECTS OF LAND AND VEGETATION MANAGEMENT MEASURES ON RUNOFF AND SEDIMENT YIELD FROM A SMALL WATERSHED - A CASE STUDY

By
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THESIS
Submitted in partial fulfilment of the requirement for the degree

**Master of Technology
in
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2000

DECLARATION

I hereby declare that this thesis entitled **"Simulation of the Effects of Land and Vegetation Management Measures on Runoff and Sediment Yield from a Small Watershed – A Case Study"** is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship, or other similar title, of any other University or Society.

Tavanur **Vinod Kumar. P. R.**

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Certified that this thesis entitled **"Simulation of the Effects of Land and Vegetation Management Measures on Runoff and Sediment Yield from a Small Watershed – A Case Study"** is a record of research work done independently by Mr. Vinod Kumar, P. R., under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship, or associateship to him.

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Vinod Kumar. P. R.

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Symbols and Abbreviations

ARS	-	Agricultural Research Service
ASAE	-	American Society of Agricultural Engineers
ASCE	-	American Society of Civil Engineers
C	-	cover and management factor
°C	-	degree Celsius
CLIGEN	-	Climate Generator
cm	-	centimetre(s)
CREAMS	-	Chemicals, Runoff, and Erosion from Agricultural Management Systems
CWRDM	-	Centre for Water Resources Development and Management
DRH	-	Direct Runoff Hydrograph
DSG	-	Direct Sediment Graph
EI	-	storm energy times maximum 30-minute intensity
EPIC	-	Erosion Productivity Impact Calculator
et al	-	*et alia*, and other people
etc.	-	*et cetera*, and the rest
Fig.	-	figure
ft	-	feet
g	-	gram(s)
h	-	hour(s)
ha	-	hectares
i.e.	-	that is
in.	-	inches
IS	-	Indian Standards
IUH	-	Instantaneous Unit Hydrograph
IUSG	-	Instantaneous Unit Sediment Graph
k	-	kilo
K	-	soil erodibility factor

KCAET	-	Kelappaji College of Agricultural Engineering and Technology
kg	-	kilogram(s)
km	-	kilometre(s)
L	-	slope-length factor
LS	-	topographic factor
m	-	metre(s)
min	-	minute(s)
ml	-	millilitre
mm	-	millimetre(s)
MUSLE	-	Modified Universal Soil Loss Equation
No.	-	Number
NSERL	-	National Soil Erosion Research Laboratory
P	-	support practice factor
Ph.D	-	Doctor of Philosophy
R	-	rainfall and runoff erosivity factor
RUSLE	-	Revised Universal Soil Loss Equation
s	-	second(s)
S	-	slope-steepness factor
T	-	tonne(s)
t	-	ton(s)
t_{pk}	-	time to peak
UH	-	Unit Hydrograph
USA	-	United States of America
USDA	-	United States Department of Agriculture
USG	-	Unit Sediment Graph
USLE	-	Universal Soil Loss Equation
viz.	-	namely
WEPP	-	Water Erosion Prediction Project
/	-	per
%	-	per cent
°	-	degree

Introduction

INTRODUCTION

Our existence depends largely upon the thin layer of soil from which we produce most of our food, fibre and timber. More than two-thirds of the world's population today is living in the developing countries where agriculture production is not keeping pace with population increase. Increased food production could be achieved by expanding cultivable areas, and intensifying production and application of new technology in agricultural production. The expansion of cultivable areas, however, offers the least solution to the problem as most of the countries especially in Asia have little or no room for expansion.

A major problem facing areas already under cultivation, thus aggravating the situation, is the seriousness of soil degradation and loss of soil fertility due to indiscriminate use of agricultural lands, forests, and grazing lands. The process of soil erosion and transportation causes damage in many ways. They include erosion of the soil at its origin reducing the fertility, its transportation in stream channels causing regime problems and deposition of sediments in the lakes, reservoirs, etc., which reduces their water storage capacity and utility.

The control of erosion by water and wind is of great importance in the maintenance of crop fields and mitigation of agricultural non-point pollution. Not only soil is lost in the process of erosion, but also a proportionally higher percentage of plant nutrients, organic matter, and fine particles of eroded material is lost. In agriculture, soil erosion from farmland forms one of the major causes of water pollution. Also the loss of the land by erosion itself reduces production of food and fibre.

It takes more than 100 years to form one centimetre of soil and for that purpose it is a non-renewable source and its loss is a matter of great concern (Hudson, 1981). Conservation of soil, the basic natural resource, is a key to sustained production of food, fibre and fuel, the basic necessities of all beings.

In the world where we live, the two basic resources are the land and the people. Fundamental development reaches back finally to the land. The successful combination of human and land resources determines the progress. Economic stability burgeons from good soil used intelligently and protected from erosion and from prevention of unnecessary wastage of rainfall by excessive runoff. Few are able to visualize the benefits that would accrue if soils could be adequately protected by sound soil conservation measures.

India has about 25 per cent of its geographical area under mountainous region. More than 80 per cent of the annual rainfall in India is obtained from the south-west and north-east, monsoons occurring from June to October. This leads to either flooding because of environmental degradation and uneven rainfall or drought because of the erratic monsoon behaviour in the lean season. Activities like reckless tree felling, excessive grazing, plugging of natural drains, road construction, mining, and unscientific farming practices including shifting cultivation have accelerated the rate of erosion and land degradation through various processes. Latest estimates as per SAARC 1992 (South Asian Association for Regional Co-operation), show that nearly 53 per cent of India's area (123.6 million ha) is subjected to various types of land degradation.

An estimated 6000 million tons of soil are getting lost annually from the Indian sub-continent. This not only leads to loss of major nutrients, viz., Nitrogen, Phosphorus and Potassium (NPK), ranging from 5.37 to 8.34 million tons per year, but also reduces utility and life span of multipurpose river valley projects (Das, 1985). The rivers carry approximately 2052 million tons of eroded material; out of which 1572 million tons get carried into the sea while the remaining 480 million tones get deposited in various reservoirs. The available data indicates that the observed sedimentation rates in some of the major reservoirs of India range from 1.45 to 7.50 times the estimated sedimentation rates at the planning stage (Dhruvanarayan and Babu, 1983).

Also the river beds rise every year which leads to frequent floods and river shifting. It is pertinent to note that Kosi river has shifted 110 km from east to west during the period from 1731 to 1963 in Bihar (Rao, 1995). Besides, about 7800 km^2 of land in Bihar and 1300 km^2 in Nepal were destroyed after being covered by sand deposits. It wiped out towns and villages during its shifting course, displacing an estimated 6.5 million persons.

In Kerala, about 1.5 million ha of land is affected by soil erosion. It is reported that 560 km of coast line of Kerala is subjected to sea erosion. Out of the total geographical area of 38.86 lakh ha in the State nearly 19 lakh ha of land is highly vulnerable to soil erosion hazards. The undulating topography, the high intensity rainfall spread over two monsoons, increasing demand for arable lands, and consequent denudation of forests have accentuated the problem of soil erosion in the State.

The modern thinking, which assigns to soil conservation a more comprehensive and more positive role in the sustained improvement complemented by the preservation of available resources, should form the central concept of planning. Soil conservation is not merely regarded as a technical problem. Soil and water conservation for watersheds is currently receiving high priority in India because of its impact on the protection of badly eroded land and its various resources, and the improvements that can be effected on such lands. In addition, reduction in capacity of useful life of reservoir than planned can be cured only with successful implementation of soil conservation measures in catchment.

From the very start of conservation programme, the fieldwork has been supported by a programme of research through which new tools and methods of control and prevention, as well as improvements on present tools and techniques, has been sought from day to day. As fast as discoveries have been made, they were seen carried to the farmers who were cultivating the lands to which these discoveries applied. The fundamental initiative in this direction imparts the necessity to comprehend the process of erosion and its controlling factors. The man-made alterations on land and vegetation have significant effects on erosion, and could be considered as the only reason by which the soil lost by erosion preponderates the soil built by natural process. Thus the understanding of the effects of land and vegetation management measures on soil erosion has become momentous in the diagnosis of the problem. This study is an attempt to simulate the effects, which the land and vegetation management measures can produce on runoff and sediment yield from a small watershed as a case study. The watershed selected for the study has different types of agricultural practices, which influence the hydrological processes as well as the erosion process. The runoff and sediment yield resulted from individual storm events were analysed to comprehend the hydrological response and erosion process of the watershed. The Universal Soil Loss Equation, Unit Sediment Graph theory, and WEPP hillslope / watershed model were used to simulate soil erosion process accompanying single storm events.

Review of literature

Review of literature

REVIEW OF LITERATURE

Scientific planning for soil and water conservation requires knowledge of the relation between those factors that cause loss of soil and water, and those that help to reduce such losses. Controlled studies in field plots and small watersheds have supplied much valuable information regarding these complex factor-interrelations, and these findings have been converted to sound practices in numerous areas. This chapter reviews the past researches conducted to study the response of soil to rainfall in terms of water and sediment yield.

2.1 Soil Loss Equation

Developing procedures to estimate field soil loss began during 1940s in the Corn Belt region in the USA, which has been referred to as the slope-practice method. Zingg (1940) published an equation relating soil loss ratio, length, and percentage of slope. Smith (1941) added crop and conservation practice factors and the concept of a specific soil loss limit, to develop practices for some specified areas. Musgrave (1947) developed an equation, widely known as Musgrave equation, by adding rainfall factor and re-appraising the Corn Belt factor values. The equation developed by Musgrave, ensuring the analysis of data collected from 20 different stations in the USA by considering 40,000 storms in experimental plots, is as follows:

$$E = f\,C\,S^{1.35}\,L^{0.35}\,P^{1.75} \qquad ...(2.1)$$

where,

E = soil erosion, in./year;

f = a numerical value that is proportional to the erodibility of the soil;

C = lack of ground cover effectiveness in prevention of erosion expressed as proportion;

S = slope , %;

L	=	length of slope, ft, and
P	=	maximum 30-min intensity, 2-year frequency rainfall, in.

A graphical solution of the equation was published in 1952 and was used by the Soil Conservation Service in the USA.

Ellison (1947) defined soil erosion as a process of detachment and transportation of soil materials by erosive agents. For rainfall erosion, these agents are rainfall and runoff. He pointed out that each has both detaching and transporting capacity, and must be studied separately. Ellison determined the relationship between splash loss and rainfall as,

$$G = K\ V_d^{0.33}\ d^{1.07}\ i^{0.65} \qquad ...(2.2)$$

where,

G	=	soil interrupted in splash samples during 30 minutes period, g;
V_d	=	velocity of the drops, m/s;
d	=	diameter of the drops, mm;
I	=	intensity of rainfall , cm/h, and
K	=	a constant.

The two equations above mentioned are seldom used , these days, to predict the soil erosion. Nevertheless, these equations served as the basic premises for later soil loss prediction theories like Universal Soil Loss Equation.

2.2 Universal Soil Loss Equation (USLE)

The Universal Soil loss Equation (USLE) was developed at the National Runoff and Soil Loss Data Center established in 1954 by the Science and Education Administration (formerly Agricultural Research Service) of the USA in co-operation with Purdue University. Federal State co-operative research projects at 49 locations contributed more than 10,000 plot-years of basic runoff and soil loss data to this center for summarizing and overall statistical analyses. After 1960, rainfall simulators were used on field plots to fill some of the gaps in the data needed for factors evaluation. Analyses of this large assembly of basic data provided several major improvements to the soil loss equation by incorporating the following:

1. a rainfall erosion index evaluated from local rainfall characteristics.
2. a quantitative soil erodibility factor that is evaluated directly from soil property data and is independent of topography and rainfall differences.
3. a method of evaluating cropping and management effects in relations to local climatic conditions.
4. a method of accounting for the effects of interactions between crop systems, productivity levels, tillage practices, and residue management.

The equation enabled a planner to predict the average rate of soil erosion for each of the various alternative combinations of crop systems, management techniques and control practices at any particular site. The predicted losses were compared with soil erosion that permitted a high level of crop productivity sustained economically and indefinitely. Thus specific guidelines were established for effecting erosion control within the specific limits. The soil loss limits were defined based on factors like soil depth, physical properties, and other characteristics affecting root development, seeding losses, soil organic matter reduction and plant nutrient losses.

The USLE is an erosion model designed to predict the long term average soil losses due to rainfall from specific field areas having specified cropping and management systems. It computes the soil loss for a given site as the product of six major factors whose most likely values at a particular location can be expressed numerically. Erosion variables reflected by these factors vary considerably about their means from storm to storm, but effects of the random fluctuations tend to average out over extended periods.

The soil loss equation is,

$$A = RKLSCP \qquad ...(2.3)$$

where,

A = computed soil loss, t / acre-year. It is expressed in the units selected for K and for the period selected for R. In practice, these are usually so selected that they compute A in tons per acre per year. But other units also can be selected.

R = rainfall and runoff factor. It is the number of rainfall erosion index units plus a factor for runoff from snowmelt or applied water where such runoff is significant.

K = soil erodibility factor. It is the soil loss ratio per erosion index unit for a specified soil as measured on a unit plot, which is defined as a plot of 72.6 ft length of uniform 9 per cent slope continuously in clean-tilled condition.

L = slope length factor. It is the ratio of soil loss from the field slope length to that from a 72.6-ft length under otherwise identical condition.

S = slope steepness factor. It is the ratio of soil loss from the field gradient to that from a 9 per cent slope under otherwise identical conditions.

C = cover and management factor. It is the ratio of soil loss from an area with specified cover and management to that from an identical area in tilled continuous fallow.

P = support practice factor. It is the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight row farming up and down the slope.

2.2.1 Rainfall and runoff factor

Rills and sediment deposits observed after an unusually intense storms led to the conclusion that significant erosion is associated with only a few storms, or that it is solely a function of peak intensities. However, Wischmeier (1962), after analyses of more than 30 years measurements, showed that this is not the case. The data revealed that a rainfall factor used to estimate average annual soil loss must include the cumulative effects of the many moderate-sized storms, as well as the effects of occasional storms.

The numerical values used for rainfall and runoff factor (R) in the soil loss equation quantifies the effect of raindrop impact, amount, and rate of a runoff likely to be associated with rain. The research data indicated that when factors other than rainfall are held constant, storm soil losses from cultivated fields are directly proportional to a rainstorm parameter identified as EI, which is an abbreviation for energy times intensity (Wischmeier, 1959). By definition, the value of EI for a given rainstorm equals the product of total storm energy times the maximum 30-min intensity (I_{30}) where E is in hundreds of foot-tons per acre (ft-t/acre) and I_{30} is in inches per hour (in./h).

The data showed that rainfall energy itself is not a good indicator of erosive potential. Rain drop erosion increases with intensity. The I_{30} component indicates the prolonged-peak rates of detachment and runoff. The product term, EI is a statistical interaction term that reflects how total energy and peak intensity are combined with transport capacity.

The energy of a storm is a function of the amount of rainfall and of all the storm's component intensities. Wischmeier and Smith (1958) stated that median drop size increases with rain intensity. Gunn and Kinzer (1949) presented a direct correlation between terminal velocities of free falling water drops and drop size. Since the energy of a given mass is proportional to velocity-squared, rainfall energy is directly related to rain intensity. Wischmeier and Smith (1958) expressed this relationship by the following equation:

$$E = 916 + 331 \log_{10} I \qquad \dots (2.4)$$

where, E is kinetic energy in foot-tons per acre-inch, and I is intensity in inches per hour. A limit of 3 in./h is imposed on I, by the finding that median drop size does not continue to increase when intensities exceed 3 in./h. Rain showers of less than ½ inch remaining separated from showers of greater than ½ inch, by more than 6 h were omitted from the erosion index computations, unless as much as 0.25 inch of rain fills in 15 min. The relation of soil loss to this parameter is linear and its individual storm values are directly additive. The sum of the storm EI values for a given period is a numerical measure of the erosive potential of the rainfall within that period. The average annual total of the storm EI values in a particular locality is the rainfall erosion index for that locality.

Ateshian (1974) presented an analytical approach to yield simple empirical formulae for estimation of rainfall erosion index. The erosion index, EI/100, was calculated for various values of total rainfall and plot of the calculated erosion index on log-log paper resulted in a straight line. The erosion index developed for an individual 24-h duration is represented by the following equation:

$$EI/100 = a\,(P_{24\text{-}hr})^b \qquad \dots (2.5)$$

in which,

$P_{24\text{-}hr}$ = rainfall depth, for a 24-h duration storm, in.,

'a' and 'b' = constants.

Individual storm erosion index values were calculated for various durations and rainfall depths. The graphical relationship yielded the following equation:

$$\text{Individual storm erosion index} = \frac{aP^b}{(Hr)^c} \qquad \ldots(2.6)$$

where,

P = storm rainfall depth, in., and

Hr = duration of rainstorm, h.

However, Kenneth (1975) commended that it was not realistic to assume that the rainfall at various places could be expressed by one dimensionless rainfall graph. Kenneth and Simanton (1975) recommended that with additional study and analysis, it can be shown that EI values computed for only the time when precipitation rate exceeds infiltration rate are more realistic than the EI values computed for the total storm depth and duration.

Kieth (1980) presented a method, which provides R_{st} value (erosivity factor for individual storm, EI/100) for individual storm events of any selected standard design frequency and duration for different storm types. A general equation, relating maximum 30-min intensity for storm of any duration and total volume of precipitation, was also presented for different storm types:

$$EI = P \alpha D^{\beta} \qquad \ldots (2.7)$$

in which,

P = total storm rainfall, in.;

D = storm duration, h, and

α, β = constants for any given storm types.

The relationship between total rainfall, duration, and R_{st} values was presented in the form of following equation:

$$EI/100 = R_{st} = a\,P^{fD} / D^{b} \qquad ...(2.8)$$

in which, a and b are constants depending on the type of storm and power to which rainfall 'P' is raised is also a function of duration (fD). The function (fD) was evaluated by regression equation.

Among other erosivity indices proposed, the better known ones being AI_m and KE. Lal (1976) defined AI_m as the product of the amount of rainfall per storm, A, in mm, and its maximum 75-min intensity, I_m, in mm/h. The index then has the unit mm^2/h. Hudson(1981) computed KE according to the following equation:

$$KE = 29.8 - 127.5 / I, \quad I > 25 \text{ mm/h} \qquad ... (2.9)$$

where, KE has the same units as R factor in the USLE, and I is the rainfall intensity in mm/h. In practice, KE is computed as outlined above for R factor, except that time intervals with an intensity below 25 mm/h (1 in./h) is ignored.

Richardson *et al.*, (1983) developed a model, which has been tested and verified extensively on the North American continent. The model is based on the general relationship between erosivity index R and the daily or event rainfall N:

$$R = a\,N^{b} \qquad ...(2.10)$$

where, 'a' and 'b' are model parameters.

Based on R and N data from 11 locations in the USA, the parameters 'a' and 'b' were estimated by linear regression of the log-transformed variables. The 'b' value was found to be invariant in time and space, and hence it was assigned a value of 1.81, while the values of 'a' varied in time and space.

The estimation of rainfall and runoff factor (R) based on event rainfall according to above relationships was almost inapplicable for the present study, as the rainfall data collected were insufficient.

2.2.2 Soil erodibility factor

The difference in erosion caused by the properties of soil itself, when all other factors are same, is referred as the soil erodibility. Though several early attempts, dated back to early 1930s, were made to determine criteria for scientific classification of soils according to erodibility, the classifications used for erosion prediction were only relative rankings. Differences in the natural susceptibilities of soils to erosion were difficult to quantity from field observations. The soil erodibility factor (K), in the USLE is an experimentally determined quantitative value. For a particular soil, it is the rate of soil-loss per erosion-index unit measured on a "unit-plot", which has been arbitrarily defined as follows:

A "unit-plot" is 72.6 ft long plot, with a uniform lengthwise slope of 9 per cent, in continuous fallow, tilled up and down the slope. Continuous fallow, for this purpose, is that land which has been tilled and kept free of vegetation for more than 2 years. During the period of soil loss measurements, the plot is plowed and placed in conventional corn-seedbed condition each spring, and is tilled as needed to prevent vegetative growth and severe surface crusting. When all of these conditions are met L,S, C, and P have a value of 1.0 and K equals A/EI T; where A is average annual soil loss.

As the direct measurements of the erodibility factor were costly and time consuming, an integral study was initiated in 1961 to achieve a comprehension of how and to what extent various properties of a soil affect soil erodibility. A soil erodibility nomograph, developed by Wischmeier *et al.,* (1971) for farm land and construction sites, provided a more generally applicable working tool. For soils containing less than 70 per cent silt and very fine sand, the nomograph solves the following equation:

$$100\ K = 2.1\ M^{1.14}\ (10^{-4})\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3) \qquad ...(2.11)$$

where,

K	=	soil erodibility;
M	=	particle size parameter as defined below;
a	=	per cent organic matter;
b	=	soil structure code used in soil classification, and
c	=	profile permeability class.

The mechanical analysis data were effectively described by the parameter M, which equals per cent silt (0.01-0.002 mm) times the quantity 100-minus-per cent-clay.

2.2.3 Topographic factor

The length and steepness of the slope substantially affect the rate of soil erosion by water. The two effects have been evaluated separately, as slope length and steepness factor. They are represented in the soil loss equation as L and S factors, respectively. In field application, however, the two are considered as a single topographic factor, LS. The factor LS is the expected ratio of soil loss per unit area from a field slope to that from a plot of 72.6 ft length and uniform 9 per cent slope under otherwise identical conditions.

2.2.3.1 Slope length effect

Slope length has been defined by Smith and Wischmeier (1957) as the distance from the point of origin of overland flow to either of the points described below (which ever is limiting for major part of the area under consideration): the point where either slope gradient decreases enough that deposition begins, or runoff water enters a well defined channel that may be part of a drainage network or a constructed channel. The effect of slope length on runoff per unit area is generally assumed negligible. However, the soil loss per unit area generally increases substantially as slope length increases.

The first kind of procedures for soil loss estimation has been referred to as the slope practice method. Zingg (1940) observed that average erosion rate over a length of uniform slope had been found to vary with the slope length. He proposed the following relationship between soil loss and slope-length:

$$A \propto \lambda^{m} \qquad \cdots(2.12)$$

where,

A	=	soil loss per unit area, t;
λ	=	horizontal slope-length, ft, and
m	=	slope length exponent.

Wischmeier and Smith (1958) reported that apparent values up to 0.9 for m were obtained for some of the data analysed.

The plot data showed that average soil loss per unit area is proportional to the power of slope length (Wischmeier and Smith (1958)). The L factor, which is the ratio of the field soil loss to the corresponding loss from 72.6 ft slope-length, was expressed as follows:

$$L = (\lambda / 72.6)^{m} \qquad \cdots(2.13)$$

where 'λ' is the field slope-length in feet and 'm' is the slope length exponent. It was suggested that 'm' assumes the values 0.5 if the per cent slope is 5 or more, 0.4 on slope of 3.5 to 4.5 per cent, 0.3 on slope of 1 to 3 per cent and 0.2 on uniform gradient less than 1 per cent. Wischmeier and Smith (1965) suggested that the existing field plot data did not establish a general value greater than 0.5 for 'm' on slopes steeper than 10 per cent.

Meyer *et al.,* (1975) suggested that large values for slope length exponent were associated with increased rill erosion. Analyses conducted by Meyer and Romken (1976) indicated that the slope length exponent increased with slope length. Meyer and Harmon (1985) confirmed that the slope length exponent was near zero for very flat slopes. Mutchler and Greer (1980) recommended the values of 'm' as 0.15 for slopes less than 0.5 per cent and 0.2 for slopes between 0.5 and 0.1 per cent. Foster (1982) and Lombardi (1979) found that the slope length exponent 'm' varies greatly with location and it was indicated that slope length exponent increases with slope steepness.

McCool *et al.,* (1989) used the theoretical considerations and data interpretation by Foster *et al.,* (1982) in developing revised relationship for the slope length exponent in the USLE. The soil loss was obtained as the sum of interrill erosion and rill erosion, and is expressed as follows:

$$D = D_I + D_r \qquad \text{...(2.14)}$$

where,

D = soil loss;

D_i = interrill erosion, and

D_r = rill erosion.

An equation for interrill erosion was formulated by Foster (1982), which is of the following form:

$$D_i = a_i\, V_r\, i_p\, K_i\, S_i\, C_i\, \alpha_i\, \delta_i \qquad \text{...(2.15)}$$

where

D_I = soil loss per unit area;

a_i = coefficient;

V_r = volume of rainfall;

i_p = measure of peak rainfall intensity (often the maximum 30-min intensity);

K_i = interrill erodibility factor;

S_i = interrill slope steepness factor;

C_i = interrill soil management factor;

α_i = interrill canopy factor, and

δ_i = interrill ground cover factor.

Foster *et al.,* (1982) derived a basic equation for rill erosion:

$$D_r = K_r(\tau_e - \tau_{cr})\, C_r \qquad \text{.............................(2.16)}$$

where

D_r = soil loss per unit area;

K_r = rill soil erodibility factor;

τ_e = effective shear stress of the flow acting on the soil surface;

τ_{cr} = critical shear stress for the soil (τ_e must exceed this value for rill erosion to occur), and

C_r = rill soil management factor.

Foster *et al.,* (1982) approximated the equation for rill erosion for a storm, assuming that the critical shear stress is negligible (τ_{cr}=0)

$$D_r = a_r\ (Vu\ ip)^b\ \lambda\ \mathrm{Sin}\,\theta\ K_r\ C_r\, \xi^{\,3} \qquad \text{...(2.17)}$$

where,

a_r = a coefficient;

V_u = volume of runoff per unit area;

i_p = peak excess rainfall ratio;

b = an exponent of value about 0.6;

θ = slope angle;

λ = slope length;

ξ = ratio of flow velocity with cover and roughness to flow velocity over a bare, smooth soil;

K_r = rill soil erodibility factor, and

C_r = rill soil management factor.

The slope (m_p) of the curve of D versus λ has been given for any point λ, by the equation (Foster *et al.*, 1977):

$$m_p = \beta / (1+\beta) \qquad \text{...(2.18)}$$

where,

β = ratio of rill to interrill erosion

$$= \frac{a_r (V_u \sigma_p)^b \ \lambda \ \text{Sin}\ \theta \ \ K_r C_r \xi^3}{a_i V_r i_p K_i S_i C_i \alpha_i \ \delta_i}$$

McCool *et al.,* (1989) obtained a relationship for β based on slope length and exponent, after assuming that individual corresponding factors from the rill and interrill erosion equations are equal.

$$\beta = \lambda \ \text{Sin}\ \theta / S_i \qquad \text{...(2.19)}$$

where,

β = ratio of rill to interrill erosion;

λ = slope-length;

θ = slope angle, and

S_i = slope steepness factor.

When length and slope terms of the above equation were normalized to 22.1 m length and 9 per cent slope,, the ratio of rill to interrill erosion β was obtained as follows:

$$\beta = \frac{(\lambda / 22.1)(\text{Sin}\ \theta / 0.0896)}{(3.0\ \text{Sin}^{0.8}\theta \ + \ 0.56)} \qquad \text{...(2.20)}$$

where,

β = ratio of rill to interrill erosion, and

θ = slope angle.

The length term was deleted from the equation as the data of Meyer and Romken (1976) indicated that the exponent of slope length increased for lengths beyond 22 m. Also, for slope-length less than 4 to 6 m, due to the effect of slope length on 'β' and 'm', the slope length factor increases as slope length decreases.

The values of β and subsequently, m have been obtained using equation 2.15 and 2.16. However, owing to the susceptibility of interrill and rill erosion, the value of β was accordingly modified before substituting in equation 2.18, for finding out 'm'. Also the rate of rill erosivity and interrill erosivity have been correlated with rainfall intensity and infiltration rate.

2.2.3.2 Per cent slope

Runoff from cropland generally increases with increased slope gradient, but the relationship is influenced by factor such as crop, surface roughness and profile saturation. In natural slope-effect studies, the logarithm of runoff from row crop was linearly and directly proportional to per cent slope. With good medowed and with smooth bare surfaces, the relationship was insignificant. The effect of slope on runoff decreased in extremely wet periods.

Soil loss increases much more rapidly than runoff as slope steepens. Zingg, A.W., was one of the early researchers to relate erosion to slope steepness (Zingg, 1940). He indicated, from the analyses of simulated rainfall data, that soil loss varied with slope steepness to the 1.49^{th} power and for application recommended the following relationship for slope factor:

$$S = (s/9)^{1.4} \qquad (2.21)$$

where S is the slope steepness factor and s is slope steepness in per cent. The '9' in the denominator of the equation normalises Zingg's original equation to 9 per cent steepness for consistency with the USLE unit-plot concept.

The next slope factor equation in the series soil loss equations that preceded the USLE was the equation by Smith and Whitt (1947), that was normalised to 9 per cent steepness, and can be written as:

$$S = 0.025+0.052\ s^{4/3} \qquad ...(2.22)$$

The slope factor in empirical equation developed by the Musgrave (1947) is:

$$S = (s / 9)^{1..35} \qquad ...(2.23)$$

Smith and Wischmeier (1957) reported a slope steepness function in their review of factors affecting sheet and rill erosion. When normalized to 9 per cent slope, their equation was as follows:

$$S = 0.00650\ s^2 + 0.0453\ s + 0.0650 \qquad ...(2.24)$$

The slope steepness factor S in the USLE (Wischmeier and Smith , 1978) expresses the effect of slope gradient on sheet and rill erosion. According to them, the equation published for S in Agricultural Handbook No. 537,the guideline manual for USLE, is:

$$S = 65.4 \text{ Sin } \theta + 4.56 \text{ Sin } \theta + 0.0054 \qquad ...(2.25)$$

This equation (2.25) is identical to the equation (2.24) except that per cent slope, s, was used instead of sine of the slope angle.

Smith and Wischmeier's equation for the Blacksburg data, when normalized to a 9 per cent slope, was

$$S = 0.044 + 0.10\ s - 0.0073\ s^2 \qquad ...(2.26)$$

The effect of slope steepness on erosion is nearly linear in this equation. However, Smith and Wischmeier gave this relationship minor treatment in their 1957 article and in later major USLE publications (Wischmeier and Smith, 1965, 1978). The only change from 1965 to 1978, in the S factor was to change slope per cent, which is actually tangent of the slope angle to sine of the slope angle, which is consistent with the relationship for the shear force of surface flow on its boundary (Chow, 1959).

$$\tau = \gamma R \sin\theta \qquad ...(2.27)$$

where, τ = shear stress of the flow on the boundary; γ = weight density of the runoff, and R = hydraulic radius. On slopes less than about 20 per cent, values of sine and tangent of the slope angle are nearly equal. Above 20 per cent, tangent of the slope angle increases rapidly and approaches infinity for a vertical slope where as sine of the angle approaches one. For slope of such steepness, no field data are available to test these values.

Another major USLE slope factor equation is the one recommended for application of the USLE to steep slopes (McCool *et al.,* 1987).

$$S = (\sin\theta / 0.0896)^{0.6} \qquad ...(2.28)$$

This equation was derived from measured cross-sections of rill on slopes ranging from 15 to 50 per cent.

Field data from about 20 studies on the effect of slope on sheet and rill erosion were analysed, to review the relationship for the slope steepness factor in the USLE by McCool *et al.,* (1987). The relationships derived from the analyses can be applied to a range of slope steepness less than 9 per cent and equal to or greater than 9 per cent. Application to slopes greater than 18 per cent represents an extrapolation beyond the observed data.

The relationships more reasonably predict soil loss values for research students on both low and steep slopes as compared to those values computed with the existent USLE slope-steepness relationship. Therefore, the following equations have been recommended by McCool *et al.,* (1987) for the use in the USLE:

$$S = 10.8 \sin\theta + 0.03, s \leq 9\% \quad ...(2.29)$$

$$S = 16.8 \sin\theta - 0.50, s \geq 9\% \quad ...(2.30)$$

where,

S = USLE slope steepness factor, and

θ = angle of slope for a steepness of s, expressed in per cent.

Above equations do not apply to short slopes where all of erosion is caused by raindrop impact and runoff freely discharges at the end of the slope. For these short slopes, the recommended slope factor equation is:

$$S = 3.0 \sin^{0.8}\theta + 0.56 \quad ...(2.31)$$

where,

S = USLE slope steepness factor, and

θ = angle of slope for a steepness of s, expressed in per cent.

This equation does not apply to slopes longer than 4 m.

2.2.4 Cover and management factor

The cover and management factor (C) in the soil loss equation is the ratio of soil loss from land cropped under specific conditions to the corresponding loss from clean-tilled continuous fallow. This factor measures the combined effect of all the interrelated cover and management variables. The loss that would occur on a particular field if it were continuously in fallow condition, was computed as the product of RKLS in the soil-loss equation.

Actual loss from the cropped field is usually much less than this amount. Just how much less depends on the particular combination of cover, crop sequence and management practices.

More than 10,000 plot years of runoff and soil loss data from natural rain, and additional data from a large number of erosion studies under simulated rainfall were analysed to obtain empirical measurements of the effect of cropping system and management on soil loss, at successive stages of crop establishment and development. Soil losses measured on the cropped plot were compared with corresponding losses from clean tilled, continuous fallow to determine the soil loss reduction ascribable to the effects of the cropping system and management. The reductions were analysed to identify and evaluate influential subfactors, interrelations and correlations. The value of C on a particular field is determined by many variables that can be influenced by management decisions. Major variables include crop canopy, residue, mulch, incorporated residue, tillage, land-use residual and their interactions. Each of these effects may be treated as subfactors whose numerical value is the ratio of soil loss with the effect to corresponding loss without it. Wischmeier (1975) represented the C factor as the product of all the pertinent subfactors:

$$C = C_1 C_2 C_3 \qquad \text{... (2.32)}$$

where, C is the cover and management factor for the USLE; C_1 is the effect of crop canopy and includes factors such as height of canopy, per cent of area covered by the canopy, and drop size (type-I effect); C_2 is the effect of mulch and close growing vegetation in direct contact with soil surface, the primary factor being the per cent of area covered (type-II effect); and C_3 is the residual effect of land use, including subsurface root network development and biological activity in soil that is undisturbed for long periods of time (type-III effect).

De Tar *et al.,* (1980) modified Wischmeier's (1975) approach for developing C values to handle the problem in landscaped areas. The effect of canopy cover was obtained from Wischmeier's plot of the type-I effect versus the per cent of ground covered by the canopy, for various heights of canopy. The equation produced was:

$$C_1 = [1 - F_1 P_c (1 - P_m) (1 - C_H)] [1 - P_1 P_c (1 - F_2)] \quad \text{... (2.33)}$$

where, F_1 is the decimal fraction of EI index occurring when there is a protective canopy; P_c is the actual decimal fraction of the entire area covered by the canopy; P_m is that decimal fraction of the entire area protected by the type-II effect; C_H is the type-I effect for 100 per cent canopy over bare, undisturbed soil; F_2 is the factor which represents that decimal fraction of the rainfall which has been termed "Vertical density" effect, and it takes into account the amount of water intercepted and moved downward through the stem and branches to the ground.

The type-II and type-III effects are combined into a curve as a plot of C_m versus P_m,

where,

$$C_m = C_2 C_3 \quad \text{... (2.34)}$$

and C_m might be termed as the combined mulch-residual effect.

It was observed that the landscaped area best fitted what Wischmeier called an "unmanaged woodland". The recommendation was to use 0.7 times the values for "permanent pasture, rangeland, and idle land", whenever P_m is less than 0.15. The final equation formulated was as follows:

$$C = 0.7\, C [1 - F_1 P_c (1-P_m) (1-C_H)] [1 - F_1 P_c (1 - F_2)] \quad \text{...(2.35)}$$

For, P_m less than 0.75.

For, P_m greater than or equal to 0.75, Wischmeier's "managed wood-land " method has been recommended, where a weighted average has been used.

$$C = P_m (C_L + (1 - P_m) C_B \quad \text{...(2.36)}$$

where,

$$C_L = 0.001, \text{ and}$$

$$C_B = 0.05 [1 - F_1P_c(1 - C_H)] [1 - F_1P_c(1 - F_2)].$$

If C_B is less than 0.003, it is recommended to substitute $C_B = 0.003$.

The following equation was developed by De Tar *et al.,* (1980) for predicting the C factor in the USLE, which uses plant characteristics as the basis:

$$100(1-C) = B = A + \sum_{i=1}^{5} W_i R_i$$
$$= A + W_1R_1 + W_2R_2 + W_3R_3 + W_4R_4 + W_5R_5 \quad \text{...(2.37)}$$

The Rs' are field rating for plant characteristics. They include the factors of canopy height (R_1), vertical density (R_2), leaf out time (R_3), canopy cover (R_4), and litter cover (R_5), which are based on the definition in Appendix I.

Using the equations (2.35) and (2.36) to determine values for B, a multiple regression analysis was done by Ross *et al.,* (1980). A regression equation of reasonably excellent fit was obtained, especially for species with less than 80 per cent litter cover. The regression equation yielded for P_m less than 0.80, was of the following form:

$$B = 100 (1 - C) \quad \text{...(2.38)}$$
$$= 77.9 + (0.06 R_1 + 1.38 R_2 + 0.67 R_3 + 1.00 R_4) / R_5 + 3.59 R_5$$

The regression equation produced high values of B with litter cover more than 80 per cent. Using only the data for 60 per cent and 80 per cent litter cover (R_5 = 5 and 6), the regression equation of the following form was produced with high degree of correlation and less variability:

$$B = 100\,(1-C) \quad \text{.......................} (2.39)$$

$$= 86.4 + (2.10.R_2 + 0.36.R_3 + 0.51.R_4)/R_5 + 1.99.R_5$$

for, P_m greater than or equal to 0.60.

It was found that canopy height (R_1) had little effect on B values when predicted with data for 60 per cent and 80 per cent litter cover. These equations, as argued by the developers, have been representing accurate evaluation of the best estimates of C values.

In the Revised Universal Soil Loss Equations (RUSLE) a subfactor method has been used to compute values of C factor(Kenneth *et al.*, 1991). The values of C factor are weighted average of soil loss rates (SLRs') that represent the soil loss for a given condition at a given time to that of a unit plot. The soil loss rates (SLRs') are computed as a function of four sub factors: prior land use, canopy, ground cover and soil effects. The sub factor relationship is given by the equation:

$$C = PLU.\ CC.\ SC.\ SR \qquad ...(2.40)$$

where, PLU is the prior land use subfactor, CC is the canopy subfactor, SC is the surface cover subfactor and SR is the surface roughness subfactor. To deal with varied effectiveness of surface cover factor in the RUSLE, the following equation is used:

$$SC = \exp(-b\,M) \qquad ...(2.41)$$

where, SC is the mulch or ground cover sub factor value and M is the percentage of ground cover. The coefficient 'b' is assigned a value either 0.025, the value in the USLE ; 0.035, the new "typical" value in the RUSLE or 0.05 for certain conditions. The value of 'b' is increased as the tendency of the soil for rill erosion to dominate over interrill erosion increases.

2.2.5 Support practice factor

By definition factor P in the USLE is the ratio of soil loss with a specific support practice to the corresponding loss with up and down slope culture. The most important of these supporting crop land practices are contour tillage, strip cropping on the contour, and terrace systems. A joint meeting of Science and Education Administration, and Soil Conservation Service-workshop group of the USA at Purdue University in 1956, adopted a series of contour P value that varied with slope. They included guidelines for slope length limits for effective contouring, based largely on judgement. The P values for contour strip cropping with reference to strip width and landslope per cent were recommended by the slope practice workshop, and were considered to be approximately maximum. Values of P factor recommended for contour-farmed broadbase, steep backslope, and level terraces vary with land slope. However, it has been recognized that the erosion control benefits of terraces are much greater than indicated by P values (Wischmeier and Smith, 1978).

2.3 Estimation of Soil Loss for Individual Storms

Estimates of soil loss for individual storms are required in analysis of non-point source pollution problems and for defining cost effective solutions. Erosion estimates for individual storms are required for probability analysis of erosion from selected design or observed storms. The USLE is widely used satisfactorily to estimate average annual soil loss from rainfall. Without modification, it is unsatisfactory for estimating soil loss from individual storms.

Williams (1975) proposed a modification to the USLE, *i.e.,* modified USLE or MUSLE, in which EI_{30} index was replaced by a newly derived index. The index so derived for R *factor* (rainfall runoff erosivity factor of USLE) provided a capacity to predict sediment yields from individual storms better than that was achieved by using the EI_{30} index. The new index for erosivity factor, composed of the runoff volume and the peak runoff rate, is as follows:

$$R = 11.8\,(Q \cdot q_p)^{0.56} \qquad ...(2.42)$$

where,

R = erosivity factor;

Q = volume of storm runoff, m^3 , and

q_p = peak runoff rate, m^3/s.

However, this index almost ignores the effect of rainfall energy on erosion. Onstad and Foster (1975) described a mathematical procedure to estimate soil detachment and transport, and consequently, sediment yield for single storms on watershed basis with better recognition of rill and interrill contributions. The improved index is represented as follows:

$$R_m = 0.5 \cdot EI_{30} + Q_T\, q_p^{1/3} \qquad ...(2.43)$$

where,

R_m = erosivity;

Q_T = storm runoff volume, m^3, and

q_p = storm peak runoff rate, m^3/s.

Eventhough runoff is main transporting agent and major factor in detaching soil particles from the soil during rill erosion, this index presupposes that an event having many peaks can be characterized by just one peak. Altering what constitutes separation between events can have a substantial effect on the index value for an event and aggregated value of the index over some period of time, such as month or season. In addition, some reduction in time base for determining the peak rainfall intensity has been considered necessary in order to account for the erosive effect of short duration high intensity storms (Lal, 1976). The storm events selected for the study always resulted in single peaked runoff hydrograph. Hence, the analysis in this study did not strictly require separate consideration for rainfall.

The erosivity index, QE_A index, avoided the needs to specifically determine the peak values (Kinnell, 1993). This index was based on the product of runoff rate (Q) and rainfall kinetic energy flux or rate of expenditure of rainfall kinetic energy (E_A).

$$QE_A\text{index} = \sum_{i=1}^{T}(QE_A)_i \qquad \ldots(2.44)$$

where, T is the no. of time units in a rainfall event. Subsequent analyses of the results from laboratory experiments conducted by Kinnell (1993) showed that sediment transport by rain impacted flow varied with flow depth and velocity, in such a manner that temporal variations in flow discharge and rainfall energy have a significant influence on sheet and interrill erosion.

Kinnell (1995) reported that in past, hydrological considerations had received little direct attention within R factor used in the USLE and this situation remains in the RUSLE also. Some consequences of replacing EI_{30} erosivity index by the I_XE_A index, an index based on the product of the excess rainfall rate (I_X) and rainfall kinetic energy flux (E_A), were considered in the study conducted by Kinnell (1995). One consequence of replacing the EI_{30} erosivity index by the I_XE_A index in an event based on empirical model was to provide the capacity to give separate consideration to soil-topography-vegetation-management-climate interactions on sediment concentration and runoff separately. Also, as the basis of the I_XE_A index is more consistent with the sediment transport principles, the particular index has the capacity to enhance the prediction of sediment movement across the landscapes by that used, or more correctly, misused USLE technology (Kinnell, 1995). The excess rainfall rate (I_X) was used as a surrogate for Q even when the infiltration rate used to determine I_X was assumed to be constant throughout a storm:

$$I_x = I - I_s;\ I > I_s \qquad \ldots(2.45)$$

$$I_x = 0;\ I \le I_s$$

where,

I = rainfall rate, and

I_s = infiltration rate.

where,

E_A = rainfall kinetic energy flux.

The storm rainfall erosion model that resulted from replacing the EI_{30} index with the I_xE_A index was represented, by Kinnell (1995), as:

$$A_e = K_e L_f S_f C_f P_f \sum_{j=1}^{T} (I_x E_A)_j \qquad \ldots(2.46)$$

where,

E_A = rainfall kinetic energy flux;

A_e = soil loss (mass per unit area) for a rain storm of duration T;

K_e = soil factor with values that vary between events;

L_f = slope length factor;

S_f = slope gradient factor;

C_f = crop (vegetation) factor, and

P_f = soil erosion protection factor.

2.3.1 Kinetic energy of rainfall

Kinnell *et al.*, (1994) analysed data on rainfall and runoff on a per-storm basis, from about 150 erosion events at Holly Springs in terms of the EI_{30}, QE_A and I_xE_A indices. Rainfall kinetic energies were based on the following relation:

$$E_A = 29.0\, I\, [\, 1 - 0.72 \exp(\, 0.05\, I\,) \qquad \ldots(2.50)$$

where, E_A has units of $J / m^2.h$ (United States customary units) and I (rainfall intensity) has units of mm/h. This equation follows directly from the intensity unit kinetic energy relationship used in RUSLE (Renard *et al.* ,1993).

The experiments at Gunnedah by Kinnell *et al.,* (1994) yielded a relation for rainfall kinetic energies of the following form:

$$E_A = 29.0\ I\ [\ 1 - 0.596 \exp(\ 0.0404\ I\ ) \qquad ...(2.51)$$

where,

E_A is in units of $J/ m^2.h$, and I is in mm/h.

Both methods recommended by Kinnell (1993, 1995) use a term, E_A, to represent rainfall kinetic energy. The computation of the term, E_A, has been based on above-mentioned empirical equations. Hence, its scope is limited to the specific areas mentioned above. Therefore, its application in the present study would not have yielded better accuracy.

2.4 Conversion of USLE Units

International application of the USLE necessitated conversion of USLE units and dimensions to the SI metric units. However, when basic data for the USLE factors are in SI units, values for the USLE factors can be computed directly in SI units without conversion from US customary units (Foster *et al.*, 1981).

2.5 Sediment Graph

Sherman (1932) recognized the relationship between the hydrograph's base time dependency on duration and proportionality of the hydrograph's ordinates to the amount of excess precipitation. Circa 1932, Sherman presented the Unit Hydrograph concept, which has been recognized as one of the most powerful methods of prediction in hydrology.

In the early 1940s, Johnson (1943) first recognized the relationship that existed between hydrograph and the Sediment Graph in certain watersheds. The parallel loci characteristics of consequent and peak discharge graphs enabled the construction of a Unit Sediment Graph. The Unit Sediment Graph is analogous to Unit Hydrograph, however, the ordinate units of the unit graphs are not similar. Heidel (1956) pointed out that depending up on the location of gaging point in a watershed, the Sediment Graph peak would precede, coincide with or lag behind the hydrograph peak.

The method formulated by Oswald (1974) is applicable to certain small watersheds, and can estimate sediment discharge on per-storm basis depending on the amount of effective precipitation. The original premise proposed in this study was that the Unit Hydrograph concept as applied to Direct Runoff Hydrograph was directly analogous in the analysis of Sediment Graph. A form of Unit Sediment Graph was indeed developed whose standard unit was 1.0 tonne for a given duration, distributed over the watershed area, analogous to Unit Hydrograph analysis of 1.0 in. of excess (effective) rainfall over the same area.

In case of stage hydrograph, baseflow was assumed to comprise both ground water flow and interflow. Baseflow for the Sediment Graph was assumed to be sediment flow prior to the beginning of the rise of a Sediment Graph for a particular storm event. Excess runoff and the associated sediment mobilized were determined as follows:

$$ER = \frac{2}{24}\sum_{i=1}^{2n-1}\frac{Q_{Di}}{A\,(26.9)} \qquad \ldots(2.52)$$

$$ES = \frac{2}{24}\sum_{i=1}^{2n-1}\frac{S_{Di}}{A} \qquad \ldots(2.53)$$

where,

ER	=	excess runoff, in./square mile;
ES	=	sediment mobilized, T/square mile;
Q_{Di}	=	direct water discharge, ft^3/s;
S_{Di}	=	direct sediment discharge, T/day, and
A	=	watershed area, square mile.

The term '26.9' is a factor for converting the remaining elements of the equation in tons per square mile and 'n' is the number of 2-h increments to which hydrograph time base was divided.

Individual Unit Sediment Graph ordinates were determined as follows:

$$USO_i = \frac{S_{Di}}{ES} \qquad ...(2.54)$$

in which, USO_i is Unit Sediment Graph ordinate in square miles per day. Multiplying USO_i by ES (T/square mile) yields S_{Di} (T/day). The Direct Sediment Graph ordinates were converted to individual "series" graph ordinate as follows:

$$SGO_i = \frac{S_{Di}}{ER} \qquad ...(2.55)$$

in which, SGO_i is an individual "series" graph ordinate, in T/day per inch of excess runoff per square mile.

In order to utilize a Unit Sediment Graph in generating Sediment Graph of a particular storm event, the total amount of sediment mobilized during the event would have to be known or estimated. A relationship has been determined between total sediment mobilized (ES) and excess runoff (ER) for single storm events.

Renard and Laurson (1975) computed Sediment Graph by multiplying the storm hydrograph flow rates by concentrations predicted with a sediment transport model. The application is limited to areas where sediment transport model is applicable, and the parameters can be determined successfully. However, it is not generally applicable to agricultural watersheds because it does not relate to source of erosion. Bruce *et al.*, (1975) described a Sediment Graph model, based on erosion and transport capacity. But several parameters must be optimized using gauged data. These parameters have to be replaced by physical descriptors for using in ungaged watersheds.

Williams (1978) developed a Sediment Graph model based on an Instantaneous Unit Sediment Graph (IUSG) applicable to ungaged agricultural watersheds. Storm Sediment Graph were predicted by convolving source runoff with an IUSG which is similar to the Instantaneous Unit Hydrograph (IUH), such that it is the distribution of sediment from an instantaneous burst of rainfall mobilizing one unit of sediment. The model depends on erosion sources, and only sediment from surface erosion is modeled. The IUSG ordinates are the products of ordinates of the IUH and sediment concentration. The initial sediment concentration of the IUSG has been assumed to vary linearly with source runoff volume; just as flow rate varies linearly with source runoff volume for IUH. The sediment concentration has been estimated by considering the sediment routing equation, based on travel time and particle size, developed by Williams (1975):

$$Y = Y_0 \, e^{-\beta T (d)^{1/2}} \qquad \text{...(2.56)}$$

where,

Y is sediment yield at a particular channel section; Y_0 is the sediment yield at an upstream section; β is the routing coefficient; T is the travel time between the two sections; and d is mean sediment particle diameter. The value of Y is predicted with Modified-USLE or MUSLE (Williams, 1975).

$$Y = 11.8 \, (V q_P)^{0.56} \, K \, (LS) \, C \, P \qquad \text{... (2.57)}$$

where, V is the runoff volume expressed in m^3, q_p is the peak rate of runoff in m^3/s; K is soil erodibility factor; LS is topographic factor; C is crop management factor; P is erosion control practice factor. The routing coefficient is derived from in the following equation.

$$\beta = \frac{-\ln(q_p / Q_p)^{0.56}}{T_p (d)^{1/3}} \qquad \ldots(2.58)$$

where, Q_p is the peak source runoff rate and T_p is the watershed time to peak. Sediment rates of the IUSG are the product of IUH flow rates and the sediment concentration distribution for one unit of runoff:

$$U_i = q_i \cdot c_i \qquad \ldots(2.59)$$

where, U is the IUSG flow rate; q is the IUH flow rate, and c is sediment concentration. The sediment concentration at any time Ψ is defined by concentration equation.

$$C_\Psi = C_0 e^{-\beta\Psi (d)^{1/2}} \qquad \ldots(2.60)$$

The initial sediment concentration C_0 produced by an instantaneous burst of one unit of runoff is a function of the detachment force of the runoff and rainfall. C_{0i} can be solved from the equation:

$$C_{0i} = \frac{(YQ_1)}{(g\sum_{j=1}^{m} Q_j^2)^{-1}} \qquad \ldots(2.61)$$

where,

$g = \int_0^\alpha e^{-\beta\gamma(d)^{1/2}} q d_\psi$;

γ = density of water, and

m = no. of source runoff increments.

Srivastava *et al.*, (1984) analyzed runoff and sediment-flow graph from a small watershed to determine the memory-less and dynamic prediction equation of sediment yield rate for the linear time-invariant dynamic model. A Unit Sediment Graph watershed fluvial system was hypothesized as a lumped dynamic system in the sense that it received surface runoff as quantitative input and acted according to and concertedly under given hydrometeorological and physiographical constraints to produce sediment yield as quantitative output. The present and recent past runoff-ratios reflect all the physiographical and soil characteristics of the watershed. The sediment yield ratio at the present time interval is considered as a function of the recent past sediment yield ratio. The number of parameters were reduced in order to obtain the following parsimonious sediment yield prediction equations:

$$\ln S_t = C + U_0 \ln Q_t \qquad \text{...(2.62)}$$

$$\ln S_t = C + U_0 \ln Q_t + W_1 \ln S_{t-1}$$

$$\ln S_t = C + U_0 \ln Q_t + U_0 \ln Q_{t-1} + W_1 \ln S_{t-1}$$

The Unit Sediment Graph method was employed by utilizing the runoff information as the basis for the prediction of sediment flow concentration. Individual Sediment Graph ordinates were determined as:

$$USO_i = \frac{S_{Di}}{ES} \qquad \text{...(2.63)}$$

where, USO_i is the Sediment Graph ordinate in ha/s; S_{Di} is the sediment flow rate in kg/s; and ES is the total sediment mobilized in kg/ha.

Chen and Kyo (1986) developed a new rigorous synthetic procedure to generate Unit Sediment Graphs for ungaged watersheds, based on a 1-h Unit Sediment Graph, which was defined as the Direct Sediment Graph resulting from one unit of effective sediment yield of a storm of 1-h duration distributed uniformly over the basin at a uniform rate. The instance of a log-transformed linear relationship between the effective runoff rate and the effective sediment yield rate, found by Chen (1984), has been made into use. It was noted that Effective Runoff Rate (ERR) responds according to the Effective Rainfall Intensity (ERI), while Effective Sediment-yield Ratio (ESR) responds according to the variation of the Effective Sediment Erosion Intensity (ESRI). It was postulated conceptually that the Effective Rainfall Intensity generates its counterpart the Effective Sediment Erosion Intensity, which, through the Unit Sediment Graph, results in a Sediment Graph. A relationship of the form $ESEI = \alpha (ERI)^{\beta}$ was used to evaluate Effective Sediment Erosion Intensity; where ESEI is Effective Sediment Erosion Intensity and ERI is Effective Rainfall Intensity. For the approximation of Effective Sediment Erosion Intensity, α and β were taken as the same coefficients used in the relationship between Effective Sediment-yield Ratio and Effective Runoff Rate. It was further assumed that effective sediment erosion occurred during the same period of effective rainfall and sediment erosion intensities were directly related to the rainfall intensities. Also the sum of Effective Sediment Erosion Intensities must be equal to Effective Sediment mobilized during the effective rainfall period specified.

Once the ordinates of a Unit Sediment Graph have been established by dividing the corresponding Direct Sediment Graph by the total sediment yield under the Sediment Graph. The resulting Direct Sediment Graph due to a number of one-hour Effective Sediment Erosion Intensities was obtained as follows:

$$Q_s(t) = \sum_{i=1}^{n} USG[D, t-(i-1)D]ESEID \qquad ....(2.64)$$

where,

$Q_s(t)$ = Direct Sediment Graph ordinates;

USG_i = Unit Sediment Graph ordinates;

ESEI = Effective Sediment Erosion Intensity , and

D = time interval for each Effective Sediment Erosion Intensity pulse.

The model produced the Direct Sediment Graph (DSG) at a given location of watershed as output using Effective Sediment Erosion Intensity (ESEI) as input which is the counterpart of the Effective Rainfall Intensity (ERI).

The regional 1-h Unit Sediment Graph was obtained by averaging all representative USGs' from all gaged watersheds. Finally, with peak sediment discharge (q_{sp}) as the dependant variable, soil characteristic (erodibility) (I_2) and geomorphologic parameters (I_3) as the independent variables, a linear regression function of the form $q_{sp} = f (I_2, I_3)$ was derived. Similarly, time base $T_s = f (I_2, I_3)$, and peak time $t_{sp} = f (I_2, I_3)$ were obtained. The USG for a specific watershed was synthesized from the derived regional dimensionless Unit Sediment Graph, by multiplying its ordinates and abscissa by q_{sp} and T_s respectively.

Kumar and Rastogi (1987) developed a conceptual catchment model of Instantaneous Unit Sediment Graph (IUSG) for Sediment Graph prediction and to determine the effect of soil conservation measures on sediment from a mountainous watershed by routing mobilized sediment through a series of linear reservoirs. The rainfall was conceptually, related to sediment mechanism through the linear reservoir concept similar to that outlined by Nash (1957). The conceptual model was formulated by routing the mobilized sediment through a cascade of equal linear reservoirs to represent an IUSG. But the model did not implicitly account for geometric configuration of the watershed. The Unit Sediment Graph, derived by Instantaneous Unit Sediment Graph, was convolved with mobilized sediment volume for the generation of the Direct Sediment Graph. The sediment mobilized during a storm was related to the rainfall excess by an expression of the form:

$$ES = a \cdot ER^{b} \quad \text{.................................(2.65)}$$

where,

ES = sediment mobilized, $t.km^2$;

ER = rainfall excess, $mm.km^2$, and

'a' and 'b' are coefficients.

This equation was used for computation of mobilized sediment during a storm, for which the Sediment Graph is desired.

A conceptual model of an Instantaneous Unit Sediment Graph, for the prediction of suspended sediment, was developed by Das and Agarwal (1990) using the concepts of time-area diagram outlined by Clark (1945). The dependence of the shape of the hydrograph on the travel time through the basin, and shape and storage characteristics of the basin, was conceptualized to hold true for the Sediment Graph. Similar to the development of hydrographs, in the development of Sediment Graphs, it was assumed that the watershed storage of sediment also applies two functions to the sediment mobilized (equivalent to rainfall runoff excess) in the watershed. The first is the translation of sediment mobilized through the watershed, and the second is its attenuation. Translation has been represented by a time-area histogram. It was assumed that a linear reservoir is hypothetically available at the watershed outlet to provide the requisite attenuation. By routing the flow through the linear reservoir, IUSG (of suspended sediment) for the watershed was determined. Assuming that the inflow ratio of sediment mobilized to the system is I, the outflow ratio of sediment is Y, and the sediment storage is S, the continuity equation in numerical form for the sediment flow has been expressed as:

$$\ddot{I} - \ddot{Y} = \frac{\Delta S}{\Delta t} \quad \text{...(2.66)}$$

Using subscripts 1 and 2 to represent the beginning and the end of the period respectively, the equation is expressed as:

$$\frac{(I_1 + I_2)\,\Delta t}{2} = \frac{(Y_1 + Y_2)\,\Delta t}{2} = S_1 - S_2 \qquad ...(2.67)$$

The Muskingham routing equation, when applied for suspended sediment, can be expressed as:

$$S = K\,(X\,I + (1 - X)\,Y) \qquad ...(2.68)$$

where, X is a dimensionless weighing factor, which expresses the relative importance of inflow and outflow, in determining sediment storage of suspended sediments, and K is the sediment storage constant. The equations (2.67) and (2.68) are reduced to:

$$Y_2 = m_0\, I_2 + m_1\, I_1 + m_2\, Y_1 \qquad ...(2.69)$$

where,

$$m_0 = \frac{-\,K_x + 0.5\,\Delta t}{K - K_x + 0.5\,\Delta t}$$

$$m_1 = \frac{K_x + 0.5\,\Delta t}{K - K_x + 0.5\,\Delta t}$$

$$m_2 = \frac{K - K_x + 0.5\,\Delta t}{K - K_x + 0.5\,\Delta t}$$

The value of x was assumed to be zero as the successive flow rates of the time-area diagram were to be routed through a linear reservoir of sediment. It was found that $m_0 = m_1$. Thus the equation simplifies to:

$$Y_2 = 2\,m_0\, I + m_2 \qquad ...(2.70)$$

which evaluates the ordinates of the IUSG. The value of runoff storage coefficient was measured by trial and error method.

Clark (1945) developed a relationship for runoff storage coefficient as a function of length and slope of the mainstream.

$$K = C\,L\,P^{-1/2} \qquad ...(2.71)$$

where, L is the length of longest waterway from the outlet, P is the mean channel slope of the waterway and e is a coefficient for sediment flow properties of the watershed. Linsley *et al.*,(1949) suggested another formula for the determination of runoff storage coefficient:

$$K = b\,L\,A^{1/2}\,P^{-1/2} \qquad ...(2.72)$$

where, A is the area of drainage basin and 'b' is a coefficient for the sediment properties of the basin.

Raghuwanshi *et al.*,.(1993) developed a conceptual model for the development of IUSG based on the routing of time-area histogram to generate wash load for a given storm event. The method of estimating IUSG, based on a combined approach of translation and attenuation, has been achieved by routing the time-area histogram of the mobilized sediment through a linear channel using Manning's routing equation. The equation used was analogous to Muskingham routing equation. The time of concentration, T_c, used in time-area histogram analysis was calculated using the empirical equation proposed by Kirpich (1940).

$$T_c = 0.0195\,L^{0.77}\,S_m^{-0.385} \qquad ...(2.73)$$

where, L is the main stream length (m); S_m is the equivalent uniform main slope of the watershed and was computed using the equation.

$$S_m = \left[\frac{n}{\frac{1}{\sqrt{S_1}}+\frac{1}{\sqrt{S_2}}+\ldots\ldots\ldots\ldots+\frac{1}{\sqrt{S_n}}}\right]^2 \qquad ...(2.74)$$

in which S_1, S_2,........, S_n are the slopes of the individual segments of the stream, and 'n' is the no. of individual segments.

The storage constant K, required for determining the attenuation of the inflow due to the channel storage, was evaluated using the following relationship:

$$K = \frac{\Delta V_s}{\Delta S} \qquad \ldots(2.75)$$

where, ΔV_s is the volume under a narrow band of the recession curve of the Sediment Graph and ΔS is the incremental sediment flow ratio over the band of flow ratio.

The total amount of mobilized sediment during the storm event must be known or estimated, in order to generate a Sediment Graph for a particular storm using the Unit Sediment Graph. To compute the mobilized sediment during the storm event, a relationship between mobilized sediment and excess rainfall was developed.

$$ES = a \cdot ER^b \qquad \ldots(2,76)$$

where,

ES = mobilized sediment, t/km^2;

ER = total excess-rainfall during the storm, mm, and

'a' and 'b' are coefficients.

The study does not invoke simulation under ungaged condition. So the estimation of soil erosion using IUSG was not necessary. However, the relationship between excess rainfall and sediment mobilized due to storm events was derived for the study.

2.6 Water Erosion Prediction Project (WEPP) model

The USDA – Agricultural Research Service (ARS) scientists and engineers initiated the Water Erosion Prediction Project (WEPP) to develop a new and improved erosion prediction technology. The technology was supposed to be process oriented and conceptually, a significant enhancement over the USLE. Therefore, the WEPP model was developed as "new generation water erosion prediction technology for use .... in soil and water conservation, environmental planning and assessment " (Foster and Lane, 1987). The WEPP is based on fundamentals of stochastic weather generation, infiltration theory, hydrology, soil physics, plant science, hydraulics, and erosion mechanics. The hillslope or landscape profile application of the model (which formed the fundamental core of the watershed model) provides advantages over existing erosion prediction technology: (1) state-of-the-art capability for estimating spatial and temporal distributions of net soil loss (or gain, in the case of deposition) for the entire hillslope or discrete points on the hillslope; and (2) the ability to extrapolate over a broad range of conditions that are difficult to test due to practical or economical reasons (Nearing *et al.*, 1990).

Following the original publication and distribution of the WEPP hillslope model in 1989 a substantial number of modifications have been made to increase applicability (usability), and to improve reliability. Some of the improvements were contained completely within the computer code and did not require changes in model input (for example, Representation of non-uniform overland-flow hydrology gave significant enhancements to model usability (Stone *et al.*, 1994).

The WEPP watershed-model is an extension of the WEPP hillslope-model. A beta version of the watershed model was completed in 1991, but it was not officially released. The beta version contained simple empirical equations for prediction of channel transmission-losses and peak runoff-rates, and it did not maintain a continuous water balance for the channels.

The WEPP watershed-scale model is based on fundamentals of erosion theory, soil and plant science, channel flow hydraulics and rainfall-runoff relationships. The WEPP watershed-scale model has been acclaimed as a continuous simulation-tool that extends the capability of the WEPP hillslope-model to provide erosion prediction technology for small cropland and range-land watershed applications. The model contains hillslopes, channels and impoundment as primary components. The hillslope and channel components have been further divided into hydrology and erosion components. Channel infiltration was formulated by the Green-Ampt Mein-Larson infiltration equation. A continuous water balance has been maintained including calculation of evapotranspiration, soil water percolation, canopy rainfall-interception and surface depressional-storage. The channel peak runoff ratio has been calculated using either a modified rational-equation or the equation used in the CREAMS model. Flow depth and hydraulic shear stress along the channel have been computed using regression equation based on the numerical solution of the steady-state spatially varied flow equations.

Detachment, transport and deposition within constructed channels or concentrated flow gullies have been calculated by a steady-state solution to the sediment continuity equation. The impoundment component routes runoff and sediment through several types of impoundment structures including farm ponds, culverts, filter-fences, and check dams (Ascough *et al.*, 1997).

Materials and Methods

MATERIALS AND METHODS

Soil erosion is one of the major problems attached to agriculture and environment. It is also a primary source of sediment that pollutes streams and fills reservoirs. Understanding the underlying causes of soil erosion and various factors influencing the process is the primary step towards the solution of the erosion related problems. The pertinent study is objectivized to assess the influence of land and vegetation management measures on soil erosion from a small watershed. The materials used and the methodology employed in the study are described under this chapter.

3.1 Watershed

The watershed selected for the study forms part of the Development Unit-IX of Attapadi region, in Palghat district. There are different kinds of land management across the watershed, viz., agricultural fields, barren lands left behind after tree felling, paddy fields, densely vegetated areas, etc. Its undulating topography and high intensity rainfall contribute to higher rates of runoff and soil erosion. Therefore, the watershed offers sufficient scope to study the effects of land and vegetation management measures on runoff and erosion processes. This is situated between 11^0 0' and 11^0 5' N latitude, and 76^0 32' 30" and 76^0 37' 30" E longitude. The watershed extends over an area of 9.2 km^2, with a maximum stream length of 6.44 km. The elevation difference between highest and lowest point is 200 m, where the lowest point being the gauging station at an elevation of 670 m above mean sea level. The location map of the watershed is shown in Fig. 3.1.a and Drainage map is shown in Fig. 3.1.b.

3.2 Climate

Climate is one of the major factors affecting soil erosion and the climatic factors are beyond the power of human to contröl. The rainfall is the major climatic factor, which influences the runoff and soil erosion. Although, factors

Fig. 3.1.a Location map of the watershed

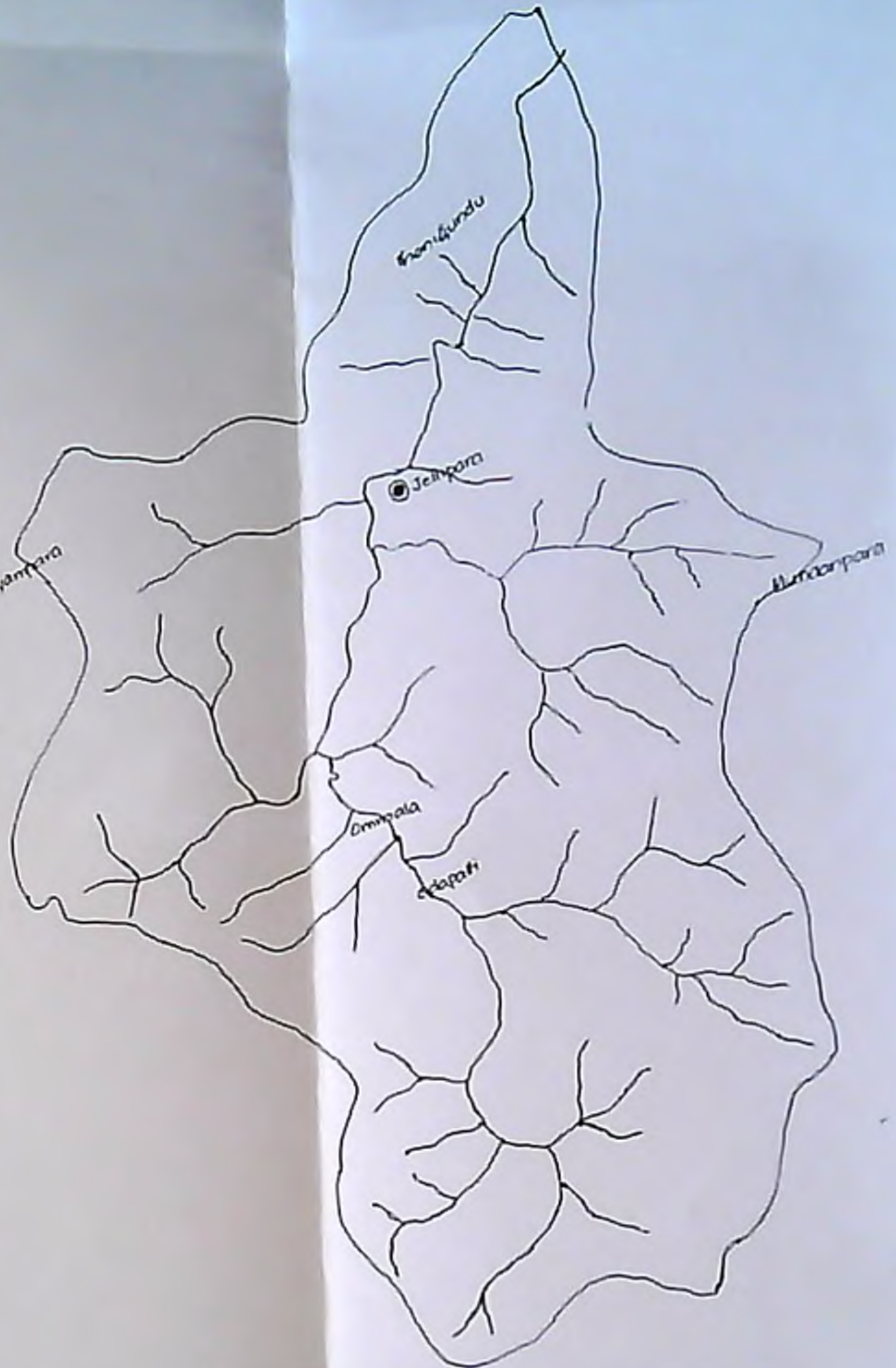

Fig. 3.1.b Drainage map of the watershed

Scale – 1 : 25000

Channels

Boundary

Raingauge station

like wind, temperature, humidity, evaporation, etc., have influence on runoff process, the rainfall erosion is less directly related to these factors.

3.2.1 Rainfall

The rainfall during the south-west monsoon is predominant in the watershed, in terms of amount as well as intensity. The isolated storm events, selected for the study, were observed during this period. Thus the observations of rainfall were done during the south-west monsoon months, viz., June and July, under the assumption that these months contribute large proportions of soil erosion. The rainfall data were collected during the months of June and July in 1998 and 1999. The location of the raingauge station is shown in Fig. 3.1. The observations were done using non-recording raingauge for daily rainfall and recording raingauge for continuous records during isolated storm events selected for the study. The storm, which resulted in isolated single-peaked hydrographs were chosen for the study. The storm events, selected, were observed on 21-06-'98, 29-06-'98, 19-07-'98, 11-06-'99, 18-06-'99, 06-07-'99, and 17-07-'99.

3.3 Soil Properties

The physical properties of soil affect the infiltration capacity and the process through which soil particles are detached and transported. The texture, organic matter content, permeability, and infiltration rate were determined for the study. The textural composition and organic matter content were determined for the samples collected from the surface soil at hillslope and paddy field, and subsoil at a depth 30 cm. The permeability and infiltration studies were conducted for the soils at hillslope and paddy field. The soil samples for permeability study were taken from two locations at hillslope and one location at paddy field.

3.3.1 Soil texture

The soil texture is one of the physical properties that has profound influence on soil detachability and transportability. The textural compositions of various soil separates were determined by sieve analyses and sedimentation analyses. The textural composition of the soil was determined by particle size distribution analysis, according to IS 2720 (part IV). The particle size distribution of the portion of the soil sample, passing through 4.75-mm IS sieve and retained on 75-micron IS sieve, was determined by sieve analysis. The portion of the soil particles passing through 75-micron IS sieve was analysed by sedimentation method to determine its particle size distribution.

3.3.1.1 Sieve analysis

The particle size distribution of the portion of soil sample with particle diameter above 75 micron was determined by wet sieve analysis. The portion of a soil, approximately 200 g, passing through 4.75-mm IS sieve was oven-dried, soaked and washed over the nest of sieve comprising 2-mm IS sieve, 425-micron IS sieve and 75-micron IS sieve. Two grams of dispersing agent (sodium hexametaphosphate) was added per litre of the water used for soaking and washing. The fraction of soil particles retained on each sieve was oven dried at 105 to 110^0 C, and weighed to account the particle size distribution.

3.3.1.2 Sedimentation analysis

The fraction of the soil particles passing through 75-micron IS sieve during sieve analysis, out of the portion passing 4.75-mm IS sieve, was subjected to sedimentation analysis by hydrometer method. The sample weighing 50 g from air-dried soil passing through the 4.75-mm IS sieve was weighed and placed in a conical flask. One hundred and fifty milliliters of hydrogen peroxide was added to the soil sample in the conical flask. After stirring, the mixture was left to stand overnight in the conical flask covered with glass. The mixture in the conical flask was gently heated in an evaporating dish to reduce the volume, to about 50 ml by boiling. The mixture was oven dried at 105 to 110^{0}C, and weighed. The oven-dried soil thus obtained in evaporating dish was added with 100 ml of sodium hexametaphosphate solution, and warmed gently for 10 minutes. (The sodium hexametaphosphate solution was prepared by dissolving 33 g of sodium hexametaphosphate and 7 g of sodium carbonate in distilled water to make one litre of solution). The soil mixture in evaporating dish was transferred to the 75-micron IS sieve, using a jet of distilled water. The soil suspension passing through 75-micron IS sieve was transferred to 1000-ml measuring cylinder and was made up to 1000 ml by adding distilled water. This suspension was used for sedimentation analysis. The material retained on 75-micron IS sieve was oven-dried and weighed.

The soil suspension in the measuring cylinder was shaken vigorously. On cessation of shaking, the measuring cylinder was allowed to stand still and the stopwatch was started. The hydrometer was immersed and allowed to float freely in the suspension. The hydrometer readings were taken after periods of half, one, two, and four minutes. The hydrometer was removed, rinsed and kept in a cylinder of distilled water. The hydrometer was re-inserted in the suspension and readings were taken after periods of 8,15, and 30 minutes, one, two, and four hours. The last reading was taken at the end of 24-h period, while readings were taken once or twice within 24 hours after 4-h period hydrometer reading. The diameter, and the per cent by mass of particles smaller than the corresponding equivalent particle diameter were calculated using the formulae given in Appendix II.

3.3.2 Organic matter content

The organic matter content was determined based on the organic carbon present in the soil. The organic matter content was obtained from organic carbon content by multiplying it with 1.724. The organic carbon content of soil was found out by titration. One gram of the soil sample (passing through 0.5-mm IS sieve) was weighed into a 250-ml flask. Ten millilitre of 1-N Potassium Chromate ($K_2Cr_2O_7$) solution was pippetted into the flask and swirled gently, until soil and reagents were mixed. Afterwards, it was swirled vigorously for one minute. Hundred millilitres of distilled water was added to this mixture after allowing it to stand for 30 min. Three to four drops of indicator were added to it and titrated with 0.5-N Ferrous Sulphate ($FeSO_4$) solution. As the endpoint was reached, the solution took on a greenish cast and then changed to dark green. At this point the Ferrous Sulphate solution was added drop by drop until the colour changed sharply from blue to red, in reflected light against a white background. The percentage organic carbon in the soil on air-dry basis is given by:

$$\text{per cent organic carbon} = \frac{(M_e\, K_2Cr_2\, O_7 - M_e\, FeSO_4)\ 0.3\ f}{\text{mass of air dry soil in grams}} \qquad \text{... (3.1)}$$

where,

f = correction factor, and

M_e = normality of solution x volume of solution used, ml.

3.3.3 Permeability

The permeability of the soil was determined using a falling head permeameter as per IS 2720 (part XXVII). The soil sample was collected in a steel cylinder of 10 cm diameter and 13 cm length, to obtain undisturbed soil specimen for permeability analyses. The soil specimen was placed in permeameter assembly, of which the top inlet was connected to the selected standpipe. The bottom outlet was opened and time interval required for the water level to fall, from a known initial head to a known final head measured above the center of the outlet, was recorded. The standpipe was refilled with water, and the test was repeated till three successive observations gave nearly same time interval. The time intervals were recorded for the drop in head from the initial to final values, as in the first determination. The coefficient of permeability of the soil was calculated as described in Appendix III.

3.3.4 Infiltration studies

The infiltration studies were conducted at different locations in the watershed using double ring infiltrometer. This infiltrometer consisted of two concentric rings, which were driven into the ground surface, and were filled with water. The outer ring was believed to supply the water that migrated laterally and at the same time saturate the soil next to the inner ring. Water in the inner ring was then thought to be able to move vertically into the soil. The cylinders were 25 cm deep and were installed at a depth of about 10 cm in the soil. The inner cylinder, from which the infiltration measurements were taken, was 30 cm in diameter and the outer cylinder, which was used to form the buffer pond, was 60 cm in diameter. The water level in the inner cylinder was monitored with a hook gauge. A known quantity of water was added to inner cylinder, which was filled up to a specific level. The hook gauge was set at this specific level. A stopwatch was used to note the time the added water reached the specific level. The difference, between the quantity of water added and the volume of water in the cylinder at the instant it reached the point, was taken as the quantity of water that infiltrated during the time interval between the start of filling and the first observation. After the first reading, hook gauge readings were noted at frequent intervals to determine the amount of water that had infiltrated during the time interval. Water was added quickly after each measurement in order to maintain an approximately constant average infiltration head. The buffer pond was filled with water immediately after filling the inner cylinder. Water levels in the inner cylinder and the buffer pond were kept approximately the same.

The functional relationship between accumulated infiltration, Y, and elapsed time, t, was best represented by the equation $Y = a t^{\alpha} + b$, where a and b are constants. The values of Y and t were plotted on a log-log scale to get a straight-line relationship, and infiltration equations were derived.

3.4 Geomorphologic Parameters of the Watershed

A multitude of dimensionless parameters has been proposed to quantitatively define linear and areal aspects of the watershed shape. The parameters, relevant to the study, worked out for the watershed were form factor, shape factor, circularity ratio, elongation ratio, mean basin slope, drainage density, and bifurcation ratio. These factors also involved watershed length, which was defined as length of the main stream from its source (projected to boundary of the watershed) to the outlet.

3.4.1 Form factor

The form factor, is defined as the ratio of the basin area to the square of the basin length. The form factor, R_f is given by the equation:

$$R_f = A / L^2 \qquad ...(3.2)$$

where,

A = area of the basin, m^2, and

L = length of the basin, m.

A value of form factor equal to unity refers to a square basin, where the tributaries often tend to come together and join the main stream at the centre of the area. Consequently, the separate runoff peaks generated by a heavy rainfall in the individual tributaries reach the main stream together separately and temporarily, thereby resulting in a large and rapid increase in runoff. The shape factor is the reciprocal of the form factor.

3.4.2 Circularity ratio

The circularity ratio of a basin is defined as the ratio of the basin area to the area of circle having the same perimeter as the basin. The circularity ratio, R_c is given by the formula:

$$R_c = \frac{4 \pi A}{P^2} \qquad ...(3.3)$$

where,

A = area of the basin, m^2, and

P = perimeter of the basin, m.

For a circular basin the value of 'R_c' is equal to 1.0. In this basin, water from lower, middle and upper catchments reaches the outlet in less time and cause higher discharge during a shorter period.

3.4.3 Elongation ratio

The elongation ratio is defined as the ratio of the diameter of a circle, whose area is same as the basin area, to the length of the basin. The elongation ratio, R_e is expressed as:

$$R_e = \frac{2\sqrt{\frac{A}{\pi}}}{L} \qquad ...(3.4)$$

where,

A = area of the basin, m^2, and

L = length of the basin, m.

In the case of a more elongated basin the value of 'R_e' approaches unity. If the basin is long and narrow the tributaries tend to be relatively short and are more likely to join the main stream at intervals along its length. This means that after a heavy rainfall over the area, the runoff peaks of the lower tributaries would have left the catchment before the peaks of the upstream tributaries have reached the basin outlet. Elongated catchments are thus less subjected to high runoff peaks.

3.4.4 Mean basin slope

A simple measure of average ground slope within a basin usually employed in hydrological analysis, is the mean basin slope.

$$\text{Mean basin slope} = \frac{\text{Total length of contour (m) x contour interval (m) x 100}}{\text{Basin area (m}^2\text{)}}$$

Steep slopes generally have high surface runoff values and low infiltration rates. Consequently they add to the steepness of the hydrographs and lead to relatively high peaks of discharges. The high velocity and proportions of overland flow easily lead to sheet, rill, and ultimately, gully erosion.

3.4.5 Drainage density

The drainage density of a basin is defined as the length of drainage per unit area. The term, D_d is expressed as.

$$D_d = L/A \qquad ...(3.5)$$

where,

L = total length of channels of all orders in the drainage basin, km, and

A = area of the drainage basin, km^2.

This term is a measure of the closeness (density) of channels and an indication of the drainage efficiency and the length of overland flow, as well as the index of the relative proportions.

3.4.6 Bifurcation ratio

The bifurcation ratio of channels of a particular order is the ratio of the number of channels of the immediate lower order to that of the particular order considered. It is expressed as:

$$R_{bn} = \frac{\text{No. of channels of (n-1) order}}{\text{No. of channels of n order}} \quad ...(3.6)$$

where,

R_{bn} = bifurcation ratio of particular order of channels.

3.4 Runoff

Streamflow representing runoff phase of the hydrologic cycle was measured amenable to fairly accurate assessment unlike other variables. The flow discharge in a stream was related to the stage through a series of careful measurements. The stage of stream, the water surface elevation above the point of zero flow in the stream, was measured by noting the elevation of the water surface in contact with a fixed graduated staff. The stage measurements were made at 30-min time intervals except near the peak. Near the peak, measurements were made at 15-min time intervals to clearly define the peak. The velocity of flow corresponding to each stage level was noticed using surface floats. The stage level readings observed at different time intervals were converted into rates of runoff by area-velocity method.

3.5 Sediment Concentration

The samples of sediment were collected at different intervals to determine the distribution of its concentration with respect to time during the period of runoff event. The duration of sampling and time intervals selected were in conjunction with the discharge measurement. The sediment sampling was done in a single vertical section of the stream. The collection of samples were made at a depth equals to 0.6 times the depth of flow along the vertical central line of the section. The possibility of depth integrating sampling was restricted, because the sampler was not filled when it was lowered to the bottom and raised again to the surface, especially at smaller depths. The concentrations of sediments in the samples were determined on weight basis by dividing the weight of dry sediment obtained after oven drying by the weight of the suspension.

3.6.1 Sediment sampler

The sediment samples were taken at regular intervals during the runoff process accompanying a rainfall event. A United States Department of Hydrology (USDH) depth-integrating sampler used in the study is shown in Plate I. It consisted of a can of capacity 500 ml, into which water along with sediment was collected. The inlet of the sampler was a detachable unit so that the diameter at the entry could be adjusted to suit the velocity of flow. There was a graduated rod, which was screwed on to the sampler for lowering into stream. The can is removed at the end of the sampling to collect the sediment sample.

3.6 Hydrograph

A streamflow hydrograph at any point on a stream is a graph of the time distribution of water discharge at that point. The hydrographs that resulted due to isolated storm events were obtained by plotting single peaked skew distribution of stream flow, chronologically. The rates of flow corresponding to different time intervals were plotted on the ordinate and time on the abscissa. The rates of flow through the stream corresponding to different time intervals were obtained by converting the stage heights into discharge using area-velocity method.

3.7.1 Baseflow separation

The delayed flow that reaches a stream, essentially, as ground water flow is called baseflow. Many times delayed interflow is also included under

(Plate I Sediment sampler)

this category. The Direct Runoff Hydrograph is obtained from stream flow hydrograph after baseflow separation. The baseflow is deducted from the stream flow hydrograph in the following ways.

The baseflow can be separated, by drawing a straight-line tangent to both the limbs at their lower portions. This method is very simple, but it is approximate and can be used for preliminary estimates.

In the fixed base method, surface runoff is assumed to end at a fixed time, N days after the hydrograph peak. The baseflow, before the surface runoff began, is projected a head to the time of the peak. A straight line is used to connect this projection at the peak to the point on the recession limb at N days after the peak, where $N = 0.83\ A^{0.2}$, and A is the drainage area, km^2. Baseflow can also be separated by drawing a line from the point of rise to the point on the recession limb, N days after peak.

The above two methods could not be used for the present study because the value of N obtained (31 hours) was more than the total base period of the hydrographs in all the instances.

The variable slope method of baseflow separation was applied for this particular study. In this method, the baseflow curve before the surface runoff began is extrapolated forward to the time of peak discharge, and the baseflow curve after surface runoff ceases is extrapolated backward to the point of inflection on the recession limb. A straight line is used to connect the endpoints of the extrapolated curves. This type of separation is preferred where groundwater contributions are relatively large and reach the stream fairly rapidly. The method of baseflow separation is shown in Appendix IV.

3.8 Unit Hydrograph

The Unit Hydrograph is the unit pulse response function of the linear hydrologic system. First proposed by Sherman (1932), the Unit Hydrograph (originally named unit-graph) of a watershed has been defined as a Direct

Runoff Hydrograph resulting from unit depth of excess rainfall generated uniformly over the drainage area at a constant rate for an effective duration. The Unit Hydrograph was obtained from Direct Runoff Hydrograph based on the assumption of time invariant and linear response of the direct runoff to the effective rainfall in the watershed.

The Unit Hydrograph ordinates were obtained by dividing the ordinates of direct-runoff hydrograph by the volume of runoff under Direct Runoff Hydrograph converted to the equivalent depth (in centimeters) distributed uniformly over the entire drainage basin.

3.9 Sediment Graph

It is generally observed that suspended sediment concentration in a stream arises and declines in a manner similar to that of streamflow due to an isolated runoff event. The sediment discharge due to runoff is the product of water discharge and sediment concentration. The sediment concentrations at different time intervals in conjunction with the streamflow hydrograph ordinates were determined by sediment sampling. Thus the sediment discharge distribution for the duration of runoff event was determined and was plotted against the time. The Sediment Graph obtained in this manner, commensurate with the Direct Runoff Hydrograph.

3.10 Direct Sediment Graph

The Direct Sediment Graph (DSG) accompanying a rainfall event was prepared from Sediment Graph after the baseflow separation. The DSG was conceptualized as the sediment mobilized due to the effect of a rainfall event. The procedure employed in baseflow separation was same as the procedure used for the runoff hydrograph described in Appendix IV. The Direct Sediment Graph was utilized in developing the Unit Sediment Graph (USG).

3.11 Unit Sediment Graph

The Unit Sediment Graph (USG) was developed whose standard unit was one tonne (1000 kg) for a given duration, distributed over the watershed area analogous to the Unit Hydrograph analysis of 1 cm of excess rainfall over the same area. The construction of Unit Sediment Graph entails a procedure similar to that of Unit Hydrograph derivation. The sediment mobilized from a particular rainfall was estimated as the area of Direct Sediment Graph. The sediment mobilized was calculated as follows.

$$ES = QS/A \qquad ...(3.7)$$

where,

ES = sediment mobilized, T/km^2;

QS = total sediment mobilized , T, and

A = area, km^2.

The ordinates of Unit Sediment Graphs were calculated, by dividing the Direct Sediment Graph ordinates by the sediment mobilized expressed in tonnes per square kilometre. The procedure is reproduced as equation in the following fashion:

$$USO_i = Sd_i / ES \qquad ...(3.8)$$

where,

USO_i = i^{th} Unit Sediment Graph ordinate;

Sdi = i^{th} Direct Sediment Graph ordinate, and

ES = sediment mobilized, T/km^2.

3.12 Universal Soil Loss Equation (USLE)

The USLE has been most universally accepted soil loss prediction tool to estimate annual soil loss from rainfall. This procedure is founded on an empirical soil loss equation that is believed to be applicable whenever numerical values of its factors can be estimated. The USLE was used in the present study to simulate the soil erosion processes concomitant with single storm event. The equation (2.3) described in Chapter II was used to predict the soil loss. The equation can be expressed as follows:

$$A = R\ K\ LS\ C\ P \qquad ...(3.9)$$

where,

A = soil loss;

R = erosivity;

K = erodibility;

LS = topographic factor;

C = cover and management factor, and

P = support practice factor.

The methodology adopted to determine various factors, which form variables in the equation, are described in the following sections.

3.12.1 Erosivity factor

The USLE has been widely used to satisfactorily estimate average annual soil loss from rainfall. Nevertheless, without modification, the satisfactory adaptation of the equation for estimating soil loss resulting from single storm is seen not viable. The per-storm basis application of the USLE was accomplished after modification of the erosivity factor (R) with due concern to the effect of runoff. Williams (1973) postulated different erosivity factors for individual storm events.

Williams (1975) put forward an erosivity factor for the USLE to apply on a per-storm basis. He replaced rainfall erosivity factor with a runoff factor to develop Modified-USLE (MUSLE). The MUSLE is expressed as:

$$Y = 11.8\ (Q\ .\ q_p)^{0.56}\ K..L.S.C.P \qquad ...(3.10)$$

where,

Y = sediment yield from an individual storm, T;

Q = storm runoff volume, m^3;

q_p	=	peak runoff rate, m^3/s;
K	=	soil erodibility factor;
LS	=	slope length and gradient factor;
C	=	crop management factor, and
P	=	erosion control practice factor.

3.12.2 Erodibility factor

The soil erodibility factor (K), an experimentally determined quantitative value, was calculated using an equation based on the mechanical analysis data. The specified equation for the soil erodibility factor is represented in the following form:

$$100\ K = 21.1 \cdot M^{1.14}(10\text{-}4)\ (12\text{-}a) + 3.25\ (b\text{-}2) + 2.5\ (c\text{-}3) \qquad \ldots(3.11)$$

where,

M	=	particle size parameter which equals per cent silt (0.1 - 0.002 mm) times the quantity 100-minus-per cent day;
a	=	per cent organic matter;
b	=	soil structure code, and
c	=	profile permeability class.

3.12.3 Topographic factor

The topographic factor (LS) involves both the slope-length and slope-steepness factors. The slope length factor (L) was calculated using the equation:

$$L = (\lambda / 22.1)^{m} \qquad \ldots(3.12)$$

where,

L	=	slope length factor;
λ	=	slope length, m, and

m = 0.5, if the per cent slope is 5 or more;
0.4, for the slopes 3.5 to 4.5 per cent, and
0.3, for the slopes 1 to 3 per cent.

The slope steepness factor(S) was calculated based on the equation:

$$S = 65.41 \sin^2\theta + 4.56 \sin\theta + 0.065 \quad \text{.................... (3.13)}$$

where,

S = slope steepness factor, and

θ = angle of slope.

The Revised-USLE (RUSLE) uses revised factors for the both the slope length and slope steepness factors, accountable to the ratio of the interrill and rill erosion. The revised slope-length factor used was determined using the following equations:

$$L = (\lambda / 22.1)^m \quad \text{...(3.14)}$$

where,

L = slope length factor;

λ = slope length, m, and

m = $\beta / (\beta + 1)$.

where,

β = ratio of rill to interrill erosion, or

$$\beta = \frac{(\text{Sin}\,\theta / 0.0896)}{(3.0\ \text{Sin}^{0.8}\theta + 0.56)} \quad \text{...(3.15)}$$

The revised slope steepness factor was decided based on the following equation

$$S = 10.8\ \text{Sin}\,\theta + 0.03\ ;\ S < 9\% \quad \text{...(3.16)}$$

$$S = 16.8\ \text{Sin}\,\theta - 0.50\ ;\ S \geq 9\% \quad \text{...(3.17)}$$

where,

S = slope steepness factor, and

θ = angle of slope.

3.12.4 Cover and management factor

The comprehensive effect of all the inter-related cover and management variables is encapsulated into the cover and management factor (C). The C factor in the soil loss equation is the ratio of the soil loss from land cropped under specified conditions to corresponding loss from clean-tilled continuous fallow. The equation (2.37) described in Chapter II (De Tar *et al.*,1980) of the form specified below was used to predict the C factors in the USLE:

$$100(1-C) = B = A + \sum_{i=1}^{5} W_i R_i$$

$$= A + W_1R_1 + W_2R_2 + W_3R_3 + W_4R_4 + W_5R_5 \qquad \ldots(3.18)$$

The Ws' are weightage given to Rs' which stand for plant characteristics. The Rs' include the factors of canopy height (R_1), vertical density (R_2), leaf on-time (R_3), canopy cover (R_4), and litter cover (R_5).

The watershed area was divided into five sections to represent different land and vegetation management systems. They are Paddy fields, Barren lands, Vegetable crops, Mixed crop system, and Tuber crops. The C factor values were computed for these management systems based on the above-said formula. The representative C factor of the watershed was computed as weighted average of the C factor values for different systems, with weights being the representative areas.

3.12.5 Support practice factor

The decelerating effect on soil erosion due to support practices is accounted in the support practice factor (P). The P factor has been assigned value based on the type of soil protection measure adopted and its effectiveness in the control of erosion. The P factor values were determined for different management system specified above. The representative P factor for the watershed was calculated similar to that of C factor as mentioned above.

3.13 WEPP Hillslope / Watershed Model

The WEPP erosion model represents the prediction technology based on fundamental hydrologic and erosion mechanics science. The WEPP allows both spatial and temporal estimates of erosion and deposition on watersheds consisting of hillslopes and channels. The satellite Programs accompanying the WEPP program consisted of an interface and several file builders, and graphics programs. The interface is meant to be an easy-to-use tool for the user to organize input, output, and run files. The WEPP hillslope / watershed model was used in the study to simulate the runoff and soil erosion processes. The model is WEPP hillslope / watershed-model, Beta 3.0 version and is adaptable to Windows95/98/NT platform. The distributed input parameters include rainfall amounts, intensity, soil-textural qualities, plant growth parameters, residue-decomposition parameters, effect of tillage implements on soil properties and residue amounts, slope shape, slope steepness and orientation, and soil erodibility parameters. Unlike the usual procedure of continuous simulation, the simulation was done on single storm event basis. Thus the sensitivity of plant growth parameters, residue-decomposition parameters, effect of tillage and residue amounts was meager. The model as applied to hillslopes can be subdivided into nine conceptual components: climate generation, winter processes, irrigation, hydrology, soils, plant growth, residue decomposition, hydraulics of overland flow, and erosion. The pertinent simulation used in this study has been limited to components of climate, hydrology, hydraulics of overland flow, soils and erosion, because only these components form imperative in event based simulation. The entire watershed area was divided into ninety-eight hillslopes and, simulation of runoff and erosion processes were done for each hillslope for the single storm events.

Results and Discussion

RESULTS AND DISCUSSION

The soil erosion is acclaimed as one of the major agricultural perils and environmental hazards. Understanding of this complex phenomenon has been a big challenge owing to the heterogeneity of the conditions and environments under which it prevails. The present study is aimed to comprehend the effects of man-made alterations on the soil erosion by water, on a small watershed. The watershed, Development Unit-IX of Attapadi region, in Palghat district, was selected for the study. The results obtained from the study are presented and discussed in this chapter.

4.1 Climate

The climatic factors bear a profound influence on hydrological processes and erosion. The various factors like precipitation, temperature wind, and humidity attribute to the major differences among runoff regimes in the regions of similar geology and morphology. Temperature in conjunction with sunshine, wind, and humidity governs the evaporation losses and subsequently, the hydrological cycle. Rainfall as an input to the watershed forms the most prevalent form of precipitation and influences the runoff generation.

4.1.1 Rainfall

The daily values of rainfall received by watershed during the two south-west monsoon months of June and July in 1998 and 1999 are shown in Fig. 4.1 to 4.4. The total rainfall during the months of June and July, in 1998, was 1407 mm. The maximum daily rainfall during the period in 1998 was 104 mm which occurred on 22nd of June. The average daily received during the period was 23 mm. The total rainfall during the corresponding period in 1999 was 1130 mm. The maximum daily rainfall during this period was 70 mm which occurred during two days, on 18th of June and 28th of July. The average daily rainfall during this period was 18.50 mm. The daily rainfall values during the

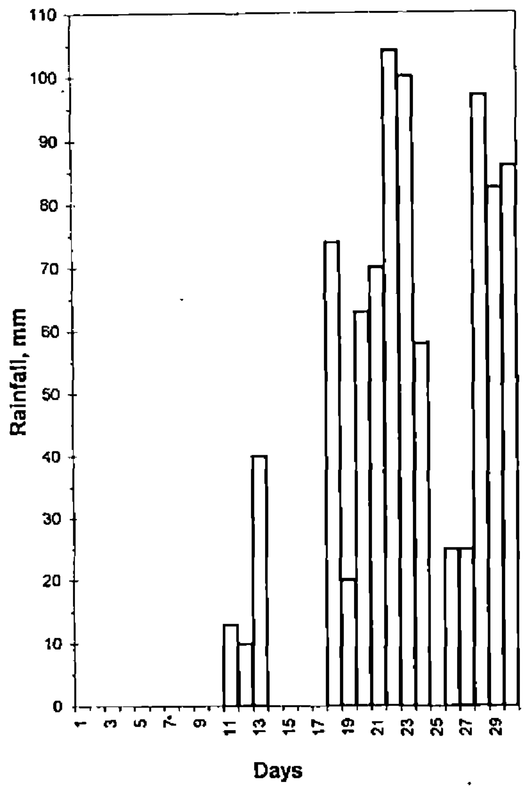

Fig. 4.1 Daily rainfall in June 1998

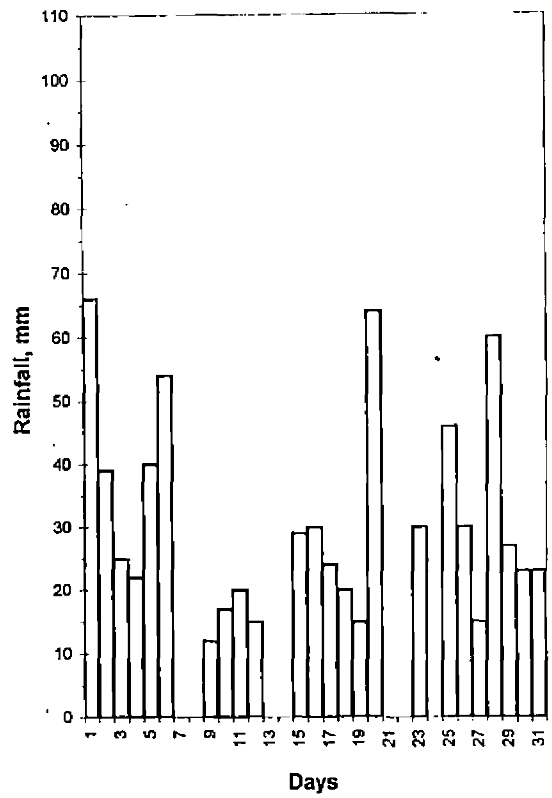

Fig. 4.2 Daily rainfall in July 1998

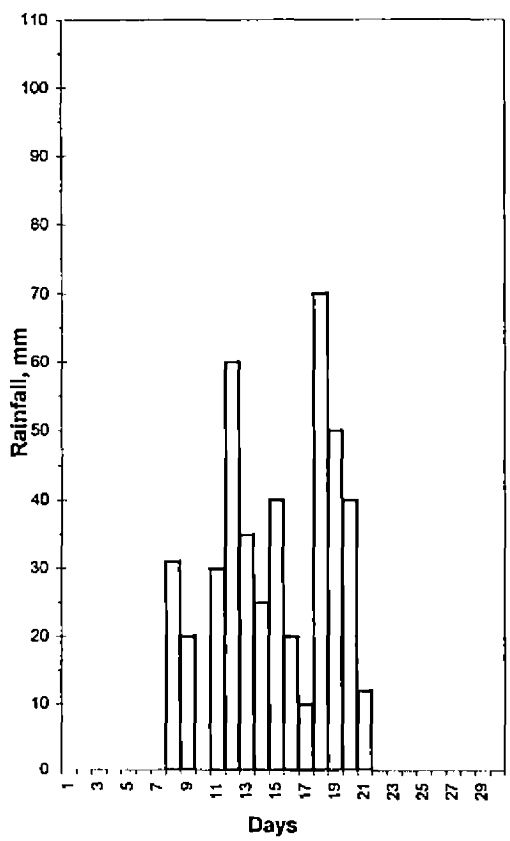

Fig. 4.3 Daily rainfall in June 1999

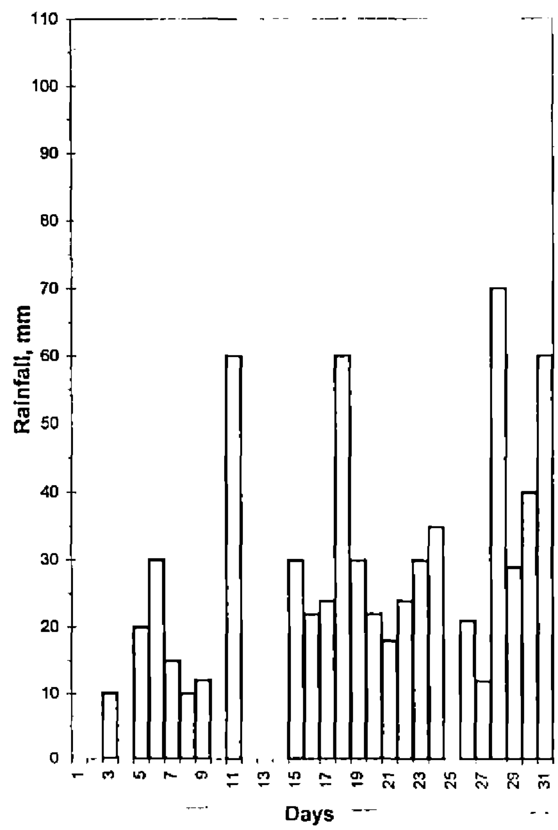

Fig. 4.4 Daily rainfall in July 1999

months of June and July, in 1998 and 1999, are given in Appendix V.

4.2 Soil Properties

Soil properties are momentous in the hydrological as well as erosion processes. The soil properties are determinants in the infiltration process, hydraulic conductivity, soil moisture storage and consequently, the hydrologic events. Also the soil characteristics, viz., soil erodibility and transportability, are highly influential in soil erosion. The soil samples collected from the watershed were analyzed for particle size distribution, organic matter content, permeability, and infiltration. The collected soil samples indicated that the soil generally comes under coarse-grained division, since, in all the samples, more than half of the total materials by weight had diameter larger than 75 micron.

The soil texture analysis was done to obtain the particle size distribution of the soil samples collected from hillslope, paddy field and subsoil below a depth of 30 cm. The respective proportions of sand, silt and clay fragments of the soil collected from hillslope are 61, 23 and 16 per cent. The soil sample collected from paddy field showed the similar proportions as 72.5, 13.5 and 14 per cent, respectively. Similarly, the soil sample collected from a depth of 30 cm showed that the proportions of sand, silt and clay distribution as 59, 14 and 27 per cent, respectively. The particle size distribution curves of the soil samples collected from the three locations are shown in Fig. 4.5. The particle size distribution data of the three soil samples are shown in Appendix VI.

The organic matter content of the soil collected from hillslope is 1.98 per cent. The soil samples collected from paddy field and subsoil at a depth of 30 cm were found have organic matter content of 1.03 and 0.52 per cent respectively.

The permeability study conducted with falling head permeameter rendered an average value of 2.63×10^{-3} cm/s for the coefficient of

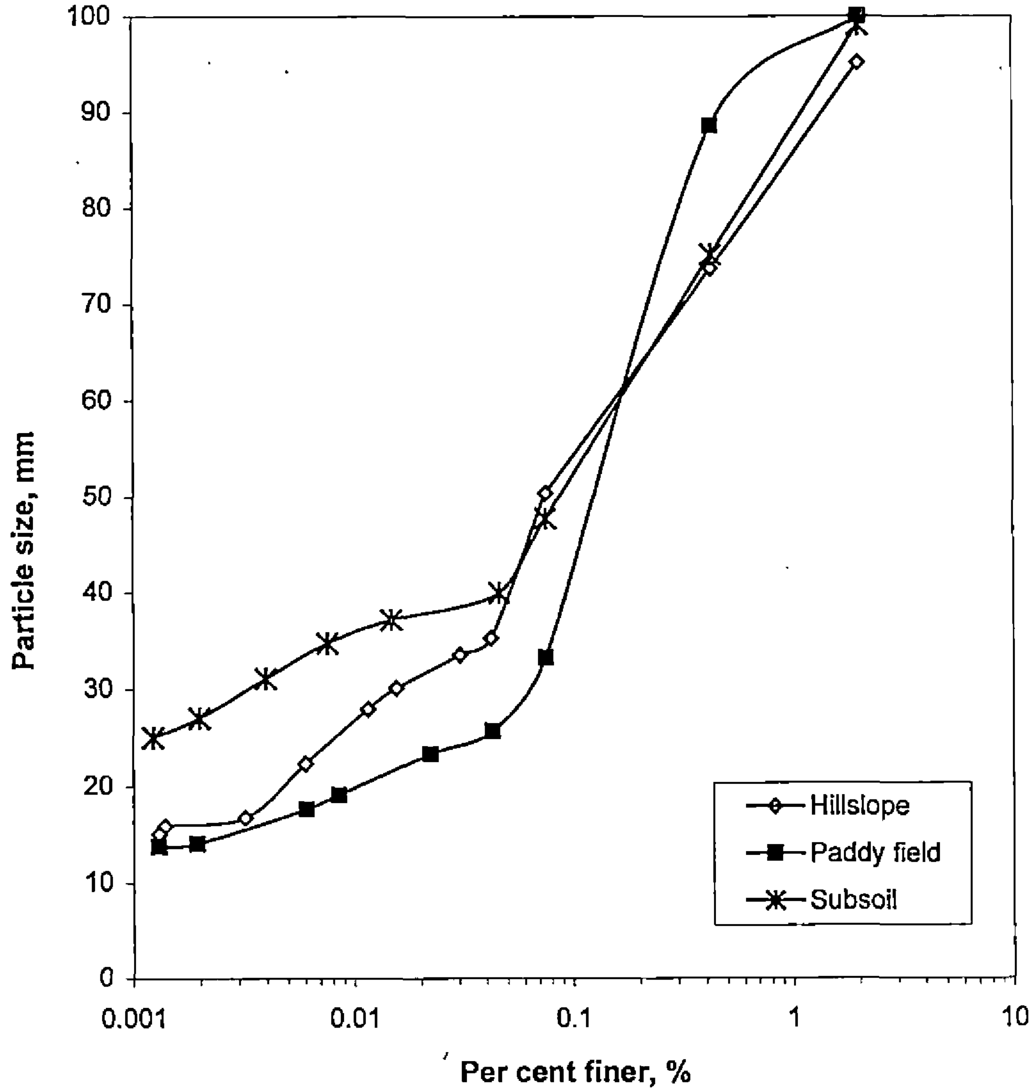

Fig. 4.5 Particle size distribution curves of the soils

permeability. The minimum and maximum values observed for the particular coefficient were 2.3×10^{-3} and 3.04×10^{-3} cm/s, respectively.

4.3 Infiltration

The infiltration defines the readiness of soil to absorb the precipitation falling on it and constitutes the major chunk of initial losses. Therefore, the amount of infiltration and its rates decide the volume of water available for runoff generation. The infiltration measurements were done at three locations in the watershed. The average infiltration rates and cumulative infiltration for the different locations are given in Appendix VII. The infiltration characteristics of soils are shown in Figure 4.6 to 4.11. The infiltration rates of the soils at hillslopes were greater than that of the paddy field. The maximum rates of infiltration (infiltration capacity) for the two hillslope locations were 30 and 24 cm/h, and respective basic infiltration rates were 3.0 and 2.4 cm/h. The paddy field has an infiltration capacity of 12 cm/h, and basic infiltration rate of 1.6 cm/h. The basic infiltration rate and infiltration capacity for the three measurements are presented in Appendix VII.

The infiltration characteristic curves for the soils of the three locations are shown in Fig. 4.6, 4.8 and 4.10. The cumulative infiltration's is plotted against time on log-log scale for all the three cases and are shown in Fig. 4.7, 4.9 and 4.11. The infiltration equations derived from these plots, for the three locations, are as follows:

for paddy field,

$$Y = 0.142\ t^{1.126} + 0.002 \qquad \text{...(4.1)}$$

for hillslope I,

$$Y = 0.403\ t^{0.871} + 0.0056 \qquad \text{...(4.2)}$$

for hillslope II,

$$Y = 0.401\ t^{0.9419} - 0.0069 \qquad \text{...(4.3)}$$

where,

Y = accumulated infiltration, cm, and

t = elapsed time, min.

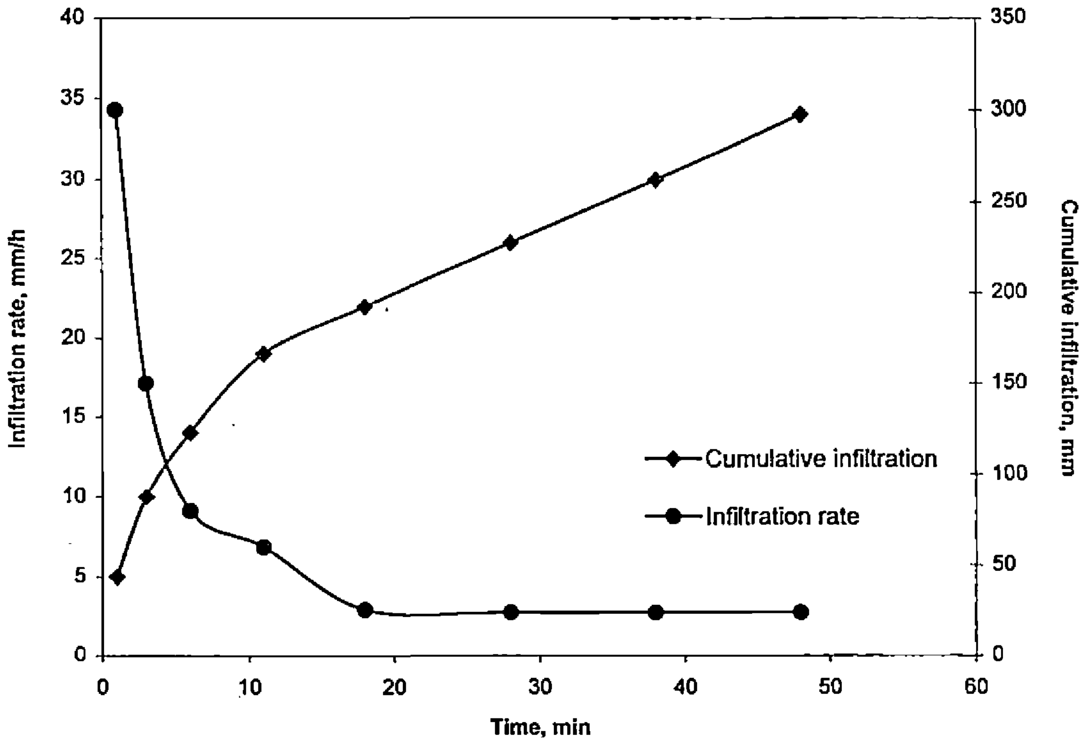

Fig. 4.6 Infiltration characterestic curve of hill slope I

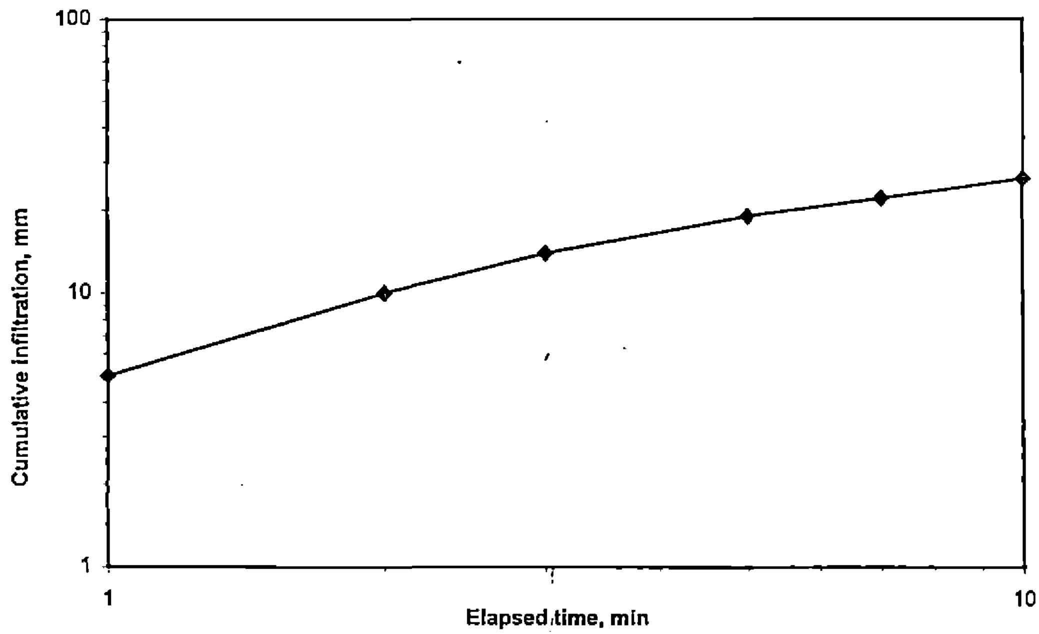

Fig. 4.7 Log-Log plot of cumulative infiltration and elapsed time of hill slope I

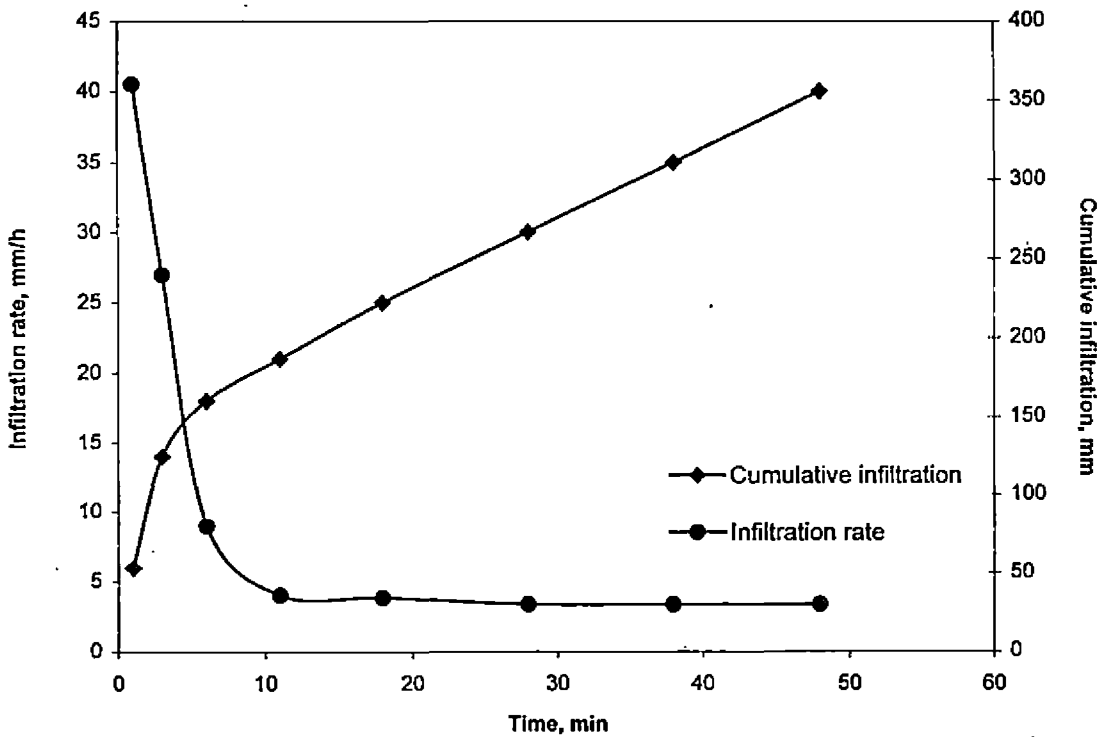

Fig. 4.8 Infiltration characterestic curve of hill slope II

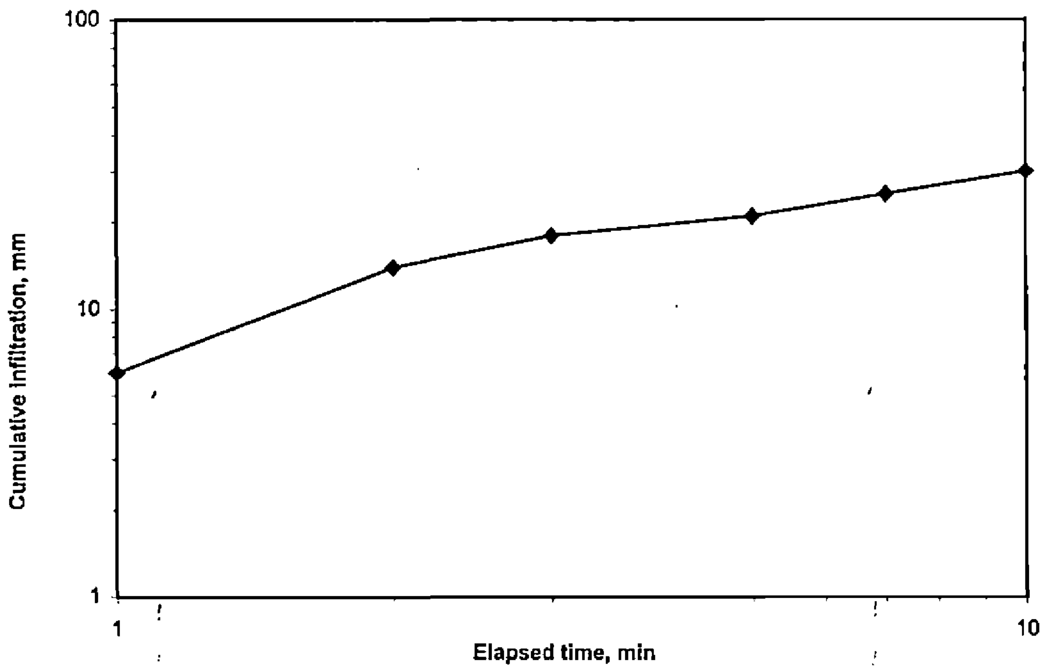

Fig. 4.9 Log-Log plot of cumulative infiltration and elapsed time of hill slope II

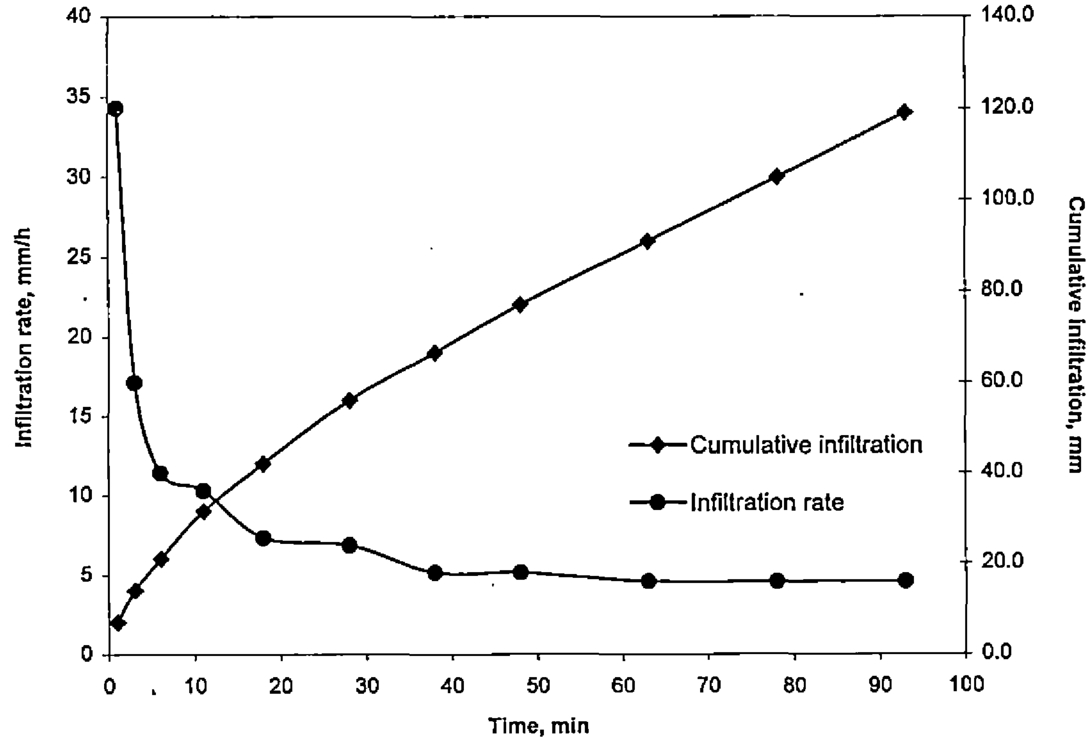

Fig. 4.10 Infiltration characterestic curve of paddy field

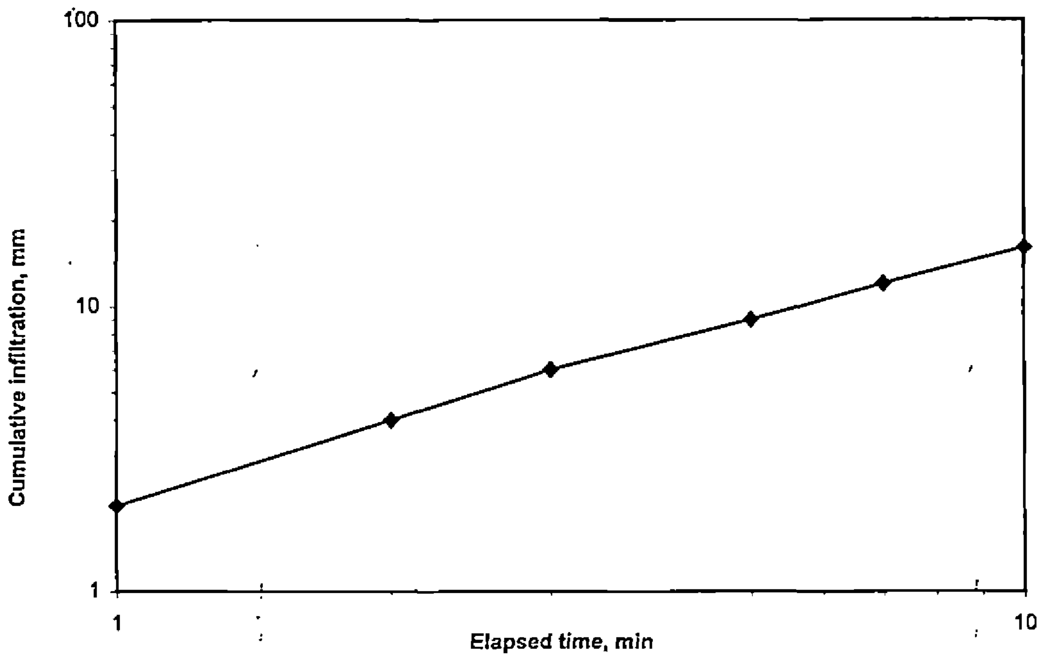

Fig. 4.11 Log-Log plot of cumulative infiltration and elapsed time of paddy field

4.4 Geomorphologic Parameters of the Watershed

The basin shape is an important factor that influences the runoff process. The shapes affects the runoff, through its influence on flood intensities and mean travel-time of a drop of water from its most remote point, on the surface of the catchment to its outlet in the mainstream. The slope of the catchment is another germane topographical factor that has influence on the relative importance of movement of water through, on, and over the soil. Furthermore, as the speed of water movement tends to increase with slope, runoff in steeply sloping areas will reach the streams quickly.

The geomorphologic parameters of watershed are presented in the Table 4.1. The form factor has a low value of 0.222, which represents that watershed is less "square". The circularity ratio is slightly greater than elongation ratio. The mean slope of the watershed is 24.8 per cent.

$$\text{Mean slope} = \frac{\text{Total length of contour (4550 m)} \times \text{Contour Interval (50 m)} \times 100}{\text{Basin area (9188000 m}^2\text{)}}$$

$$= \quad 24.78 \text{ per cent.}$$

$$\text{Drainage density} = \frac{\text{Total length of channels (25.03 km)}}{\text{Total area of watershed (9.18 km}^2\text{)}}$$

$$= 2.72$$

The drainage density was calculated as 2.72 for the watershed. Different geomorphologic characteristics with regard to the channels of the watershed were calculated and are represented in Table 4.2.

Table 4.1 Geomorphologic parameters of the watershed

Drainage area (km^2)	Basin Length (km)	Perimeter (km)	Form factor	Shape factor	Circularity ratio	Elongation ratio
(A)	(L)	(P)	(A/L^2)	(L^2/A)	$\frac{4\pi A}{P^2}$	$\frac{2(A/\pi)^{-1}}{L}$
9.188	6.44	14.50	0.222	4.508	0.55	0.535

Table 4.2 Geomorphologic parameters of the watershed with regard to channels

Drainage area (km^2)	Perimeter (km)	Order	No. of streams	Stream length (km)	Bifurcation ratio	Mean length (km)
9.2	14.50	1	45	14.40		0.32
		2	7	5.19	6.43	0.74
		3	2	3.44	3.5	1.72
		4	1	2.00	2.00	2.00
Total			55	25.03		

Maximum basin length - 6.44 km

4.5 Hydrograph

The Direct Runoff Hydrograph (DRH) attributed to the selected storm events were derived from storm hydrograph after the separation of baseflow according to the procedure described in Article 3.7.1. The Direct Runoff Hydrograph of each storm was utilized for constructing Unit Hydrograph of the corresponding storm event. The Direct Runoff Hydrographs and the Unit Hydrographs constructed are delineated in Fig. 4.12 through 4.25. The ordinates of storm hydrographs, baseflows, Direct Runoff Hydrographs and Unit Hydrographs are given in Appendix VIII.

The Direct Runoff Hydrographs (DRH) and the Unit Hydrograph (UH) for the rainfall event occurred on 21.06.98 are shown in Fig. 4.12 and 4.13. The total rainfall was 5.5 cm and the duration was 45 minutes. The peak registered a flow rate of 15.25 m^3/s, which was after 2 h and 45 min since the commencement of rainfall. The base period of DRH was five and half hours, and the effective rainfall resulted, expressed as depth, was 1.08 cm which was equivalent to a runoff volume of 99472 m^3.

Figure 4.14 and 4.15 present the DRH and the corresponding UH produced from the rainfall event occurred on 29.06.98. The resultant volume of runoff delivered due to the storm was estimated as 84780 m^3, which is equivalent to 0.922 cm of rainfall excess expressed as depth. The peak flow rate was 14.57 m^3/s and it was delayed by 3 h from the commencement of the storm. The UH derived is defined by a peak value of 15.81 m^3/s, after a time lag of 3 h from beginning of the storm. The storm amount was 5 cm and the duration of the storm event was one hour.

The DRH and the UH developed for the storm event on 19.07.98 are given in Fig. 4.16 and 4.17. The rainfall amount was 3 cm and the duration was 45 min. The peak flow rate observed after 3 h from the commencement of the rainfall was 6.76 m^3/s. The total runoff volume generated by the rainfall event was estimated as 35810 m^3, equivalent to 0.39 cm of rainfall excess. The UH has a peak flow rate of 17.23 m^3/s delayed by 3 h since the inception of rainfall.

Figure 4.18 and 4.19 show the DRH and UH derived for the storm event on 11.06.99. The rainfall amount was recorded as 3.5 cm, which occurred for a duration of one hour. The peak flow rate was 6.65 m^3/s, which was observed after a period of 3 h since the beginning of the storm event. The total runoff volume was 47160 m^3, equivalent to a rainfall excess of 0.47 cm. The UH obtained has a peak of 14.17 m^3/s with the same time to peak as that of DRH.

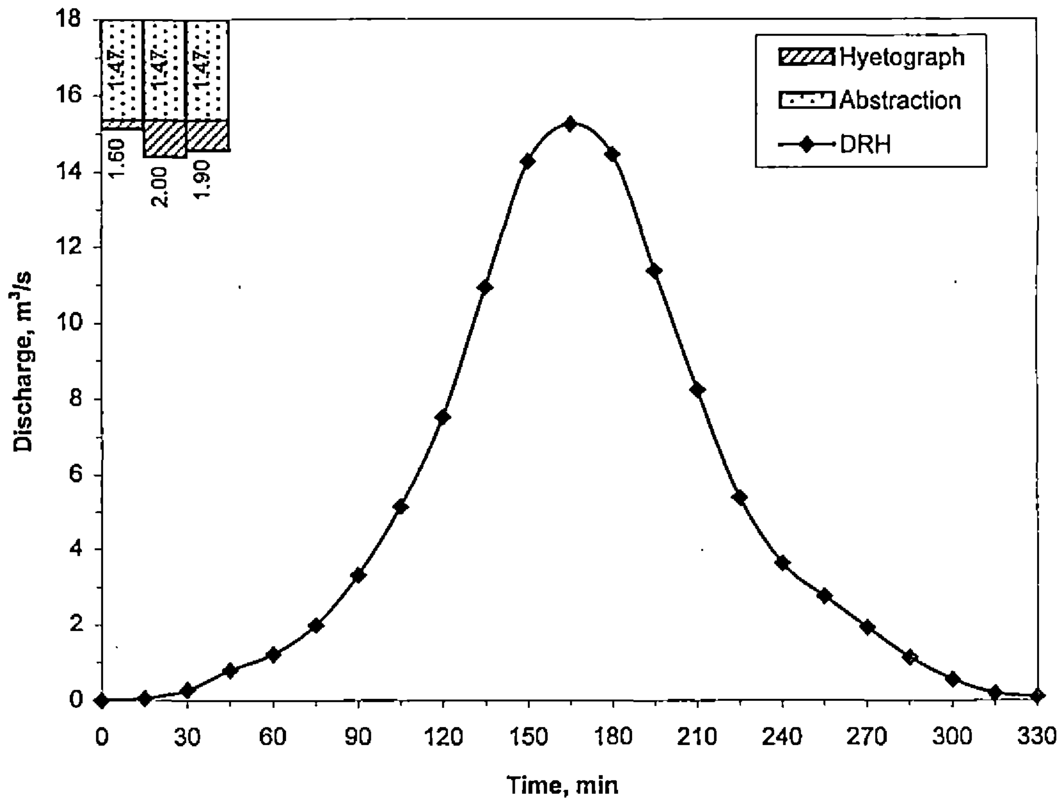

Fig. 4.12 Direct Runoff Hydrograph of the storm event on 21.06.98

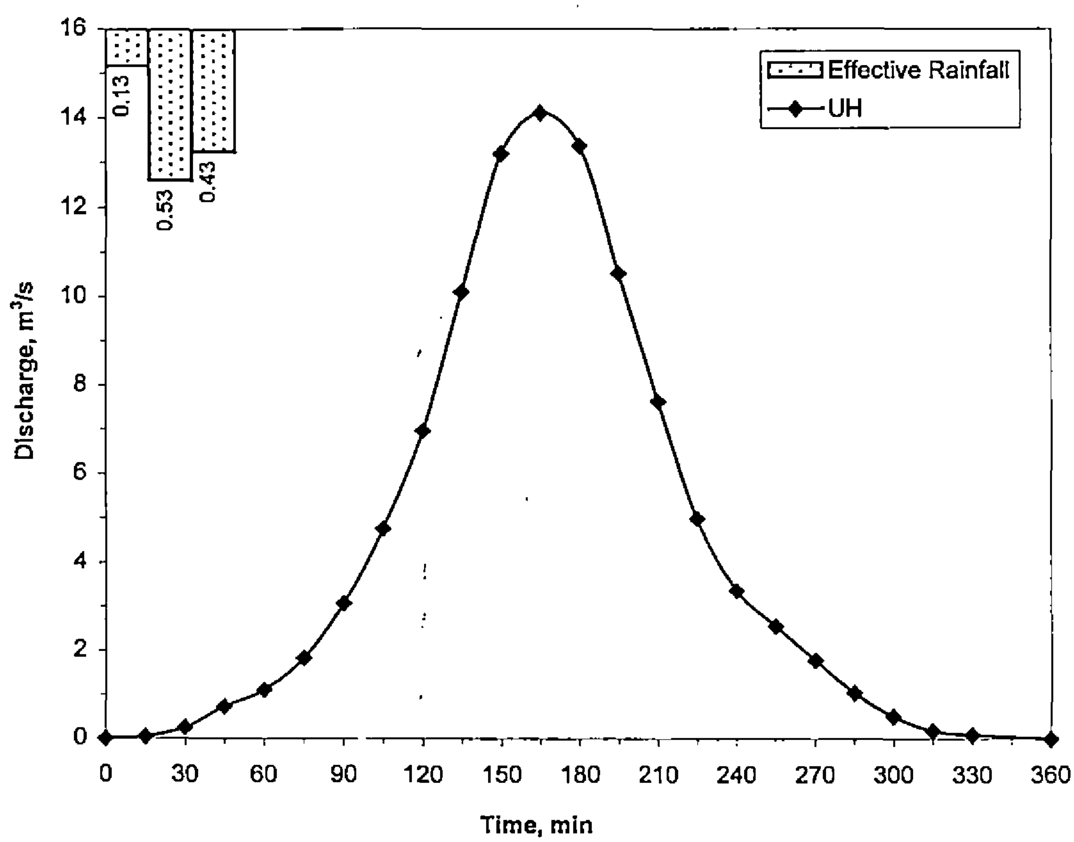

Fig. 4.13 Unit Hydrograph of the storm event on 21.06.98

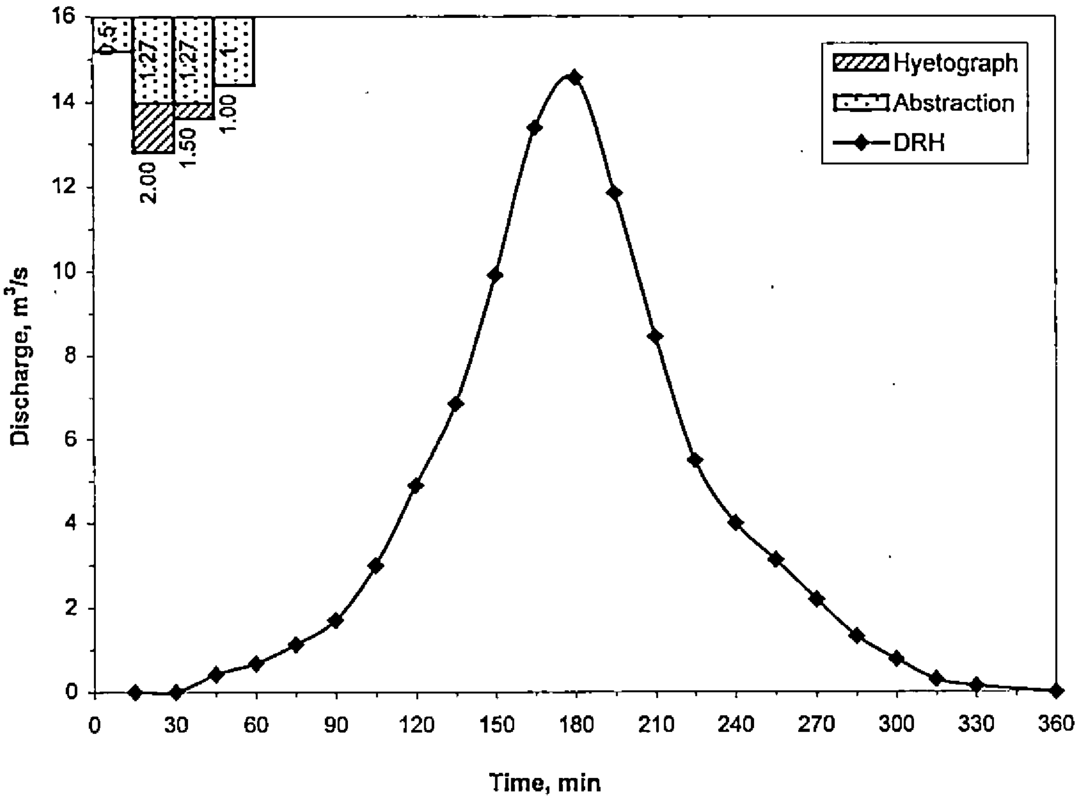

Fig. 4.14 Direct Ruoff Hydrograph of the storm event on 29.06.98

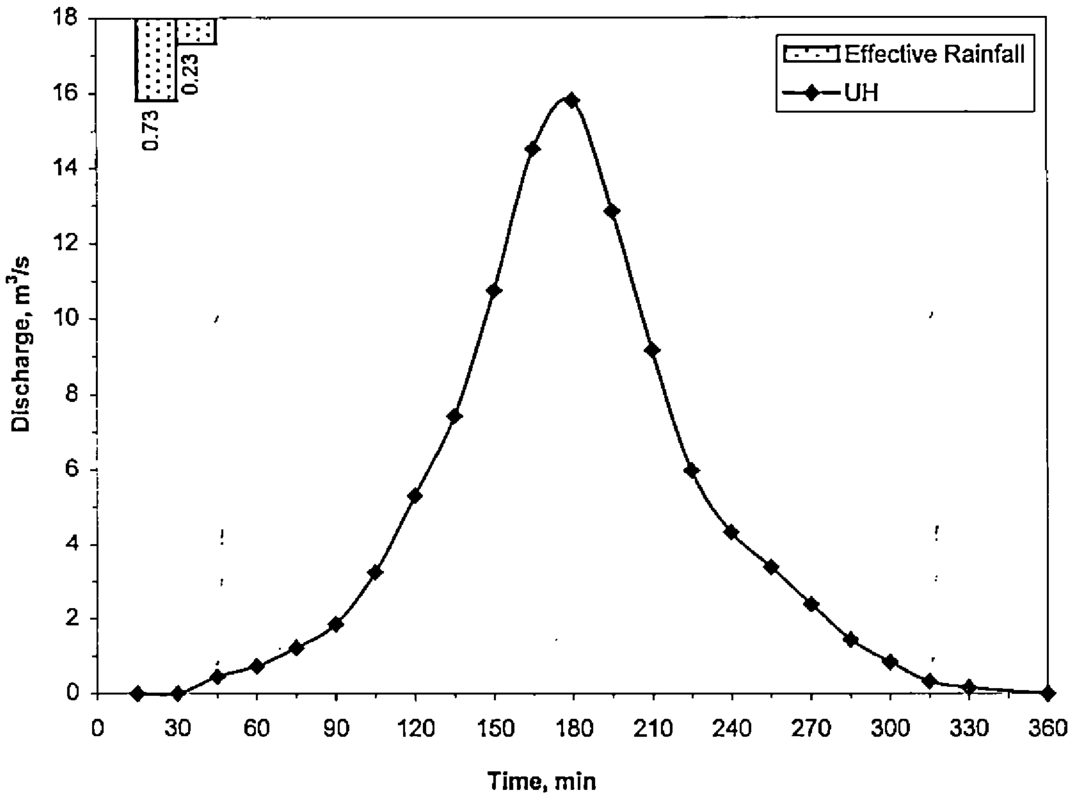

Fig. 4.15 Unit Hydrograph of the storm event on 29.06.98

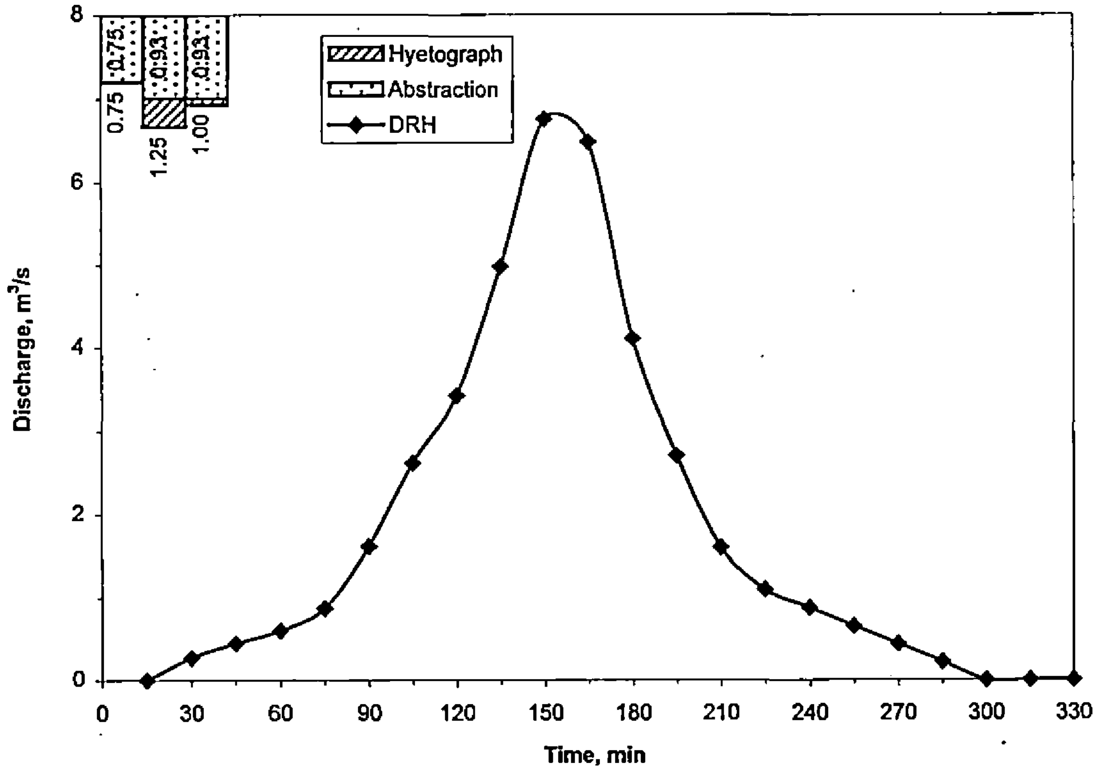

Fig. 4.16 Direct Ruoff Hydrograph of the storm event on 19.07.98

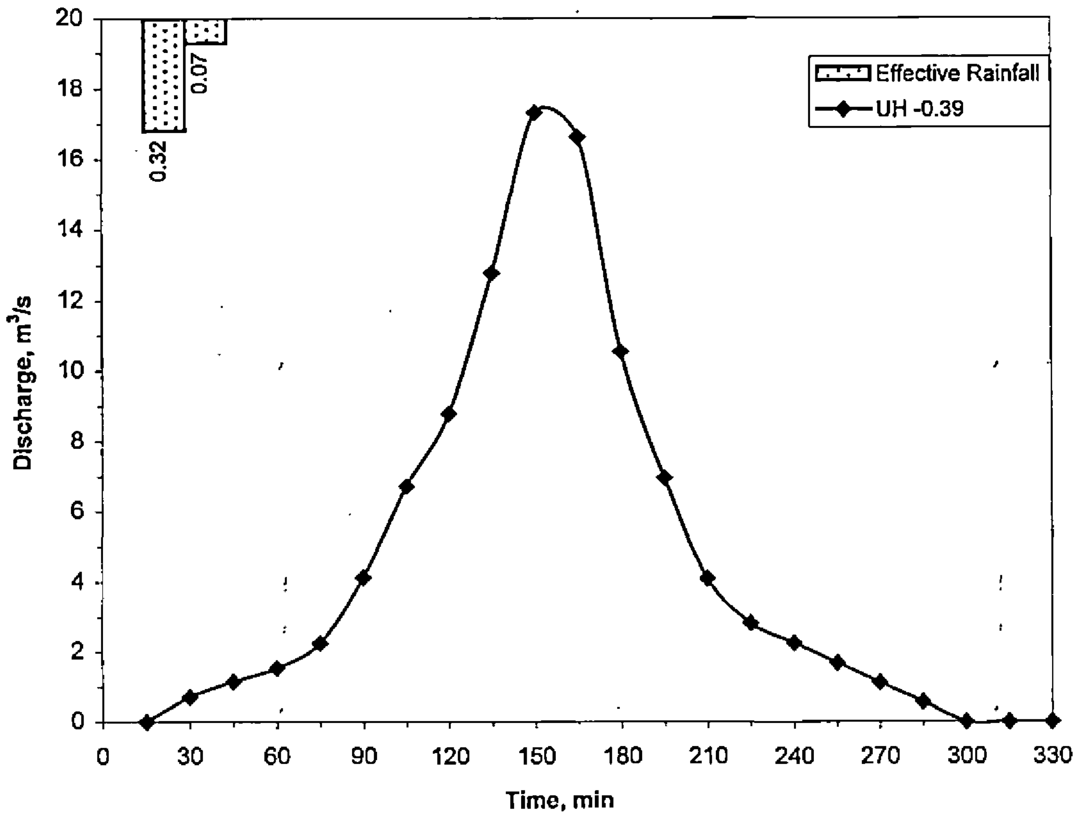

Fig.4.17 Unit Hydrograph of the storm event on 19.07.98

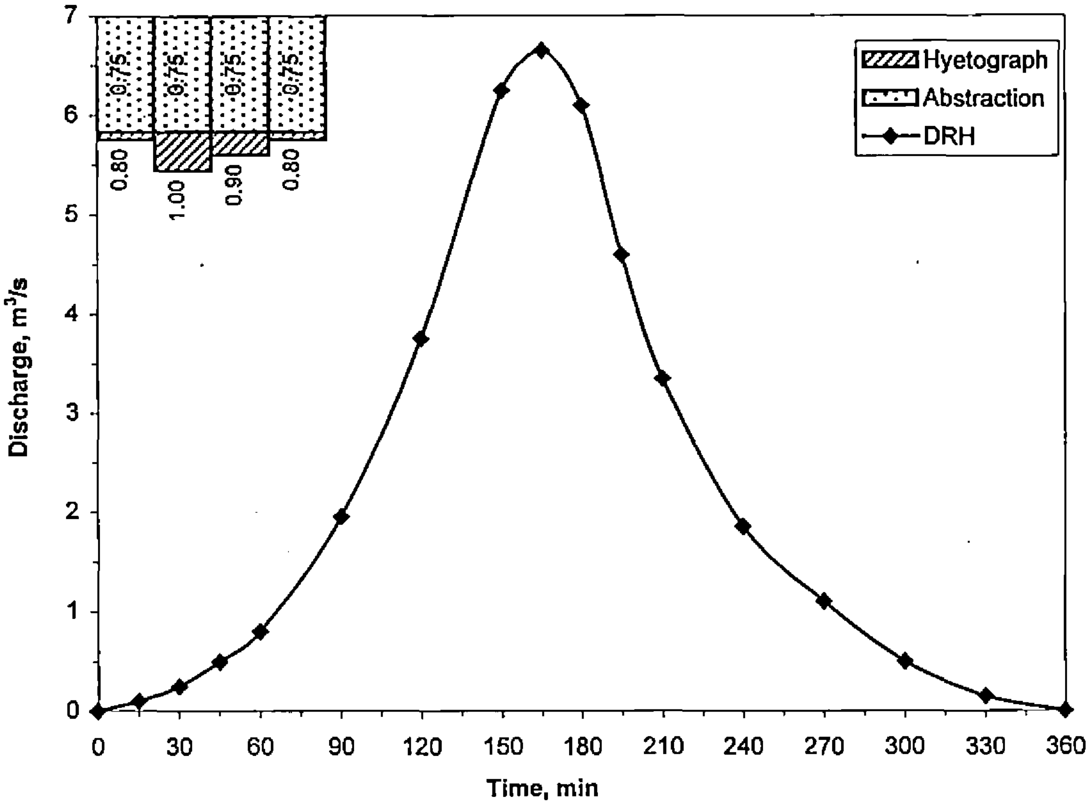

Fig. 4.18 Direct Ruoff Hydrograph of the storm event on 11.06.99

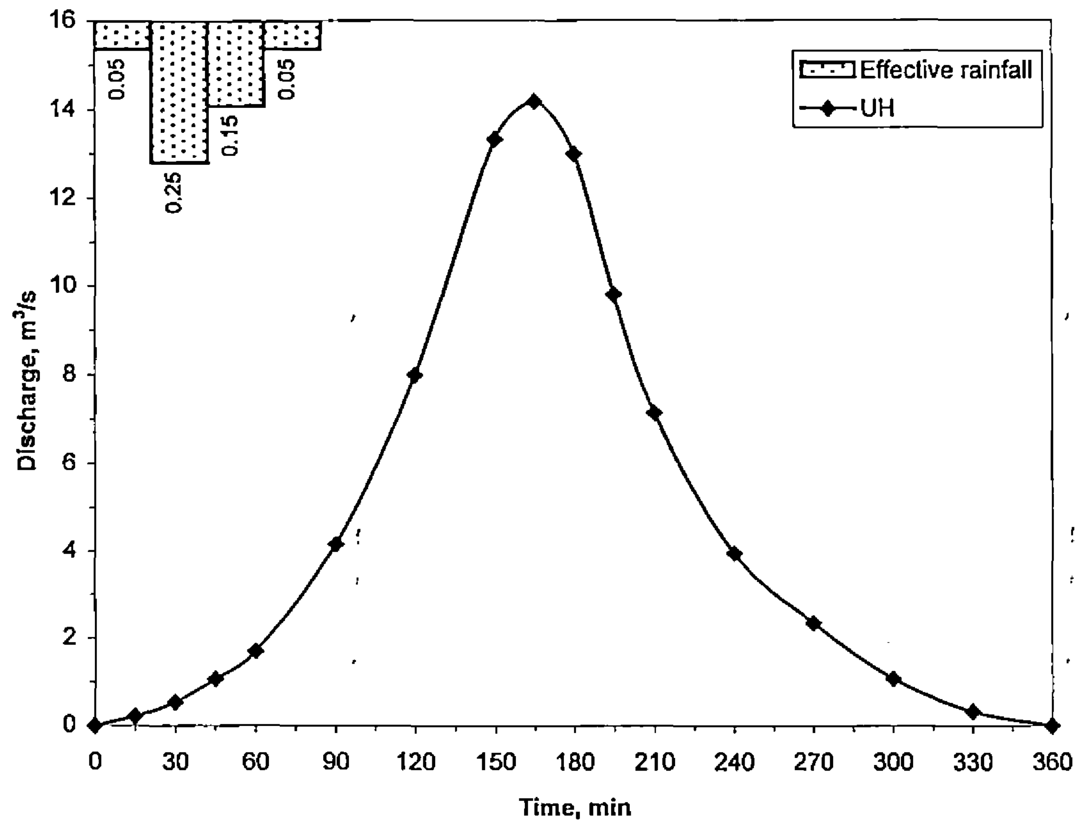

Fig. 4.19 Unit Hydrograph of the storm event on 11.06.99

The storm event occurred on 18.06.99 produced DRH and UH, which are shown in Fig. 4.20 and 4.21. The storm amount was 3 cm, which occurred for a duration of 30 min. The peak flow rate of DRH is 10.66 m^3/s after 3 h from the commencement of the rainfall. The runoff generated out of the storm event was 61724 m^3 when expressed as volume and 0.67 cm when expressed as depth of rainfall excess. The peak of the UH is 15.86 m^3/s, which occurred after 3 h from the beginning of the storm event.

The DRH and UH for the rainfall event on 6.07.99 are represented in Fig 4.22 and 4.23. The rainfall amount of 2.5 cm was occurred for a period of 45 min. The total runoff volume produced from the storm was 15358 m^3, analogous to a rainfall excess depth of 0.16 cm. The DRH has the peak ordinate of 2.1 m^3/s with the time to peak 2 h and 45 min. The UH ordinate at the peak is 13.14 m^3/s with the same time to peak as that of DRH.

The storm event occurred on 17.07.99 produced the DRH and the UH as shown in Fig. 4.24 and 4.25. The amount of storm was 6 cm, which occurred for duration of 1 h and 15 min. The peak flow rate observed after 3 h since the commencement of rainfall event, was 26.75 m^3/s. The runoff volume produced from the event was 167128 m^3 or 1.81 cm when expressed as depth of rainfall excess. The peak of the UH was 14.71 m^3/s observed after a time interval of 3 h since the beginning of the storm event.

4.6 Sediment Graph

The temporal distribution of sediment discharge through the channel at watershed outlet was monitored for the selected storm events. The sediment discharge was plotted against time to obtain the Sediment Graph. The Sediment Graph ordinates are given in Appendix IX. The baseflow was separated from the Sediment Graph to develop the Direct Sediment Graph (DSG) as described in Article 3.7.1. The Unit Sediment Graphs (USG) were developed for the selected storm events. The ordinates of the Sediment Graph, DSG and USG are shown in Appendix IX.

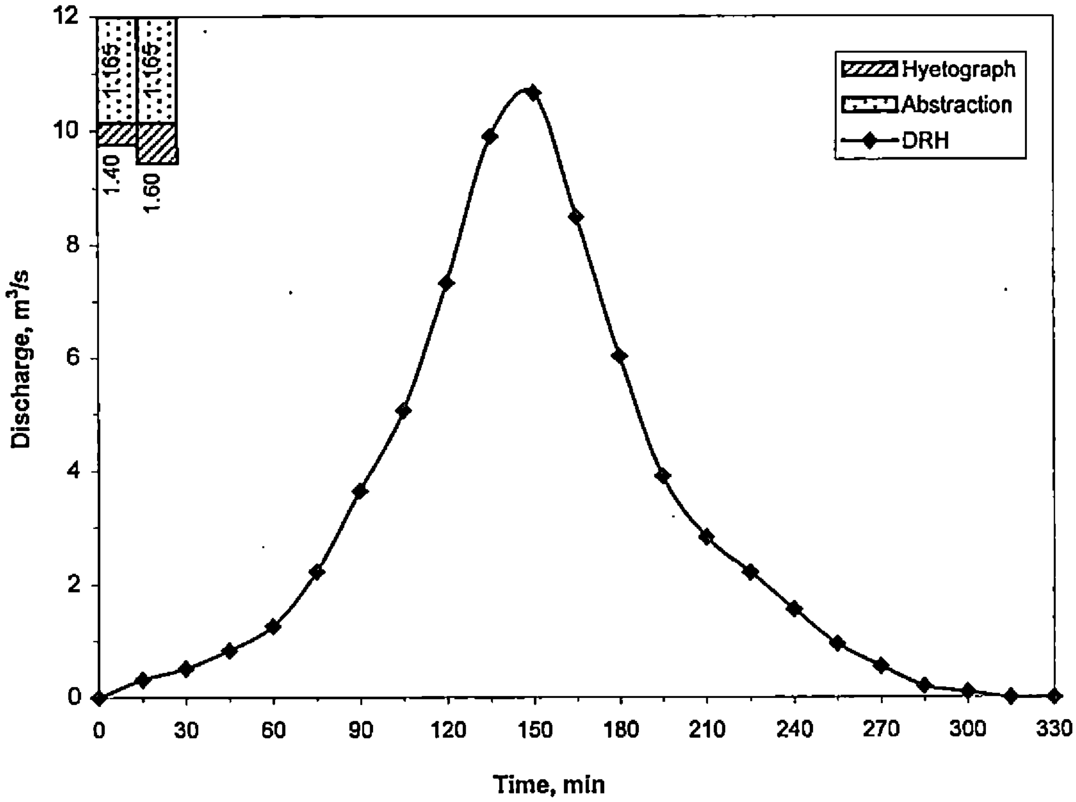

Fig. 4.20 Direct Ruoff Hydrograph of the storm event on 18.06.99

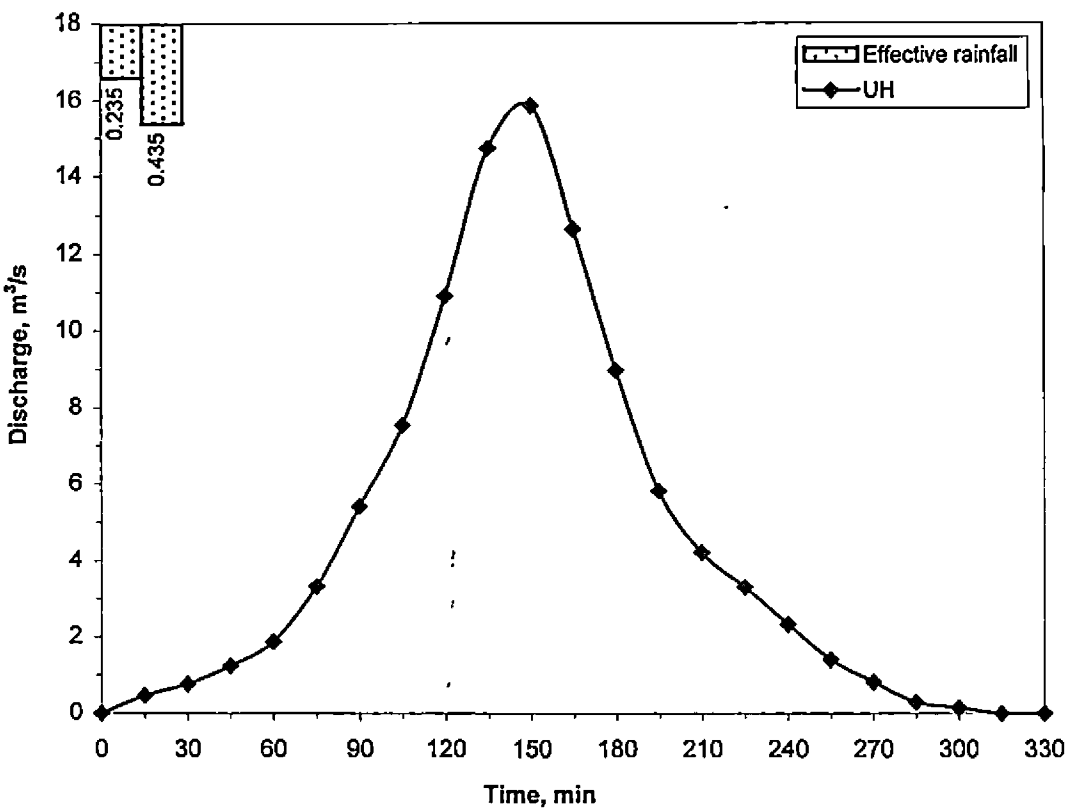

Fig. 4.21 Unit Hydrograph of the storm event on 18.06.99

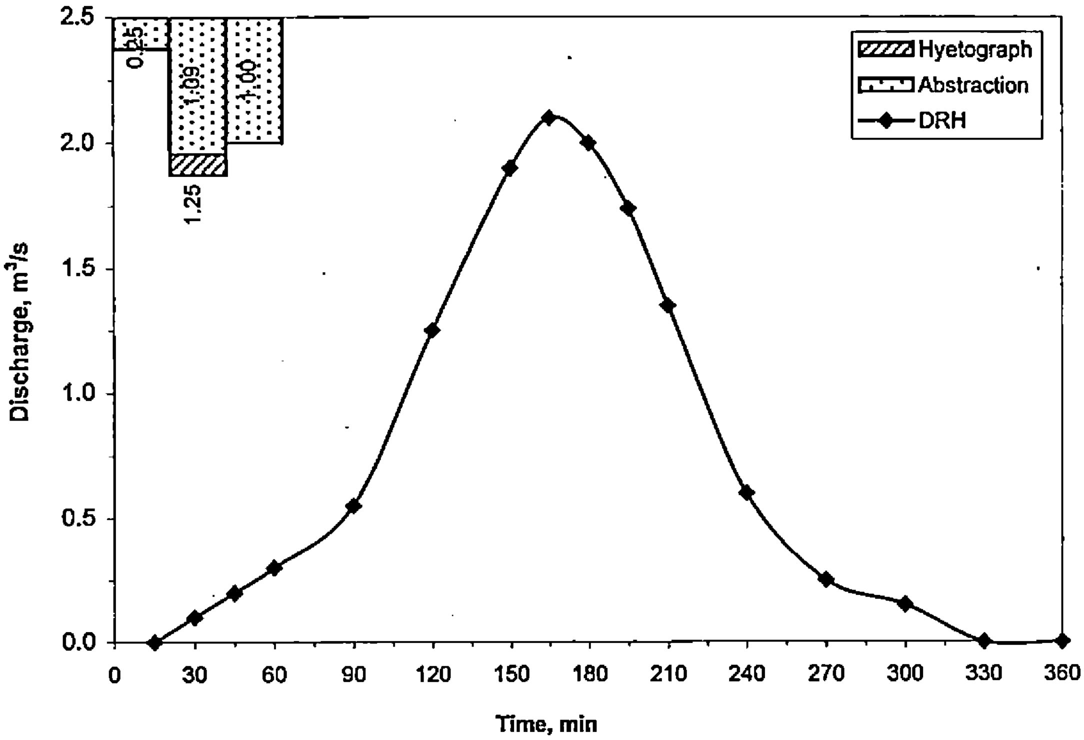

Fig. 4. 22 Direct Ruoff Hydrograph of the storm event on 06.07.99

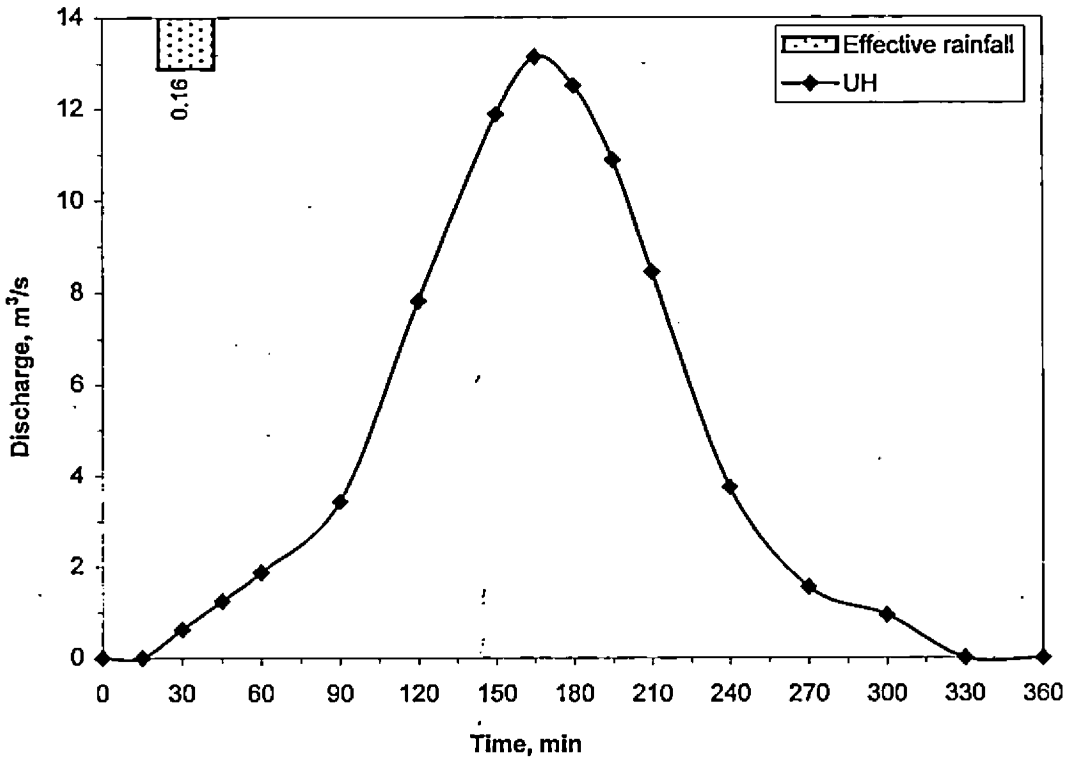

Fig. 4. 23 Unit Hydrograph of the storm event on 06.07.99

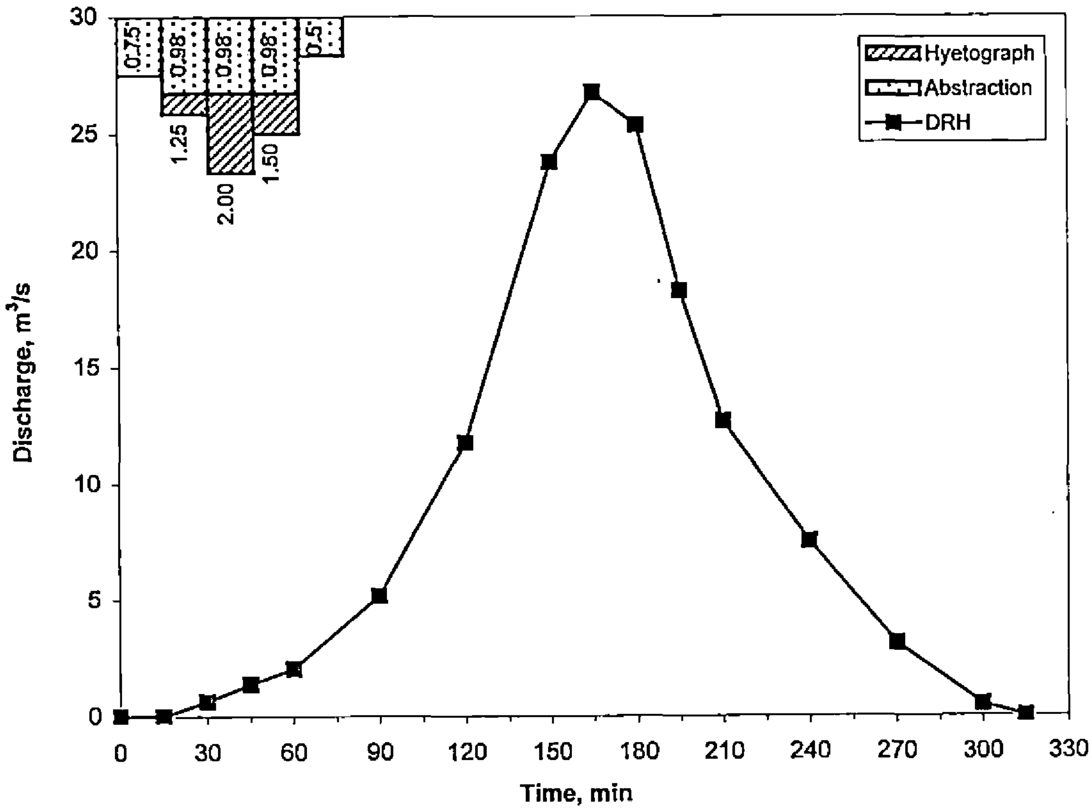

Fig. 4. 24 Direct Ruoff Hydrograph of the storm event on 17.07.99

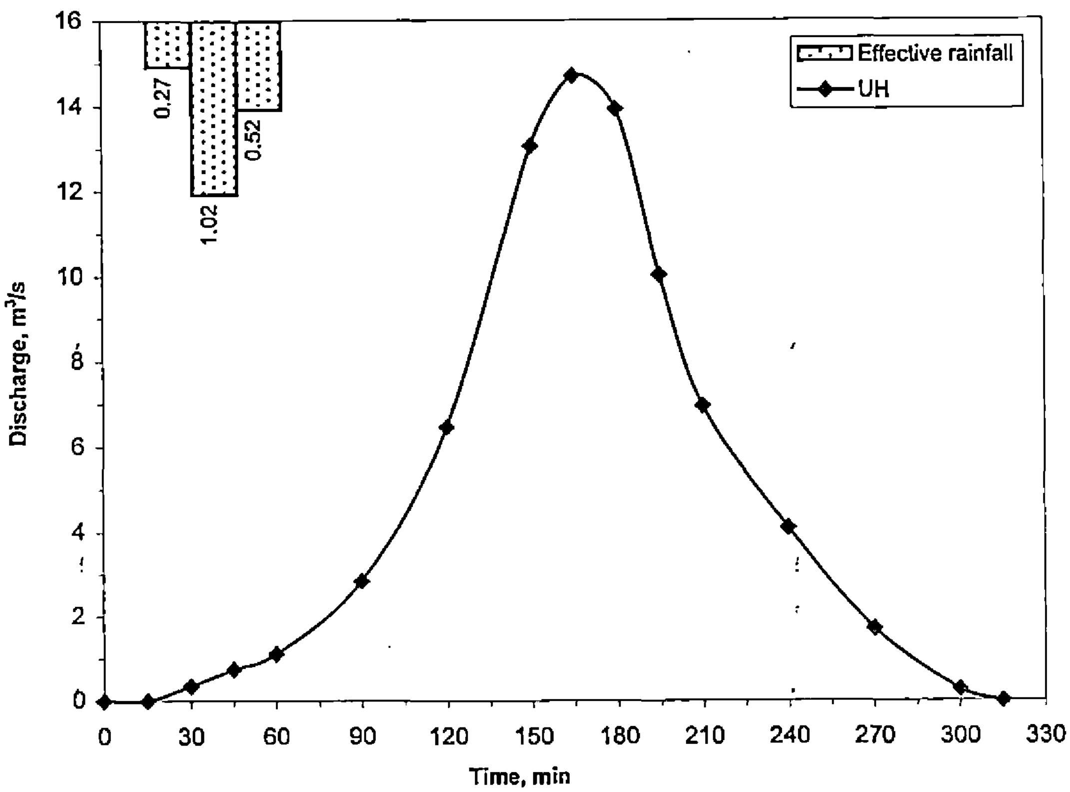

Fig. 4. 25 Unit Hydrograph of the storm event on 17.07.99

The DSG and the associated USG derived for the storm event on 21.06.98 are shown in Fig. 4.26 and 4.27. The peak rate of flow of sediment discharge was observed as 42.71 kg/s with a time to peak (t_{pk}) of 165 min. The total sediment mobilized as the result of the storm event was estimated as 290 tonnes. The ordinate of USG derived has a peak of 1.35 with the same t_{pk} as that of DSG.

The DSG and USG developed for the storm event on 29.06.98 are shown in Fig. 4.28 and 4.29. At the peak of the DSG, flow rate was observed as 40.84 kg/s with t_{pk} as 165 min. The peak of the USG denotes a rate of flow of 1.495 kg/s with a t_{pk} of 165 min. The total amount of sediment mobilized as a result of the storm was estimated as 251 tonnes.

Figure 4.30 and 4.31 represent the DSG and USG deduced from the storm event recorded on 19.07.98. The total sediment mobilized from the watershed with the effect of the storm was 109 tonnes. The peak of the DSG has a flow rate of 19.91 kg/s with the t_{pk} as 150 min. The peak of the USG is 1.67, while the t_{pk} was 150 min.

The storm event on 11.06.99 resulted in the derivation of the DSG and USG shown in Fig. 4.32 and 4.33. The amount of sediment delivered out of the watershed due to the storm was computed as 152 tonnes. The peak rate of sediment discharge was observed as 23.3 kg/s and the t_{pk} was 150 min. The peak of USG was computed as 1.41 with the t_{pk} 150 min.

The DSG and USG from the storm event on 18.06.99 are shown in Fig. 4.34 and 4.35. The peak rate of sediment flow was 28.85 kg/s and the t_{pk} was 150 min. The peak of the USG was observed as 1.34, while t_{pk} was 150 minutes. The total amount of sediment mobilized by the effect of storm event was estimated as 171 tonnes.

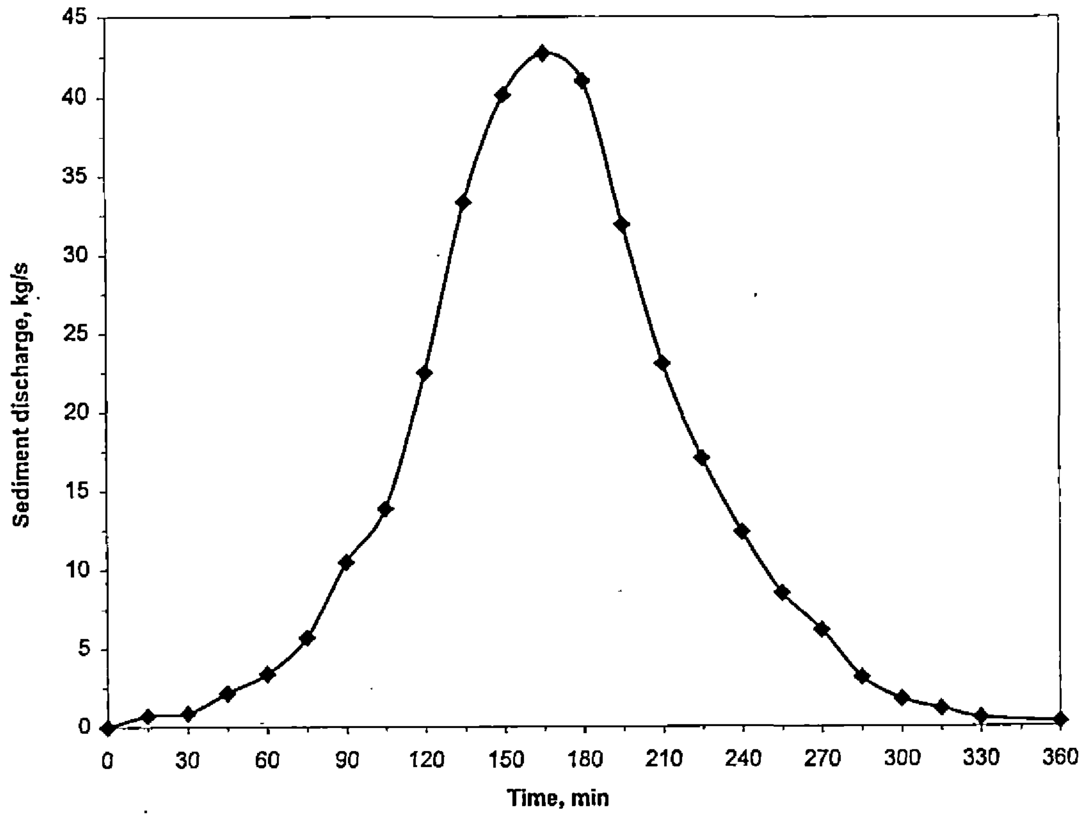

Fig. 4.26 Direct Sediment Graph of the storm event on 21.06.98

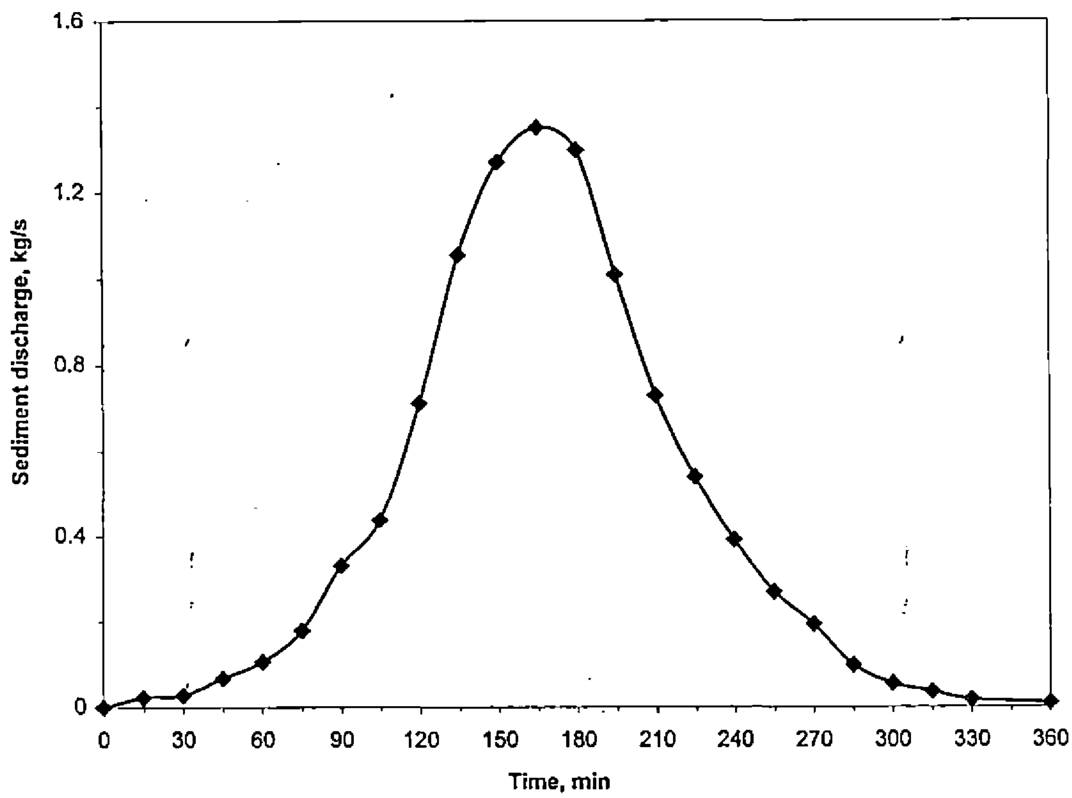

Fig. 4.27 Unit Sediment Graph of the storm event on 21.06.98

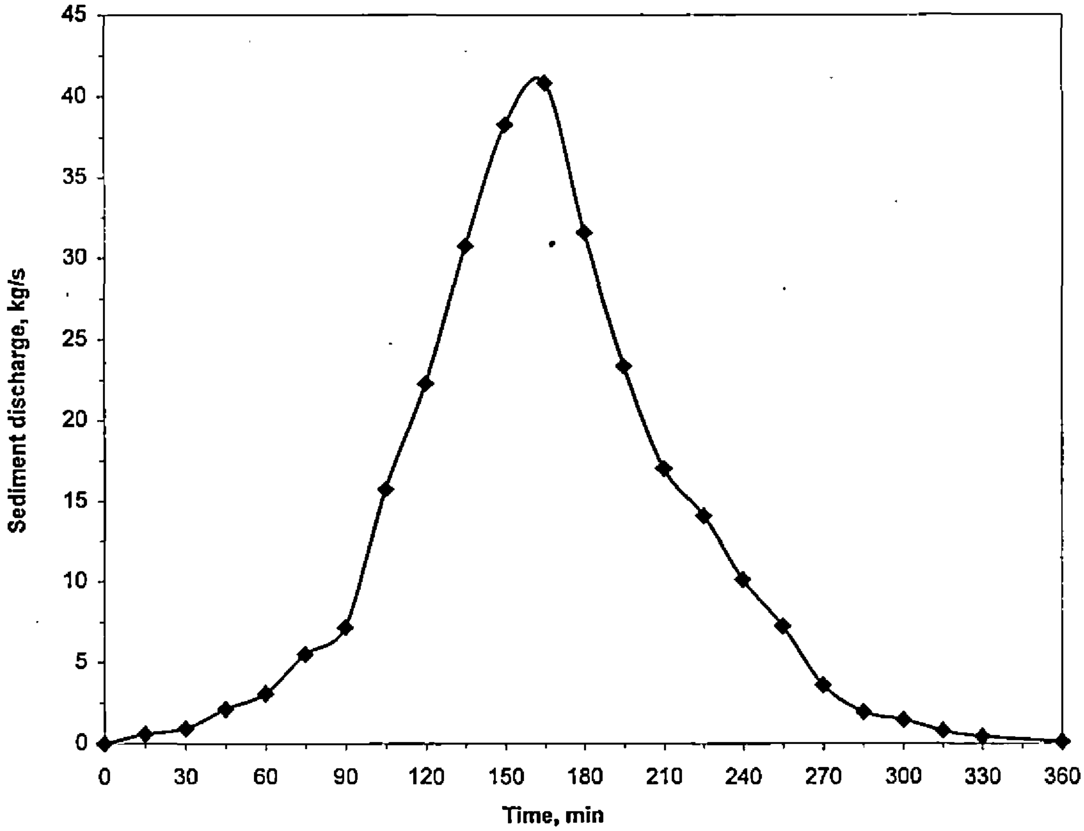

Fig. 4.28 Direct Sediment Graph of the storm event on 29.06.98

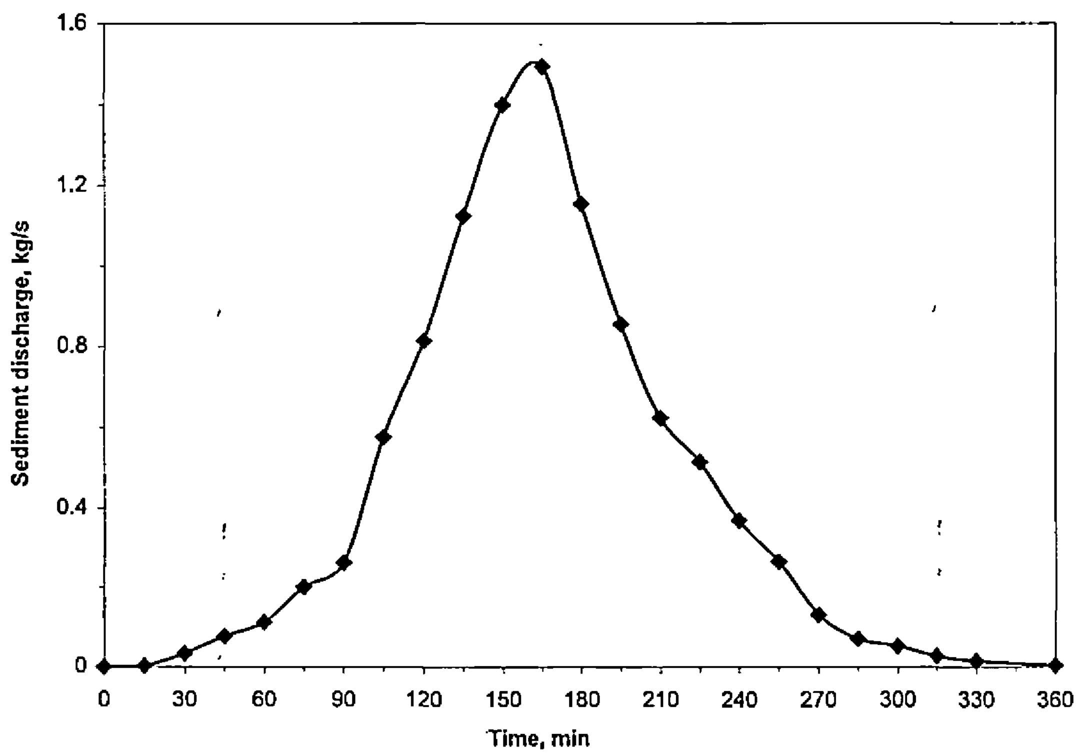

Fig. 4.29 Unit Sediment Graph of the storm event on 29.06.98

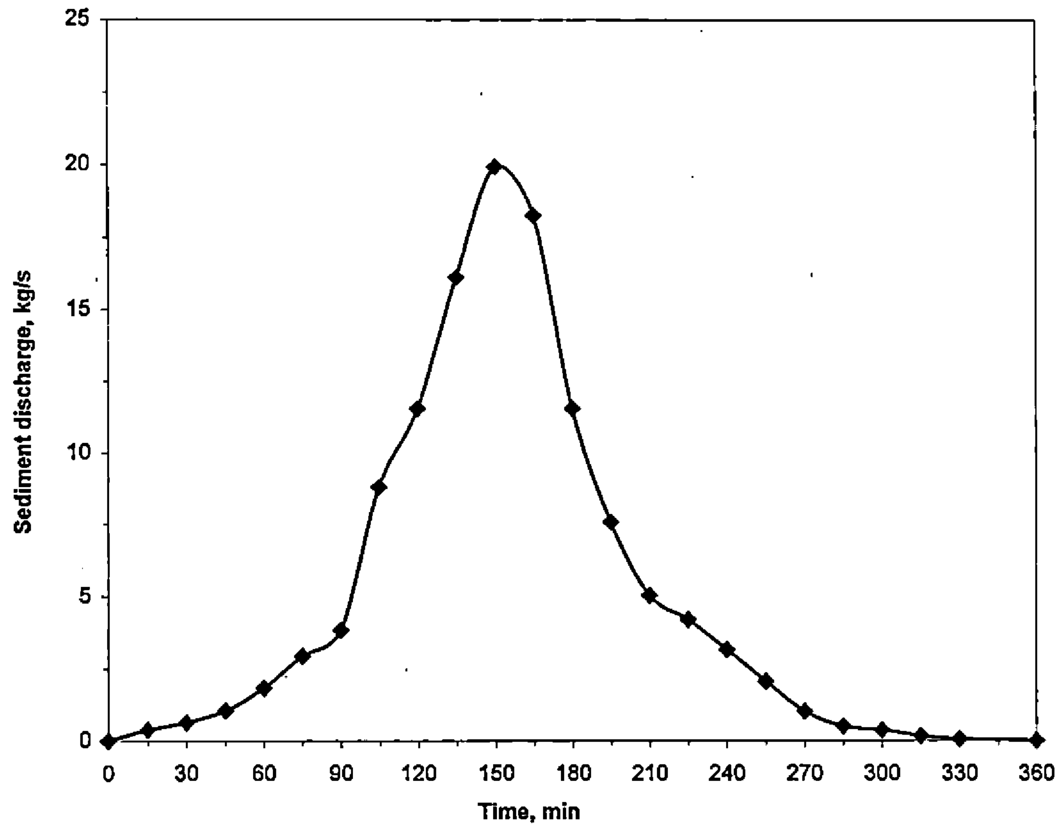

Fig. 4.30 Direct Sediment Graph of the storm event on 19.07.98

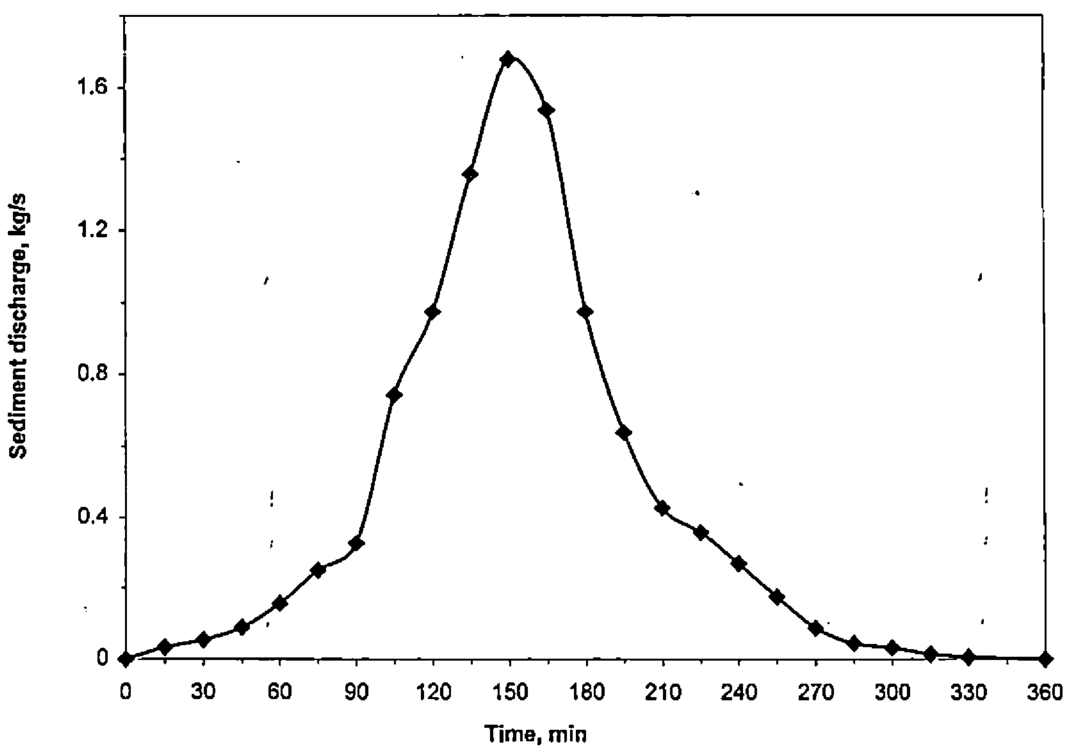

Fig. 4.31 Unit Sediment Graph of the storm event on 19.07.98

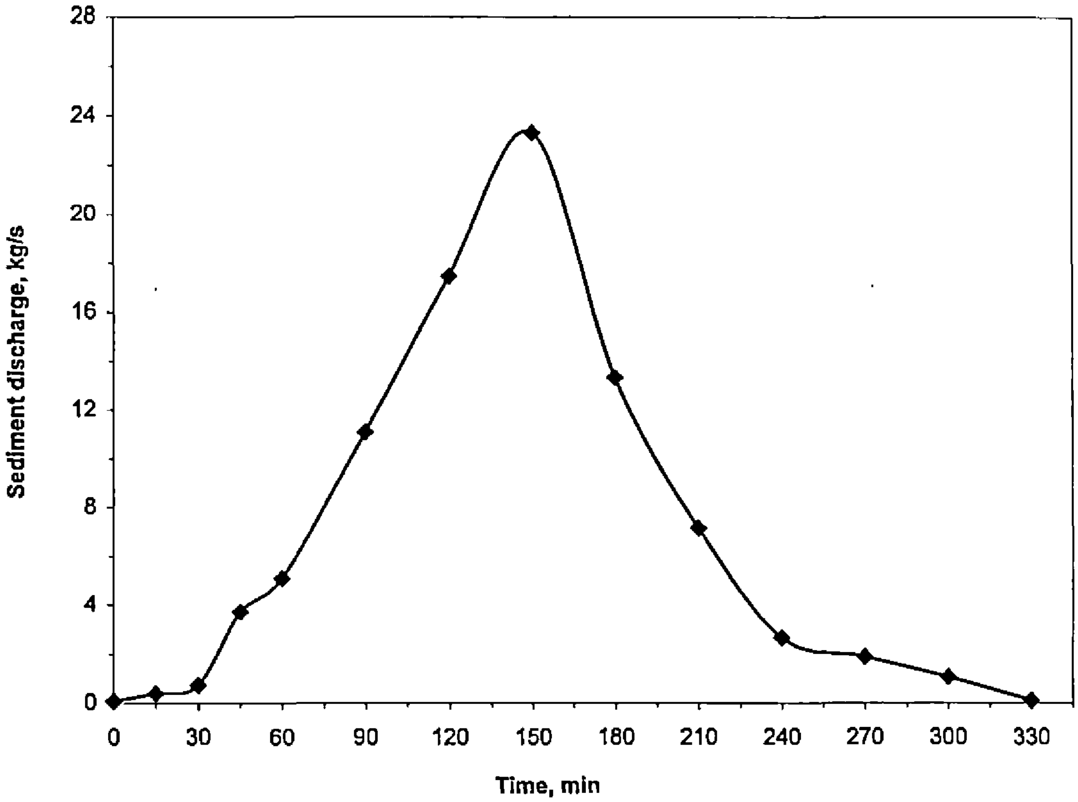

Fig. 4.32 Direct Sediment Graph of the storm event on 11.06.99

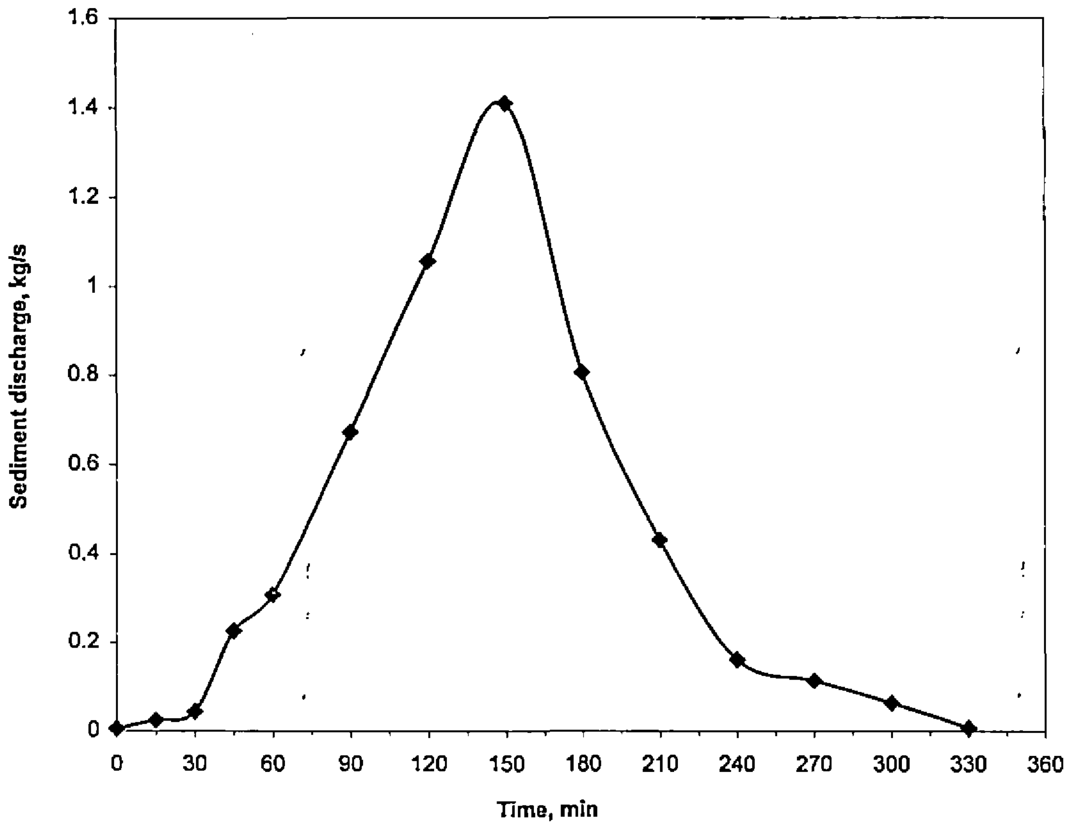

Fig. 4.33 Unit Sediment Graph of the storm event on 11.06.99

Figure 4.36 and 4.37 represent the DSG and USG developed for the storm event on 6.07.99. The total amount of sediment passed through the outlet due to the effect of storm event, during the base period of 6 h, amounted to 43 tonnes. The peak rate of sediment flow occurred at 165 minutes on abscissa was 6.9 kg/s. The peak of the USG is 1.32, while the t_{pk} was same as that of DSG.

The DSG and USG developed for the storm event on 17.07.99 are presented in Fig. 4.38 and 4.39. The peak rate of sediment flow was 75.87 kg/s and the t_{pk} was 165 min. Similarly, the peak of the USG, with the t_{pk} as 165 minutes, was computed as 1.65. The total sediment load mobilized out of the watershed during the period was estimated as 422 tonnes.

4.7 Excess Rainfall - Sediment Yield Relationship

The sediment mobilized during a storm was related to the rainfall excess with the aid of a plot shown in Fig. 4.40. The sediment mobilized, in T/km^2, was plotted against effective rainfall, expressed as depth in cm, on a log - log plot. The sediment mobilized during a particular storm event showed a direct correlation with the effective rainfall. The relation between the sediment mobilized and rainfall excess can be expressed in the following form:

$$ES = 28.566\ ER^{0.9385} \qquad ...(4.4)$$

where,

ES = sediment mobilized, T/km^2, and

ER = rainfall excess, cm.

The scope of the relationship can be, henceforth, exploited in the estimation of the sediment mobilized due to single storm events, particularly when sediment discharge monitoring is not done. The 'r^2' value obtained for the relationship is 0.9864.

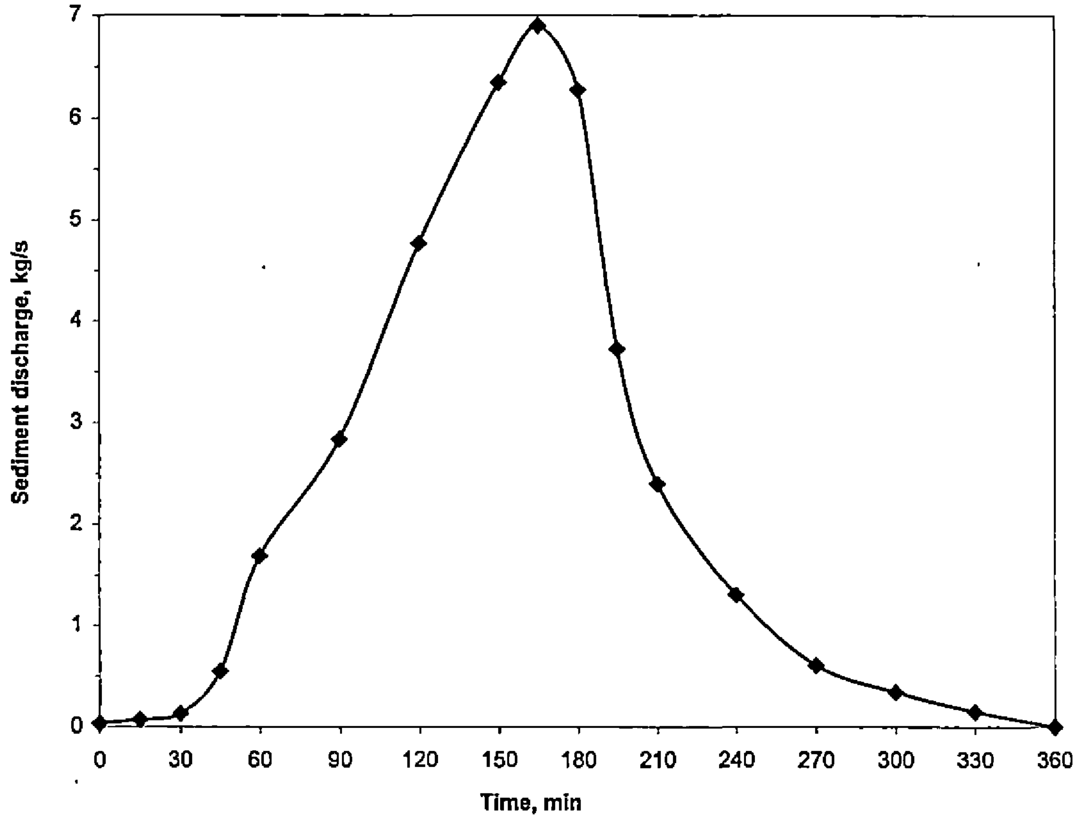

Fig. 4.36 Direct Sediment Graph of the storm event on 06.07.99

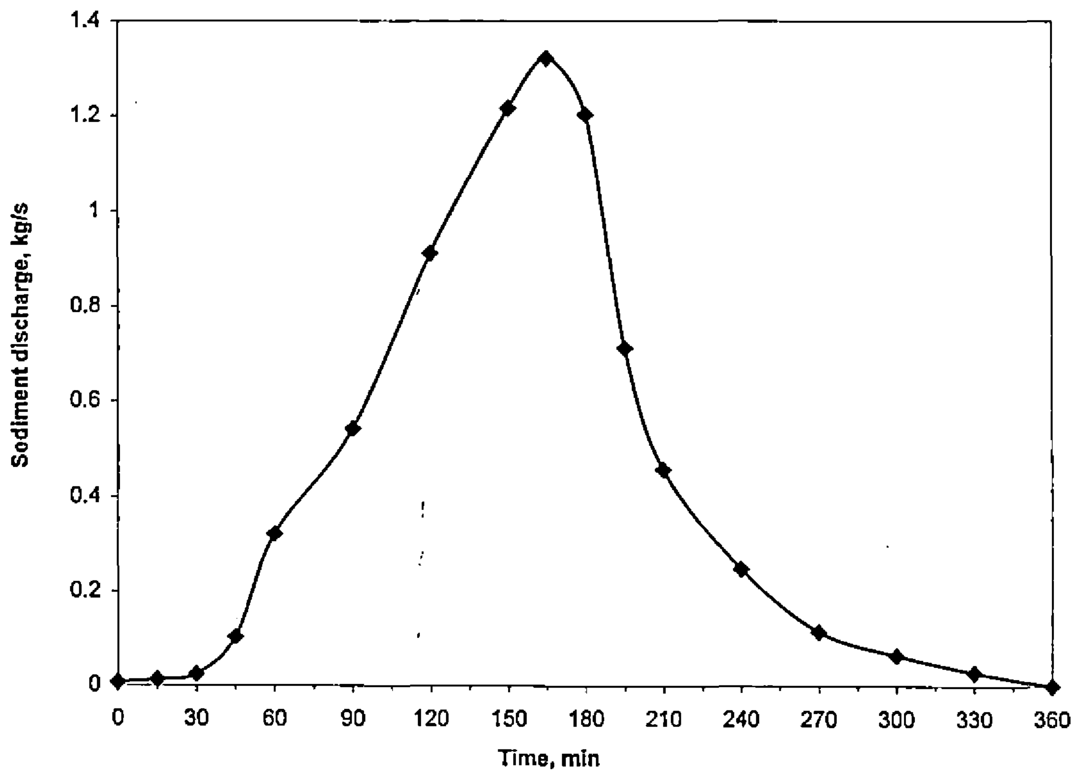

Fig. 4.37 Unit sediment graph of the storm event on 06.07.99

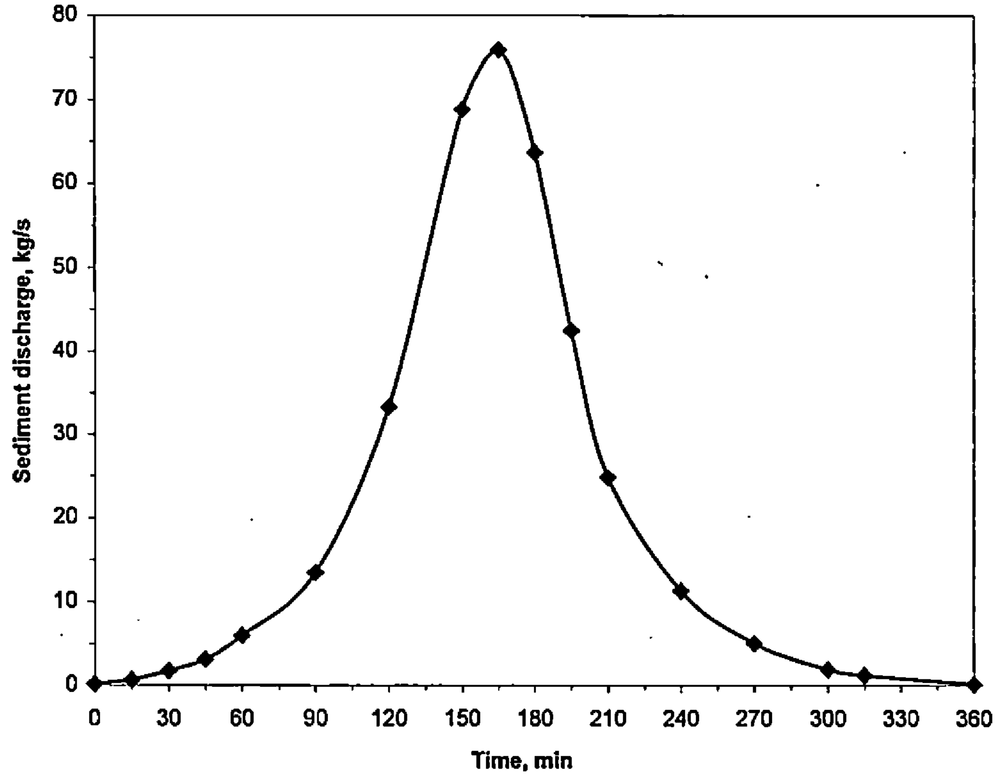

Fig. 4.38 Direct Sediment Graph of the storm event on 17.07.99

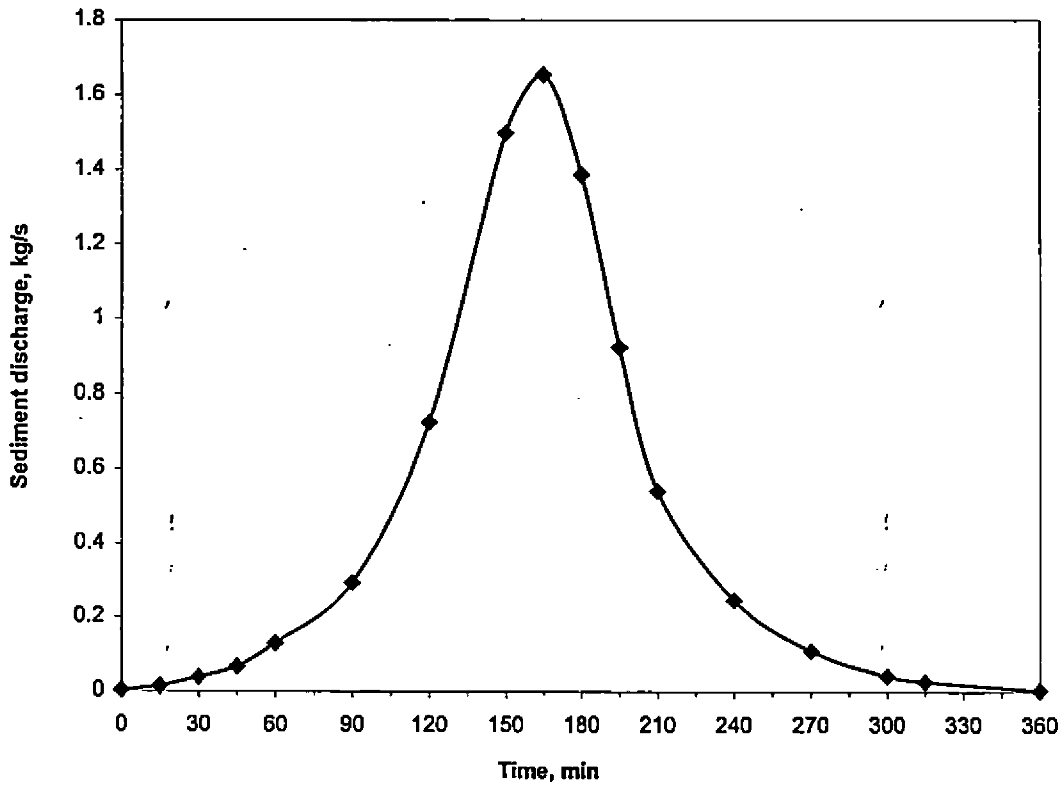

Fig. 4.39 Unit Sediment Graph of the storm event on 17.07.99

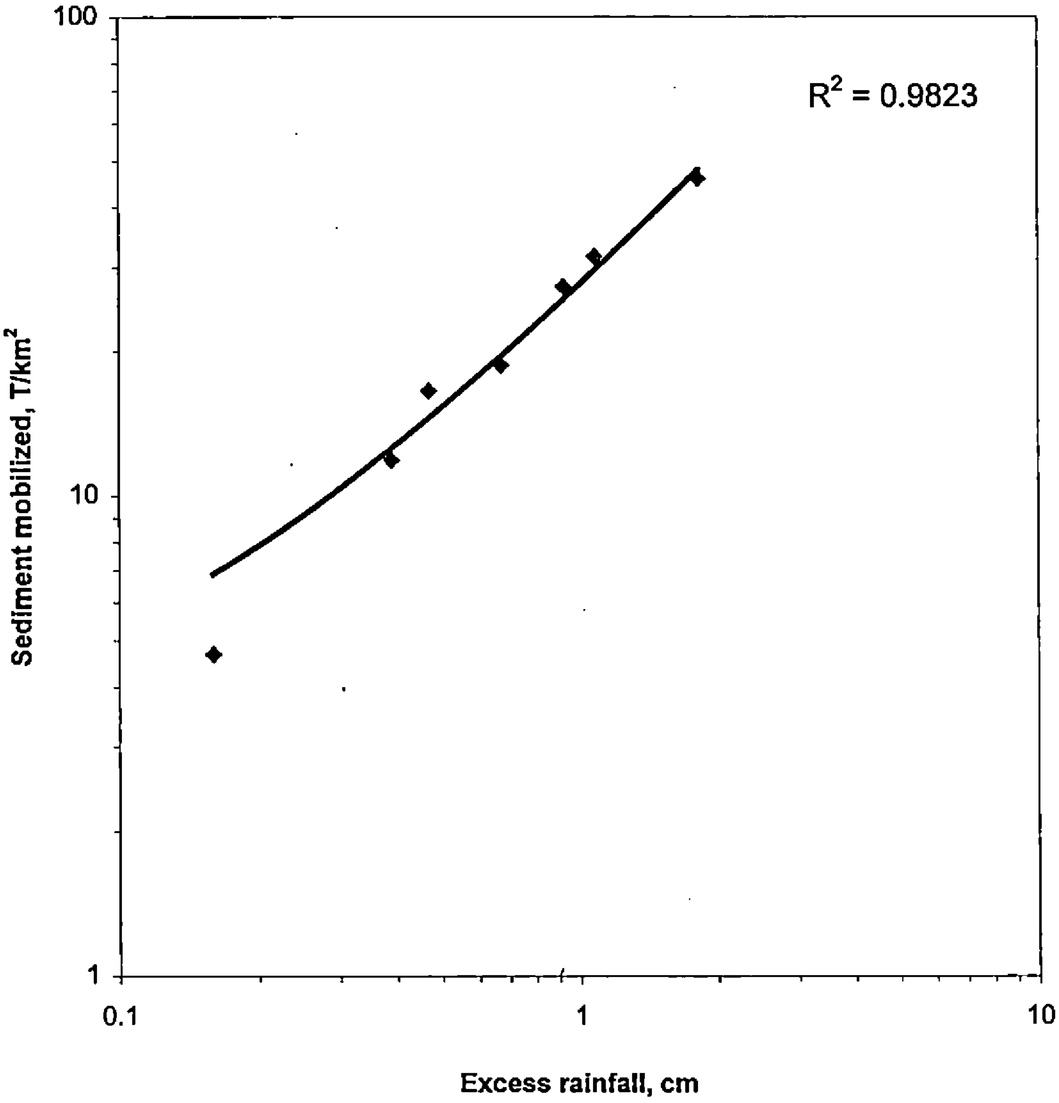

Fig. 4.40 Relationship between excess rainfall and sediment mobilized

4.8 Universal Soil Loss Equation

The erosivity factor (R) was calculated using the method described in Modified-USLE (MUSLE)(Williams, 1975). The R values, for the selected storms calculated, are given in Table 4.3. The R factor values were related to runoff process as the two variables used in the computation were total runoff volume and peak rate of runoff. Thus the R factor has a direct relation with effective rainfall, and is represented by the expression as follows:

$$R = 35033\ ER - 2058 \qquad ...(4.5)$$

where,

R = erosivity factor, and

ER = effective rainfall, cm.

The germane relation holds a 'r^2' value of 0.9981.

Table 4.3 Erosivity factor values of the storm events

Date	Runoff volume (Q) [m^3]	Peak runoff rate (q_p) [m^3/s]	R factor (11.8 Q q_p)
21-06-'98	99472	15.26	34147
29-06-'98	84780	14.57	30436
19-07-'98	35810	6.76	12212
11-06-'99	47160	6.65	14120
18-06-'99	61724	10.66	21381
06-07-'99	15358	2.10	3950
17-07-'99	167128	26.75	62530

The slope length (L) and slope steepness (S) factors were determined according to USLE and RUSLE for each hillslopes. The values of these factors for each hillslopes are given in Appendix X. The L and S factors, for the watershed as a whole, were computed as the weighted average of the respective factors observed for the hill slopes with weights being the areas of hillslopes. The L factors observed according to RUSLE gave greater values than that with USLE. The representative value L factor for the entire watershed has a value of 5.608 and 4.071, when determined as per RUSLE and USLE respectively. Similarly, S factors were also computed for the hillslopes according to RUSLE and USLE methods. The S factors were observed to be greater in the case USLE than RUSLE for all the hillslopes. The representative estimate of S factor, for the watershed as a whole, is given by the value of 3.227 and 4.716, as per RUSLE and USLE respectively. The topographic factor (LS) which is the product of L and S factors for the watershed is greater when computed using USLE method than with RUSLE method. The pertinent factor gave a value of 19.20 for USLE application and 18.10 for RUSLE application.

The cover and management factor (C) values were estimated for the areas with different types of land and vegetation management. The values are given in Table 4.4. The cover and management factor was computed as weighted average of the C factor values for areas with different vegetation management, with weights being representative areas. The C factor was highest on the field having tuber crops, which has a value of 0.049. The area under paddy cultivation has the least value, 0.00135, for C factor among all the vegetation systems. The C factor, comprehensively representing the cover and management effect for the entire watershed area, was estimated as 0.0169.

Table 4.4 C and P factors for different management systems

Management System	Area (m^2)	C factor	P factor
Paddy field	1467044	0.00135	0.90
Barren land	2275319	0.02330	1.00
Vegetable crop system	2036436	0.01500	0.90
Mixed crop system	2114973	0.00305	1.00
Tuber crop system	1293813	0.04920	0.90
Watershed	9187585	0.01695	0.9478

The support practice factor, P factor, values were fixed on judgement based on USLE approximations. The areas in watershed that have been utilized for cultivation and provided with protective measures are represented by a value of 0.90 as support practice factor. The other areas, where there is absence of conservation measures are assigned with a value of 1.0 as P factor. The weighted average of the P factor, with associated area as weight, was computed as 0.9478 and has been chosen to represent the support practice for the watershed.

4.8.1 Application of USLE and RUSLE

The utilities of the USLE and the upgraded RUSLE were effectuated in the estimation of sediment delivered through the outlet of the watershed, on per-storm basis. The parameters employed in both equations were same with disparity confined to the values of the topographic factors (LS). The RUSLE framework offers more relevance to interrill and rill erosion. The computed values of mobilized sediment for different storm events are shown in Table 4.5. The estimates, however, revealed the incidence of higher values for the USLE used estimation than the RUSLE. The RUSLE and USLE possessed same value for all the parameter with exception being the LS factor, which has a higher value for the USLE computation than the RUSLE. Hence it resulted in greater values of soil erosion estimates when computed with the USLE than the RUSLE.

Table 4.5 Sediment yields of the storm events (observed and predicted with USLE and RUSLE)

Date	Sediment yield, tonnes		
	Observed	Predicted	
		USLE	RUSLE
21-06-'98	290.537	343.974	324.140
29-06-'98	251.007	306.592	288.914
19-07-'98	108.810	123.917	115.924
11-06-'99	151.731	142.244	134.942
18-06-'99	171.475	215.378	202.959
06-07-'99	43.080	39.797	37.504
17-07-'99	422.081	629.887	593.566

Fig 4.41 and 4.43 represent the plot of observed and computed amount of sediment delivered through watershed with the USLE and the RUSLE, respectively. The USLE and the RUSLE both registered an 'r^2' value of 0.9724 indicating similar fluctuations from the observed values. Nevertheless, the USLE produced more difference in five cases, as the values predicted by both methods were greater than the observed values. The sediment mobilized estimated by the RUSLE and the USLE are lesser than the observed sediment discharge in two events occurred on 11.06.99 and 6.07.99.

4.9 Sediment Discharge during Different Months

The sediment discharges during different months were sampled. The streamflow and sediment discharges thus obtained are shown in Table 4.6.

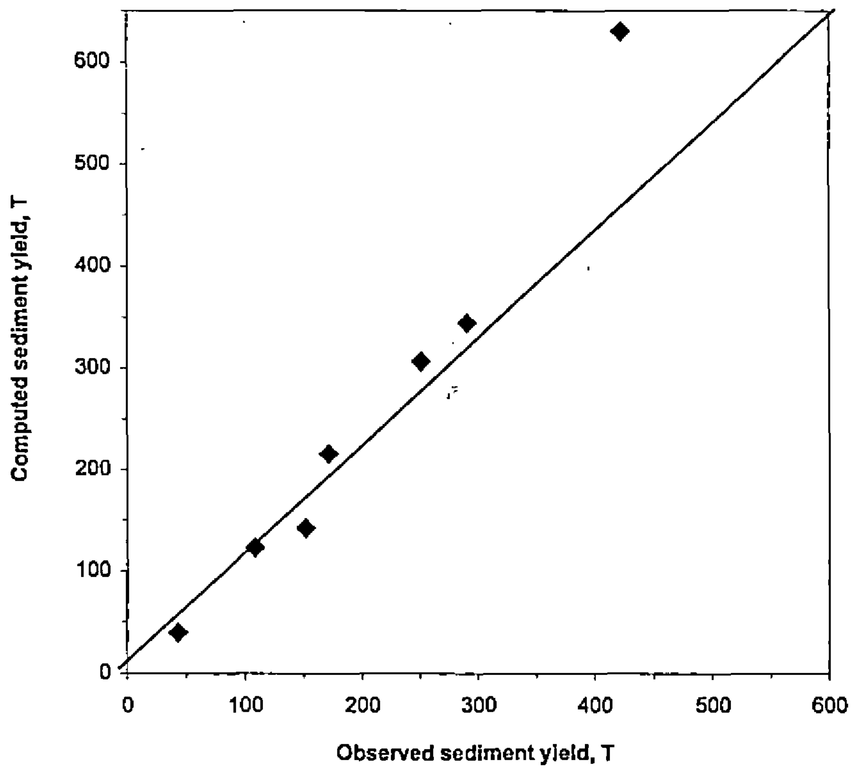

Fig. 4.41 Relationship between sediment yields (observed and computed with USLE)

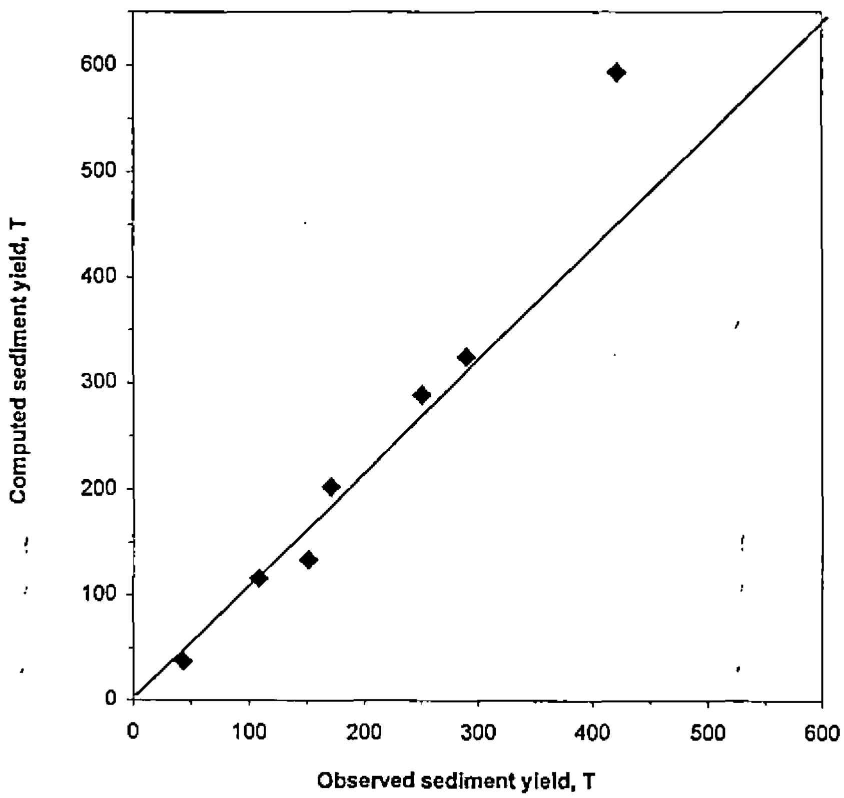

Fig. 4.42 Relationship between sediment yields (observed and computed with RUSLE)

Table 4.6 Streamflow and sediment discharges recorded in different months

Month	Streamflow (m^3/s)	Sediment discharge (kg/s)
November 1998	0.2399	0.0152
December 1998	0.0013	0.00001
January 1999	0.0364	0.0033
February 1999	0.0220	0.0003
April - 1999	0.0222	0.0008
May 1999	0.0031	0.0004
June 1999	0.0843	0.0026
July 1999	0.8269	0.0652

The sediment discharge showed a linear regression with streamflow discharge. The relationship is expressed as follows:

$$Y = 0.07925\ X - 0.00127 \qquad ...(4.6)$$

where,

X = streamflow, m^3/s, and

Y = sediment discharge, kg/s.

The 'r^2' value for the relation was calculated as 0.994.

4.10 Application of WEPP

The simulation of the soil erosion process accompanying a rainfall event was performed with WEPP hillslope-profile model. The model comprised nine components: climate generation, winter processes, irrigation, hydrology, soils, plant growth, residue decomposition, hydraulics of overland flow, and erosion. The simulations in the study were undertaken for individual rainfall events. Therefore, the execution of CLIGEN (Climate Generating model) and EPIC (Erosion Productivity Impact Calculator) was obviated. Nevertheless, some of the parameters had to be procured based on judgement. The model was applied to each hill slope to simulate the soil erosion and runoff generation processes during four storm events. The output consisted of the runoff produced, expressed in mm of depth, and the net amount of soil eroded, expressed in T/ha, from the hillslope. The estimates of runoff and soil erosion from individual hillslopes were integrated to obtain the respective values for the watershed as a whole.

The synthetic Unit Hydrographs of different duration were constructed using Instantaneous Unit Hydrograph (IUH) derived for the watershed. These Unit Hydrographs were utilized to develop DRHs' for specific storms. The results obtained in the form of depth of runoff from the model were utilized to develop DRHs' for different storm events based on the synthetic Unit Hydrographs derived for similar duration. Figures 4.43 to 4.46 show the DRHs' so developed for the four storm events upon which simulation was performed, along with observed DRHs'. The runoff values obtained from the simulation for the selected rainfall events are shown in Table 4.7. In all the four simulations, the predicted runoff values were less than observed runoff values. Also, the variation of the predicted values from the observed values was very large, as could be observed from the predicted and the observed DRHs'.

Table 4.7 Excess rainfall and sediment mobilized (observed and predicted by WEPP)

Date	Effective rainfall, cm		Sediment mobilized, tonnes	
	Observed	Predicted	Observed	Predicted
11-06-'99	0.46	0.233	108.81	136.39
18-06-'99	0.67	0.424	171.47	216.47
06-07-'99	0.16	0.105	43.00	41.48
17-07-'99	1.81	01.48	422.08	570.41

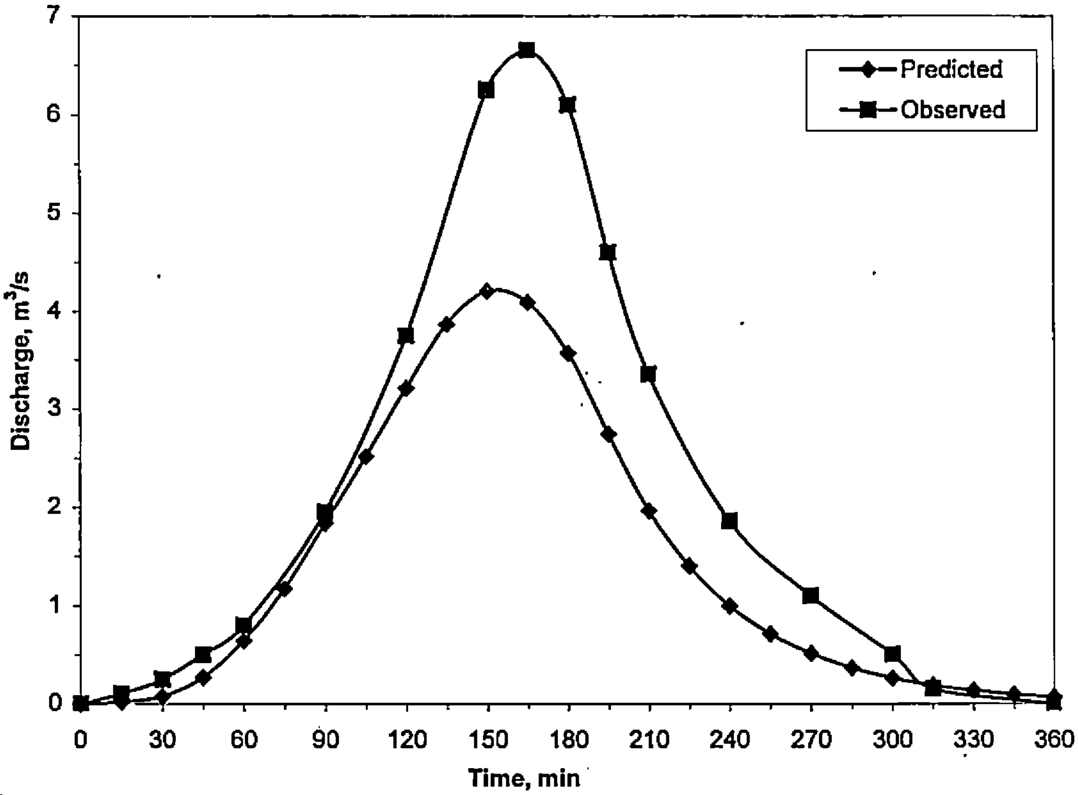

Fig. 4.43 Direct Runoff Hydrograph of the storm event on 11.06.99
(observed and predicted with WEPP)

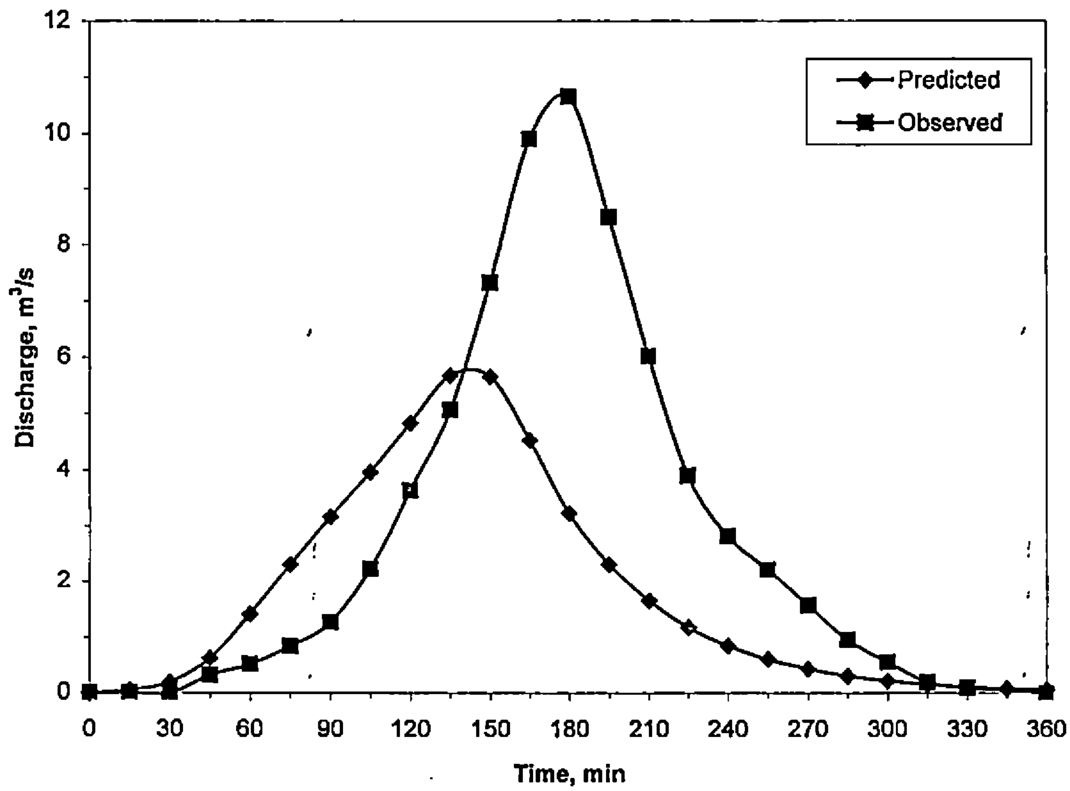

Fig. 4.44 Direct Runoff Hydrograph of the storm event on 18.06.99
(observed and predicted with WEPP)

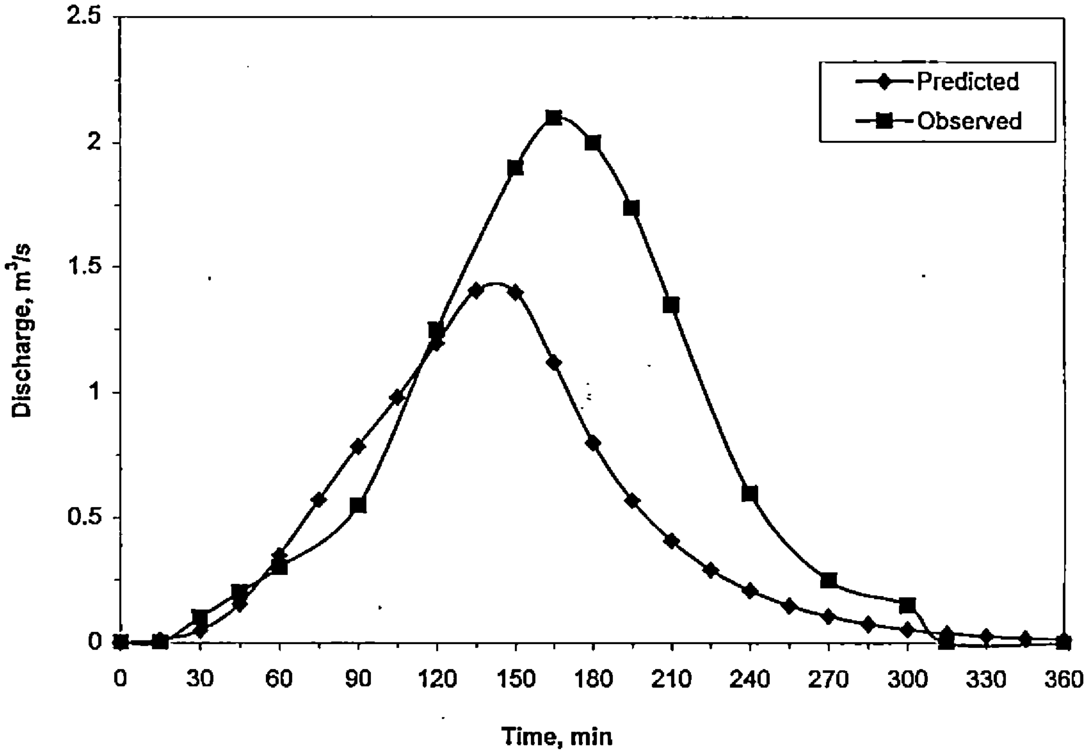

Fig. 4.45 Direct Runoff Hydrograph of the storm event on 06.07.99 (observed and predicted with WEPP)

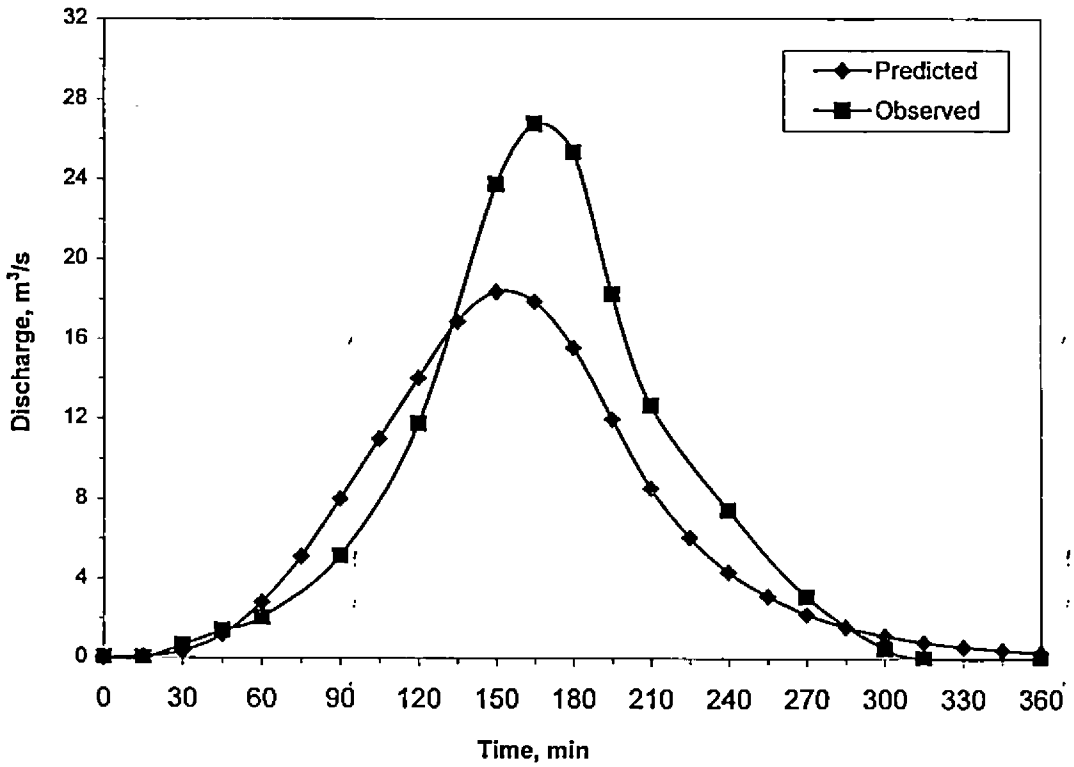

Fig. 4.46 Direct Runoff Hydrograph of the storm event on 17.07.99 (observed and predicted with WEPP)

Similarly the USGs' of the storms with approximately equal duration were averaged arithmetically, and thus 30-min and 60-min duration USGs' were developed. The DSGs' for the four storms were derived using these USGs' by multiplying its ordinates with the sediment mobilized, computed by the model, expressed as T/km^2. The predicted and observed DSGs' are shown in Fig. 4.47 through 4.50. The instances of exaggerated prediction were there in the soil loss prediction except for the rain storm event on 06-07-'99. However, the predicted values of sediment yield were in conformation with observed values. The trend of the predicted and observed DSGs' shows that the simulation of the soil erosion process was more reliable compared to that of runoff process.

The soil losses simulated by the WEPP model for different management systems, for the four selected storm-events, are given in Table 4.8. The effective sediment mobilized and runoff generated from hill slope, which were predicted using the model, were summed to obtain the total sediment mobilized and runoff produced from each management system.

Table 4.8 Runoff and sediment yield from different management systems (predicted with WEPP)

Date: 11-06-99

Management system	Sediment mobilized (T/km^2)	Runoff (cm)
Mixed crop system	0.35	0.033
Barren land	16.19	0.118
Paddy field	3.87	0.270
Vegetable crop system	7.42	0.423
Tuber crop system	60.03	0.430

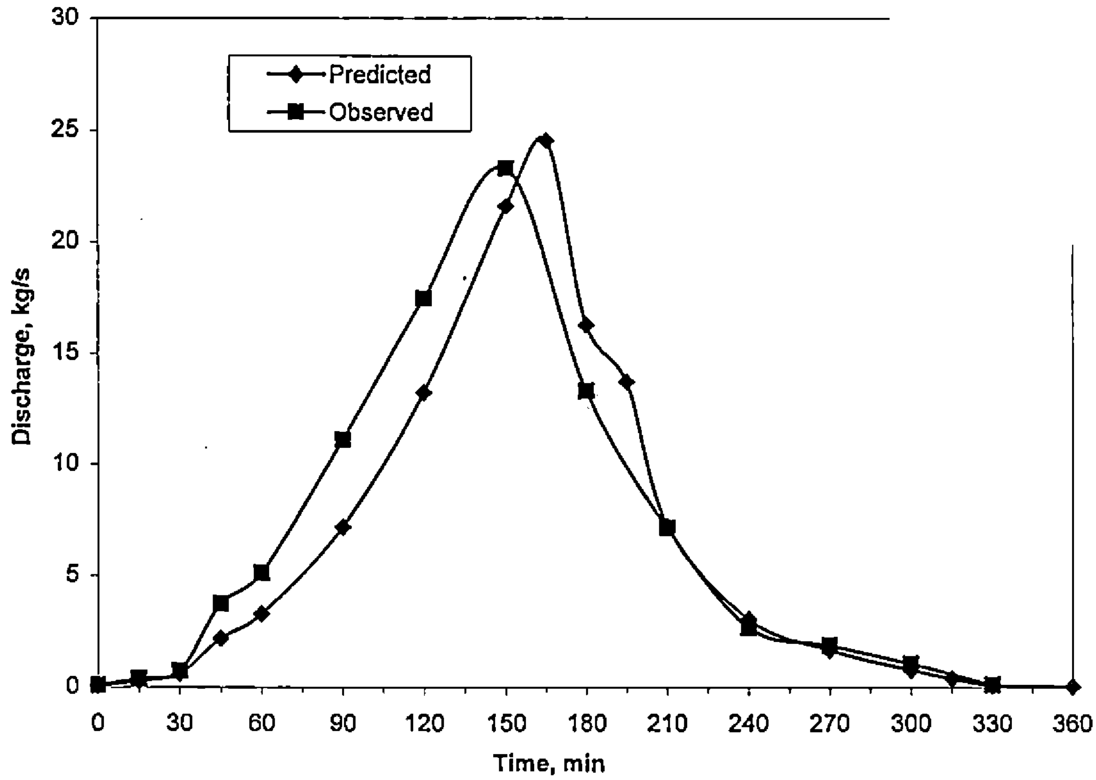

Fig. 4.47 Direct Sediment Graphs of the storm event on 11.06.99 (observed and predicted with WEPP)

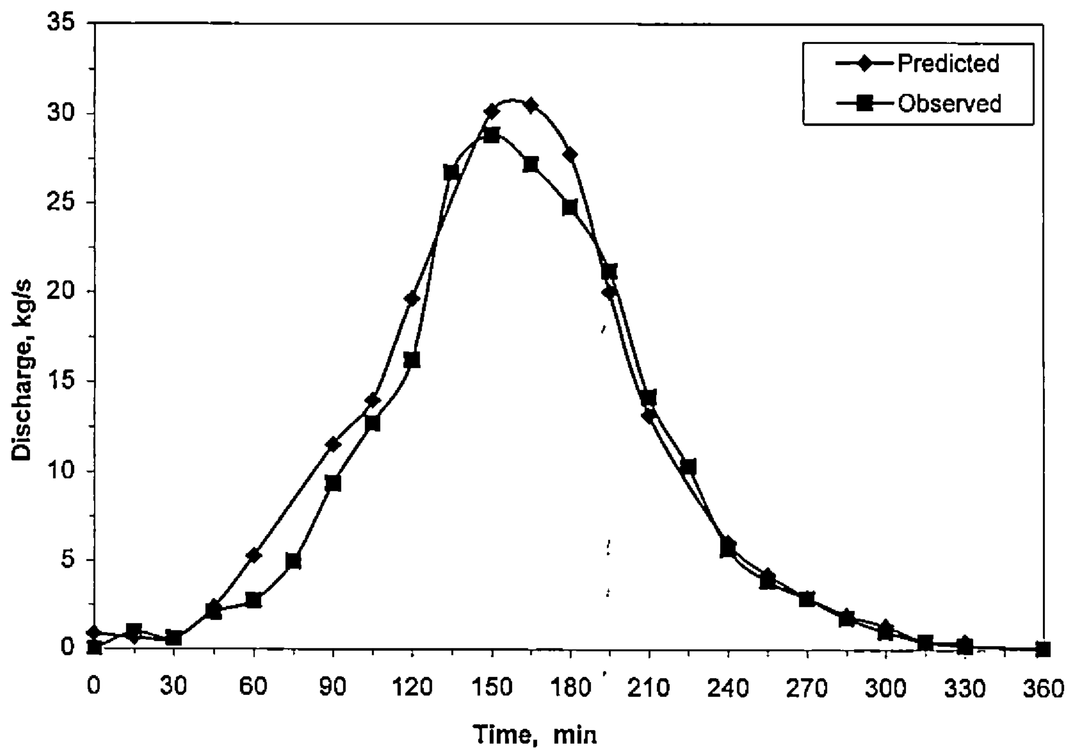

Fig. 4.48 Direct Sediment Graphs of the storm event on 18.06.99 (observed and predicted with WEPP)

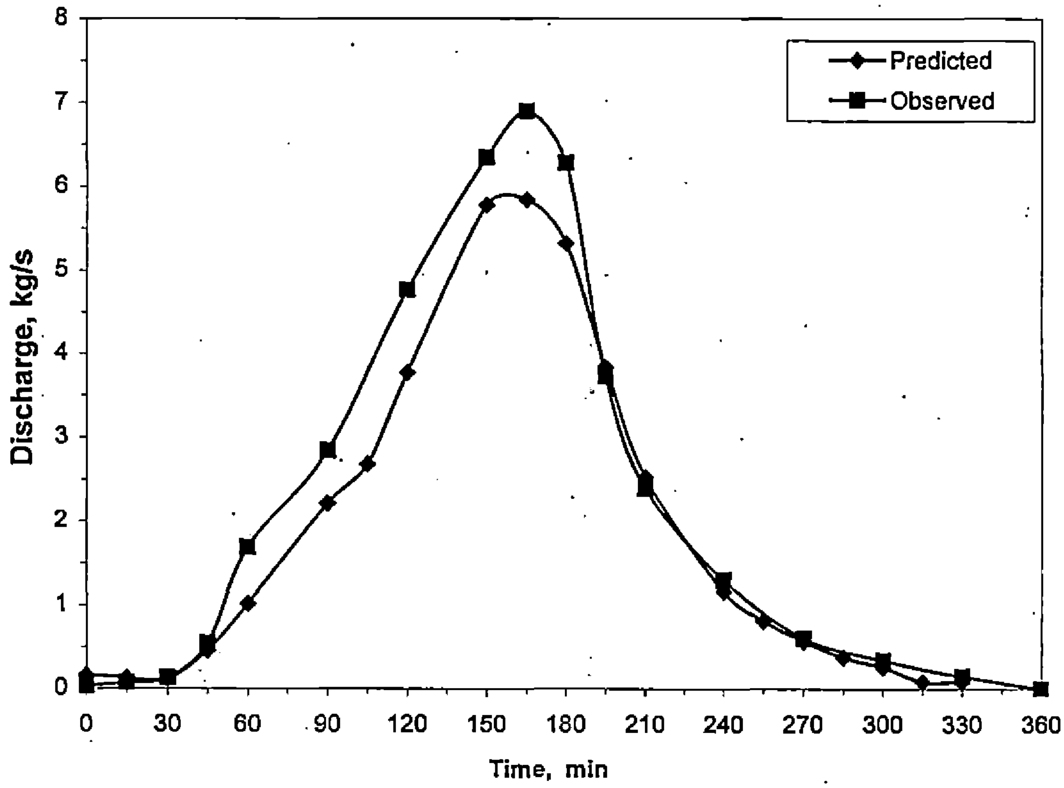

Fig. 4.49 Direct Sediment Graphs the of storm event on 6.07.99 (observed and predicted with WEPP)

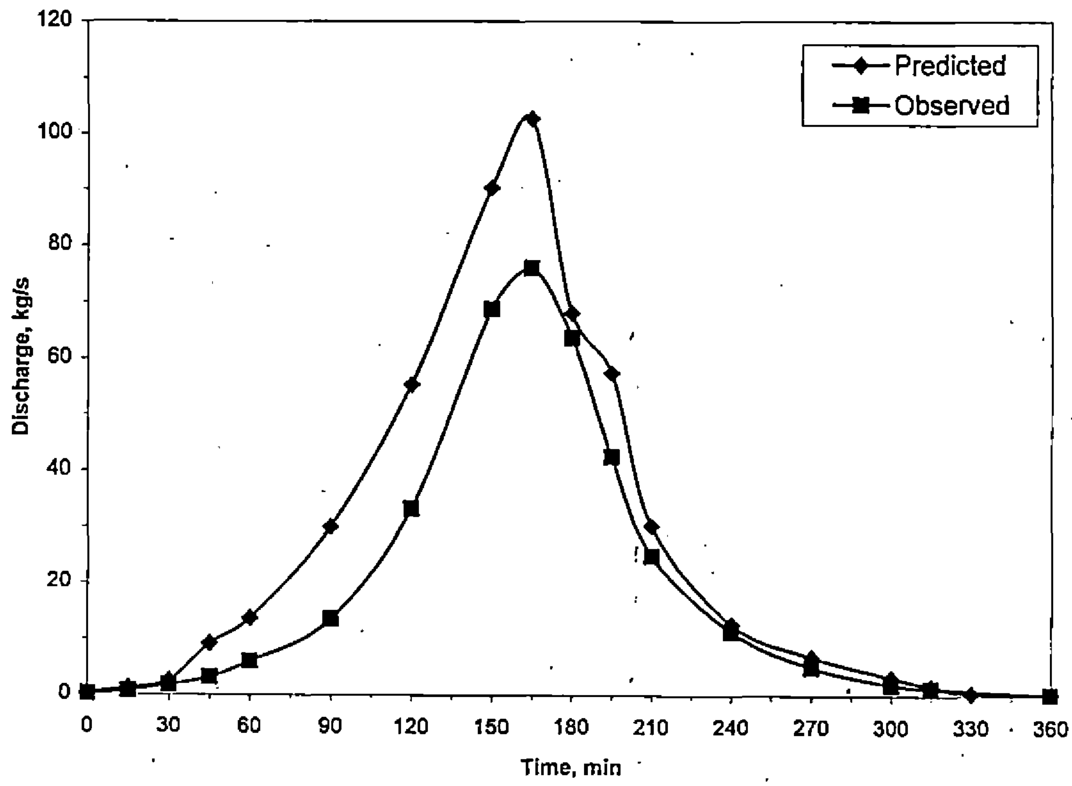

Fig. 4.50 Direct Sediment Graphs of the storm event on 17.07.99 (observed and predicted with WEPP)

(Table 4.8. Continued)

Date: 18-06-99

Management system	Sediment mobilized (T/km^2)	Runoff (cm)
Mixed crop system	6.53	0.083
Barren land	38.31	0.264
Paddy field	2.94	0.422
Vegetable crop system	9.74	0.692
Tuber crop system	70.28	1.091

Date: 06-07-99

Management system	Sediment mobilized (T/km^2)	Runoff (cm)
Mixed crop system	0.018	0.012
Barren land	1.856	0.046
Paddy field	0.756	0.206
Vegetable crop system	2.70	0.164
Tuber crop system	23.54	0.151

Date: 17-07-99

Management system	Sediment mobilized (T/km^2)	Runoff (cm)
Mixed crop system	12.23	0.48
Barren land	135.47	1.19
Paddy field	2.71	1.37
Vegetable crop system	15.49	2.28
Tuber crop system	130.64	2.25

The areas under tuber crops cultivation dominated in erosion process contributing major chunk of the sediment mobilized during rainfall event. These areas provided only canopy protection where crops were present. So soil in the areas without canopy protection was directly exposed to raindrops. Also, the soil surface was in loosened condition with tapioca cultivation. These factors can be assumed as reason for higher rates of erosion associated with these areas. The land, which has been left barren after felling and overgrazing, rendered minimal protection against soil erosion after harvesting. Therefore, these lands produced substantially large quantities of soil erosion, as could be observed from the model output. The paddy fields produced comparatively lesser rate of erosion. The reason could be attributed to flatness of the land, and ground protection offered by plants against raindrops. The areas with thick vegetation, *i.e.*, trees and shrubs (named as 'Mixed'), provided fairly good canopy cover and ground cover, and thereby, enabled these areas to resist excessive erosion. The areas with vegetable crops also gave fairly enough canopy as well as ground cover, thereby, reduced the extent of erosion.

Summary and Conclusion

SUMMARY AND CONCLUSION

Soil erosion is universally acclaimed as a serious threat to man's well being. The rainfall remains the dominant agent causing soil erosion in India. Major portion of the rainfall activity in the country is confined to south-west and north-east monsoon periods. This has aggravated the problems by causing floods in monsoon periods and draught in rainless period. In Kerala, the scenario is worsened due to undulating topography, high intensity rainfall, and denudation of forest. Hence, the soil and water conservation has become imperative for the protection of land, rehabilitation and improvement of badly eroded land, and curing of sedimentation problem. The soil and water conservation measures involve land alteration and cropping management. The pertinent study is focused on the simulation of the effects of the land and vegetation management measures on runoff and sediment-yield from a small watershed. The watershed selected for the study forms part of the Development Unit-IX of Attapadi region, in Palghat district. The watershed encompasses an area of 9.2 km^2.

The rainfall data showed predominant rainfall activity in south-west monsoon periods. The observations were made for the two south-west monsoon periods of 1998 and 1999. The total rainfall during months of June and July in 1998 was 1407 mm, while that of 1999 was 1130 mm. Otherwise, average daily rainfall value for the particular period in 1998 was 23mm and that of 1999 was 18.5 mm.

The soil properties pertinent to erosion, viz., soil texture, organic matter, permeability, and infiltration, were analyzed. The soil texture analysis gave the respective proportions of sand, silt and clay fragments of the soil collected from hillslope as 61, 23 and 16 per cent. The soil sample collected from paddy field showed the similar proportions as 72.5, 13.5 and 14 per cent, respectively. Similarly, the soil sample collected from subsoil at a depth of 30 cm showed the proportions of sand, silt and clay distribution as 59, 14 and 27 per cent, respectively.

The organic matter content of the soil collected from hillslope is 1.98 per cent. The soil samples collected from paddy field and subsoil at a depth of 30 cm were found have organic matter content of 1.03 and 0.52 per cent respectively.

The permeability study conducted with falling head permeameter rendered an average value of 2.63×10^{-3} cm/s for the coefficient of permeability. The minimum and maximum values observed for the particular coefficient were 2.3×10^{-3} and 3.04×10^{-3} cm/s, respectively.

The infiltration studies, conducted on hillslopes and paddy field, showed greater infiltration rates for the former. The infiltration equations derived for different fields are as follows:

for paddy field,

$$Y = 0.142\ t^{1.126} + 0.002 \qquad ...(5.1)$$

for hillslope I,

$$Y = 0.403\ t^{0.871} + 0.0056 \qquad ...(5.2)$$

for hillslope II,

$$Y = 0.401\ t^{0.9419} - 0.0069 \qquad ...(5.3)$$

where,

Y = accumulated infiltration, cm, and

t = elapsed time, min.

The geomorphologic parameters of the watershed were calculated to delineate the shape and topographical parameters influencing the hydrological process. The form factor has a low value and represents a less "square" shape of the watershed. The circularity ratio and elongation ratio have roughly the same values lingering around the value of 0.55, which shows that the watershed has a mixed representation of both shapes. The total number of streams is 55 with highest channel order of 4. The drainage density of the watershed is 2.721, where as the maximum basin length is 6.44 km.

was done with the USLE and the RUSLE variables. The values computed sing the USLE were more than that of the RUSLE method owing to the

The runoff and sediment discharges resulted from individual storm events were recorded at the outlet. The storm events were selected so as to render single peaked hydrographs. The Direct Runoff Hydrographs as well as Direct Sediment Graphs were derived for each storm events. The graphs were utilized in the computation of effective rainfall and sediment mobilized due to the storm events. The Unit Hydrographs and corresponding Unit Sediment Graphs were also deduced for the storm events.

The effective rainfall and sediment mobilized due to the rainfall showed a direct correlation. The relation between rainfall excess and the sediment mobilized, which has an 'r^2' value of 0.986, is expressed as follows:

$$ES = 28.57\ ER^{0.9385} \qquad ...(5.4)$$

where, ES is the sediment mobilized in T/km^2, and ER is the rainfall excess in cm. The sediment discharges observed during different months were correlated with stream flow discharges. The relationship is as follows:

$$Y = 0.07925\ X - 0.00127 \qquad ...(5.5)$$

where,

X = streamflow, m^3/s, and

Y = sediment discharge, kg/s.

'r^2' = 0.994

The parameters of the Universal Soil Loss Equation (USLE) were computed. The erosivity factor (R) for individual storm events were calculated using Modified-USLE (MUSLE). The erosivity factor showed a linear correlation with the effective rainfall, which is represented as an equation of the following form:

$$R = 35033\ ER - 2058 \qquad ...(5.6)$$

where,

R = erosivity factor, and

ER = effective rainfall, cm.

The 'r^2' value of the relation is 0.998.

The soil erodibility factor (K) for the watershed was obtained as 0.0326. The topographic factor (LS) comprising slope length factor (L) and slope steepness factor (S) was calculated using the USLE and the RUSLE method. The topographic factor computed using the USLE method was more than that of the RUSLE method. The cover and management factor values (C) were estimated for areas with different types of vegetation management. The highest value of C factor was obtained for the area under tuber crop cultivation, where as the lowest value for the specific parameter was obtained for paddy cultivated area. The support practice factor (P) values estimated as per USLE approximations ranged between 0.9 and 1.0 for areas under different land management measures. The representative values of C and P factors for the entire watershed were obtained as the weighted average of the particular values for different management systems, with weights being the areas.

The estimation of the soil erosion resulted from individual storm events was done with the USLE and the RUSLE variables. The values computed using the USLE were more than that of the RUSLE method owing to the greater LS factor associated with the USLE method. Nonetheless, both methods registered an 'r^2' value of 0.9724, which shows similar variation with both methods.

The WEPP-model was used for the simulation of the runoff and soil erosion processes resulting from individual storm events. The execution of Climate Generating component (CLIGEN) and Plant Productivity Calculator (EPIC) was unnecessary as the simulations were done on per-storm basis. The predicted values of runoff expressed in mm of depth showed larger variation with the observed values for all the simulated events. Meantime, the estimations of mobilized sediment during the rainfall, by the model, were found to be more reliable when compared with the observed values. The areas under tuber crops cultivation showed highest amount of erosion for all the simulated events. The least amount of erosion occurred from paddy and mixed crops for two simulated events, each.

The rainfall forms the important factor in the soil erosion process due to its detaching and transporting capacity. However, this factor is beyond human control, and only its effects can be minimized by suitable practices. The soil characteristics and topography of the land influence the soil erosion due to their effect on detachment and deposition. These factors are also difficult to be influenced directly, but their effects can moderated by soil conservation measures. The land use is the only the factor, affecting soil erosion, which is directly controllable by human. The extent of rainfall losses as runoff and soil losses can be reduced through sound conservation practices. The watershed pertinent to this study includes areas under different land and vegetation management measures. The areas that are left barren after uncontrolled tree felling offered minimal protection to soil, and hence, resulted in excessive rates of erosion. The hillslopes with tuber crops cultivation left behind loosened soil surface after harvesting. Therefore, the extent of erosion was extreme in these areas, as the topography was steep. The barren lands and areas under tuber crops cultivation contributed to the major portion of the soil eroded from the watershed. Meanwhile, other areas offered more defense against the erosion due to good canopy and ground cover.

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* originals not seen

Appendix I

Table 1. Definitions of field ratings for observed plant characteristics

		Characteristics	Comments
R_1		Height to lowest stem	For large-leafed plants this height should be measured at the drip line; for others it may be at a point, somewhat, closer to the center of the plant.
	1	110 cm or more	
	2	31-109 cm	
	3	51-80 cm	
	4	20-51 cm	
	5	0-19 cm	
R_2		Vertical density	
	1	Low	Plants with little or no chance for intercepted water to move down stems and branches to the ground. Most trees fall into this category. Corresponds to $F_2 = 1.0$*
	2	Medium	Plants with many closely spaced stems and branches, but less than 50% of them angle out and upward from the centre of the plant at 45° or more from horizontal. Corresponds to F_2=0.7
	3	High	Plants with closely spaced stems and branches, most of which angle up and outward from the center of the plant at angles greater than 45° from horizontal. (Hicks yew is a good example.) Corresponds to F_2=0.4
R_3		Leaf-out time	
	1	Deciduous, late leaf-out Corresponds to F_1=0.7*	The time difference between early and late leaf-out is about 1 month.
	2	Deciduous, early leaf-out Corresponds to F_1=0.8	
	4	Evergreen. Corresponds to F_1=1.0	

R_4	Canopy cover	
1	0-10 %	These percentages expressed as a decimal = P_c*. The per cent cover is the per cent of the total soil surface area that can not be hit by vertically falling rain because of the canopy.
2	11-20 %	
3	21-30 %	
4	31-40 %	
5	41-50 %	
6	51-60 %	
7	61-70 %	
8	71-80 %	
9	81-90 %	
10	91-100 %	
R_5	Litter cover	
1	0-25 %	These percentages expressed as a decimal = P_m*. The per cent cover here is the per cent of the total soil surface covered with a substantial depth of residue, mulch, compacted duff, litter or vegetation in direct contact with soil.
2	26-35 %	
3	36-45 %	
4	46-55 %	
5	56-70 %	
6	71-85 %	
7	86-100 %	

APPENDIX II

Calculations used in sedimentation analysis for determining Particle size distribution

The diameter of the particle in suspension at any sampling time 't' was calculated with the following formula:

$$D = \sqrt{\frac{30\mu}{980(G - G_1)} x \sqrt{\frac{H_R}{t}}} \qquad \ldots(1)$$

where,

D	=	diameter of particles in suspension, mm;
M	=	coefficient of viscosity of water, poises;
G	=	specific gravity of soil fraction used in sedimentation analysis;
G_1	=	specific gravity of water;
H_R	=	effective depth corresponding to hydrometer reading corrected for meniscus, cm, and
t	=	time elapsed between beginning of sedimentation and taking of hydrometer reading, min.

The per cent by mass (W) of the particles smaller than smaller than the corresponding equivalent particle diameter was calculated using the following formula:

$$W = \frac{100 \quad G_s (R_h + m_t - x)}{W_b \quad (G_s - 1)} \qquad \ldots (2)$$

where,

G_s	=	specific gravity of soil particles;
W_b	=	weight of soil after pre-treatment;
R_h	=	hydrometer reading corrected for meniscus;
M_t	=	temperature correction, and

x = dispersing agent correction.

The specific gravity of soil particles was found as follows:

$$G = \frac{m_2 - m_1}{(m_4 - m_1) - (m_3 - m_2)} \quad \dots (3)$$

where,

m_1 = mass of density bottle, g;

m_2 = mass of bottle and dry soil, g;

m_3 = mass of bottle, soil and water, g, and

m_4 = mass of bottle when full of water only, g.

APPENDIX III

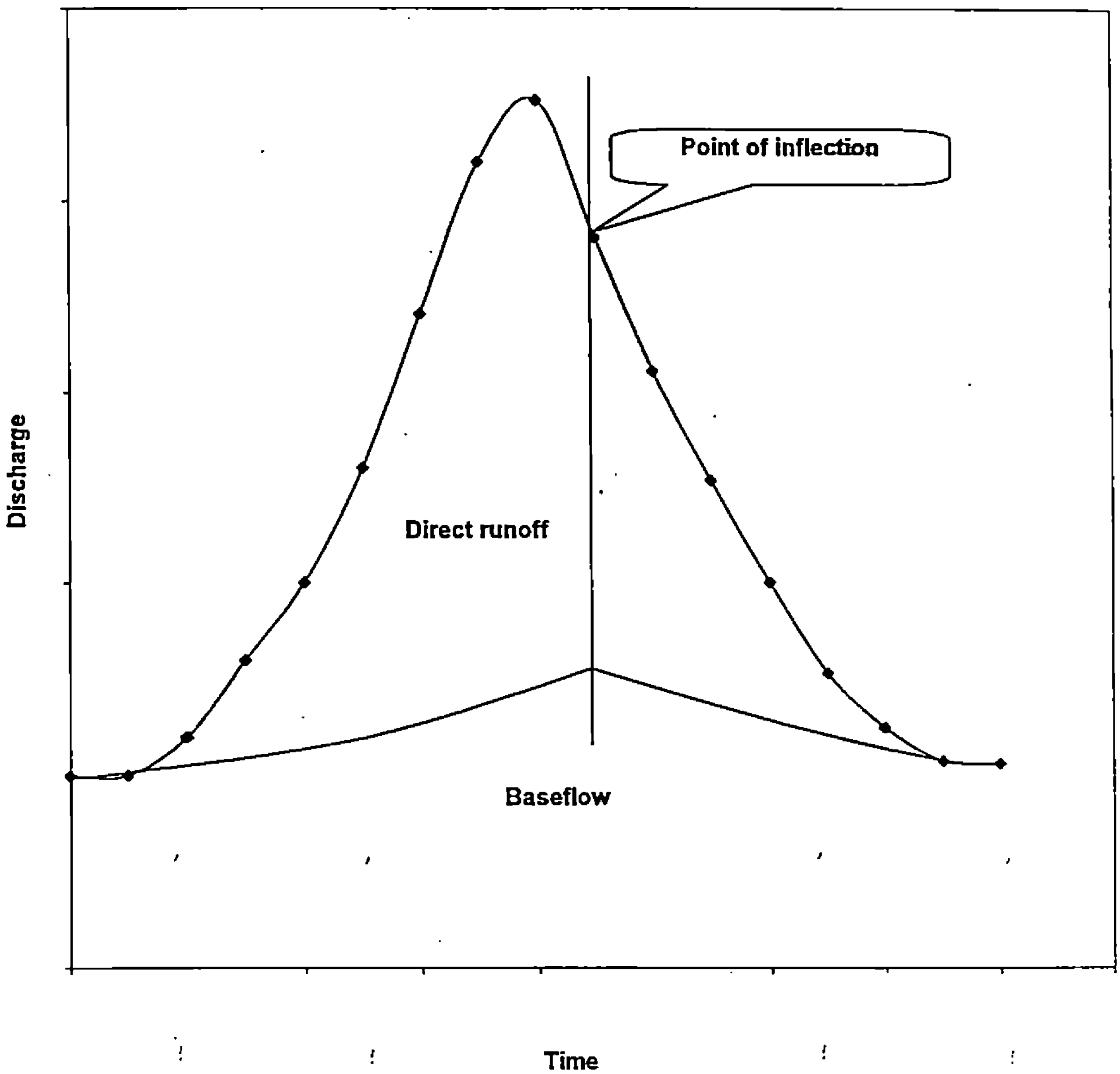
Permeability studies

1. Area of stand pipe (a) 38.485 cm^2
2. Length of the sample (L) 13 cm^2
3. Cross sectional area (A)
   of sample 78.54 cm
4. Initial Head (h_1) 105.7 cm
5. Final Head (h_2) 95.7 cm
6. Time interval

Test No.	Time interval (min)		
	Sample I	Sample II	Sample III
1	280	260	210
2	275	256	205
3	271	230	209
Average	275.33	248.67	208
Coefficient of permeability (cm/s)	2.3×10^{-3}	2.546×10^{-3}	3.044×10^{-3}

Appendix IV

Baseflow separation



Hydrograph

APPENDIX V

Daily rainfall of the months June and July in 1998 and 1999

Day	Rainfall, cm			
	June-1998	July-1998	June-1999	July-1999
1	0	66	0	0
2	0	39	0	0
3	0	25	0	10
4	0	22	0	0
5	0	40	0	20
6	0	54	0	30
7	0	0	0	15
8	0	0	31	10
9	0	12	20	12
10	0	17	0	0
11	13	20	30	60
12	10	15	60	0
13	40	0	35	0
14	0	0	25	0
15	0	29	40	30
16	0	30	20	22
17	0	24	10	24
18	74	20	70	60
19	20	15	50	30
20	63	64	40	22
21	70	0	12	18
22	104	0	0	24
23	100	30	0	30
24	58	0	0	35
25	0	46	0	0
26	25	30	0	21
27	25	15	0	12
28	97	60	0	70
29	82.5	27	0	29
30	86	23	0	40
31		23		60

APPENDIX VI

Particle size distribution of soils

Particle size distribution of soil at a depth of 30 cm		Particle size distribution of soil at paddy field		Particle size distribution of soil at hillslope	
Particle size, mm	Per cent finer, %	Particle size, mm	Per cent finer, %	Particle size, mm	Per cent finer, %
0.0012	25.04	0.0013	13.76	0.0013	15.05
0.0020	27.06	0.0019	14.06	0.0032	16.77
0.0040	31.10	0.0061	17.65	0.0060	22.37
0.0076	34.73	0.0085	19.15	0.0115	27.96
0.0148	37.16	0.0221	23.33	0.0302	33.55
0.0458	39.98	0.0426	25.73	0.0420	35.27
0.075	47.72	0.075	33.24	0.075	50.37
0.425	75.06	0.425	88.62	0.425	73.63
2.000	99.11	2.000	100	2.000	95.19

APPENDIX VII

Infiltration studies

Infiltration measurements on paddy field

Elapsed time t, (min)	Cumulative time (min)	Initial reading I, (mm)	Final reading F, (mm)	Difference I-F (mm)	Cumulative infiltration q, (mm)	Infiltration rate (mm/h)
1	1	150	148	2.0	2.0	120
2	3	148	146	2.0	4.0	60
3	6	146	144	2.0	6.0	40
5	11	144	141	3.0	9.0	36
7	18	141	138	3.0	12.0	25.7
10	28	138	134	4.0	16.0	24
10	38	134	131	3.0	19.0	18
10	48	131	128	3.0	22.0	18
15	63	128	124	4.0	26.0	16
15	78	124	120	4.0	30.0	16
15	93	120	116	4.0	34.0	16

Infiltration measurements on Hillslope I

Elapsed time t, (min)	Cumulative time (min)	Initial reading I, (mm)	Final reading F, (mm)	Difference I-F (mm)	Cumulative infiltration q, (mm)	Infiltration rate (mm/h)
1	1	170	165	5	5	300
2	3	165	160	5	10	150
3	6	160	156	4	14	80
5	11	156	151	5	19	60
7	18	151	148	3	22	26
10	28	148	144	4	26	24
10	38	144	140	4	30	24
10	48	140	136	4	34	24

Infiltration measurements on Hillslope II

Elapsed time t, (min)	Cumulative time (min)	Initial reading I, (mm)	Final reading F, (mm)	Difference I-F (mm)	Cumulative infiltration q, (mm)	Infiltration rate (mm/h)
1	1	40	34	6	6	360
2	3	86	78	8	14	240
3	6	74	70	4	18	80
5	11	70	67	3	21	36
7	18	67	63	4	25	34
10	28	63	58	5	30	30
10	38	58	53	5	35	30
10	48	53	48	5	40	30

APPENDIX VIII

Ordinates of storm hydrograph, baseflow, Direct Runoff Hydrograph (DRH) and Unit Hydrograph (UH)

DATE 21.06.98					DATE 29.06.98				
Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)	Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)
0	1.84	1.84	0.00	0.00	0	1.68	1.68	0.00	0.00
15	2.11	2.11	0.00	0.00	15	1.90	1.90	0.00	0.00
30	2.75	2.48	0.27	0.25	30	2.62	2.21	0.42	0.45
45	3.53	2.74	0.79	0.73	45	3.09	2.42	0.68	0.74
60	4.32	3.12	1.20	1.11	60	3.87	2.74	1.13	1.22
90	7.19	3.87	3.32	3.07	90	6.36	3.36	2.99	3.25
120	12.02	4.49	7.53	6.97	120	10.74	3.89	6.85	7.43
135	15.79	4.85	10.94	10.12	135	14.11	4.20	9.91	10.74
150	19.51	5.23	14.28	13.20	150	17.89	4.51	13.38	14.51
165	20.75	5.50	15.26	14.11	165	19.29	4.72	14.57	15.81
180	20.25	5.79	14.46	13.38	180	16.81	4.96	11.85	12.85
195	17.49	6.11	11.38	10.53	195	13.69	5.24	8.45	9.16
210	13.90	5.66	8.25	7.63	210	10.36	4.86	5.50	5.97
240	8.40	4.75	3.65	3.37	240	7.22	4.09	3.13	3.39
270	5.90	3.97	1.93	1.79	270	4.76	3.43	1.33	1.44
300	3.78	3.22	0.55	0.51	300	3.10	2.80	0.30	0.32
330	2.84	2.74	0.10	0.09	330	2.35	2.35	0.00	0.00
360	1.94	1.94	0.00	0.00	360	1.75	1.75	0.00	0.00

DATE 19.07.98					DATE 11.06.99				
Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)	Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)
0	1.26	1.26	0.00	0.00	0	1.38	1.38	0.00	0.00
15	1.41	1.41	0.00	0.00	15	1.60	1.50	0.10	0.21
30	1.83	1.55	0.27	0.70	30	1.95	1.70	0.25	0.53
45	2.11	1.66	0.45	1.15	45	2.30	1.80	0.50	1.07
60	2.43	1.83	0.60	1.54	60	2.80	2.00	0.80	1.70
90	3.79	2.18	1.61	4.13	90	4.35	2.40	1.95	4.16
120	5.89	2.47	3.43	8.79	120	6.50	2.75	3.75	7.99
150	9.55	2.80	6.76	17.33	150	9.40	3.15	6.25	13.32
165	9.41	2.92	6.48	16.63	165	9.90	3.25	6.65	14.17
180	7.17	3.06	4.11	10.53	180	9.50	3.40	6.10	13.00
195	5.86	3.14	2.71	6.95	195	8.20	3.60	4.60	9.80
210	4.53	2.93	1.60	4.10	210	6.70	3.35	3.35	7.14
240	3.39	2.52	0.88	2.25	240	4.70	2.85	1.85	3.94
270	2.55	2.12	0.44	1.12	270	3.50	2.40	1.10	2.34
300	1.78	1.78	0.00	0.00	300	2.50	2.00	0.50	1.07
330	1.50	1.50	0.00	0.00	330	1.75	1.60	0.15	0.32
360	1.28	1.28	0.00	0.00	360	1.40	1.40	0.00	0.00

(...Continued)

(Appendix VIII continued...)

DATE 18.06.99					DATE 06.07.99				
Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)	Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)
0	1.47	1.47	0.00	0.00	0	0.88	0.88	0.00	0.00
15	1.66	1.66	0.00	0.00	15	1.00	1.00	0.00	0.00
30	2.20	1.88	0.32	0.47	30	1.20	1.10	0.10	0.63
45	2.56	2.04	0.52	0:77	45	1.45	1.25	0.20	1.25
60	3.12	2.28	0.84	1.25	60	1.60	1.30	0.30	1.88
90	5.00	2.77	2.23	3.32	90	2.05	1.50	0.55	3.44
120	8.24	3.18	5.06	7.54	120	2.85	1.60	1.25	7.82
135	10.75	3.43	7.33	10.91	135	3.21	1.67	1.55	9.73
150	13.56	3.66	9.90	14.74	150	3.63	1.73	1.90	11.89
165	14.48	3.82	10.66	15.86	165	3.85	1.75	2.10	13.14
180	12.51	4.01	8.50	12.65	180	3.75	1.75	2.00	12.51
195	10.22	4.19	6.03	8.97	195	3.50	1.76	1.74	10.89
210	7.80	3.90	3.90	5.81	210	3.00	1.65	1.35	8.45
240	5.52	3.31	2.21	3.29	240	2.10	1.50	0.60	3.75
270	3.72	2.77	0.95	1.41	270	1.50	1.25	0.25	1.56
300	2.49	2.29	0.20	0.29	300	1.25	1.10	0.15	0.94
330	1.93	1.93	0.00	0.00	330	1.00	1.00	0.00	0.00
360	1.52	1.52	0.00	0.00	360	0.90	0.90	0.00	0.00

DATE 17.07.99				
Time, (min)	Discharge (m^3/s)	Baseflow (m^3/s)	DRH (m^3/s)	UH (m^3/s)
0	2.50	2.50	0.00	0.00
15	3.00	3.00	0.00	0.00
30	4.24	3.60	0.64	0.35
45	5.48	4.10	1.38	0.76
60	6.79	4.75	2.04	1.12
90	11.16	6.00	5.16	2.84
120	18.75	7.00	11.75	6.46
135	24.85	7.62	17.90	9.55
150	32.00	8.25	23.75	13.06
165	35.50	8.75	26.75	14.71
180	34.59	9.25	25.34	13.93
195	28.00	9.75	18.25	10.03
210	21.65	9.00	12.65	6.95
240	14.96	7.50	7.46	4.10
270	9.35	6.25	3.10	1.70
300	5.50	5.00	0.50	0.27
315	4.40	4.40	0.00	0.00
360	2.72	2.72	0.00	0.00

APPENDIX XI

Sediment mobilized and excess rainfall (predicted using WEPP model)

Date - 11.06.99

Hill Slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)	Hill slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)
1	27344	0.007	0.500	50	58984	0.128	5.330
2	32031	0.000	0.440	51	180859	0.000	0.130
3	33984	0.000	0.440	52	97656	0.000	0.220
4	30469	0.454	1.690	53	74609	0.000	0.380
5	28125	0.047	0.850	54	133984	0.000	0.290
6	32422	0.026	2.670	55	63281	0.000	0.520
7	60547	0.047	3.430	56	156250	0.074	4.440
8	49805	0.197	6.750	57	229688	0.038	3.380
9	22461	0.000	0.510	58	111328	0.123	6.060
10	10938	0.093	1.190	59	152734	0.080	4.770
11	21875	0.017	0.600	60	89063	0.207	8.500
12	58594	0.000	0.480	61	87109	0.022	2.370
13	35156	0.000	0.440	62	129297	0.026	2.060
14	22266	0.027	1.760	63	93750	0.137	5.570
15	23828	0.047	0.990	64	287109	0.619	4.350
16	51758	0.034	1.100	65	117188	0.105	5.410
17	89844	0.018	1.810	66	73438	0.154	1.340
18	33203	0.126	0.950	67	54297	0.481	1.970
19	34180	0.112	5.840	68	211719	0.000	0.170
20	33203	0.270	1.830	69	190234	0.000	0.380
21	83984	0.032	2.410	70	108984	0.000	0.220
22	17578	0.000	0.670	71	100000	0.000	0.250
23	41992	0.002	0.590	72	64453	0.066	4.230
24	104688	0.000	0.200	73	128516	0.019	2.320
25	43945	0.000	0.330	74	239063	0.040	0.730
26	39063	0.002	0.330	75	93359	0.294	1.500
27	56641	0.261	1.180	76	199219	0.527	4.350
28	24609	0.013	0.950	77	46484	0.129	6.680
29	50781	0.216	0.660	78	85938	0.024	0.790
30	78125	0.261	0.650	79	221094	0.012	2.180
31	90234	0.020	1.750	80	12156	0.020	2.080
32	67188	0.552	1.800	81	53516	0.324	2.040
33	69141	0.021	0.800	82	67969	0.337	2.100
34	101953	0.155	1.300	83	150391	0.268	3.350
35	60156	0.033	2.740	84	233203	0.430	3.460
36	85938	0.079	1.200	85	177734	0.908	5.100
37	79297	0.035	1.800	86	73438	1.090	7.080
38	58594	0.016	1.580	87	112109	0.098	6.960
39	128906	0.014	1.620	88	79688	0.228	9.470
40	94922	0.007	0.790	89	135547	0.014	1.880
41	56250	0.091	1.370	90	114453	1.011	6.060
42	42969	0.011	1.460	91	121875	0.023	2.010
43	114063	0.016	1.950	92	103906	0.015	1.690
44	47656	0.140	7.290	93	96484	0.065	1.170
45	93750	0.481	1.810	94	54688	0.494	2.540
46	50000	0.102	5.690	95	105078	0.054	0.990
47	126953	0.078	4.400	96	128906	0.029	0.540
48	116797	0.000	0.110	97	82422	0.081	0.870
49	153516	0.015	0.750	98	91016	0.163	1.520

(...Continued)

APPENDIX IX

Ordinates of Sediment Graph, baseflow, Direct Sediment Graph (DSG) and Unit Sediment Graph (USG)

DATE 21.06.98					DATE 29.06.98				
Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)	Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)
0	1.84	1.84	0.00	0.00	0	0.44	0.44	0.00	0.00
15	2.82	2.11	0.71	0.02	15	0.56	0.58	0.58	0.00
30	3.35	2.48	0.88	0.03	30	0.68	0.94	0.94	0.03
45	4.89	2.74	2.15	0.07	45	0.75	2.13	2.13	0.08
60	6.52	3.12	3.40	0.11	60	0.87	3.07	3.07	0.11
90	14.34	3.87	10.47	0.33	90	1.20	7.17	7.17	0.26
120	26.96	4.49	22.47	0.71	120	1.35	22.26	22.26	0.81
135	38.21	4.85	33.35	1.05	135	1.52	30.73	30.73	1.12
150	45.37	5.23	40.14	1.27	150	1.71	38.24	38.24	1.40
165	48.20	5.50	42.71	1.35	165	1.90	40.84	40.83	1.49
180	46.81	5.79	41.03	1.30	180	2.10	31.54	31.54	1.15
195	38.04	6.11	31.93	1.01	195	1.90	23.35	23.35	0.85
210	28.71	5.66	23.05	0.73	210	1.77	17.03	17.03	0.62
240	17.12	4.75	12.37	0.39	240	1.49	10.10	10.10	0.37
270	10.11	3.97	6.14	0.19	270	1.10	3.60	3.60	0.13
300	4.99	3.22	1.76	0.06	300	0.85	1.44	1.44	0.05
330	3.31	2.74	0.57	0.02	330	0.74	0.44	0.44	0.02
360	2.24	1.94	0.30	0.01	360	0.70	0.13	0.13	0.00

DATE 19.07.98					DATE 11.06.99				
Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)	Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)
0	0.00	0.00	0.00	0.00	0	0.24	0.24	0.00	0.00
15	0.06	0.06	0.00	0.00	15	0.33	0.24	0.09	0.01
30	0.58	0.19	0.39	0.03	30	0.64	0.24	0.40	0.02
45	0.96	0.32	0.64	0.05	45	1.14	0.41	0.73	0.04
60	1.44	0.38	1.05	0.09	60	4.15	0.41	3.73	0.23
90	3.54	0.60	2.94	0.25	90	5.74	0.65	5.09	0.31
120	9.59	0.80	8.80	0.74	120	12.11	1.00	11.11	0.67
150	17.03	0.92	16.11	1.36	150	18.59	1.12	17.47	1.06
165	20.97	1.05	19.91	1.68	165	21.60	1.24	20.35	1.23
180	19.32	1.10	18.22	1.54	180	24.66	1.36	23.30	1.41
195	12.50	0.95	11.55	0.97	195	19.60	1.30	18.30	1.10
210	8.39	0.82	7.57	0.64	210	14.55	1.24	13.31	0.81
240	4.88	0.68	4.21	0.35	240	8.13	1.00	7.13	0.43
270	2.57	0.50	2.07	0.17	270	3.44	0.77	2.67	0.16
300	0.92	0.40	0.52	0.04	300	2.35	0.47	1.88	0.11
330	0.52	0.34	0.18	0.01	330	1.67	0.62	1.05	0.06
360	0.39	0.32	0.07	0.01	360	0.77	0.65	0.12	0.01

(...Continued)

(Appendix IX continued...)

DATE 18.06.99					DATE 06.07.99				
Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)	Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)
0	0.23	0.23	0.00	0.00	0	0.05	0.05	0.00	0.00
15	0.23	0.23	0.00	0.00	15	0.09	0.05	0.04	0.01
30	1.31	0.38	0.93	0.04	30	0.12	0.05	0.07	0.01
45	1.12	0.53	0.59	0.03	45	0.18	0.05	0.13	0.02
60	2.70	0.60	2.09	0.10	60	0.60	0.05	0.55	0.10
90	5.87	0.88	5.00	0.23	90	1.74	0.05	1.69	0.32
120	13.89	1.16	12.73	0.59	120	2.92	0.08	2.84	0.54
135	17.46	1.22	16.24	0.76	135	3.85	0.09	3.80	0.72
150	28.11	1.37	26.74	1.25	150	4.87	0.10	4.77	0.91
165	30.37	1.52	28.85	1.34	165	6.47	0.12	6.35	1.22
180	28.78	1.57	27.21	1.27	180	7.03	0.13	6.90	1.32
195	26.41	1.63	24.79	1.16	195	6.43	0.15	6.28	1.20
210	22.64	1.45	21.19	0.99	210	3.87	0.15	3.72	0.71
240	11.55	1.23	10.33	0.48	240	2.52	0.13	2.39	0.46
270	4.82	0.94	3.88	0.18	270	1.42	0.12	1.30	0.25
300	2.51	0.72	1.79	0.08	300	0.72	0.11	0.61	0.12
330	1.03	0.60	0.43	0.02	330	0.44	0.10	0.34	0.07
360	0.79	0.56	0.23	0.01	360	0.25	0.10	0.15	0.03

DATE 17.07.99				
Time, (min)	Discharge (kg/s)	Baseflow (kg/s)	DSG (kg/s)	USG (kg/s)
0	1.20	1.20	0.00	0.00
15	1.38	1.20	0.18	0.00
30	1.88	1.20	0.68	0.01
45	2.97	1.20	1.77	0.04
60	4.38	1.25	3.13	0.07
90	7.30	1.30	6.00	0.13
120	15.07	1.60	13.47	0.29
135	25.00	1.70	23.30	0.50
150	35.06	1.80	33.26	0.72
165	71.20	2.40	68.80	1.50
180	79.07	3.10	75.97	1.65
195	67.45	3.80	63.65	1.39
210	45.75	3.30	42.45	0.92
240	28.15	3.30	24.85	0.54
270	14.21	2.90	11.31	0.25
300	7.25	2.20	5.05	0.11
315	3.52	1.60	1.92	0.04
360	2.64	1.40	1.24	0.03

APPENDIX X

USLE and RUSLE slope steepness (S) and slope length (L) factors

Hill slope	USLE S factor	RUSLE S factor	USLE L factor	RUSLE L factor	Hill slope	USLE S factor	RUSLE S factor	USLE L factor	RUSLE L factor
1	9.98	5.48	3.45	5.38	50	9.49	5.32	3.83	6.17
2	9.26	5.24	3.53	5.49	51	2.83	2.42	5.78	8.16
3	10.17	5.54	3.43	5.34	52	2.53	2.23	4.39	5.72
4	11.82	6.06	3.43	5.45	53	5.22	3.67	3.76	5.48
5	10.11	5.52	2.66	3.78	54	4.19	3.17	3.76	5.27
6	2.67	2.32	3.65	4.65	55	5.37	3.73	3.49	5.00
7	3.86	3.01	3.71	5.11	56	1.54	1.50	4.12	4.69
8	3.71	2.92	3.76	5.15	57	2.68	2.32	4.15	5.43
9	6.88	4.37	3.23	4.70	58	9.81	5.43	3.10	4.64
10	16.09	7.25	2.38	3.38	59	6.05	4.03	3.36	4.85
11	10.78	5.74	2.71	3.91	60	5.58	3.83	2.61	3.45
12	11.68	6.02	3.28	5.12	61	1.68	1.62	4.99	5.94
13	6.44	4.19	3.05	4.32	62	2.54	2.23	5.24	7.06
14	4.77	3.46	3.05	4.14	63	10.78	5.74	3.36	5.25
15	4.40	3.28	3.83	5.45	64	4.33	3.24	4.45	6.55
16	5.42	3.76	3.94	5.86	65	5.58	3.83	3.45	4.95
17	3.20	2.64	4.76	6.66	66	5.37	3.73	3.49	5.00
18	3.86	3.01	4.12	5.82	67	9.79	5.42	3.10	4.65
19	9.35	5.27	3.15	4.71	68	1.35	1.34	4.05	4.44
20	7.53	4.62	3.36	5.01	69	5.29	3.70	4.19	6.30
21	5.22	3.67	4.61	7.11	70	5.58	3.83	2.91	3.98
22	6.25	4.12	2.81	3.86	71	4.24	3.20	4.70	6.98
23	8.49	4.97	3.03	4.43	72	5.42	3.76	3.94	5.86
24	4.69	3.42	4.76	7.25	73	3.25	2.67	5.32	7.66
25	6.34	4.15	3.76	5.66	74	3.32	2.71	4.57	6.41
26	9.35	5.27	3.85	6.20	75	7.53	4.62	3.76	5.81
27	9.66	5.38	4.12	6.82	76	3.25	2.67	4.61	6.43
28	6.34	4.15	3.76	5.66	77	3.86	3.01	2.91	3.78
29	5.58	3.83	5.05	8.10	78	5.38	3.74	4.37	6.68
30	4.41	3.28	5.05	7.71	79	2.19	2.00	4.90	6.28
31	3.42	2.76	5.45	7.99	80	12.43	6.24	3.45	5.53
32	13.27	6.48	3.45	5.57	81	1.89	1.78	3.15	3.65
33	3.41	2.76	4.79	6.81	82	1.98	1.85	3.10	3.63
34	7.53	4.62	3.76	5.81	83	1.54	1.50	4.76	5.49
35	4.11	3.13	4.29	6.19	84	2.26	2.05	4.54	5.80
36	6.21	4.10	3.57	5.26	85	3.10	2.58	4.12	5.56
37	1.78	1.69	4.90	5.92	86	3.48	2.79	3.68	4.96
38	2.19	2.00	4.90	6.28	87	4.54	3.35	3.10	4.19
39	2.19	2.00	4.90	6.28	88	8.19	4.86	2.32	3.08
40	9.66	5.38	2.91	4.26	89	0.72	0.69	5.05	4.46
41	3.48	2.79	3.36	4.44	90	5.73	3.89	4.29	6.59
42	6.95	4.40	3.45	5.12	91	2.00	1.87	5.05	6.33
43	1.28	1.28	4.12	4.46	92	3.64	2.89	4.45	6.32
44	3.25	2.67	2.66	3.29	93	2.08	1.92	3.94	4.82
45	9.77	5.41	3.36	5.19	94	9.06	5.17	2.86	4.13
46	0.76	0.75	3.49	3.23	95	4.65	3.40	4.35	6.47
47	5.41	3.75	3.83	5.65	96	10.08	5.51	3.26	4.99
48	0.98	0.99	3.91	3.90	97	2.42	2.15	4.12	5.26
49	5.85	3.94	4.45	6.95	98	2.87	2.44	3.57	4.60

APPENDIX XI

Sediment mobilized and excess rainfall (predicted using WEPP model)

Date - 11.06.99

Hill Slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)	Hill slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)
1	27344	0.007	0.500	50	58984	0.128	5.330
2	32031	0.000	0.440	51	180859	0.000	0.130
3	33984	0.000	0.440	52	97656	0.000	0.220
4	30469	0.454	1.690	53	74609	0.000	0.380
5	28125	0.047	0.850	54	133984	0.000	0.290
6	32422	0.026	2.670	55	63281	0.000	0.520
7	60547	0.047	3.430	56	156250	0.074	4.440
8	49805	0.197	6.750	57	229688	0.038	3.380
9	22461	0.000	0.510	58	111328	0.123	6.060
10	10938	0.093	1.190	59	152734	0.080	4.770
11	21875	0.017	0.600	60	89063	0.207	8.500
12	58594	0.000	0.480	61	87109	0.022	2.370
13	35156	0.000	0.440	62	129297	0.026	2.060
14	22266	0.027	1.760	63	93750	0.137	5.570
15	23828	0.047	0.990	64	287109	0.619	4.350
16	51758	0.034	1.100	65	117188	0.105	5.410
17	89844	0.018	1.810	66	73438	0.154	1.340
18	33203	0.126	0.950	67	54297	0.481	1.970
19	34180	0.112	5.840	68	211719	0.000	0.170
20	33203	0.270	1.830	69	190234	0.000	0.380
21	83984	0.032	2.410	70	108984	0.000	0.220
22	17578	0.000	0.670	71	100000	0.000	0.250
23	41992	0.002	0.590	72	64453	0.066	4.230
24	104688	0.000	0.200	73	128516	0.019	2.320
25	43945	0.000	0.330	74	239063	0.040	0.730
26	39063	0.002	0.330	75	93359	0.294	1.500
27	56641	0.261	1.180	76	199219	0.527	4.350
28	24609	0.013	0.950	77	46484	0.129	6.680
29	50781	0.216	0.660	78	85938	0.024	0.790
30	78125	0.261	0.650	79	221094	0.012	2.180
31	90234	0.020	1.750	80	12156	0.020	2.080
32	67188	0.552	1.800	81	53516	0.324	2.040
33	69141	0.021	0.800	82	67969	0.337	2.100
34	101953	0.155	1.300	83	150391	0.268	3.350
35	60156	0.033	2.740	84	233203	0.430	3.460
36	85938	0.079	1.200	85	177734	0.908	5.100
37	79297	0.035	1.800	86	73438	1.090	7.080
38	58594	0.016	1.580	87	112109	0.098	6.960
39	128906	0.014	1.620	88	79688	0.228	9.470
40	94922	0.007	0.790	89	135547	0.014	1.880
41	56250	0.091	1.370	90	114453	1.011	6.060
42	42969	0.011	1.460	91	121875	0.023	2.010
43	114063	0.016	1.950	92	103906	0.015	1.690
44	47656	0.140	7.290	93	96484	0.065	1.170
45	93750	0.481	1.810	94	54688	0.494	2.540
46	50000	0.102	5.690	95	105078	0.054	0.990
47	126953	0.078	4.400	96	128906	0.029	0.540
48	116797	0.000	0.110	97	82422	0.081	0.870
49	153516	0.015	0.750	98	91016	0.163	1.520

(...Continued)

(Appendix XI continued...)

Date – 18.06.99

Hill Slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)	Hill slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)
1	27344	0.000	0.000	50	58984	0.765	1.260
2	32031	0.000	0.000	51	180859	0.000	0.000
3	33984	0.000	0.000	52	97656	0.000	0.000
4	30469	0.000	0.000	53	74609	0.000	0.000
5	28125	0.000	0.000	54	133984	0.000	0.000
6	32422	0.014	0.600	55	63281	0.000	0.000
7	60547	0.015	0.650	56	156250	0.012	0.520
8	49805	0.014	0.620	57	229688	0.244	0.710
9	22461	0.000	0.000	58	111328	1.425	1.940
10	10938	0.000	0.000	59	152734	0.023	1.000
11	21875	0.000	0.000	60	89063	1.170	2.180
12	58594	0.000	0.000	61	87109	0.028	0.550
13	35156	0.000	0.000	62	129297	0.010	0.410
14	22266	0.000	0.000	63	93750	1.540	1.740
15	23828	0.000	0.000	64	287109	0.200	0.750
16	51758	0.000	0.000	65	117188	0.651	1.310
17	89844	0.010	0.420	66	73438	0.000	0.000
18	33203	0.000	0.000	67	54297	0.000	0.000
19	34180	1.615	1.880	68	211719	0.000	0.000
20	33203	0.000	0.000	69	190234	0.000	0.000
21	83984	0.046	0.630	70	108984	0.000	0.000
22	17578	0.000	0.000	71	100000	0.000	0.000
23	41992	0.000	0.000	72	64453	0.440	1.010
24	104688	0.000	0.000	73	128516	0.150	0.560
25	43945	0.000	0.000	74	239063	0.000	0.000
26	39063	0.000	0.000	75	93359	0.000	0.000
27	56641	0.000	0.000	76	199219	0.137	0.560
28	24609	0.000	0.000	77	46484	1.532	2.210
29	50781	0.000	0.000	78	85938	0.000	0.000
30	78125	0.000	0.000	79	221094	0.103	0.570
31	90234	0.007	0.300	80	12156	0.005	0.250
32	67188	0.000	0.000	81	53516	0.000	0.000
33	69141	0.000	0.000	82	67969	0.000	0.000
34	101953	0.000	0.000	83	150391	0.039	0.250
35	60156	0.283	0.760	84	233203	0.152	0.580
36	85938	0.000	0.000	85	177734	0.270	0.780
37	79297	0.356	0.590	86	73438	0.315	1.070
38	58594	0.175	0.500	87	112109	0.601	1.690
39	128906	0.009	0.400	88	79688	2.500	4.780
40	94922	0.000	0.000	89	135547	0.100	0.420
41	56250	0.000	0.000	90	114453	0.304	0.890
42	42969	0.000	0.000	91	121875	0.010	0.420
43	114063	0.012	0.510	92	103906	0.010	0.440
44	47656	0.834	1.850	93	96484	0.000	0.000
45	93750	0.000	0.000	94	54688	0.000	0.000
46	50000	1.448	1.680	95	105078	0.000	0.000
47	126953	0.509	1.050	96	128906	0.000	0.000
48	116797	0.000	0.000	97	82422	0.000	0.000
49	153516	0.000	0.000	98	91016	0.000	0.000

(...Continued)

(Appendix XI continued...)

Date – 06.07.99

Hill Slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)	Hill slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)
1	27344	0.000	0.170	50	58984	0.042	1.940
2	32031	0.000	0.160	51	180859	0.000	0.050
3	33984	0.000	0.170	52	97656	0.000	0.080
4	30469	0.074	0.650	53	74609	0.000	0.130
5	28125	0.000	0.300	54	133984	0.000	0.100
6	32422	0.005	2.310	55	63281	0.000	0.180
7	60547	0.008	2.680	56	156250	0.012	3.190
8	49805	0.062	4.270	57	229688	0.012	1.230
9	22461	0.000	0.280	58	111328	0.041	2.210
10	10938	0.035	0.650	59	152734	0.014	3.610
11	21875	0.000	0.210	60	89063	0.084	3.740
12	58594	0.000	0.170	61	87109	0.004	2.030
13	35156	0.000	0.160	62	129297	0.004	1.620
14	22266	0.002	0.680	63	93750	0.044	2.010
15	23828	0.001	0.380	64	287109	0.241	1.660
16	51758	0.001	0.430	65	117188	0.034	1.970
17	89844	0.003	1.470	66	73438	0.002	0.520
18	33203	0.001	0.370	67	54297	0.082	0.760
19	34180	0.037	2.120	68	211719	0.000	0.050
20	33203	0.019	0.710	69	190234	0.000	0.090
21	83984	0.005	1.890	70	108984	0.000	0.200
22	17578	0.000	0.230	71	100000	0.000	0.090
23	41992	0.000	0.210	72	64453	0.022	1.540
24	104688	0.000	0.070	73	128516	0.006	0.840
25	43945	0.000	0.180	74	239063	0.001	0.280
26	39063	0.000	0.120	75	93359	0.028	0.580
27	56641	0.023	0.460	76	199219	0.206	1.490
28	24609	0.001	0.370	77	46484	0.043	2.490
29	50781	0.033	0.250	78	85938	0.001	0.310
30	78125	0.057	0.250	79	221094	0.004	0.820
31	90234	0.003	1.410	80	12156	0.010	0.810
32	67188	0.104	0.700	81	53516	0.031	0.790
33	69141	0.001	0.310	82	67969	0.034	0.810
34	101953	0.002	0.500	83	150391	0.106	1.150
35	60156	0.011	1.000	84	233203	0.169	1.190
36	85938	0.002	0.500	85	177734	0.353	1.750
37	79297	0.012	0.650	86	73438	0.441	2.530
38	58594	0.005	0.570	87	112109	0.034	2.630
39	128906	0.003	1.370	88	79688	0.110	4.810
40	94922	0.000	0.280	89	135547	0.005	0.770
41	56250	0.001	0.530	90	114453	0.397	2.080
42	42969	0.001	0.560	91	121875	0.004	1.600
43	114063	0.003	1.690	92	103906	0.003	1.450
44	47656	0.049	2.820	93	96484	0.001	0.450
45	93750	0.084	0.700	94	54688	0.075	0.980
46	50000	0.049	2.070	95	105078	0.001	0.380
47	126953	0.026	1.600	96	128906	0.000	0.190
48	116797	0.000	0.030	97	82422	0.001	0.340
49	153516	0.001	0.290	98	91016	0.003	0.590

(...Continued)

(Appendix XI continued...)

Date – 17.07.99

Hill Slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)	Hill slope	AREA (m^2)	Sediment mobilized (t/ha)	Excess rainfall (mm)
1	27344	0.797	7.060	50	58984	0.270	28.850
2	32031	0.477	6.310	51	180859	0.000	1.830
3	33984	0.499	6.940	52	97656	0.362	3.170
4	30469	2.937	15.280	53	74609	0.000	5.360
5	28125	0.650	10.840	54	133984	0.000	4.090
6	32422	0.026	15.540	55	63281	0.068	7.340
7	60547	0.034	16.630	56	156250	0.045	17.830
8	49805	0.109	27.560	57	229688	0.086	20.200
9	22461	0.581	7.330	58	111328	0.242	28.850
10	10938	2.385	19.840	59	152734	0.049	18.570
11	21875	0.908	8.500	60	89063	0.347	28.850
12	58594	0.219	6.890	61	87109	0.022	14.510
13	35156	0.000	6.320	62	129297	0.020	12.340
14	22266	0.495	15.510	63	93750	0.276	28.850
15	23828	0.759	11.490	64	287109	1.430	29.130
16	51758	0.697	12.350	65	117188	0.225	28.850
17	89844	0.016	11.410	66	73438	1.406	13.790
18	33203	1.310	11.080	67	54297	2.802	16.170
19	34180	0.226	28.850	68	211719	0.000	2.790
20	33203	1.842	15.750	69	190234	0.461	3.650
21	83984	0.025	13.790	70	108984	0.000	8.180
22	17578	0.546	9.290	71	100000	0.000	3.520
23	41992	0.659	8.330	72	64453	0.177	28.850
24	104688	0.145	2.810	73	128516	0.055	17.720
25	43945	0.107	4.750	74	239063	0.680	8.620
26	39063	0.607	4.830	75	93359	2.158	14.570
27	56641	2.181	12.870	76	199219	1.310	29.130
28	24609	0.574	11.080	77	46484	0.242	28.850
29	50781	1.838	7.820	78	85938	0.599	9.420
30	78125	2.225	7.720	79	221094	0.044	19.350
31	90234	0.016	10.920	80	12156	0.023	17.030
32	67188	3.348	15.670	81	53516	1.988	16.350
33	69141	0.534	9.490	82	67969	2.019	16.500
34	101953	1.499	13.570	83	150391	0.576	20.040
35	60156	0.084	18.900	84	233203	0.894	20.230
36	85938	1.038	12.990	85	177734	1.995	29.130
37	79297	0.093	15.670	86	73438	1.993	29.130
38	58594	0.048	14.450	87	112109	0.198	28.850
39	128906	0.013	10.700	88	79688	0.395	28.850
40	94922	0.764	10.370	89	135547	0.043	17.000
41	56250	1.003	13.930	90	114453	2.017	29.130
42	42969	0.485	14.350	91	121875	0.019	12.330
43	114063	0.017	12.870	92	103906	0.014	11.280
44	47656	0.249	28.850	93	96484	0.876	12.810
45	93750	2.935	15.690	94	54688	3.395	24.250
46	50000	0.215	28.850	95	105078	0.822	11.440
47	126953	0.197	28.850	96	128906	1.115	7.690
48	116797	0.000	2.080	97	82422	1.001	10.320
49	153516	0.524	8.850	98	91016	1.401	14.620

SIMULATION OF THE EFFECTS OF LAND AND VEGETATION MANAGEMENT MEASURES ON RUNOFF AND SEDIMENT YIELD FROM A SMALL WATERSHED - A CASE STUDY

By

VINOD KUMAR, P. R.

ABSTRACT OF A THESIS

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in
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Faculty of Agricultural Engineering and Technology

Kerala Agricultural University

Department of

Land and Water Resources and Conservation Engineering

KELAPPAJI COLLEGE OF AGRICULTURAL ENGINEERING AND TECHNOLOGY

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2000

ABSTRACT

Conservation of soil by sound measures forms one of the fundamental premises towards a sustained future. The management of land and vegetation has profound influence in conservation programme. To simulate the effect of land and vegetation management measures on runoff and sediment yield from a watershed, a study was conducted at Development Unit-IX of Attapadi region, in Palghat district. The relationship between effective rainfall and sediment mobilized due to rain storm was established as; $ES = 28.57\ ER^{0.9385}$; where ES is the effective sediment mobilized in T/ km^2 and ER is the effective rainfall in cm. The Universal Soil Loss Equation (USLE) was applied on per–storm basis to estimate the soil erosion. The Modified-USLE (R) factor was used to represent the erosivity factor in the soil loss estimation. The topographic factor (LS) was computed using the USLE and Revised-USLE methods. This particular parameter computed with the USLE was more than that of the RUSLE. The amount of soil erosion predicted with the USLE were more than that of the RUSLE due to greater LS factor associated with the USLE method. However both methods provided an 'r^2' value of 0.9724. The WEPP-model was applied to simulate the runoff and soil erosion processes during individual rainstorm events. The model provided reliable simulation of the erosion process, but the runoff values were under-predicted for all the simulated events. The hillslopes cultivated with tuber crops gave maximum erosion per unit area during the simulation. The reason could be assumed as the absence of sufficient ground and canopy cover in this areas, which possessed a loosened surface after harvesting. The lands left as barren after

tree felling also had increased rates of erosion during the simulation, which could be due to the lack of vegetative protection. While the paddy field had lesser rates of erosion owing to the flatness of land and vegetation cover. The other areas yielded reduced rates of erosion due to good canopy cover as well as surface cover provided by closely growing vegetation.